Sentinel North Research Internship

Sea ice dynamics in the changing Lincoln Sea, Arctic Ocean

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I wanted to mention that this work is also a contribution to ArcticNet's High Impact Program "Marine Production in a Changing Arctic Ocean".

Contents

Glossary

Acronyms

AO Arctic Ocean

LIA Last Ice Area

CCGS Canadian Coast Guard Fleet

SIC Sea-Ice Concentration

AMSR2 Advanced Microwave Scanning Radiometer 2

GCOM-W1 Global Change Observation Mission - Water specialising

ARTIST Arctic Radiation and Turbulence Interaction Study

ASI ARTIST Sea-Ice

GDAL Geospatial Data Abstraction Library

OC-CCI Ocean Colour - Climate Change Initiative

ESA European Space Agency

CDOM Coloured Dissolved Organic Matter

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Introduction

The Arctic Ocean (AO) participates in the climate regulation by contributing about 10% to the global oceanic carbon pump. It has an ability to absorb carbon dioxide (CO2) thanks to both its cold waters, which promote the dissolution of CO2, and its highly productive continental shelves, which help to sequester carbon. However, the AO is currently warming up drastically and fast, which has both local and global consequences that are yet uncertain. Over the last 40 years, the sea-ice extent in the AO decreased about 10% per decade, and the multi-year ice dropped about 70% (ice is multi-year when it survived at least one summer and usually exceeds 1.5 meters). These changes endanger an entire ecosystem that depends on sea-ice.

"The Last Ice Area" (LIA), located between the North of Canada and Greenland, is now known as the last place of multi-year sea-ice (Moore et al., 2021 [1]). The Lincoln Sea is part of the LIA (figure 1), which is a refuge for unique endemic sea-ice ecosystems. However, the physical, chemical, and biological properties of the Lincoln Sea are poorly understood.

Therefore, the main objective of this research project is to fill some of these knowledge gaps by characterising sea-ice and phytoplankton dynamics. To achieve this goal, the following three specific objectives will be covered: (1) derive sea ice-free periods, also known as open periods (defined as the period between sea ice melt and freeze-up); (2) highlight the spatial patterns of openings in the LIA; and (3) characterise the phytoplankton dynamics in the LIA over the past 10 years.

This study provides new insights into the oceanographic understanding of this important Arctic refuge and its changes. In addition, expeditions will take place in the LIA, including two ice camps at Alert (2024, 2025) and two overseas missions on the CCGS (Canadian Coast Guard Fleet) Amundsen icebreaker (2023, 2024). Thus, this study will help the research team to better understand the dynamics in this area before embarking on this pioneering expedition.

1 Material and methods

1.1 Sea-Ice Concentration (SIC)

Satellite-derived sea-ice concentrations (SIC) were downloaded from the University of Bremen (`https://www.uni-bremen.de/en/`). This product is obtained by Advanced Microwave Scanning Radiometer 2 (AMSR2) derived from the GCOM-W1 satellite (Global Change Observation Mission - Water specialising). This SIC data covers the period from July 2012 to the present.

The SIC were extracted with the ARTIST (Arctic Radiation and Turbulence Interaction Study) Sea-Ice algorithm (ASI) applied to microwave radiometers data of the AMSR2 sensor. The geoTIFF data are generated with GDAL (Geospatial Data Abstraction Library). Data were gridded on a polar stereographic grid (EPSG code 3413, Arctic) with a spatial resolution of 3.125km. To obtain these data, the AMSR2 sensor measures the brightness temperature, i.e. the microwave radiance at a frequency channel of 89 GHz. Thus, it is possible to get values of sea-ice concentration while there are clouds.

1.2 Chlorophyll *a* concentration

Chlorophyll *a* (Chl *a*) concentrations were downloaded from OC-CCI (Ocean Colour - Climate Change Initiative) program (`https://climate.esa.int/en/projects/ocean-colour/data/`) launched by the European Space Agency (ESA). Chl *a* concentration was estimated using all OCI, OCI2, OC2, OC3, OCx and OC5 algorithms [2]. The data were regridded similarly to the sea-ice concentration data for comparison.

SIC and clouds prevent Chl a retrievals, resulting in missing data. In addition, there are less than six months of Chl *a* time series in the Arctic Ocean due to the polar night. This implies a less data throughout the year, and possible biases to be evaluated (e.g., for the annual mean Chl *a* concentration).

1.3 Areas of interest

This study focuses on the Lincoln Sea, but covers the entire region as far south as northern Baffin Bay. The entire area lies between latitudes 75°N and 85°N, and between longitudes 40°W and 80°W. Therefore, the 10° difference in latitude implies large differences in SIC concentration. For this reason, the area is divided into four areas of interest (Figure 1), numbered 1 to 4 and defined from north to south according to hydrodynamic context and topographic properties. The first area is the northernmost, and the fourth area is the southernmost.

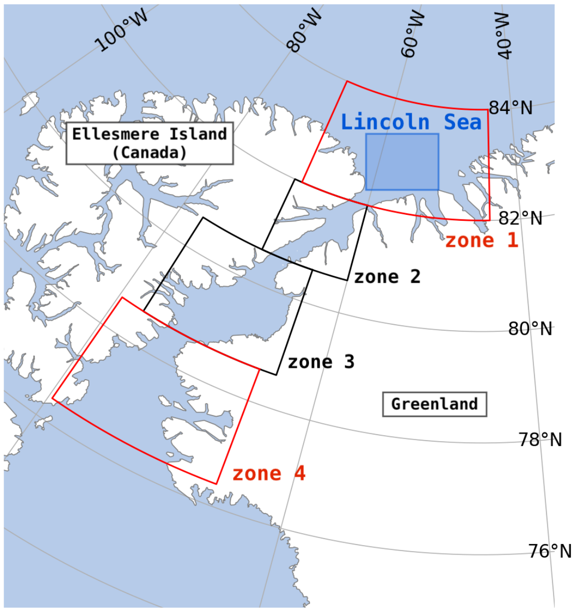

Figure 1 – Map showing the four areas

1.4 Definition of an open area

The satellite data provide SIC for each pixel at a resolution of 3.125km. According to the literature, a pixel is said to be open when the SIC is less than 15% (e.g. Bensassi et al., 2016 [3]; Andrews et al., 2017 [4]; Andrew et al., 2018 [5]). To calculate the ice cover for each area, pixels below 15% of SIC were summed to obtain the percentage of SIC of the region. It is more common to represent ice coverage than ice opening. Thus, a value of 100% means that 100% of the pixels are not open, i.e. above 15% ice. A value of 80% means that 20% of the pixels are open, i.e. below 15% ice.

SIC varies substantially from day to day. An area cannot be considered open when the ice cover is no longer 100%. It is therefore necessary to find another threshold to define the start and end dates of the sea-ice free period. Unfortunately, it is impossible to have the same criteria for each area, because they are too different in SIC dynamics. If the threshold is too high, the southern area would be open all year, but if the threshold is too low, the northern area would be closed all year. The choice of criterion is subjective, but remains the same for each year in a given area.The first area is considered open when the ice coverage is less than 98% for at least 4 days, and it is closed when the ice coverage is greater than 98% for at least 5 days. The fourth area is open when the ice cover is less than 80% for at least 15 days, and it is closed when the ice cover is greater than 80% for at least 6 days.

2 Results

2.1 Sea-ice coverage

In each area, we can see openings usually near August of each year (Figure 2). However, there is a significant variation of opening between areas 1 in the North (Figure 2a) and 4 in the South (Figure 2d).

As expected, a north-south cascade effect is noticed. In the first area, the maximum opening is less than 12% for the last ten years, while it is less than 70% in the second area. Areas 3 and 4 open up completely. In 2018, an unusual sea ice opening occurred in February in each area (Figure 2) due to intense winds and increased temperature, preventing sea ice production [2]. In contrast, there is no opening in 2017 in the first area in early August unlike other years. The opening is too small to be detected as an opening, but it occurred earlier in May (Figure 2a).

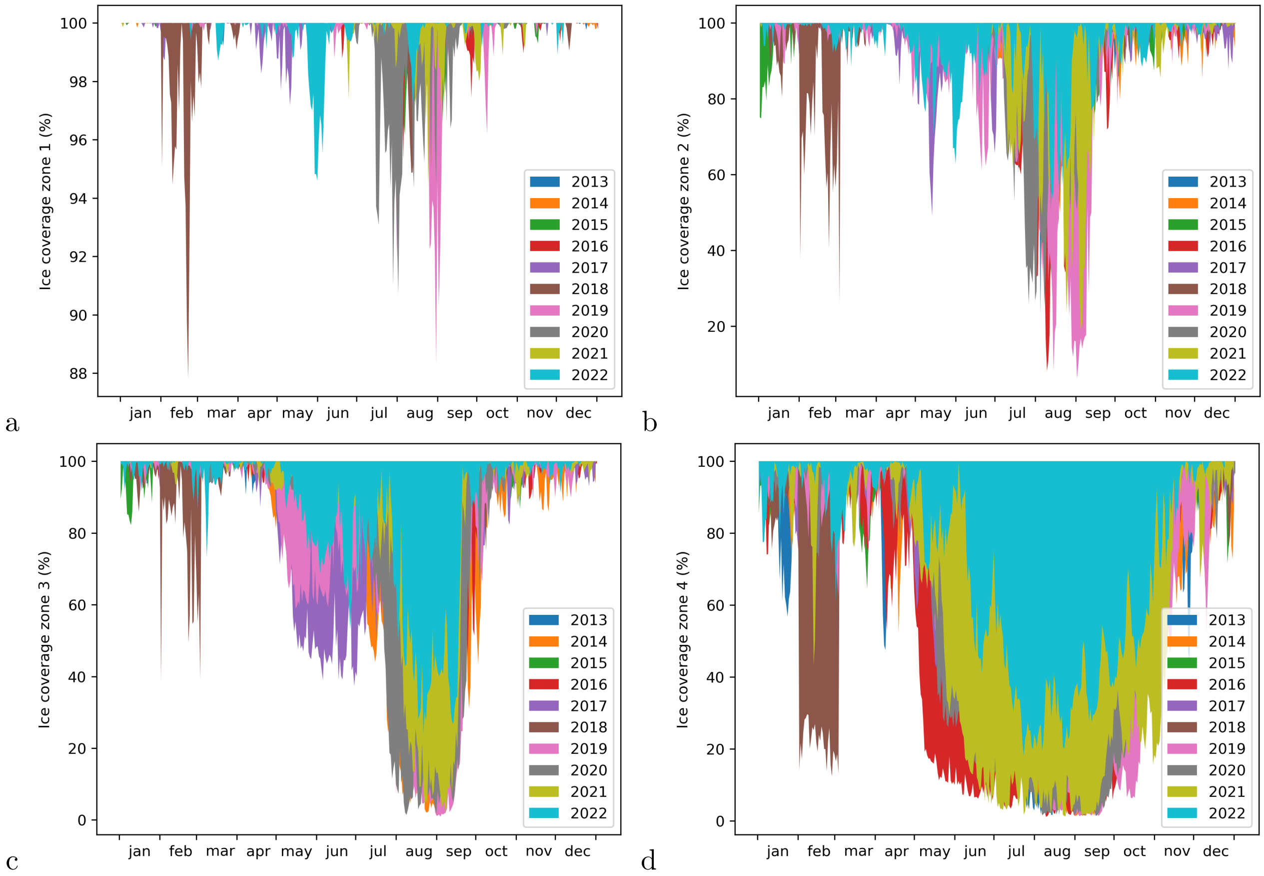

Figure 2 – Sea-ice coverage in areas 1 (a), 2 (b), 3 (c) and 4 (d)

2.2 Duration of sea-ice opening

Figure 3 highlights the opening duration for each area and year. The dots and their size indicate respectively the date of maximum opening and the amplitude of the opening. Again, the maximum opening is about 10% in the first area (Figure 3a), and 100% in the fourth area (Figure 3b). The first area was not yet sea ice free in summer ten years ago, but since then its openings have become increasingly longer (Figure 3a). The analysis of sea ice dynamics provides information on the duration, opening and closing of each area. However, this analysis does not provide info on the spatial distribution of openings in the areas.

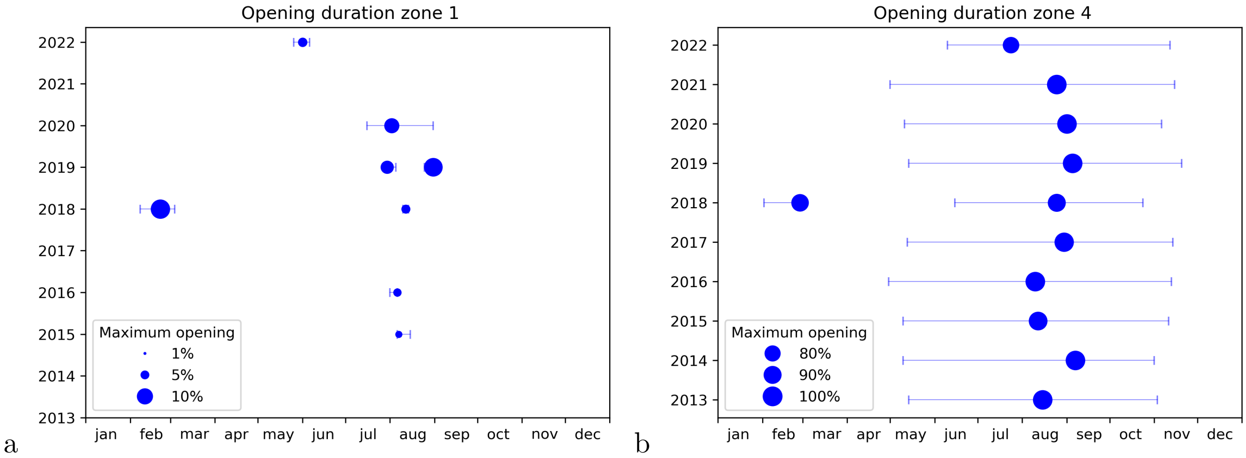

Figure 3 – Opening periods in areas 1 (a) and 4 (b)

2.3 Spatial representation of sea-ice opening

The sea ice opening maps are obtained by summing the number of days in the year when there is less than 15% ice, for each pixel of the area. Thus, we have 40 maps, one for each year and each area. Figure 4 shows the spatial representation of sea ice openness in the first area in 2018 (Figure 4a) and in the fourth area in 2018 (Figure 4b). The remaining maps are presented in Appendix 1.

For each area, trends in opening over the past 10 years were examined. In the first area, opening period lasts less than 35 days per year and is mainly concentrated on the west coast (Figure 4a). Opening is lower in 2013, 2014, 2017, and 2021 (Appendix 1, Figure 6), supporting Figure 3a. The second area is often open on the east coast for an average of 80 days per year (Appendix 1, Figure 7). The third area does not show an obvious pattern. Depending on the year, it is open to the south or on the east coast to the north for an average of over 200 days per year. Only the year 2014 is open on the west coast (Appendix 1, Figure 8). The fourth area, north of Baffin Bay, is always open on the east coast for an average of 300 days per year (Figure 4b). At times, the opening also extends to the west coast, in 2016, 2019, 2020, and 2021 (Appendix 1, Figure 9).

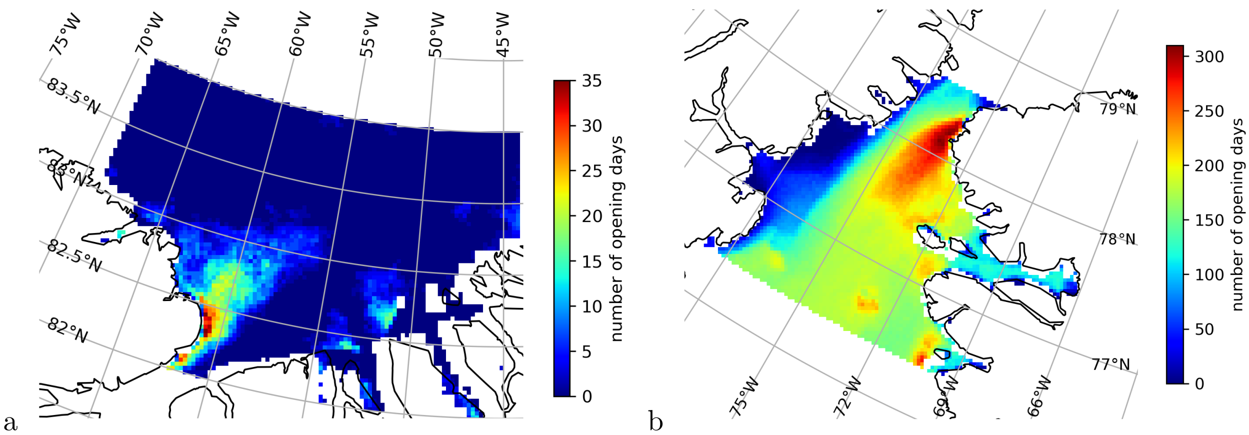

Figure 4 – Maps of sea-ice opening duration in 2018 in areas 1 (a) and 4 (b)

2.4 Mean annual Chl *a* concentration

The annual average Chl *a* concentration in 2018 is shown in Figure 5a. Maps for other years are provided in Appendix 2 Figure 10. There is no obvious pattern or change in Chl *a* concentration over time. As mentioned earlier, the average annual Chl *a* concentration is highly dependent on the number of data over the year. For this reason, we have also plotted the observation maps for each year in Figure 5b. The other years are shown in Appendix 2, Figure 11. However, we can notice that for most years there is more Chl *a* in the north than in the south (Figure 5a).

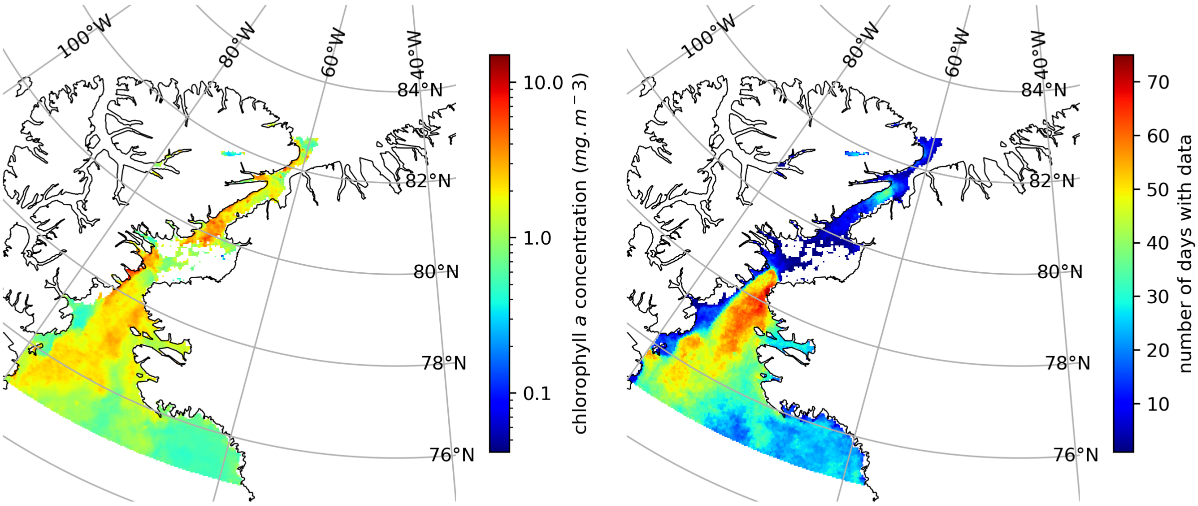

Figure 5 – Map of mean annual Chl a concentration in 2018

3 Discussion

3.1 Sea-ice coverage

Due to climate change, we expected to see an increasing sea-ice opening, both in duration and extent. However, the results are not so linear and simple. Indeed, sea-ice dynamics can be very different from day to day, which sometimes gives the illusion that an opening or closing is occurring, when it is not. It is therefore difficult to determine a robust criterion for sea-ice opening or closing. Moreover, even though we can see a slowly appearing opening over the past decade or so, there are still years without a clear opening, such as in 2017 or 2021 (Figure 3a).

3.2 Duration of sea-ice opening - a non robust criterion

As mentioned earlier, the criteria are not robust enough, as they differ from area to area. Moreover, the choice of these criteria remains subjective, based on the graph of sea ice cover for each year. If we had more than ten years of time series, we could find more robust criteria. For example, the first area could be even more closed before, so the new criterion could show that 2013 and 2014 are eventually open.

3.3 Spatial representation

Although the spatial distribution provides insight into the number of opening days in a year, it does not provide the opening date. It is therefore important to support it with sea-ice coverage graphs. Since we just mentioned that sea ice dynamics can be very different from day to day, it appears that the number of opening days plotted on the spatial distribution (Figure 4) is significantly greater than the August opening period. For example, Figure 4a shows that the west coast is open for 35 days in 2018. In contrast, in Figure 3a, this area is only open for a few days in August, and about half a month in mid-February. This could also be related to additional opening days throughout the year.

3.4 Mean annual Chl *a* concentration

Interestingly, the southern areas have lower Chl *a* concentrations, which can be explained by two hypotheses. First, there are now new sea ice free areas to the north that were previously closed, now allowing phytoplankton growth. It is possible that higher phytoplankton biomass is gradually moving northward, with lower Chl *a* concentrations in the south, as well as lower nutrient availability. In addition, high glacier inputs could also lead to higher nutrient and colored dissolved organic matter (CDOM) concentrations, which could impact Chl *a* biomass.

Note that a limitation already mentioned above is that there is a lot of missing data due to clouds, sea-ice and a short growing season. Thus, the average annual Chl *a* concentration could be biased, further work is needed to evaluate this.

4 My experience in the Takuvik Laboratory

This five month internship in the International Research Laboratory Takuvik was a rewarding experience, both in terms of increasing my personal programming skills and learning about the field of oceanography. In my engineer school in France, I study programming, signal and image processing. This internship allowed me to improve my programming skills in satellite image processing a lot. However, I did not know anything about the field of oceanography and primary production, which I had to learn about in order to understand and interpret my results.

I also had the opportunity to present a poster at the annual scientific reunion of Quebec Ocean. This experience was also very enriching. I was impressed to see all the current research around the oceans. I presented my work and my results to about ten persons and learned about others' research.
One of the main reasons I wanted to work in the Takuvik Lab is for its values in environment, which are reflected in all the research projects. I definitely know that I want to work for this purpose. The social meetings with the PhD students participated to this experience. This introduced me to a whole new world, including marine biodiversity and nanoplastics for instance.

Furthermore, being surrounded by research professionals and PhD students has helped me in my professional thinking. Despite the difficulties I have talked with other students, the research field is where I see my professional career going. I have one year left before I graduate as an engineer, but after that, I will maybe come back for a thesis, here in Canada or elsewhere.

My mission was to find the openings period and extent during the last decade to prepare a future expedition in the Lincoln Sea (REFUGE-ARCTIC) and see the impact on ecosystem biodiversity and productivity. I think I have achieved my goal, even if the research can still be pursued further. I hope my programs and my results will help for the future.

5 Conclusion

After five months of studying sea ice and Chl *a* dynamics, we are beginning to better understand sea-ice patterns in the Lincoln Sea. However, ten years of data are not sufficient to observe clear trends in time and space. Therefore, the study will be continued in the coming months with data beginning in 1998. The next step will also be to compare maps of sea-ice and annual Chl *a* concentration to determine the potential impact of sea ice opening on Chl *a* concentration.

6 Appendices

6.1 Appendix 1 - Maps of openings in the four areas for each year

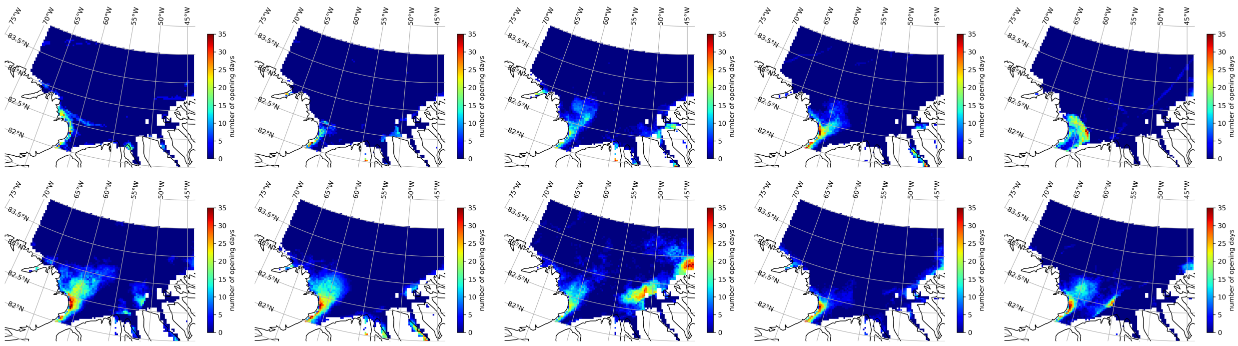

Figure 6 – Maps of opening in area 1 from 2013 to 2022

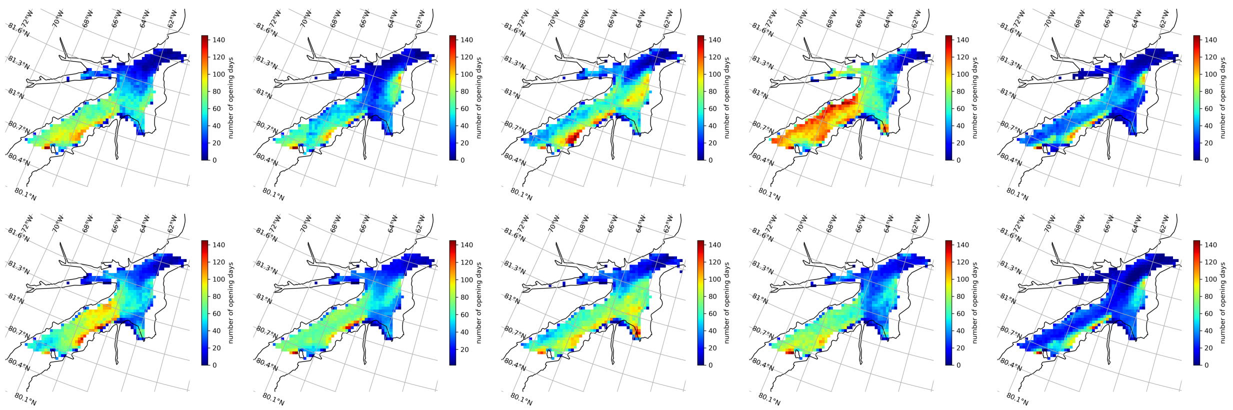

Figure 7 – Maps of opening in area 2 from 2013 to 2022

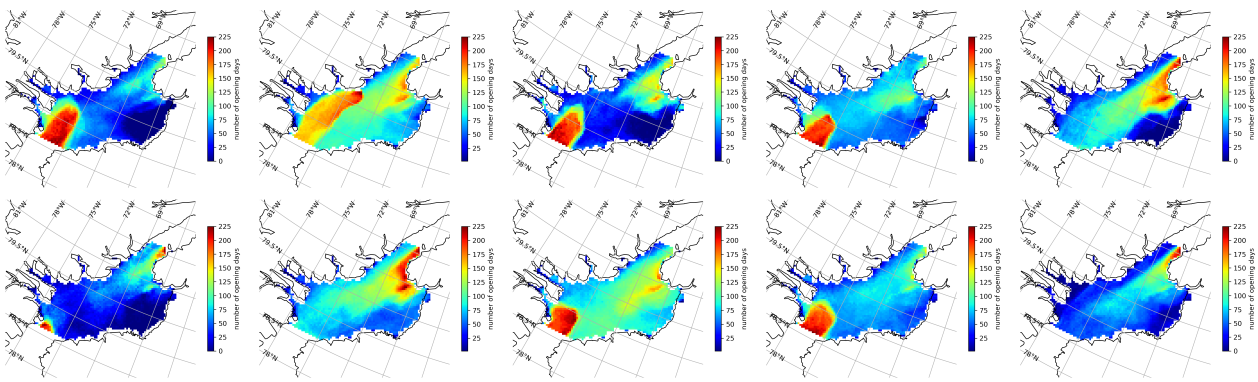

Figure 8 – Maps of opening in area 3 from 2013 to 2022

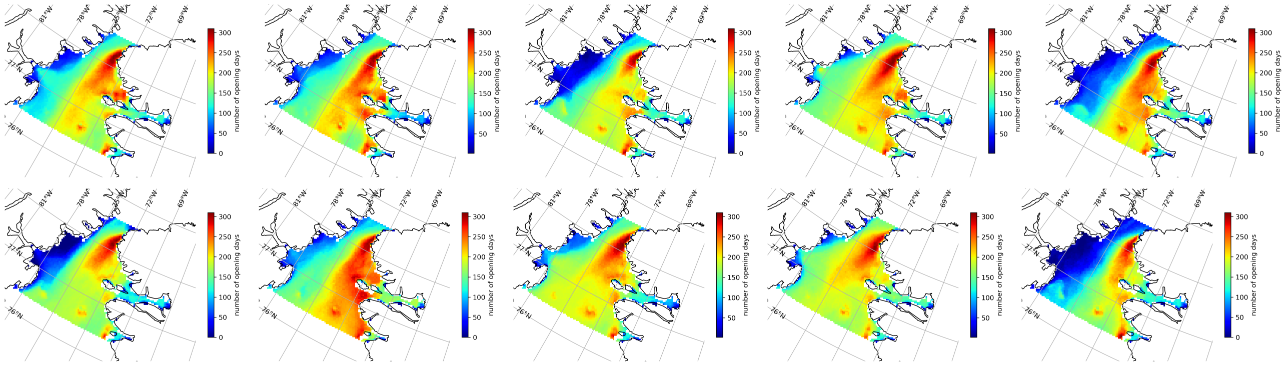

Figure 9 – Maps of opening in area 4 from 2013 to 2022

6.2 Appendix 2 - Maps of mean annual Chl *a* concentration

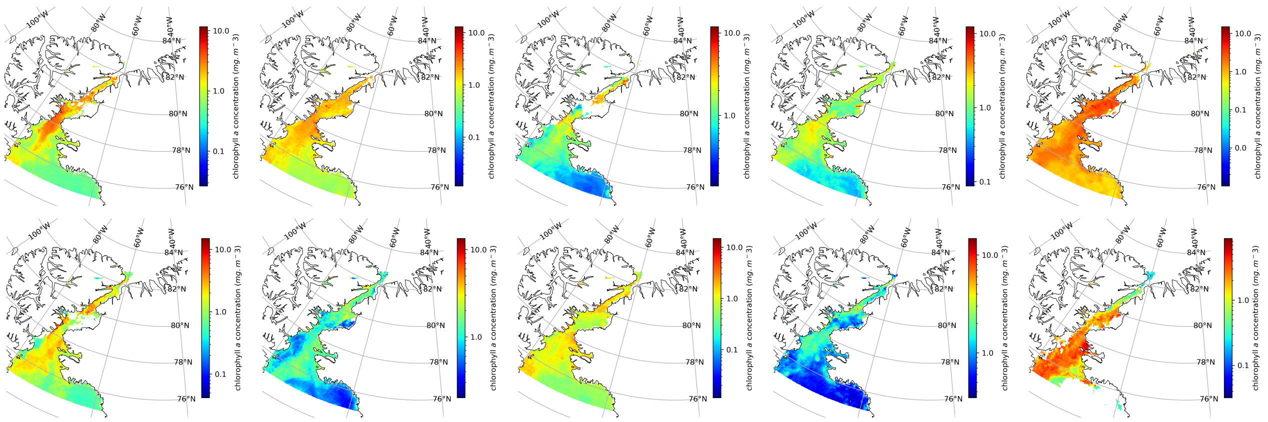

Figure 10 – Maps of mean annual Chl a concentration from 2013 to 2022

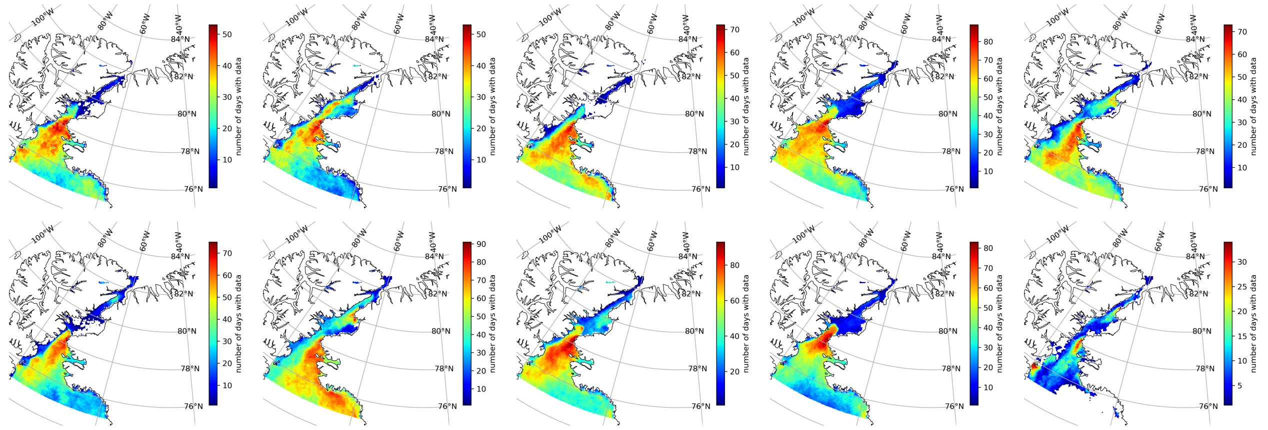

Figure 11 – Maps of the number of days with chlorophyll data from 2013 to 2022

7 References

[1] Moore, G.W.K., Howell, S.E.L., Brady, M. et al. Anomalous collapses of Nares Strait ice arches leads to enhanced export of Arctic sea ice. *Nat Commun* **12**, 1 (2021). https://doi.org/10.1038/s41467-020-20314-w

[2] Plymouth Marine Laboratory. Ocean Colour Climate Change Initiative(OC_CCI) – Phase 3. Product User Guide for v5.0 (2020). https://docs.pml.space/share/s/okB2fOuPT7Cj2r4C5sppDg

[3] Sami Bensassi, Julienne C. Stroeve, Inmaculada Martínez-Zarzoso, Andrew P. Barrett; Melting ice, growing trade?. *Elementa: Science of the Anthropocene* 1 January 2016; 4 000107. doi: https://doi.org/10.12952/journal.elementa.000107

[4] Jonathan Andrews, David Babb, David G. Barber; Climate change and sea-ice: Shipping accessibility on the marine transportation corridor through Hudson Bay and Hudson Strait (1980–2014). *Elementa: Science of the Anthropocene* 1 January 2017; 5 15. doi: https://doi.org/10.1525/elementa.130

[5] Jonathan Andrews, David Babb, David G. Barber (2018); Climate change and sea-ice: Shipping in Hudson Bay, Hudson Strait, and Foxe Basin (1980–2016). *Elementa: Science of the Anthropocene* 1 January 2018; 6 19. doi: https://doi.org/10.1525/elementa.281

Résumé

L'Océan Arctique joue un rôle essentiel dans la régulation du climat et subit actuellement des changements significatifs, comme la fonte de la glace de mer. La mer de Lincoln, située entre le nord du Canada et le Goënland, est d'autant plus intéressante à étudier qu'elle reçoit des eaux à la fois de l'Atlantique et du Pacifique, notamment des eaux provenant de la dérive transpolaire et riches en nutriments. Ainsi, la fonte de la glace de mer rend la production primaire possible. Dans l'objectif d'aider une expédition dans la mer de Lincoln en 2023 et 2024, cette étude consiste à analyser précisément les dynamiques de glace (i.e. ouverture, extension, durée) et comment cette dynamique influence la dynamique de la production primaire. Les données de concentration de glace de mer proviennent du satellite Aqua MODIS dérivées d'AMSR2, couvrant la période de 2013 à 2022. Dans cette étude, la mer de Lincoln a été divisée en quatre aires d'intérêt, du nord au sud. On extrait de chaque aire l'évolution de la couverture de glace de mer en fonction du temps, ainsi qu'une représentation spatiale du taux d'ouverture de la glace de mer, et ce pour chaque année. Les résultats mettent en valeur une ouverture croissante et plus étendue avec le temps. De plus, on peut noter une ouverture importante et inhabituelle ayant lieu en février 2018. Pour compléter cette étude, la prochaine étape consiste à étudier la productivité de ces aires nouvellement libres de glace de mer (en utilisant les données de concentrations en chlorophylle *a* dérivées du satellite CCI en tant que proxy). Les résultats de cette étude dans son ensemble vont montrer comment les changements de dynamique de glace de mer dans cette région sensible de l'Arctique vont altérer les modèles spatiaux de productivité et les tendances temporelles de la dernière décennie.

Abstract

The Arctic Ocean participates in the climate regulation and is currently undergoing drastic changes, such as the sea-ice melting. The Lincoln Sea, between the north of Canada and Greenland, is interesting to study as it receives both Atlantic and Pacific water, including nutrient-rich water from the transpolar drift. Thus, sea-ice melting makes primary production available. In support of an expedition to the Lincoln Sea in 2023 and 2024, this study's goal is to analyse precisely the sea-ice dynamics (i.e. opening, extent, duration) and how it influences the dynamic of primary production. Sea-ice concentration's data comes from Aqua MODIS satellite derived from AMSR2 over the period 2013 to 2022. In this study, it comes to divide the Lincoln Sea into four areas, from north to south. From each area are extracted the evolution of sea-ice coverage over the time and a spatial representation of the sea-ice opening rate, for each year. These results highlight a growing and extending opening with time. One important observation is an unusual opening which occurred in February 2018. To complete this study, the next step will be to assess the productivity (using CCI satellite-derived Chl *a* concentrations as a proxy) of these newly sea-ice free waters. The results of this study will ultimately reveal how changes in sea-ice dynamics in this sensitive Arctic region will alter spatial patterns of productivity and drive temporal trends over the past decade.