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NRC-OCRE-2022-TR-002

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Summary

In Northern Canada, Inuit communities rely heavily on sea ice for commuting, hunting, fishing and other traditional activities. From their perspective, this platform may be considered an infrastructure in its own right. Over the last several decades, the extent, thickness, surface conditions and overall dynamics of sea ice have been affected by climate change. While scientists are actively studying these phenomena, the observers best able to contribute answers to key questions are the people that actually use the ice and experience that environment on a day-to-day basis, i.e. the Inuit. What is presented in this report is a method to research climate change impact, which could be conducted by members of the Northern communities. This is done through the combined use for two software platforms. The first one is the Canadian Arctic Shipping Risk Assessment System (CASRAS), a user-friendly database developed by NRC, which incorporates ice maps from the Canadian Ice Service (CIS) as well as historical datasets on climate. With Microsoft (MS) Excel, the second software, parameters such as air temperature and wind data were extracted from CASRAS and analyzed. For this exercise, the report focuses specifically on ice cover formation and break-up in Hudson Bay, over the last 30 to 40 years. Statistically significant trends were identified. The ice cover in that inland sea has required more time to develop into a fully established ice cover (an increase of 3 to 4 days per decade). Ice break-up initiation has begun earlier in the Spring/Summer, i.e. that shift is estimated at about 5 days per decade. In Arviat, an increase of about 0.3 m/s per decade in wind speed is documented in the Fall. Because these observations are for the whole of Hudson Bay, they provide a general perspective on the overall evolution of the ice cover (as opposed to local conditions). Ultimately, this type of work could be fed into climate models of future ice conditions.

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1. Introduction

The Arctic Archipelago is home to more than 200,000 inhabitants, most of whom are Indigenous[1]. This includes a large number of Inuit communities, many of which rely on sea ice for commuting, hunting, fishing and other traditional activities. Over the centuries, these communities have acquired a profound understanding of that environment and its ecosystem. They have learned to draw from them for their livelihood and well-being [1-5]. In the last several decades, however, the sea ice extent, thickness and overall dynamics have changed as a consequence of climate evolution [6-8]. The Inuit are experiencing this impact first-hand [2, 9-11]. A warmer climate has been delaying ice growth and the achievement of a sufficient thickness for safe travel, with a consequent reduction in the time window used for traditional activities. Loss of equipment, injuries or death, and expensive search and rescue operations are attributed, at least in part, to a decreased familiarity with sea ice behavior due to changes in climate patterns.

The work presented in this report stems from communications held in 2021 between NRC and members of the Arviat community (Figure 1). These were preliminary discussions on means of better addressing concerns with traveling on ice. One raised by the Arviat community was being able to predict ice at the floe edge, i.e. the margin of the fast ice. Ice concentration, its behavior, air temperature, winds, currents, and moon phase are some of the parameters that Inuit take into account to assess the behavior of that margin and that of the drift ice beyond it. These discussions led to the production of a first NRC report [12], which provided an overview of food insecurity amongst Inuit communities, as well as an update on the impact of a changing climate on the usage of sea ice as a traveling platform. The present report follows up on that previous one.

2. Rationale

There is much to know about sea ice dynamics. While scientists have been actively studying these phenomena, the observers best able to contribute answers to key questions are the people that actually use the ice and experience that environment on a day-to-day basis. It has been acknowledged that the complementarity in scientific and Inuit traditional knowledge, referred to as ‘Two ways of Knowing’ [1], has to be mobilized. Hence, to best understand and tackle the challenges related to a changing sea ice environment [5, 13-16]. One of several ways to achieve that complementarity, or at least a step in that direction, is to provide Northerners with tools they could use to understand these changes, i.e. to answer questions relevant to them and to investigate issues that matter to their communities. The now well-known SmartICE initiative [17, 18] is an example of an initiative that can build “training and capacity among Inuit in the communities while empowering them to design and manage their own community-based

[1] https://www.international.gc.ca/world-monde/international_relations-relations_internationales/arctic-arctique/index.aspx?lang=eng

research" [18, p. 18]. That knowledge, in turn, can be used, for instance, to feed into sea ice models or to validate the interpretation of satellite imagery.

Reciprocally – and this represents an additional step – a community could avail itself of the research tools required not only to acquire data but also to conduct their own analyses on climate impact and address their own questions about the environment they live in, i.e. research by Inuit for Inuit. This aligns with the National Inuit Strategy on Research [19], and the research already taking place in Inuit Nunangat. From Pfeifer [20]:

> *If research is how responsible policy is arguably made, and the way through which southern institutions can be challenged for their role in maintaining the power status quo, then Inuit need research and meaningful collaboration. Altering methods to create space for Inuit voices and knowledge to be heard and documented in the research process (i.e. what needs to be researched, how to conduct the research, how to disseminate results) is a necessary step. Better yet, Inuit can do our own research to benefit our communities.*

Figure 1: Hudson Bay with territorial and provincial jurisdictions, and the location of various communities. Arviat is located in the upper left.

3. Objectives

This report's salient objective is to explore practical examples of research tools and data analysis methods on sea ice and climate data. It is an exercise intended to assess the analyses' capability to decipher trends in ice cover evolution and climate behavior over the last four to five decades. For this exercise, and in the light of discussions with members of the Arviat community, the focus is on freeze-up and break-up patterns. However, because regional ice maps will be used, such analyses are not meant to understand local conditions as much as to decipher trends over time in Hudson Bay as a whole. The report documents an endeavor that could be tackled by community members, if there is an interest, to address their own questions.

4. Method

A convenient starting point for this endeavor are the products delivered by the Canadian Ice Service, namely the ice maps, as explained below. The idea was then to test the effectiveness of the Canadian Arctic Shipping Risk Assessment System (CASRAS), an NRC in-house tool, for the extraction of ice maps and climate data, while using Microsoft (MS) Excel for data interpretation and 'trend' visualization. While MS Excel is relatively accessible, CASRAS is presently deployed only to selected Canadian government bodies. However, the development of a more widely accessible web version is underway. These tools – CASRAS and MS Excel – would constitute good candidates for usage by members of Northern communities.

For this report, data were extracted from CASRAS and plotted on x-y graphs, to identify trends (for instance, in how sea ice coverage has evolved over the last few decades). The 'Fall' season in this report is assumed to extend from September to December, inclusively – this generally represents the time during which the ice cover is forming. The 'Winter/Spring' season extends from January to May, inclusively – this represents the time when on-ice traveling takes place.

As part of the exercise, an elementary analysis was done on the statistical significance of the various plots produced as part of this work. This is seen as a first step in being able to appreciate the value of trend lines and data scatter[2]. Is the relationship reliable or due to chance? How much variability is there in the data? More information is provided in Appendix B, which also contains a table with statistical data.

[2] https://hbr.org/2016/02/a-refresher-on-statistical-significance

5. Sources of information

5.1. CASRAS

CASRAS was developed by the NRC to provide individuals and organizations with a stand-alone software platform for collecting and analyzing Arctic marine information relevant to shipping and icebreaking operations. It is an in-house tool developed by an NRC team of Arctic sea ice specialists and software developers, with input from industry experts, government stakeholders, ship captains, academia and community representatives [21, 22]. The development of the software began in 2014, and its ultimate objective has been to empower users to assess Arctic marine risks and increase the safety of shipping activities. CASRAS allows for storing, searching and analyzing data relevant to shipping activities in the Arctic, with integrated risk assessment tools. The system is presently in use by the Canadian Coast Guard, Department of National Defence, Transport Canada and the Government of Northwest Territories. As of this writing, means of forecasting ice conditions are being developed, along with a web-based version of the system [23].

Note that while CASRAS is designed to support navigation, it could conceivably be adapted to meet the requirements of the Northern communities.

CASRAS incorporates several historical datasets, e.g. marine weather, marine hydrography, physical oceanography, marine protected areas and sea ice conditions. The latter comprises CIS' Regional Charts. Using CASRAS' convenient user interface, one can quickly retrieve the charts over a time frame of interest. In other words, CASRAS can be used, as is done for this report, mostly as a simple image and climate data dispenser, i.e. information on historical ice extents for chosen locations and time periods. Figure 2 shows CASRAS being used onboard a vessel, along with the main user interface of the software. CASRAS presently contains 81 datasets and over 220,000 files, for a total of approximately 250 GB of data. An example view of some datasets within the CASRAS software is shown in Figure 3.

Figure 2: CASRAS software being used onboard a vessel in Summer 2017 (image courtesy of Captain D. Fowler).

Figure 3: Launch screen of CASRAS software.

5.2. Canadian Ice Service (CIS)

The Canadian Ice Service (CIS) is a division of the Meteorological Service of Canada, itself a branch of Environment and Climate Change Canada (ECCC), a federal government department. CIS provides information on ice conditions in Canada's navigable waters and maintains an archive of ice charts on sea ice conditions extending back to 1960 [24]. Amongst its products are 'Regional Ice Charts', which are generated every week. There are five overlapping regional charts (Figure 4): Western Arctic, Eastern Arctic, Hudson Bay, Eastern Coast and the Great Lakes. The one of interest to the present study is Hudson Bay.

CIS' regional ice charts are based on an analysis and integration of data from various sources, namely satellite imagery, weather and oceanographic information, and visual observations from ships and aircrafts.[3] Imagery interpretation is done by a team of experts at CIS. For the regional charts, this analysis is done from data spanning several days, so as to have complete coverage of the area.

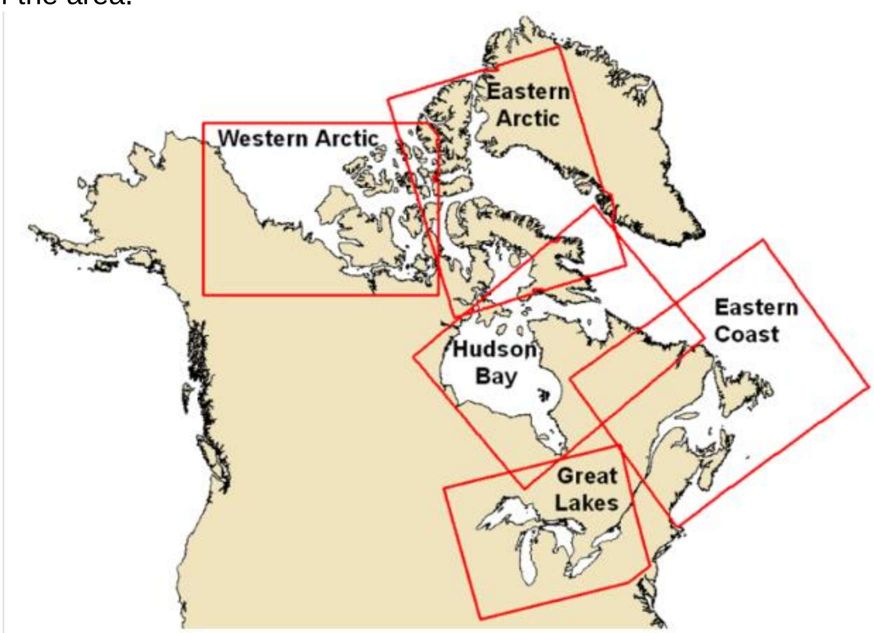

Figure 4: Coverage of Canada's icy waters is done by CIS' five regional charts[4].

5.3. North American Regional Reanalysis (NARR)

NARR climate data [25, 26] have been incorporated into CASRAS. These data were obtained by combining historical observations with today's weather models, a well-known procedure

[3] https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/products-guides/chart-descriptions.html

[4] https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/archive-overview/information-about-data.html

referred to as 'reanalysis'[5]. The data generated are from October 1978 to the present, and analyses were made eight times daily. Air temperatures and winds from 1979 to 2020 from that source were used to conduct the analyses presented in this report.

6. Sea ice cover evolution in Hudson Bay

In this section, the ice cover in Hudson Bay is examined, to identify potential trends in the way it has evolved over the last five decades. A compendium of regional ice charts was extracted from CASRAS - an example of one such chart is shown in Figure 5. Each color represents a concentration in tenth (Figure A1). The various colors correspond to different ice concentrations. Colored zones can also be divided (by black lines) into sub-zones, which will not be dealt with in this report.

To analyze ice conditions in Hudson Bay, every ice chart from 1971 to 2020 (50 years) was examined. Two aspects were addressed: 1) Ice cover formation – the transition from open water conditions to full ice coverage in the Fall, and 2) the process of ice break-up in the Winter/Spring.

For illustrative purposes, Appendix A shows regional charts extracted from CASRAS at four-year intervals, from the Fall to early Winter.

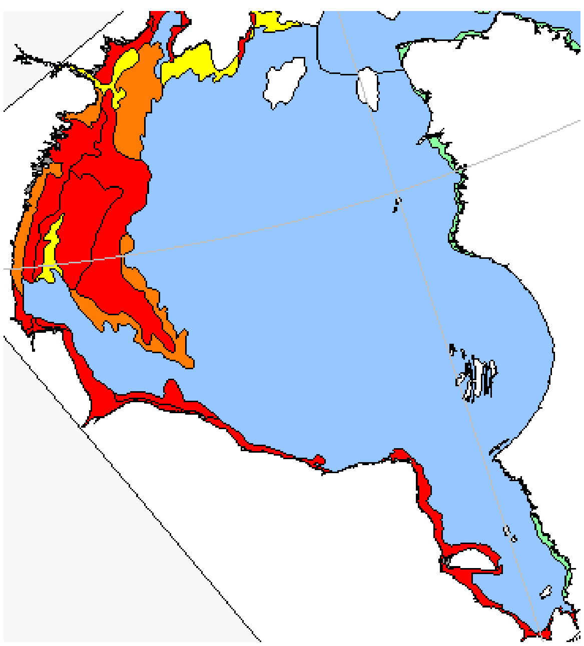

Figure 5: Example of a regional ice chart of Hudson Bay, produced by CIS – this one is for the week of December 16, 2020. The color coding is from the World Meteorological Organization (WMO) – see Figure A1 in Appendix A.

[5] https://www.youtube.com/watch?v=FAGobvUGl24, https://www.ecmwf.int/assets/elearning/da/da1/story_html5.html

6.1. Ice cover formation

Ice cover formation was examined for each year within the 50 years. The date of the *latest chart showing ice-free conditions* (Figure 6), and the date of the *earliest chart indicating 100% coverage* (Figure 7), were noted. These were then plotted on an x-y diagram – this is shown in Figure 8.

Figure 6: A CIS regional ice chart showing 100% ice free in Hudson Bay.

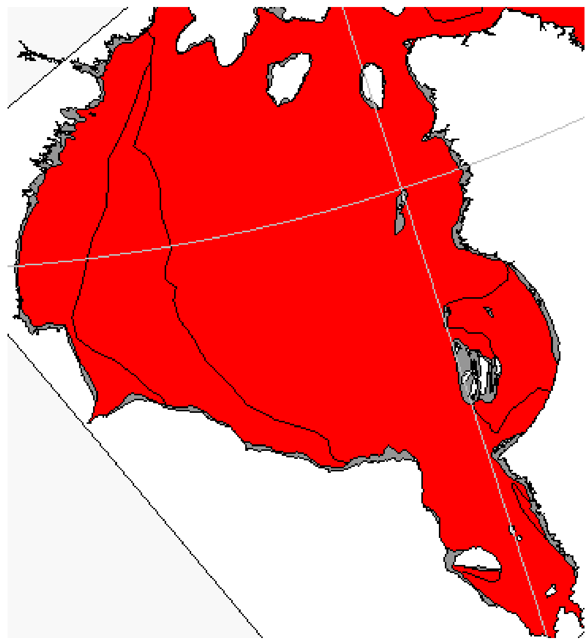

Figure 7: A CIS regional ice chart showing 100% ice coverage in Hudson Bay.

In that figure, we observe the following:

- Over the last 50 years, the 100% open water (ice-free) conditions extended from September 19th to October 29th (with an outlier in 2010). This is consistent with what is reported by Stirling et al. [27] from Western Hudson Bay. The data scatter is considerable, and no trend is observed over the years.
- In the last 50 years, the date for 100% ice coverage progressively migrated from early December to early January, i.e. a linear regression in Figure 8 indicates a change of 4 days per decade. That trend is considered statistically valid. The scatter band on each side of it is about two weeks early, with a progressive reduction in the later years.

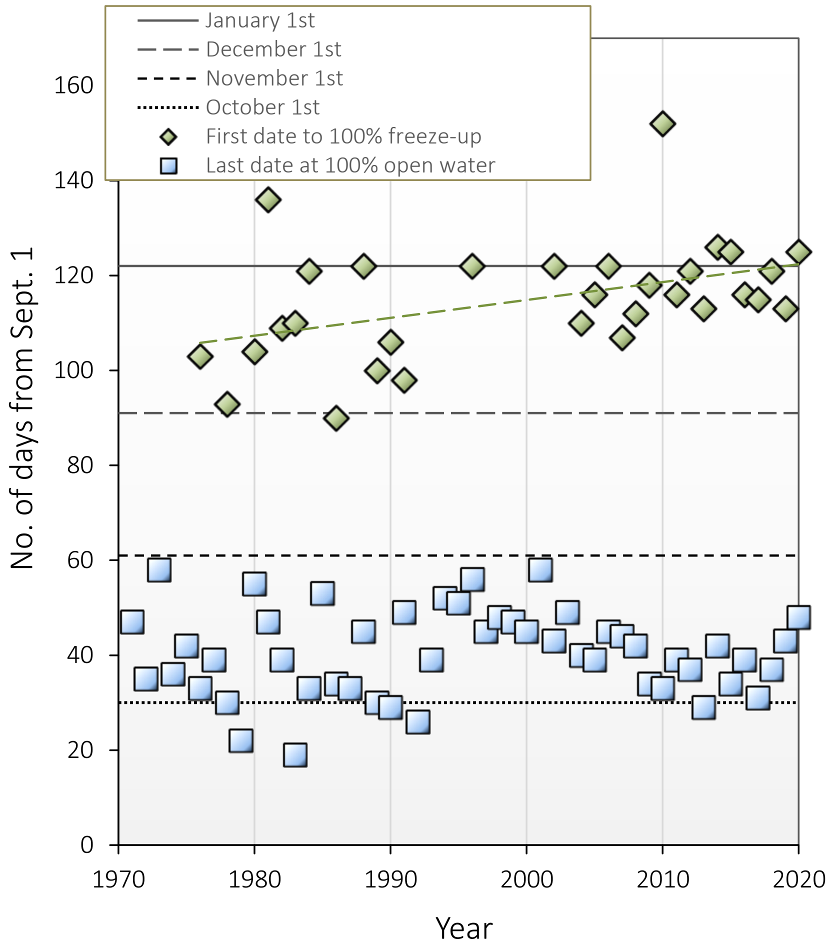

Figure 8: Number of days between Sept. 1 and the latest CIS chart showing 100% open water conditions (blue squares), and the earliest with full ice coverage (green lozenges). Only the latter shows a statistically significant time dependency, i.e. the linear trend line indicates full coverage has been pushed back at a rate of 4 days per decade.

The number of days from the last date when there was 100% open water to the first date when it was 100% freeze-up was determined for each year. This is shown in Figure 9:

- In the last 50 years, that number ranged from about 50 to 90 days, i.e. a linear regression indicates a change of 3.4 days per decade.
- The reduction in data scatter mentioned above is clearer in that figure, i.e. it begins in the mid-1990s. The reason is not known – it could be related to a change in environmental factors (i.e. air temperature, winds, currents).

In addition, based on the regional charts (such as those included in the appendix):

- Ice coverage always begins from the north and north-west, then moves toward the center of the bay while also extending southward along the western coastline.
- Ice coverage typically begins along the north-western shorelines; it typically ends around the Belcher Islands.

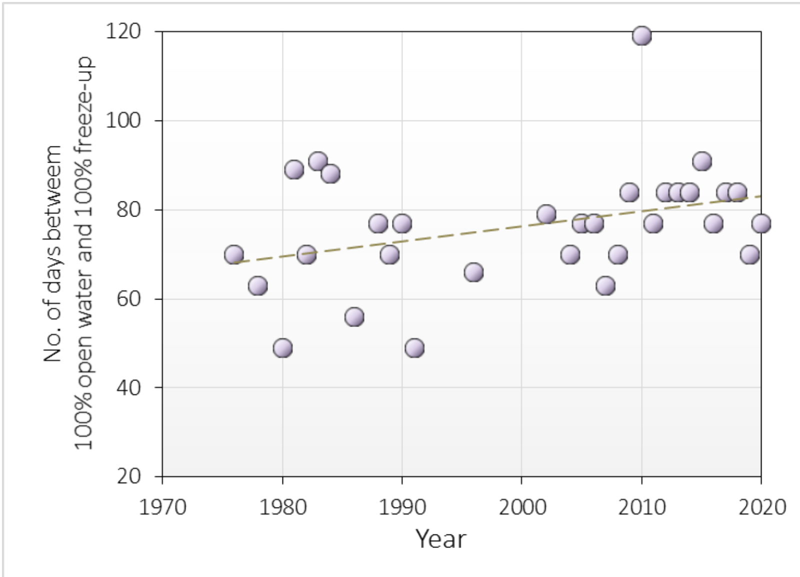

Figure 9: The number of days between 100% open water in the Fall and 100% ice coverage in Winter, with a linear trend indicating the number of days have increased by 3.4 days per decade.

6.2. Ice break-up to open water conditions

To get information on ice break-up, two dates were collected: after the very first sign of ice breakup; and just after the full bay was 100% open water. An example of ice break-up initiation is shown in Figure 10. The first signs of break-up were when small areas of 4-6 tenth (or more) of open water appeared on the charts, as well as a few, localized, very small expanses of open water along the coastlines.

An example of a progression to 100% open water is shown in Figure 11. As ice cover melting proceeded, the remaining ice typically resided in the south-central part of the bay, separated from the coastlines by a thin fringe of open water. Initial break-up ranged from April to June; 100% open water conditions occurred between late July and mid-September (Figure 12). A reduction in the number of days to break-up over the years is observed, equivalent to 4.7 days per decade. No time dependency is observed for the time to 100% open water.

Figure 13 shows a time dependency in the number of days between initial break-up and 100% open water, with an increase of 4 days per decade. In Figure 14, the number of days between 100% freeze-up and initial break-up indicates a trend, corresponding to a decrease of about 9 days per decade.

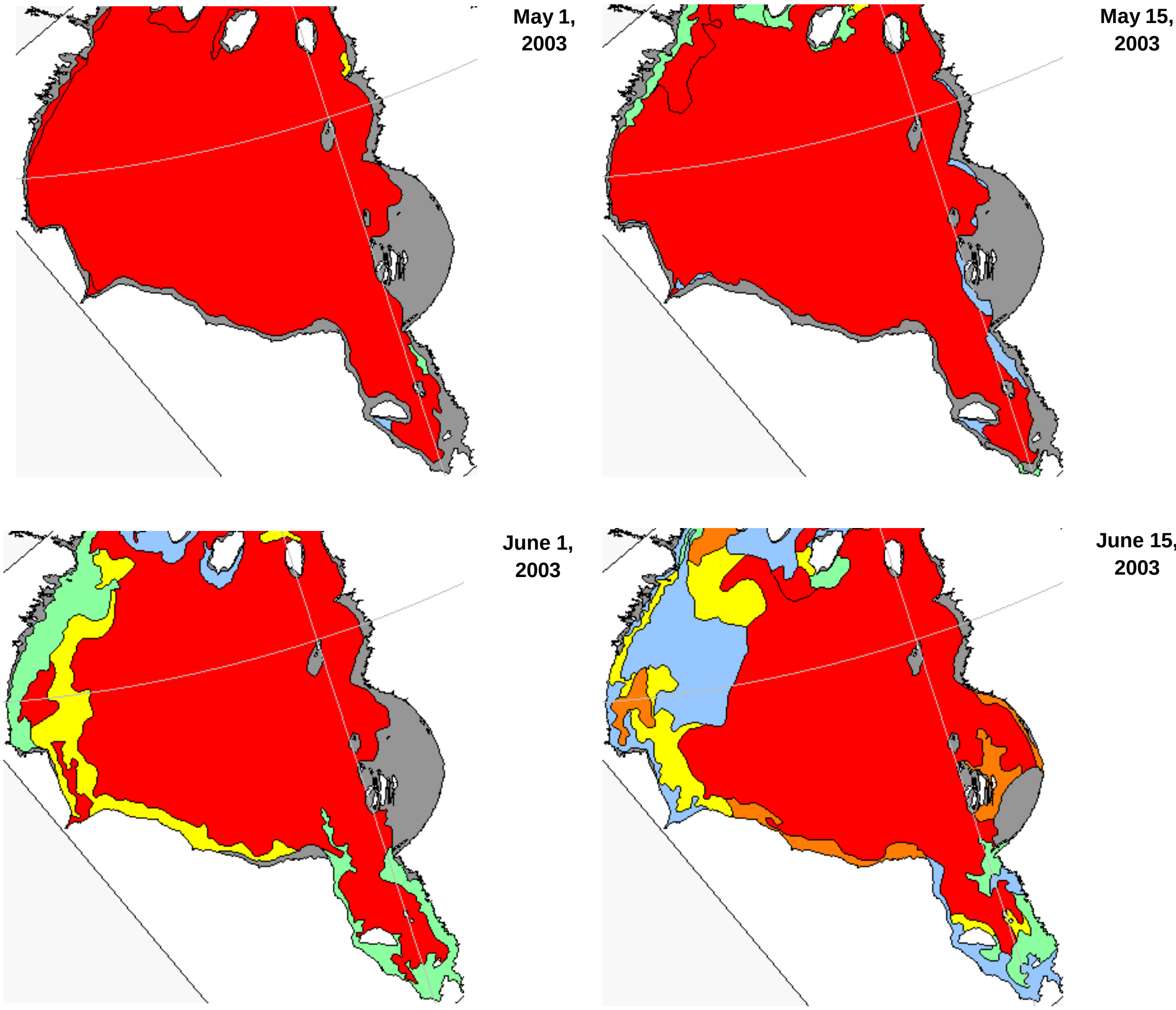

Figure 10: Example (from 2003) of break-up initiation in Hudson Bay on CIS ice charts extracted from CASRAS. See Figure A1 for color coding. For that year, break-up was in early May.

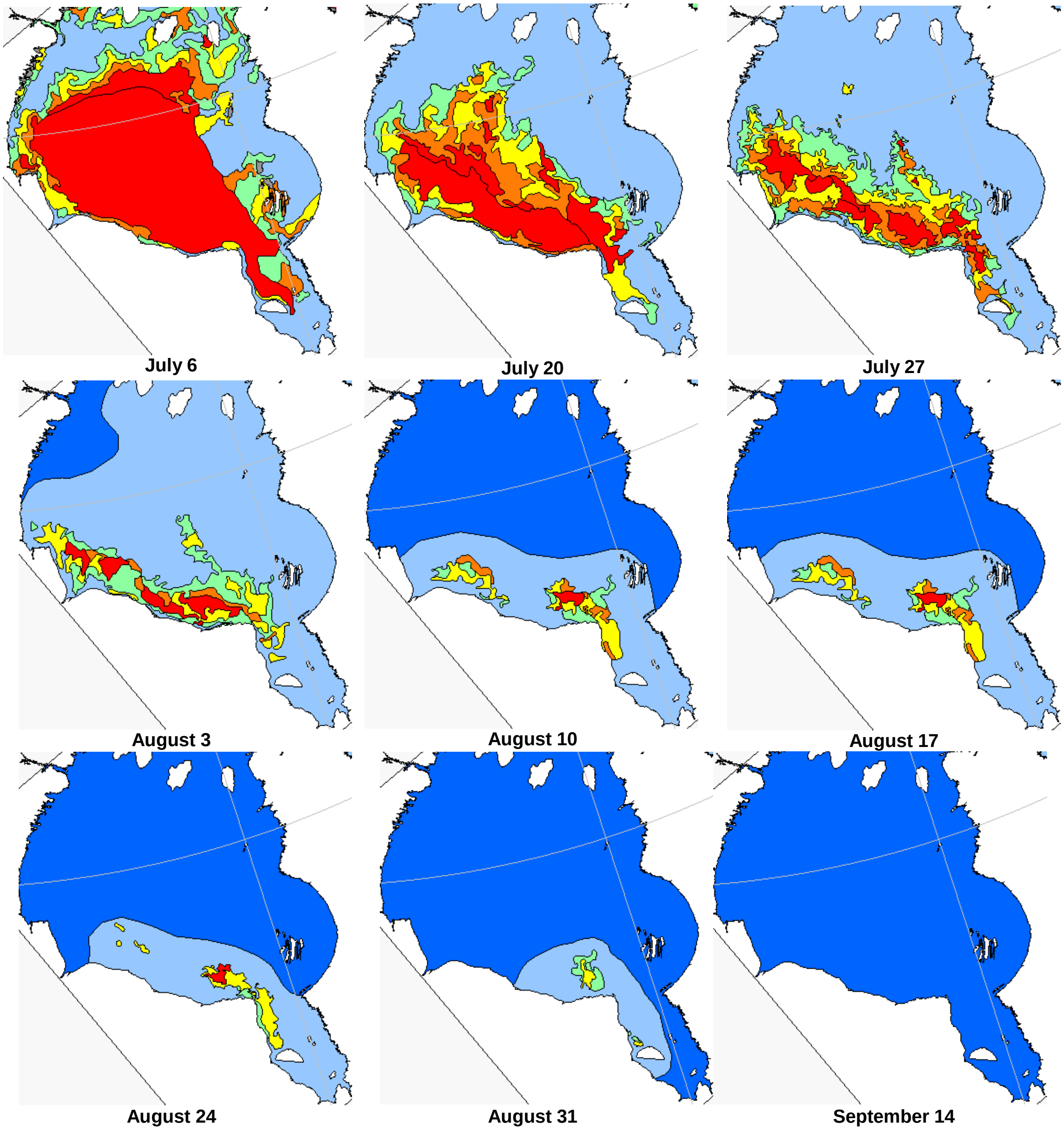

Figure 11: Example (from 2009) of a progression toward complete break-up in Hudson Bay on CIS ice charts extracted from CASRAS. See Figure A1 for color coding. For that year, 100% open water conditions were in early September.

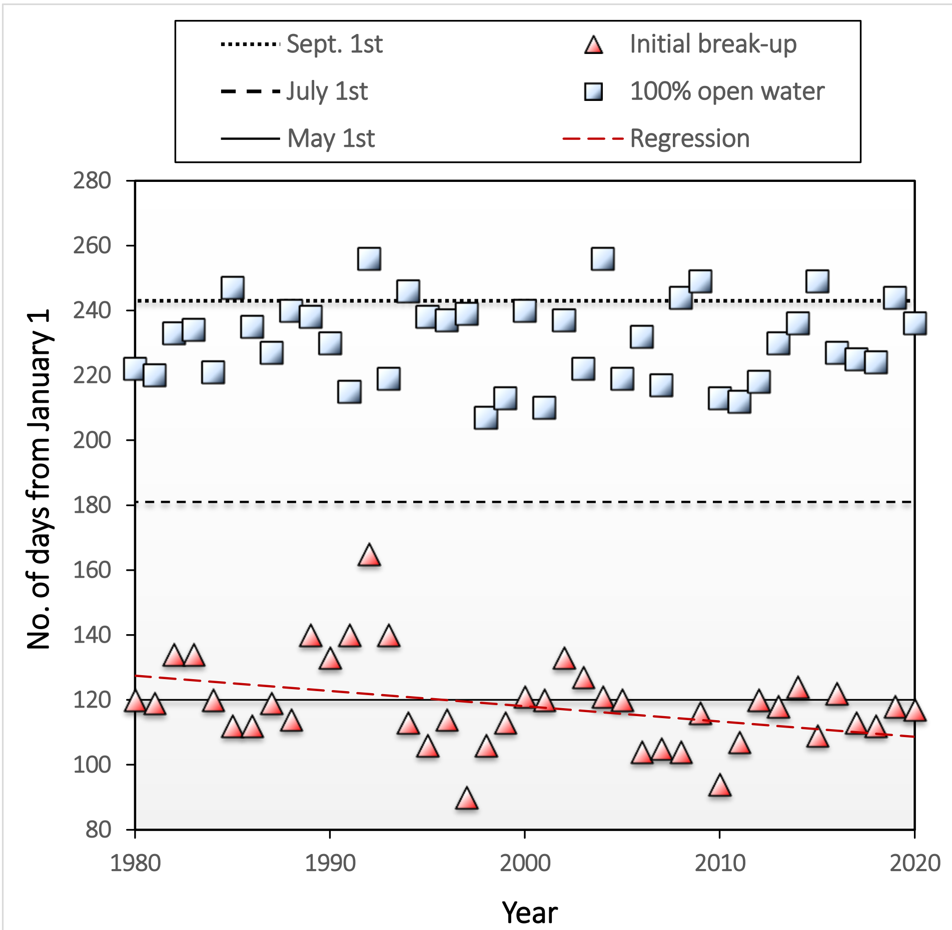

Figure 12: The number of days from January 1st to initial ice cover break-up and to 100% open water conditions. A decrease of 4.7 days per decade is observed for the former, but no statistically significant trend in the latter.

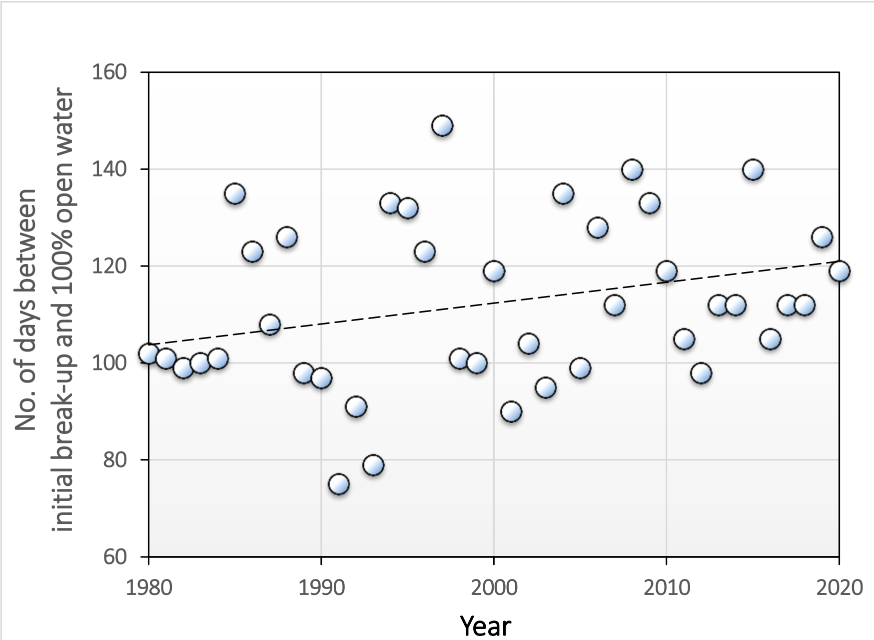

Figure 13: Number of days between initial break-up and 100% open water over Hudson Bay – that apparent trend, however, is not statistically significant.

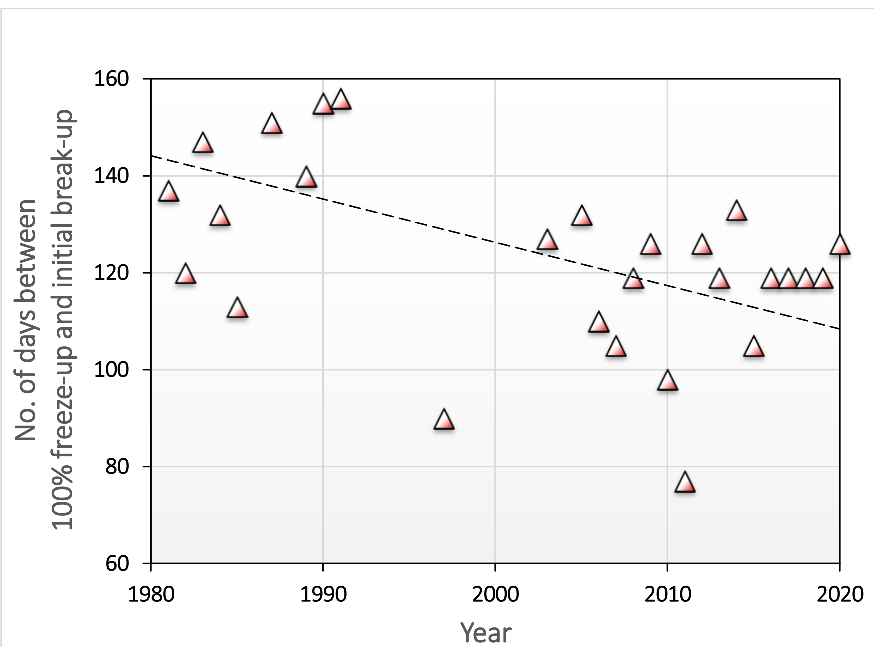

Figure 14: Number of days between 100% freeze-up and initial break-up, with a decrease of about 9 days per decade.

7. Climate data over Hudson Bay

In this section, climate data, namely air temperature and wind speed and direction, are examined, so as to identify possible trends over the last four decades.

7.1. Air temperature and FDD

For this analysis, a function integrated inside CASRAS was applied to historical temperatures collected at three different weather stations: Whale Cover Airport, Sanikiluak Airport and Peawanuck. This function provided the number of freezing degree-days (FDD), a common parameter in cryospheric studies – it is the sum of the average daily degrees for a given time period[6]. This information was generated for the last four decades, from September 1 to December 31, the time during which the ice cover develops. In Figure 15, a plot shows the variation in FDD for the three stations over the years. Whale Cove is the coldest and Sanikiluak is the warmest. All three datasets show a reduction of FDD over time, but only the data from Sanikiluak is statistically significant, with a reduction of 54 FDD per decade. The latter dataset is also the most complete; it will be used for what follows.

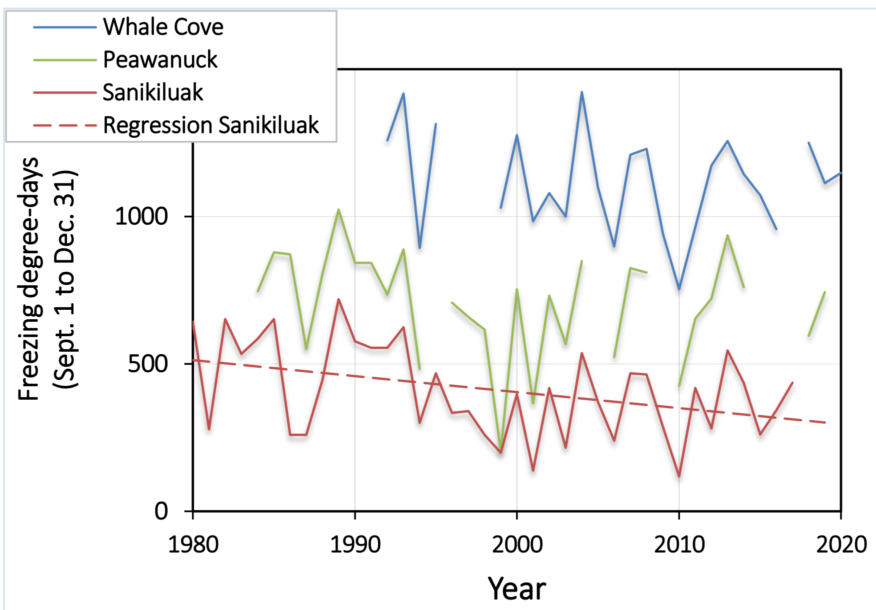

Figure 15: The variation in the number of freezing degree-days from 1980 to 2020 from air temperature data collected at three different weather stations around Hudson Bay. A linear regression is shown for the Sanikiluak data, corresponding to a reduction of about 54 freezing degree-days per decade.

In Figure 16, the influence of the FDD in any given year on sea ice cover evolution is shown, in the Fall, to achieve full ice coverage, and in the Spring, up to initial break-up. Both data sets show a linear trend. It can be seen that the higher the number of FDD, the less time is required

[6] For instance, if for Day 1, 2 and 3, the average temperature is -15ºC, -20ºC and -25ºC, respectively, and assuming a freezing point of 0ºC, then the FDD would be 60 for those three days. In the analysis, this procedure was applied for all days in a year, and assuming a freezing point of -2ºC (for saline water).

to form a full ice cover (i.e. a decrease of 0.04 day per FDD). Conversely, the higher the number of FDD, the more time is required before break-up initiation (i.e. an increase of 0.1 day per FDD).

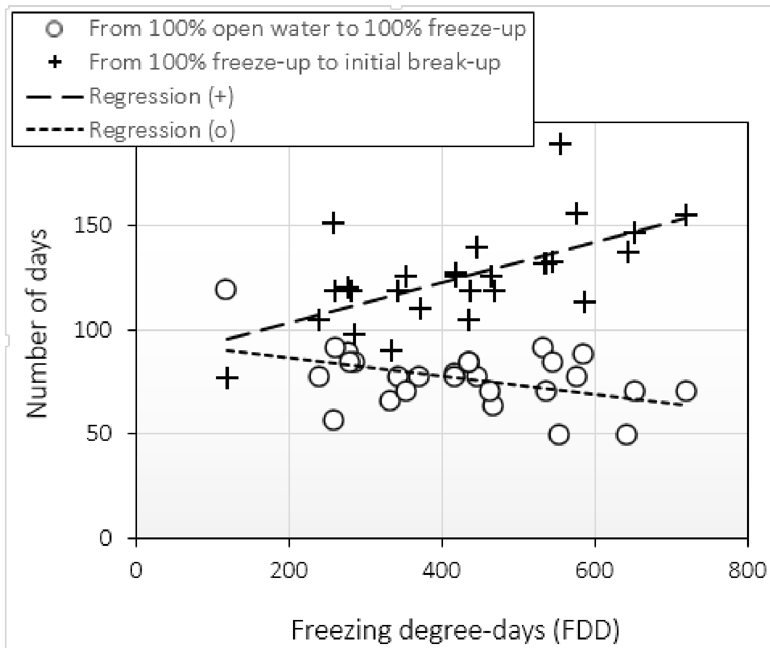

Figure 16: Influence of FDD on the number of days 1) between 100% open water and 100% freeze-up (reduction of about 0.04 day per FDD), and 2) between 100% freeze-up and initial break-up (increase of about 0.1 day per FDD), from 1980 to 2020 over Hudson Bay.

7.2. Wind speed

NARR mean wind speed data were extracted from CASRAS and analyzed. Two sets of data were looked into – one focusing on Sanikiluak and Whale Cove, the other focusing on Arviat. (For reference purpose, 1 m/s is equivalent to 3.6 km/h, 2.3 mi/h or 1.9 knots.)

7.2.1. Sanikiluak and Whale Cove

NARR data produced for every day of each year, i.e. the mean is for every day from each location, were used for this analysis. An average of all mean daily temperatures over the Fall and Winter/Spring is plotted in Figure 17. Wind speeds are higher in the Fall than they are in the Winter/Spring; they are also higher in Sanikiluak than in Whale Cove. No statistically significant trend is observed for either location over the four decades. Figure 18 is an alternative representation of the same data, but where the Fall and Winter/Spring data are plotted against one another. Most data points lie below the 1:1 line, which is another indication that wind speeds in the Fall (on the horizontal axis) are generally higher than those in the Spring/Winter.

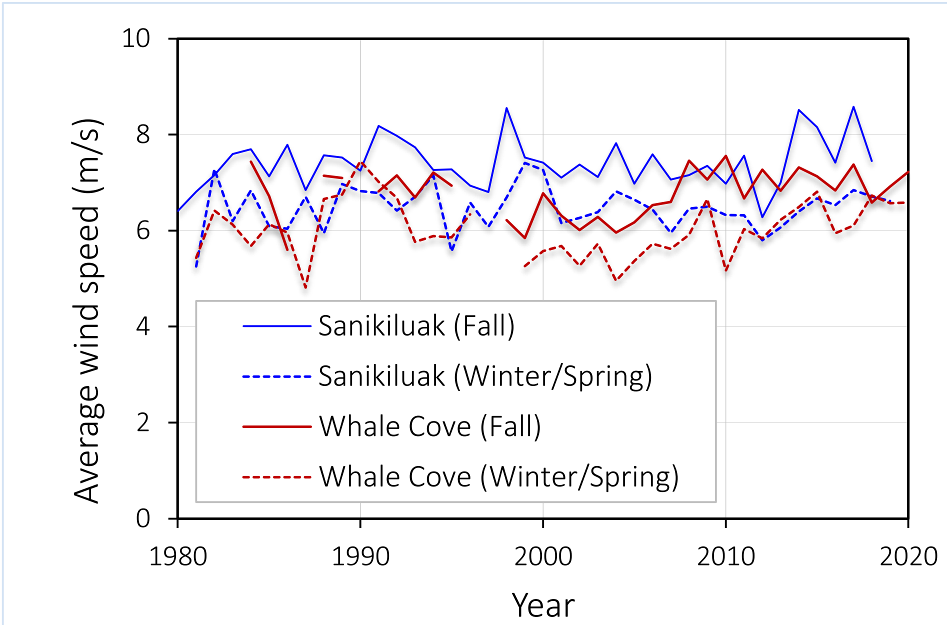

Figure 17: Average wind speed over the last four decades at Sanikiluak and Whale Cove, for the Fall and the Winter/Spring. No statistically significant variation is observed over the four decades.

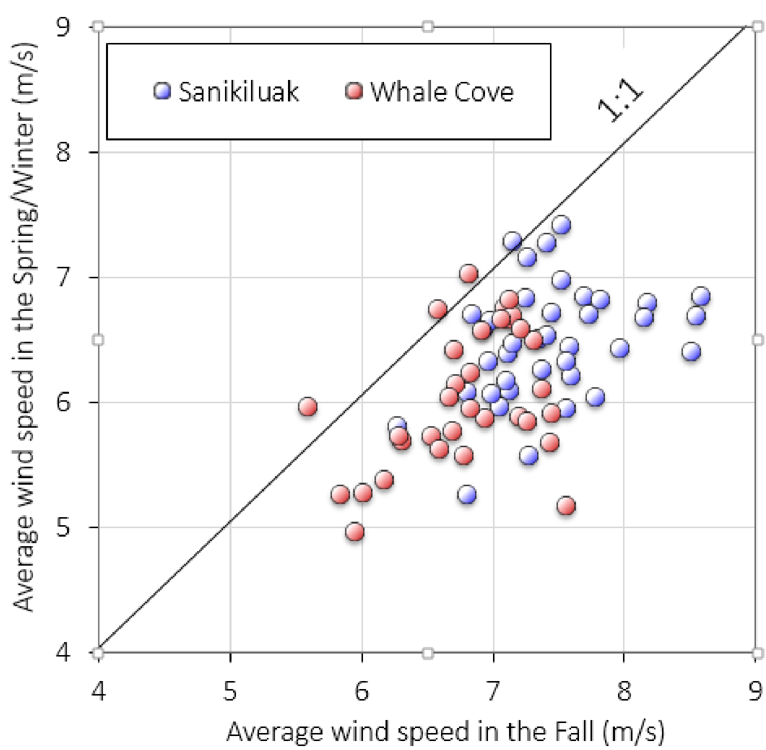

Figure 18: A comparison between average wind speed in the Fall with that in Winter/Spring in Sanikiluak and Whale Cove. They generally Fall below the 1:1 line, i.e. wind speeds are higher in the Fall than in the Winter/Spring; they are also higher in Sanikiluak than in Whale Cove.

7.2.2. Arviat

Wind speed data from Arviat were also extracted from NARR in CASRAS but at a higher time resolution. Instead of daily means, i.e. the mean speed was for each of six 3-hour intervals every day. Using the average of these means, a similar plot as that in Figure 17 is shown in Figure 19. The Fall data show a statistically significant increase of about 0.3 m/s per decade. The Winter/Spring data do not show any variation. Figure 20 was also produced with the higher resolution NARR data, to better appreciate the distribution of wind speed in the Fall and the Winter/Spring. Higher speeds are recorded in the Fall, but the most common wind speed for both is from 2 to 4 m/s.

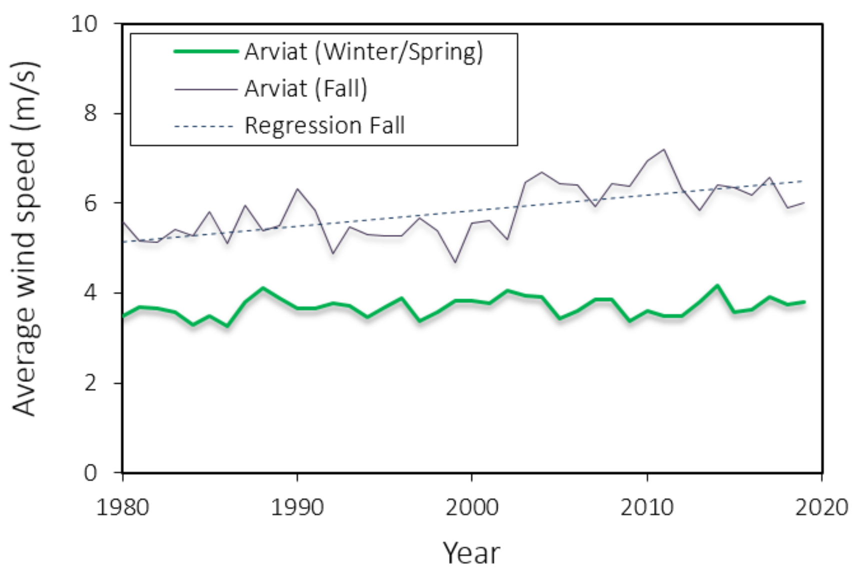

Figure 19: Average wind speed over the last four decades at Arviat, for the Fall and the Winter/Spring. The Fall data display a statistically significant increase of about 0.3 m/s per decade. The Winter/Spring data do not show any variation.

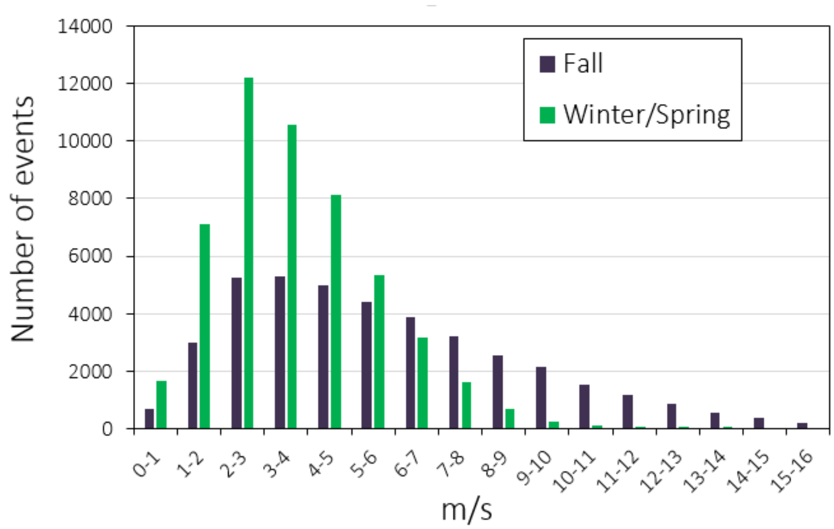

Figure 20: Distribution of wind events as a function of speed for the Arviat location, in Fall and Winter/Spring.

Wind speed at Arviat as a function of the month was also investigated, as displayed in Figure 21. That figure complements Figure 20 in showing that the highest wind speeds have been in either September, October or December. It also complements Figure 19 in showing a general increase over the years in the Fall.

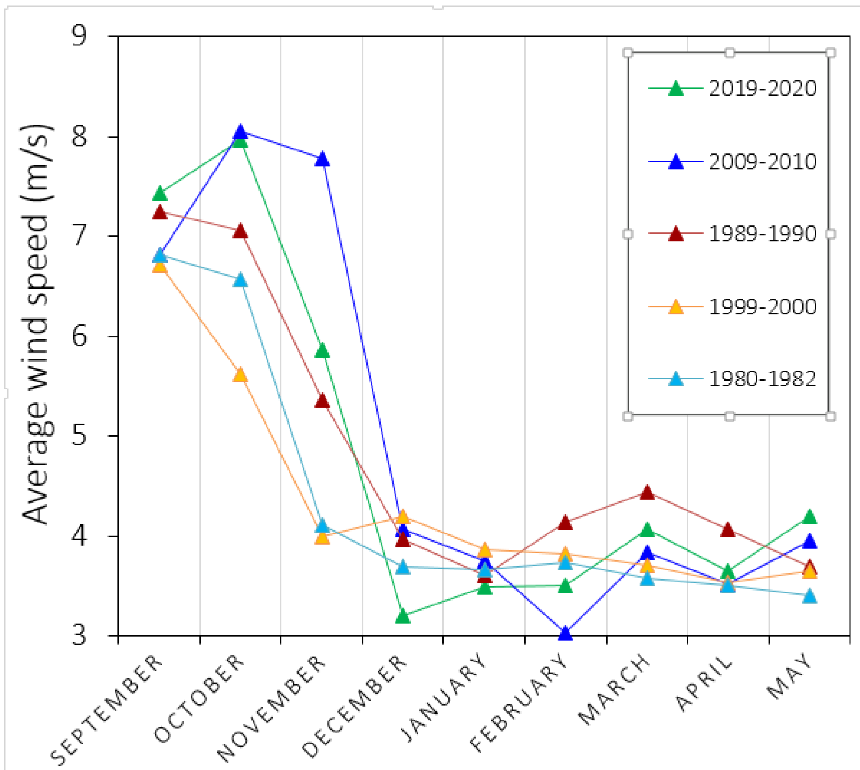

Figure 21: Average wind speed at Arviat as a function of the month of the year, for several two-year time spans over the last four decades.

Figure 22 is an alternative plot of wind speed for six particular months over the four decades. There again, September and October show higher speeds, with those of November on the rise since about 2000. Of all these trends, that for October, November and May are statistically significant, with an increase in wind speed of 0.5, 0.8 and 0.2 m/s per decade, respectively.

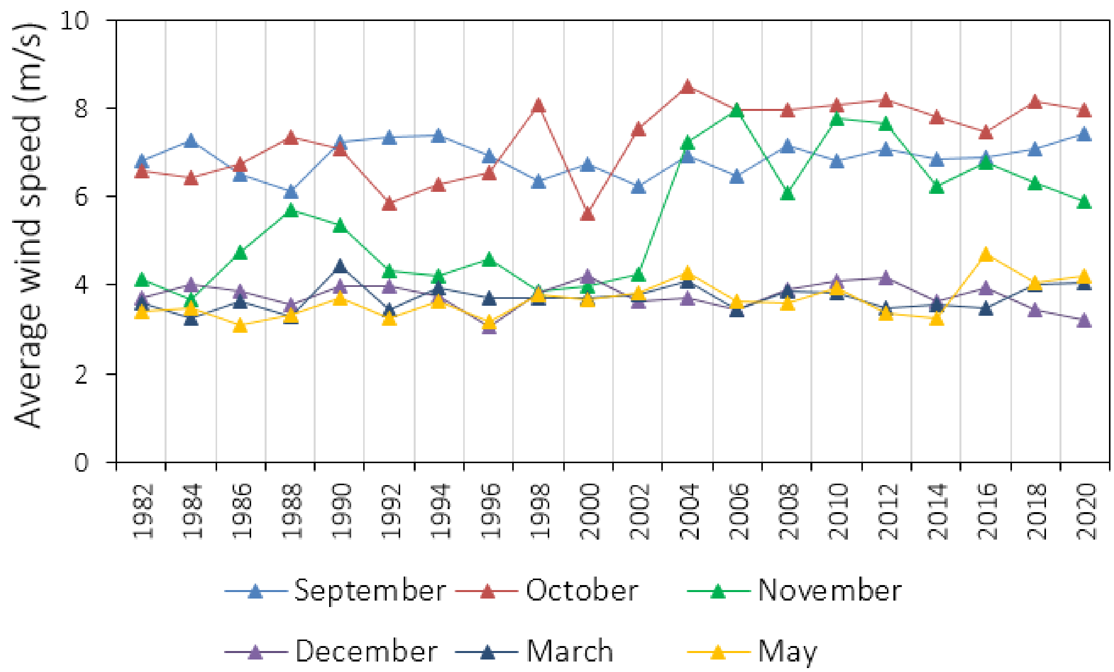

Figure 22: Average wind speed at Arviat as a function of the year, for September, October, November, December, March and May, over the last four decades. October, November and May display a statistically significant increase in wind speed of 0.5, 0.8 and 0.2 m/s per decade, respectively.

7.3. Wind direction

Information on wind direction for the Arviat location was extracted from the same higher frequency NARR data as those used for wind speed. In what follows, 0 (or 360), 90, 180 and 270 degrees represent North (N), East (E), South (S) and West (W), respectively. These are the direction where the wind is coming from. Figure 23 shows wind speed as a function of wind direction. Each point is the mean speed inside six four-hour periods every day, from September to May and over the last four decades. As can be seen, the wind is from all directions, but speeds tend to be higher from the SSE, and also from the N but to a lesser extent.

Figure 24 attempts to decipher a trend in the yearly wind direction average, but there is no indication there is any. They show predominant wind directions in Fall and Winter/Spring from the S to SE.

Figure 25 provides similar information as that in Figure 24, but where the directions are for individual months instead of for the full year. There again, there is no evidence of any trend over time. Figure 26 is complementary to Figure 25. It shows a shift from about 140 deg. to 180 deg. from January to May.

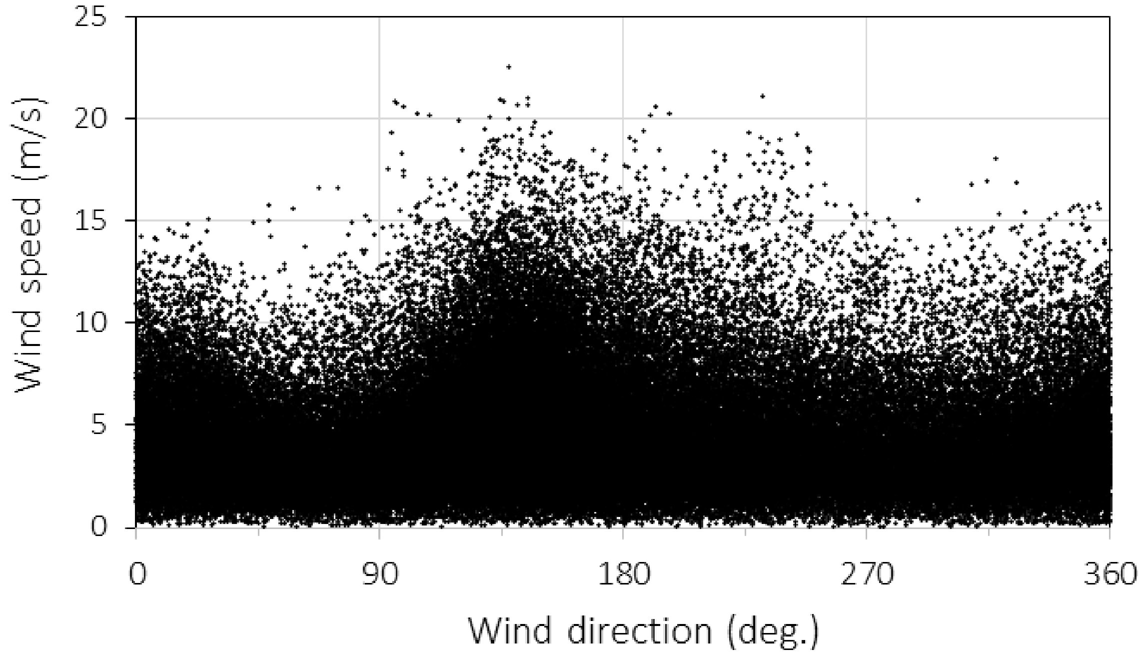

Figure 23: Wind speeds as a function of wind direction during the Fall and Winter/Spring at Arviat. Each point is the mean speed inside six four-hour periods every day, from September to May and over the last four decades (n=121,928).

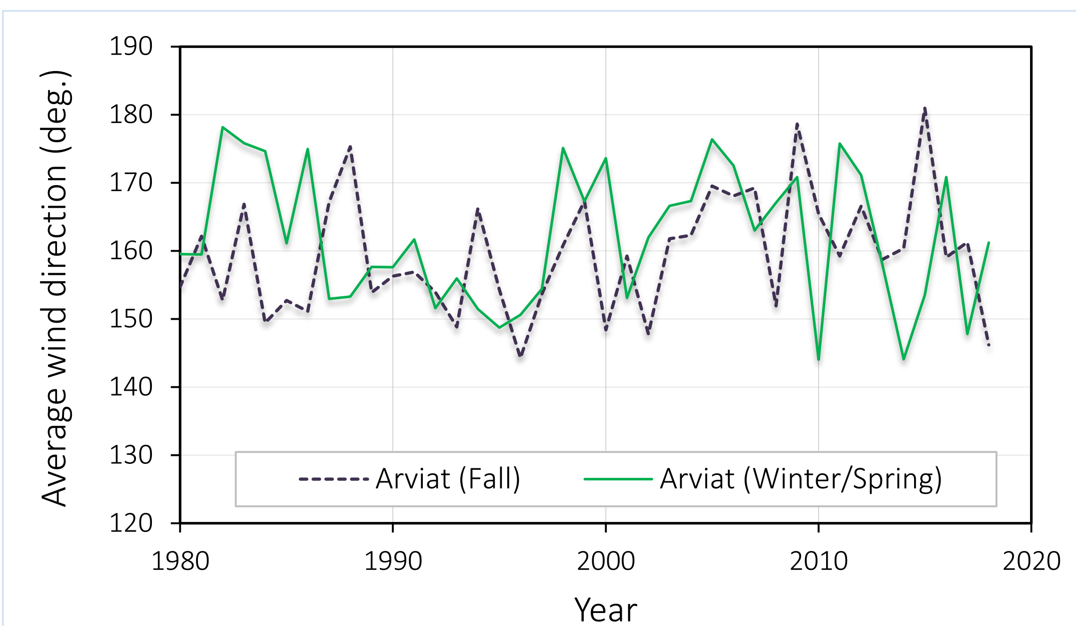

Figure 24: Wind direction at Arviat averaged for each year, during Fall and Winter/Spring and over four decades. There is no statistically significant trend.

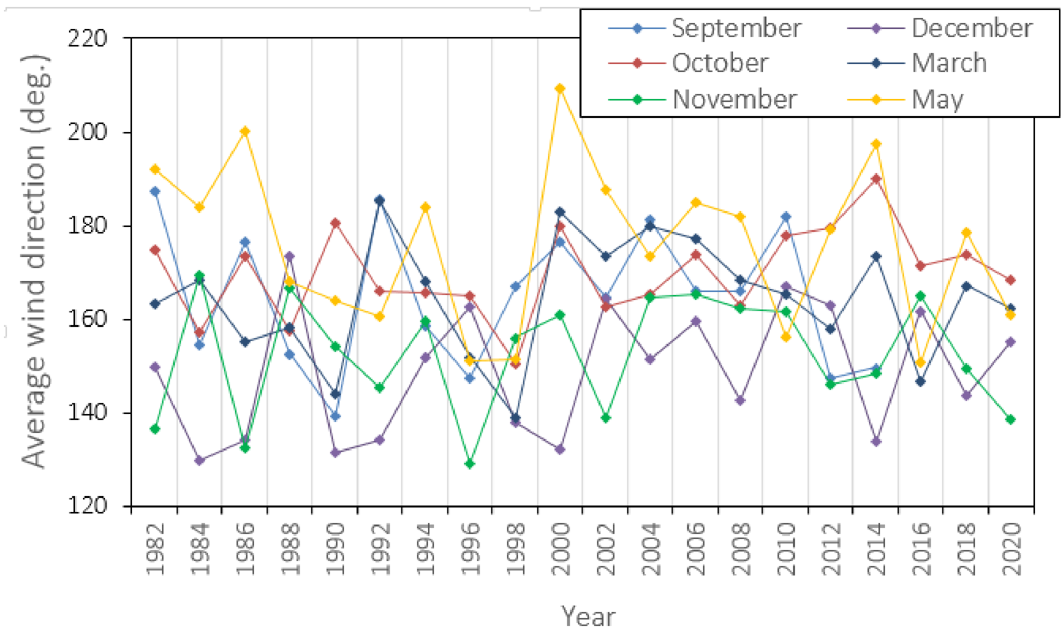

Figure 25: Average wind direction for September, October, November, December, March and May across four decades. There is no statistically significant trend.

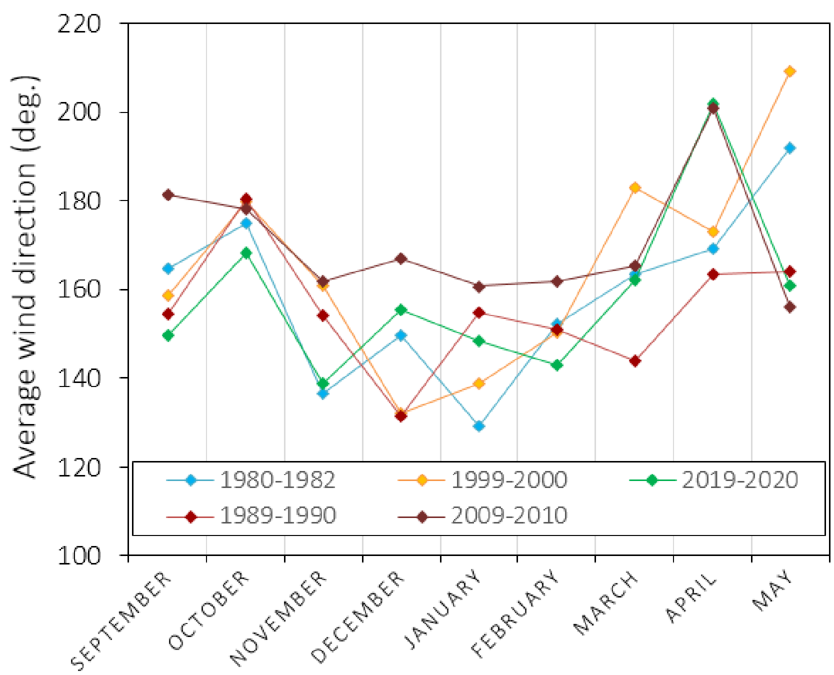

Figure 26: Average wind direction for all months from September to May, averaged over two years across the four decades.

8. Outcome and discussion

The analyses presented in this report focused on ice cover formation and break-up in Hudson Bay over the last 30 to 40 years. They were meant as a test case for this exploratory exercise in using CASRAS as a data provider, and MS Excel, for data interpretation. Because this was done at a regional scale, the outcome is too coarse to be relevant to any particular community in providing short-term guidance on local conditions.

With regards to sea ice evolution in Hudson Bay, a few trends were identified, based on average rates over the full 30-40 year period:

- The ice cover in Hudson Bay has required more time to develop into a fully established ice cover. That delay is estimated at 3 to 4 days per decade.
- Ice cover to break-up initiation has begun earlier in the Spring/Summer, i.e. that shift is estimated at about 5 days per decade.
- The time during which a full ice cover was maintained, i.e. before the initial break-up, has been diminishing at a rate of about 9 days per decade.
- There has been some indication of an increase in the amount of time between initial break-up and 100% open water conditions. The rate at which this has been occurring is about 4 days per decade.

The number of FDD, a reflection of how cold the air temperature is over a given time period, has been decreasing at a rate of 54 FDD per decade at Sanikiluak. Such a decrease is generally consistent with the observations made on the ice cover evolution. There are also some indications that wind speed has been changing with time. In Arviat, an increase in wind speed is documented, about 0.3 m/s per decade in the Fall.

These observations are merely examples of what could be generated in a more extensive study. They help improve our understanding of sea ice evolution in a number of ways. For example:

- The observed trends for the ice coverage could potentially be extended into the future, so as to anticipate ice conditions or variability.
- Climate modeling of future ice conditions, or FDD analysis using modeled future temperatures, could be used in conjunction with the extrapolated trends.

For a more in-depth study (beyond the scope of what is reported herein), these observations could be compared with those made by other investigators. For instance, a similar procedure as that described in this report was used by Laidler et al. [16] to understand ice cover dynamics and correlate their analyses with Inuit usage of sea ice. An earlier ice break-up has also been reported by Stirling et al. [27], who point out a shift from July to June in western Hudson Bay. In addition, the impact of climate change on sea ice has been approached from various angles – recent examples include those of Levine et al. [7], Jenkins and Dai [8], and Zampieri and Goessling [28].

9. Conclusion

This report is meant to be a proof of concept. Using CASRAS as an all-in-one information provider for ice maps and climate data, some basic trends in the evolution of the ice cover over Hudson Bay, as well as air temperature and wind patterns, were identified. MS Excel, a widely available software, was used to generate linear trends. Because these observations are for the whole of Hudson Bay, they are not relevant to local conditions, i.e. they cannot assist with ice access by a particular community in any given sector – that is SIKU's[7] domain. Instead, they provide a general perspective on the regional evolution of the ice cover over time. What is presented in this report is effectively a method to research climate change impact. Ultimately, this type of work could be fed into climate models of future ice conditions.

A more extensive exploration of these tools would be a promising avenue to improve the observer's understanding of global sea ice evolution. One possibility is to bring together some form of 'user guide' or training session, with additional information on the usage of CASRAS and MS Excel, as well as other prospective tools. Northerners are well positioned to conduct and benefit from this type of research because they live the environment. As such, they are better able to decide what parameters need to be addressed, why and how to best interpret the outcome. Their input could prove valuable in guiding the future development of these methods and adapting them to their own requirements.

10. Acknowledgements

The work reported herein was funded by Infrastructure Canada through the Climate Resilient Built Environment (CRBE) initiative managed by NRC. An appreciation is extended to Dr. R.M.W. Frederking, for helpful comments during the preparation of this report.

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Appendix A – Freeze-up of Hudson Bay

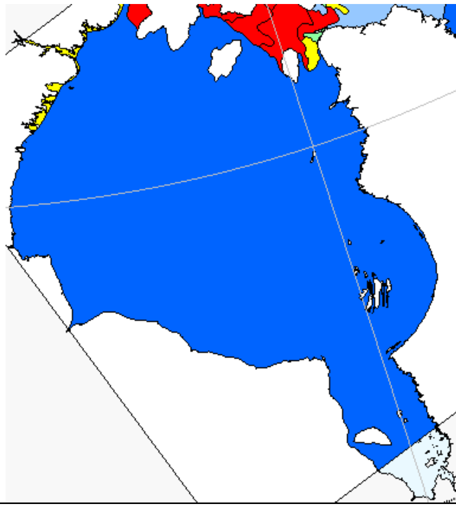
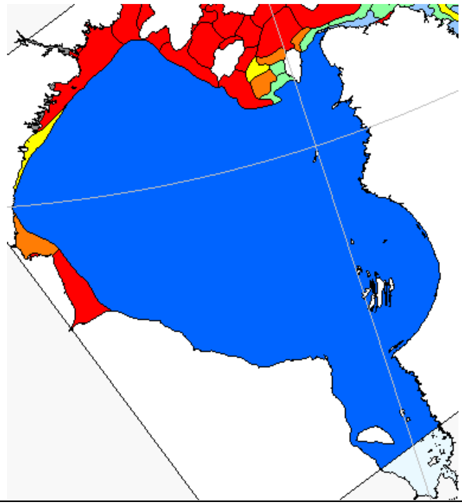
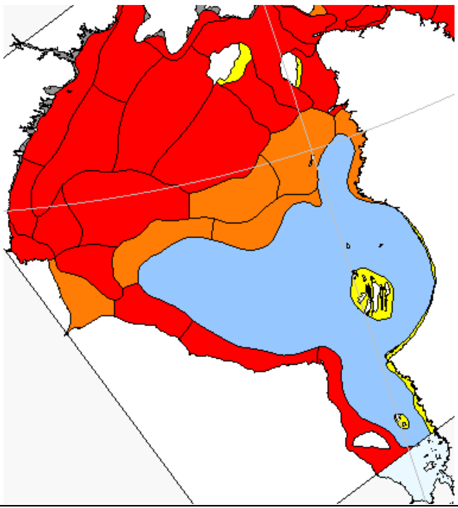
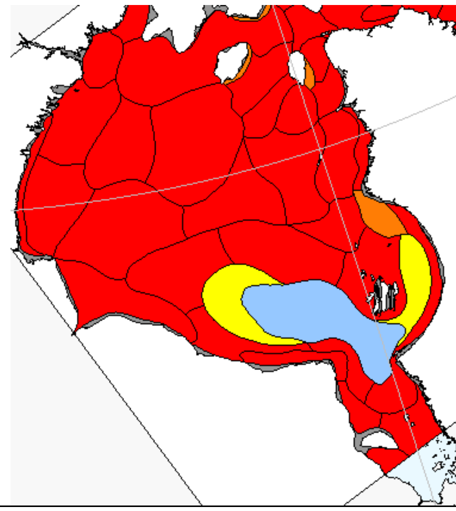
This appendix is a compendium of ice charts produced by the Canadian Ice Service (CIS), which were extracted from CASRAS, an NRC in-house tool designed to facilitate visualization and extraction of CIS ice charts as well as other data. These are referred to as 'regional' charts. They are at a four-year interval, from 1972 to 2020, for a total of 13 sets. Although CIS produces them every week, for this analysis, only six charts per year were selected and included in this appendix. This selection was done to provide an adequate perspective of the ice cover evolution in Hudson Bay, which usually starts in mid-October or later and is completed by mid- to end of December.

The sequence depicts the progressive freeze-up of Hudson Bay from October up to January every year. The legend for these charts is shown in Figure A1, and is from the World Meteorological Organization (WMO).

6:Fast ice
5:9/10 - 10/10 (very close ice)
4:7/10 - 8/10 (close ice)
3:4/10 - 6/10 (open ice)
2:1/10 - 3/10 (very open ice)
1:Open Water
0:Ice Free

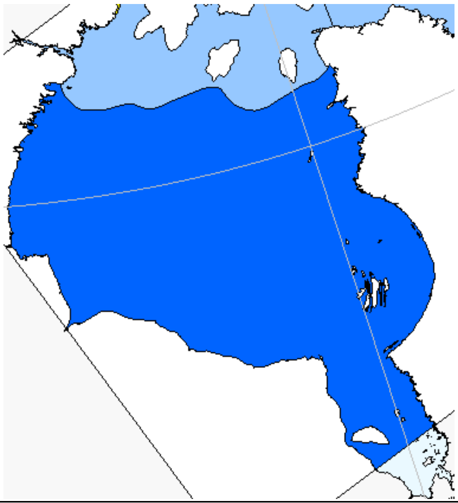
Figure A1: Example of a legend accompanying the regional charts. Note that '1' is less than 1/10 total concentration.

1972

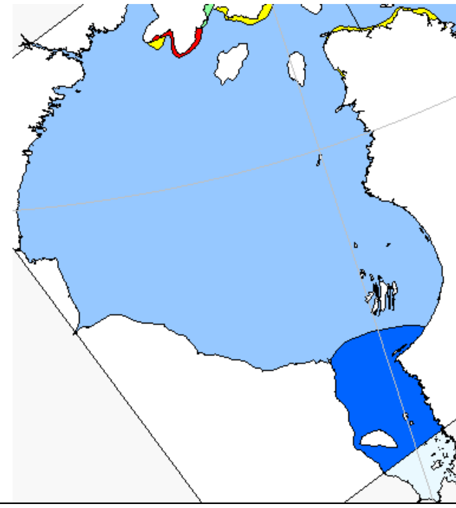
October 13	October 27
	
November 10	**November 24**
	
December – Early/Mid	**December – Late**
[Not available]	[Not available]

1976

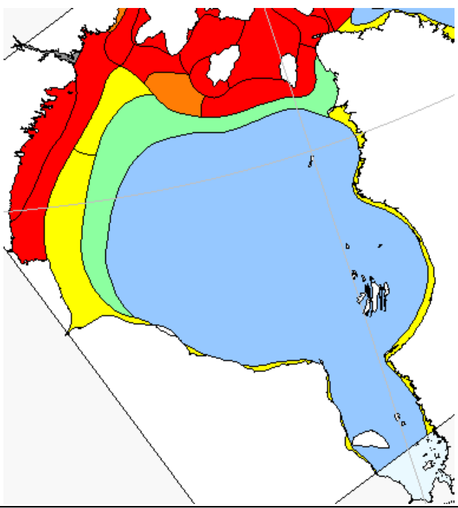
October 11



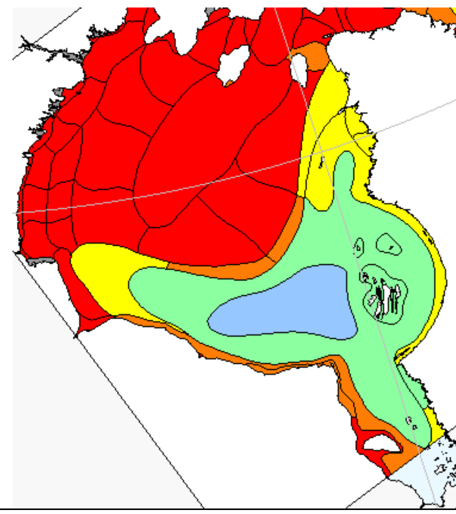
October 25



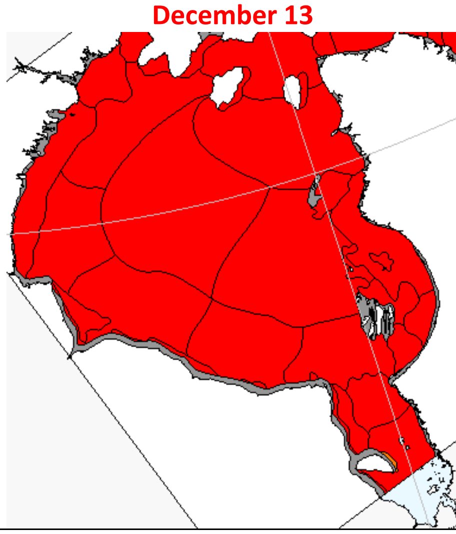
November 15



November 29



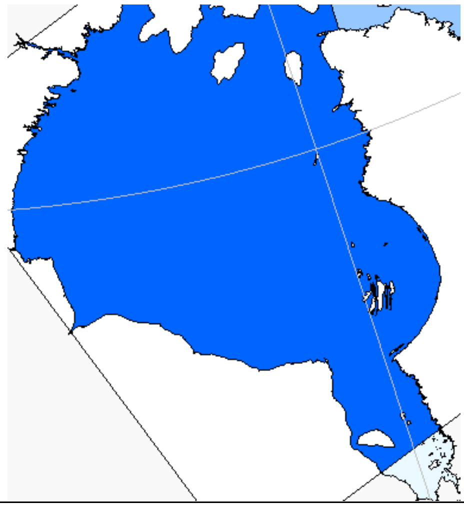
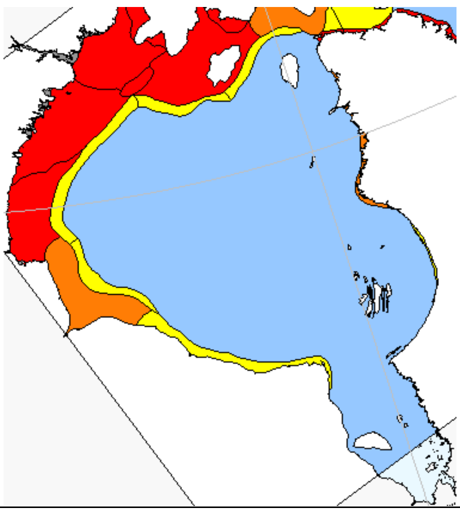
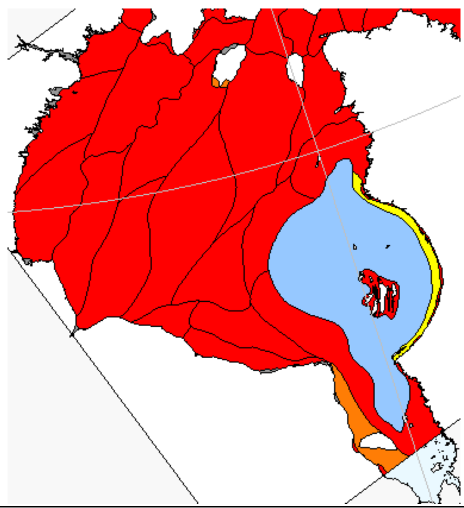
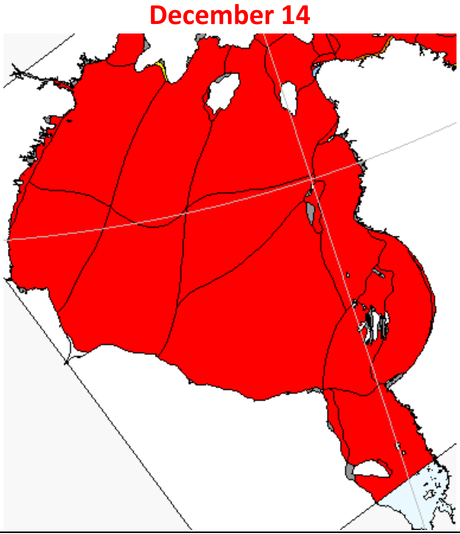
December 13



December – Late

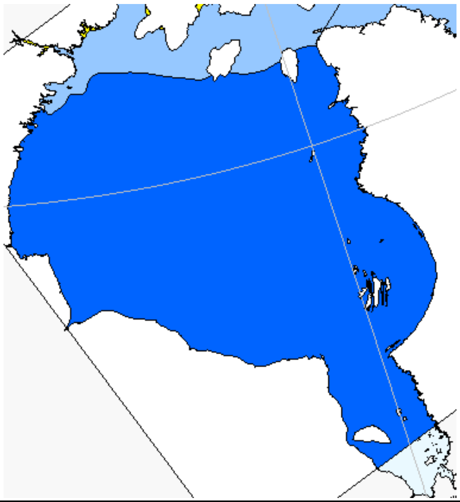
[Not available]

1980

October 12 	October 26 
November 16 	November 30 
December 14 	December – Late [Not available]

1984

October 11



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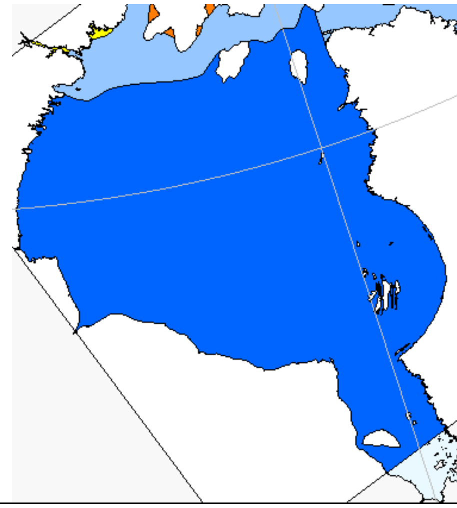

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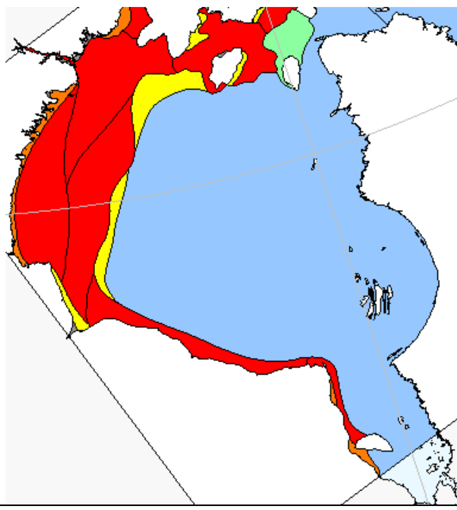

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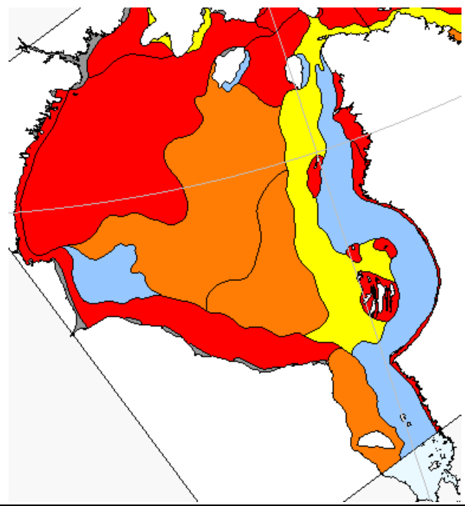
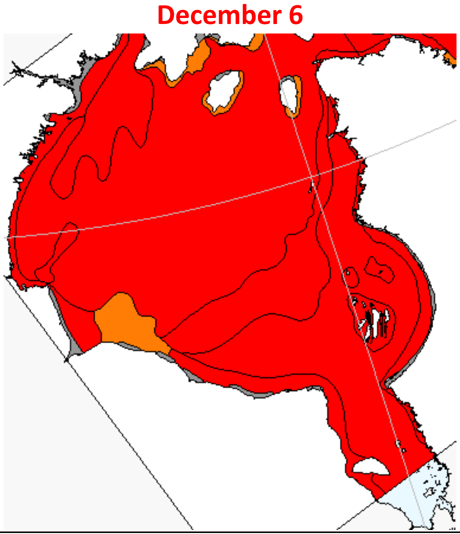
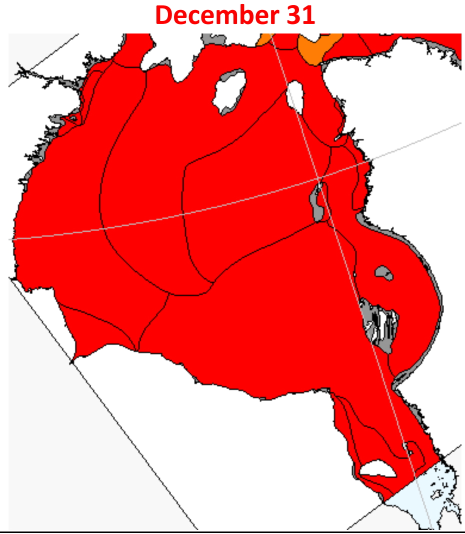


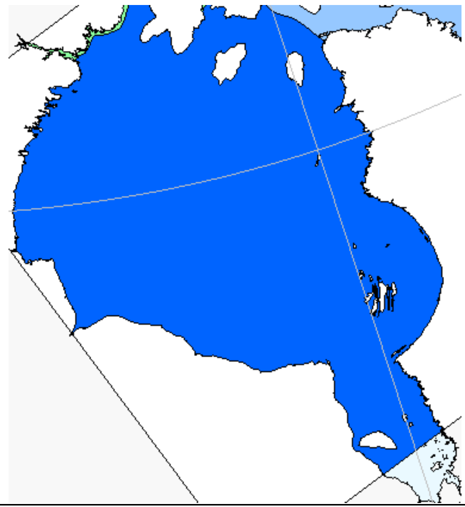
December 6

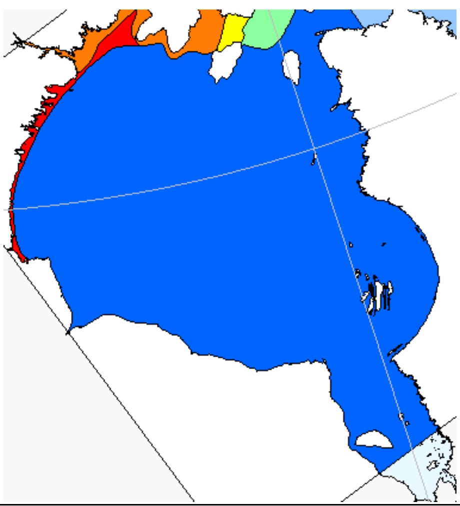
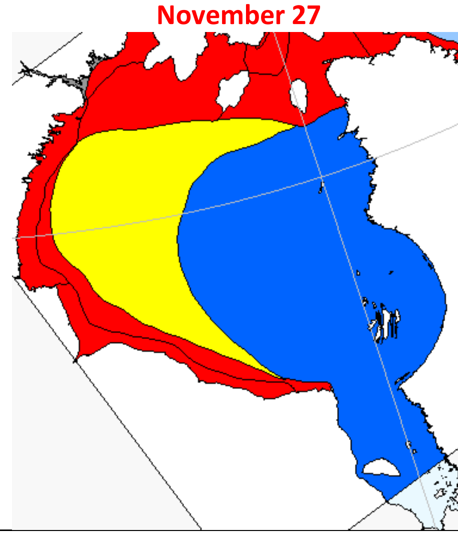


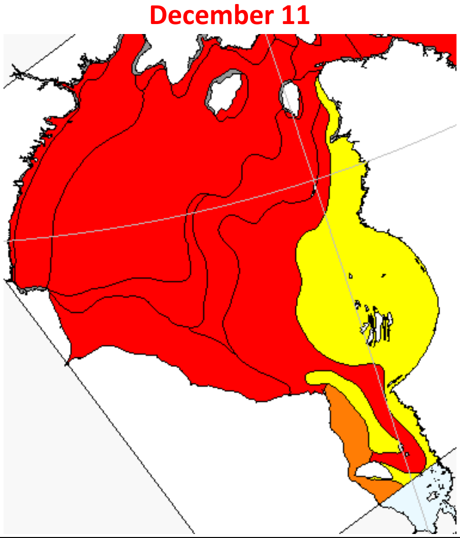
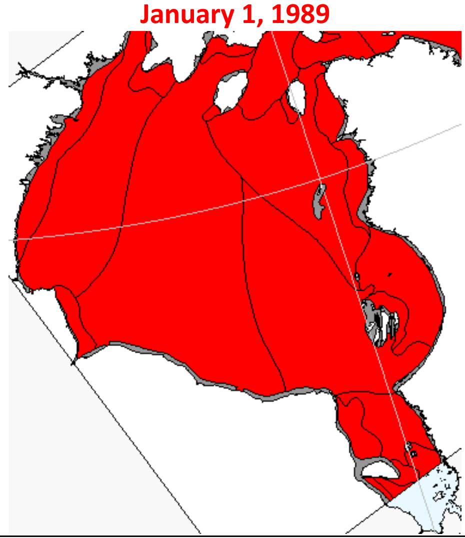
December 31



1988

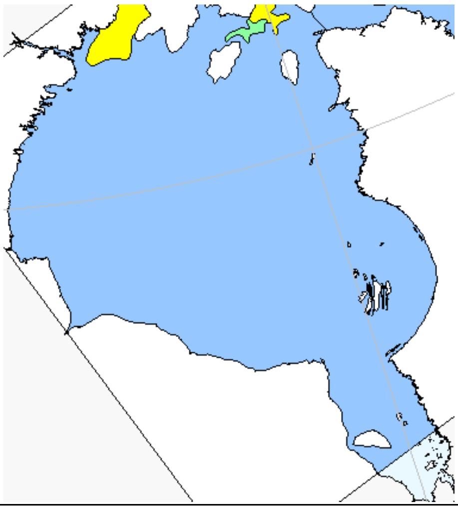
October 16	October 23
	

November 13	November 27
	

December 11	January 1, 1989
	

1992

October 11



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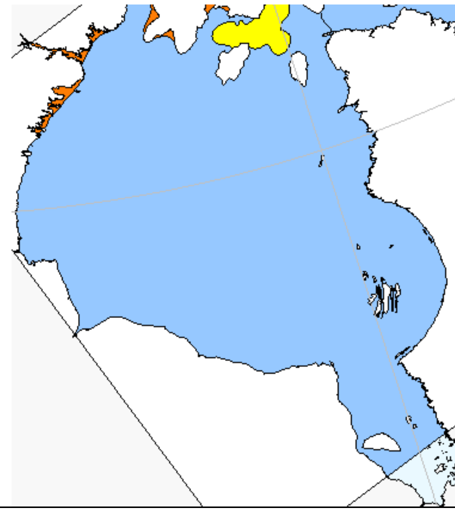

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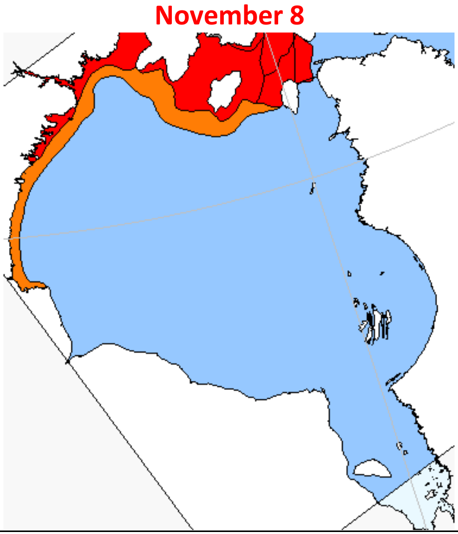

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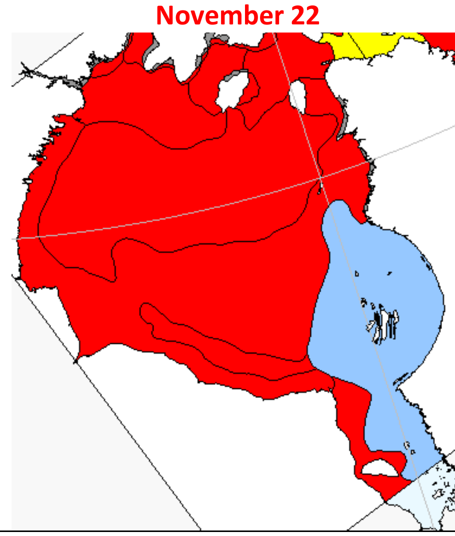
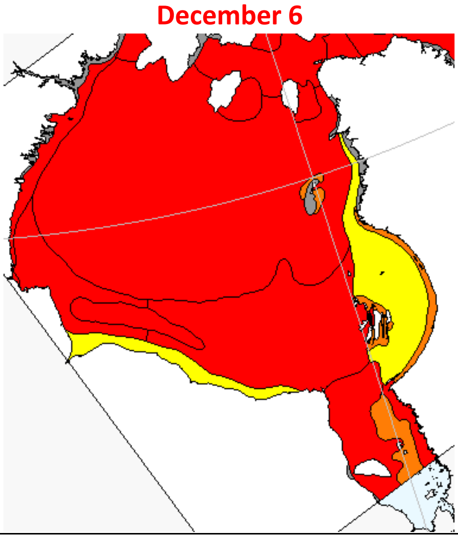
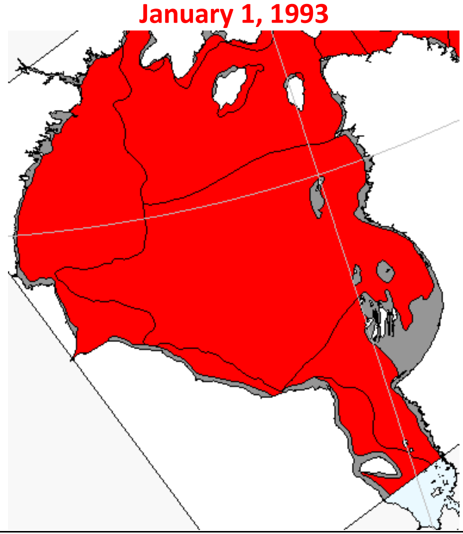


December 6

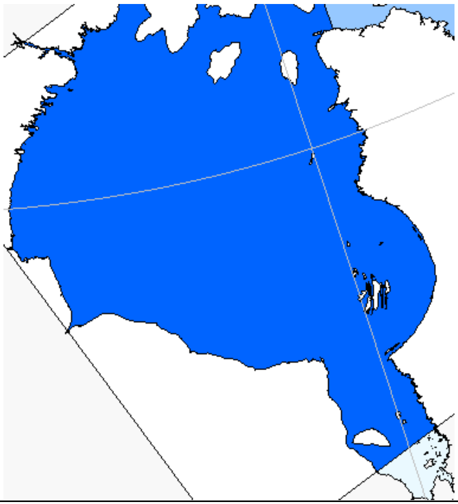


January 1, 1993



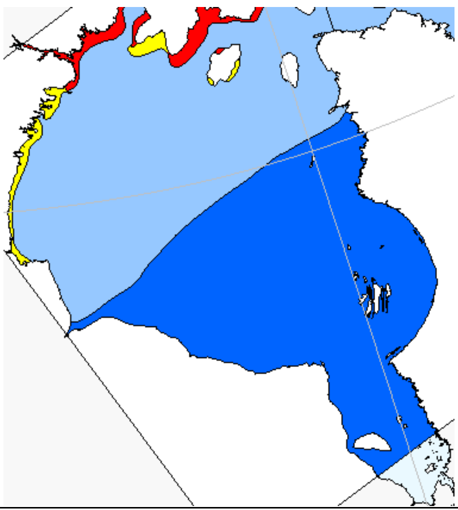
1996

October 13



October 27

November 10



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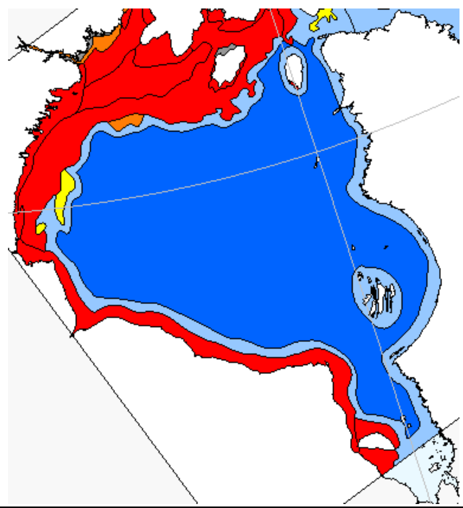

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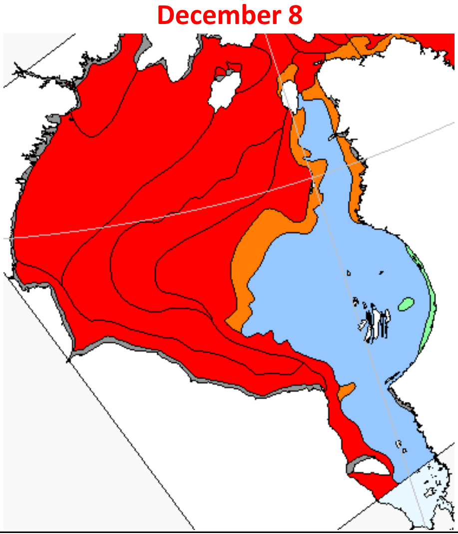

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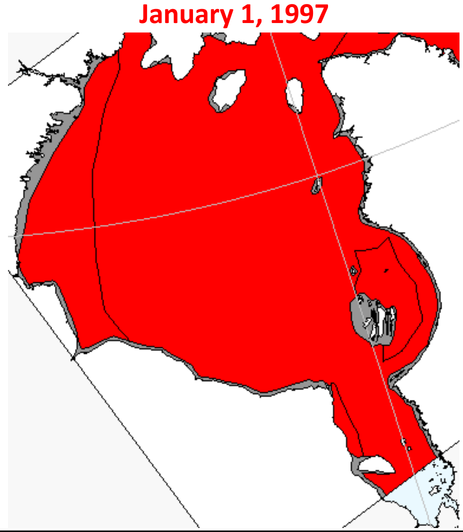
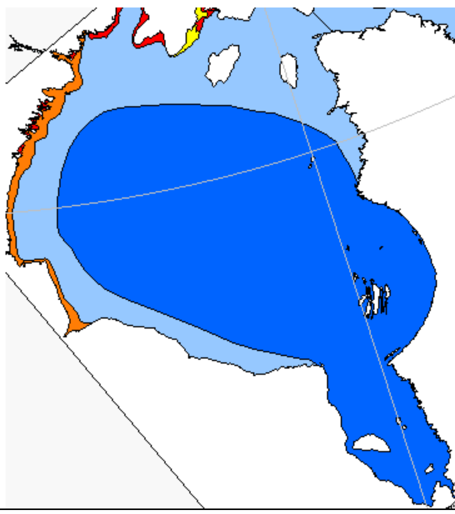


2000

October 9

October 23

November 6



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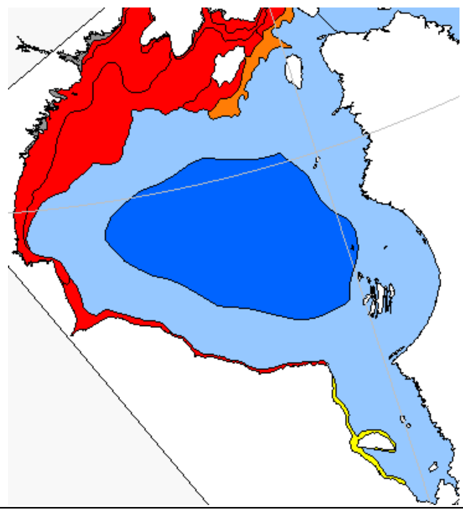

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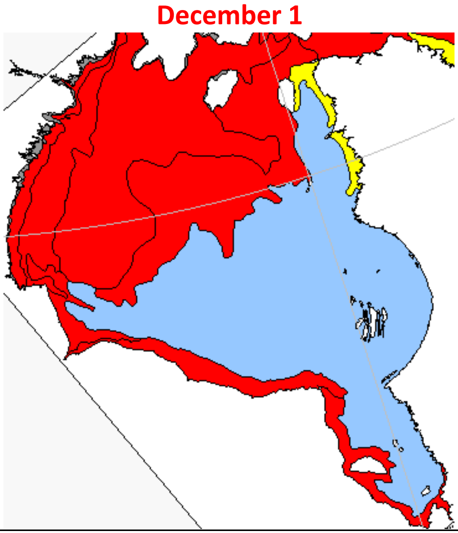

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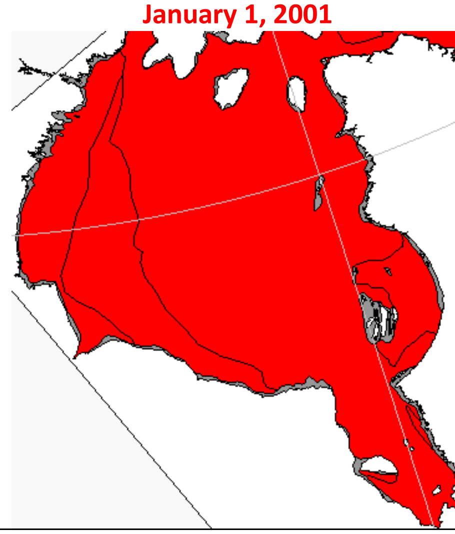
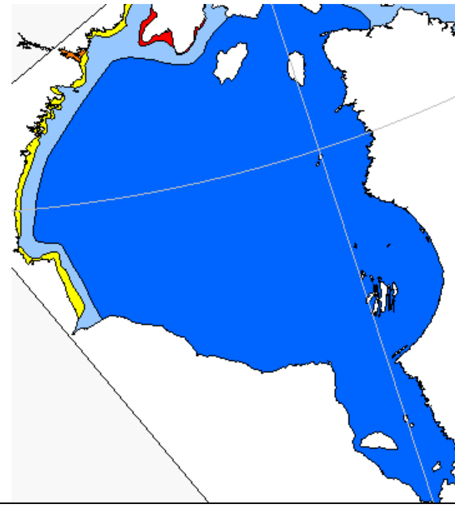


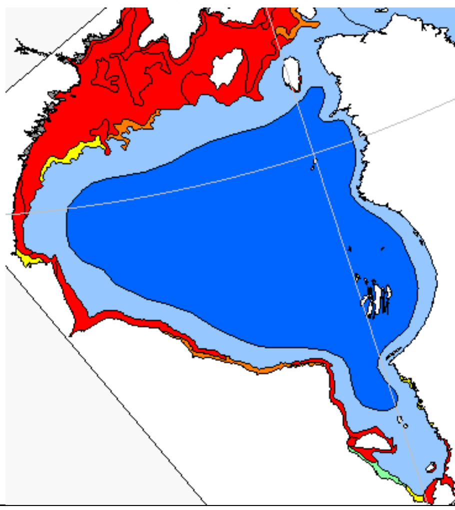
2004

October 11

October 25



November 15



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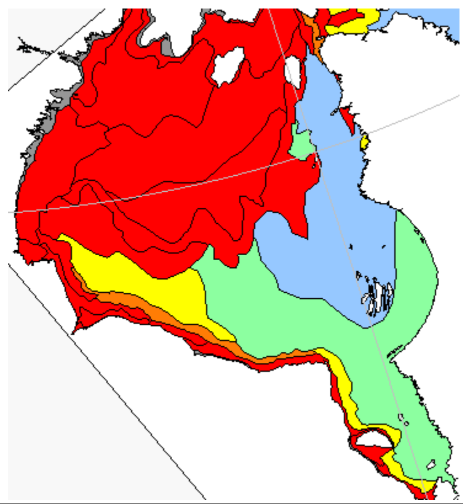

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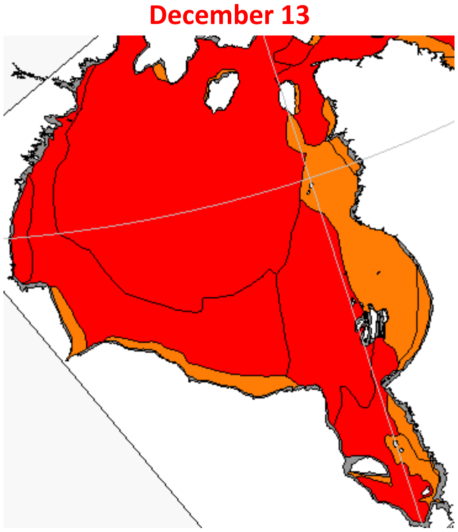

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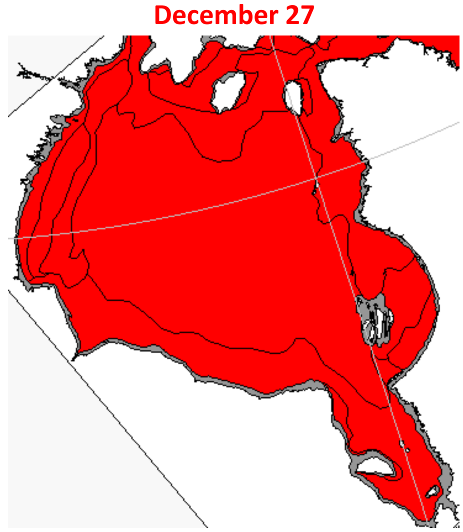
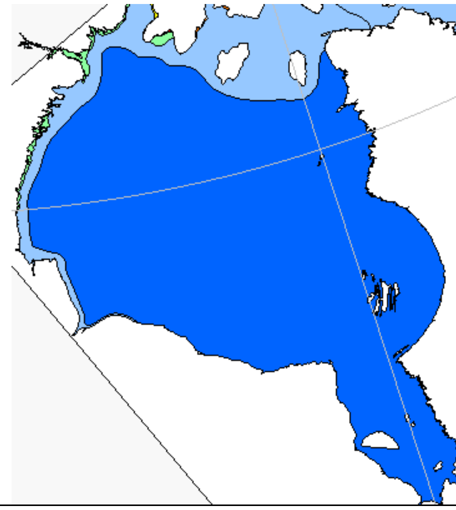


2008

October 13

October 27



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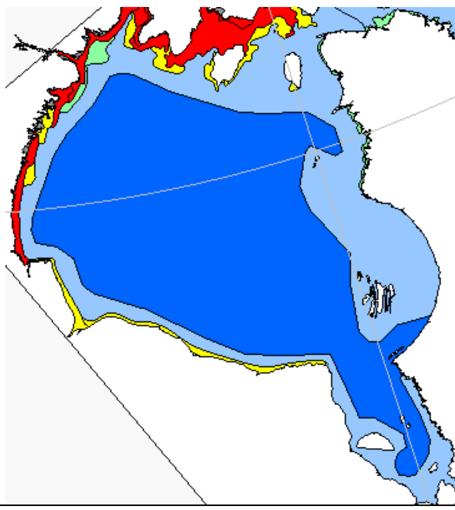

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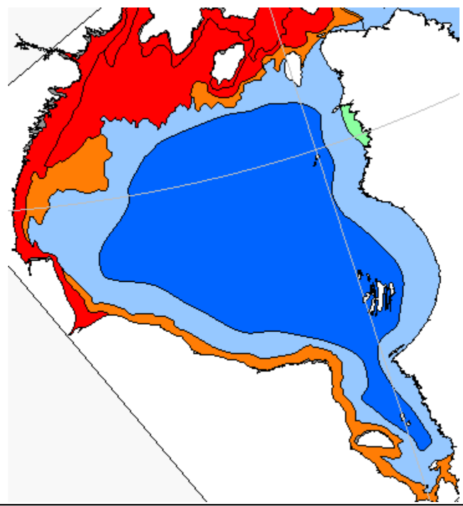

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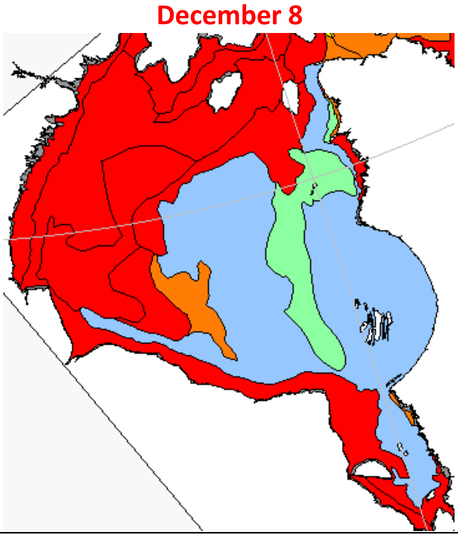

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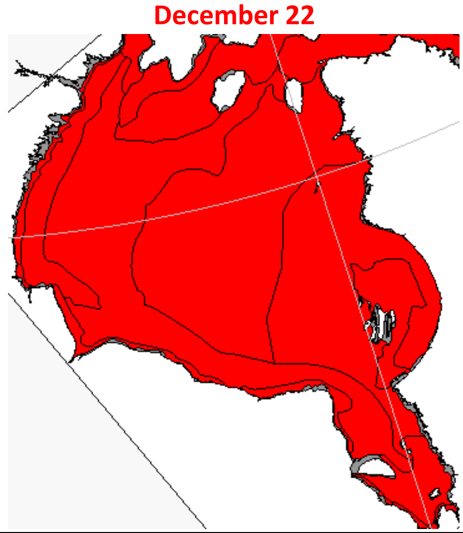

2012

October 15

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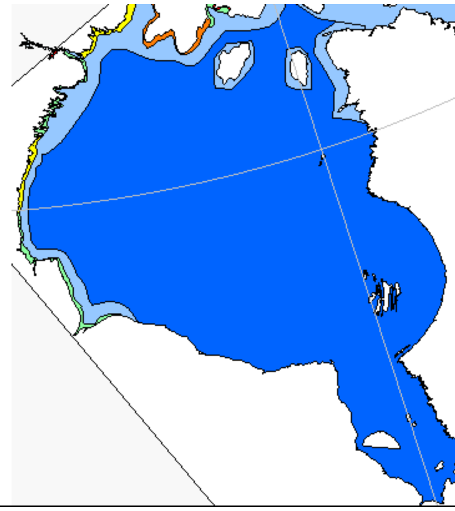

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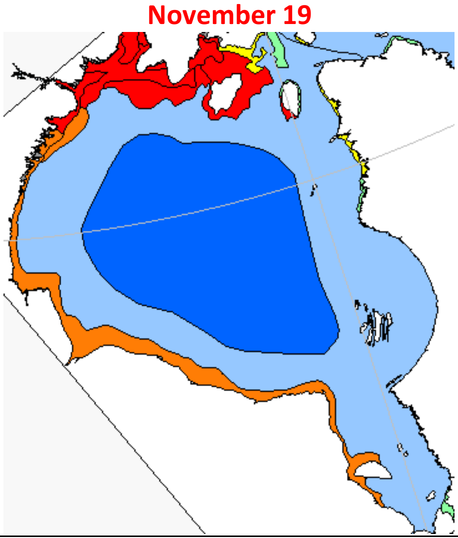

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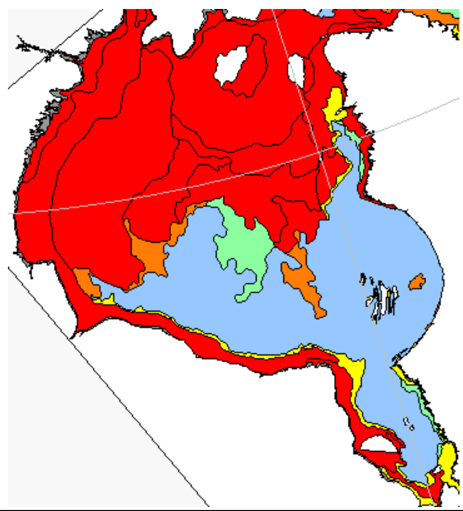

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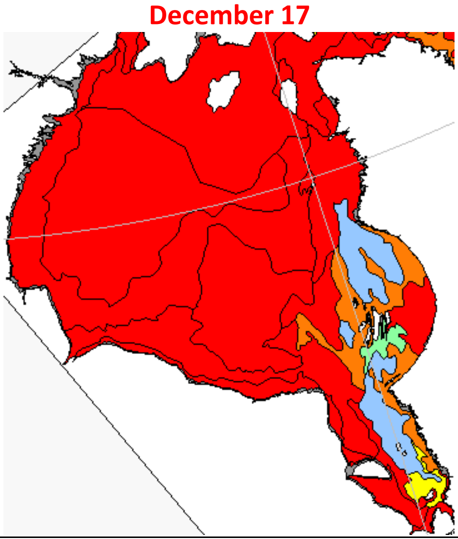

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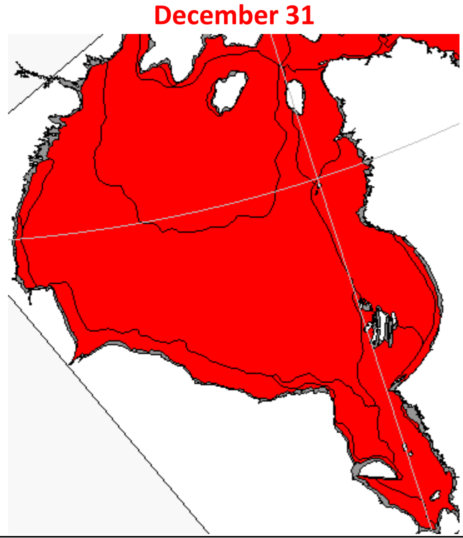
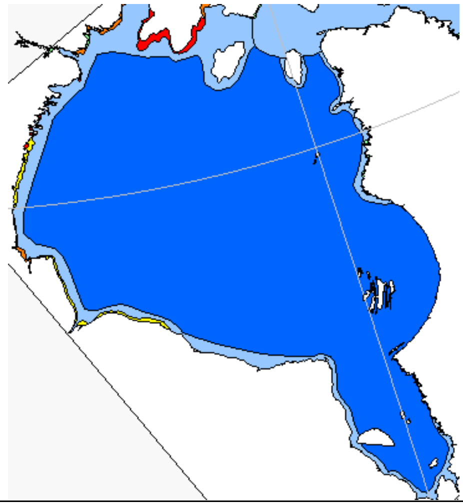


2016

October 17

October 31



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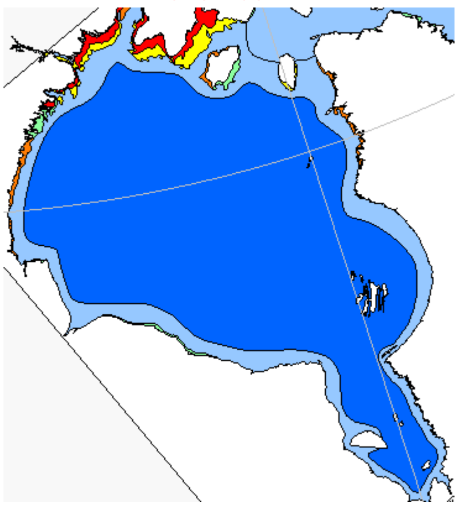

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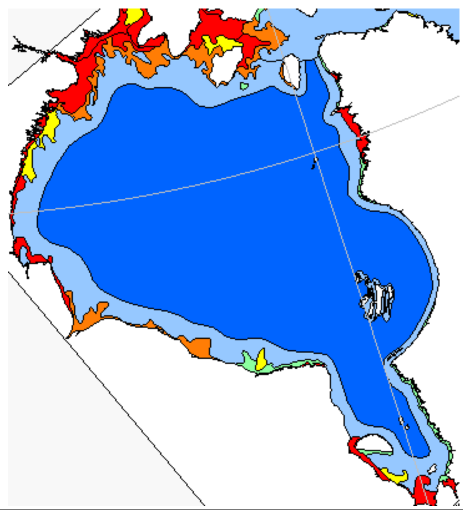

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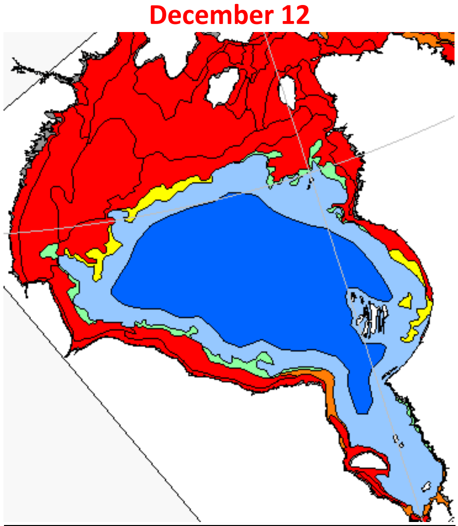

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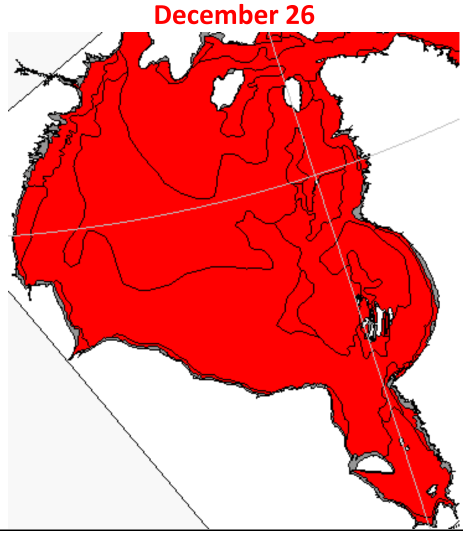
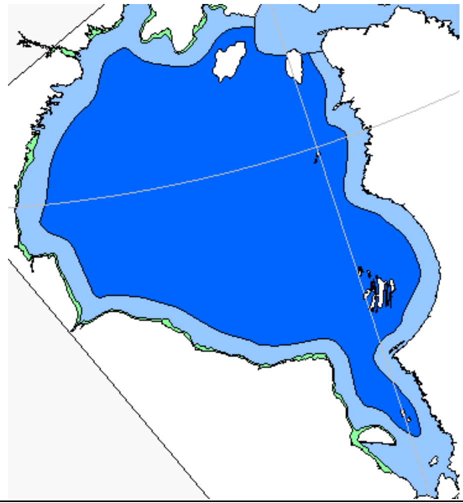


2020

October 12

October 26



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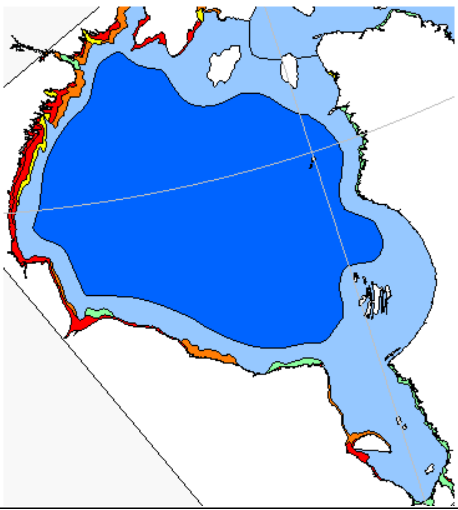

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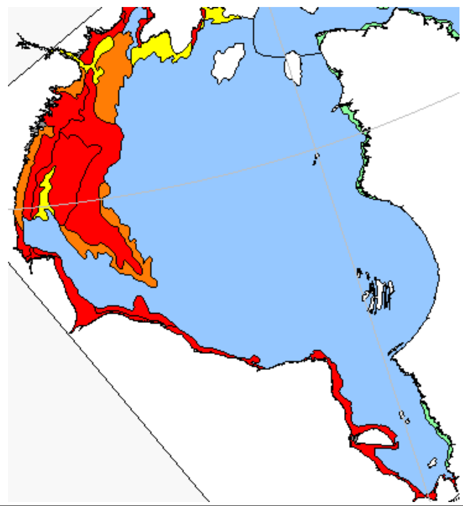
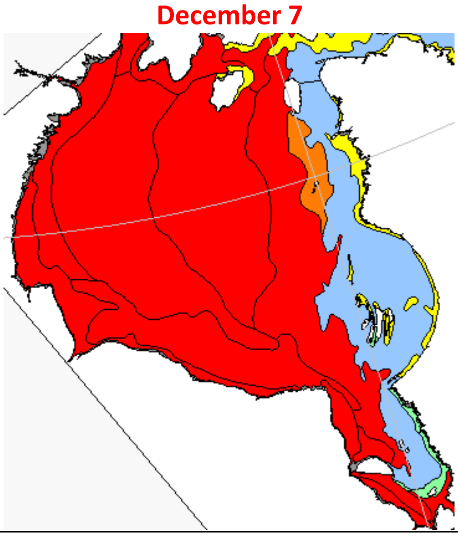


December 7



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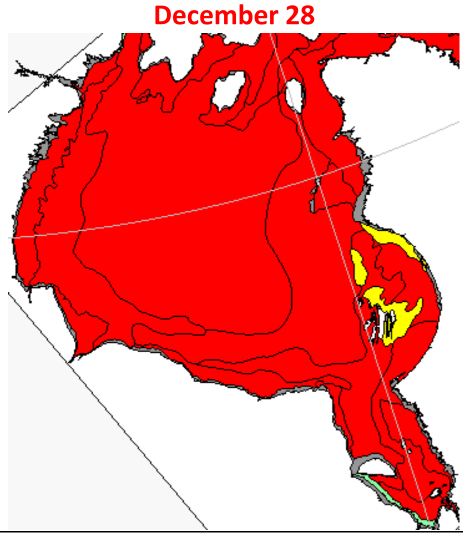

Appendix B – Statistics

Plotting one parameter against another on an x-y graph, as done in this report, is the simplest approach to identify whether or not x affects y, i.e. if and how y varies as a function of x. That relationship was assumed to be linear (as opposed to exponential, logarithmic, polynomial, etc.), which is a usual 'first step' in this type of analysis. A generic example of a linear relationship is shown in Figure B1a. The linear regression is described by an equation in the form of $y=mx+b$, where m is the slope, or regression coefficient, and b is where the line intersects the y axis when $x=0$. To better understand these correlations, two parameters can be used: 1) the R-squared value (R^2), and 2) the P value. Both parameters can be investigated using functions inside MS Excel.

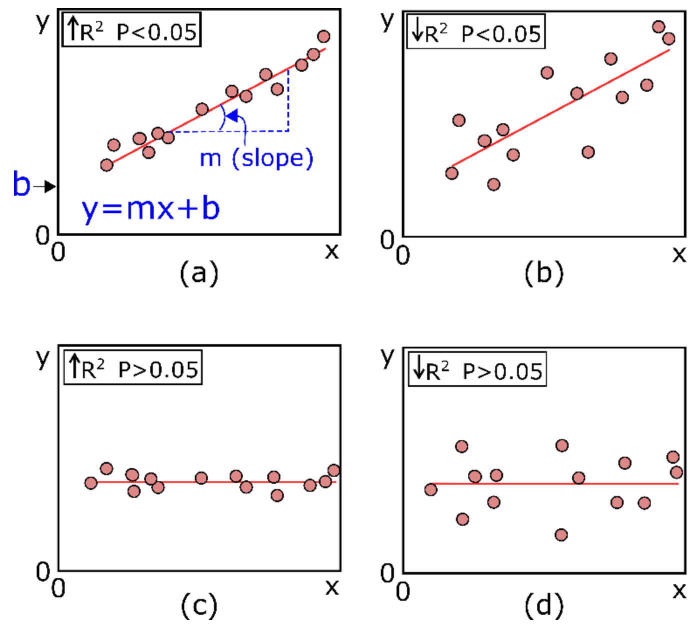

Figure B1: Differences between the meaning of R squared (R^2) and P values with an idealized set of data points and a linear regression through these data: a) Description of a linear regression (y=mx+b) for a high R^2 and a low P value; b) low R^2 and low P value; c) high R^2 and high P value; d) low R^2 and high P value.

<u>R-squared value</u>

The R^2 value can vary between 0 and 1 (i.e. 0% and 100%) and is a standard measure of how well a linear regression fits the data, i.e. it is a measure of the amount of data scatter (or variance). A higher value is better able to predict the behavior of the y variable. In Figure B1, (a) and (b) show the same regression line, but with more data scatter in the latter. This means that the regression can be used to foresee the future, but with less certainty in (b) than in (a).

<u>P value</u>

The P value is used to estimate the extent to which y depends on x. How far away from the horizontal should a regression line be before the dependency is considered 'statistically significant'. For this exercise, a P value of less than 0.05 (5%) will be considered statistically significant, i.e. a low chance (1 in 20) that the dependency is not real.

Table B1 provides information on these various parameters for each figure presented in this report. A potential follow-up on this cursory exam would be to further investigate the relevance of this information to sea ice.

Table B1: Statistical information for the graphs in this report in which a relationship was investigated. A positive number for the slope m of that trend indicates an increase; a negative number indicates a decrease. Data in rows not shaded in grey indicate a statistically significant trend (P value equal to or larger than 0.05).

Link to figure	Horizontal (x) axis	Vertical (y) axis	m (slope)	y-intercept	R square	P Value
		Units:	*day/year*	*day*	*no units*	*no units*
Figure 8	Year	Last date at 100% open water	0.01	13.9	0.00	0.8822
	Year	First date to 100% freeze-up	0.38	-639.8	0.19	0.0135
Figure 9	Year	No. of days between 100% open water and 100% freeze-up	0.34	-598.7	0.13	0.0482
Figure 12	Year	No. of days to initial break-up	-0.47	1057.5	0.15	0.0103
	Year	No. of days to 100% open water	-0.04	308.1	0.00	0.8153
Figure 13	Year	No. of days between initial break-up and 100% open water	0.43	-749.5	0.09	0.0527
Figure 14	Year	No. of days between 100% freeze-up and initial break-up	-0.89	1914.7	0.26	0.0048
Figure 15	Year	Number of FDD – Whale Cove	-4.466 FDD/year	10079.743 FDD	0.07	0.1952
	Year	Number of FDD – Sanikiluak	-5.438 FDD/year	11279.6 FDD	0.16	0.0116
	Year	Number of FDD – Peawanuk	-3.416 FDD/year	7535.0 FDD	0.04	0.3033
Figure 16	FDD	No. of days from 100% open water to 100% freeze-up	-0.04 day/FDD	95.5	0.21	0.0172
	FDD	No. of days from freeze-up to initial break-up	0.10 day/FDD	84.0	0.40	0.0004

Figure 17	Year	Average wind speed (Sanikiluak, Fall)	0.01 m/s / year	-9.7	0.03	0.2619
	Year	Average wind speed (Sanikiluak, Winter/Spring)	0.001 m/s / year	3.8	0.00	0.8388
	Year	Average wind speed (Whale Cove, Fall)	0.004 m/s / year	-1.3	0.01	0.5981
	Year	Average wind speed (Whale Cove, Winter/Spring)	0.003 m/s / year	-0.1	0.00	0.7136
Figure 18	Average wind speed (Fall) - Sanikiluak	Average wind speed (Winter/Spring) - Sanikiluak	0.31 No unit	4.2 m/s	0.12	0.0354
	Average wind speed (Fall) - Whale Cove	Average wind speed (Winter/Spring) - Whale Cove	0.46 No unit	2.9 m/s	0.18	0.0144
Figure 19	Year	Average wind speed (Fall) - Arviat	0.04 m/s / year	-66.5 m/s	0.46	0.000002
	Year	Average wind speed (Winter/Spring) - Arviat	0.004 m/s / year	-5.2 m/s	0.06	0.1341
Figure 22	Year	Average wind speed September	0.01 m/s / year	6.8 m/s	0.03	0.4922
	Year	Average wind speed October	0.05 m/s / year	6.4 m/s	0.43	0.0016
	Year	Average wind speed November	0.08 m/s / year	4.0 m/s	0.44	0.0013
	Year	Average wind speed December	-0.004 m/s / year	3.8 m/s	0.03	0.4995
	Year	Average wind speed March	0.01 m/s / year	3.6 m/s	0.06	0.3151
	Year	Average wind speed May	0.02 m/s / year	3.3 m/s	0.34	0.0071

Figure 24	Year	Average wind direction (Fall) - Arviat	0.13 deg./year	-98.0 degrees	0.03	0.2667
	Year	Average wind direction (Winter/Spring) - Arviat	-0.06 deg./year	284 degrees	0.01	0.6409
Figure 25	Year	Average wind direction September	-0.18 deg./year	169 degrees	0.02	0.5209
	Year	Average wind direction October	0.26 deg./year	164 degrees	0.11	0.1613
	Year	Average wind direction November	0.08 deg./year	151 degrees	0.01	0.7476
	Year	Average wind direction December	0.33 deg./year	142 degrees	0.08	0.2310
	Year	Average wind direction March	0.09 deg./year	162 degrees	0.01	0.7218
	Year	Average wind direction May	-0.27 deg./year	180 degrees	0.03	0.4412