The Meridional Overturning Circulation north of the AR7W and A25-Ovide lines in recent decades

Damien Desbruyères, Nathalie Daniault, Herlé Mercier, Virginie Thierry, Igor Yashayaev, Pascale Lherminier, Artem Sarafanov

damien.desbruyeres@ifremer.fr - Laboratoire de Physique des Océans - UMR 6523 CNRS/IFREMER/IRD/UBO

Ifremer, BP 70, 29280 Plouzané Cédex, FRANCE

1. Introduction

In the northern North Atlantic, warm surface waters of subtropical origins are progressively densified through atmospherically-driven and internally-driven processes before returning southward in the deep ocean.This light-to dense conversion of water masses drives the so-called Meridional Overturning Circulation (MOC), a key contributor to the climate-relevant heat transport in the North Atlantic sector. Of particular interest is the contribution of convectively-formed Labrador Sea Water (LSW) to the basin-scale MOC, an issue rarely assessed with observational datasets. The present study is aimed to:

(1) provide a time-mean estimate of the MOC across the merged AR7W/A25-Ovide line during the 2002-2010 time span

(2) quantify the impact of Labrador Sea Water (LSW) formation rate on the recent (1990's versus 2000's) MOC variability.

These questions are adressed using repeated hydrographic surveys along the AR7W transect in the Labrador Sea and the A25-Ovide line in the eastern subpolar gyre, altimetry data and inverse modelling. Following the approach of Pickart and Spall (2007, JPO), the distinction will be made between the MOC_z in the depth space (the net sinking) and the MOC_σ in the density space (the water mass transformation).

3. The 2002-2010 time-mean circulation

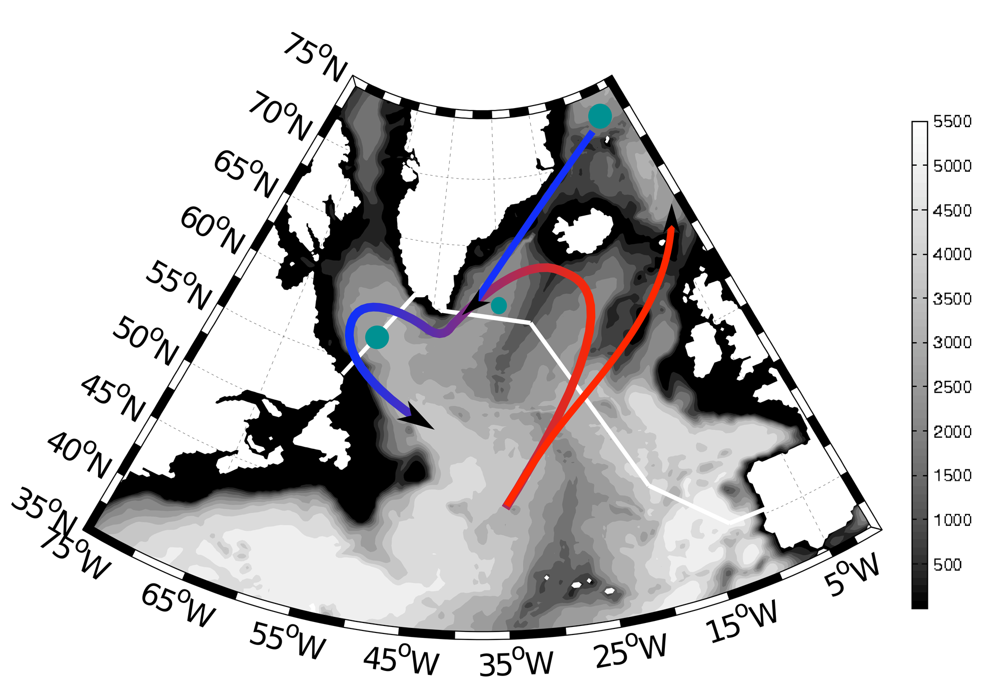

Figure 1. Bathymetry of the North Atlantic (in m) and positions of the A25-Ovide and AR7W sections. The light-to-dense conversion of water masses is grossly schematized (green circles: deep-convection sites

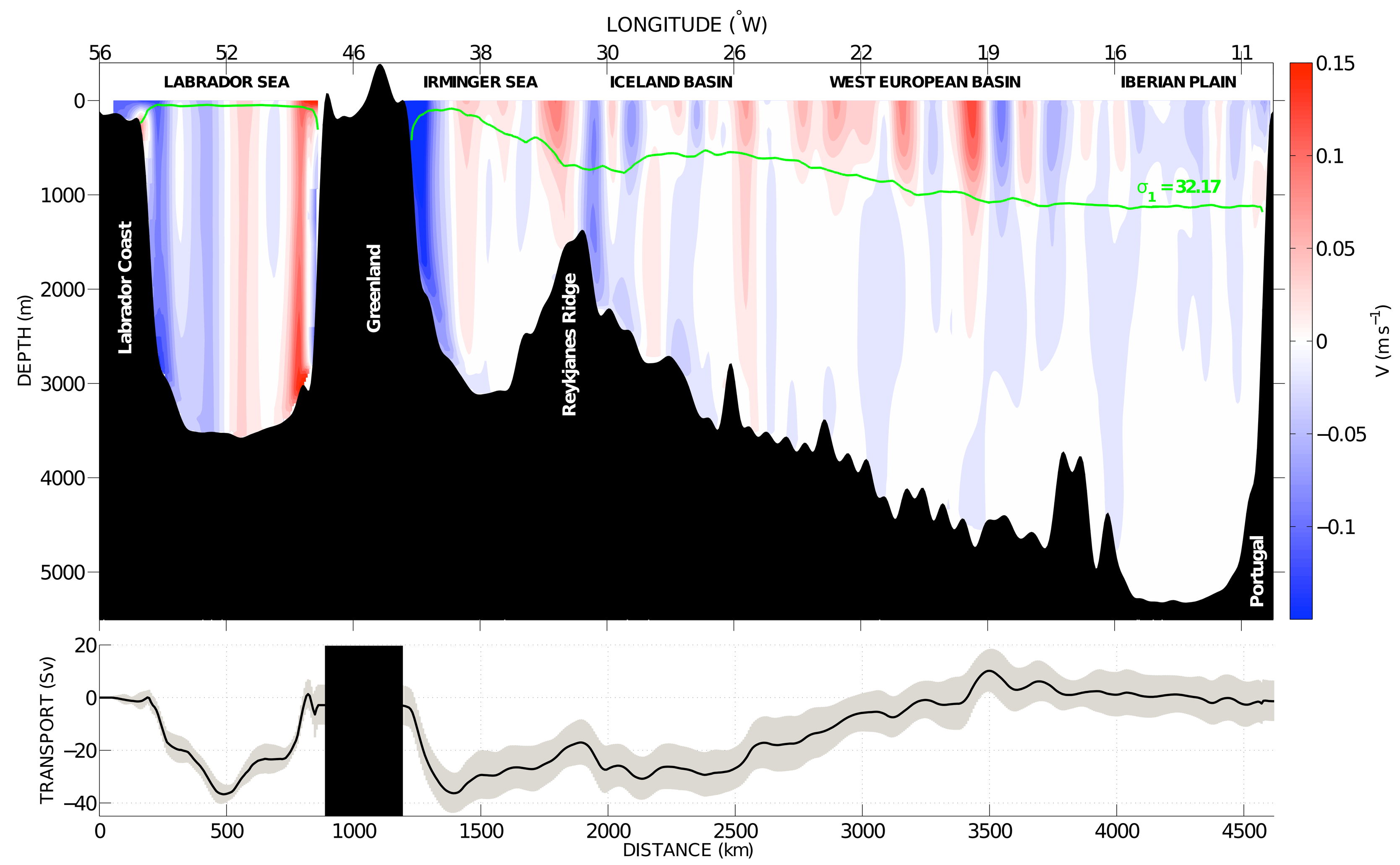

Figure 2. Time-mean (2002-2010) absolute velocity field along the AR7W/A25-Ovide merged line. The isopycnal surface $\sigma_1 = 32.17$ at which the maximum overturning is reached is shown in green. The bottom panel shows the vertically-integrated transport cumulated from the Labrador coast to Portugal (in Sv).

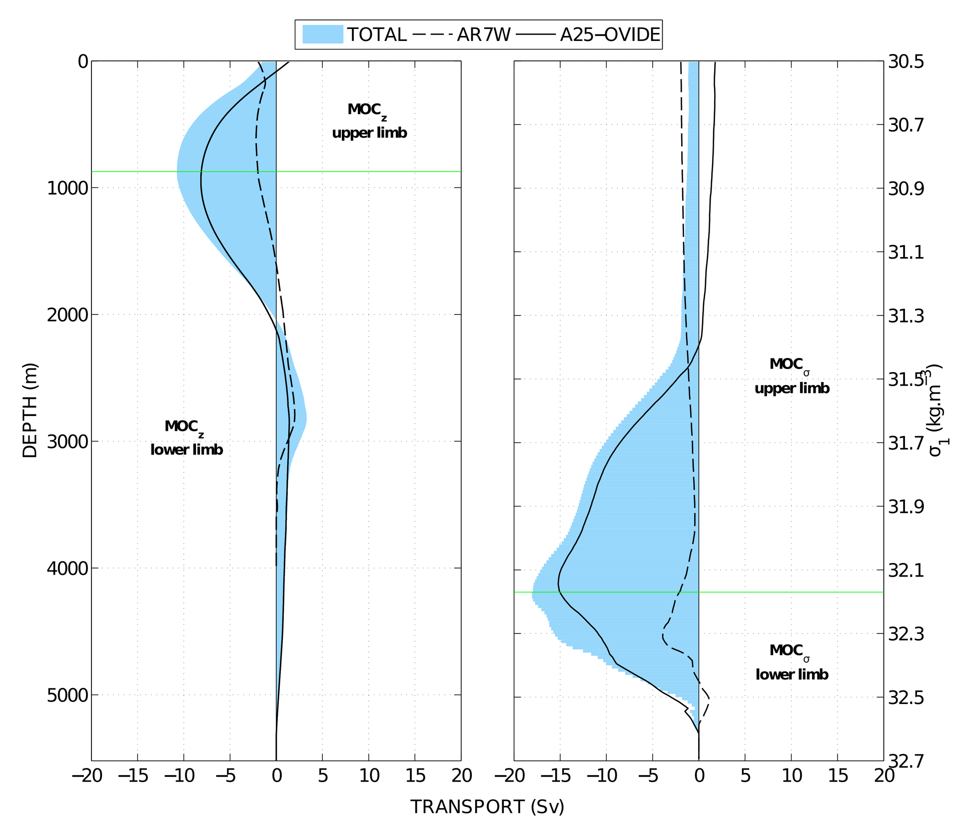

Figure 3. Time-mean (2002-2010) MOC streamfunctions in the (left) depth and (right) density spaces (in Sv). The total MOC is shown in blue, the AR7W MOC with the dashed line, and the A25-Ovide MOC with the solid line. The green lines indicate the depth and density levels at which the maximum (total) overturnings occur.

The MOC_z

The maximum MOC_z reaches 10.7 ∓ 1.4 Sv at 875 m depth across the AR7W/A25-Ovide merged line (Figure 2, left), with a 23% contribution from the Labrador Sea.

The maximum MOC_z across AR7W (resp. A25-Ovide) amounts to 2.9 ∓ 0.8 Sv at 613 m (resp. 8.1 ∓ 1.3 Sv at 945 m). This agrees with the usual description of the North Atlantic Deep Water, with LSW overlying overflow-derived waters from the Nordic Seas.

The MOC_σ

The maximum MOC_σ reaches 18 ∓ 1.8 Sv at $\sigma_1 = 32.17$ across the AR7W/A25-Ovide merged line (Figure 2, right), with a 17% contribution from the Labrador Sea.

The local MOC_σ at AR7W reaches its maximum value at a denser level (4.7 ∓ 1.3 Sv at $\sigma_1 = 32.3$) than the local MOC_σ across A25-Ovide (15.2 ∓ 1.1 Sv at $\sigma_1 = 32.14$).

It shows that the convection in the Labrador Sea mainly densifies the water masses that already belong to the lower limb of the MOC_σ after their passage through the eastern subpolar gyre.

2. Tools and Methods

Repeated hydrographic surveys along the AR7W section in the Labrador Dea (summer 2002-04-06-08-10 and summer 1990-92-92-94-96) and A25-Ovide section between Greenland and Portugal (2002-04-06-08-10) provide time-mean gridded hydrographic and relative velocity fields in the subpolar gyre.

The absolute velocity fields at AR7W are retrieved by adding the absolute surface geostrophic currents at each depth level, obtained from the mean dynamic topography of Rio and Hernandez (2004) and altimetry-derived sea-level anomalies from the AVISO 1/3° topography (e.g. Sarafanov et al., 2012, JGR). An inverse model was used for the A25-Ovide section (Lherminier et al., 2010, DSR).

4. Decadal variability at AR7W (1990's vs. 2000's)

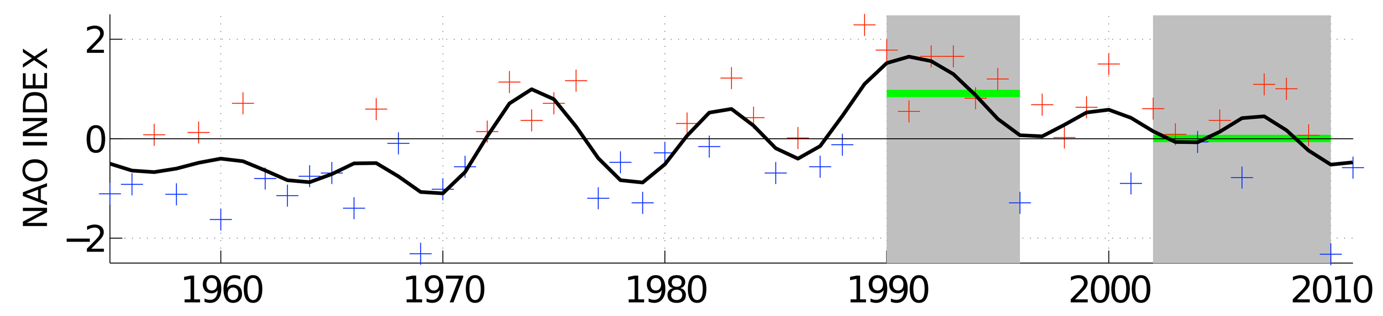

Figure 4. Normalized NAO index defined as the first principal component of sea-level pressure in the North Atlantic (crosses: annual values; black line: 3-year low pass filtered signal). The gray shading indicates the two periods discussed in the present study (mean NAO index in green).

1990-1996: positive NAO conditions: dense and deep LSW product.

2002-2010: neutral NAO conditions, light and shallow LSW product.

What impact on the MOC at AR7W?

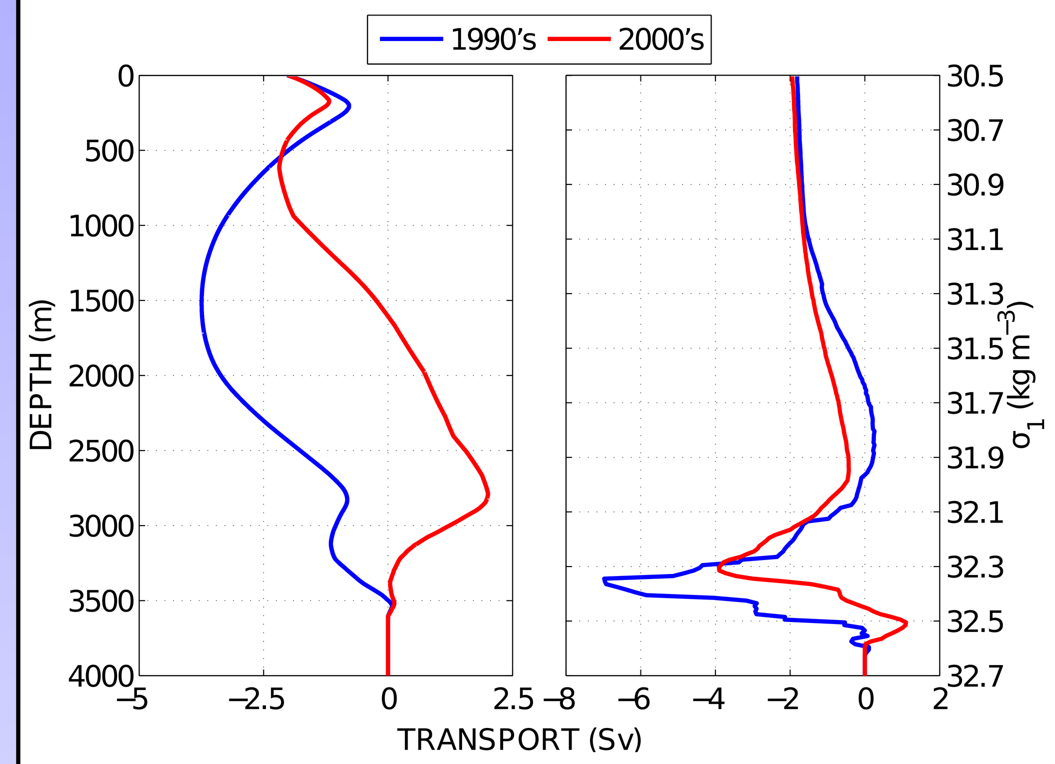

Figure 5. The MOC streamfunctions across AR7W in the (left) depth and (right) density spaces for the (blue) 1990-1996 and (red) 2002-2010 years (in Sv).

Both the MOC_z and MOC_σ underwent important decadal changes in their intensity and spatial structure (Figure 4).

The MOC_z

The maximum MOC_z reached 3.7 ∓ 1.2 Sv at 1500 m in 1990-96. Assuming no changes at A25-Ovide, this leads to a total MOC_z 1.4 Sv stronger than in the 2000's and a transport weighted depth of its lower limb 613m deeper.

The MOC_σ

The maximum MOC_σ reached 7 ∓ 1.5 Sv at $\sigma_1 = 32.35$ in 1990-96. Interestingly, assuming no changes at A25-Ovide, the magnitude of the total MOC_σ remained unchanged between both decades, while the transport-weighted density of its lower limb switched from 32.47 to 32.36.

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5. Conclusion

In the 2002-2010 years, the total MOC_z (10.7 ∓ 1.4 Sv) was primarily induced by net sinking east of Greenland (77%). The total MOC_σ (18 ∓ 1.8 Sv) was largely induced by the densification of Atlantic waters in the eastern subpolar gyre and in the Nordic Seas (83%). About 40% of the basin-scale water mass transformation occurred in the horizontal plane.

Further examination of the preceding decade (1990-1996) suggests strong variability in the Labrador Sea: the MOC_z and MOC_σ across the AR7W section respectively decreased by 1.5 Sv and 3 Sv from the early 1990's to the 2000's.

The changing LSW formation rate did not significantly affect the basin-scale amplitude of water mass transformation across the AR7W-A25-Ovide section, as the densification in the Labrador Sea occurred within the lower MOC_σ limb. Nevertheless, changes in the LSW formation rate was not without effects, and changed the magnitude and depth of sinking as well as the density of the deep waters that will then spread southward in the North Atlantic as part of the lower MOC limb.