Atlantic circulation change still uncertain

K. Halimeda Kilbourne[1], Alan D. Wanamaker[2], Paola Moffa-Sanchez[3], David J. Reynolds[4], Daniel E. Amrhein[5], Paul G. Butler[4], Geoffrey Gebbie[6], Marlos Goes[7,8], Malte F. Jansen[9], Christopher M. Little[10], Madelyn Mette[11], Eduardo Moreno-Chamarro[12], Pablo Ortega[12], Bette L. Otto-Bliesner[5], Thomas Rossby[13], James Scourse[4], and Nina M. Whitney[6,14]

[1]University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, MD, USA

[2]Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA, USA

[3]Geography Department, Durham University, Durham, UK

[4]Centre for Geography and Environmental Sciences, University of Exeter, Penryn, UK

[5]Climate and Global Dynamics Laboratory, National Center for Atmospheric Research, Boulder, CO, USA

[6]Woods Hole Oceanographic Institution, Falmouth, MA, USA

[7]Cooperative Institute for Marine and Atmospheric Studies, University ofMiami, Miami, FL, USA

[8]Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, FL, USA

[9]Department of the Geophysical Sciences, The University of Chicago, Chicago, IL, USA

[10]Oceanography Department, Atmospheric and Environmental Research, Inc., Texas, TX, USA

[11]US Geological Survey, St Petersburg Coastal and Marine Science Center, St Petersburg, FL, USA

[12]Barcelona Supercomputing Center, Barcelona, Spain

[13]Graduate School of Oceanography, University of Rhode Island, Kingston, RI, USA

[14]University Corporation of Atmospheric Research, Boulder, CO, USA

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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 is 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-Sánchez et al. [2] compiled a comprehensive set of palaeoclimate proxy data from the North Atlantic and Arctic regions using objective criteria to identify high-quality datasets of ocean conditions that span the past two millennia (Fig. 1). Although no direct (singular) proxy for AMOC exists, the palaeoceanographic proxy data compiled by Moffa-Sánchez et al. [2] highlight the spatial and temporal complexities of the ocean state in modern times and the recent past. When all the available proxy records potentially related to AMOC variability and twentieth 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 palaeoceanography and palaeoclimatology towards more objective and transparent data selections 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 to provide 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 probably 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], although 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. article [1] have substantial caveats that were not discussed. Reconstructing the strength of AMOC more than a few decades ago relies on palaeoclimate and palaeoceanographic 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 as to whether the available evidence supports the conclusion that AMOC is currently undergoing an unprecedented shift and/or 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 are an unre- liable indicator of AMOC variability [5,6] because these temperatures can have multiple drivers and the spatial AMOC/sea surface temperature 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 do not directly respond 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 nineteenth 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 a 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] comes 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 the AMOC strength. Similar methods have been used to examine the other parts of the deep AMOC limb, which include the Nordic Overflows, with results that are not con- sistent with the conclusions reached by Caesar et al. [1] (for example, see refs., [11-13]), 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 twentieth and twenty-first 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 the RAPID array data between 2004 and 2012 is really more of a stepwise shift [14] and is probably a part of the 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 an investigation into decadal-to-multidecadal variability and suggest a modest decline in transport [17], but others show no trend [18,19], and one record [20] shows a recent strengthening of the AMOC at subpolar latitudes. Although 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, and also 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 work to reconcile the data and answer the important question as to whether the AMOC and/or its components have, indeed, slowed down in recent centuries.

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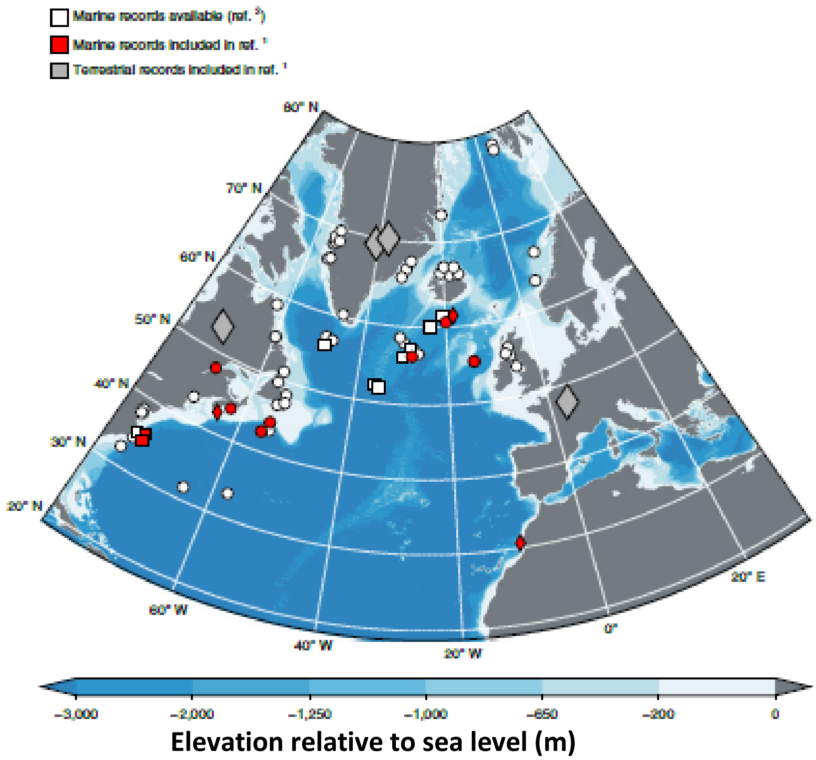

Figure 1. Available well-dated northern North Atlantic palaeoceanographic records include proxies for temperature, salinity, sea ice and ocean circulation. Surface (circles) and deep ocean (squares) records screened by Moffa-Sánchez et al. [2] (white) are compared with the subset of data (red) used by 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 and/or archives in the same location are offset for visibility.