# The water mass structure and transports in the Atlantic Subpolar Gyre

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## Highlights

- We found inter-annual and decadal variability in the distribution of the main water masses of the North Atlantic Subpolar Gyre and in their relative contributions to the Atlantic Meridional Overturning Circulation (AMOC) for the period 1997-2000s. This time span marks a transition from high NAO (North Atlantic Oscillation) index (more intense horizontal circulation associated) to neutral/low NAO index (weaker circulation).
  - The distribution of the main water masses obtained from an Optimum Multiparameter (OMP) analysis (Tomczak and Large, 1989; Álvarez et al., 2004; Carracedo et al., 2012; Pardo et al., 2012) were combined with the velocity field resulting from a box inverse model (Lherminier et al., 2007, 2010; Gourcuff et al., 2011; Mercier et al., 2013), thus providing the net transport of each water mass.
- The northward circulation of the upper limb of the AMOC weakened from 17.5 Sv in 1997 to 9.4 Sv in the 2000s, mainly due to a reduction in the transports associated to the North Atlantic Central Waters ($ENACW_{16°}$+$ENACW_{12°}$+$ENACW_{8°}$). This loss of strength of the upper limb of the AMOC within this period was partially balanced by the weakening of the transports associated to intermediate waters: the Labrador Sea Water (LSW) (from 4.6 Sv to 3.6 Sv) and the Subpolar Mode Water from the Irmingen Sea (IrSPMW) (from 8.2 Sv to 4.7 Sv).

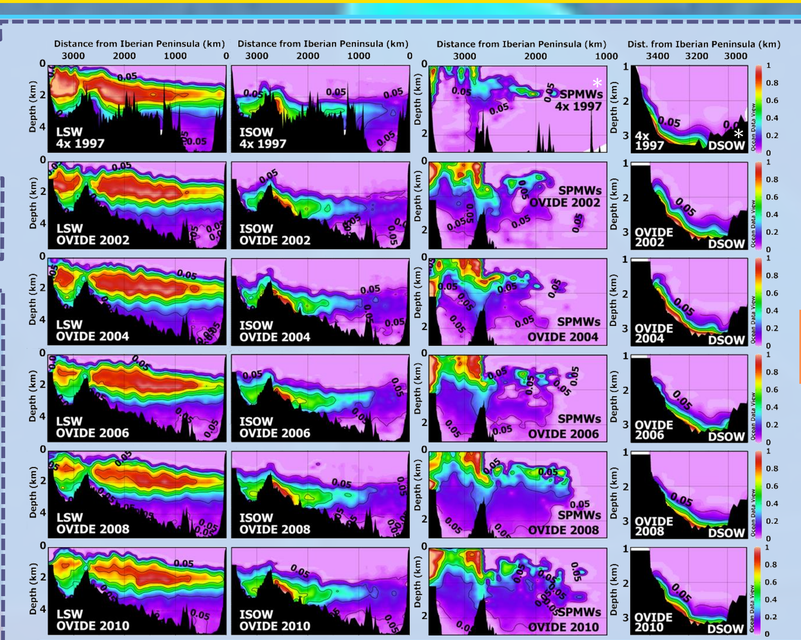
## Motivation

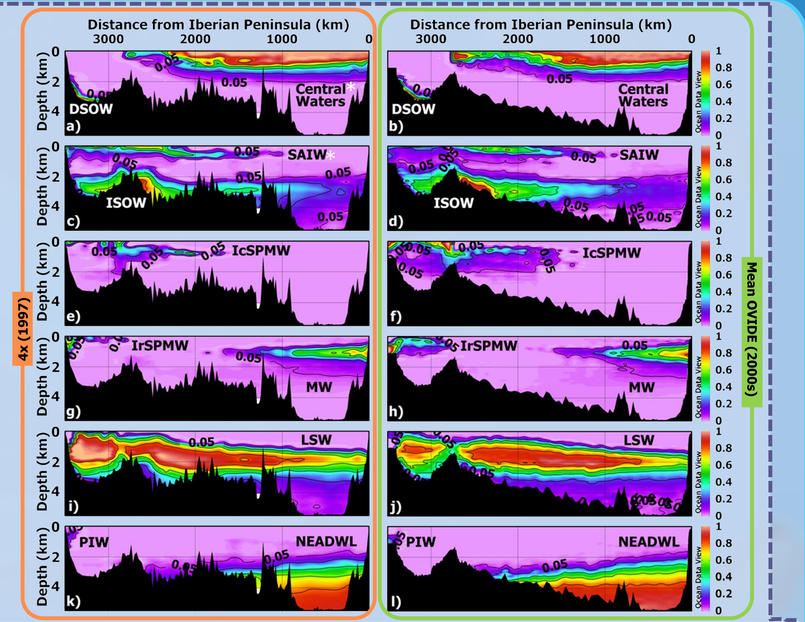
The North Atlantic Subpolar Gyre's (NASPG) circulation and interactions with the atmosphere contribute to the warm-to-cold water mass transformation, a process that impacts the intensity of the Atlantic Meridional Overturning Circulation (AMOC). In the NASPG, the North Atlantic Oscillation (NAO) is the dominant mode of the atmospheric variability, which influences the shape of the gyre and hence its circulation.

Our aim is to study the water mass structure and the water mass transports in the NASPG. This allows us to provide the relative contributions of each water mass to the AMOC and to evaluate the water mass transformation in the North Atlantic. We also investigate the inter-annual and decadal variability in the water mass distributions and transports between two periods under different NAO regimes.

## Results

SPMWs=IcSPMW+IcSPMW
$DSOW=DSOW_1+DSOW_2$
Central Waters=$ENACW_{16°}$+$ENACW_{12°}$+ $ENACW_{8°}$
$SAIW=SAIW_1+SAIW_2$
The $NEADW_U$ contribution is not shown since this water mass was decomposed into its source waters (MW, LSW, ISOW and $NEADW_L$).




- The Central Waters present two cores: a thicker one associated with the northward flow of the North Atlantic Current and a narrower one associated with the southward recirculation of these waters over the eastern flank of the Reykjanes Ridge. The two cores are separated by the SAIW.
- The sinking of the IcSPMW and the IrSPMW can be associated to the processes of transformation that undergo these waters, which some earlier studies postulated to be the result of entrainment of the waters from below. In fact, the western core of the SPMWs (IcSPMW+IrSPMW) extends towards the center of the Irmiger Basin and erodes the upper part of the LSW, which indicates deep convection.
- The LSW presents a progressive thinning and shoaling. The greater strength of the NASPG in 1997 (4x section) can be associated with a greater presence and a deepening of the LSW.
- The distribution of the MW coincides with the tongue of maximum S and minimum $O_2$ in each section.
- The presence of the PIW supports the statement of the existence of shelf waters entrainment into the DSOW. No substantial temporal changes can be appreciated in both overflows (DSOW and ISOW).
- The older $NEADW_L$ represents the dominant deep water mass south of 40ºN and its distribution follows the high $SiO_2$ concentrations at the bottom of the Iberian Basin (influence of Antarctic Bottom Water).

## How we did it?


### Source Water Types

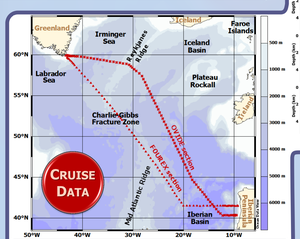
| * | $\theta^{SWT}$ °C | $S^{SWT}$ pss | $SiO_2^{SWT}$ µmol kg$^{-1}$ | $NO_3^{SWT}$ | $PO_4^{SWT}$ | $O_2^{SWT}$ |
|---|---|---|---|---|---|---|
| **$ENACW_{16°}$** | 16.00±0.13 | 36.200±0.021 | 0.21±0.12 | 0.00±0.16 | 0.00±0.01 | 257.0±7.2 |
| **$ENACW_{12°}$** | 12.30±0.18 | 35.660±0.029 | 0.00±0.82 | 5.88±1.11 | 0.29±0.07 | 270.4±7.8 |
| **$ENACW_{8°}$** | 8.00±0.11 | 35.230±0.016 | 3.44±2.20 | 11.25±1.16 | 0.68±0.01 | 286.0±5.7 |
| **MW** | 11.74±0.22 | 36.500±0.011 | 8.00±0.15 | 15.13±0.21 | 0.72±0.03 | 190.0±7.9 |
| **$SAIW_1$** | 6.00±0.20 | 34.700±0.029 | 5.12±2.20 | 11.66±1.16 | 0.85±0.07 | 293.6±9.0 |
| **$SAIW_2$** | 4.50±0.20 | 34.800±0.029 | 10.79±2.20 | 17.03±1.16 | 2.49±0.07 | 293.6±9.3 |
| **IcSPMW** | 6.50±0.07 | 35.120±0.006 | 5.90±0.16 | 14.43±0.16 | 0.68±0.01 | 272.0±8.9 |
| **IrSPMW** | 5.00±0.020 | 35.014±0.013 | 8.87±0.36 | 17.92±0.35 | 1.00±0.02 | 272.0±9.2 |
| **LSW** | 3.00±0.19 | 34.870±0.024 | 10.04±0.78 | 15.74±0.76 | 0.95±0.12 | 303.7±9.7 |
| **ISOW** | 2.60±0.08 | 34.980±0.003 | 12.44±0.97 | 14.23±0.56 | 0.83±0.04 | 291.3±9.8 |
| **$DSOW_1$** | 1.30±0.06 | 34.905±0.006 | 9.74±0.54 | 16.00±0.84 | 1.44±0.06 | 310.0±10.1 |
| **$DSOW_2$** | 1.00±0.01 | 34.825±0.065 | 4.27±0.47 | 10.3±0.72 | 0.17±0.05 | 315.0±10.2 |
| **PIW** | 0.00±0.20 | 34.650±0.029 | 8.37±2.20 | 9.62±1.16 | 0.00±0.07 | 311.5±10.5 |
| **$NEADW_U$** | 2.50±0.08 | 34.940±0.007 | 30.00±0.63 | 18.84±0.55 | 1.12±0.05 | 269.4±9.8 |
| **$NEADW_L$** | 1.98±0.03 | 34.895±0.003 | 50.00±0.36 | 22.76±0.47 | 1.35±0.04 | 245.4±9.9 |

* Source Water Types:
ENACW=Eastern North Atlantic Central Water
MW=Mediterranean Water
SAIW=Subarctic Intermediate Water
SPMW=Subpolar Mode Water
(Ic=Iceland Basin)
(Ir=Irminger Sea)
LSW=Labrador Sea Water
ISOW=Iceland-Scotland Overflow Water
DSOW=Denmark Strait Overflow Water
PIW=Polar Intermediate Water
NEADW=North East Atlantic Deep Water
($_U$=upper)
($_L$=lower)

### Mixing Figures

| | | | |
|---|---|---|---|
| $ENACW_{16°}$ | $ENACW_{12°}$ | | |
| MW | $ENACW_{12°}$ | $ENACW_{8°}$ | |
| $SAIW_1$ | $ENACW_{12°}$ | $ENACW_{8°}$ | |
| LSW | ISOW | IcSPMW | $NEADW_U$ |
| LSW | MW | $ENACW_{8°}$ | $NEADW_U$ |
| LSW | MW | ISOW | $NEADW_L$ |
| LSW | $SAIW_1$ | IrSPMW | $ENACW_{8°}$ |
| LSW | IcSPMW | IrSPMW | $SAIW_1$ |
| LSW | IcSPMW | ISOW | $NEADW_U$ |
| LSW | ISOW | $DSOW_1$ | $DSOW_2$ |
| PIW | $SAIW_1$ | $SAIW_2$ | IrSPMW |

### Cruise Data



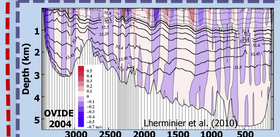

Location of the hydrographic stations of the FOUREX (hereafter 4x) (1997) and OVIDE (2002, 2004, 2006, 2008, 2010) sections, and major topographical features of the Subpolar North Atlantic.

### Water Masses Distributions

### Combination

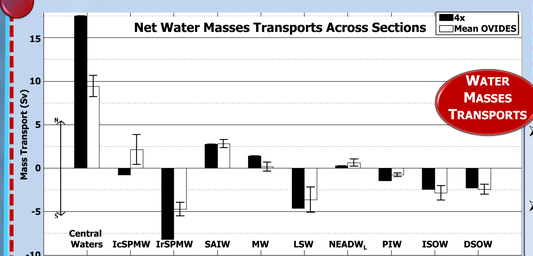
### Velocity Field

2nd Step




Obtained using a box inverse model constrained by direct acoustic Doppler current profiler velocity measurements and by an overall mass balance (Lherminier et al., 2007, 2010) coupled with altimetry data (Gourcuff et al., 2011; Mercier et al., 2013).

### Water Masses Transports




- AMOC's upper limb=Central Waters+IcSPMW+SAIW+MW → Northward flow of 19.7 Sv in 1997 and 14.4 Sv in the 2000s.
  - The weakening of the upper limb of the AMOC from 1997 to the 2000s is mainly attributed to a weakening of the northward transport of the Central Waters.
- AMOC's lower limb=IrSPMW+LSW+ISOW+DSOW+PIW → Southward flow of 18.2 Sv in 1997 and 13.9 Sv in the 2000s.
  - The weakening of the upper limb of the AMOC is partially balanced by a weakening of the southward transports of the IrSPMW and the LSW.

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