Climate tipping points could lock in unstoppable changes to the planet. How close are they?

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Continued greenhouse gas emissions risk triggering climate tipping points. These are self-sustaining shifts in the climate system that would

lock-in devastating changes, like sea-level rise, even if all emissions ended.

The first major assessment in 2008 identified nine parts of the climate system that are sensitive to tipping, including ice sheets, ocean currents and major forests. Since then, huge advances in climate modeling and a flood of new observations and records of ancient climate change have given scientists a far better picture of these tipping elements. Extra ones have also been proposed, like permafrost around the Arctic (permanently frozen ground that could unleash more carbon if thawed).

Estimates of the warming levels at which these elements could tip have fallen since 2008. The collapse of the west Antarctic ice sheet was once thought to be a risk when warming reached 3°C-5°C above Earth's pre-industrial average temperature. Now it's thought to be possible at current warming levels.

In our new assessment of the past 15 years of research, myself and colleagues found that we can't rule out five tipping points being triggered right now when global warming stands at roughly 1.2°C. Four of these five become more likely as global warming exceeds 1.5°C.

These are sobering conclusions. Not all of the news coverage captured the nuance of our study, though. So here's what our findings actually mean.

Uncertain thresholds

We synthesized the results of more than 200 studies to estimate warming thresholds for each tipping element. The best estimate was either one that multiple studies converged on or which a study judged to be particularly reliable reported. For example, records of when ice sheets had retreated in the past and modeling studies indicate the Greenland ice

sheet is likely to collapse beyond 1.5°C. We also estimated the minimum and maximum thresholds at which collapse is possible: model estimates for Greenland range between 0.8°C and 3.0°C.

Within this range, tipping becomes more likely as warming increases. We defined tipping as possible (but not yet likely) when warming is above the minimum but below the best estimate, and likely above the best estimate. We also judged how confident we are with each estimate. For example, we are more confident in our estimates for Greenland's ice sheet collapse than those for abrupt permafrost thaw.

This uncertainty means that we do not expect four climate tipping points to be triggered the first year global temperatures reach 1.5°C (which climate scientists suggest is possible in the next five years), or even when temperatures averaged over several years reach 1.5°C sometime in the next couple of decades. Instead, every fraction of a degree makes tipping more likely, but we can't be sure exactly when tipping becomes inevitable.

This is especially true for the Greenland and west Antarctic ice sheets. While our assessment suggests their collapse becomes likely beyond 1.5°C, ice sheets are so massive that they change very slowly. Collapse would take thousands of years, and the processes driving it require warming to remain beyond the threshold for several decades. If warming returned below the threshold before tipping kicked in, it may be possible for ice sheets to temporarily overshoot their thresholds without collapsing.

For some other tipping points, change is likely to be more dispersed. We estimate that both tropical coral reef death and abrupt permafrost thaw are possible at the current warming level. But thresholds vary between reefs and patches of permafrost. Both are already happening in some places, but in our assessment, these changes become much more

widespread at a similar time beyond 1.5°C.

Elsewhere, small patches of the Amazon and northern forests might tip and transition to a savannah-like state first, bypassing a more catastrophic dieback across the whole forest. Model results that are yet to be published suggest that Amazon tipping might occur in several regions at varying warming levels rather than as one big event.

There may also be no well-defined threshold for some tipping elements. Ancient climate records suggest ocean currents in the North Atlantic can dramatically flip from being strong, as they are now, to weak as a result of both warming and melting freshwater from Greenland disrupting circulation. Recent modeling suggests that the threshold for the collapse of Atlantic circulation depends on how fast warming increases alongside other hard-to-measure factors, making it highly uncertain.

Into the danger zone

There are signs that some tipping points are already approaching. Degradation and drought have caused parts of the Amazon to become less resilient to disturbances like fire and emit more carbon than they absorb.

The front edge of some retreating west Antarctic glaciers are only kilometers away from the unstoppable retreat. Early warning signals in climate monitoring data (such as bigger and longer swings in how much glaciers melt each year) suggest that parts of the Greenland ice sheet and Atlantic circulation are also destabilizing.

These signals can't tell us exactly how close we are to tipping points, only that destabilization is underway and a tipping point may be approaching. The most we can be sure of is that every fraction of further warming will destabilize these tipping elements more and make the initiation of self-

sustaining changes more likely.

This strengthens the case for ambitious emissions cuts in line with the Paris agreement's aim of halting warming at 1.5°C. This would reduce the chances of triggering multiple climate tipping points—even if we can't rule out some being reached soon.

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