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The Atlantic Meridional Overturning Circulation (AMOC): Risks, Tipping Points, and Adaptation

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Agenda

1. **AMOC 101**
2. Latest Science and Impacts
3. Discussion: Implications for adaptation

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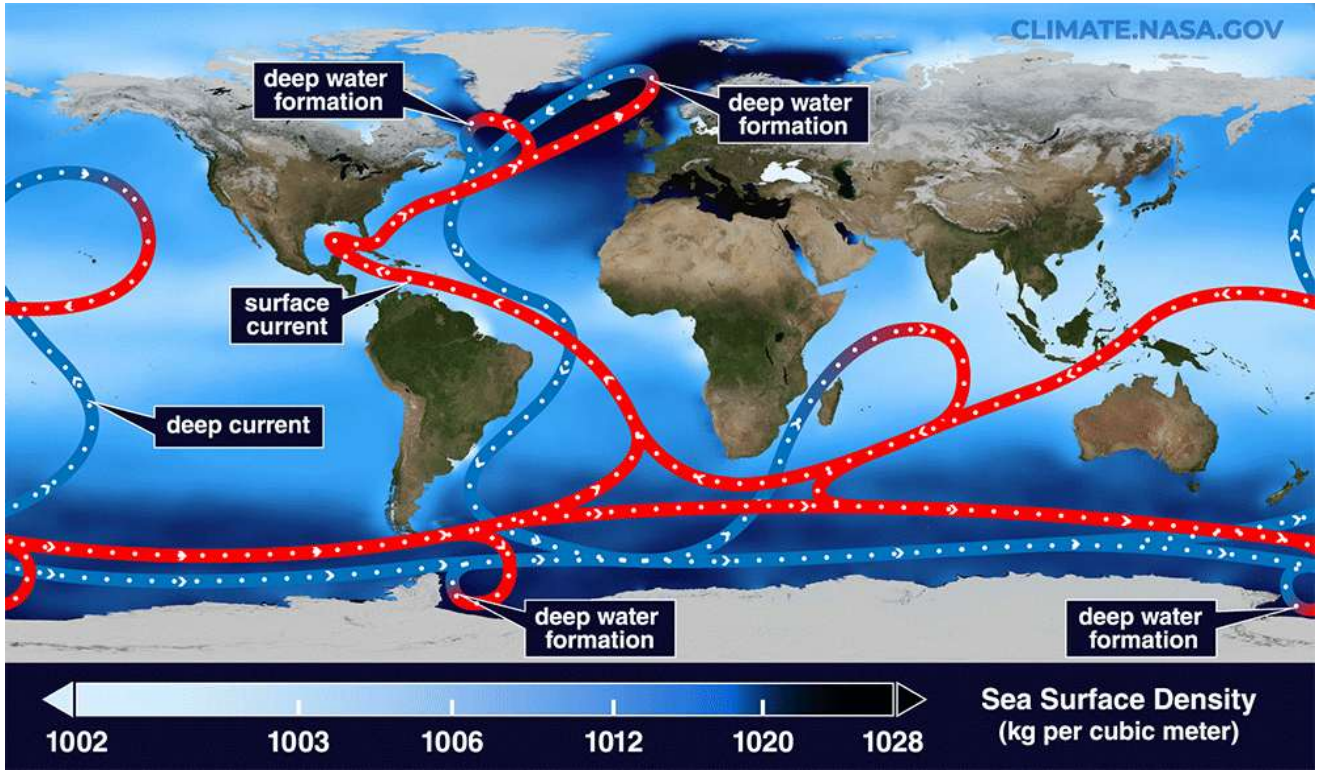
What is the AMOC?



- The Atlantic Meridional Overturning Circulation (AMOC) is a system of ocean currents (including the Gulf Stream) that transports **warm water** northward from the tropics to the North Atlantic and **cold water** southward, at depth.
- This circulation is driven by differences in temperature and salinity, which create differences in water density (thermohaline circulation).

https://science.nasa.gov/earth/earth-atmosphere/slowdown-of-the-motion-of-the-ocean/

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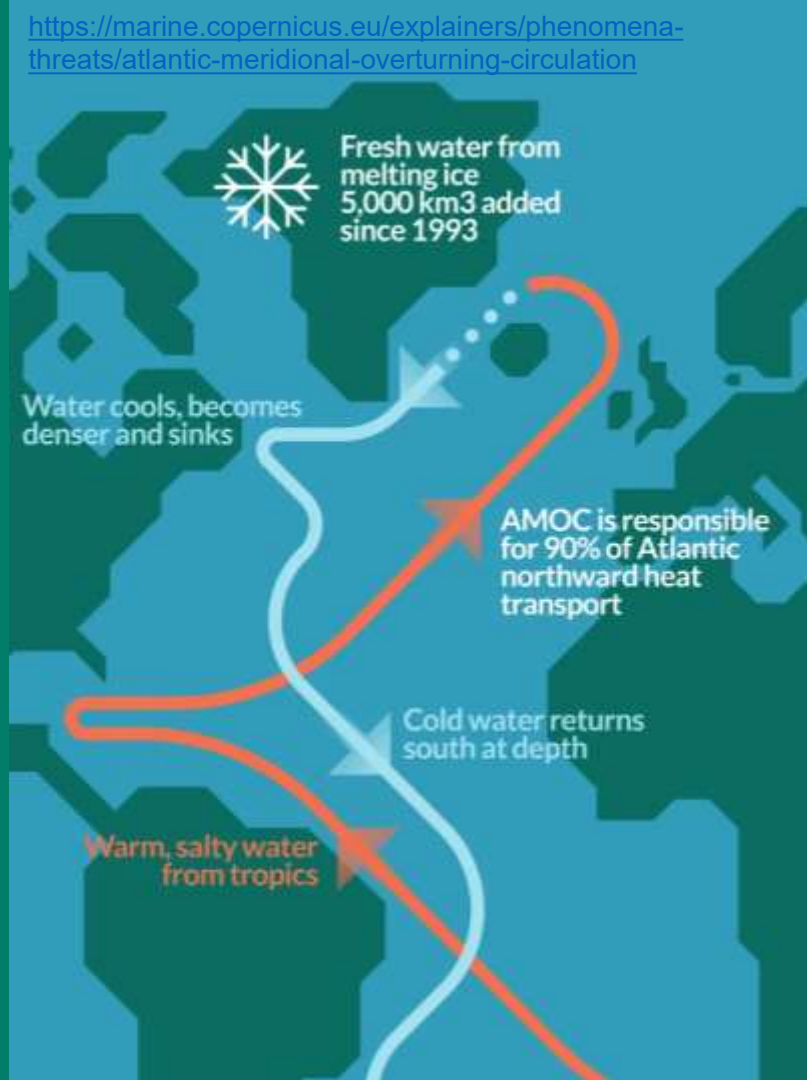
What is the AMOC?

- Salinity
  - As water is transported away from the equator, it cools and becomes more dense due to an increase in salinity
  - This denser water sinks and is replaced by warmer surface water.
- Temperature
  - Water travelling from the poles towards the equator warms and becomes less dense.
  - This water rises and helps drive the THC.
- Wind
  - Surface water (up to 400m deep) is affected by surface winds.
  - Much of the heat transfer in the Atlantic occurs because of the Gulf Stream.

https://marine.copernicus.eu/explainers/phenomena-threats/atlantic-meridional-overturning-circulation



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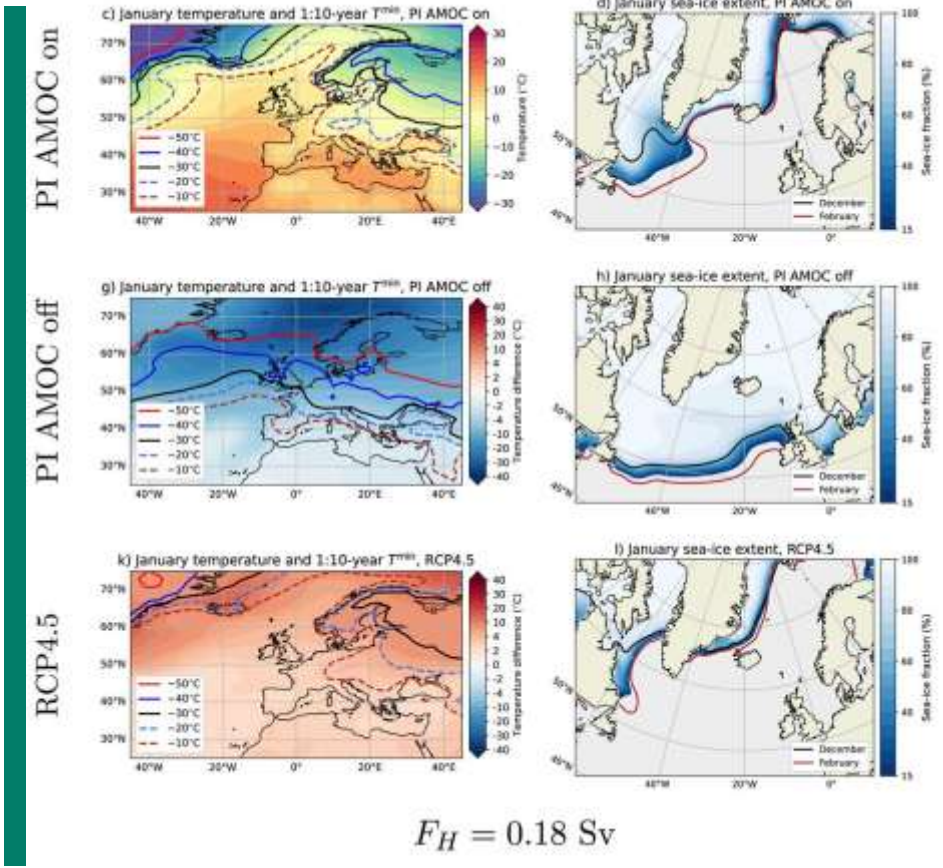
Why is the AMOC important?

- Climate Regulation:
  - Transports ~1.3 petawatts of heat northward (equivalent to 100x global energy consumption).
  - Keeps Europe 5–10°C warmer than it would otherwise be.

https://doi.org/10.1029/2025GL114611



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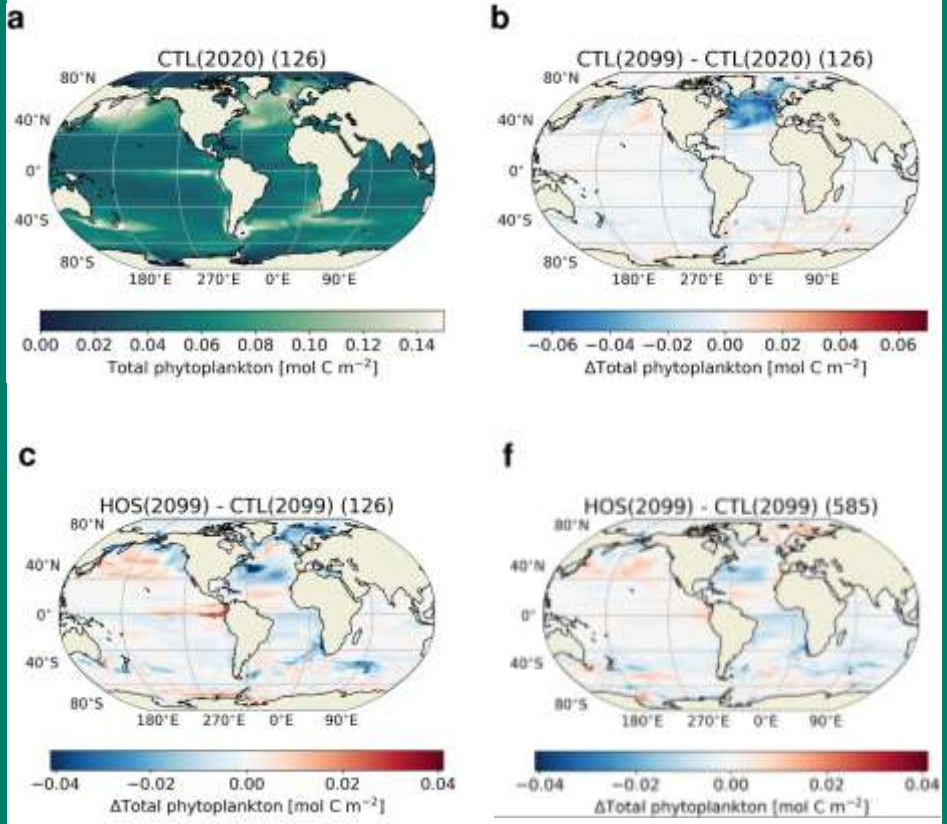
Why is the AMOC important?

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2024EF004741

- Ecosystems:
  - Nutrient distribution supports fisheries (e.g., North Atlantic cod).
  - A weakening AMOC leads to a significant reduction in phytoplankton biomass, which cascades up the food chain, threatening marine biodiversity and global fisheries and impacting food security.



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Why is the AMOC important?

- Human systems influences:
  - Temperature extremes.
    - UK has milder winters than similar latitudes because of AMOC influence.
  - Monsoon timing and locations.
  - Sea level.
  - Marine productivity.
  - Food security.

- AMOC is a vital natural system that underpins human health, economic stability, and environmental balance.

https://www.fisheries.noaa.gov/feature-story/accurately-accounting-economic-value-marine-ecosystems

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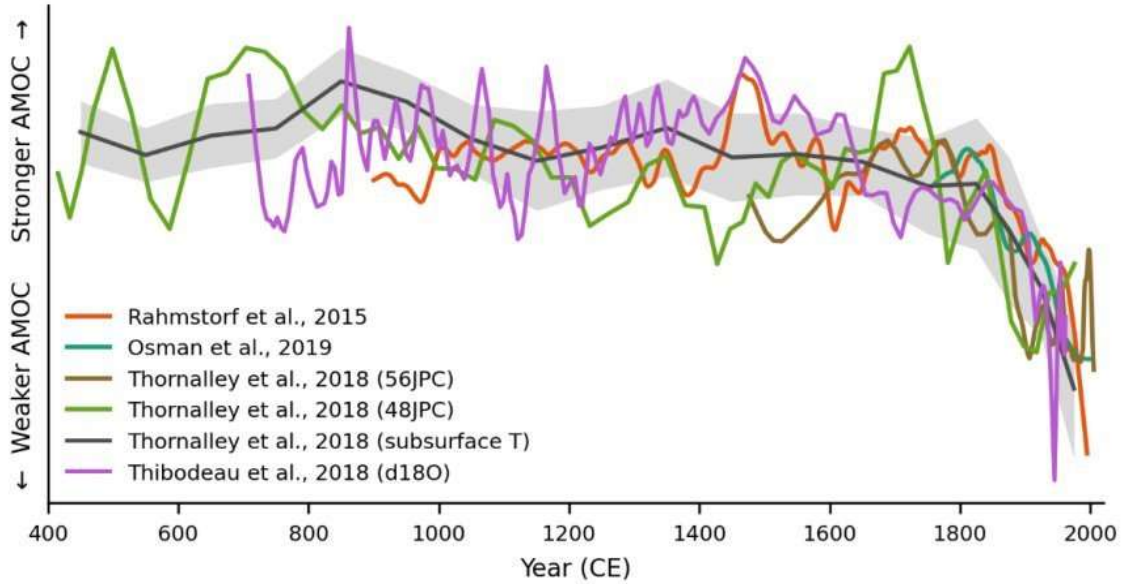
How do we know the AMOC is changing?

- Proxy data (e.g., sediment cores, coral records):
  - AMOC has shut down or weakened in the past (e.g., Younger Dryas, ~12,000 years ago).



https://doi.org/10.5194/egusphere-2026-2110

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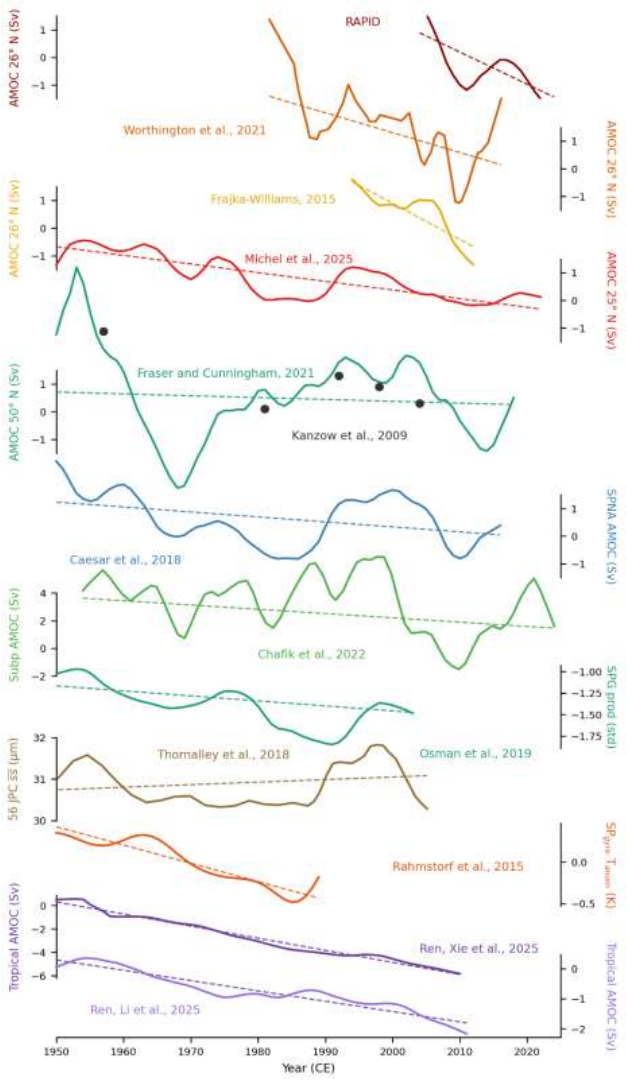
How do we know the AMOC is changing?

- Direct measurements (since 2004, e.g., RAPID array):
  - ~15% weakening since 2004 (Caesar et al., 2021).



https://doi.org/10.5194/egusphere-2026-2110

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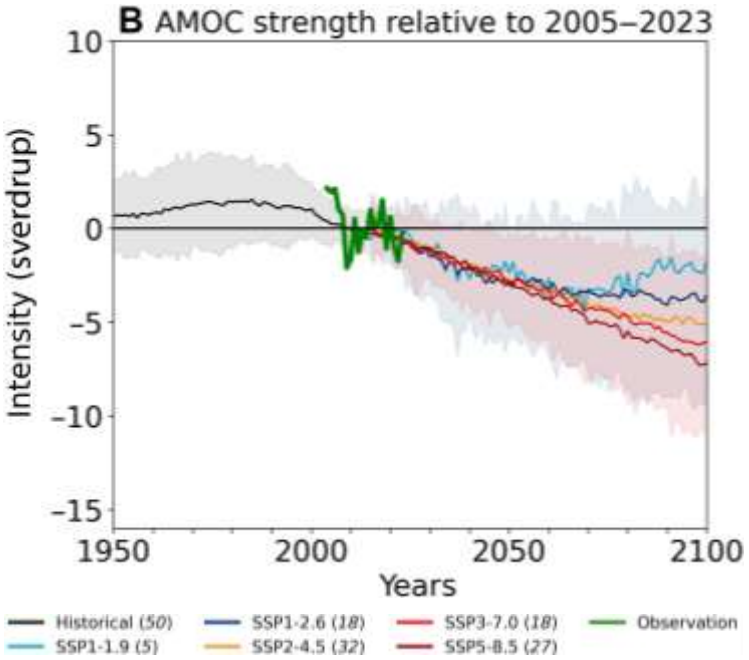
How do we know the AMOC is changing?

- Model reconstructions and projections:
  - *Medium confidence* of a projected AMOC decline by 2100 (**24%** in SSP1-2.6 to **39%** in SSP5-8.5; IPCC AR6).
  - There is *medium confidence* that an abrupt collapse will not occur before 2100 (IPCC AR6).
  - Abrupt collapse of AMOC before 2100 is very unlikely, but by 2300, an AMOC collapse is as likely as not for high-emissions scenarios.



https://www.science.org/doi/full/10.1126/sciadv.adx4298

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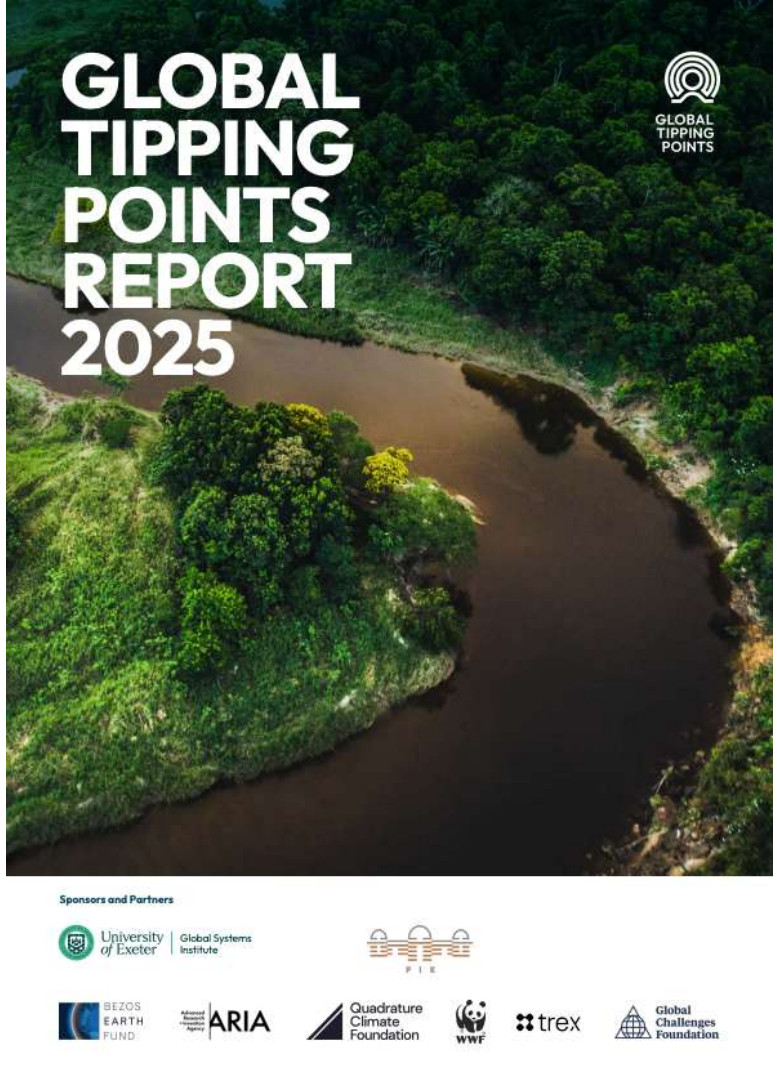
What is a Tipping Point?

- Definition:
  - A threshold beyond which a system undergoes irreversible and self-perpetuating change.
- AMOC Tipping Elements:
  - Freshwater input (e.g., Greenland ice melt dilutes saltwater, reducing sinking).
  - Ocean warming (warmer water is less dense, reducing downwelling).



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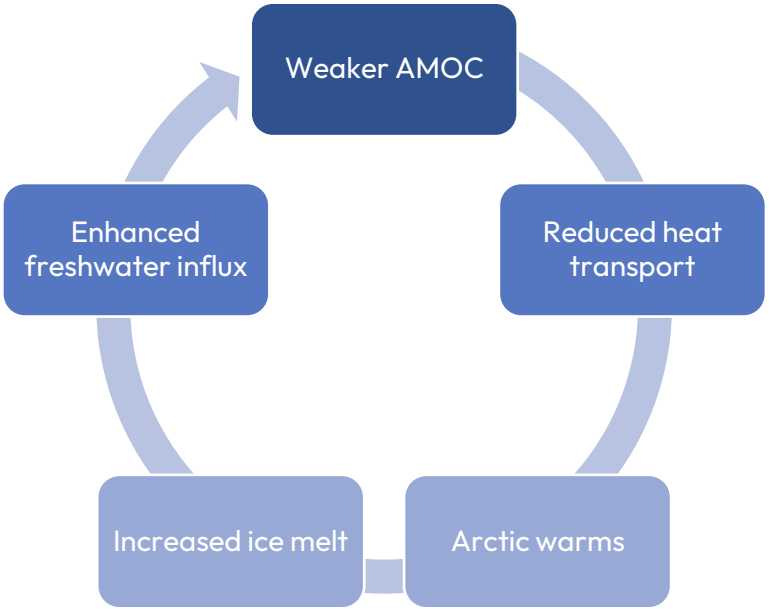
  - Feedback loops.



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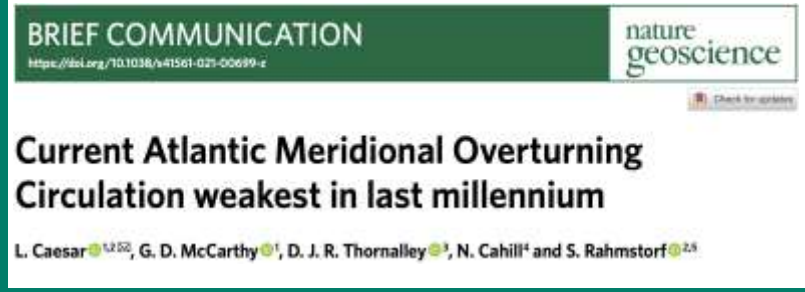
Latest science on AMOC stability

- Observed slowdown: AMOC at weakest in 1,000 years (Caesar et al., 2021).
- Recent study suggests 50% decline by 2100 (Portmann et al., 2026).
  - 51 ± 8% (90% probability)


BRIEF COMMUNICATION

nature geoscience

Current Atlantic Meridional Overturning Circulation weakest in last millennium

L. Caesar, G. D. McCarthy, D. J. R. Thornalley, N. Cahill and S. Rahmstorf


Science Advances

RESEARCH ARTICLE

Observational constraints project a ~50% AMOC weakening by the end of this century


The Guardian

News Opinion Sport Culture Lifestyle

Oceans

Critical Atlantic current significantly more likely to collapse than thought

Scientists say finding is 'very concerning' as collapse would be catastrophic for Europe, Africa and the Americas

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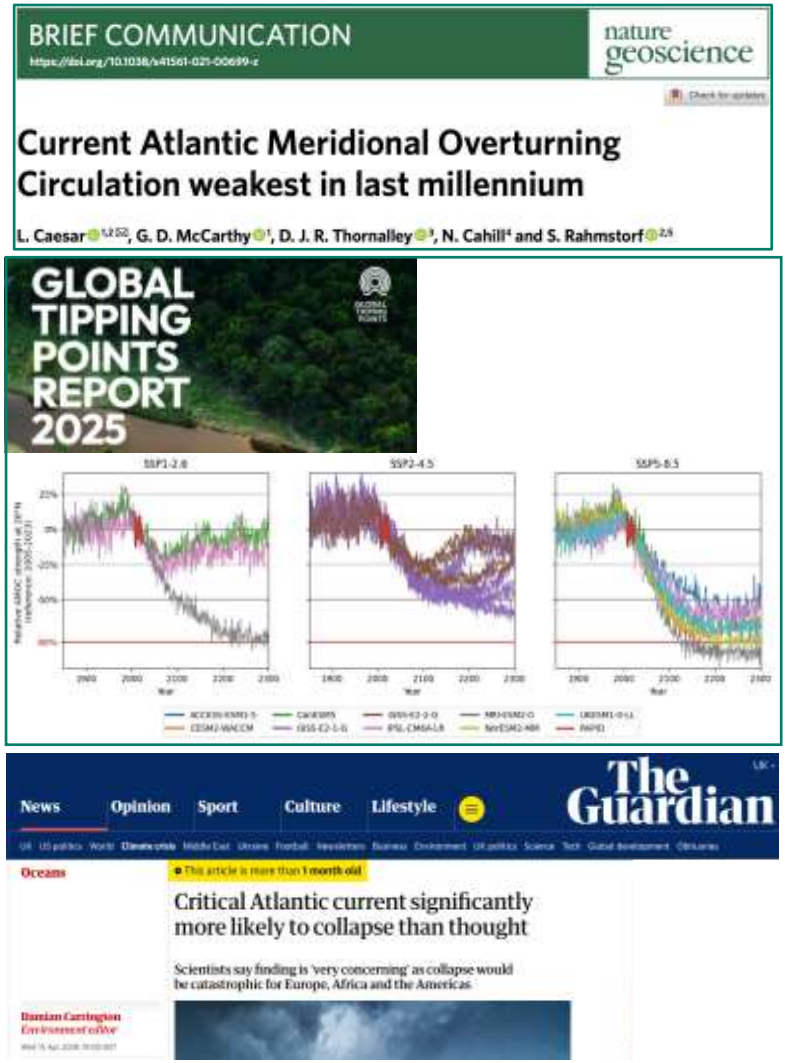
Latest science on AMOC stability

- Observed slowdown: AMOC at weakest in 1,000 years (Caesar et al., 2021).
- Tipping point estimates:
  - Current models suggest 3–4°C global warming could trigger collapse (but uncertainty remains).
  - Recent studies suggest tipping could occur at 2°C if freshwater input accelerates.
- Irreversibility: Even if warming stops, recovery could take centuries to millennia.



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What could an AMOC collapse look like?

- Within decades:
  - North Atlantic cooling (e.g., UK/Scandinavia 5–10°C cooler).
  - Sea level rise (up to 1 meter on U.S. East Coast due to ocean circulation changes).
  - Monsoon disruptions (e.g., Sahel droughts, Indian monsoon failures).
  - Amazon dieback (reduced moisture transport).
- Global impacts:
  - Fisheries collapse (e.g., North Atlantic cod, tropical tuna).
  - Increased storminess in the North Atlantic.
  - Agricultural losses (e.g., European crop failures).
  - Conflict.
  - Mass migration.

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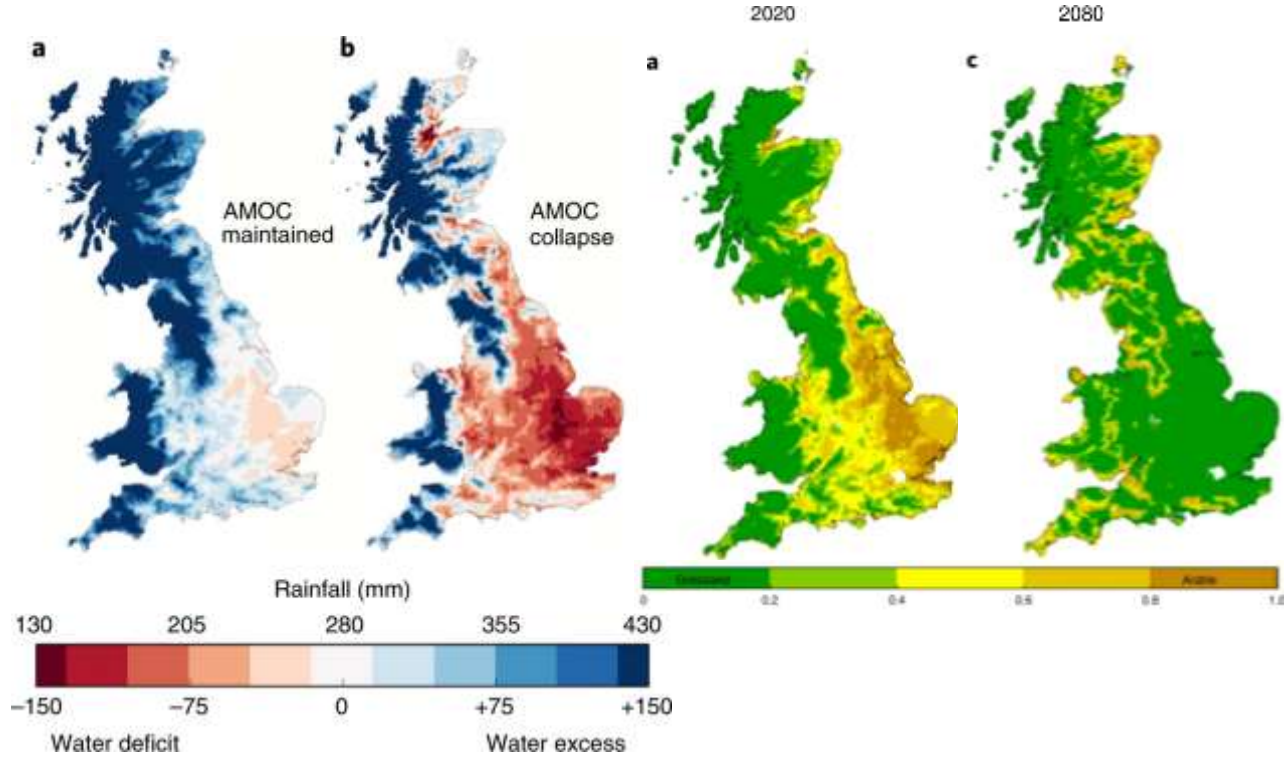
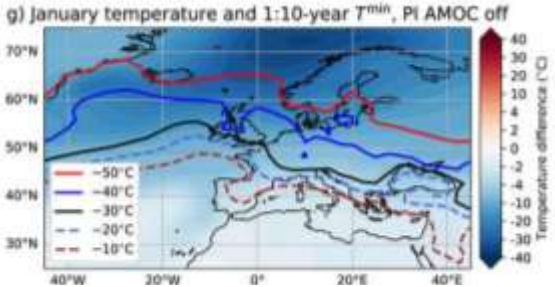
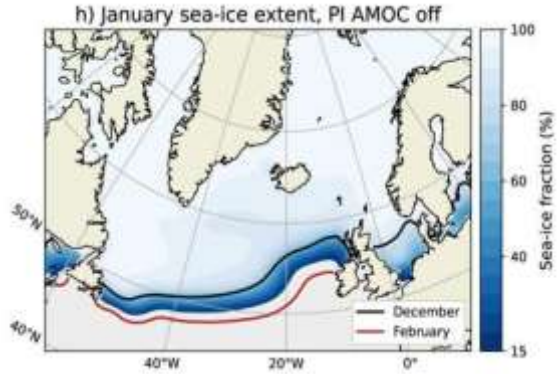
What could AMOC collapse look like in the UK?



https://www.nature.com/articles/s43016-019-0011-3

AMOC tipping at 2°C





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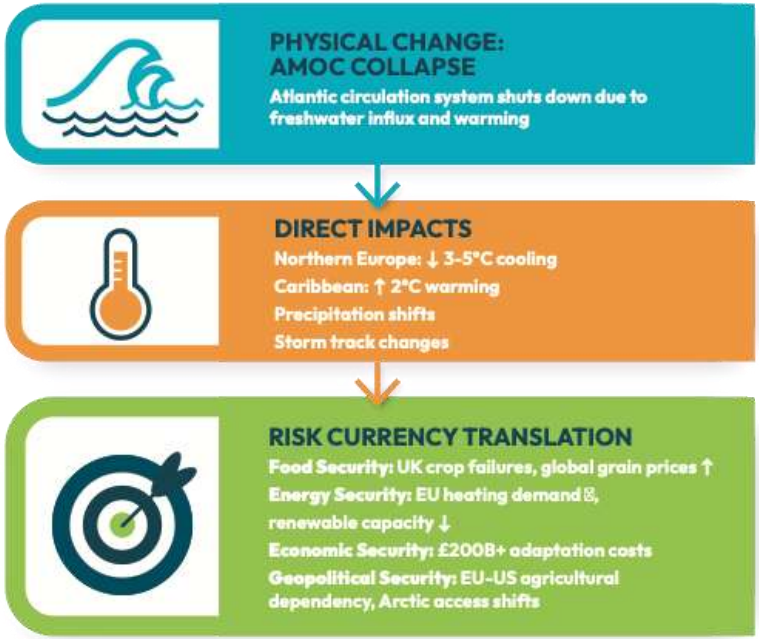

- **Agriculture**: UK farmland values at risk; global grain price volatility
- **Insurance/Reinsurance**: Fundamentally uninsurable changes to UK/European weather patterns; Lloyd's of London exposure
- **Real Estate**: Northern European coastal property repricing; UK agricultural land value collapse
- **Energy**: Heating demand surge overwhelming renewable capacity; gas price spikes
- **Sovereign**: UK adaptation costs £200B+; widening bond spreads for exposed nations
- **Supply Chains**: European food security crisis; agricultural commodity price shocks
- **Precautionary Response**: Iceland has elevated AMOC to national security threat; signalling need for conservative investment positioning

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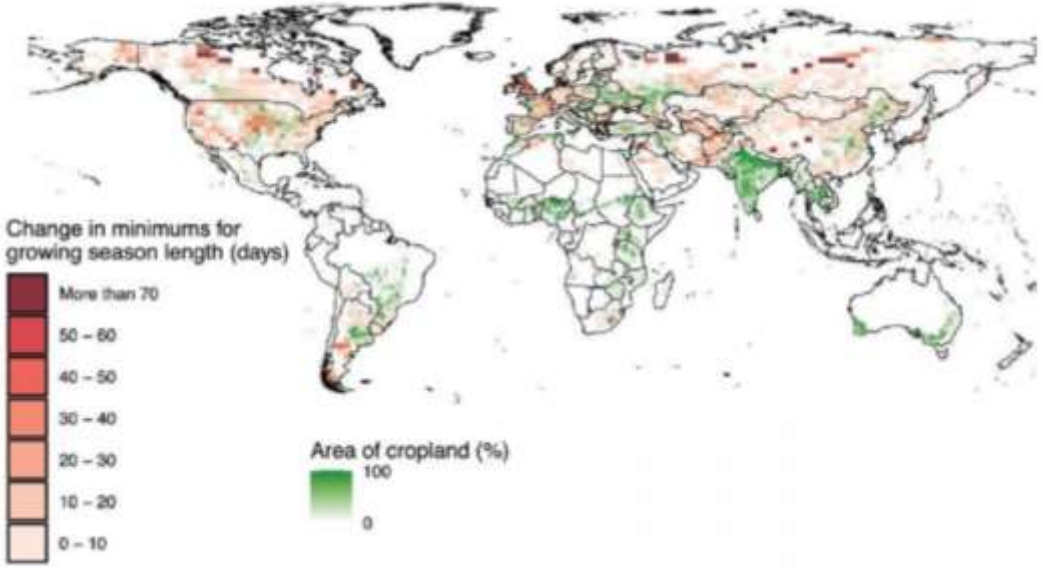
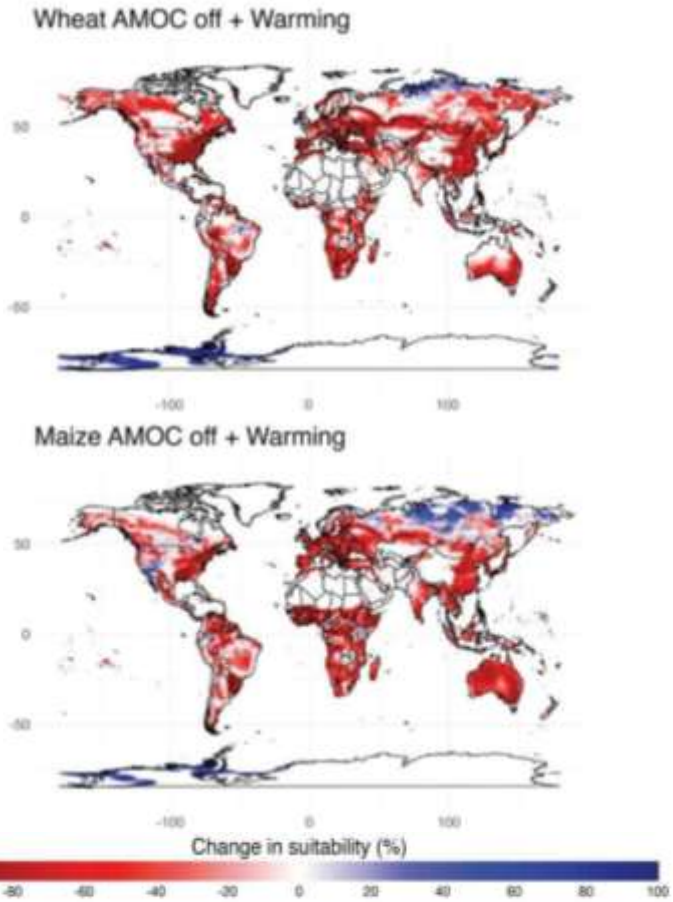
What could AMOC collapse look like globally?





Modelling results comparing minimum growing season length (GSL) in pre- and post-collapse in an SPG collapse scenario, mapped over crop growing locations (in green), with darker shading representing larger reductions in GSL.
Source: Laybourn et al. (2024), Figure 2.6, with permission from the IPPR.

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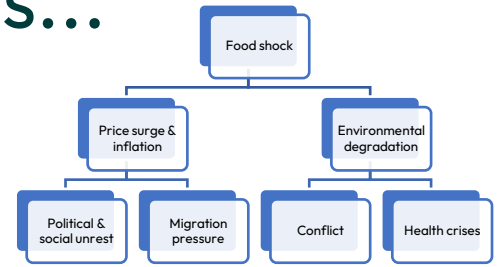
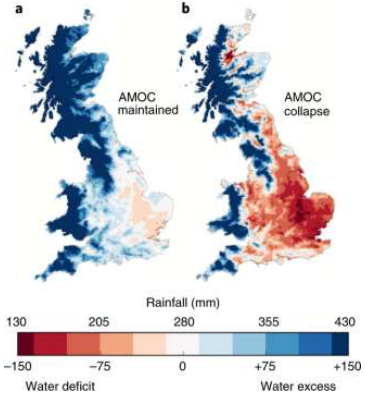
Ripple effects…



Hazard → Direct impact → Cascading impacts → Systemic risk



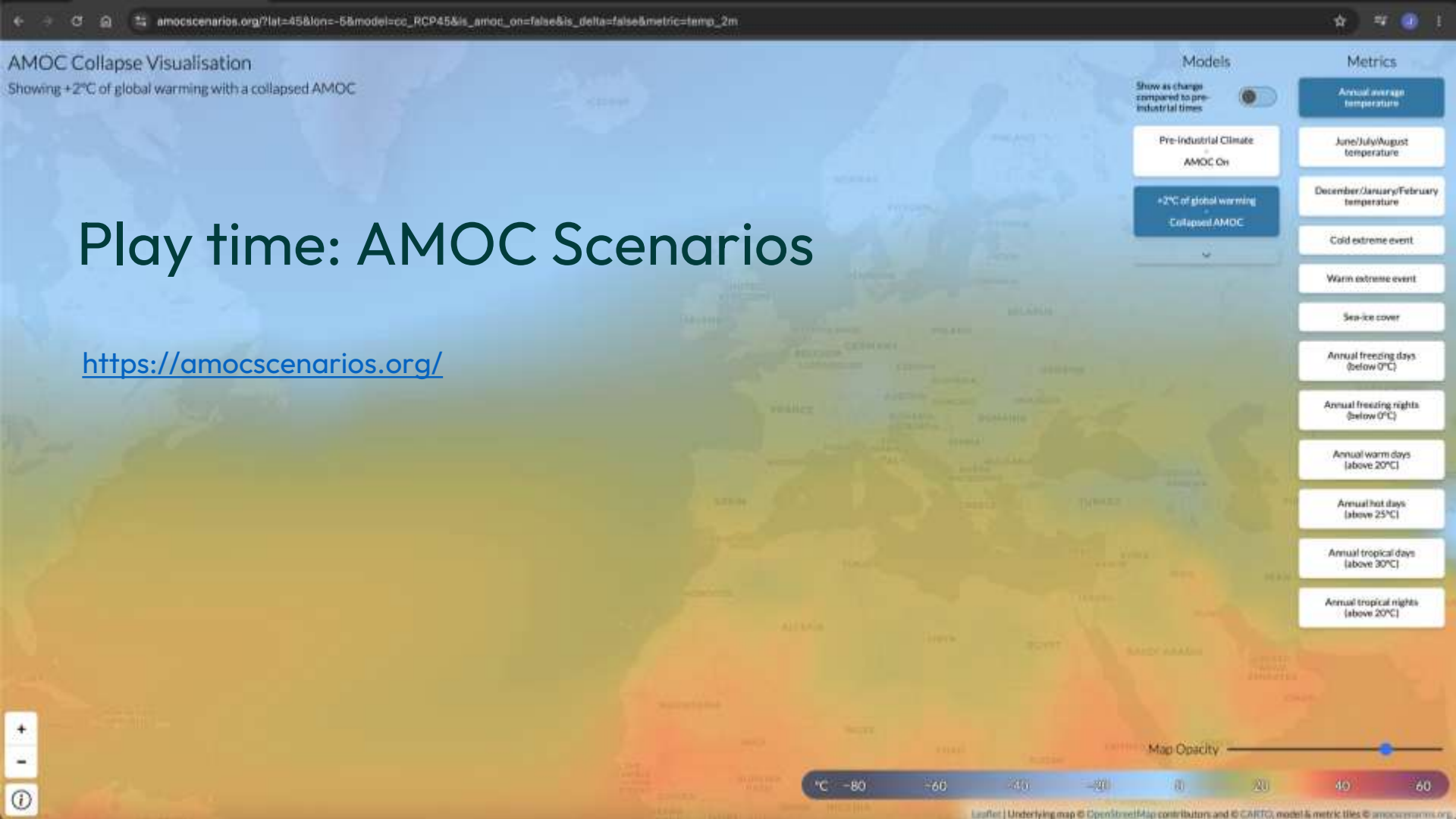
National Security in a Rapidly Heating World

"A world where the impossible today is becoming the inevitable of tomorrow"

"A renewed emphasis on home defence and resilience is also imperative"

There is "a backdrop of persistent transnational challenges, including climate change and environmental degradation which:

- are creating new geographical realities and competition for resources;
- are driving migration, instability, and more frequent humanitarian disasters;
- and demand military adaptation for operations in more extreme weather conditions."



Play time: AMOC Scenarios

https://amocscenarios.org/

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What does this mean for life in the UK?

- AMOC risks are often overlooked in adaptation plans because:
  1. Uncertainty: “We don’t know exactly when/if it will collapse.”
  2. Long-term horizon: Impacts may manifest beyond 2100.
  3. Global scale: Local planners struggle to address teleconnected and cascading risks (e.g., Sahel droughts affecting European migration).
- Precautionary principle: Even low-probability, high-impact risks deserve attention.
- Cascading effects: AMOC collapse could amplify other crises (e.g., food insecurity, conflict).

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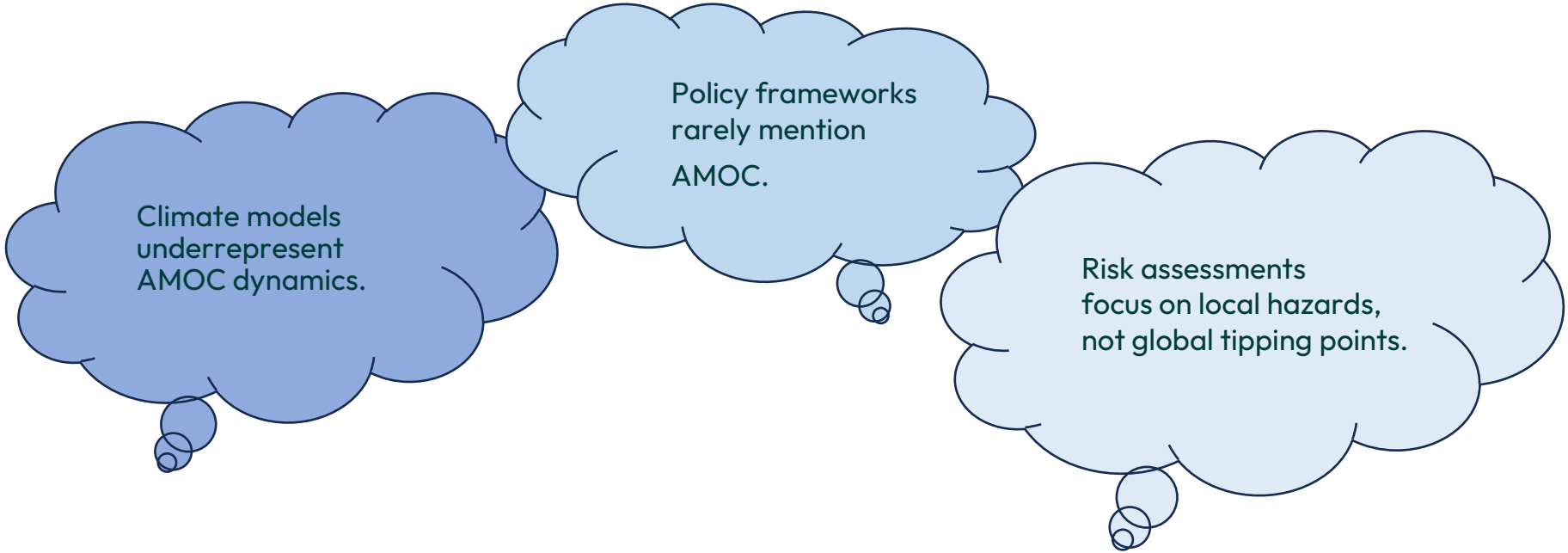
How to integrate AMOC risks into adaptation

Current gaps



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How to integrate AMOC risks into adaptation

Opportunities for action

- Scenario planning:
  - Include AMOC collapse as a low-probability, high-impact scenario in national adaptation plans.
- Monitoring & early warning:
  - Support AMOC observation systems (e.g., RAPID array expansions).
  - Develop tipping point indicators (e.g., freshwater anomalies in the subpolar North Atlantic).
- Policy integration:
  - EU Adaptation Strategy: Add AMOC risks to climate resilience reports.
  - UNFCCC: Push for global risk assessments of tipping points.
- Local adaptation:
  - Agriculture: Diversify crops for cooler/wetter conditions in NW Europe.
  - Coastal zones: Plan for accelerated sea-level rise (even if AMOC slows Gulf Stream, sea levels may rise due to thermal expansion).
  - Disaster risk reduction: Prepare for increased storminess and migration pressures.

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Key takeaways

- The AMOC is vital for climate stability, but it is weakening.
- Tipping is possible beyond 2°C warming, with *irreversible*, global impacts.
- Adaptation must include AMOC risks, even if uncertain—precaution is key.
- Local actions (e.g., scenario planning, monitoring) can build resilience.

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Additional resources

- Global Tipping Points Report: https://global-tipping-points.org/
- Intergovernmental Panel on Climate Change. (2023). Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, H. Lee & J. Romero, Eds.). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647
- Intergovernmental Panel on Climate Change. (2021). Chapter 9: Ocean, cryosphere and sea level change. In Climate change 2021: The physical science basis (AR6 Working Group I). Cambridge University Press. https://doi.org/10.1017/9781009157896
- The outlook for a climate-regulating ocean current is...not good. https://www.sciencenews.org/article/climate-regulating-ocean-current-amoc
- New article in Nature explores North Atlantic cooling and implications for AMOC research: https://jpi-climate.eu/news/new-article-explores-north-atlantic-cooling-and-implications-for-amoc-research/
- https://www.jpi-oceans.eu/en/atlantic-meridional-overturning-circulation
- A Nordic Perspective on AMOC Tipping: https://pub.norden.org/temanord2026-504/
- The security blind spot: Cascading climate impacts and tipping points threaten national security: https://www.ippr.org/articles/security-blind-spot