Role of decadal variability in recent weakening of the Atlantic Overturning Circulation

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The North Atlantic in Global Ocean Reanalyses

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Role of decadal variability in recent weakening of the Atlantic Overturning Circulation

The Atlantic Meridional Overturning Circulation (AMOC) has weakened significantly over the past decade[1]. Global climate models project weakening in response to anthropogenic climate change and one study has suggested that this is already occurring. However, ocean model simulations based on historical conditions have often found an increase in overturning up to the mid-1990s, followed by a decrease. It is therefore not clear whether the observed weakening over the last decade is part of decadal variability or a persistent weakening.

Here we examine a state-of-the-art global-ocean reanalysis product, GloSea5, which covers the years 1989 to 2015 and closely matches observations of the AMOC at 26.5ºN, capturing the interannual variability and decadal trend with unprecedented accuracy. The reanalysis data place the 10 years of observations - April 2004 to February 2014 - into a longer-term context and suggest that the observed decrease in the overturning circulation is consistent with a recovery following a previous increase. We find that density anomalies which propagate southwards from the Labrador Sea are the most likely cause of these variations. We conclude that decadal variability likely played a key role in the decline of the AMOC observed over the last decade, however our method cannot be used to attribute changes to natural or anthropogenic causes.

Results are published in Jackson et al, 2016.[2]

Model description

GloSea5 is a global ocean and sea ice reanalysis based on the NEMO[3] ocean model with a nominal horizontal resolution of 0.25º and 75 vertical levels. It uses the NEMOVAR assimilation scheme with multiple length scales to estimate background covariances[4]. Observations of subsurface ocean profiles, sea surface temperatures, sea ice concentrations and sea level anomalies from altimetry are assimilated.

Experiments are conducted which cover the period 1995-2015.

The AMOC

The AMOC at 26.5ºN in GloSea5 bears a striking resemblance to the observations, despite these observations not being used for the reanalysis (Fig 1). The reanalysis:

- Captures the interannual variability (correlation of 0.87)
- Captures the decadal trend in the AMOC (-0.30 Sv/year from April 2004-Feb 2014, compared to observations of -0.41 /pm 0.18 Sv/year)
- Trend is seen in the AMOC-Ekman (upper mid ocean + Florida Straits) component

The partitioning of flow between the Florida Straits and the upper mid ocean components is not captured (possibly because of lack of resolution), however the total transport is captured suggesting some large-scale constraint.

This is the first time a model has shown such a good agreement with the RAPID observations of the AMOC.

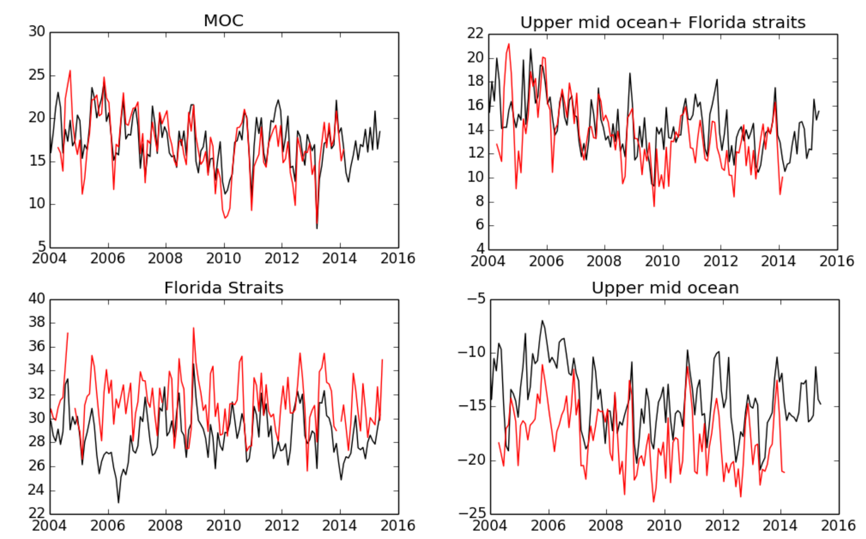


Fig 1. Comparison of the AMOC components at 26.5ºN for GloSea5 (black) and the RAPID observations (red)

The GloSea5 reanalysis extends further back in time than the observations allowing us to put the recent trend into context (Fig 2)

In the previous decade we see a strengthening of the AMOC. This suggests that the observed trend is not part of an ongoing decline, however does not rule out the possibility of a longer term decrease that would only be detectable after more years of observations.

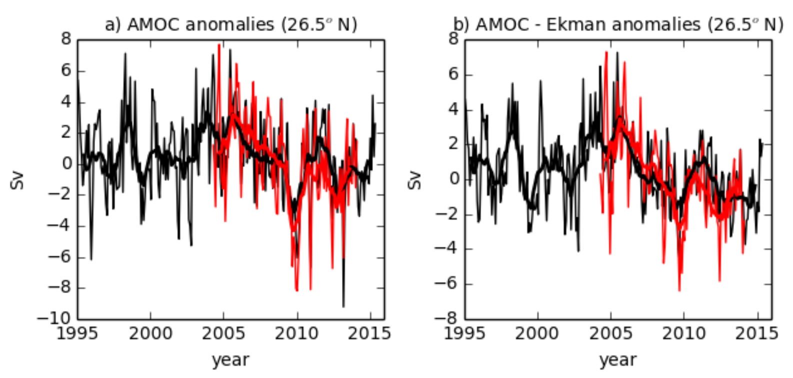


Fig 2. Full timeseries of the AMOC at 26.5ºN (with a monthly climatology removed) for GloSea5 (black) and the RAPID observations (red)

Changes in density

Previous studies have suggested a connection between the recent AMOC decrease and decreasing density in the Labrador sea[5]. GloSea5 captures temperature, salinity and density changes in the Labrador Sea (Fig 3).

GloSea5 also shows the propagation of anomalously dense, then anomalously light water from the Labrador sea southwards to 26.5ºN (Fig 4).

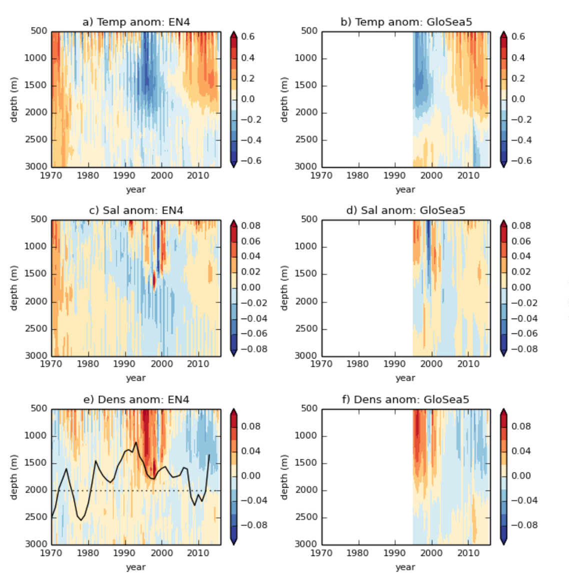


Fig 3. Profiles in the central Labrador sea from observations (EN4) and GloSea5

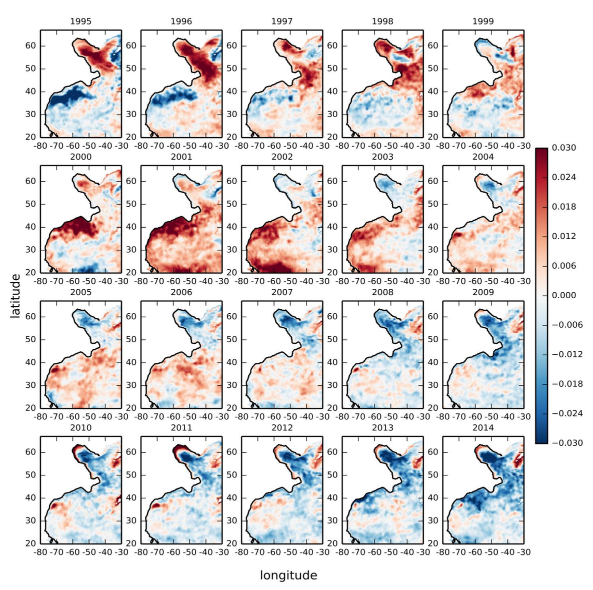


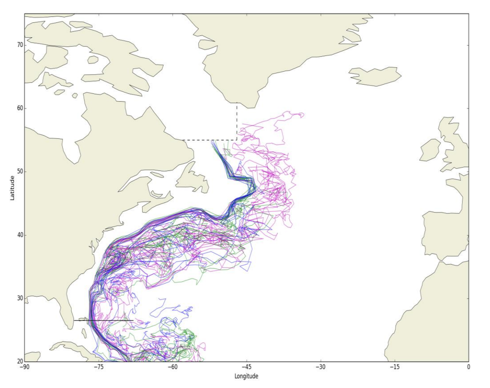
Fig 4. Annual mean density anomalies at 1795m in the NW Atlantic

An advective pathway

To assess the advection of dense anomalies from the Labrador Sea to 26.5ºN we used the offline package Ariane[6] to track water parcels exiting the Labrador Sea (Fig 5). We find:

- Faster pathways from the Labrador Sea to 26.5ºN for parcels near the western boundary (blue tracks), and slower pathways (pink tracks) for parcels in the interior that are affected by eddies.

- The modal average timescale is 7-8 years which is consistent with the timescales seen from the propagation of density anomalies. It is also consistent with observational estimates



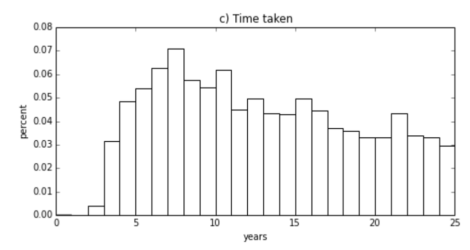


Fig 5. Pathways of water parcels leaving the Labrador sea and reaching the west region at 26.5ºN. Left: example pathways for parcels taking <6 years (blue), 6-10 years (green), or >10 years (pink). Right: histogram of years taken.

References

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The North Atlantic in Global Ocean Reanalyses

Following on from previous work[1] showing that the AMOC in the GloSea5 reanalysis compares well with observations, we present:

1. Preliminary comparisons of the AMOC in an ensemble of reanalyses. Results suggest that several similar reanalyses capture the recent AMOC weakening trend and most predict a strengthening from 2001-2005.

2. Preliminary assessment of the North Atlantic heat transports and budgets in the GloSea5 reanalysis. GloSea5 shows a weakening heat transport over the observational period, although this is less than in the observations. Atlantic heat content shows decadal variability, however we are still investigating the respective roles of advection, surface fluxes and assimilation.

We are planning a multi-model paper to assess and investigate recent Atlantic changes(AMOC, deep water formation, ocean heat transport and content) across an ensemble of reanalyses. We welcome contributions from other reanalyses and groups. Contact details are at the bottom.

Model description

GloSea5 is a global ocean and sea ice reanalysis based on the NEMO ocean model with a nominal horizontal resolution of 0.25º and 75 vertical levels. It uses the NEMOVAR assimilation scheme with multiple length scales to estimate background covariances. Observations of subsurface ocean profiles, sea surface temperatures, sea ice concentrations and sea level anomalies from altimetry are assimilated.

Other reanalyses considered all use NEMO at the same resolution, and assimilate similar observations. Different results are due to differences in model parameters/parameterisations and assimilation schemes.

AMOC in an ensemble of reanalyses

Fig 6 shows the RAPID decomposition as a running 12 month mean (black lines are observations from the RAPID array[7])

- All reanalyses show a significant decreasing trend from 2004-2015 in the AMOC and in AMOC-Ekman. Most show an increasing trend from 2001-2005.
- Prior to 2001 two reanalyses show unusual behaviour
- All struggle to capture the partition between Florida Straits and Upper Mid Ocean transport
- One reanalysis does well at capturing the upper and lower N Atlantic deep water trend. This is the reanalysis with the best depth profile (Fig 7)

Future plans include: the AMOC at other latitudes, including the OSNAP section; looking at water properties in the Labrador Sea; and looking at Atlantic heat transport and content.

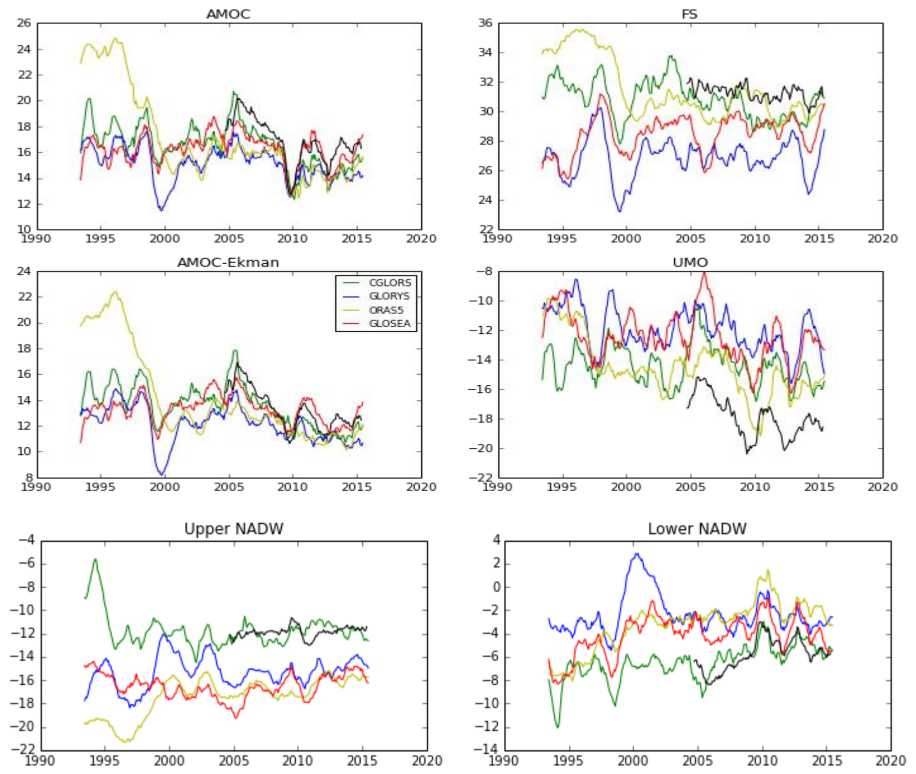

Fig 6. Time series (12 month running mean) of AMOC components from a RAPID-style decomposition. Black lines are the observations.

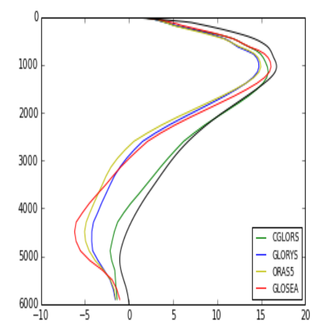

Fig 7. Profiles of the AMOC at 26N. The black line is the observations

References

7. Data from the RAPID-WATCH MOC monitoring project are funded by the Natural Environment Research Council and are freely available from www.rapid.ac.uk/rapidmoc
8. Data from the RAPID-MOCHA program are funded by the U.S. NationalScience Foundation and U.K. Natural Environment Research Council and are freely available at www.rapid.ac.uk/rapidmoc and www.rsmas.miami.edu/users/mocha
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North Atlantic heat budget in GloSea5

Comparing the GloSea5 meridional heat transport in the Atlantic with that from the RAPID-MOCHA[8] observations (Fig 8) shows

- A good agreement between the observational estimate and the reanalysis in terms of the monthly variability (correlation 0.78)
- The trend in the heat transport in the reanalysis over the 10 year period is a lot smaller than that in the observations

Atlantic ocean heat content by latitude is compared with EN4[9] (Fig 9). The EN4 analysis (Good et al, 2013) is a quality-controlled optimal interpolation of in situ observational profile data, so unlike the GloSea5 reanalysis it does not include a dynamical model. Both use observational profiles of T and S from EN4 but GloSea5 also assimilates other observational data types.

- Both show a decadal-scale transition from cool anomalies to warm in the subpolar gyre, but anomalies are of a smaller magnitude in GloSea5.
- In the subtropics both show a recent warming since 2013. In the latitude band 35-45N, the general patterns are similar, but the warm anomaly in the mid-1990s is substantially stronger in GloSea5, and there is less high-frequency variability.

A study of the heat budget (not shown) suggests that the data assimilation temperature increments applied to the GloSea5 reanalysis strongly contribute to the warm anomaly in the mid-1990s. Further work is ongoing to examine the heat budget in more detail including understanding how much of these changes in heat content are caused by changes in surface heat fluxes, changes in ocean heat transport, and by assimilation of temperature observations.

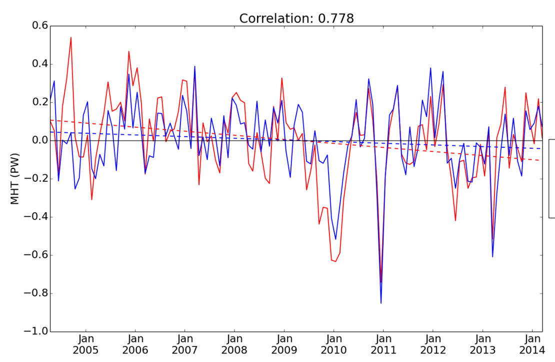

Fig 8. Ocean meridional heat transport at 26.5N. Anomalies from a monthly climatology.

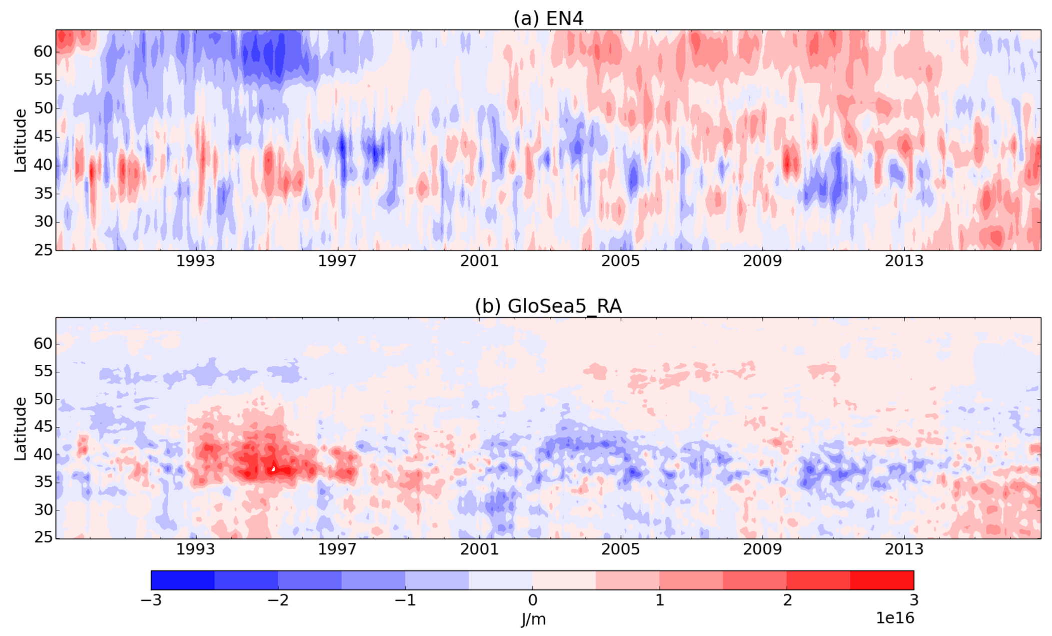

Fig 9. Heat content anomalies relative to a monthly climatology. Each panel shows the zonally integrated total column heat content as a function of latitude and time (in Joules per meter latitude)

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