Investigating the links between the surface and the ocean interior in the changing sea ice covered Arctic.
Étude des liens entre la surface et l'intérieur de l'océan Arctique recouvert de glace de mer.

HOW TO APPLY :

Please send **for April 5th 2024** in a single PDF file to the following address: edsml.brest@univ-brest.fr with camille.lique@ifremer.fr et Louis-Philippe_Nadeau@uqar.ca en copie:

1) a cover letter explaining the applicant's background and how this fits in with the proposed project;
2) a curriculum vitae (including scientific papers, grants, awards, missions at sea, etc.);
3) all university transcripts;
4) two letters of recommendation (one of which must be from a supervisor of the student's research work).

PhD supervisors
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Summary in French and English
The Arctic environment is changing at an alarming and unprecedented rate. The most striking evidence is the large and fast shrinking and thinning of the sea ice pack that has accelerated recently, which is driving significant changes of the properties of the ocean surface and interior. The goal of this PhD project is to study the links between the sea ice conditions, the properties of the mixed layer and the ocean interior in the Arctic Basin, using a hierarchy of numerical models, complemented by the analysis of available observational dataset. We will first investigate the important processes at play for the spatial and temporal variability of the mixed layer, in relation to the local sea ice conditions and atmospheric forcing. This will provide a better knowledge of the ocean surface buoyancy forcing that will be further used to quantify the water mass transformations in the Arctic basin and infer the dynamical equilibrium of the Arctic interior. Results from this project should provide new insights on how the Arctic Ocean might evolve in a future warming climate.

La région polaire Arctique est en pleine mutation. Le signal le plus visible est la diminution de l'extension estivale de la couverture de glace qui n'a cessé de s'accélérer depuis quelques décennies, avec des conséquences importantes pour les propriétés de la surface et de l'intérieur de l'océan Arctique. L'objectif de cette thèse est d'étudier les liens entre les conditions de glace de mer, les propriétés de la couche mélangée et l'intérieur de l'océan dans le bassin arctique, en

utilisant une hiérarchie de modèles numériques complétée par l'analyse d'observations disponibles. Nous commencerons par étudier les processus importants pour la variabilité spatiale et temporelle de la couche mélangée, en relation avec les conditions locales de glace de mer et les forçages atmosphériques. Cela permettra de mieux connaître le flux de flottabilité à surface de l'océan, qui servira par la suite à quantifier les transformations de masses d'eau dans le bassin Arctique, puis à en déduire l'équilibre dynamique de l'intérieur de l'Arctique. Les résultats de ce projet devraient fournir de nouvelles perspectives sur la façon dont l'océan Arctique pourrait évoluer dans un contexte de réchauffement climatique.

Keywords / Mots clés : Arctic Ocean, Ocean – Sea ice modelling, large scale circulation, water mass transformation

<u>Description of the project</u>

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<u>A) Context:</u>

The Arctic system, as a whole, is in transition. The most striking evidence is the large and rapid shrinking of the sea ice cover (Stroeve et al. 2012), and climate models project that the transition to an ice-free summertime Arctic Ocean could occur within this century (Notz and the SIMIP community 2020), with potential impacts for the global ocean and climate, as well as new prospects for the socio-economic activities in the region. In its current state, sea ice forms a barrier between the atmosphere and the ocean, impeding the injection of wind energy to the ocean (Rainville et al. 2011), and mediating the flux of heat and freshwater from the atmosphere to the ocean surface. As the sea ice pack is thinning and retreating further and for longer each year, the flux received at the ocean surface will be strongly modified, with expected important implications for the ocean stratification, ventilation and large-scale circulation. Yet, those changes are still poorly constrained from observations or numerical models, regardless of their complexity or resolution (e.g. Lique et al. 2016).

Understanding the important processes at play in the mixed layer is key to understanding the on-going transformations in the Arctic region, as it connects the Arctic surface with the ocean interior. Observations over the past three decades have suggested a pan-Arctic shoaling of the mixed layer depth (Peralta-Ferriz & Woodgate 2015), driven by the strong freshening (and associated increased stratification) of the surface layer, resulting from an intensification of the hydrological cycle and river runoffs (Bintanja & Selten, 2014) and an excess sea ice melt. These observations, as well as idealized and realistic modeling studies (e.g. Davis et al. 2016), provide evidence that the mixed layer seasonal cycle and the stratification are currently set by thermodynamical processes in the Arctic (linked with the sea seasonal cycle of the sea ice pack). Yet, mooring observations in seasonal ice-free regions (Rainville & Woodgate 2009) and results from climate coupled models (Lique et al. 2018) suggest that dynamical processes might be locally important and play a bigger role in the future. Finally, an improved knowledge of the Arctic mixed layer properties in relation to surface forcing is also crucial to pin down the dynamics at play in the full depth Arctic Basin. Under certain assumptions, the knowledge of the surface buoyancy fluxes allows a direct quantification of water mass transformation (e.g. Walin 1982), as well as the residual overturning circulation in the Basin (e.g. Marshall 1997).

B) Objectives and overall methodology:

The aim of this PhD project is to investigate the link between the sea ice conditions, the properties of the mixed layer and the ocean interior in the Arctic Basin. Specific questions include:

1) What sets the temporal and spatial variations of the mixed layer depth and properties in the Arctic Basin?
2) By which mechanisms and on which timescales the properties of the mixed layer are transferred to the ocean interior?
3) How much the on-going and future transformation of the Arctic region might affect the mixed layer and its link to the interior?

To achieve these objectives, we will employ a hierarchy of numerical models, complemented by the analysis of available observational dataset. A high resolution regional ocean-sea ice model of the Arctic region is currently developed at LOPS as part of different on-going projects and model outputs will be available for initial analysis in this project. We will then use setting up idealized process configurations, of the kind previously developed at ISMER (ref LP).

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C) Programme of research

- Understanding the variability of the mixed layer in the ice-covered Arctic.

The student will first use model outputs to document the spatial heterogeneity of the seasonal cycle of the mixed layer depth, its timing and its temperature and salinity properties. Results from the simulations will be compared against observational estimates, making use for instance of the ITP dataset that is publicly available (www.whoi.edu/itp/). The variations of the mixed layer properties will be investigated, in regard to the local sea ice conditions and atmospheric forcing as well as the stratification found below the mixed layer. From this analysis, we should be able to determine when and where the dynamical forcing might become as important as the thermodynamical forcing. Although this study is pretty simple and straightforward, it has not been done before and should lead to a first publication.

- Inferring the ocean interior water mass transformations from the surface flux

Building on the previous study, we will use model outputs to quantify the variations in water mass transformations under the surface mixed layer over the past decades, following the methodology of Abernathey et al. (2016) developed for the Southern Ocean. Model simulations are required to obtain a pan-Arctic description of the surface buoyancy fluxes at the interface between sea ice and the ocean surface, which can be further broken down into thermal and haline (from precipitation, evaporation, river runoff and sea ice processes) contributions. Seasonal and interannual variations will be quantified, and again put in relation to change of the sea ice conditions. We could also consider performing the same diagnostics on additional simulations, in which the atmospheric conditions (and thus the sea ice conditions) are representative of a future warmer climate, in order to gain insight on how the Arctic interior might change in the future.

- *Investigating the role of buoyancy forcing on the Arctic residual circulation.*

From the knowledge of the surface buoyancy forcing and their modulation by mixed layer processes, one can theoretically infer the residual mean circulation (i.e the difference between the Eulerian mean circulation and the eddy-induced circulation, e.g Marshall & Radko 2003). This framework and its application in idealized process models is routinely applied to the Southern Ocean in order to gain insight on the dynamics at play (Marshall & Radko 2003, Badin & Williams 2010, amongst many others). While the dynamics at play in the Arctic Beaufort Gyre shares many characteristics with the ACC, there is no attempt in the literature to apply this framework to the Arctic. The student will use the knowledge already gained on the surface buoyancy forcing and mixed layer processes to set up an idealized process model (QG model with sea ice component).

Timeline: Months are numbered from M1 to M36

M1-M9: Literature review and initial analysis of the mixed layer variability from model outputs and ITP observations.

M10-M12: Writing up of a first publication on the mixed layer variability

M13-M18: Quantification of the surface buoyancy flux and the resulting water mass transformation based on the Walin framework

M19-M24: Set up of the process model

M25-M30: Determination of the residual circulation in the Arctic Basin

M31-M33: Writing up of a second publication.

M34-M36: Thesis writing and defense

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