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The Significance of Climate Tipping Points for Finland: Latest Information on the Possible Shutdown of the Atlantic Meridional Overturning Circulation (AMOC) and Preventive Climate Actions

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Key messages

- **Globally:** Climate warming affects the stability of the Atlantic Meridional Overturning Circulation (AMOC), and concerns about the potential shutdown of the AMOC within this century have grown. A shutdown would lead to cooling in the northern hemisphere, warming in the southern hemisphere, and a southward shift of monsoon rainfall zones. Since the possibility of an AMOC shutdown cannot be ruled out, it is crucial to understand its societal impacts both globally and regionally.
- **In Europe:** The impacts of an AMOC shutdown would be extremely significant for Western and Northwestern Europe. Europe's climate would cool significantly, especially in winter.
- **In Northern Europe and Finland**, the impacts would be particularly strong. The latest modeling results show that in Finland, the average mid-winter temperature would decrease by about 20°C and the average mid-summer temperature by about 5°C, not accounting for the partially compensating warming due to ongoing climate change. Such cooling would significantly affect housing, transportation, and ecosystems.
- **The most effective measure to prevent an AMOC shutdown is to limit the rate of global warming.** Warming accelerates the melting of the Greenland ice sheet and Arctic sea ice, as well as changes in precipitation and river flows, which are key factors in the weakening of the AMOC. **We emphasize that there is no scientific consensus yet on the likelihood of an AMOC shutdown.**

Short Introduction

This policy brief discusses the current state of the global climate, the present scientific understanding of climate system tipping points, and the governance implications with policy recommendations. In our scientific review, we focus on the latest information on the current state of the Atlantic Meridional Overturning Circulation (AMOC) and its possible shutdown. We discuss the temperature impacts of an AMOC shutdown based on recently published modeling results[1] and the resulting regional effects for Finland as part of the Academy of Finland's ACCC flagship research program on the impacts of and adaptation to climate change.

A climate system tipping point can be defined as a critical threshold, whose crossing causes self-reinforcing and irreversible changes in the climate system's functioning. Tipping points are concerning because, once crossed, the effects of climate change can accelerate and become uncontrollable, making a return to the previous climate state very difficult or impossible. Currently, we are aware of 25 potential climate system tipping points that can be triggered as climate change progresses and that would have severe global or regional consequences for nature and societies. Some of these tipping points are no longer "low probability, high impact" events but are becoming "high probability, high impact" events as climate change advances[2].The recent discourse on tipping points has been fueled by the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6)[3], the 2023 report on global climate system tipping points[2], and the latest observations and modeling studies, particularly concerning the potential near-term tipping point of the Atlantic Meridional Overturning Circulation (AMOC). The risks associated with tipping points are increasingly being discussed in new seminars and events addressing future threats[4].

The potential proximity of tipping points also means that climate change may be more unpredictable than how it is currently addressed in climate policy discussions and international governance systems.

Critical signs of instability have been observed in the Greenland and West Antarctic ice sheets, which have already entered a state of continuous melting, in the Amazon rainforest system, and in the Atlantic Meridional Overturning Circulation (AMOC). In our policy recommendation, we focus on the impacts of an AMOC shutdown for Northern Europe, and particularly for Finland. The risks of an AMOC shutdown are significant for the Nordic countries, endangering ecosystem viability, food security, the economy, and living conditions.

Current state of climate

In 2023, the global annual-average temperature exceeded by 1.4°C the pre-industrial average temperature for the first time, while the warming calculated linearly from a 50-year time series has now reached 1.2°C. Since 1979, the Arctic region has warmed nearly four times faster than the

[1] Van Westen,R. et al. (2024) "Physics-based early warning signal shows that AMOC is on tipping course." *Sci. Adv* 10.6.

[2] Lenton, T.M., et al. (eds) (2023), University of Exeter, Exeter, UK, https://global-tipping-points.org/

[3] IPCC AR6 Working Group 1: Technical Summary | Climate Change 2021: The Physical Science Basis

[4] e.g., Gregow, H. (2023), "Tarvitsemme ilmastoneutraaliuuden vallankumouksen (We need a climate neutrality revolution, in Finnish)" Futura 2/2023 – tutuseura.fi.

global average[5], and the Arctic sea-ice has lost over 50% of its volume due to warming. While 2023 record temperatures were influenced by the natural El Nino climate pattern in the Eastern Pacific, there are growing concerns that the global warming rate has accelerated.

The Earth warms when it radiates less energy back into space than it receives from solar radiation. The imbalance in the energy flux is now at its highest since the commencement of CERES satellite observations in 1997. This imbalance is 1.4 W/m^2 (2020-2023 average), meaning that 0.4% of all solar radiation received by the Earth is now being used to warm the climate system, roughly double the average from 2005-2015. Only a small portion (1%) of this heat remains in the atmosphere, while the majority is absorbed by the oceans (89%). Additionally, 6% of the heat goes to land surface warming and 4% to glacier melting[6].

The effects of this warming on the global climate system are severe and far-reaching. They manifest as deadly heatwaves, the melting of the Greenland ice sheet, Arctic sea ice, and permafrost, and changes in global ocean dynamics affecting large-scale weather patterns. In 2023, the heat content of the world's oceans increased by about 15×10^{21} Joules[7], an energy equivalent of roughly eight Hiroshima bombs per second. Ocean warming is also associated with changes in salinity and currents, as well as intense marine heatwaves in surface waters.

AMOC shutdown

AMOC is the most significant Atlantic Ocean current system, transporting warm water as a near-surface flow from the south towards Europe, interacting with atmospheric winds, and returning cooled water as a near-bottom flow back towards the south. AMOC is part of the broader general ocean circulation, driven by winds and thermohaline circulation, which is based on density gradients caused by differences in water temperature (thermo) and salinity (haline). Due to its role in heat transport, AMOC plays a crucial role in regulating the temperatures, precipitation, and weather patterns across the globe, and particularly in Europe.

There is relatively compelling evidence, based on the use of multiple proxies, that AMOC has slowed down by approximately 15% since 1950 and is now at its weakest in over 1,600 years[8,9]. After the peak of the last ice age (20,000 years ago), it is likely that AMOC has stopped several times due to meltwater from retreating glaciers (17.5, 14.7, 12.9, and 11.7 thousand years ago). These stoppages were followed by a significant decrease in temperatures in the northern

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[5] Rantanen, M., et al. (2022) "The Arctic has warmed nearly four times faster than the globe since 1979." *Communications earth & environment* 3.1: 168. https://www.nature.com/articles/s43247-022-00498-3

[6] von Schuckmann, et al. (2023) “Heat stored in the Earth system 1960–2020 (2023): where does the energy go?” Earth Syst. Sci. Data, 15, 1675–1709, https://doi.org/10.5194/essd-15-1675-2023

[7] Cheng, L., et al. (2024) "New Record Ocean Temperatures and Related Climate Indicators in 2023." *Advances in Atmospheric Sciences*: 1-15, https://link.springer.com/article/10.1007/s00376-024-3378-5

[8] Caesar, L., et al. (2021) "Current Atlantic Meridional Overturning Circulation weakest in last millennium, *Nat. Geosci.,* 14, 118–120."

[9] Rahmstorf, S. (2024): Is the Atlantic Overturning Circulation Approaching a Tipping Point?, Oceanog, https://doi.org/10.5670/oceanog.2024.501.

hemisphere and an increase in temperatures in the southern hemisphere before the circulation slowly recovered[10].

Several recent studies, based on various methods, have suggested that AMOC might be on the verge of shutting down already within this century[1,11,12], primarily due to the decrease in salinity of North Atlantic surface waters caused by meltwater from Greenland and Arctic sea ice. The potential shutdown of AMOC is anticipated from warning signals that examine changes in the natural variability of the circulation before a critical transition. These studies found such warning signals in long sea surface temperature time series and modeled heat transport in the southern hemisphere.

An IPCC's special report[13] states that the probability of a complete AMOC shutdown by 2300 is about 50% under high future greenhouse gas emission scenarios. Although more recent studies have raised concerns that the IPCC's estimate might be too conservative, there is no scientific consensus on the likelihood of an AMOC shutdown within the next hundred years. This is because observations of the circulation have not been conducted long enough or comprehensively enough to fully understand its current state. Additionally, current climate models do not predict a rapid collapse of AMOC within the next hundred years under any warming scenario. Instead, they predict a steady and gradual weakening of the flow[14], and hence the AMOC's impact on climate change during this century would be minor[15]. However, some estimates suggest that the AMOC modeled by current climate models might be too stable[10], and that a collapse could indeed occur within this century[12].

The nature of an AMOC shutdown – whether it would be a rapid collapse occurring over decades, or a gradual one taking up to 300 years, or something in between – remains uncertain. A rapid collapse can be seen as a concerning but unlikely scenario, with the range of warming that could trigger such a collapse based on current knowledge being 1.4-8.0°C[16]. It is also possible that an AMOC shutdown would not be complete but only partial, affecting the so-called Subpolar Gyre south of Greenland[3,10,16], which would still have significant impacts on Europe's climate.

In any case, it is clear that the effects of an AMOC shutdown would be very significant for the global climate system, and especially for Northern Europe. The most effective measure to prevent

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[10] Pöppelmeier, F., et al. "Multi-proxy constraints on Atlantic circulation dynamics since the last ice age." *Nature geoscience* 16.4 (2023): 349-356.

[11] Boers, N. "Observation-based early-warning signals for a collapse of the Atlantic Meridional Overturning Circulation." *Nature Climate Change* 11.8 (2021): 680-688

[12] Ditlevsen, P, and Ditlevsen, S. "Warning of a forthcoming collapse of the Atlantic meridional overturning circulation." *Nature Communications* 14.1 (2023): 1-12.

[13] https://www.ipcc.ch/srocc/chapter/chapter-6/

[14] Weijer, W., et al. "CMIP6 models predict significant 21st century decline of the Atlantic meridional overturning circulation." *Geophysical Research Letters* 47, no. 12 (2020): e2019GL086075.

[15] Liu, F., et al. "Climate impacts of a weakened Atlantic Meridional Overturning Circulation in a warming climate." *Science advances* 6, no. 26 (2020): eaaz4876.

[16] Armstrong McKay, et al. "Exceeding 1.5 C global warming could trigger multiple climate tipping points." *Science* 377, no. 6611 (2022): eabn7950.

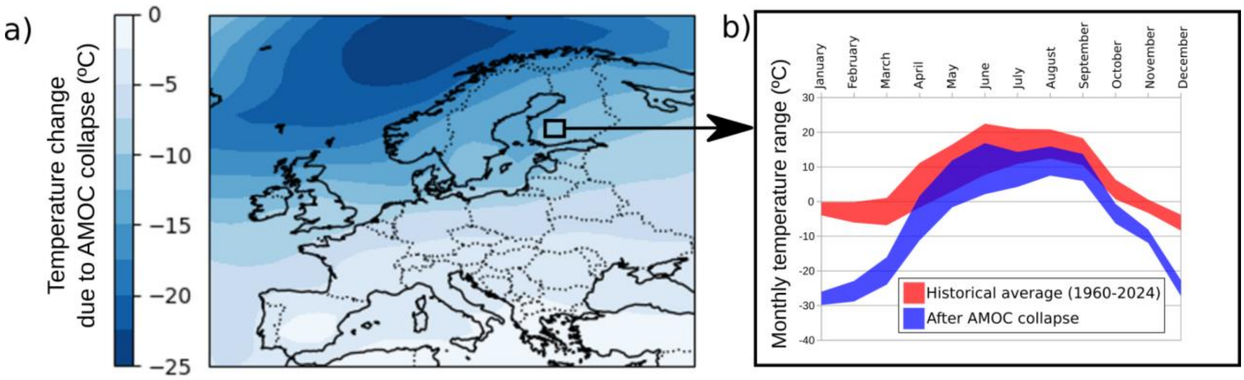
an AMOC shutdown is to limit climate warming and the rate of warming, which accelerates the melting of the Greenland ice sheet and Arctic sea ice, key factors in the weakening of AMOC. Practically, this means that global greenhouse gas emissions must be rapidly reduced, as delayed emission reductions leading to rapid climate warming increase the likelihood of an AMOC shutdown.

A better understanding of signals predicting an AMOC shutdown requires research with high-resolution models that account for Greenland meltwater, and comprehensive observations and additional monitoring of AMOC characteristics. It also requires an understanding of the role of natural variability in the climate system's contribution to AMOC variability and better knowledge of the effects of changes in local radiative forcing, such as due to atmospheric aerosols, on the flow.

Impacts of AMOC shutdown

If the AMOC were to stop quickly and completely, the effects on the global climate system would be significant[1,2,9,12]. Within a few decades, surface temperatures would decrease, and winds would strengthen across the entire northern hemisphere, both on land and at sea. Heat would concentrate in the Southern Ocean and South Atlantic, and sea levels would rise by over a meter along the east coast of North America. Precipitation would decrease significantly across Europe. Precipitation would also change across the equatorial region with a southward shift in monsoon zone and shifts in precipitation could contribute to the collapse of ecosystems like the Amazon rainforest. The extent of northern sea ice would increase, while southern sea ice would decrease. Overall, an AMOC shutdown would significantly impact global food security and access to clean water.

Northern Europe would experience a phase of rapid cooling, where the rate of cooling would counteract the current warming caused by global climate change, especially during winters.



Kuva 1: (a) Temperature impacts in Europe due to a complete AMOC shutdown, based on the results of van Westen et al. (2024)[2]. (b) Impact on monthly temperatures in Southern Finland (Jokioinen).

Figure 1a shows the modeled annual average temperature response in Europe after a complete AMOC shutdown[2]. The shutdown of AMOC would significantly lower temperatures in Northern

Europe, with the North Atlantic covered in sea ice during winters, extending as far south as the southern part of the British Isles. In addition to cooling, overall precipitation would decrease. Without considering the partially compensating warming due to ongoing climate change, the annual average temperature decrease in Finland would range from 15°C in Southern Finland to over 20°C in Northern Finland. The annual cycle would intensify: mid-summer temperatures would cool by about 5°C, while January-February average temperatures would drop by 20-25°C (Figure 1b). Windspeeds would increase significantly[17]. The Baltic Sea would experience longer periods of ice cover, with ice extending to the southern Baltic in March.

If the AMOC tipping point were around the year 2050, rapidly advancing climate change could mask some of the changes for Europe, and by the end of the century, the climate of mainland Europe might resemble pre-industrial times in terms of temperatures, although with reduced precipitation and stronger winds. Winters in Fennoscandia would be colder than in the pre-industrial era[18].

Policy considerations[2,19]

Currently, there are no adequate international governance regimes that address the risks associated with climate system tipping points. No international or regional institution includes these threats in their agenda.

The diverse impacts of tipping points in terms of geographical and temporal scales, and across different components of the climate system, require a tailored governance approach for each tipping point. Moreover, risk management systems should differ across the phases of the tipping process: (1) before the tipping, (2) during the reorganization of the system after the tipping, and (3) stabilizing the system into the new state. In the pre-tipping phase, governance should focus on prevention, early warning and monitoring, knowledge accumulation, impact anticipation, and risk assessment. In the reorganization and stabilization phases, it is important to manage impacts through adaptation, disaster preparedness, and loss and damage management. In all cases, polycentric and anticipatory approaches, system risk management, and justice and equity – including intergenerational equity – are crucial.

There are established global and regional institutions focused on the governance of climate, biodiversity, oceans, forests, the Arctic, and Antarctica that could take responsibility for managing tipping points. This would require reorganization and strengthening of these institutions' functions. The novelty and scope of risk awareness related to tipping points may also require new governance approaches and policy measures to address them.

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[17] Orihuela-Pinto, B., et al. "Interbasin and interhemispheric impacts of a collapsed Atlantic Overturning Circulation." *Nature Climate Change* 12, no. 6 (2022): 558-565.
[18] Liu, W. et al. "Overlooked possibility of a collapsed Atlantic Meridional Overturning Circulation in warming climate." *Science Advances* 3, no. 1 (2017): e1601666.
[19] Milkoreit, M., et al 'Governance for Earth System Tipping Points – a Research Agenda.' January 2024, preprint DOI: 10.2139/ssrn.4740935

The international climate change regime is most suitable policy arena for addressing the risks associated with tipping points. However, this issue is not included in current climate negotiations. Key relevant workstreams in the UN climate regime include discussions on climate neutrality and targets for limiting warming, peak emissions timelines, nationally determined contributions, global stocktake, as well as adaptation and loss and damage.

Public communication about the risks associated with tipping points can present significant challenges: on one hand, increased awareness of tipping points and their risks can spur climate action; on the other hand, it can lead to strong emotional reactions, fear of the future, and paralyzing effects on action. Therefore, communication about the risks and impacts of tipping points should be balanced with solution-focused messaging that aims to build a sense of empowerment and responsibility.

Recommendations

• Several major climate system tipping points are already near and may be crossed at lower levels of warming than previously assumed, potentially leading to catastrophic and cascading impacts globally or locally. We recommend that policymakers consider how to prepare for and manage the risks associated with tipping points.

• Research funding should be directed towards climate models and observational monitoring. The impacts of climate system tipping points should also be examined more closely at the societal level.

• Prevention is the key strategy for combating the risks associated with climate system tipping points. Finland can proactively engage in international climate policy by advocating for rapid reductions in greenhouse gas emissions, increasing sustainable carbon dioxide removal capacity, and addressing drivers of climate system tipping points not directly related to climate change, such as deforestation.

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