PhD offer – Laboratory of Physical and Spatial Oceanography (LOPS) – Ifremer.

Project title and acronym

Western boundary dynamics and overturning circulation in the subpolar North Atlantic
VERTIGO (VERTIcal dynamics of the subpolar Gyre Overturning)

Host institute and supervisors

Ifremer, National Centre for the Exploitation of the Oceans, Brest, France.
Laboratory of Physical and Spatial Oceanography (LOPS), Ocean and Climate group.

Herlé Mercier, herle.mercier@ifremer.fr, 0033 2 98 22 42 86

Damien Desbruyères, damien.desbruyeres@ifremer.fr, 0033 2 29 00 85 05

Project presentation

Summary

The ocean general circulation plays a critical role in regulating Earth Climate by transporting and sequestrating physical and biogeochemical properties (heat, freshwater, carbon, oxygen) over long spatial and temporal scales. A key yet vulnerable component of this global circulation is the downwelling of North Atlantic surface waters within the lower limb of the Meridional Overturning Circulation (MOC). Theoretically, this downwelling must occur along continental margins through complex interactions between the atmosphere, the mean ocean circulation and the turbulent mesoscale field. Those interactions have been so far mainly studied with idealized models and only locally and briefly observed, but they recently became quantifiable in the "real" ocean thanks to major efforts in sustaining global and systematic in situ observation, most especially in the Subpolar Atlantic. The proposed PhD primarily aims the study of ocean dynamics connecting upper and deep layers near along the continental slopes of the North Atlantic subpolar gyre (SPG). We will seek precise and novel estimations of the vertical volume flux and its distribution within the basins, along with detailed description of the dynamical balances at play and their expected evolution in the current context of global change. The analysis will largely rely on various observational products (autonomous floats, hydrography sections, altimetry data, atmospheric reanalysis) but will also be completed by modelling approaches.

Background and methodology

The Earth's energy balance is strongly disrupted by the anthropogenic rise in the greenhouse gas content of the atmosphere. The oceans absorb 93% of the excess energy generated by this imbalance (Rhein et al., 2013). Describing the dynamics connecting the different ocean compartments is therefore essential to help diagnose ongoing changes and their potential evolutions in a future context (eg freshening of surface waters by melting sea ice and ice caps). As part of this thesis, we are interested in the exchanges of properties between the upper and deep layers of the North Atlantic SPG, and in particular in the net downwelling of surface waters between the upper and lower limbs of the MOC (Buckley & Marshall, 2016, see also Figure 1). Building on global ocean observation networks (Argo, GO-SHIP, altimetry), we propose to study these dynamic links between ocean surface and deep ocean in order to better understand their vulnerabilities in the context of ongoing climate change.

The location of the net downwelling of surface waters has long been associated with the Labrador and Irminger seas because the intensity of convective mixing within these basins, which can exceed 2000 m depth, shows significant correlations with the MOC intensity. But the role of deep convection in the interior of those marginal seas in driving a net sinking is actually minor, as the waterways in the convective chimneys are compensated for by peripheral water lifts (Marshall & Schott, 1999). Net downwelling is rather confined along the continental margins of the convective basins and controlled "geostrophically" by through the modification of boundary current properties by eddy fluxes (Straneo, 2006). The associated theory has been widely described via idealized models (Spall, 2008, 2010, Straneo, 2006) and validated by laboratory experiments (Cenedese, 2012). It has recently been revisited via the analysis of realistic numerical models that confirm the presence of very high vertical velocities along the margins of the SPG (Katsman et al., 2018). However, the description of this boundary sinking and its related mechanisms via in situ observations is still largely incomplete (Pickart & Spall, 2007, Spall & Pickart, 2001). This is the main objective of the presently proposed thesis.

A mapping of the average hydrographic properties along the subpolar continental margins over the period 2000-2020 will be realized. This will be mainly derived from Argo data (see Figure 2) and validated locally via high resolution ship-born measurements collected along key hydrographic sections (e.g. AR7W, A25-OVIDE, OSNAP). From this mapping of the western SPG edge, an estimate of the vertical volume flux will be calculated, then described and contrasted with that resulting from numerical models. The altimetry products will be an additional tool to study the mechanisms involved in these vertical volume flows. They will be used to track mesoscale eddies from the boundary currents into the basin interiors. Argo floats co-located in these eddies will provide the temperature and salinity anomalies through which the boundary-to-interior buoyancy transport will be estimated (Dong et al., 2014, Hátún et al., 2007, Qiu & Chen, 2005). This eddy contribution to the cooling of the boundary current will be compared to that deduced from local fluxes at the air-sea interface diagnosed from atmospheric reanalysis. Finally, the impact of the "large-scale" cooling of the subpolar gyre observed since the mid-2000s (Robson et al., 2016) on the intensity of boundary downwelling will be investigated, through observation if possible, and via the analysis of high-resolution models that have reached a satisfactory degree of realism to study the local dynamics of the boundary currents and their variability (Katsman et al., 2018). The description of net downwelling in the SPG will be complemented by a separate analysis on the water mass transformation in the SPG, ie by estimates of the full diapycnal volume flux (including its horizontal component) computed using well-established theory (Walin, 1982). This thesis will therefore aim to increase our knowledge of the MOC in two different coordinate systems (depth and density) and will enable us to hypothesize their respective evolutions in the current context of global warming, a problem at the heart of the discussions in the "North Atlantic" international community.

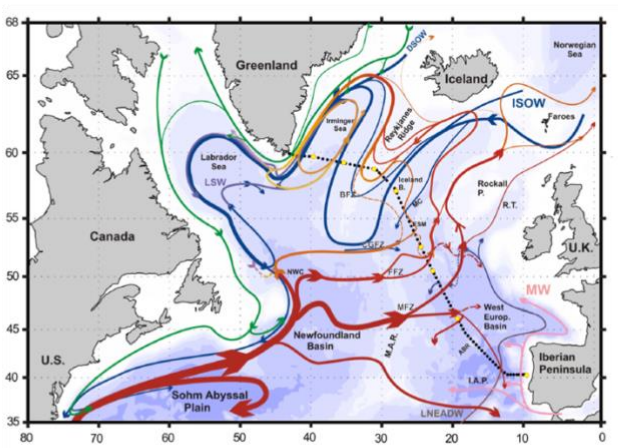

Figure 1. The circulation of the North Atlantic subpolar gyre, with major current branches following the continental slopes of the basins. This thesis focuses on the vertical fluxes of properties within these large boundary currents (blue lines). Daniault et al (2016)

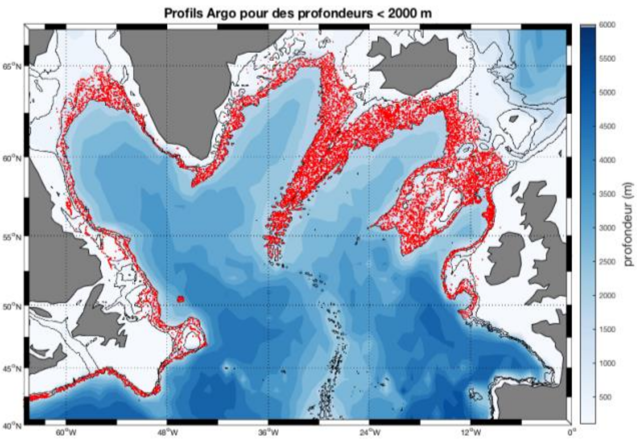

Figure 2. Argo profiles along the continental slope of the SPG (depth < 2000 m).

Main objectives

• Map the properties of the SPG boundary currents (temperature, salinity, density) and deduce the intensity of the local downwelling connecting the upper and lower branches of the MOC.

• Identify the dynamic mechanisms associated with this "downwelling" (e.g., large-scale circulation, local air-sea fluxes, eddy-driven fluxes).

• Contrast estimates of net downwelling with estimates of water mass transformation within the SPG and contextualize their respective mechanisms (e.g. natural and anthropogenic change).

Timeline

• Months 1 to 3: Bibliography, tools in hand, and work on the scientific issues to be addressed.

• Month 4 to 15: Argo data interpolation along the SPG boundary. Comparison / validation with GO-SHIP hydrographic data. Estimation of the associated vertical volume flow and comparison with the "total" water mass transformation in the SPG.

• Months 16 to 18: Disseminate results in a first publication.

• Months 19 to 30: Study of the mechanisms controlling the vertical volume flow (e.g. air-sea flux, average current, mesoscale activity) via the combined analysis of hydrographic data, altimetry, and atmospheric reanalysis. Investigation of temporal variability from numerical simulations.

• Months 31 to 36: Disseminate results in a second publication and redaction of the thesis manuscript.

Applicant

Master degree in physical oceanography, dynamic meteorology, or related discipline. Good knowledge of computer programming for environmental data analysis (Matlab, Python, ...). Good knowledge of English language (written and spoken).

Bibliography

de Boisséson, E., Thierry, V., Mercier, H., Caniaux, G., & Desbruyères, D. (2012). Origin, formation and variability of the Subpolar Mode Water located over the Reykjanes Ridge. *Journal of Geophysical Research: Oceans*, *117*(C12), n/a-n/a. https://doi.org/10.1029/2011JC007519

Buckley, M. W., & Marshall, J. (2016). Observations, inferences, and mechanisms of the Atlantic Meridional Overturning Circulation: A review. *Reviews of Geophysics*, *54*(1), 5–63. https://doi.org/10.1002/2015RG000493

Cenedese, C. (2012). Downwelling in Basins Subject to Buoyancy Loss. *Journal of Physical Oceanography*, *42*(11), 1817–1833. https://doi.org/10.1175/JPO-D-11-0114.1

Desbruyères, D. G., Purkey, S. G., McDonagh, E. L., Johnson, G. C., & King, B. A. (2016). Deep and abyssal ocean warming from 35 years of repeat hydrography. *Geophysical Research Letters*, *43*(19), 10,356-10,365. https://doi.org/10.1002/2016GL070413

Dong, C., McWilliams, J. C., Liu, Y., & Chen, D. (2014). Global heat and salt transports by eddy movement. *Nature Communications*, *5*, 1–6. https://doi.org/10.1038/ncomms4294

Hátún, H., Eriksen, C. C., & Rhines, P. B. (2007). Buoyant Eddies Entering the Labrador Sea Observed with Gliders and Altimetry. *Journal of Physical Oceanography*, *37*(12), 2838–2854. https://doi.org/10.1175/2007JPO3567.1

Katsman, C. A., Drijfhout, S. S., Dijkstra, H. A., & Spall, M. A. (2018). Sinking of Dense North Atlantic Waters in a Global Ocean Model: Location and Controls. *Journal of Geophysical Research: Oceans*, 3563–3576. https://doi.org/10.1029/2017JC013329

Marshall, J., & Schott, F. (1999). Open-Ocean Convection ' Theory , and Models Observations ,. *Reviews of Geophysics*, *37*(98), 1–64. https://doi.org/10.1029/98RG02739

Pickart, R. S., & Spall, M. A. (2007). Impact of Labrador Sea Convection on the North Atlantic Meridional Overturning Circulation. *Journal of Physical Oceanography*, *37*(9), 2207–2227. https://doi.org/10.1175/JPO3178.1

Qiu, B., & Chen, S. (2005). Eddy-Induced Heat Transport in the Subtropical North Pacific from Argo, TMI, and Altimetry Measurements. *Journal of Physical Oceanography*, *35*(4), 458–473. https://doi.org/10.1175/JPO2696.1

Rhein, M., Rintoul, S. R., Aoki, S., Campos, E., Chambers, D., Feely, R. A., … Wang, F. (2013). Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate Change 2013 - The Physical Science Basis*, 255–316. https://doi.org/10.1017/CBO9781107415324.010

Robson, J., Ortega, P., & Sutton, R. (2016). A reversal of climatic trends in the North Atlantic since 2005. *Nature Geoscience*, *9*(7), 513–517. https://doi.org/10.1038/ngeo2727

Spall, M. A. (2008). Buoyancy-Forced Downwelling in Boundary Currents. *Journal of Physical Oceanography*, *38*(12), 2704–2721. https://doi.org/10.1175/2008JPO3993.1

Spall, M. A. (2010). Dynamics of Downwelling in an Eddy-Resolving Convective Basin. *Journal of Physical Oceanography*, *40*(10), 2341–2347. https://doi.org/10.1175/2010JPO4465.1

Spall, M. A., & Pickart, R. S. (2001). Where Does Dense Water Sink? A Subpolar Gyre Example*. *Journal of Physical Oceanography*, *31*(3), 810–826. https://doi.org/10.1175/1520-0485(2001)031<0810:WDDWSA>2.0.CO;2

Straneo, F. (2006). On the Connection between Dense Water Formation, Overturning, and Poleward Heat Transport in a Convective Basin*. *Journal of Physical Oceanography*, *36*(9), 1822–1840. https://doi.org/10.1175/JPO2932.1

Walin, G. (1982). On the relation between sea-surface heat flow and thermal circulation in the ocean. *Tellus*, *34*(2), 187–195. https://doi.org/10.3402/tellusa.v34i2.10801