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

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Abstract. Climate tipping points are not committed to occur automatically upon crossing critical thresholds in global warming, as is often assumed. Instead, it is possible to temporarily overshoot a threshold without causing tipping, provided the duration of the overshoot is short. In this Idea, we demonstrate that restricting the time over 1.5 °C would considerably reduce tipping point risks.

The goal of the Paris Climate Agreement (2015) is to keep long-term global warming well below 2 °C, and, if possible, below 1.5 °C, relative to pre-industrial levels. Global warming has already exceeded the 1.5 °C threshold for a period of 12 months (Copernicus Climate Change Service, 2024). Maintaining long-term warming at 1.5 °C necessitates decarbonisation rates that are highly unlikely given the current progress (Bossy et al., 2024). Therefore, at the very least, eventual stabilisation at this threshold suggests that a temporary overshoot of the 1.5 °C level is becoming increasingly likely.

Many elements of the climate system are vulnerable to large and abrupt changes, often referred to as tipping points (Lenton et al., 2008). Figure 1a presents a probabilistic risk assessment for the number of elements of the climate system that could experience tipping at various levels of stabilised global warming. Note, however, that the impacts of tipping are very heterogeneous for different Earth system elements. An uncertainty range is determined from the estimated ranges of each element's warming threshold location, as provided in a recent assessment of climate tipping points (Armstrong McKay et al., 2022); see the Supplement (Ritchie et al., 2025) for more details. Even if warming could be stabilised at 1.5 °C without overshoot, the most likely scenarios indicate that between one and four elements may eventually tip (see Fig. 1a). Stabilising warming at the upper limit of the Paris Climate Agreement (2015) (2 °C) raises the most probable range to between four and seven elements tipping. Current climate commitments are projected to result in global warming of 2.7 ± 0.2 °C by the end of the century (Climate Action Tracker, 2024). Stabilising at this warming level could broaden the range to between 7 and 10 elements tipping. However, under these commitments, warming would continue beyond 2100. If warming were only to stabilise near 4 °C, the range would shift to between 10 and 13 major Earth system elements tipping (Fig. 1a). A lower bound of tipping thresholds above 4 °C only applies to the collapse of Arctic winter sea ice and the East Antarctic ice sheet.

However, system inertia means that tipping is not committed once the tipping threshold is crossed, as is often implicitly assumed (e.g. Rockström et al., 2023). In the media, it is often incorrectly implied that tipping is instantaneous upon crossing the threshold (e.g. *The Guardian* article: "World on brink of five 'disastrous' climate tipping points", September 2022). Instead, tipping can still be avoided if the exceedance of a threshold has a short duration compared to the characteristic timescale of the tipping element. Previously, Ritchie et al. (2019) showed that tipping point risk depends on both

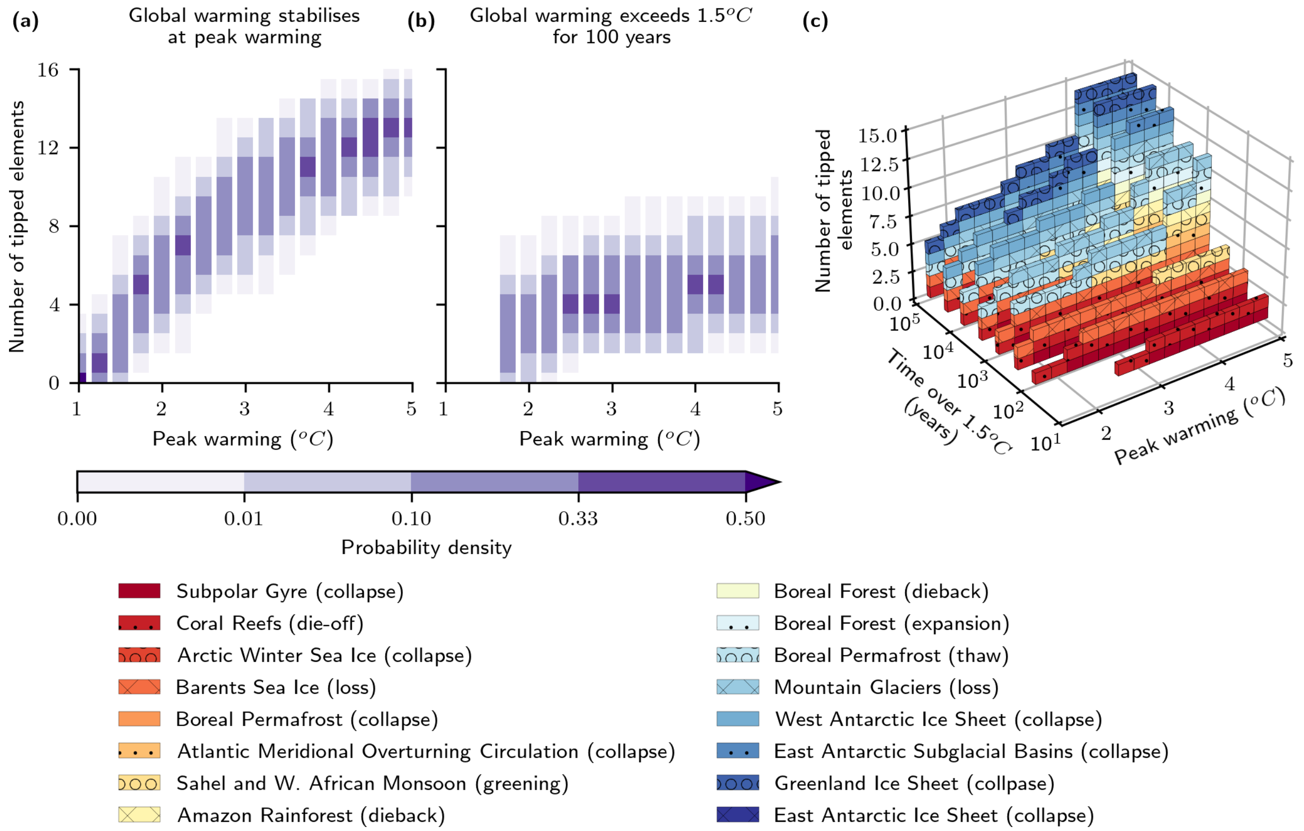

Figure 1. Tipping risk of different climate system elements for different overshoot profiles. Probabilistic number of elements of the climate system, binned by increments of 0.25 °C, that undergo tipping for temperature **(a)** stabilising and **(b)** exceeding 1.5 °C for 100 years for different levels of peak global warming. **(c)** 3D projection of the number of tipped elements based on the peak global warming and the time over 1.5 °C (on a logarithmic scale). Individual tipping elements are represented by colour and hatching and are colour-coded according to their tipping timescale, with the fastest-tipping elements in red and the slowest-tipping elements in blue. Uncertainty ranges given in panels **(a)** and **(b)** and represented by purple shading are calculated after an exponentially modified Gaussian distribution is fitted to each of the tipping timescales and threshold values given in Armstrong McKay et al. (2022) by assuming that the lower, central, and upper estimates correspond to the 5 %, 50 %, and 95 % cumulative density levels, respectively. Panel **(c)** uses the central estimates only to display the individual tipping elements.

the threshold temperature, represented by a fold bifurcation, and the timescale of the tipping element. In general, tipping elements with slow timescales allow overshoots that avoid tipping, whereas fast-tipping elements leave very little margin for overshoot without tipping (Ritchie et al., 2021). Given that the recent comprehensive study of Armstrong McKay et al. (2022) provides estimates of both timescales and critical warming thresholds for a broad set of Earth system components, we can now combine the analyses of Armstrong McKay et al. (2022) and Ritchie et al. (2021) to show the dependence of tipping point risks on both peak global warming and the duration of exceedance of 1.5 °C. The Supplement (Ritchie et al., 2025) details how the theory has been advanced to accommodate both the tipping timescale and the exceedance of a predefined temperature (here, 1.5 °C) using a simple conceptual model modified from Wunderling et al. (2021). The theory assumes a symmetric overshoot profile; however, as shown previously, more realistic, asymmetric profiles have also provided good agreement with the theory (Ritchie et al., 2021).

Panel (b) of Fig. 1 is of identical format to panel (a), except that now warming only remains above 1.5 °C for 100 years. Comparing panel (b) to panel (a) shows a notable difference, with the number of elements that could undergo tipping considerably reduced. If global warming peaked at 2 °C but the time over 1.5 °C was limited to 100 years, the likely range of elements to tip would drop to between two and four elements, compared with four to seven if warming stabilised at 2 °C. An overshoot of 100 years that reaches a peak warming of 3 °C would have the most likely result of 4 elements tipping, which compares to a range of 8 to 11 if the warming instead stabilised at its peak.

Panel (c) provides the 3D picture of the individual elements that tip (now using the best estimates for thresholds and timescales given in Armstrong McKay et al., 2022) for overshoot profiles characterised by both peak warming and time over 1.5 °C (panel animation using the best estimates provided as the Supplement). Without the uncertainties, panels (a) and (b) would be cross sections of panel (c), namely the left-hand “back wall” and the second visible row from the front right, respectively. Panel (c) demonstrates that fast-tipping elements (red blocks) would only avoid tipping if the overshoot duration were short (only decades over 1.5 °C), combined with a small peak overshoot (notably, the coral reefs and subpolar gyre are the most susceptible to tipping). For example, if the duration of exceedance of 1.5 °C is less than 30 years and the peak warming is less than 2.5 °C, it may be possible to avoid all the tipping elements considered here (shown by the incomplete red bar at the front of panel c). In contrast, the slowest-tipping elements (blue blocks) are not committed to tip until the time over 1.5 °C approaches 1000 years, despite these elements possessing some of the lowest warming thresholds. 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). The accumulation of tipped elements in the back corner of panel (c) is because this is where both peak warming and time over 1.5 °C are large. It is important to highlight that not all of these overshoot profiles would be plausible, even with carbon dioxide removal technologies, and 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. However, assessing the limits of feasibility is outside the scope of this study.

In this study, we also 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 of some tipping elements 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).

Our study challenges the frequent assumption that the commitment to tip occurs as soon as a critical threshold is crossed. Instead, the number of elements that would undergo tipping is severely reduced if the duration of exceedance of the Paris 1.5 °C can be kept below a century. Furthermore, this analysis suggests that the tipping of all elements considered here could be avoided if global warming over 1.5 °C is restricted to 30 years and peak warming is kept below 2.5 °C.

Code and data availability. The code used to generate Fig. 1 can be found in Ritchie et al. (2025, https://doi.org/10.5281/zenodo.17047632, last access: 3 September 2025).

Video supplement. The animation of Fig. 1c is provided in Ritchie et al. (2025, https://doi.org/10.5281/zenodo.17047632, last access: 3 September 2025).

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