ESD Ideas: Climate tipping is not instantaneous – the duration of an overshoot matters
Reviewer Responses

We are grateful for the constructive reviewer comments received on our manuscript. These comments are repeated in black, and our responses are given in blue.

Response to Reviewer 3

Ritchie et al. describe the concept of overshooting tipping points in their ESD ideas. They state that crossing a tipping point is not an instantaneous event but rather emerges over a finite time. This allows, in theory, for the prevention of a tipping point by reversing the forcing, i.e., global warming, to previous levels. They demonstrate that restricting the time above 1.5°C above pre-industrial levels would reduce risks associated with tipping points. For this, they combine results from a recent review paper about tipping elements (McKay et al., 2022) and from an earlier conceptual study about the overshooting concept by Ritchie et al. (2021).

The manuscript is clearly written and understandable for a broader audience. I fully agree that the topic of overshooting tipping points and considering their timescales is generally important. I also agree with the authors that the notion of the instantaneousness of tipping points is no longer appropriate. At the same time, I struggle to see the novelty of the presented concepts/results, at least for the scientific community. While I see that this misconception of the instantaneousness of tipping points is very prevalent in the public media/opinion, I am not sure if this is also the case in recent scientific publications; at least some references would be needed to back up this claim. Alternatively, a reframing of the presented work in relation to the misconception in the public rather than the scientific community might need to be considered.

Additionally, I think the manuscript partly oversimplifies the tipping point/overshoot concept in a manner that could convey overconfidence in the results, especially for non-experts. This can be easily avoided by stating the limitations of the results and discussing uncertainties.

General comments

I struggle to see the novelty of the presented concept, as I do not agree with the authors that this is very new information. As I understand it, the ESD Ideas format is intended for novel ideas or concepts. However, the idea that tipping is not instantaneous is not new (e.g., their own paper Ritchie et al., 2021), and it is not surprising to me that tipping can be avoided in conceptual models when the overshoot temperature and time are limited. I could imagine this manuscript, including the supplement, being included as a section in a more detailed manuscript.

The novelty of the Idea is that for the first time it provides an assessment for the implications of overshoot for all tipping elements (as opposed to a select few as previously considered) identified in the Armstrong-McKay et al. (2022) study. We intend to target a broader and policy-oriented audience to highlight the importance that tipping is not committed upon crossing the threshold. Therefore we have written a new opening paragraph to contextualise the study more clearly.

It seems like uncertainties related to the threshold levels are not mentioned anywhere in the main text. I think it should at least be stated that there is considerable uncertainty related to tipping point thresholds, even in McKay et al. (2022). Generally, I feel that the manuscript is written in a way that takes the concept of tipping elements/points for granted without considering the uncertainties. This gives the impression that the results shown are considered to be absolute truth. I wonder if it is possible to repeat the analysis with upper and lower limits for the individual tipping point thresholds and show them in the supplementary information or in an extended figure.

In Fig 1a and 1b we now provide an assessment of uncertainties, but keep Fig 1c the same. Detailing the methods, we now write at the end of the Supplementary Material "Panels (a) and (b) in Figure 1 of the

main paper, plot the probability density for the number of tipped elements in colour. An exponentially modified Gaussian distribution is fitted, using least squares, to each element's tipping timescale and threshold location. The lower, best, and upper estimates are assumed to correspond to the 5, 50, and 95% cumulative probability density levels. In the scenario where no estimate is given for either the upper or lower value, the best estimate is used instead. A random sample is then drawn from each of the 32 distributions to provide the threshold location and tipping timescale for each of the 16 tipping elements. Assuming these threshold and timescale values the inverse square law is used as previously to calculate the number of elements that would tip for each warming scenario. The process is repeated 1,000 times to thus generate the probability density for the number of tipped elements for each scenario."

The results remain qualitatively the same; importantly there is still a large reduction in the number of elements that would undergo tipping if the overshoot duration is restricted to 100 years (Fig 1b) compared with stabilising the temperature at its peak (Fig 1a). The main text and figure caption has been re-worked to reflect these changes.

I do not see any mention in the main text that the results are based on a, arguably, very simple conceptual model.

We now mention multiple times that the results are based on a simple conceptual model. However, we also note that the results align well with simulations from two state-of-the-art models for the Greenland ice sheet despite using a simple conceptual model. We write, "Specifically, the Greenland ice sheet is found not to tip until the overshoot duration is greater than 10,000 years, which agrees well with simulations from two state-of-the-art numerical models (Bochow et al., 2023), despite assuming a simple conceptual model."

Generally, I think some more references are needed for some statements (see also specific comments).

We have now added some more references including a reference to support the statement about the assumptions that tipping is committed upon crossing the threshold.

I don't think the supplementary information is easy enough to access/find. Additionally, the supplement is almost as long as the ESD Ideas itself. I wonder why this is not expanded upon and submitted as a regular research article.

The Supplementary Material is provided in the list of references including a URL, which takes the reader directly to the PDF. The Idea at its core is to highlight, to a wider audience, the importance of accounting for timescales when considering overshoot scenarios by providing a comprehensive assessment for all tipping elements identified in the Armstrong-McKay et al. (2022) study. We think this makes the study align well with the format of ESD Ideas.

Coupling between the elements is ignored, but it is only stated in the supplement. It should at least be stated in the main text. Although, I wonder how much value the results have if coupling between the tipping elements is completely ignored, given that we know there is interaction between the individual elements (e.g. Wunderling et al., 2024).

Interactions are not included in this study and that is now mentioned in the main manuscript, citing Wunderling et al. (2024). However, the thresholds are, at least partly, informed by climate model simulations which have some interactions built in.

Given the broad target audience and policy relevance of the manuscript, I think it would be a good idea to comment on the feasibility of the presented overshoot scenarios. A recent study showed that there likely is an overconfidence in overshoot scenarios and temperature decline after an overshoot might not even be possible (Schleussner et al. 2024).

We agree with the reviewer, and have now added the following to address the feasibility of the overshoot

scenarios, "It is important to highlight that not all of these overshoot profiles would be plausible, even with carbon dioxide removal technologies, particularly the front right corner. Specifically, considerations such as technical, economic and sustainability can limit the scales required at which carbon dioxide must be removed for such overshoots to be possible (Schleussner et al., 2024). Moving away from this front right corner and towards the back left corner coincides with increasing the feasibility of the overshoot profiles.".

Specific comments

L.1: "as is often assumed" — I would expect some references for that claim. In fact, there have been recent studies showing that tipping is generally not instantaneous (e.g., Bochow et al. (2023) or Höning et al. (2024)). I would almost claim that within the broad scientific community, it is known that tipping is not instantaneous.

We have reformulated slightly to mention that a commitment to tipping is often assumed once a threshold has been crossed. We have now added a reference in the main text where a similar statement appears as opposed to in the abstract. Some other examples that make similar assumptions include "A tipping point is when a temperature threshold is passed, leading to unstoppable change in a climate system..." (World on brink of five 'disastrous' climate tipping points, Guardian Sept 2022); "Crossing Earth system tipping points would have "catastrophic" impacts on societies" (Q&A: Climate tipping points have put Earth on 'disastrous trajectory', Carbon Brief Dec 2023); "Crossing these thresholds would disrupt the Earth's systems triggering the collapse of ice sheets" (Climate change: Six tipping points 'likely' to be crossed, BBC News Sept 2022). Note in the literature and media, a tipping point is often referred to as the threshold.

L.8: There is no reference for the Barents Sea ice threshold. Is this also taken from McKay et al. (2022)?

Yes it was, but now due to the inclusion of an uncertainty assessment this whole paragraph has been reworked.

L.47: I am not sure if defining "extremely short" as several decades is appropriate.

We have removed "extremely".

L.53: Here again, I would expect references for the statement: "conventional wisdom that the commitment to tip occurs as soon as a critical threshold is crossed." I don't agree that this is "conventional wisdom" anymore.

We have provided a reference earlier when this statement is first given in the main text.

L.38 (supplement): How realistic is this choice of α, and what influence does it have on the results? I would guess that for some tipping elements, e.g., Antarctica (Garbe et al. (2020)) or Greenland (Bochow et al. (2023), Höning et al. (2023 and 2024)), the curvature parameter could be roughly estimated.

The choice of $\alpha = 1$ is arbitrary and we suggest that this should be an area of future research as the information is not currently available in the Armstrong-McKay et al. (2022) study. Note in the previous version a small mistake was found that meant the α would not affect the overshoot duration (as the scaling on the forcing cancelled out the change of curvature). We have therefore reworked the model slightly, including introducing two parameters. A scaling parameter, β, that does not feature in the inverse square law and the α that still provides a measure of the curvature of the equilibrium curve. We still set $\alpha = 1$ and so the results are unchanged. We have also checked how the allowed overshoot duration compares for to that which can be calculated via the Stommel-Cessi AMOC model (Cessi, 1994). If the best estimates of the Armstrong-McKay et al. (2022) study are used then our choice of $\alpha = 1$ corresponds to an order of magnitude stricter condition on the square of the overshoot duration than the Stommel-Cessi model would suggest (a tipping timescale of 100 years would make it the same order of magnitude, but still more restrictive). In the Supplementary we now write "Note that this choice of α corresponds to a conservative choice for the AMOC according to the Stommel-Cessi model (Cessi, 1994), which would allow the square of the overshoot duration to be an order of magnitude larger. However, further research is required to determine the curvature parameter for

all tipping elements."

The colors in the plot are a little bit hard to distinguish. I wonder if a different color palette would make the plot more accessible.

We have now added four different hatching styles to make it easier to distinguish between the different tipping elements.

Garbe, J., Albrecht, T., Levermann, A. et al. The hysteresis of the Antarctic Ice Sheet. Nature 585, 538–544 (2020). https://doi.org/10.1038/s41586-020-2727-5

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Höning, D., Willeit, M., Calov, R., Klemann, V., Bagge, M., & Ganopolski, A. (2023). Multistability and transient response of the Greenland ice sheet to anthropogenic CO2 emissions. Geophysical Research Letters, 50, e2022GL101827. https://doi.org/10.1029/2022GL101827

Bochow, N., Poltronieri, A., Robinson, A. et al. Overshooting the critical threshold for the Greenland ice sheet. Nature 622, 528–536 (2023). https://doi.org/10.1038/s41586-023-06503-9

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David I. Armstrong McKay et al., Exceeding 1.5°C global warming could trigger multiple climate tipping points.Science377, eabn7950(2022).DOI:10.1126/science.abn7950

Schleussner, CF., Ganti, G., Lejeune, Q. et al. Overconfidence in climate overshoot. Nature 634, 366–373 (2024). https://doi.org/10.1038/s41586-024-08020-9

Wunderling, N., von der Heydt, A. S., Aksenov, Y., Barker, S., Bastiaansen, R., Brovkin, V., Brunetti, M., Couplet, V., Kleinen, T., Lear, C. H., Lohmann, J., Roman-Cuesta, R. M., Sinet, S., Swingedouw, D., Winkelmann, R., Anand, P., Barichivich, J., Bathiany, S., Baudena, M., ... Willeit, M. (2024). Climate tipping point interactions and cascades: A review. Earth System Dynamics, 15(1), 41–74. https://doi.org/10.5194/esd-15-41-2024