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

Editor

Dear authors,

The reviewers were quite satisfied with your revised manuscript, and there are only a few minor suggestions for improvement. I therefore decided for publish subject to minor revisions that are reviewed by me.

Looking forward to the published article.

Best,
Axel

Dear Editor,

We are pleased to hear that the reviewers were satisfied with the last round of revisions and that you have decided to publish subject to minor revisions. We have now carefully addressed the remaining comments, including those regarding the curvature parameter in our model. This has helped us to establish that our model was over parameterised and thus, without loss of generality, we can set $\alpha = 1$, as changing α would in effect be changing the tipping timescale.

We look forward to seeing our manuscript published in Earth System Dynamics soon.

Yours sincerely,

Paul Ritchie (on behalf of all authors)

Response to Reviewer 1

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

I would like to thank the authors for carefully addressing the reviewers' concerns, and the new version of the manuscript is much improved, especially regarding the many caveats of the simple conceptual modelling approach taken here. The uncertainty analysis in figures 1a+b has also improved the robustness of the results.

I have a few remaining concerns specifically regarding the curvature parameter:

- From my understanding, the curvature parameter alpha turns out to be very important for the overshoot duration, as the overshoot timescale scales with 1/alpha (equation 7 of the Supplementary Material). While the curvature parameter is mentioned in the manuscript, the discussion in L33-38 of the revised manuscript is unnecessarily vague. It would be best if this scaling was explicitly acknowledged in the main text and acknowledged as an important uncertainty for the estimate of safe overshoot durations.

- While I appreciate that the authors have looked into the issue of setting alpha=1 in a conceptual AMOC model, it would be useful if this example was actually worked out in a bit more detail in the supplementary material ("one order of magnitude larger" is a bit too vague, and it is unclear how alpha was derived in this conceptual model).

- In addition, I wonder if (a) the Stommel model is a suitable example because the it uses freshwater forcing, not global warming, as its control parameter, and (b) if it would be feasible to estimate alpha from quasi-equilibrium experiments with state-of-the-art models (e.g., Garbe et al. 2020; van Westen et al. 2024). These simulations do not need to be analyzed, but a brief comment on the theoretical feasibility on deriving alpha from quasi-equilibrium experiments (instead of knowing the full bifurcation diagram in equilibrium) would be very helpful for the community.

We have realised that equation (5) in the SM (repeated here):

$$\tau_i \frac{\mathrm{d}x_i}{\mathrm{d}t} = -\frac{4\alpha_i^3}{27\beta_i^2 \Delta T_{\mathrm{crit,i}}^2} x_i^3 + \alpha_i x_i + \beta_i \Delta T, \tag{1}$$

is over parameterised. This can be seen by rewriting the equation as:

$$\tau_i \frac{\mathrm{d}x_i}{\mathrm{d}t} = -\frac{4\alpha_i}{27\gamma_i^2 \Delta T_{\mathrm{crit,i}}^2} x_i^3 + \alpha_i x_i + \alpha_i \gamma_i \Delta T, \tag{2}$$

where we have defined $\beta_i/\alpha_i =: \gamma_i$. On the right hand side, a single α_i term appears and therefore, changing α_i would effectively change the timescale τ_i. Hence, without loss of generality, we can set $\alpha_i = 1$. It is important to note that the parameter γ_i does not feature in the inverse square law (equation (8) in SM) and thus its choice does not impact the allowed overshoot duration. We have updated the SM accordingly with the reformulation of the equation now included in the SM as equation (6).

Specific comments:

It would be good if the concern of reviewer 2 that simply counting the number of tipped elements will not give a representative picture in terms of impacts could be explicitly acknowledged somewhere in the article (even though it is impossible to quantify exactly).

On the first mention of the figure and as we count the number of tipped elements, we now also note that "... the impacts of tipping are very heterogeneous for different Earth system elements."

L20: "and so if . . . ": break this sentence and start a new one with "If . . . ". Otherwise this sentence might suggest a link between the 2.7 ± 0.2°C by 2100 and 4°C stabilization, but the Climate Action Tracker does

not assess stabilization levels.

We have split the sentence into two as suggested.

L21: "very unlikely" is this following IPCC-calibrated language?

Yes, it was following the IPCC terminology. However, for clarity, we have decided to rephrase the sentence to highlight that these two elements are the only elements to "have the lower bound of their tipping thresholds above 4°C."

L24: Use "e.g." with this reference

Added as suggested.

L45: Remove comma after "3°C"

The comma has been removed.

L63: It would be good to add a comment after this sentence that the feasibility cannot be assessed in this study.

We have now added "However, assessing the limits of feasibility is outside the scope of this study."

L66: "threshold values may have been determined" → "threshold values of some tipping elements may have been determined" (you mention in your replies that for ice sheets, for example, they appear to be equilibrium values)

Changed as suggested.

L71: Following the discussion in the first round of reviews, it seems appropriate to replace "conventional wisdom" with a more neutral term.

Following the other reviewer's suggestion this has been changed to "frequent assumption".

L73: "all tipping elements could be avoided" → "tipping of all elements considered here could be avoided"

Changed as suggested.

Video supplement: It would be great to have a version that includes the uncertainty assessment. Also, please deposit this in a repository for more permanent archival (github does not guarantee that).

We have decided not to include an additional animation. However, we further emphasise that the animation we do provide uses the best estimates. We have now given the video supplement a fixed DOI by linking the github repository to Zenodo.

The degree signs look like italic "o"s, please use the actual degree sign (° or °) throughout.

This typo has now been corrected throughout the manuscript.

Supplementary Material: I would suggest adding a table or figure which shows the values (or distributions) used from the Armstrong McKay study. Otherwise, the reader needs to flip between three different documents (this article, the supplementary material and the Armstrong McKey et al. paper) to follow along.

A table has now been added to show the values used from the Armstrong McKay study.

check that all mathematical symbols are defined explicitly. It is also unclear why a new scaling parameter beta is introduced and what it scales.

We have ensured that all mathematical symbols are defined explicitly. The parameter β (and later γ) is required to ensure that the units agree. We add specifically "that $[\beta]$ scales between temperature and the units of the state variable x". Please note that it was the parameter α that was not required, because as explained above, changing this effectively changes the tipping timescale.

SM L50: could you briefly justify the choice of an exponentially modified Gaussian distribution?

This is one of the simplest distributions that can "accommodate skewed distributions".

SM L52: "no estimate is given" To how many elements does this apply?

We now explicitly state that these refer to the timescales of the coral reefs, East Antarctic ice sheet, Barents sea ice and boreal forests. Based on this request, we now write in the papr: "Note, for the coral reefs, East Antarctic ice sheet, and the Barents sea ice only, one timescale estimate is given and so these are assumed to have no uncertainty. Similarly, the upper estimate for the timescales of the boreal forests are unknown and so the upper estimate takes the value of the best estimate for both dieback and expansion respectively, these modifications are included in Table 1."

Garbe et al. 2020, https://www.nature.com/articles/s41586-020-2727-5
Van Westen et al. 2024, https://www.science.org/doi/10.1126/sciadv.adk1189

Response to Reviewer 3

We are pleased to hear that we addressed all of the reviewer's comments and that there are only some minor comments remaining. These comments are repeated in black, and our responses are given in blue.

The authors addressed all of my comments. I have some minor remarks remaining, mostly regarding phrasing.

L.24: In accordance with the authors' response to my previous comment (previously L.1), I suggest either expanding the sentence or adding another short sentence that addresses the framing of tipping points in the media as instantaneous events.

We have now added the following sentence to address the framing of tipping points in the media as instantaneous events: "In the media it is often incorrectly implied that tipping is instantaneous upon crossing the threshold (e.g. Guardian article: "World on brink of five 'disastrous' climate tipping points", September, 2022)."

L.71: I still do not like the phrase "conventional wisdom" here, as it seems to overlook some of the progress made in recent years. I understand what the authors mean, but I would recommend rephrasing it to something like "frequent assumption" or a similar expression.

We have rephrased as suggested.