Project title and acronym

Dynamics of the Deep Western Boundary Current in the North Atlantic Subpolar-Subtropical Transition Zone

A component of the ANR **CROSSROAD** project

Host institute and supervisors

Ifremer, National Centre for the Exploitation of the Oceans, Brest, France.
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Project presentation

Summary

A key vector for climate signal propagation is the North Atlantic Deep Water (NADW), an ocean water mass that connects with the atmosphere at high northern latitudes before sinking and spreading southward within the lower limb of the Meridional Overturning Circulation. The rate and extent of NADW spreading and the modification of its properties *en route* are largely determined by a complex dynamical system within the subpolar-subtropical "Transition Zone" of the North Atlantic and its two topographic choke points: Flemish Cap and the Grand Banks of Newfoundland. Existing observations, however, only enable a partial description of typical circulation and mixing patterns and cannot support a comprehensive mechanistic understanding of NADW dynamics in this key region. The goal of the PhD is to help providing the missing process-oriented assessment of NADW dynamics across the subpolar-subtropical "Transition zone" using dedicated in situ observations. An emphasis will be put on the description of multi-scales interactions and the underlying mixing-driven water mass transformations that is likely to break the meridional coherence of the deep western boundary current system. This PhD is funded by the ANR CROSSROAD project.

Background

The distribution of heat, freshwater, biogeochemical parameters (e.g. carbon), and pollutants (e.g. plastic) in the ocean is at the heart of current environmental concerns[1]. The observation and modelling of ocean currents, which largely control their distributions from the basin scale to the dissipation scale, is essential to describe the anthropogenic climate transition and reduce uncertainties on its long-term projection and impacts. An essential vector for the propagation of climate-relevant quantities within the global ocean interior is the North Atlantic Deep Water (NADW), a dense water mass that regularly connects with the atmosphere at high northern latitudes before sinking and spreading southward as far as the Indian and Pacific Oceans[2]. The NADW, which occupies the deep limb of the so-called Atlantic Meridional Overturning Circulation (AMOC – Fig. 1) plays a key role on heat uptake[3], on the spreading of Arctic-origin freshwater anomalies[4], and on the penetration of anthropogenic carbon into the abyss[5]. Such a role has placed the NADW and hence the AMOC at the heart of the oceanographic community interests[6], with an ultimate goal of foreseeing their responses to future climate changes at high latitudes, such as, for instance, the expected weakening of deep convection throughout increased meltwater discharge from the Greenland ice sheet[7].

The southward export of NADW was for a long time simplified as a confined laminar flow, heading continuously southward from high latitudes along the western Atlantic margins: the so-called Deep Western Boundary current (DWBC)[8] (Fig. 1). This paradigm has now been revised, as improved observational and modelling capabilities revealed the NADW circulation as a three-dimensional system with complex patterns of vertical and meridional connectivity underpinned by strong multi-scale interactions (large-scale, mesoscale, submesoscale). Such complexity is largely determined by local ocean dynamics around a Transition Zone (TZ) that separates subpolar and subtropical basins: Flemish Cap and the Grand Banks of Newfoundland (Figure 1). This wide underwater plateau represents an important topographic obstacle for the southward propagation of NADW, and encompasses several processes that can significantly affect its intrinsic properties. Those include topography-controlled inertial separation of the boundary current towards eddy-driven recirculating gyres[9] and dispersive pathways[10], near-shore recirculation associated with the meandering North Atlantic Current (NAC)[11], intense eddy-driven vertical motions[12], or isopycnal stirring and diapycnal mixing near the steep continental slopes[13,14]. A thorough observation-driven description of those physical processes constitutes therefore a prerequisite for predicting how fast and how far forthcoming high-latitude climate changes could imprint the deep ocean globally. The aim of this PhD is to contribute to this effort using a dedicated observational dataset gathered in summer 2023 and 2024 in the TZ. A particular emphasis will be put on the respective roles of large-scale, meso-scale and small-scale processes in shaping the DWBC transport and NADW properties as it transits from subpolar to subtropical regions.

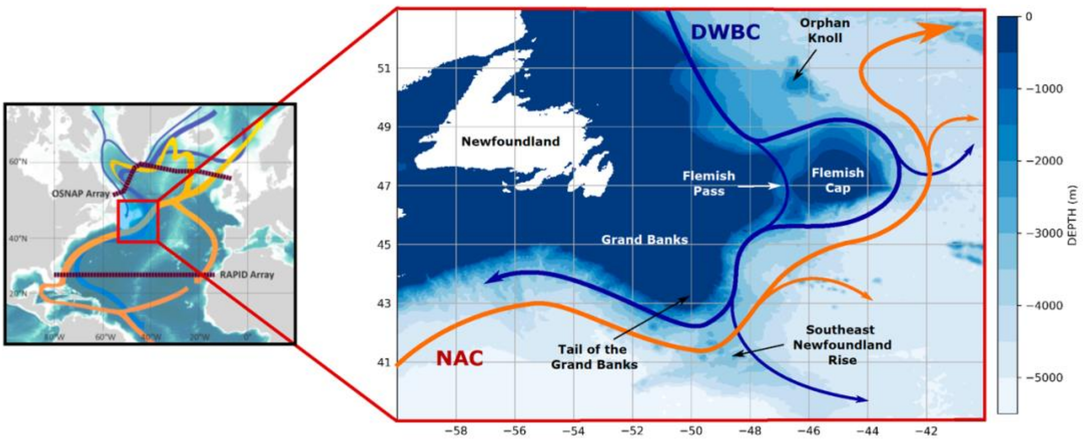

Figure 1 : The large-scale circulation in the Transition Zone of the North Atlantic. The North Atlantic Current (i.e. the upper limb of the AMOC) and the Deep Western Boundary Current (DWBC) are shown in red and blue, respectively.

Objectives and Methodology

O1. Build a high-resolution climatological data product of the TZ (CLIMTZ)

<u>Tools</u>: multi-source hydrography data (WOA18, Argo and Deep-Argo, partner's cruise). <u>Methods</u>: optimal interpolation.

A primary step will be dedicated to the construction of a new climatology of the TZ during the period 2002 – 2023. To that aim the World Ocean Database 2023 will be complemented by a large CTD-LADCP dataset collected in the TZ by German collaborators since 2003, as well as by profiles from the rapidly-growing Deep-Argo database. All profiles will be combined into a regional optimal interpolation tool[15] to yield a high-resolution (1/4°) three-dimensional and full-depth gridded fields of temperature and salinity of the TZ. This will be referred to as the CLIMTZ product hereafter.

O2. Describe the large-scale hydrography and dynamics of the TZ in summer 2024 with a focus on meridional connectivity.

<u>Tools</u>: CLIMTZ, CROSSROAD 2024 hydrography. <u>Methods</u>: geostrophic calculation, water mass property analysis

The CLIMTZ regional climatology (**O1**) will serve as a crucial reference for the analysis of hydrography datasets acquired during the 2023 MSM121 and 2024 CROSSROAD summer cruises, and which were specifically designed to study the meridional connectivity of the DWBC-NADW system including the role of mesoscale and submesocale processes in shaping this connectivity (Figure 2). This dataset will comprise about 150 full-depth CTD-LADCP profiles (from the 2023 and 2024 surveys), about 40 VMP profiles (from the 2024 survey), and several finescale "tow-yo" transects at key dynamical hot-spots (from the 2023 and 2024 surveys).

The MSM121 and CROSSROAD datasets will here be analysed to describe the large-scale properties of NADW (temperature, salinity, buoyancy) and those of the DWBC (velocity, transport) upstream, within and downstream of the TZ in summer 2023 and 2024 Departure from the CLIMTZ regional climatology will be described in order to highlight any important anomalies transiting in the TZ. Particular attention shall be paid on the along-stream modification of the boundary current system from subpolar to subtropical latitudes, with detailed focus on two sub-regional hydrography surveys at Flemish Cap and the tail of the Grand Banks. This description will be inserted in a budget-like approach to yield a synoptic estimate of the along-stream water mass transformation in the TZ.

> **O3. Describe the meso-scale and fine-scale dynamics of the TZ in summer 2024 with a focus on mixing-driven water mass transformation.**
>
> *<u>Tools</u>: CLIMTZ, CROSSROAD 2024 microstructure and "tow-yo" transects. <u>Methods</u>: derivation of mixing and instability metrics.*

The CROSSROAD 2024 dataset will then be analyzed to elucidate the respective contribution of isopycnal stirring and turbulent diapycnal mixing in driving this water mass transformation. This task will include investigations of submesocale instabilities and their potential roles in sustaining vigorous mixing and lateral exchanges of well-mixed boundary current waters and stratified interior waters. The CLIMTZ regional climatology will here be useful to provide the three-dimensional property gradients needed to infer mixing-related quantities. A submesoscale-resolving and terrain-following numerical simulation of the TZ will be available to contextualize the observational snapshot studied in **O1**and **O2**.

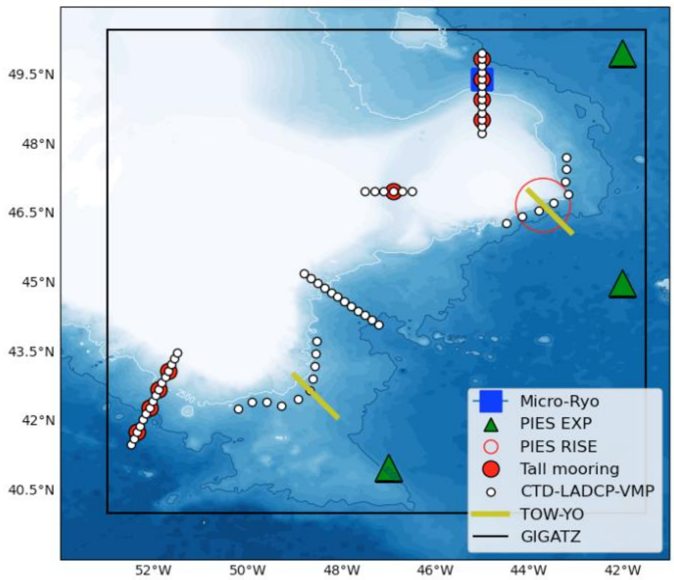

Figure 2 : CROSSROAD and EPOC fieldworks. The data to be analysed as part of the PhD include CTD-LADCP-VMP stations (white dots – preliminary plan) and high-resolution tow-yo sections (yellow sections). Other instrumental components include a microstructure mooring (blue square), 9 tall moorings (red dots) and 17 Pressure-Inverted Echo Sounders (green triangles).

Timeline (suggestive)

- Months 1 to 3: Bibliography, tools in hand, and work on the scientific questions to be addressed.
- Month 4 to 6: Construction of the CLIMTZ product
- Month 7 to 20: Analysis of the CROSSROAD 2024 dataset: large-scale dynamics (paper #1)
- Month 21 to 32: Analysis of the CROSSROAD 2024 dataset: small-scale dynamics (paper #2)
- Months 33 to 36: Redaction of the manuscript

Applicant

The selected candidate will join the "Ocean and Climate" team of the Laboratory for "Ocean Physics and Satellite remote sensing" and interact with several senior researchers. He/she will closely collaborate with two early-career researchers working on complementary aspects of the TZ dynamics with alternative tools and approaches (high-resolution modelling and mooring data). Moreover, the CROSSROAD ANR project (https://crossroad.ifremer.fr/) is paralleled by the EPOC Horizon Europe project (https://epoc.blogs.uni-hamburg.de/), which will ensure fruitful collaborations with several European partners (University of Bremen and Hamburg in particular), as well as the opportunity to participate to fieldwork activities.

The selected candidate will possess a Master or equivalent degree in physical oceanography, dynamic meteorology, or related discipline. He/she will have good knowledge of computer programming for environmental data analysis (Matlab, Python, ...) and good skills in English language (written and spoken).

Applicants should send a CV and a motivation statement (and a reference letter if available) by email to damien.desbruyeres@ifremer.fr, cmertens@uni-bremen.de, and virginie.thierry@ifremer.fr. Selected candidate may be contacted for a short interview.

Starting date: September 2024

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