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 2

This Idea makes the relevant point that climate tipping elements do not tip instantly upon crossing a critical threshold in global mean temperature – the tipping risk depends on the duration of the overshoot as well as the peak exceedance value. The authors illustrate this statement by calculating whether various proposed tipping elements tip for different combinations of exceedance duration and peak warming, based on a simplified formula (Ritchie et al. 2019) and threshold/timescale estimates of Armstrong McKay et al. (2022).

The text is clearly written, and the results coherently support the main argument. I agree with the authors that it is crucial to consider the timescales of the forcing relative to the internal timescales of the tipping element for assessing tipping risk, an aspect sometimes ignored in the broader debate. However, I am concerned that the article oversimplifies the problem of climate tipping under overshoots and is therefore misleading particularly for a non-specialist audience. Without additional contextualization, there is a risk that the article perpetuates misunderstandings about tipping points rather than correcting them. I believe this can be solved by replacing some of the descriptive text with a brief, yet critical discussion of the assumptions, uncertainties and real-world complexities involved.

Major comment

My main critique is that the results described in this work convey a deceptive sense of certainty. The presentation suggests that whether a tipping element will tip can be determined with certainty from knowledge of the peak warming level and duration above 1.5 degrees C, independently of the other tipping elements. This depiction neglects that

- The warming threshold and timescale estimates in Armstrong McKay et al. (2022) have considerable uncertainty ranges.
- A sharp critical threshold may not exist for all tipping elements.
- Besides peak and duration, the shape of the forcing protocol may matter.
- For a given forcing protocol, tipping may be sensitive to the initial condition (see e.g. Romanou et al. 2023, Mehling et al. 2024).
- The climate tipping elements interact (Wunderling et al. 2024). The fact that interactions are neglected here is only mentioned in the Supplementary Material.
- Global warming levels are a climate response to forcing themselves and may not be an appropriate control parameter for all tipping elements considered.

This implies that the results in Fig. 1 have a significant uncertainty themselves and should be viewed probabilistically. While I think the results are still interesting in their current form, I ask the authors to better clarify in the main text that the results are simply the outcome of combining the best estimates of Armstrong McKay et al. (2022) with the adapted inverse-square law under multiple simplifying assumptions, and to highlight the inherent uncertainties.

In Fig 1a and 1b we now provide an assessment of uncertainties, but we have kept Fig 1c as previously so that the individual tipping elements can still be identified. We have used colour to represent the probability density for the number of elements tipped for each scenario. 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.

We have commented that "The theory assumes a symmetric overshoot profile, however, as shown previously, more realistic, asymmetric profiles have also provided good agreement to the theory (Ritchie et al., 2021)". Although we do not consider interactions directly the thresholds themselves are at least partly informed by climate model simulations which have some interactions built in. Nevertheless, we still note that we do not directly consider interactions as well as your other three remaining points that will lead to further uncertainties by writing in the penultimate paragraph, "In this study we do not consider the possibility that tipping elements can interact (Wunderling et al., 2024). However, some of the tipping thresholds provided in the Armstrong McKay et al. (2022) study are likely to account for some of these interactions. Furthermore, the threshold values may have been determined from transient climate simulations rather than corresponding to equilibrium values as assumed here, which would bias the results. We assume that the thresholds can be represented by a fold bifurcation, but this might not always be true which could lead to further uncertainty. Other factors to consider are the applicability of global warming as a forcing for all tipping elements and sensitivities to initial conditions (Mehling et al., 2024; Romanou et al., 2023)."

Specific comments

L. 53: The authors frame their Idea as a challenge of the "conventional wisdom" that tipping occurs instantaneously. However, the authors' previous work (Ritchie et al. 2019, 2021) and related studies (Bochow et al. 2023, Wunderling et al. 2023) have already debunked this "wisdom" and established the idea in the field over the past years. This questions how innovative the idea is in this work. If the authors' aim is thus to establish the concept among a wider audience, clarifying the underlying assumptions for obtaining Fig. 1 is especially important.

We have made a slight reformulation that the "conventional wisdom" is that tipping is committed once the threshold is crossed. We have added a high profile reference to support this statement at the first opportunity in the main text. 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. However, we do indeed intend to target a broader and policy-oriented audience to establish this concept more widely.

Could the authors comment on how their results might depend on the specific shape of the forcing protocol, i.e. steepness, asymmetry, etc.?

Although the theory assumes a symmetric forcing profile, the theory has previously been shown to align well for more realistic overshoot profiles that are asymmetric. We now write "The theory assumes a symmetric overshoot profile, however, as shown previously asymmetric profiles have also provided good agreement to the theory (Ritchie et al., 2021)".

L. 17-19: In my opinion, counting the number of Earth system elements tipping is not very informative, as the tipping elements have highly heterogeneous impacts. Perhaps the cumulative impact of multiple elements tipping could be viewed in a different way?

This is a good suggestion, but would require further research. Furthermore, we want to highlight the importance of tipping timescales, and identifying individual tipping elements helps emphasise that the fast tipping elements are those that are at greater risk of tipping.

The reference list seems rather selective, perhaps owing to the short format of the Idea. I note that all scientific articles cited in the main text are led by the same institution. Additional references underlying the authors' approach (e.g., Wunderling et al. 2021) are only cited in the Supplementary Material. If allowed by the format, adding further references to the main text would help putting this article into context.

We now provide a greater variety of references, but the Ideas format is limited to 15 references.

Technical comments

L. 16: Ref. Climate Action Tracker (2021) – is this a reference from the peer-reviewed literature and, if not, could the specific study be cited here?

We have updated the reference to 2024 and also now provide a URL to the resource.

L. 1: The figure labels are almost too small to read.

The figure labels have been increased to match the size of the text in the manuscript.

L. 25: ...without tipping (Ritchie et al. 2021).

This has been corrected as suggested.

L. 28: ...of 1.5C. Our...

Punctuation has now been added.

L. 31-32: The relevance of the curvature of the equilibrium branch for tipping risk is not explained. Only in the Supplementary Material it is stated that a fold bifurcation is assumed for all tipping elements. This assumption may not hold for all tipping elements catalogued in Armstrong McKay et al. (2022).

The curvature of the equilibrium branch informs how quickly the stability of the equilibrium is changing. A faster decrease would cause a greater lag (system would be further from equilibrium) and so would help facilitate an overshoot without tipping. We now write "Ideally, a third piece of information that details how quickly the stability of the initial stable state decreases as the tipping threshold approaches (for instance, inferred from the curvature of the equilibrium branch) would be available. A faster decline in stability would mean that the tipping element is further from equilibrium and would help facilitate an overshoot that does not result in tipping." We also now note on multiple occasions that the threshold is assumed to be represented by a fold. We write that this could lead to further uncertainty "We assume that the thresholds can be represented by a fold bifurcation, but this might not always be true which could lead to further uncertainty."

L. 39: No comma after Barents sea ice

This paragraph has been heavily revised after the inclusion of an uncertainty assessment and so this sentence no longer exists.

L. 44: Period missing after supplement)

Punctuation has now been added.

L. 46-47: The sentence “These fast tipping elements would…” seems redundant, especially given the final sentence (L. 55-56), and the space could be used to comment on limitations/uncertainties instead.

Agreed, we have deleted the sentence as suggested.

Supplementary Material

L. 3: “…elements of the Earth system, and based…” – should the “and” be there?

Thank you the “and” has now been removed.

L. 23: change “expecting” to “expected”

This has been corrected.

Bochow et al., “Overshooting the critical threshold for the Greenland ice sheet” (2023) https://doi.org/10.1038/s41586-023-06503-9

Mehling et al., “Limits to predictability of the asymptotic state of the Atlantic Meridional Overturning Circulation in a conceptual climate model” (2024) https://doi.org/10.1016/j.physd.2023.134043

Romanou et al., “Stochastic Bifurcation of the North Atlantic Circulation under a Midrange Future Climate Scenario with the NASA-GISS ModelE ” (2023) https://doi.org/10.1175/JCLI-D-22-0536.1

Wunderling et al., “Global warming overshoots increase risks of climate tipping cascades in a network model” (2023) https://doi.org/10.1038/s41558-022-01545-9

Wunderling et al., “Climate tipping point interactions and cascades: a review” (2024) https://doi.org/10.5194/esd-15-41-2024