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There is no real evidence for a diminishing trend of the Atlantic meridional overturning circulation

A. Parker[a,*], C.D. Ollier[b]

[a] *School of Engineering and Physical Science, James Cook University, Townsville, QLD, Australia*

[b] *School of Earth and Environment, University of Western Australia, Crawley WA, Australia*

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Abstract

The Atlantic Meridional Overturning Circulation (AMOC) is part of the great ocean "*conveyor belt*" that circulates heat around the globe. Since the early 2000s, ocean sensors have started to monitor the AMOC, but the measurements are still far from accurate and the time window does not permit the separation of short term variability from a longer term trend. Other works have claimed that global warming is slowing down the AMOC, based on models and proxies of temperatures. Some other observations demonstrate a stable circulation of the oceans. By using tide gauge data complementing recent satellite and ocean sensor observations, the stability of the AMOC is shown to go back to 1860. It is concluded that no available information has the due accuracy and time coverage to show a clear trend outside the inter-annual and multi-decadal variability in the direction of increasing or decreasing strength over the last decades.

Keywords: Ocean circulation; Conveyor belt; Global warming; Climate change.

1. Introduction

The Atlantic Meridional Overturning Circulation (AMOC) is a critical part of the Earth's climate system transporting heat from the tropics and Southern Hemisphere toward the North Atlantic. The recent period of monitoring with ocean sensors cover is very short and does not permit the separation of short term variability from long term trends [3,13,17,4,16,18].

A recent study by Rahmstorf et al. [12] claims, based on models and proxies, that global warming is slowing down the circulation of the ocean. They say that their computational maps of temperature patterns over the 20th century show a significant area of cooling in the Northern Atlantic near Greenland and suggest that this cooling may be due to a reduction in the AMOC over the 20th century and especially after 1970. They believe the AMOC weakness after 1975 is an unprecedented event in the past millennium. They claim that further melting could contribute to further weakening of the AMOC.

The models and proxies of Rahmstorf et al. [12] predict the overturning circulation is slowing down as the greenhouse gases warm the planet and the melting ice adds freshwater to the ocean, but actual observations so far as Willis [18] and Rossby et al. [13] show no signs of any slowdown in the circulation.

2. Prior ocean circulation results

Satellite observations of sea surface height (SSH) and temperature, salinity and velocity from profiling buoys are used to estimated changes in the northward-streaming, upper part of the AMOC at latitudes around 41° N [18]. The 2004 through 2006 mean overturning is discovered to be 15.5 ± 2.4 Sv (10^6 m^3/s). There is no noteworthy trend in the overturning intensity from 2002 to 2009. Altimeter data, in any case, suggests an increment of 2.6 Sv since 1993, consistent with a North Atlantic warming over this same period. Despite significant seasonal to inter-annual oscillations, these

* Corresponding author.

E-mail address: albertparker@y7mail.com (A. Parker).

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observations show that there was no considerable weakening of the AMOC in the past 7 years and there is no reason to suppose the weakening could have extended to the past two decades.

The stable pattern is confirmed by Rossby et al. [13] also based on true measurements, who say two decades of directly measured velocity over the Gulf Stream current show no evidence of a diminishing circulation. They found that, utilizing a well-constrained definition of Gulf Stream width, the mean surface layer transport is 1.35×10^5 m^2/s, while the yearly reduction is computed at only 0.13%. Accounting for geostrophic effects translates in to a mean cross-stream sea level difference of 1.17 m with sea level diminishing 0.03 m over the 20 year period considered. This number is not significant at the 95% uncertainty level, and it is also about 2 to 4 times less than that alleged from the apparent "hotspot" of accelerated sea-level rise on the Atlantic coast of North America of Sallenger, Doran & Howd [14], shown in Parker [6,7] to be the upward motion of a multi-decadal oscillation.

Fig. 1 presents (a) the 2002 to 2014 combined SSH-Argo estimate of the 41° N AMOC calculated from a combination of satellite altimetry and Argo data as described in Willis [18], ($AMOC^{S\text{-}A}$ hereafter), plus (b) the 2002 to 2014 AMOC SSH only ($AMOC^{SSH}$ hereafter) that is based on only satellite altimeter data and regression coefficients, as described in Willis [18], (c) a comparison of the two results and (d) the AMOC SSH only 1993 to 2015. The data has been downloaded from JPL [2].

The overturning is defined as the sum of 0–1130 m geostrophic and Ekman transports. All the time series represent three-months running averages. The uncertainty in the SSH-Argo estimate is computed in a single 3-months average time step. The uncertainty in the SSH only estimate is an average value estimated over the entire time period. This uncertainty is only a guideline, and for periods earlier than 2002 systematic errors may be larger due to the lack of profile and subsurface drift data during that period. A complete description of the estimation procedure is available from the articles Willis [18], Willis & Fu [17], Hobbs & Willis [3].

The trend since 2002 is slightly negative for the SSH-Argo result, with a clear downtrend since 2005, Fig. 1.a. This trend is confirmed by the SSH only result over the same period, Fig. 1.b and c. The trend of the SSH only result is however positive since the start of the satellite era in 1993. The AMOC appears relatively stable and free of any reducing trend. The SSH-Argo AMOC has a linear trend of slope $-8.7990 \cdot 10^{-2}$ Sv/year over the short time window since 2002. The linear trend of the SSH only AMOC has an even more negative slope of $-16.087 \cdot 10^{-2}$ Sv/year over the short time window since 2002. However, the linear trend of the SSH only AMOC since 1993 has a positive slope of $+3.3174E \cdot 10^{-2}$ Sv/year. There is clearly a growing SSH only AMOC until about mid-2005 and a reducing SSH only AMOC afterwards as indicated by the 12 months moving average of the values averaged over 3 months, i.e. the 36 months moving average.

3. A novel amoc parameter

Very likely, the AMOC is subject to significant variability with, in addition to seasonal and inter-annual variation, multi-decadal variability that the limited amount of data does not permit us to clarify further. This should not be a surprise as up to quasi-60 years' oscillations have been shown in the Arctic temperatures and sea ice extent [10] similar to the global and local temperatures and sea levels on the worldwide scale [6,7,15]. The spectrum analysis of the surface temperature records for 11 geographical regions of Schlesinger & Ramankutty [15] exhibited a 65 to 70 years oscillation originating from the 50 to 88 years oscillations for the North Atlantic Ocean and the bounding Northern Hemisphere continents.

The AMOC SSH result is only available since 1993, but similar information may be inferred from the monthly average relative mean sea levels (MSL) measured by the tide gauges along the North Atlantic coast of the United States and Europe. We select the tide gauge of The Battery (NY) in the United States recording since 1856 and the Brest tide gauge in Europe, recording since 1807. Both tide gauges have significant gaps, especially in the distant past, that are filled by using a sine and line interpolation of the measured data. The measured MSL have been downloaded from PSMSL [11].

As the relative MSL measured by a tide gauge suffers from local factor including but not limited to the differential subsidence at the tide gauge, with linear trends of +2.83 mm/year computed for The Battery (NY) and +1.05 mm/year computed for Brest, the MSL values are first de-trended. Then, the difference in between the MSL oscillations about the linear trend in the two tide gauges, ΔMSL, is computed. To make the result comparable with the AMOC SSH only, the time steps are 3-months means, and not monthly means, with the month of the time coordinate taken as the central month of the 3-months mean. Finally, the results for the ΔMSL and the AMOC SSH only are non-dimensionalised by using the maximum and minimum values over the time window. This permits us to compare the MSL oscillations between The Battery (NY) and Brest with the AMOC SSH only over the time window January 1993 to December 2013.

Fig. 2 presents the values of the AMOC SSH Only plus the simplified AMOC, $AMOC^{MSL}$ hereafter, defined as follows:

$$AMOC^{MSL} = AMOC^{SSH}_{Mn} + \left(AMOC^{SSH}_{Mx} - AMOC^{SSH}_{Mn}\right) \cdot \frac{(\triangle MSL - \triangle MSL_{Mn})}{(\triangle MSL_{Mx} - \triangle MSL_{Mn})},$$

over the time window 1993 to 2014 in (a) and since 1856 in (b). This $AMOC^{MSL}$ based on the tide gauge readings in The Battery (NY) and Brest is relatively close to the AMOC SSH only of JPL [2] over the time window 1993 to 2014 repeating peaks and valleys of the oscillations as well as the trend. Therefore, as the tide gauge data available for The Battery (NY) and Brest cover the ΔMSL since 1856, it is possible to compute the extended $AMOC^{MSL}$ of (c) for more than 150 years. In (c) are the periodograms of the monthly