Interplay between Mesoscale Dynamics and sea ice in the Arctic.
Interactions entre la dynamique méso-échelle et la glace de mer en Arctique.

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Summary in French and English

The Arctic system, as a whole, is in transition. Interactions between mesoscale eddies and sea ice could potentially represent an important mechanism, via which the ocean contributes to the on-going and future sea ice retreat. The goal of this PhD is twofold: 1) thanks to an innovative method using satellite sea ice observations complemented with results from realistic simulations run at very high resolution, we will quantify the mesoscale activity in the ice-covered Arctic, and determine if it fundamentally differs from the other oceans, and 2) based on model simulations, we will investigate the interplay between eddies and sea ice.

Le système Arctique, dans son ensemble, est en transition. Les interactions entre les tourbillons mésoéchelle et la glace de mer peuvent potentiellement être un mécanisme important par lequel l'océan contribue à la diminution de la banquise en cours et future. L'ambition de cette thèse est double: 1) grâce à une méthode innovante d'analyse de données satellites de glace de mer et à des résultats de simulations numériques réalistes à très haute résolution, nous pourrons quantifier l'activité mésoéchelle dans le bassin Arctique recouvert de glace et déterminer si elle est fondamentalement différente des autres océans et 2) en se basant sur des résultats de simulations réalistes, nous étudierons les interactions entre les tourbillons mésoéchelle et la glace de mer.

Keywords / Mots clés : Arctic Ocean, Mesoscale dynamics, Ocean-sea ice interactions, Numerical Modelling, Satellites and in-situ observations

<u>Description of the project</u>

<u>A) Context:</u>

In the global ocean, mesoscale eddies, with typical horizontal scales ranging from a few kilometers to a few hundreds of kilometers and lifetimes of around weeks to months are ubiquitous. They account for most of the turbulent kinetic energy and are key to the long-term equilibrium of the large-scale circulation, ocean ventilation of tracers, upper-ocean biology and pollutant dispersion. In the Arctic Basin, however, observations taken under sea ice (Timmermans et al. 2012, Marcinko et al. 2015), and results from idealized numerical simulations at very high resolution (Mensa & Timmermans 2017) have pointed out that the energy at mesoscale in the Arctic interior is relatively low when compared to characteristic midlatitude open ocean dynamics. **This suggests that, at first order, the mesoscale activity could be fundamentally different between ice-covered and ice-free regions.**

Recently, observations of high temporal and spatial resolution temperature and salinity profiles from Ice-Tethered Profilers (ITP) have allowed for the first time an extensive description of eddy characteristics (e.g. Zhao et al. 2014), although this dataset remains, by nature, sparse in time and space. This lack of observability in ice-covered regions, associated with common deficiencies of Arctic numerical simulations (owing for instance to the challenge of modelling at such small deformation radius (i.e. less than 10 km) and representing the complexity of the ocean-sea ice interactions, e.g. Lique et al. 2016) has prevented us so far from fully apprehending the specificity of the mesoscale features in the Arctic compared to the other oceans, and their importance for the Arctic system.
There is, however, growing evidence in the literature that the Arctic mesoscale activity and the sea ice might mutually influence each other. The examination of images from satellites providing a description of sea ice at high resolution (Manucharyan & Thompson 2017) reveals that sea ice is carrying the signature of ocean turbulence (eddies, fronts, filaments…), and results from idealized models suggest that eddies might strongly modulate the sea ice melt/growth (e.g. Horvat et al. 2016).

This PhD project is a contribution of the project ImMEDIAT (Interplay between MEsoscale Dynamics and sea Ice in the ArcTic; PI C. Lique) funded by the JCJC ANR programme over 2019-2022.

B) Objectives and overall methodology:

The goal of the PhD project is to improve the quantification and our fundamental understanding of the mesoscale dynamics in the presence of sea ice. Specific questions addressed include:

- Can we detect mesoscale eddies in the ice-covered Arctic using satellite observations?
- How do mesoscale features and sea ice influence each other? What are the important processes for this interplay?
- Can we provide a basin scale quantification of the Arctic mesoscale activity? How is it varying on seasonal-to-interannual timescales, in relation to the sea ice conditions?
- What role do ocean eddies play in setting the Arctic large scale circulation and physical conditions?

To achieve these objectives, we will take a multi-faceted approach, using available in-situ and satellite observations (Objective #1) as well as numerical models run at eddy resolving resolution (Objective #2).

C) Programme of research

O1: *Generalize a novel method to observe mesoscale eddies under sea ice from space*

The usual 'eddy detection' performed on satellite altimetry observations is not possible in the ice-covered Arctic. Preliminary work (Lique & Rampal, to be submitted) provides evidence that a signature of some subsurface eddies captured by ITP can be found in satellite observations of sea ice concentration and drift. This discovery so far is however limited to a handful of event. The student will first generalize the method by co-localizing all the eddies detected in the ITP dataset (following the method of Zhao et al. 2014) with available satellite observations of sea ice concentration and drift, in order to statistically relate the eddy characteristics (size, depth, signature in temperature and salinity) to their signatures on sea ice. Based on this statistical relationship, we will further inverse the method, trying to detect the presence of subsurface eddies based on the signal found in sea ice observations only. Should the method prove to be robust, this would allow us to fully exploit the satellite sea ice datasets spanning over several decades, in order to acquire a pan-Arctic description of the mesoscale eddy field.

***O2:** Investigate the pan-Arctic mesoscale activity in relation to sea ice conditions in an eddy resolving model simulation*

As part of ImMEDIAT, a regional configuration of the Arctic Basinat very high resolution will be developed, making use of an existing 4km resolution Arctic configuration (developed at LOPS as part of the CMEMS-projet ArcticMix and LEFE-project FREDY), as well as the AGRIF nesting tools. Most of the technical developments will be carried out by C. Talandier (IE CNRS at LOPS) and the amount of developments made by the student will be very limited.

Based on the analysis of the eddy resolving simulation, the aim of this task is to investigate if the mesoscale activity in the ice-covered Arctic fundamentally differs from the rest of the world. The seasonal cycle of the mesoscale eddy field and the EKE will be quantified, as well as their links with the atmospheric forcing and how it is mediated by the time and space varying sea ice conditions. Years with different seasonal cycles of the sea ice conditions will be contrasted (typically 2001 and 2012 which were the two extrema over the past 2 decades in term of their September sea ice extent). The potential asymmetry between the number of cyclones and anticyclones will be quantified and dynamically investigated. The role of eddies for the transfer of heat and freshwater (horizontally and vertically) and the large scale circulation will be determined. A potential vorticity budget approach could be used, following for instance the framework proposed by Giordani et al. (2017) for the Mediterranean Sea or Deremble et al. (2014) for the North Atlantic. The role of the mesoscale features for the evolution of the sea ice conditions, through for instance an upward transfer of heat from the intermediate layer will also be examined.

Timeline: Months are numbered from M1 to M36

M1-M9: Literature review and initial analysis of the eddy detection in ITP and their signature in satellite observations.

M10-M12: Inversion and generalization of the method

M13-M15: Writing up of a first publication

M16-M20: Initial analysis of the high resolution model simulation, computing of key metrics to characterize the mesoscale field in relation to the sea ice field

M21-M30: Study of the importance of mesoscale eddy for the Arctic dynamics

M31-M33: Writing up of a second publication.

M34-M36: Thesis writing and defense

Professional preparation:

The student will be encouraged to write scientific articles for peer-reviewed journals as their research matures. In addition to publishing scientific articles, the student will present their key results at both national and international scientific conferences. This is an important aspect of raising the profile of the research and the student.

We will apply for additional funding so the student can spend one or several extended visit at the University of Oxford. The student will also be encouraged to attend advances courses in Physical Oceanography (offered through the masters at the IUEM (Brest) and to attend relevant summer schools. There may also be an opportunity to participate in a research cruise should the student wish.

D) Context and collaborations

The student will be actively contributing to the ImMEDIAT project and will thus be closely collaborating with the members of the consortium, both in France and abroad. Yearly meetings of the project are planned, which the student will of course attend.

Computational resources required will be obtained from Datarmor or at the national level (GENCI. Satellite and in-situ observations analyzed in O1 are publicly available, and guidance on the use of the satellite data will be provided by P. Rampal (NERSC Norway).

The student will also beneficiate from the existing collaborations within the European IRN Drakkar, in which several scientists and engineers from LOPS are strongly involved, as well as the LOPS-in house expertise on the analysis of satellite observations (team SIAM@LOPS).

This project also fits well within the current initiative at LOPS to develop a new synergy amongst researchers involved in different polar research activities (remote sensing of sea ice, wave observations and modeling), through the implementation of “axe transverse – recherches polaires”, which C. Lique coordinates.