Atlantic circulation change still uncertain

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Halimeda, K. [et al.]. Atlantic circulation change still uncertain. "Nature geoscience", 17 Febrer 2022, p. 1-9.
https://www.nature.com/articles/s41561-022-00896-4

Deep oceanic overturning circulation in the Atlantic (Atlantic Meridional Overturning Circulation, AMOC) is projected to decrease in the future in response to anthropogenic warming. Caesar et al.[1] argue that an AMOC slowdown started in the 19th century and intensified during the mid-20th century. Although the argument and selected evidence proposed have some merits, we find that their conclusions might be different if a more complete array of data available in the North Atlantic region had been considered. We argue that the strength of AMOC over recent centuries is still poorly constrained and the expected slowdown may not have started yet.

Recently, Moffa-Sanchez et al.[2] compiled a comprehensive set of paleoclimate proxy data from the North Atlantic and Arctic regions using objective criteria for identifying high-quality datasets of ocean conditions spanning the last two millennia (Figure 1). Although no direct (singular) proxy for AMOC exists, the paleoceanographic proxy data compiled by Moffa-Sanchez et al.[2] highlight the spatial and temporal complexities of ocean state in modern times and the recent past. When all the available proxy records potentially related to AMOC variability and 20th century observational datasets are considered, the time history of the AMOC system becomes less certain. In contrast, selecting only a subset of proxy records that share similar trends, as performed by Caesar et al.[1], provides an incomplete perspective on AMOC changes through time.

Increased data availability in recent decades has enabled a shift in the fields of paleoceanography and paleoclimatology toward more objective and transparent data selection in studies aimed at quantitatively reconstructing past variability. Such screening methods tend to minimize the impact of spurious or less reliable records on analyses and work to enhance the common signal in proxy records. Additionally, analyzing networks of suitable and carefully selected data enables robust uncertainty estimates on the resulting reconstructions, which is essential in providing confidence in the results and the ability to compare information across disciplines. Key to such work is identifying robust criteria and weighting schemes that objectively identify and utilize the most reliable data. Caesar et al.[1] use a variety of proxy records in their analysis, but do not identify the reasoning or criteria for selecting those records over many others that are likely related to aspects of AMOC dynamics (see the recent review[2]).

Objective and inclusive data selection standards are especially important when addressing AMOC, which is a system composed of many different components that can behave differently at different latitudes, depths, and timescales[3] and looking at any singular index of AMOC inherently oversimplifies the system. The complex signals in the available AMOC-related proxy variables over recent centuries support this notion[2], though many of these studies were not considered by Caesar et al.[1]

In addition to the need for objective standards, we argue that most of the records compiled in the Caesar et al. paper have substantial caveats that were not discussed. Reconstructing the strength of AMOC more than a few decades ago relies upon paleoclimate and paleoceanographic proxies because direct measurements are unavailable. Some proxies are more directly related to components of AMOC variability than others, and some sites are better situated to record specific oceanographic and atmospheric processes than others. The limited scope of data utilized combined with the inherent uncertainties in the proxies and conflicting evidence from other sources, leaves the question open whether the available evidence supports the conclusion that AMOC is currently undergoing an unprecedented shift/weakening.

Key information and rationale about the records included are lacking in Caesar et al.[1]. For example, the Rahmstorf et al.[4] AMOC reconstruction used by Caesar et al.[1] is based on the subpolar North Atlantic temperature minus the Northern Hemisphere mean temperature, each constructed from tree ring and ice core records, and a scaling coefficient derived from one climate model. These data are land-based estimates influenced by atmospheric conditions, not necessarily robust indicators of marine temperatures, and the resulting index is strongly impacted by the global warming signal[5]. Furthermore, subpolar gyre sea surface temperatures (SSTs) are an unreliable indicator of AMOC variability[5,6] because SST can have multiple drivers and the spatial AMOC/SST fingerprints used for such reconstructions are temporally non-stationary[2,5]. Variables related to marine biological processes used as evidence by Caesar et al.[1] are potentially problematic as they are not directly responding to the AMOC and their signal may be compromised by other non-physical factors. For instance, the Sherwood et al.[7] study provides nitrogen isotopic evidence of a shift in nutrient dynamics since the 19th century in the northwestern Atlantic which they attribute to local changes in water masses, and others[4] have linked to AMOC. The interpretation of this proxy is predicated on stable nitrogen utilization and nitrogen isotope signatures in the system despite massive anthropogenic perturbation of the global N cycle over the study period[8]. Additional evidence used to infer an AMOC slowdown by Caesar et al.[1] come from sortable silt records off Cape Hatteras[9], which are arguably one of the most direct proxies available for near-bottom water current speed[10]. However, this proxy assumes that the position of the bottom current is stationary through time and that these deep flow changes are representative of AMOC strength. Similar methods have been used to examine the other parts of the deep AMOC limb, including the Nordic Overflows with results that are not consistent with conclusions reached by Caesar et al.[1] (for example, see[11, 12, 13]), yet these records were not considered.

Finally, the proxy data presented by Caesar et al.[1] need to be reconciled with observations of AMOC and AMOC-related variables in the 20th and 21st centuries. Caesar et al.[1] plot a trend derived from Smeed et al.[14] to support their supposition that AMOC has significantly decreased in recent decades. However, the decreasing trend measured in RAPID data between 2004 and 2012 is really more of a stepwise shift[14] and is likely a part of decadal-scale variability with increases in AMOC from 1960 to the early 2000s[15, 16]. To date, the RAPID array observations are too short to resolve multidecadal and longer-scale variability. Some indirect or partial AMOC measures over the instrumental era permit investigation into decadal-to-multidecadal variability and suggest a modest decline in transport[17], others show no trend[18, 19], and one record[20] shows a recent strengthening of the AMOC at subpolar latitudes. While diverse regional responses are plausible amidst a large-scale AMOC decline, work remains to understand the origin of such discrepancies.

These apparently contradictory results may be reconciled with more information regarding the spatial and temporal scales of variability involved in each dataset as well as the sensitivity and fidelity of the proxies to record aspects of AMOC during a large global climate perturbation. Real and interesting subtleties and discrepancies in the data still exist, and any impression that the historical AMOC evolution is confidently known from a subset of the available data is misleading until the conflicts are resolved. Instead, highlighting apparent contradictions will help us with the work of reconciling the data and answering the important question of whether the AMOC and/or its components have indeed slowed down in recent centuries. The authors declare no competing interests.

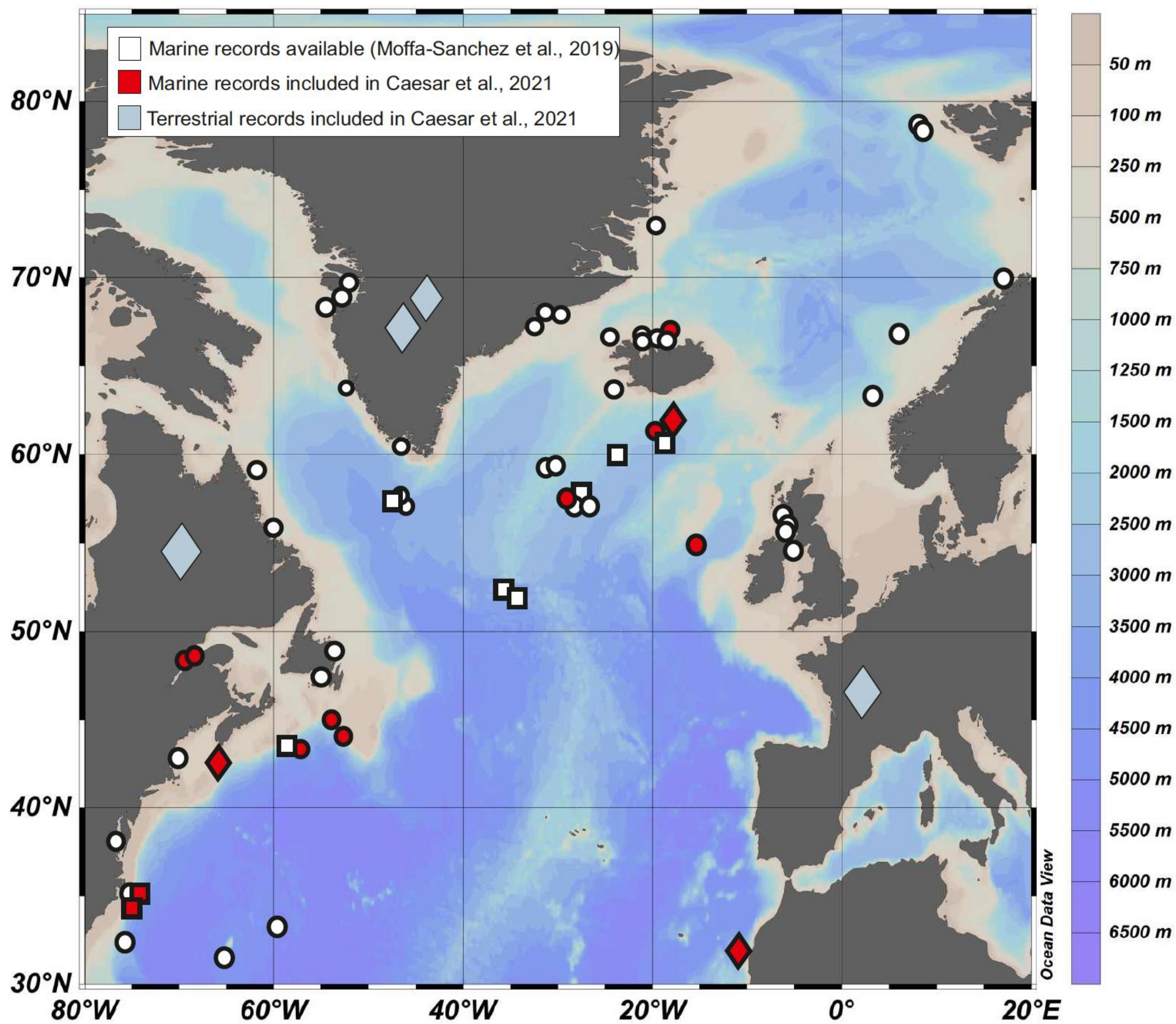

Figure 1. Available well-dated northern North Atlantic paleoceanographic records include proxies for temperature, salinity, sea ice, and ocean circulation. A full list is in Supplementary Information Table 1. Surface (circles) and deep ocean records (squares) screened by Moffa-Sanchez et al.[2] (white) are compared with the subset of data (red) used by Caesar et al.[1] The red diamonds are only presented in Caesar et al.[1] and include: biological productivity, nutrient records, and intermediate water temperatures. Multiple cores/archives in the same location are offset for visibility. Source locations, original studies, and figure-making software credits are in Supplementary Information Table 1.

Author contributions: K.H.K, A.D.W, P.M-S., and D.J.R. drafted the manuscript. All authors contributed to discussions in the conception of the work, writing, and editing the manuscript.

Acknowledgements: K.H.K. acknowledges funding from NOAA grant NA20OAR4310481. D.E.A and B.L.O-B. acknowledge support from the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under cooperative agreement no. 1852977. NW acknowledges support from the NOAA Climate and Global Change

Postdoctoral Fellowship. MFJ acknowledges support from NSF award OCE-1846821 and CML acknowledges support from NSF award OCE-1805029.This is UMCES contribution 6062.

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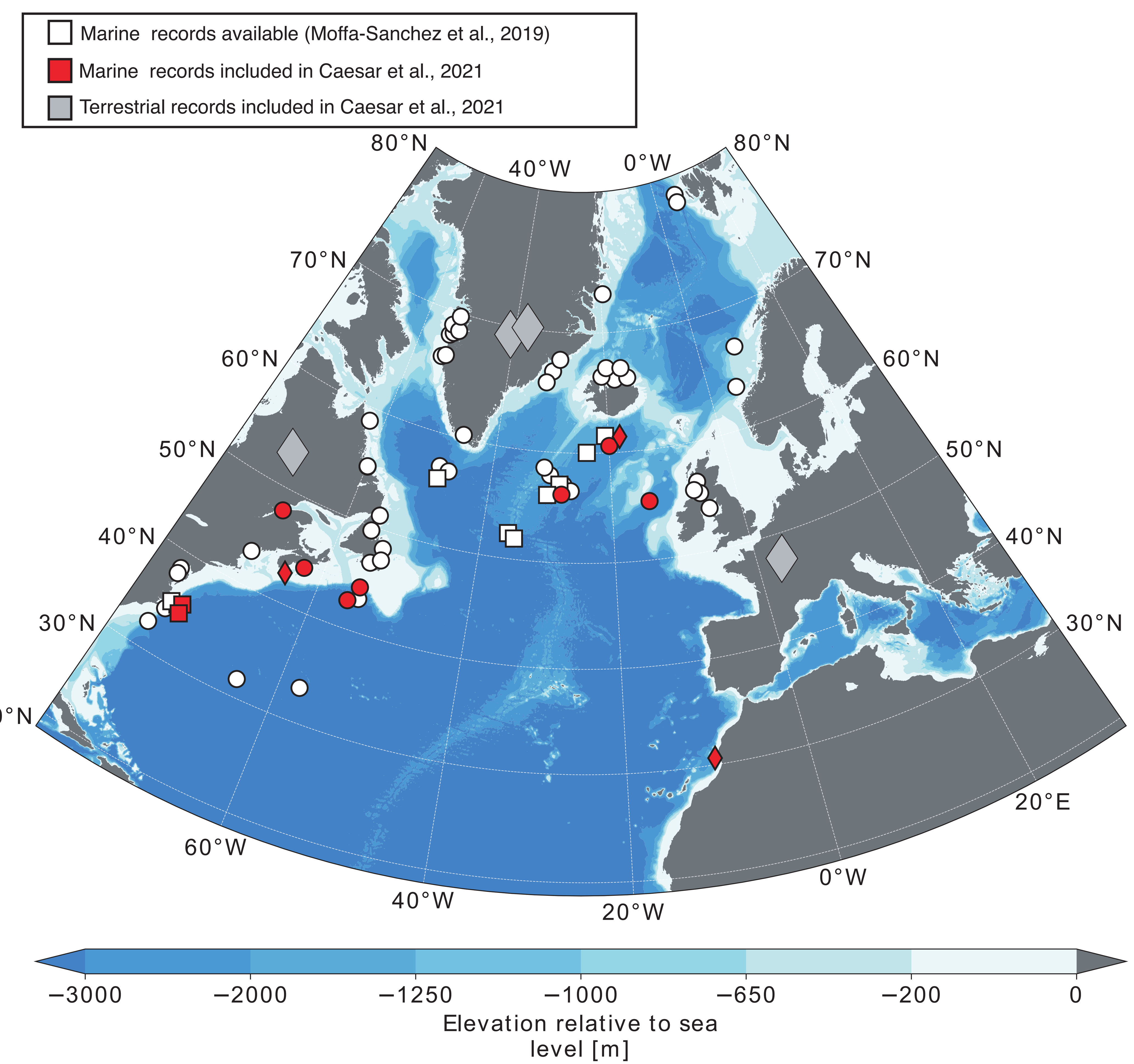
Marine records available (Moffa-Sanchez et al., 2019)
Marine records included in Caesar et al., 2021
Terrestrial records included in Caesar et al., 2021
80°N
40°W
0°W
80°N
70°N
70°N
60°N
60°N
50°N
50°N
40°N
40°N
30°N
30°N
20°N
20°E
60°W
40°W
20°W
0°W
−3000
−2000
−1250
−1000
−650
−200
0
Elevation relative to sea level [m]