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Opinion: The AMOC is weakening – time to take the evidence seriously

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Abstract. The Atlantic Meridional Overturning Circulation (AMOC) is a critical component of the climate system. Climate models have long predicted a slowing of the AMOC due to anthropogenic forcing, with a risk of passing tipping points in the future. The question of whether the AMOC is already weakening in response to global warming is still somewhat controversial. Continuous monitoring is only available for the past two decades, a period too short to tease apart contributions of natural variability and climate change. Reconstructions of AMOC strength going back further in time have different limitations which are debated in the literature. Here we review the state of this discussion. We conclude that the balance of multiple lines of evidence strongly supports a past and ongoing AMOC slowing in response to global warming.

1 Introduction

The AMOC[1] is a crucial and sensitive part of the global climate system, yet its recent evolution remains the subject of persistent debate. While some studies report a substantial long-term weakening (e.g. (Caesar et al., 2018; Thornalley et al., 2018)), others argue that no significant long-term trend can be robustly identified (e.g. (Terhaar et al., 2025; Worthington et al., 2021)). This apparent contradiction has led to a widespread perception that the observational evidence for AMOC change is inconclusive. Here, we argue that this perception is wrong. The available evidence is far more consistent than is generally appreciated; much of the differences relate to different regions or time intervals.

Climate models robustly project a weakening of the AMOC in response to anthropogenic warming (IPCC, 2021), raising the question of whether such a decline is already detectable in observations. Continuous measurements from the RAPID AMOC array exist only since 2004 (McCarthy et al., 2025), and indeed they show a weakening trend which is statistically significant and consistent with climate model projections (Drijfhout et al., 2025). Accounting for a recent adjustment (Volkov et al., 2024), the trend is **−0.8 ± 0.7 Sv** per decade. At this rate the AMOC would decline from its average ~17 Sv during the past two

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[1] The terms thermohaline circulation (THC) and Atlantic Meridional Overturning Circulation (AMOC) have historically often been used interchangeably, but they refer to different concepts. THC describes the component of the global overturning circulation driven by density differences arising from temperature and salinity, whereas AMOC refers specifically to the Atlantic overturning circulation as diagnosed from the meridional stream function, which includes both buoyancy-driven and wind-driven components. In this paper, we use AMOC in this broader dynamical sense.

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decades down to ~10 Sv by 2100, a level below which CMIP6 models suggest the AMOC to be on the way to full shutdown (Drijfhout et al., 2025). Notably, observations from four mooring arrays, focusing on the deep western overturning transport, show a meridionally consistent and highly significant weakening trend since the early 2000s. At 26°N, the decline is 2.6 ± 0.7 Sv per decade over 2004-2023, corresponding to an overall weakening from 20 Sv down to 15 Sv (Xing et al., 2026). But even more than twenty years of measurements at the RAPID mooring array are still too short to be sure to what extent the observed slowing is natural variability and to what extent a response to global warming. That is why many studies have been looking at possible tell-tale signs (so-called 'AMOC fingerprints') in ocean properties for which we have much longer measurements, often based on temperature and salinity but also other relevant data. Here we discuss what these studies have found, focusing on the AMOC in the open Atlantic up to ~50°N, since the flow branches and becomes more complex further north.

2. The appearance of the 'cold blob'

The concern about whether the AMOC is already slowing started in earnest with the appearance of a 'warming hole' or 'cold blob' in the northern Atlantic, which has been shown in IPCC reports since 2001, in the 5th and 6th report even in the Summary for Policy Makers (Fig 1). It is one of the most striking large-scale anomalies in observed climate change and this region coincides with where climate models predict cooling as a result of a weakening AMOC (Stouffer et al., 2006). The scientific community has thus been faced with the remarkable observation that, while the global ocean has warmed, the subpolar North Atlantic has not only resisted this trend but has cooled over more than a century. This feature has been widely interpreted as a fingerprint of a slowing AMOC.

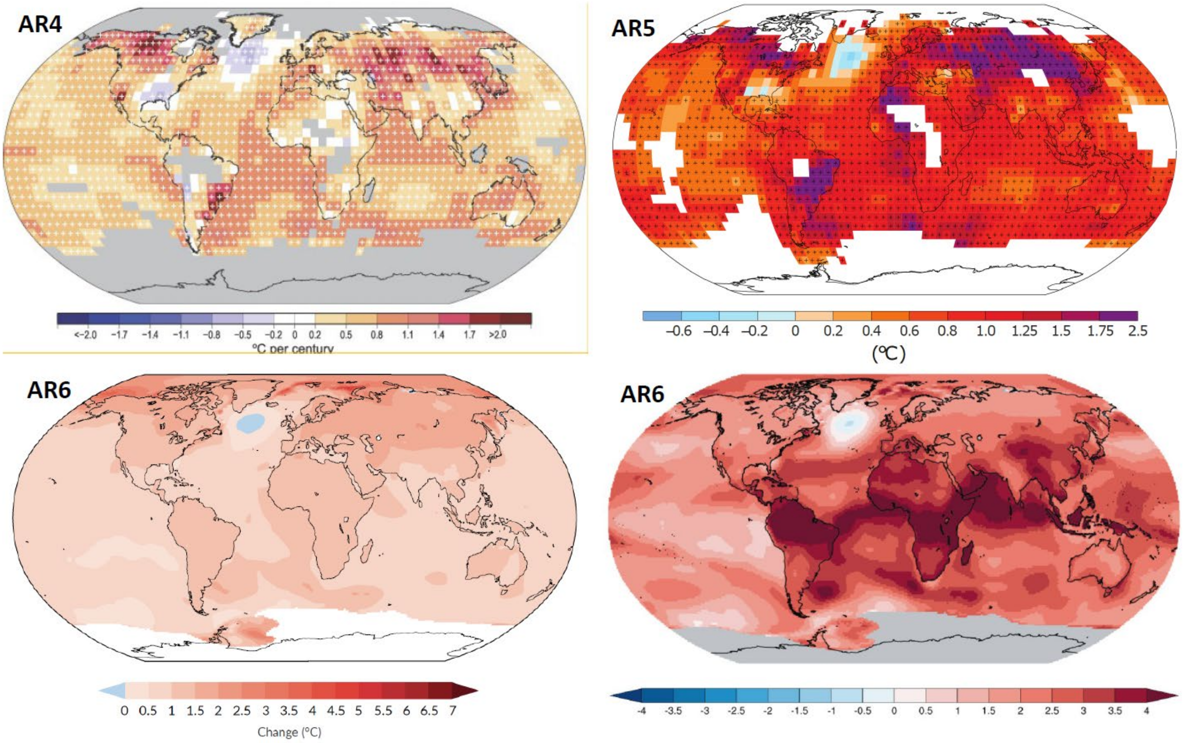

***Figure 1** The North Atlantic ‘cold blob’ in successive IPCC assessments. Near-surface air temperature change maps from AR4 (1901-2005), AR5 (1901-2012) and AR6 (1901-2020) show cooling in the subpolar North Atlantic south of Greenland. Earlier reports display the warming trend per century, while AR6 shows warming per degree of global warming (lower left) and signal-to-noise ratio (lower right). The cooling patch coincides with the region where models simulate cooling under a weakened AMOC. Adapted from IPCC AR4 WG1 Fig. 3.9, AR5 WG1 Fig. SPM.1, and AR6 WGI Fig. SPM.5.*

3. Temperature fingerprints

The link between this ‘cold blob’ and AMOC slowing is supported by both models and observations. Early work demonstrated a close correspondence between subpolar Atlantic sea surface temperature and overturning strength in climate model simulations (Latif et al., 2004). Subsequent analyses have shown that the cooling in the North Atlantic is part of a larger-scale pattern, anticorrelated with warming in the South Atlantic (Dima & Lohmann, 2010) - the so-called bipolar ‘seesaw’ (Stocker, 1998). This pattern reflects changes in northward heat transport and is a robust feature of AMOC variability (Drijfhout et al., 2012).

In 2015, (Rahmstorf et al., 2015) confirmed again the close correspondence of AMOC strength and subpolar Atlantic SST in past and future model simulations, and used the proxy surface temperature reconstruction by (Mann et al., 2008) to reconstruct

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AMOC strength since the year 900 AD. This reconstruction finds a fairly stable AMOC in the first thousand years followed by an unprecedented decline in the 20th Century.

At the same time, AMOC slowing leads to a northward shift of the Gulf Stream and associated warming along the North American coast, for reasons of vorticity conservation (Zhang, 2008). Together, these features form a characteristic spatial pattern (Fig. 2) that has been identified in both observations and model simulations and is seen in sea surface temperature trends 1870-2016 (Caesar et al., 2018). It is most robust in the cold half-year, as in summer the ‘cold blob’ is usually covered by a shallow mixed layer with a temperature dominated by surface forcing (England et al., 2025).

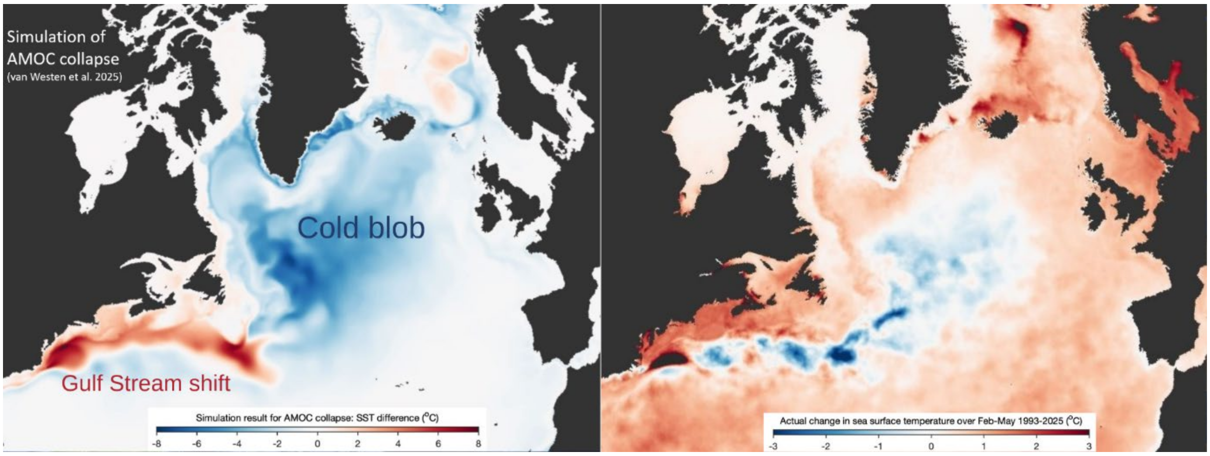

Figure 2 *Sea surface temperature change in a simulation of AMOC collapse in a strongly eddying ocean model (van Westen et al., 2025) and linear trend in Copernicus satellite observations 1993-2025. The characteristic cold blob and northward Gulf Stream shift can be seen in both, but note the observed data include a background of global warming while the model simulation shows a pure AMOC shutdown response. Figure by Ruijian Gou. This ‘fingerprint’ pattern is also seen in SST trends since the 19th Century (Caesar et al., 2018).*

Attribution studies further support the link between ‘cold blob’ and AMOC slowdown. Combining observations with climate model simulations, (Drijfhout et al., 2012) demonstrated that the warming hole is associated with AMOC changes rather than direct radiative forcing. Subsequently, (Chemke et al., 2020) showed that the warming hole has recently emerged from the internal climate variability and “is indeed caused by anthropogenic emissions of greenhouse gases, and is related by changes in the oceanic circulation”. Anthropogenic aerosol pollution has warmed the ‘cold blob’ region since 1950, since its indirect effect of strengthening the AMOC more than outweighs its direct effect on surface fluxes which would cool the sea surface in the region (Dagan et al., 2020; Qasmi, 2023).

In a similar vein, (Li & Liu, 2025) "demonstrate that only models simulating a weakened historical Atlantic overturning can broadly reproduce the observed cooling and freshening in the warming hole region." They estimate the AMOC slowing from 1900 to 2005 as between 0.1 and 0.3 Sv per decade, i.e. about **1-3 Sv**.

Although some have argued that the cold blob might be caused by surface forcing (He et al., 2022; Li et al., 2021), this has been on the basis of idealised slab ocean models without a dynamic ocean circulation, while studies using fully dynamic coupled climate models have found it is linked to AMOC changes ((Li & Liu, 2025), see above). Furthermore, reanalysis data show that in the real ocean, surface flux changes dampen multidecadal heat content changes rather than causing them. Surface heat fluxes respond to ocean heat transport changes, with periods of strong AMOC and warm SST corresponding to large surface heat loss (Rahmstorf et al., 2026).

A key reason why sea surface temperatures play a key role in reconstructing anthropogenic AMOC changes is that reliable measurements go back to the 19th Century, and especially the North Atlantic is well sampled because of the early abundance of ship traffic between Europe and North America. This long time horizon is important for distinguishing climate trends from multidecadal variability of the AMOC.

4. Heat content indicators

While surface temperatures go further back in time, subsurface heat content changes have an advantage in being less sensitive to surface forcing relative to ocean heat transport. However, deep observations are far more sparse, especially before 1950. An alternative AMOC fingerprint is based on the increasing heat content over a large region (15°S–45°N, depth range 0–2000 m) to the south of the warming hole and shows how this 'heat pile-up' correlates with the AMOC strength in models. Based on this correlation and observational heat content data, the study diagnosed an AMOC slowdown by **1.31 ± 0.39 Sv** since the 1950s (Ren, Li, et al., 2025).

A similar but more localised approach is based on the fact that according to model simulations, a weakening of the AMOC causes a warming in the equatorial Atlantic at depths between 1,000 and 2.000 meters (Ren, Xie, et al., 2025). The study concludes that this mid-depth temperature change is a better indicator for AMOC change on decadal and longer timescales than other proxies. They write: "Observations reveal a robust mid-depth warming since 1960 that emerged from natural variability in the early 2000s," and the study "estimates an AMOC slowdown of **~2 Sv** since the 1950s," consistent with the fingerprint studies discussed above (Figure 3).

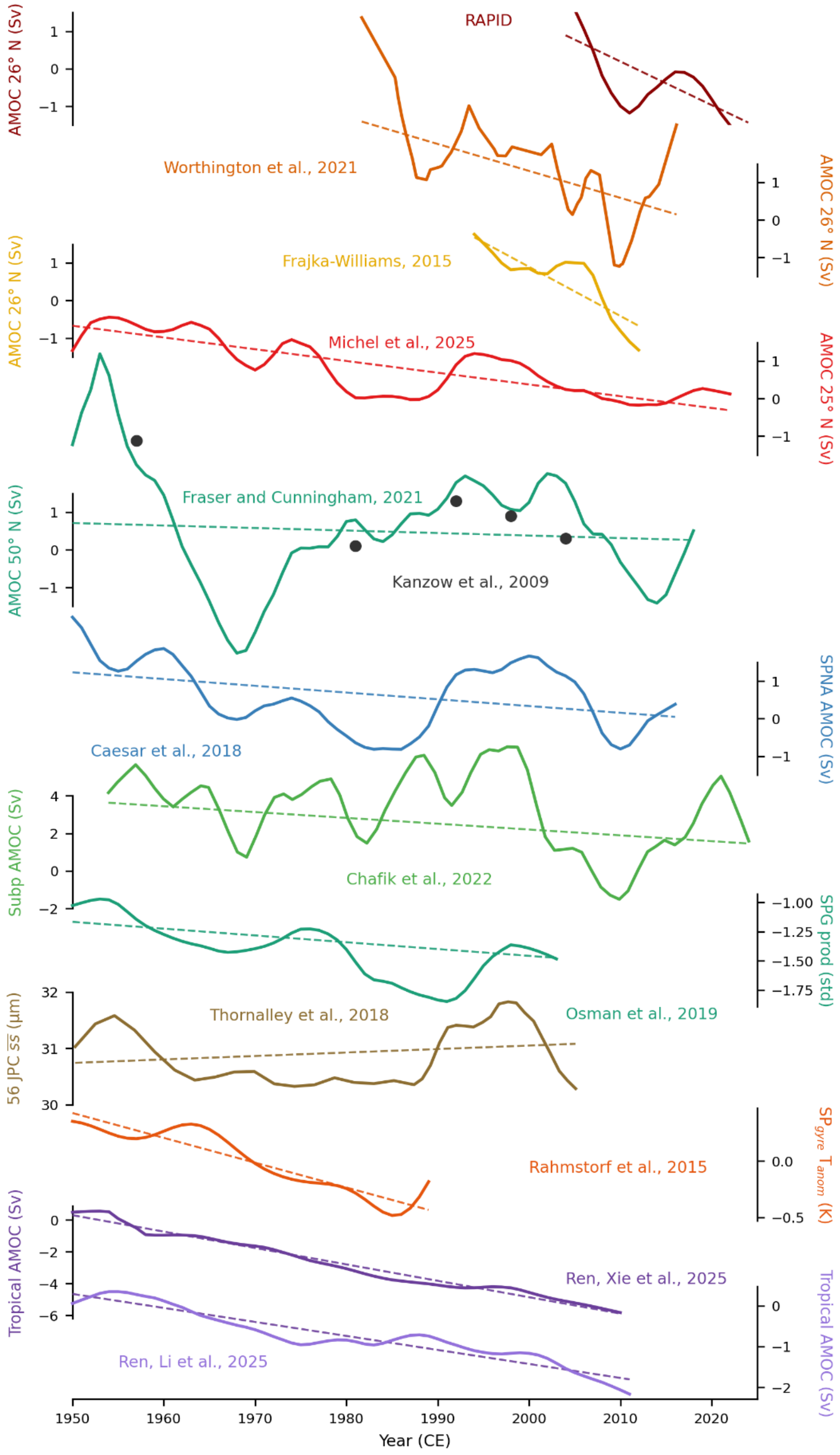
AMOC 26° N (Sv)
RAPID
Worthington et al., 2021
AMOC 26° N (Sv)
Frajka-Williams, 2015
AMOC 26° N (Sv)
Michel et al., 2025
AMOC 25° N (Sv)
Fraser and Cunningham, 2021
AMOC 50° N (Sv)
Kanzow et al., 2009
SPNA AMOC (Sv)
Caesar et al., 2018
Subp AMOC (Sv)
Chafik et al., 2022
SPG prod (std)
Osman et al., 2019
56 JPC $\overline{SS}$ (μm)
Thornalley et al., 2018
SP_{gyre} T_{anom} (K)
Rahmstorf et al., 2015
Tropical AMOC (Sv)
Ren, Xie et al., 2025
Tropical AMOC (Sv)
Ren, Li et al., 2025
1950
1960
1970
1980
1990
2000
2010
2020
Year (CE)

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Figure 3 *Observational estimates of AMOC variability since the mid-twentieth century. Shown are direct measurements and reconstructions of overturning strength (RAPID array at 26.5°N; hydrographic and mooring-based estimates including (Frajka-Williams, 2015; Fraser & Cunningham, 2021; Worthington et al., 2021) and (Bryden et al., 2005) with seasonal correction from (Kanzow et al., 2010), alongside indirect indicators of AMOC variability. These include the sea surface temperature (SST) fingerprint of the subpolar gyre (Caesar et al., 2018; Rahmstorf et al., 2015), a density-based proxy (Chafik et al., 2022), a subsurface temperature fingerprint based on equatorial Atlantic temperatures at 1000–2000 m (WOA; (Ren, Xie, et al., 2025)), and ocean heat content–based estimates for the Atlantic (15°S–45°N; Ren, Li et al., 2025). All time series (except Rahmstorf et al., 2015) are smoothed using an 8-year LOWESS filter (with a minimum fraction of 0.05); dashed lines indicate linear trends. Selected series are shown with temporal lags relative to RAPID at 26°N to account for the propagation of AMOC anomalies. Where available, lags follow published estimates, including a ~4-year lead of subpolar density anomalies (Chafik et al., 2022; Stepanov & Haines, 2014), a ~1-year lead at ~50°N (Fraser & Cunningham, 2021; Wett et al., 2023), and a ~10-year lag of subsurface equatorial temperatures (Ren, Xie, et al., 2025). Additional lags are inferred from physical considerations, including advective timescales along the western boundary (e.g. ~2-year lead for sortable silt at ~35°N) and delayed upper-ocean and biogeochemical responses in the subpolar gyre (~6 years for SST (Zhang & Zhang, 2015) and ~10 years for productivity signals (Dotto et al., 2025).*

5. Salinity fingerprints

Salinity patterns provide an additional and, in many cases, more direct tracer of AMOC variability, as they are more closely linked to water mass transport than temperature. (Holliday et al., 2020) found that in the cold blob region, the salinity has reached the lowest level in 120 years of data. While that study focuses on a recent freshening during 2012 to 2016 which they attribute to a wind-driven ocean circulation change, that does not rule out a role for reduced warm and salty subtropical waters penetrating north (Häkkinen et al., 2011). Mechanisms for a short-term anomaly and an underlying centennial trend can differ and the two combined can cause a new record, just as for heat waves over land. The centennial 'fresh blob' in the same space as the 'cold blob' also comes with a salty counterpart north of the Gulf Stream co-located with the warm part of the temperature fingerprint, suggesting the two have the same underlying link and cause.

(Zhu & Liu, 2020) propose that AMOC changes can be detected in the subtropical South Atlantic in an indicator named the Atlantic 'salinity pile-up': a relatively greater trend in basin-mean salinity increase in the subtropical Atlantic than the Indo-Pacific from the surface to the thermocline (>300 to 500 m), which is not caused by the local surface forcing but correlates with AMOC strength in climate models. They find an observed salinity change over 1900-2017 indicative of **about 2 Sv** AMOC weakening. In a follow-up study, (Zhu et al., 2023) argue that the South Atlantic salinity evolution is an optimal fingerprint not susceptible to decadal variability (which is mainly a feature of the North Atlantic) and indicating an accelerated weakening of Atlantic overturning circulation since the 1980s, consistent with the model- and data-based AMOC reconstruction of (Majumder et al., 2016). Zhu et al. (2023) interpret the South Atlantic salinity pile-up as a remote indicator of AMOC slowdown, reflecting a southward propagation of the weakening signal from the North Atlantic. This implies that the corresponding AMOC weakening at 26°N must have emerged earlier, likely by at least several years to decades.

6. Deep water renewal

The renewal and ventilation of deep water masses is a key function of the AMOC. One way to track this is to track the "age" of seawater, that is, the duration since its last contact with the ocean surface. One method to do this is to use the chlorofluorocarbon-12 and sulfur hexafluoride concentrations in sea water as abiotic tracers. This has been done for the North Atlantic for the period 1985 to 2021 by (Guo et al., 2026). The authors argue that water age provides a unique advantage in studying changes in ocean ventilation, including broad spatial coverage and longer time range than the RAPID measurements. Their study concludes that "the North Atlantic waters are generally aging", which means less deep water renewal.

Another method of analysing deep water renewal is by use of the established WMT (Water Mass Transformation) framework. This integrates hydrographic observations of ocean temperature and salinity with atmospheric reanalyses and provides a physically grounded estimate of the overturning streamfunction across the Atlantic basin. A recent study applying this WMT framework (Li et al., in review) extends back to 1940 and finds a long-term weakening of the AMOC. They estimate a weakening trend of **0.8 Sv per decade** since 1960 at 26 °North and **1.4 Sv per decade** at 34.5°South.

7. Density trends

An interesting form of evidence is density changes, since that combination of temperature and salinity effects is not just a tracer of AMOC change but also a driver of the AMOC. (Chafik et al., 2022) argue that "the strong relationship between Irminger Sea density and subpolar AMOC change present in OSNAP and GloSea5 provides us with a robust, albeit indirect, measure that can be used to examine long-term AMOC trends." They conclude that the observed Irminger Sea density decline implies an AMOC weakening of **~2.2 Sv** or 13% over the period 1950–2019, with the caveat that this trend just misses the 95% significance threshold.

8. Dynamic pressure calculations

Given that the ocean circulation is largely driven by pressure gradients and is approximately in geostrophic balance, it can in principle be computed from the momentum equations (Fraser & Cunningham, 2021; Rossby et al., 2022). However, this requires high-quality vertical water column profiles of temperature and salinity, and thus water density, to compute gradients. It further involves uncertain assumptions, e.g. about a level of no motion (Xing et al., 2026). Hence the available data before ~1950 are too sparse and uncertain to allow reasonably robust conclusions. Even after 1950 the data coverage remains a serious limitation until the turn of the 21st Century, when ocean monitoring by profiling Argo floats was established (Roemmich et al., 2009). With that in mind, the studies cited here suggest a moderate AMOC decline since 1950 and a steeper one in the past two decades, although statistical significance is low.

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9. Reanalysis data

Reanalysis data sets use atmosphere and/or ocean models to analyse the past climate evolution, thereby assimilating observational data. For example, surface fluxes from ERA5 atmospheric reanalysis data were combined with ocean heat content changes from IAP data for the period 1950–2019 by (Mayer et al., 2023) in order to provide an energy-budget-based trend estimate of the AMOC. They find that “the exact magnitude of change is uncertain, but its sign appears robust and adds complementary evidence that the AMOC has weakened over the past 70 years.” In contrast, (Terhaar et al., 2025) did not find any trend by assuming a heat balance between ERA5 surface heat flux and AMOC heat transport, but unlike Mayer et al. they did not consider heat storage, a major component of the heat budget (de Toma et al., 2022; Rahmstorf et al., 2026). A fundamental problem with the approach is that reanalysis air-sea fluxes are modelled but not constrained by any flux measurements, and the reanalysis products don’t conserve heat and require large flux adjustments.

Ocean reanalyses likewise lead to diverging results. A large decline of AMOC is found in ORAS5 (Zuo et al., 2019) (1.44 Sv/decade for 1958-2025) and ECCO-V4r4 (Forget et al., 2015) (1.05 Sv/decade for 1992-2017), and in GLORYS12V1 (Lellouche & et al., 2021) a smaller 0.28 Sv/decade for 1993-2025. While these three at least roughly agree on a moderate slowing since the mid-1990s, SODA3.15.2 shows an increasing AMOC (0.97 Sv/decade for 1980-2020). The Norwegian long coupled reanalysis CoRea1860+ (Wang et al., 2025) for 1860-2022 shows a stable AMOC until 1920 and a decline with multidecadal variations thereafter, with the last ten years being the ten weakest.

Although the majority of reanalyses supports AMOC weakening, the uncertainty of AMOC trends in these data is extremely large (Pillar et al., 2018; Sohail & Zika, 2026), so that reanalysis products are not yet suited to reconstruct the past AMOC.

10. Paleoclimate proxy data

A number of paleoclimatic studies have used different types of proxy data to reconstruct the AMOC. These were compiled and analysed statistically in (Caesar et al., 2021, 2022), who concluded that after a long and relatively stable period, there was an initial AMOC weakening starting in the nineteenth century, followed by a more rapid decline starting in the mid-twentieth century. In recent decades these data indicate the weakest AMOC in at least a millennium (Figure 4). While paleoclimatic proxy data are indirect indicators which have their limitations, it is remarkable how very different reconstructions give rather consistent results. Some use grain size of sortable silt below the North Atlantic Deep Water flow, some use isotope data (e.g. oxygen-18) or microplankton species abundances. Those proxy series covering also the full 20th Century (Osman et al., 2019;

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Rahmstorf et al., 2015; Thornalley et al., 2018) appear consistent with observations and other reconstructions (Figure 3).

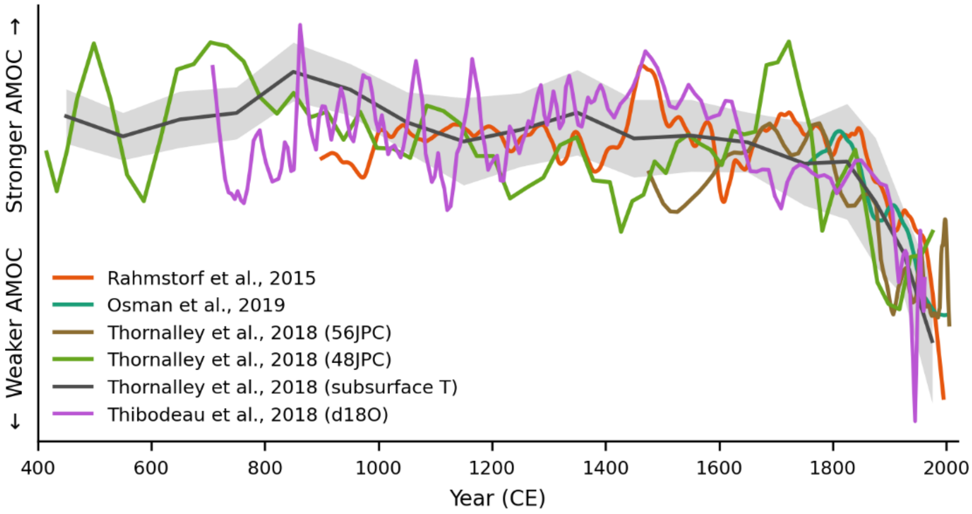

Figure 4 *Long-term reconstructions of AMOC variability over the past millennium. Shown are multi-proxy reconstructions (Osman et al., 2019; Rahmstorf et al., 2015), sediment-based proxies from the North Atlantic (Thornalley et al., 2018), including sortable silt (bottom current strength) and Mg/Ca-derived subsurface temperature and $\delta^{18}O$-based reconstruction of water masses (Thibodeau et al., 2018). All time series are smoothed using a 40-year LOWESS filter to highlight multidecadal to centennial variability. The grey shading indicates the ensemble range for the subsurface temperature proxy. These records suggest relatively stable AMOC conditions over much of the past millennium followed by a decline since the nineteenth to twentieth century.*

11. Other Approaches

As discussed above, an AMOC weakening is expected to cause a northward shift of the Gulf Stream (Figure 2) for reasons of vorticity conservation (Zhang, 2008). Therefore, (van Westen & Dijkstra, 2026) have used satellite altimeter data to analyse the Gulf Stream position for the period 1993–2024. They find a >95% statistically significant northward shift trend of 55 km during this time interval, not caused by wind changes and thus providing further indirect evidence for an ongoing AMOC weakening. For a longer timeseries, they analysed the position of the Gulf Stream north wall since 1965 as defined by the 15°C isotherm at 200 m depth. This metric likewise indicates a northward shift, with >99% significance.

(Michel et al., 2025) have trained a set of convoluted neural networks on climate model data in order to find and use the best SST pattern which correlates with AMOC strength at latitudes 20° - 60° N at 5° intervals. They then applied this to observed SST from the HadISST dataset (Rayner et al., 2003) to reconstruct the AMOC strength for 1900-2024. At all latitudes except

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35° N they find an AMOC decline, most strongly at higher latitudes from 45° N, with the decline starting in mid-20th Century and reaching a record-weak AMOC around 2010.

12. Is there evidence against an AMOC slowing?

Several studies are often cited as evidence against an AMOC weakening. Here, it is important not to compare apples and oranges. A steady or slightly increasing inflow into and deep outflow from the Nordic Seas is sometimes cited as indication of a stable AMOC – however this is an expected response to an AMOC weakening in the open North Atlantic (Roewer et al., 2025).

Some find that "natural variability has dominated" (Latif et al., 2022) – but that does not mean there hasn't also been an underlying weakening. In fact, not only the variability but also the forced AMOC response identified in this study in historic model runs shows the same SST fingerprint of AMOC slowing as shown in our Fig. 2 above (see their Fig. 2).

Some studies find an AMOC weakening but argue it is not statistically significant (Chafik et al., 2022; Rossby et al., 2022; Worthington et al., 2021). Evidence for a non-significant AMOC weakening is not evidence for no weakening. Lack of significance does not mean a trend is not real: rather, while individual short-term records may not clearly stand out from background noise, the consistent pattern across different indicators strongly supports the idea of a real underlying decline. If we evaluate multiple pieces of evidence and three largely independent data sets each find evidence for an 80% significant weakening, the conclusion is *not* that "three studies show there is no weakening". Rather, these studies taken together reinforce the evidence for an AMOC decline, increasing the confidence level. And of course, internal variability is just as likely to have *de*creased as *in*creased the observed trend – uncertainty cuts both ways.

We are not aware of any substantive evidence for an unchanging AMOC since the mid-20th Century. The one prominent study arguing for this (Terhaar et al., 2025) is based on questionable and contradictory reanalysis data, as discussed above.

13. Discussion and conclusions

The use of proxy indicators for AMOC changes invariably relies on correlations of these indicators with the AMOC, which are most often found in model simulations and are not perfect. Factors other than the AMOC strength can influence all of these indicators to a greater or lesser extent. In addition, substantial variability of the AMOC on a range of time scales makes the detection of climate-forced changes more difficult, calling for long-term data going back a century or more. Of these, sea surface temperature and salinity measurements are by far the most abundant and reliable, in particular in the northern Atlantic. The SST fingerprint pattern seen in the long-term linear trends since the 19th Century (Fig. 2; (Caesar et al., 2018)) and the 120-year record-low Irminger Sea salinity (Holliday et al., 2020) therefore have a special importance. However, any single indication of a long-term weakening of AMOC can at best provide medium confidence.

But, there now is a large variety of different indications of AMOC slowing: direct measurements as far back as they are available, dynamical methods, multiple sea surface temperature and heat content fingerprints, different salinity fingerprints including a 'salinity pile-up' in the South Atlantic, the Irminger Sea density decline, paleoclimate data such as grain sizes below the deep return flow, tracers of reduced deep-water renewal, the northward shifting Gulf Stream, and emerging machine learning reconstructions. In addition, there is also evidence for a weakening of the abyssal limb of the AMOC, which is supplied by bottom water formation near Antarctica (Biló et al., 2024; Gunn et al., 2023).

It is this large number of largely independent indicators all pointing toward an AMOC weakening which gives us high confidence in this conclusion. Where these indicators give quantitative estimates, they consistently indicate a weakening by roughly 2 ± 1 Sv since the mid-twentieth Century. Many indicators also agree on a weak AMOC in the 1980s, a strong AMOC around 2000 and a low point again near 2010.

We conclude that the balance of a large pile of evidence suggests that a past and ongoing AMOC slowing may not be certain, but it is at least very likely. This has important implications for the future evolution of the climate system, given the central role of the AMOC in regulating heat, carbon, and freshwater transport in the Atlantic. It is therefore high time to stop wavering and to take this evidence seriously.

Code and Data Availability

The code used to process the data and generate Figures 3 and 4 is available at https://gitlab.pik-potsdam.de/caesar/Rahmstorf_and_Caesar_2026. The repository contains the full analysis workflow, including data processing, smoothing, and trend estimation routines.

The datasets used in this study originate from previously published sources and are cited in the manuscript. The majority of datasets are publicly available and are accessed via URLs provided in the code repository. For datasets that are not publicly archived, access information is provided, and these data can be obtained from the original authors upon reasonable request. The availability status of each dataset is documented in the code repository.

Author contributions

SR conceptualised the study and led the manuscript writing. LC developed the code and performed the data analysis for Figures 3 and 4 as well as contributed to the interpretation of the results and writing of the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

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