Earth System Tipping Points

BRIEF #12 | 23 JUNE 2026

Summary

01 **Earth system tipping points** are critical limits in the Earth's climate and planetary sub-systems (e.g. rainforests and ice sheets) where small additional changes can trigger major and potentially irreversible shifts that continue on their own. These shifts are driven by internal feedback processes and may be difficult or impossible to reverse on human timescales, even if the original pressures (such as greenhouse gas emissions) are reduced or eliminated.

02 There are **varying degrees of scientific certainty** concerning which sub-systems may be approaching critical thresholds and how soon large-scale irreversible change could occur. In general, the probabilities of reaching tipping points rise significantly as global warming increases.

03 Despite this uncertainty, there are improved methods and growing scientific evidence that **several key Earth sub-systems are at increasing risk** of reaching (or have already begun crossing) tipping points, including:

- **Large polar continental ice sheets** may have begun long-term melt that could raise sea levels by several meters over centuries;
- Widespread loss of **warm-water coral reefs**, some of which is already underway, indicating that tipping points may already have been reached;
- Shift of parts of the **Amazon rainforest** to savanna-like conditions, triggered by a combination of deforestation and regional climate change;
- Weakening or collapse of **deep-water formation/ circulation processes** in the oceans, potentially changing large-scale ocean circulations;

Why it matters:

Earth system tipping points offer a way to understand how gradual environmental change can cross critical thresholds, creating self-organizing, irreversible transformations. Understanding the science of tipping points is critical to better managing interconnected planetary risks.

04 Tipping of any major Earth system would have **catastrophic impacts** on humans and the planet. The interaction of these systems can lead to **destabilising cascades,** meaning that irreversible change can spread from one Earth sub-system to many.

05 Even without crossing tipping points, **major societal impacts of climate change are already occurring** and likely to become more intense and widespread.

06 Emerging scientific evidence around Earth system tipping points increases the **urgency of climate change mitigation while also prioritizing resilience and adaptation strategies.**

07 Tipping points require approaches that can **better anticipate risks** and **make decisions** even when there is a **high level of uncertainty.** Building capacities to **gather and synthesize a wide range of scientific information** about Earth system change will help leaders balance the risks of different climate and environment pathways.

What are Earth system tipping points?

Earth system tipping points refer to critical thresholds within the Earth's air, water, land, and ice sub-systems. When external pressures, such as rising greenhouse gas concentrations, push these sub-systems across a critical threshold, they can undergo large, ongoing changes that fundamentally alter their structure and function. **A tipping point refers to the threshold beyond which internal feedback mechanisms sustain continued change, even if the original cause is reduced or eliminated.**

A defining characteristic of an Earth system tipping point is **nonlinear, self-reinforcing change**. Before a threshold is reached, a system may respond proportionally to external drivers such as temperature rise. This allows it to return to its earlier state if the external driver is reduced or eliminated. After a tipping point is crossed, however, the system starts to reinforce the change rather than resist it, so the change can speed up even if the original cause is reduced.

For example, melting glacier ice lowers the glacier's surface elevation, such that it is exposed to higher local air temperatures, which in turn leads to more melting. This self-reinforcing dynamic means that once melting has started, relatively small additional increases in warming can trigger disproportionately large and persistent shifts in the glacier's state (i.e. the ice continues to melt at higher rates even if the temperature does not continue to rise). The loss of ice may unfold over years, decades, or centuries, but the key feature is that once a certain threshold is crossed, the glacier reorganizes in a fundamentally different way, continuing to shrink even if external temperatures do not rise.

This non-linear behaviour has important consequences. After a tipping point is crossed, change can become **sudden, disruptive, and irreversible** on human timescales. Once this happens, self-reinforcing feedbacks can speed up change, making it hard to stop or reverse. For example, ice sheet collapse, large-scale forest loss, or permafrost thaw may continue even if global temperatures later stabilise or decline. In such cases, returning to the original state would require cooling well below the temperature at which the tipping point occurred, and in some cases full recovery may not be possible for millennia (for example, a return to previous biodiversity levels after a large extinction event). This challenge in returning to the original set of conditions is central to scientific concern about tipping points.

As parts of an interconnected Earth system, **tipping point dynamics interact with one another.** Changes in one subsystem can increase the likelihood of triggering others, creating **cascading effects across systems.** For example, significant freshwater influx to the North Atlantic following a collapse of the Greenland ice sheet could induce or contribute to reduced functioning of a major Atlantic Ocean circulation (the AMOC). In some scenarios, this could not only lead to a massive cooling in Europe, but impact monsoons worldwide, affecting global precipitation patterns and destabilising tropical rainforests.

It is important to note that **each Earth sub-system has its own mechanisms, thresholds, and timeframes for change.** The concept of a tipping point therefore broadly captures the process of a sub-system reaching irreversible, self-reinforcing change after reaching a critical threshold. While there remains uncertainty regarding the exact conditions under which specific Earth system tipping points will be crossed, **there is broad agreement that the likelihood of passing critical thresholds increases with additional global warming.** Some sub-systems, including warm-water coral reefs, are already exhibiting widespread and potentially irreversible transformations at current levels of warming. [1-14]

The current state of Earth system tipping points

Recent advances in the scientific understanding of Earth system tipping points have led to important improvements in:

(1) distinguishing **long-term changes** that become locked in and are very difficult to reverse (what scientists call "committed change") from other potentially reversible impacts;

(2) identifying **more precisely where specific tipping point thresholds may lie** (including better ways of analyzing the system's sub-components rather than the entire system as a whole);

(3) evaluating **interaction risks,** where destabilization in one system increases the likelihood of change in another.

Recent **advances in AI** are contributing to improved analysis of Earth system tipping point processes, particularly in detecting early signs of declining system resilience. Machine learning can help identify patterns in large and complex datasets, including changes in variability that may precede system shifts, and can complement process-based climate models.

However, **machine learning is only as good as the data and inputs that shape it.** Many AI systems train on existing data from the historical record, meaning that new or significantly different future scenarios may not be accurately identified.[15,16,17] Recently, physics-informed AI is enabling models to incorporate physical laws and constraints directly into AI models, greatly improving the ability for robust early prediction of tipping points. As of today, AI is best understood as a supporting tool that may help identify emerging risks.[3,18-25],

Overall, improvements in scientific understanding have enabled a more accurate picture of our Earth system, the risks facing it, and the timeframe in which sub- systems may cross tipping point thresholds.[26] That said, each Earth system displays different mechanisms of change, and scientists have varying levels of certainty about the likelihood of reaching critical thresholds. The following sections draw on these scientific advances and describe the current state of Earth sub-systems, focusing on those areas that best exemplify tipping dynamics.

Cryosphere systems:

As global temperatures rise, many parts of Earth's ice-covered regions are showing signs of tipping point behavior. In general, ice systems remain stable because their elevation and reflective surfaces help them stay cool and maintain their overall mass and coverage. However, these stabilizing feedback processes can weaken and become self-reinforcing, meaning that ice loss may continue and accelerate even if warming rates slow down. This is in part due to **melt–elevation feedback:** as ice sheets lose height, they are exposed to warmer air, which increases melting and further lowers their elevation. In addition, when snow and ice melt, they expose darker surfaces or form meltwater ponds that absorb more sunlight. This combination of loss of elevation and less reflective surfaces leads to increased local warming, which accelerates the rate of melting.

Tipping points in the cryosphere could occur within decades to centuries, with cascading effects around the world. Major loss of the West Antarctic ice sheets and/or melting of the Greenland ice sheets could lead to more than 10 meters of sea level rise. An abrupt thaw of permafrost could result in a substantial release of methane within a few years.[27]

Together, these processes can speed up the breakdown of ice sheets, glaciers, and permafrost. Some regions may eventually experience complete ice loss and increased greenhouse gas emissions from thawing permafrost. While Arctic summer sea ice is not currently assessed to show tipping point behavior, changes in Antarctic sea ice are beginning to demonstrate irreversible dynamics, though this remains uncertain and is still being actively studied.[2,14,28-33]

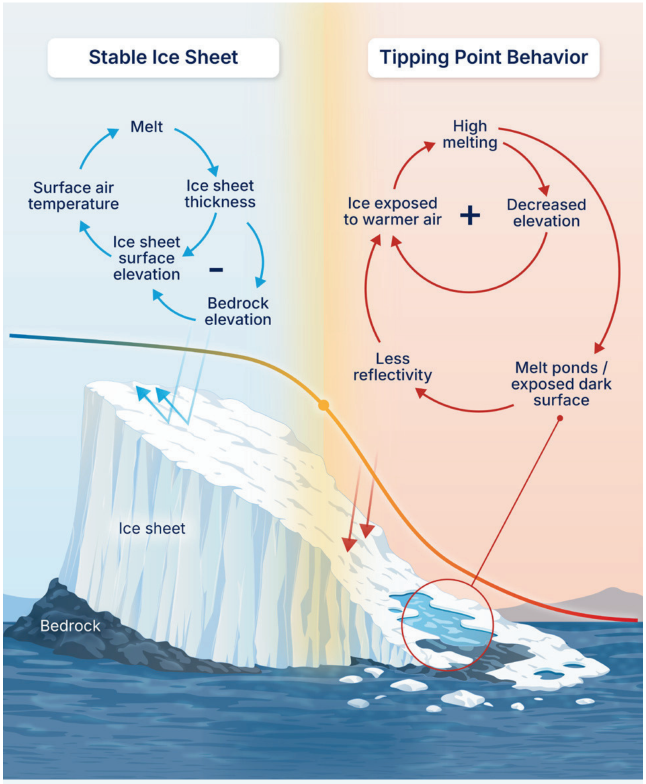


Figure 1: Feedback loops

Negative feedback stabilizes the system; positive feedback accelerates change.

Ocean and atmospheric circulations:

The Atlantic Meridional Overturning Circulation (AMOC) is a major sub-system of ocean currents that moves warm, salty surface water northward through the Atlantic. In the North Atlantic, this water cools, becomes heavier, and sinks before flowing southward deep in the ocean. This circulation of water is fundamentally important in stabilizing temperatures and other weather patterns around the world. Observations suggest that the AMOC is already circulating less strongly compared to preindustrial levels, and it is expected to weaken further as global temperatures rise. A key reason is the increasing freshwater in the North Atlantic, which makes surface waters less dense and reduces their ability to sink. This can be exacerbated by melting ice from Greenland.

If this process continues, internal feedbacks could further slow the AMOC's circulation, potentially pushing it into a much weaker state or even causing a collapse that would be difficult to reverse. Scientists are still uncertain about exactly when such a tipping point could happen and continue to study it.

Evidence from past climates shows that the AMOC has shifted between strong and weak states before. Some models suggest that in the coming decades, deep water formation in the Subpolar Gyre (a major circulation feature of the AMOC) could weaken or collapse as the climate warms, reducing the strength of the AMOC overall.[34] Similar changes may also occur in the Southern Ocean, where warming and increased meltwater from ice sheets could disrupt ocean circulation by making it harder for surface waters to sink.[34-39]

Coral reef systems:

Warm-water coral reefs are among the most immediate examples of ecosystems at risk of shifting into long-term, irreversible decline. Repeated periods of extreme ocean heat stress (marine heatwaves) give reefs less time to recover, making it more likely they will shift from coral-rich ecosystems to algae-dominated or simpler ecosystems. Research suggests that large-scale coral reef loss is likely at global warming levels of around 1–1.5°C (with ~1.2°C as a central estimate).

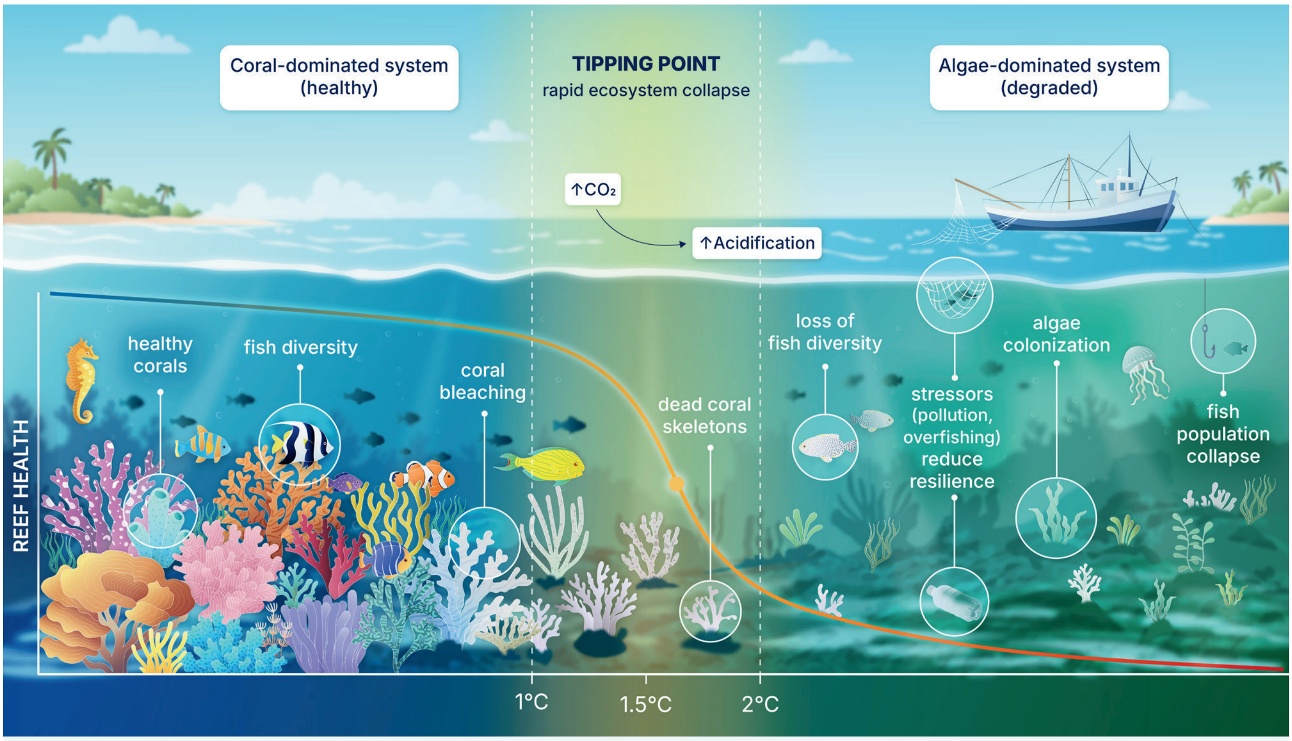


Figure 2: Coral reef collapse

Some coral reef systems may already be displaying tipping point behavior.

Beyond this range, many reef systems may no longer be able to recover, even if some individual reefs persist under favorable local conditions. Recent global bleaching events (especially those between 2023 and 2025) show that extreme heat stress is becoming frequent enough to cause widespread coral mortality, meaning that **some major coral systems may have already begun crossing tipping points.** Reefs that are already weakened by factors such as pollution, overfishing, disease, or storm damage are particularly vulnerable, as these stresses reduce their ability to recover after bleaching.[40-44]

Climate models suggest that if warming exceeds 2°C, especially alongside continued deforestation, parts of the Amazon could shift permanently toward savanna-like ecosystems. Beyond the Amazon, similar processes are being observed in boreal and temperate forests. Changes in vegetation can alter local climate – for example, by changing how much sunlight the land reflects, affecting moisture cycles and increasing fire activity.

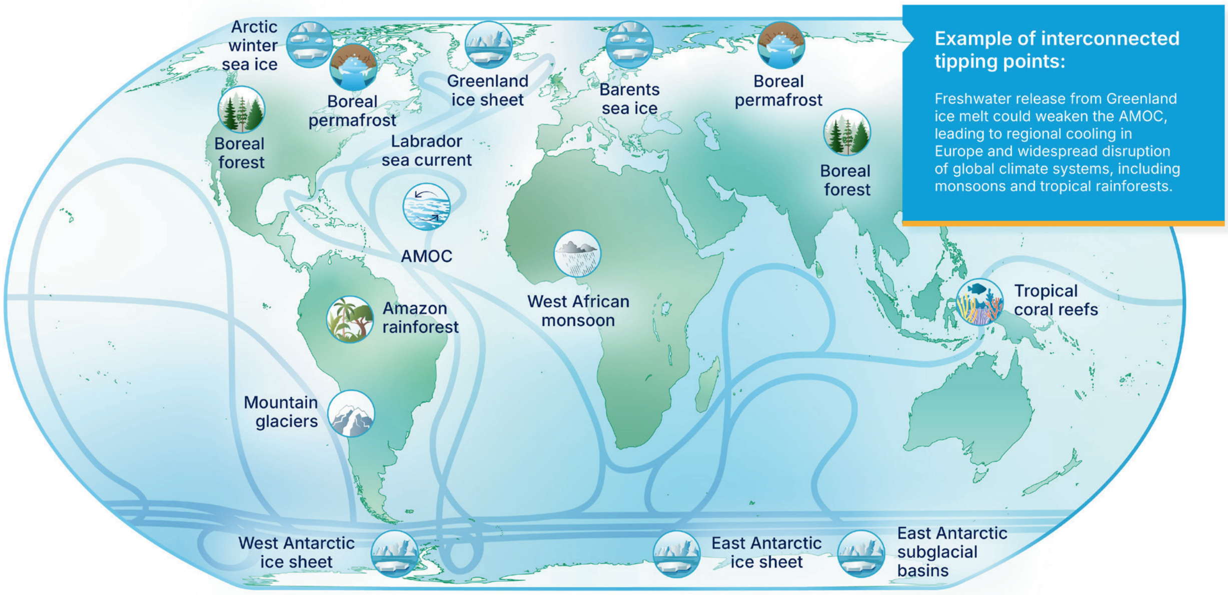


Figure 3: Global tipping points overview

Drawn from Armstrong McKay 2022.

Rainforest and forest–climate systems:

In the Amazon, scientists increasingly study tipping point risk as the result of multiple interacting pressures, rather than a single cause. Key drivers include warming, reduced rainfall, drought, deforestation, fires, and forest fragmentation, all of which affect how well the ecosystem can recover. A feature of the Amazon is that it recycles much of its own rainfall – this feedback is essential to the rainforest's ability to maintain itself. When large areas of forest are lost or damaged by drought, less moisture is recycled and rainfall can decline elsewhere in the region, and drier conditions can lead to further forest loss. At smaller scales, this process is worsened by fires, which become more likely when forests are thinner and the air is drier. Fires can also encourage the spread of grasses, making future fires even more likely.

These feedbacks could transform many forests into more open landscapes and potentially cause them, under high levels of warming, to shift from storing carbon over the long-term to releasing it.[45-47]

Risks and opportunities

Earth system tipping points represent a class of risk that exceeds incremental climate impacts. Their defining features (non-linear change, uncertain thresholds, irreversibility on human timescales, and the potential for cascading interactions) mean that damage may accelerate rapidly, propagate across regions and sectors, and persist long even after the initial cause is reduced.

Current scientific assessments indicate that several Earth sub-systems may be at risk within this century (see Annex 1 Diagram), including large ice sheets, ocean circulation systems, tropical forests and coral reef ecosystems. Indeed, **in the case of tropical coral reef systems, we may already be in a period of widespread irreversible loss.** The risk lies not only in the failure of individual sub- systems, but in the potential for interacting processes that reduce overall Earth system resilience and lead to long-term, irreversible impacts.

At the same time, advances in Earth system science create **new opportunities to understand these risks more accurately.** Improved climate models, observational datasets and paleoclimate reconstructions are enabling clearer identification of vulnerable sub- systems, better estimates of threshold ranges, and more robust distinction between short-term variability and committed long-term change. As noted above, the introduction of AI models, which add capacity to run larger and less computationally intensive ensembles, allows us to obtain more precise quantification of the likelihood of such events. Emerging methods for detecting early-warning signals of reduced resilience – including changes in variability and recovery rates – offer a future potential to identify destabilisation before a tipping point threshold is reached. Some of these advances could support more targeted monitoring of critical regions such as polar ice sheets, ocean convection zones, and tropical forests, where early signs of instability may first emerge.

Finally, it is important to recognize that, **while tipping points are a distinct and particularly consequential category of environmental risk, Earth system risks are not limited to tipping point dynamics alone.** Many significant climate-related impacts arise from gradual but accelerating changes, including increases in extreme heat, sea-level rise, and ecosystem degradation that do not depend on discrete tipping point thresholds. From this perspective, tipping points represent a crucial and urgent component of a broader risk landscape. Because these forms of risk differ in their timescales, reversibility, and levels of scientific certainty, considering them in combination can support more comprehensive assessments and more robust decision-making under uncertainty.[48]

Considerations for the UN

The scientific findings outlined in this brief indicate that **Earth system tipping point processes differ in important ways from many environmental risks traditionally addressed by international governance frameworks.** Their defining characteristics – non-linear change, uncertain thresholds, potential irreversibility, and cascading impacts across regions and sectors – mean that environmental change may occur more abruptly, be harder to reverse, and extend beyond the scope of individual policy domains.

These characteristics suggest that **existing governance approaches, which are often designed to manage gradual and sector-specific change, may face limitations in addressing systemic and cross-scale risks.** Tipping point dynamics can move across climate, ecosystems, water systems, and human development outcomes, with implications extending well beyond environmental policy into broader areas of global risk management.

At the same time, many of the policy instruments relevant to reducing exposure to tipping point risks (e.g. climate mitigation, ecosystem protection, adaptation planning, and disaster risk reduction) are already embedded within current international frameworks. A central consideration is therefore how existing approaches could account for the distinctive features of tipping point risks, including the need to operate under high levels of uncertainty, anticipate long-term and potentially irreversible change, and consider interactions across systems.

Advances in scientific understanding are improving the ability to identify vulnerable regions, assess potential thresholds, and detect early signals of system instability. Our evolving knowledge base may support more forward-looking approaches to risk assessment and planning, particularly where long-term commitments and cascading effects are possible. These advances highlight the importance of **sustained observation, data sharing, and the integration of scientific insights across governance domains.**

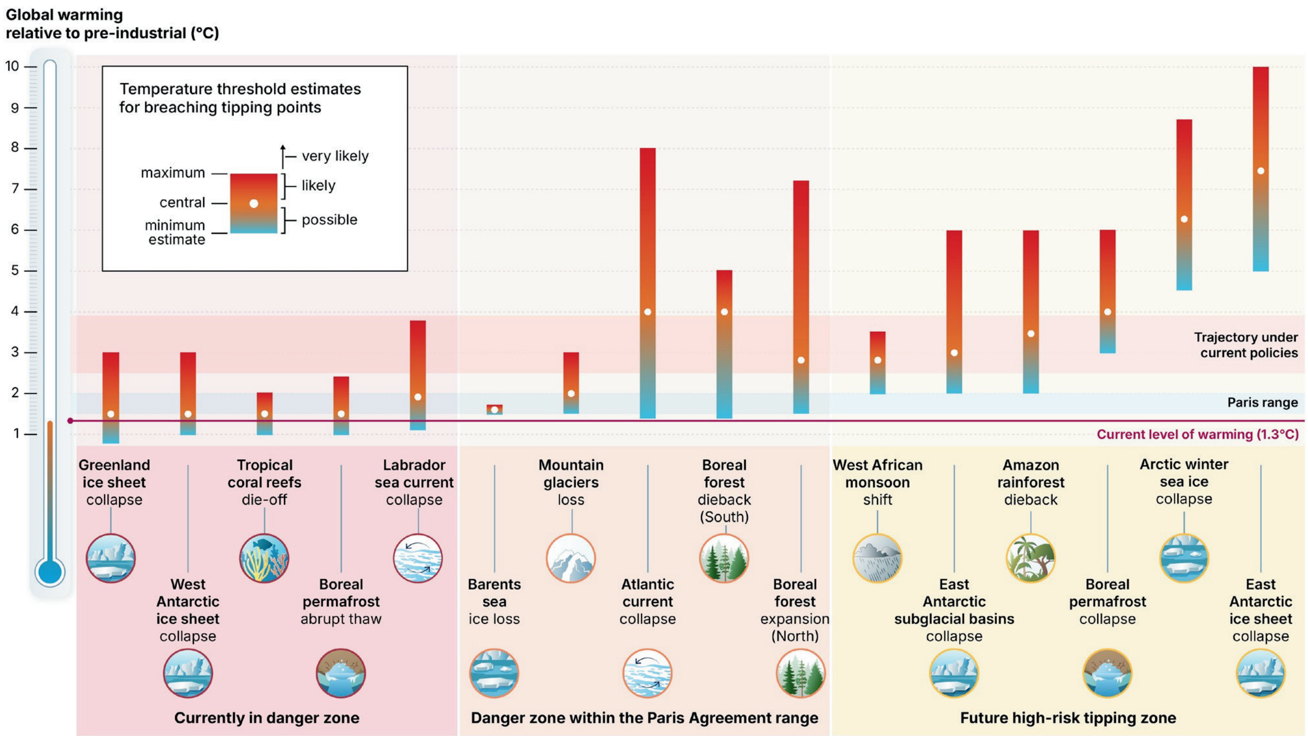
Governance approaches may need to consider not only the possibility of crossing critical thresholds, but also the cumulative impacts of ongoing change. This highlights the importance of clearly communicating different types of uncertainty, including how likely changes are, how quickly they may occur, and whether they can be reversed. Taking these factors into account within existing governance frameworks may help support responses that are effective across a range of possible futures.

Annex 1

Figure 4: Risks of climate tipping points

Based on Armstrong McKay 2022 (some ranges updated in Global Tipping Points 2025).

HOW TO READ FIGURE 4:
Figure 4 illustrates the **estimated temperature thresholds at which key planetary sub-systems may reach climate tipping points.** The current level of warming (1.3°C above pre-industrial levels), shown by the pink horizontal line, suggests that some tipping elements may already be approaching or entering their risk range. The vertical bars show the range of possible temperature increases where certain critical changes might happen. This range reflects how sure scientists are about these predictions. As the temperature goes up, more of these critical changes are expected to become possible, potentially happening suddenly or not being reversible.



Layout and illustrations created with the support of Endosymbiont GmbH
www.endosymbiont.com

ENDO SYMBIONT

DISCLAIMER: The views expressed in this brief do not necessarily reflect those of the United Nations, its affiliated agencies and programmes, or the scientific community writ large, but rather reflect the independent assessment of the Scientific Advisory Board.

Produced in partnership with the Potsdam Institute for Climate Impact Research.

References

1 Abram NJ et al. Emerging evidence of abrupt changes in the Antarctic environment. Nature. 2025;644(8077):621-633. doi:10.1038/s41586-025-09349-5

2 Armstrong McKay DI et al. Exceeding 1.5°C global warming could trigger multiple climate tipping points. Science. 2022;377(6611):eabn7950. doi:10.1126/science.abn7950

3 Dakos V et al. Tipping point detection and early warnings in climate, ecological, and human systems. Earth System Dynamics. 2024;15(4):1117-1135. doi:10.5194/esd-15-1117-2024

4 Flores BM et al. Critical transitions in the Amazon forest system. Nature. 2024;626(7999):555-564. doi:10.1038/s41586-023-06970-0

5 Kikstra JS et al. The IPCC Sixth Assessment Report WGIII climate assessment of mitigation pathways: from emissions to global temperatures. Geoscientific Model Development. 2022;15(24):9075-9109. doi:10.5194/gmd-15-9075-2022

6 Lenton TM et al. Tipping elements in the Earth's climate system. Proc Natl Acad Sci U S A. 2008;105(6):1786-1793. doi:10.1073/pnas.0705414105

7 Lenton TM et al. Climate tipping points - too risky to bet against. Nature. 2019;575(7784):592-595. doi:10.1038/d41586-019-03595-0

8 Loriani S et al. Tipping points in ocean and atmosphere circulations. Earth System Dynamics. 2025;16(5):1611-1653. doi:10.5194/esd-16-1611-2025

9 Melnikova I et al. Amazon dieback beyond the 21st century under high-emission scenarios by Earth System models. Commun Earth Environ. 2025;6(1):670. doi:10.1038/s43247-025-02606-5

10 Rahmstorf S. Is the Atlantic Overturning Circulation Approaching a Tipping Point? Oceanography. 2024;37(3):16-29. https://www.jstor.org/stable/27333920

11 Roman CRM et al. Earth System Tipping Points are a threat to Europe. JRC Publications Repository. 2025. Accessed May 19, 2026. https://publications.jrc.ec.europa.eu/repository/handle/JRC140827

12 Rotbarth R et al. Boreal forests are heading for an open state. Proceedings of the National Academy of Sciences. 2025;122(2):e2404391121. doi:10.1073/pnas.2404391121

13 Winkelmann R et al. Mapping tipping risks from Antarctic ice basins under global warming. Nat Clim Chang. 2026;16(3):341-349. doi:10.1038/s41558-025-02554-0

14 Wunderling N et al. Climate tipping point interactions and cascades: a review. Earth System Dynamics. 2024;15(1):41-74. doi:10.5194/esd-15-41-2024

15 Barnes EA et al. Indicator Patterns of Forced Change Learned by an Artificial Neural Network. Journal of Advances in Modeling Earth Systems. 2020;12(9):e2020MS002195. doi:10.1029/2020MS002195

16 Ham YG, Kim JH, and Luo JJ. Deep learning for multi-year ENSO forecasts. Nature. 2019;573(7775):568-572. doi:10.1038/s41586-019-1559-7

17 Watt-Meyer O et al. ACE2: accurately learning subseasonal to decadal atmospheric variability and forced responses. npj Clim Atmos Sci. 2025;8(1):205. doi:10.1038/s41612-025-01090-0

18 Ashwin P et al. Tipping points in open systems: bifurcation, noise-induced and rate-dependent examples in the climate system. Philos Trans A Math Phys Eng Sci. 2012;370(1962):1166-1184. doi:10.1098/rsta.2011.0306

19 Bury TM et al. Deep learning for early warning signals of tipping points. Proceedings of the National Academy of Sciences. 2021;118(39):e2106140118. doi:10.1073/pnas.2106140118

20 Huang Y et al. Deep learning for predicting rate-induced tipping. Nat Mach Intell. 2024;6(12):1556-1565. doi:10.1038/s42256-024-00937-0

21 Layritz LS et al. Early warning signs for tipping points in systems with non-Gaussian α-stable noise. Sci Rep. 2025;15(1):13758. doi:10.1038/s41598-025-88659-0

22 Lenton TM et al. Remotely sensing potential climate change tipping points across scales. Nat Commun. 2024;15(1):343. doi:10.1038/s41467-023-44609-w

23 Liu-Schiaffini M et al. Tipping Point Forecasting in Non-Stationary Dynamics on Function Spaces. arXiv. Preprint posted online January 14, 2026:arXiv:2308.08794. doi:10.48550/arXiv.2308.08794

24 Sleeman J et al. Using Artificial Intelligence to aid Scientific Discovery of Climate Tipping Points. arXiv. Preprint posted online February 14, 2023:arXiv:2302.06852. doi:10.48550/arXiv.2302.06852

25 Zhuge C, Li J, and Chen W. Deep learning for predicting the occurrence of tipping points. R Soc Open Sci. 2025;12(7):242240. doi:10.1098/rsos.242240

26 Lenton TM et al. Global Tipping Points Report 2025. Published online 2025. https://global-tipping-points.org/download/1419/

27 Programme UNE. Global Environment Outlook 7: A Future We Choose – Why Investing in Earth Now Can Lead to a Trillion-Dollar Benefit for All. 2025. doi:10.59117/20.500.11822/49014

28 Abrams JF et al. Committed Global Warming Risks Triggering Multiple Climate Tipping Points. Earth's Future. 2023;11(11):e2022EF003250. doi:10.1029/2022EF003250

29 Boers N. Observation-based early-warning signals for a collapse of the Atlantic Meridional Overturning Circulation. Nat Clim Chang. 2021;11(8):680-688. doi:10.1038/s41558-021-01097-4

30 Fox-Kemper B. Ocean, Cryosphere and Sea Level Change. In: Vol 2021. 2021:U13B-09. https://ui.adsabs.har vard.edu/abs/2021AGUFM.U13B..09F

31 Krinner G. Permafrost and ice sheets: potential abrupt and/or irreversible changes. Comptes Rendus Géoscience. 2025;357(G1):389-400. doi:10.5802/crgeos.305

32 Pattyn F, and Morlighem M. The uncertain future of the Antarctic Ice Sheet. Science. 2020;367(6484):1331-1335. doi:10.1126/science.aaz5487

33 Turetsky MR et al. Permafrost collapse is accelerating carbon release. Nature. 2019;569(7754):32-34. doi:10.1038/d41586-019-01313-4

34 Swingedouw D et al. On the risk of abrupt changes in the North Atlantic subpolar gyre in CMIP6 models. Annals of the New York Academy of Sciences. 2021;1504(1):187-201. doi:10.1111/nyas.14659

35 Böning CW et al. Emerging impact of Greenland meltwater on deepwater formation in the North Atlantic Ocean. Nature Geosci. 2016;9(7):523-527. doi:10.1038/ngeo2740

36 Caesar L et al. Observed fingerprint of a weakening Atlantic Ocean overturning circulation. Nature. 2018;556(7700):191-196. doi:10.1038/s41586-018-0006-5

37 Ditlevsen P, and Ditlevsen S. Warning of a forthcoming collapse of the Atlantic meridional overturning circulation. Nat Commun. 2023;14(1):4254. doi:10.1038/s41467-023-39810-w

38 Lozier MS et al. A sea change in our view of overturning in the subpolar North Atlantic. Science. 2019;363(6426):516-521. doi:10.1126/science.aau6592

39 Weijer W et al. Stability of the Atlantic Meridional Overturning Circulation: A Review and Synthesis. Journal of Geophysical Research: Oceans. 2019;124(8):5336-5375. doi:10.1029/2019JC015083

40 Eakin CM, Sweatman HPA, and Brainard RE. The 2014–2017 global-scale coral bleaching event: insights and impacts. Coral Reefs. 2019;38(4):539-545. doi:10.1007/s00338-019-01844-2

41 Hoegh-Guldberg O et al. Coral Reef Ecosystems under Climate Change and Ocean Acidification. Front Mar Sci. 2017;4. doi:10.3389/fmars.2017.00158

42 Hughes TP et al. Global warming and recurrent mass bleaching of corals. Nature. 2017;543(7645):373-377. doi:10.1038/nature21707

43 Smale DA et al. Marine heatwaves threaten global biodiversity and the provision of ecosystem services. Nat Clim Chang. 2019;9(4):306-312. doi:10.1038/s41558-019-0412-1

44 Sully S et al. A global analysis of coral bleaching over the past two decades. Nat Commun. 2019;10(1):1264. doi:10.1038/s41467-019-09238-2

45 Lovejoy TE, and Nobre C. Amazon tipping point: Last chance for action. Science Advances. 2019;5(12):eaba2949. doi:10.1126/sciadv.aba2949

46 Nobre CA et al. Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm. Proceedings of the National Academy of Sciences. 2016;113(39):10759-10768. doi:10.1073/pnas.1605516113

47 Ritchie PDL et al. The implications of overshooting 1.5 °C on Earth system tipping elements—a review. Environ Res Lett. 2026;21(4):043001. doi:10.1088/1748-9326/ae3cad

48 Kopp RE et al. 'Tipping points' confuse and can distract from urgent climate action. Nat Clim Chang. 2025;15(1):29-36. doi:10.1038/s41558-024-02196-8