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Nitrous oxide in the North Atlantic Meridional Overturning Circulation

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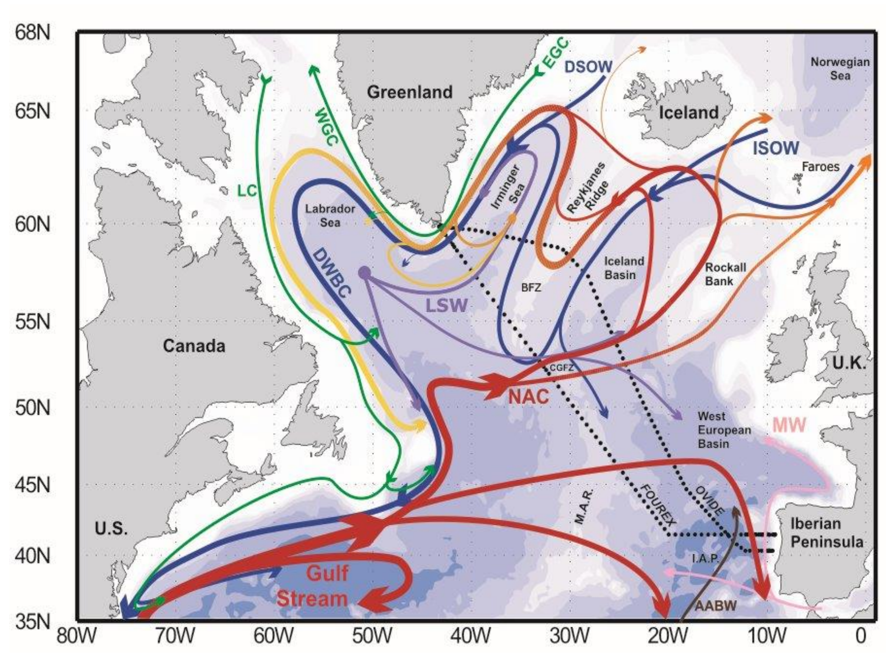
N_2O Framework & Objectives

- Nitrous oxide (N_2O) is a gaseous compound responsible for two key mechanisms within the Earth's climate: acts as a long-lived and powerful greenhouse and secondly, is currently the most important ozone depleting substance.
- The extent to which water mass mixing and ocean ventilation contribute to N_2O distribution at the scale of oceanic basins is poorly constrained. We used novel N_2O and chlorofluorocarbon (CFC) measurements along with multiparameter water mass analysis to evaluate the impact of water mass mixing and Atlantic meridional overturning circulation (AMOC) on N_2O distribution along the OVIDE section, extending from Portugal to Greenland.

- Concluding remark from this study: The most important features of the North Atlantic are mixing and southward advection of the atmospheric N_2O imprint in the lower limb of the AMOC, filled by cold, recently ventilated waters. In contrast, the upper limb of the AMOC is dominated by the production of N_2O in situ in the Iceland and West European basins, along with northward transport of mode and central waters enriched with N_2O due to accumulated remineralization in tropical and subtropical latitudes.

1 Atlantic Meridional Overturning Circulation: OVIDE experiment

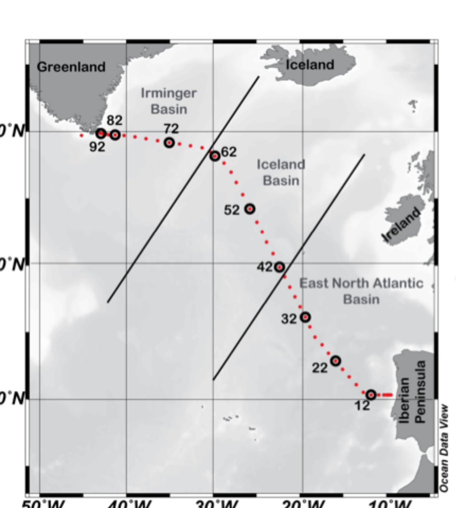
The OVIDE section was conceived as an experiment for evaluation of the changes in the Atlantic meridional overturning circulation (AMOC) and in ocean ventilation.
The **upper limb of the AMOC** is driven by the North Atlantic current, which carries warm and saline waters from the subtropics toward the north-east Atlantic, being the main contributor the ENACW. The lower limb of the AMOC is driven by the water mass formation by deep convection s in the Subpolar North Atlantic, being the LSW the most abundant in the OVIDE section.
The OVIDE has been occupied once every two years since 2002 as part of the World Ocean Circulation Experiment and CO2/Climate Variability and Predictability Research Repeat Hydrographic programs. Since 2012, N2O measurements were added to the set of properties studied in the OVIDE section.



The location of the OVIDE hydrographic section, the North Atlantic circulation scheme, the major topographical features of the Subpolar North Atlantic and the main water masses are shown in the map (Figure courtesy of Pascale Lherminier, LPEO. France, taken from García-Ibáñez et al.2015)

2 Methods

Repeated Hydrographic section: Cruises



Years

2012

2014

2016

Parameters

Salinity & Temperature

Dissolved Oxygen

Nitrate+ phosphate+ silicate

$CFCs_{11,12}$

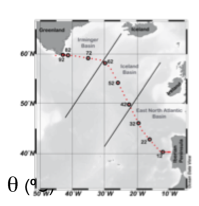
+

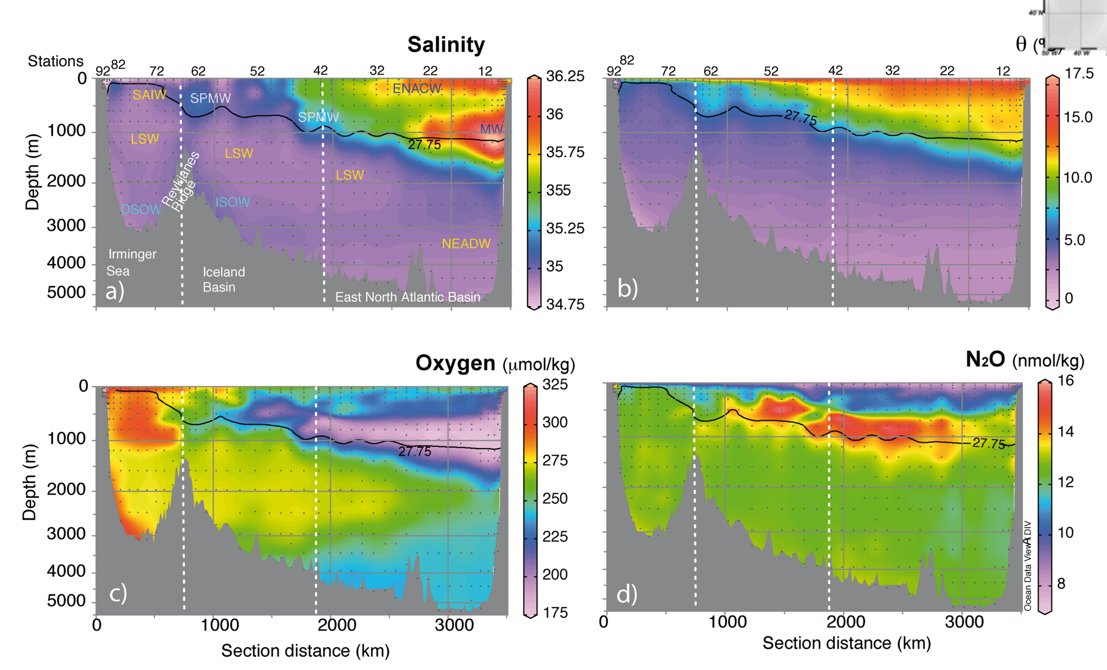
N_2O

Chemical analysis

Replicates samples for N_2O were collected using 120 mL serum vials, sealed with grey-butyl rubber septa and aluminium crimps and preserved with $HgCl_2$ to inhibit microbial activity. Trace gas samples were stored upside down in the dark until analysis in the laboratory IIM-CSIC. Dissolved N_2O was analysed by static-head space equilibration gas chromatography (GC Agilent-7890). Several intercomparison experiments have done within the INGOs EU project and SCOR WG #143 to test the analytical system with good accuracy results.

3 N_2O distribution in the OVIDE section



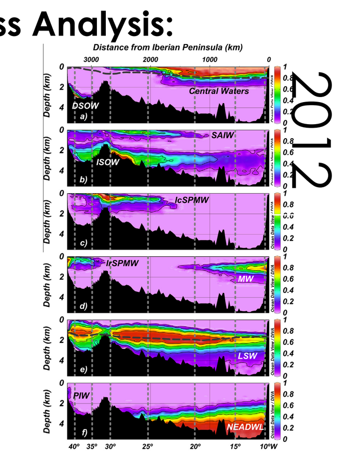


- The distributions of θ and salinity are linked to the upper and lower limbs of the AMOC : warmer and saltier upper limb moving northwards, and fresher and cold waters moving southards in the lower limbs
- The O_2 distribution shows a marked northwest–southeast gradient that is highly correlated with ventilation and overturning processes along the section. The combined effects of winter deep convection and the cold temperatures of the water masses when they are formed result in high O_2 values and in a homogeneous vertical O_2 pattern in the water column of the Irminger Sea.
- The N_2O lower values are observed in the eastern North Atlantic Basin in the warm ENACW, which increase northwards as the water cools, being the maximum N_2O surface concentrations in the Irminger Sea. The higher N_2O concentrations occurs between 600 and 1200 m in depth in the eastern North Atlantic Basin, between the upper and lower limb of the AMOC.
- Below that maximum, the N_2O concentration remains relatively homogeneous down to the bottom and close to N_2O saturation, filling the lower limb of the AMOC.
- **Why does the N_2O not match the O_2 distribution, as usually observed in oxic oceanic environments? What is the origin of the N_2O concentrations observed in the North Atlantic?**

Extended Optimum Multiparameter Water Mass Analysis:

Compute the source water type (SWT) proportions that contribute to each water sample for each cruise (X_i) and Oxygen anomaly corrected by disequilibrium of water masses when formed: $\Delta O_{2\ bio}$:

- Year 2012: García-Ibañez et al., 2015
- Year 2014:García-Ibañez et al., 2017
- Year 2016: In progress



Water mass averaged concentration of N_2O and O_2:

$$A_j = \sum_i^{11} X_{i,j}\, A_i^{MT} + \xi_j \qquad j = 1 \text{ to } 475 \text{ samples}$$

A_j is the measured concentration of *N_2O or O_2* in sample *j*,
A_i^{MT}, is the "mixing type" property = averaged concentration of *A* in the SWT *i*,
$X_{i,j}$ is the water mass fraction

Matrix of the thermohaline properties of the source water types considered in this study and averaged N_2O and O_2 concentrations in water masses obtained for 2012

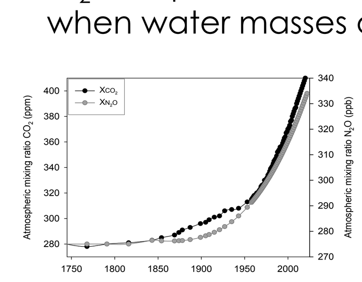
	θ [a] (ºC)	Salinity[a]	$N_2O^{MT\ b}$ (nmol kg^{-1})	$O_2^{MT\ b}$ (µmol kg^{-1})	$\Delta N_2O^{MT\ b}$ (nmol kg^{-1})	$\Delta O_{2\_bio}^{MT\ b}$ (µmol kg^{-1})
$ENACW_{16}$	16±0.13	36.20±0.02	7.88±0.34	244.73±5.20	-0.65	-3.48
$ENACW_{12}$	12.30±0.18	35.66±0.03	10.39±0.10	229.13±1.61	1.23	21.31
MW	11.7±0.2	36.500±0.011	13.28±0.25	155.95±3.84	4.64	85.43
SAIW	6.0±0.2	34.70±0.03	12.04±0.25	278.57±3.91	0.71	10.17
$SPMW_8$	8.00±0.11	35.230±0.016	15.52±0.21	195.04±3.18	5.17	94.82
$SPMW_7$	7.07±0.07	35.160±0.006	12.64±0.21	250.84±3.27	1.54	29.82
IrSPMW	5.00±0.02	35.014±0.013	12.00±0.29	316.53±4.53	-0.62	-16.46
LSW	3.00±0.19	34.87±0.02	12.64±0.10	277.14±1.53	0.17	9.75
ISOW	2.60±0.08	34.980±0.003	12.84±0.20	276.18±3.09	0.28	12.37
DSOW	1.30±0.06	34.905±0.006	13.28±0.25	302.65±10.38	-0.54	5.87
$NEADW_L$	1.98±0.03	34.895±0.003	12.33±0.14	234.39±2.11	0.78	17.68
SD			0.704	28.52	0.73	10.73

$ENACW_{16}$ and $ENACW_{12}$:, Eastern North Atlantic Central Waters of 16 and 12 ºC, respectively;
MW, Mediterranean Waters;
SAIW, Subarctic Intermediate Waters;
$SPMW_7$ and $SPMW_8$: Sub-polar Mode Waters of 7 and 8 ºC, respectively
IrSPMW, Irminger Sub-polar Mode Water;
LSW, Labrador Sea Water;
ISOW, Iceland–Scotland Overflow Water; DSOW, Denmark Strait Overflow Water; $NEADW_L$, lower North-East Atlantic Deep Water

Transient time distribution method (TTD):

Computation of mean age of water mass :

- N_2O equilibrium: Time-dependent atmospheric X_{N2O} when water masses are formed



Increases in atmospheric N_2O must be considered in order to distinguish the fraction of N_2O derived from biotic processes from that of non-biotic origin related to equilibrium with atmospheric N_2O when water masses are formed

4 Estimating the production of N_2O in ventilated regions

The AOU is widely used to infer respiration in the ocean in the basis of the assumption that the surface oxygen concentration is close to saturation with the overlying atmosphere. Nevertheless, significant oxygen disequilibrium has been observed in the high-latitude surface oceans where deep waters are formed , the case of the North Atlantic subpolar gyre.

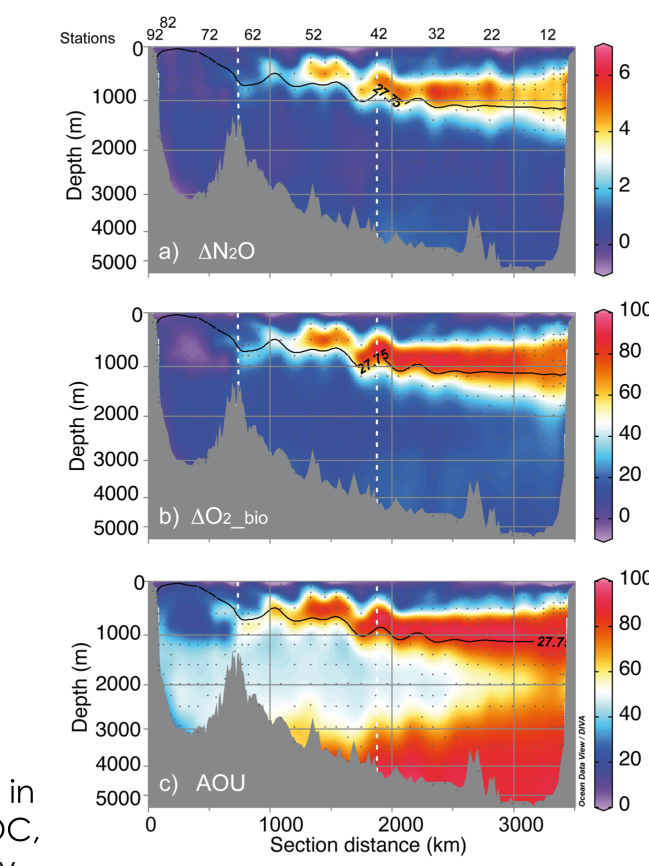
ΔN_2O) known as apparent N_2O production, used as a proxy for the biotic N_2O produced since the water mass was last in contact with the atmosphere

$$\Delta N_2O = [N_2O]_{obs} - [N_2O]_{eq}^{TTD}$$

AOU, proxi of the aerobic remineralization, do not include the disequilibrium with the atmosphere when water masses are formed.

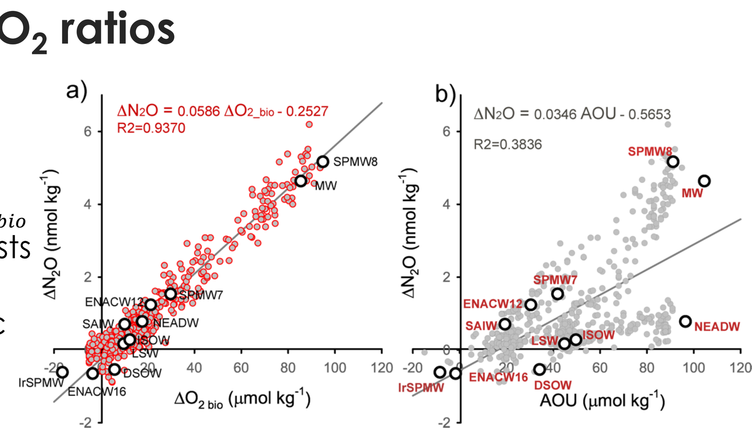
In this study, we computed the $\Delta O_{2\ bio}$ that takes into consideration the preformed properties of water masses and is equivalent to true oxygen utilization (Ito *et al.*, 2004), providing a more realistic tracer of biological oxygen consumption.

The distribution of ΔN_2O and $\Delta O_{2_{bio}}$ in the OVIDE section, point to higher impact of biological production on the observed N_2O concentrations in the upper limb than in the lower limb of the AMOC, in which N_2O concentrations are driven mainly by temperature-solubility.



Exploring the stoichiometric N_2O:O_2 ratios

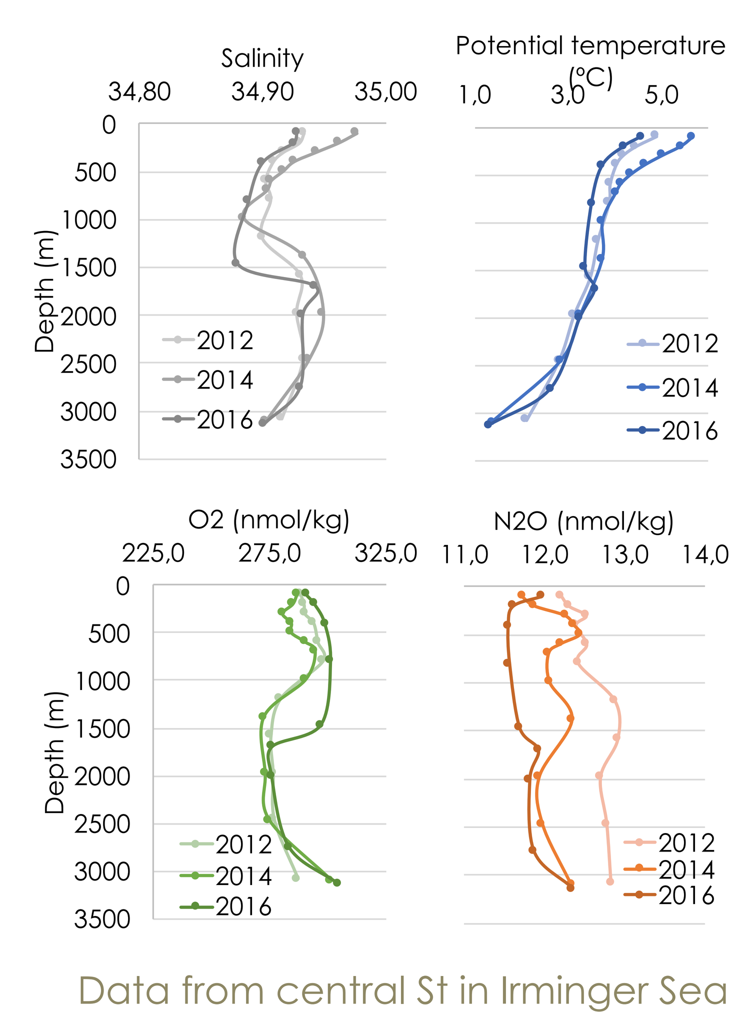
These results indicate that, when the oxygen saturation in preformed properties is considered, the stoichiometric ratio $\Delta N_2O/\Delta O_{2_{bio}}$ applies to the entire water column. This suggests that the double distributions in the correlation between ΔN_2O and AOU for the North Atlantic are probably due to biased use of AOU for ventilated waters and not to nitrification processes.



5 Work in progress

Exploring the temporal variation in the OVIDE:

2012, 2014, 2016



Data from central St in Irminger Sea

The N_2O samples were collected in the OVIDE section during the summers of 2012, 2014 and 2016. Coinciding with our study period, during 2016 recent investigations recorded the largest intensification of deep convection of the Labrador Sea Water since 1994. The imprint of this deep convection is appreciate in the vertical profile of thermohaline properties, oxygen and N_2O. This enhance the uptake capacity of greenhouse gases in the Work in progress try to decipher the uptake capacity north Atlantic subpolar gyre of the anthropogenic N2O into de deep AMOC.

Our study shows how including the N_2O measurements on hydrographic repeated sections allow to evaluate the oceanic response to large scale changes in biogeochemical processes and in oceanic circulation.

References:
-de la Paz,M., I.E. Huertas, S. Flecha, Ríos, A.F., Pérez., F.F. Nitrous oxide and methane in Atlantic and Mediterranean waters in the Strait of Gibraltar: air-sea fluxes and inter-basin exchange. Progress in Oceanography.
-de la Paz, M, García-Ibañez, M.I., Steinfeldt, R., Ríos, a. F., and Pérez, F.F. Ventilation versus biology: What is the controlling mechanism of nitrous oxide distribution in the North atlantic? Global Biogeochemical Cycles,
-García-Ibáñez, Pardo, Carracedo, Mercier, Lhermenier, Rios, Pérez. Structure, transports and transformations of the water masses in the Atlantic Subpolar Gyre . Progress in Oceanography, 05/ 2015
- García-Ibáñez, Pardo, Pérez, FF., Lhermenier, Zunino, Treguer. Water mass distribution and transports for the 2014 GEOVIDE cruise in the North Atlantic. Biogeosciences In review.

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