Environment Canada Environnement Canada

Sea Ice Climatic Atlas

Northern Canadian Waters
1981-2010

By

Canadian Ice Service
Le service canadien des glaces

Canada

Introduction

This Ice Atlas follows from our previous Canadian arctic ice atlas published in 2002. The ice years 1980-81 through 2009-10 have been used for this publication and cover a climatological time period of 30 years, the standard for representing statistical averages and extremes.

Once again we have chosen to group both the Canadian Arctic and the Hudson Bay regions
into a single atlas. We hope that this will facilitate the understanding of climatic sea ice conditions in Northern Canadian Waters as a whole.

In addition to what was contained in the previous atlas, we have added the 30 year Median of Ice Concentration When Ice Is Present.

Acknowledgements

Several people contributed to the production of this atlas and their effort and dedication should be acknowledged.

Dan Fequet: project management
Lionel Haché: analysis, climatology and editing
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**Mr Haché updated the ice regime and climatology text, which was originally written by Mr Brian Veale.*

Finally thanks to all past and present personnel involved in the data acquisition and preparation of the weekly CIS charts over all these years without whom the production of this atlas would not have been possible.

To be cost effective and environmentally friendly, this information is only available in electronic format.

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Data Used in Regional Analyses

Canadian ice charts are produced using imagery from RADARSAT-1 (since 1996) and RADARSAT-2 (since 2008). Other remote sensing data sources include Envisat, NOAA AVHRR and Modis imagery. Where possible, the interpretation of the satellite data is verified using observations from Ice Service Specialists onboard dedicated aircraft and CCG ships. In addition, the United States has exchanged ice data with us for many years: the National Ice Center at Suitland, MD; and the International Ice Patrol (IIP), under the jurisdiction of the United States Coast Guard (East Coast of Canada - sea ice and iceberg information). In addition, the Danish Meteorological Institute in Copenhagen has shared ice information covering the waters west of Greenland.

The products presented in this atlas were obtained from a statistical compilation of the Regional Ice Charts from the Canadian Ice Service for the years 1981 to 2010. Separate regional charts are produced for Western Arctic, Eastern Arctic and Hudson Bay. These have been merged in this atlas to provide a pictorial representation of climatic sea ice conditions in Northern Canadian waters as a whole. The regions shown in white are outside the boundaries of the above regional charts and no information is provided in this atlas for those regions. Please note that the regions covered by the regional charts have changed slightly over the years and we have limited our analysis to the areas for which data was consistently available over the years. This explains the exclusion of southeast portion of James Bay and the somewhat odd shape of the Beaufort Sea region.

It should be noted that the regional charts were prepared in an operation setting to support shipping activities and are subject to some limitations. They are not available on a weekly basis throughout the year but typically only during the operational season i.e. from June to November. However, since 1980 winter charts have been produced on a monthly basis and in recent years bi-weekly. This reduced winter set has been used to produce winter statistical products.

The Regional Ice Charts are not always done on the same dates each year, so a seven-day period centered on the Historical Dates has been selected for this climatological atlas. The climate data represents information from charts within three days on either side of the historical date. The historical dates are weekly starting the first of January each year.

It should be noted that the original scale of the Regional Ice Chart was 1:4,000,000 and plotted on paper maps. Although the current analyses are prepared using GIS computer applications the amount of detail and accuracy is still comparable to the original maps.

Methodology

From 1980 to 1995 the Regional ice charts were drawn on paper. These charts were digitized in the late 1990's for use in climatological studies. Since 1995 computer technology was used to generate a digital version of the charts. The Regional Ice Chart collection now encompasses over 40 years of sea ice information spanning from 1968 to the present.

Areas of fast ice in this atlas now contain a stage of development. Since 2004, this information has been added at the time of the chart production; however, for charts before that time, a senior forecaster provided estimated stages of development for areas of fast ice based primarily on Freezing Degree Days (FDDs), amongst other meteorological parameters for the period.

The ice information data is analyzed with GIS software using well-established customized scripts to produce the various statistical outputs. Once the original vector data is assigned a historical date, it is then converted to a raster data format at 1 km resolution. Various algorithms perform operations to statistically summarize the individual ice charts and output the climatological products seen in the atlas.

In preparing an ice atlas, medians rather than averages are used. If one considers a single data point near the edge of the fast ice in late spring, the ice conditions can be ten tenths when fast ice is present or open water after the ice breaks up. Rarely will the four to six tenths range of ice concentrations occur, which is the inevitable result if one averages between no ice and ten tenths. A median on the other hand will be either zero or ten tenths depending on the relative frequency of break-up before or after the given date. This is more appropriate for an atlas describing ice conditions. With a thirty-year time period, an even number of values are used for each particular grid point and the higher of the two middle values is chosen as the median, a policy that has been adopted since the production of the Hudson Bay and Approaches atlas in the early 1980s.

A review of the initial climate products revealed several inconsistencies especially for extreme events and low concentrations of old ice; it was then required to go back to the regional charts to identify the cause of the problem and correct the inconsistency. The following is a list of the types of problems identified and the measures taken to fix the climate products:

- Missing charts from June to November had an impact on week to week consistency of extreme events; adjustments were made to ensure consistency. For the May 15 products, several weeks (charts falling between May 12th and May 25th) were combined to provide a full set of charts; this accurately depicts the ice situation because there is very little change in conditions during that time.

- October 1st is the "ice birthday." Almost half of the charts within three days of this date will bear a September timestamp. First-year ice on these charts was re-coded as second-year ice for compatibility in the charts. In some years, there could be small errors introduced because of this procedure.
- Procedures for chart preparation allowed the use of multiple eggs per polygon (up to around 1984-85), as long as predominant ice and concentrations category were the same. This introduced errors in old ice distribution during the digitization process and resulted in inconsistencies in the old ice climate products. Appropriate corrections to boundaries and attributes were made directly on the climate products based on a review of the regional charts to ensure consistency from week to week as much as possible. However some inconsistencies may remain, particularly for old ice concentrations less than 4/10. These remaining inconsistencies may be more important in areas of high mobility and dispersion like Baffin Bay, Davis Strait, Foxe Basin, Hudson strait and northern Hudson Bay where it is difficult to track the evolution of low concentrations of old ice embedded in fast moving and rugged first-year ice. For the same reasons even more severe inconsistencies were found for traces of old ice that can occur almost anywhere in northern Canadian waters and it was not considered in the climate products.
- In the preparation of the regional charts, shore-fast ice can be indicated simply as generic “fast ice” (shown by "blacking in" the area where it is present), or by indicating specific ice attributes to the area (attaching an egg). Blacking in an area is the traditional method for showing fast ice in small bays and inlets and in most cases would represent the first-year stage of development. However, it was also occasionally used on the Arctic regional charts when there were varying concentrations of old ice embedded in the fast ice. This can cause a problem when computing statistics involving old ice as well as the predominant ice type. To minimise adverse effects in the charts resulting from this representation of fast ice some areas were re-analyzed and corrected.
- The winter series of charts have a very large consolidated ice area. Up until the late 1990s, charts were prepared by hand and when the scale of the digitized charts is considered, even the width of a pencil or pen could be potentially misinterpreted. Month to month differences in the consolidated area thus appeared, but were corrected.

Definition on Sea Ice Climatic Charts

Statistics Described

The ice charts contained within this atlas are derived climatological products representing the "normal" of various ice parameters. Two key statistical terms have been used to derive and describe the charts: median and frequency. The "median" is a statistical value used to examine a dataset and is calculated by ordering the dataset by its values from smallest to largest and selecting the middle value of an odd-numbered dataset or the average of the two middle values in an even-numbered dataset. The median is employed with ice statistics due to the ordinal nature of the ice attributes. For example, 9+/10 ice concentration is greater than 9/10 concentration and first-year ice is greater (thicker) than grey-white ice.

The median is more appropriate than the average or mean when considering ice attributes. As an example, in the following dataset of 5 observations of ice concentration in tenths: (10, 10, 10, 0, 0). The average value would be (10 + 10 + 10 + 0 + 0)/5 = 6/10 which would not represent a "real" ice situation while the median value of 10/10 does.

The "frequency" is another statistical technique used to examine a dataset and is calculated by summing the number of observations of an occurrence or event (e.g. presence of sea ice) and dividing by the total number of observations and expressed as a percent of the total number of observations.

The following is a description of the climate products contained in this atlas. Some products were affected to various degrees by the intrinsic problems described in the methodology section and an indication of the level of confidence is provided. The regions shown in white on the products are outside the boundaries of the regional charts and insufficient information is available for those regions.

Median of Ice Concentration

The "Median of Ice Concentration" charts consider total concentration of ice throughout the course of a year. The charts do not represent any real ice season but rather a statistical composite of all available years.

The charts represent the statistical "normal" ice concentration for the appropriate date. There is a high level of confidence with this atlas series.

Dates of Freeze-up and Break-up

The "Dates of Freeze-up and Break-up" depict the extent of ice on a bi-weekly basis during the freeze-up and break-up seasons. They provide a pictorial representation of the evolution of ice during those periods.

These products are constructed using the Median of Ice Concentration charts and thus the confidence level is high.

Median of Ice Concentration When Ice Is Present

The "Median of Ice Concentration When Ice is Present" charts consider total concentration of ice throughout the course of a year. The charts are a new addition to the atlas and are meant to assist in interpreting the complementary "Median of Predominant Ice Type When Ice Is Present" charts. The most appropriate way to interpret the charts is to view the median of ice concentration when ice is present in conjunction with the frequency of presence of sea ice charts. For example, at a particular point, the frequency of presence of sea ice might be in the range of 34-50% and the median of ice concentration when ice is present might be 9/10 to 9+/10. Thus, at this location, there is a 34-50% chance of encountering sea ice, and when ice is present, it is "normally" 9/10 to 9+/10 concentration. Additional insights may be provided by examining the Predominant Ice Type When Ice Is Present charts.

The charts represent the statistical "normal" ice concentration when ice is present for the appropriate date. The level of confidence is generally high except in areas where only a few occurrences of ice are found for a chart date.

Median of Predominant Ice Type When Ice Is Present

The "Median of Predominant Ice Type When Ice Is Present" charts consider the predominant ice type (ice type of the greatest concentration) throughout the course of a year.

The charts involve more interpretation than any of the other ice charts. The most appropriate way to interpret the charts is to view the Median Of Predominant Ice Type in conjunction with the Frequency Of Presence Of Sea Ice chart. For example, at a particular point, the frequency of presence of sea ice might be in the range of 34-50% and the median of predominant ice type when ice is present might be first-year ice. Thus, at the point, there is a 34-50% chance of encountering sea ice, and when ice is present, it is "normally" first-year ice. Additional insights may be provided by examining the Ice Concentration When Ice Is Present charts.

The charts represent the statistical "normal" predominant ice type when ice is present for the appropriate date. The level of confidence is generally high except in areas where only a few occurrences of ice are found for a chart date.

Frequency of Presence of Sea Ice (%)

The "Frequency of Presence of Sea Ice (%)" charts provide the likelihood of total concentration of ice greater than or equal to 1/10 throughout the course of a year and are anticipated to give the reader an idea of the likelihood that ice will occur at a particular location for the appropriate date.

The charts can be interpreted as the probability of encountering sea ice for the appropriate date. The charts depict above normal extent (1 to 33%), near normal extent (34 to 66%) and below normal extent (67 to 99%). The 0% line represents the maximum extent of sea ice, beyond it no ice was reported in the dataset; the 100% line represents the minimum extent of sea ice, within it there has always been ice reported in the period. There is a high level of confidence throughout this atlas series.

Median of Old Ice Concentration

The "Median of Old Ice Concentration" charts consider the concentration of old ice throughout the course of a year. The charts do not represent any real ice season but rather a statistical composite of all available years.

The charts represent the statistical "normal" concentration of old ice for the appropriate date. The level of confidence is not as high as the median of total ice but efforts have been made to ensure a reliable output product.

Frequency of Presence of Old Ice: 1 to 10/10 (%)

The "Frequency of Presence of Old Ice: 1 to 10/10 (%)" charts provide the likelihood of old ice greater than or equal to 1/10 throughout the course of a year and are anticipated to give the reader an idea of the likelihood that old ice will occur at a particular location for the appropriate date.

The charts can be interpreted as the probability of encountering old ice in concentrations of 1/10 or more for the appropriate date. The charts depict above normal extent (1 to 33%), near normal extent (34 to 66%) and below normal extent (67 to 99%). The 0% line represents the maximum extent of old ice, beyond it no old ice was reported in the dataset; the 100% line represents the minimum extent of old ice, within it there has always been old ice in concentrations of 1/10 or more reported in the dataset.

The level of confidence is generally good but is lower in areas where old ice is seldom observed or in areas of high ice mobility such as Baffin Bay, Davis Strait, Foxe Basin, Hudson strait and Northern Hudson Bay.

Frequency of Presence of Old Ice: 4 to 10/10 (%)

The "Frequency of Presence of Old Ice: 4 to 10/10 (%)" charts consider the likelihood of old ice greater than or equal to 4/10 throughout the course of a year and are anticipated to give an idea of the likelihood that old ice greater than or equal to 4/10 will occur at a particular location for the appropriate date.

The charts can be interpreted as the probability of encountering old ice in concentrations greater than or equal to 4/10 for the appropriate date. The charts depict above normal extent (1 to 33%), near normal extent (34 to 66%) and below normal extent (67 to 99%). The 0% line represents the maximum extent of

4/10 or greater old ice, beyond it no 4/10 or greater old ice was reported in the dataset; the 100% line represents the minimum extent of 4/10 or greater old ice, within it there has always been old ice in concentrations of 4/10 or greater reported in the dataset.

The level of confidence is generally good (and higher than the Frequency of Old Ice: 1 to 10/10 product) but is lower in areas where old ice is seldom observed or in areas of high ice mobility such as Baffin Bay, Davis Strait, Foxe Basin, Hudson strait and Northern Hudson Bay.

The Ice Regime in Northern Canadian Waters

In northern Canadian waters, ice is normally present in many areas throughout much of the year. In some sectors, much of the ice does not melt completely each year. Thus, for example, in the Arctic Ocean the differences between a typical chart showing the ice cover in summer and one in winter are the ice concentration and presence of openings in the pack and around the coastline. In the Canadian Arctic Archipelago, the period when air temperatures reach above freezing is very brief, so freeze-up can begin as early as August.

Ice in the sea is at the interface between the ocean and the atmosphere, and the ice may impact or attach to the land. The ice can have an enormous impact on human activities - either enabling them, or hindering or preventing them. Ice can also reduces the direct atmosphere-ocean interactions - so the ice makes a difference to the atmosphere as well as the other way around. The understanding of ice and its interactions with the atmosphere and the ocean is a fascinating and complex study.

Factors Affecting Ice in the Sea

Atmospheric Factors

Sea ice forms largely as a result of removal of thermal energy from the sea and is lost principally by addition of thermal energy from solar radiation. Variations in these energy transfer processes are largely controlled by atmospheric events.

The most significant heat removal process is the evaporation of water into the atmosphere,. Roughly, the rate of heat energy removal by the atmosphere is proportional to the difference in the temperatures of the water and the air over it, and also to the rate at which the water vapour can be removed from the interface, basically related to wind and atmospheric stability. In practice, the air temperature and knowledge of its changes can be used to estimate a date for beginning of ice formation. If there is a fairly complete ice cover, further thickening of the ice continues from radiation losses from the upper ice surface. Snow can accumulate on top of the ice and can provide insulation, reducing the loss of heat and so variations in the snow cover can have a significant effect on the growth in the thickness of the ice. In the absence of a snow cover, air temperature alone can be used to give a reasonable estimate of the thickening of the ice throughout the winter.

The ice is open to the action of winds and water currents as long as it isn't "stuck" to the land, or "shore-fast." Complex calculations can be done to estimate the dynamic interactions of the forces of air and water, as well as internal forces within the ice itself. For all practical purposes, free-floating ice will respond very quickly to any change in the water motion around it. On the other hand, the response by ice to the force of the wind takes time because of the great density difference between air and ice. The component of ice motion due to the wind is similar to the wind-driven current in situ – in fact open drift ice and the roughness of the ice surface can contribute to the development of a wind-driven current.

After ice forms along a coastline, cold seaward-moving winds often drift the ice farther away from the coast. The ice will either melt or continue to thicken, depending on whether heat energy is available in the water.

For most of the area depicted in this atlas, the ice coverage grows in the fall and early winter, reaching a limit where the thermal energy available in the oceanic water column does not permit further expansion. The ice conditions then remain much the same for several months, although there would be changes in the details.

In the spring, the main heat transfer process operating is radiation. The increasing height of the sun in the sky allows solar radiation to add heat energy to the water just as the intensity of cold air incursions and evaporative heat loss diminishes. Melting of the snow begins, and increasing incursions of warmer air allow a net positive balance in thermal energy at the surface. Puddles from the melting snow develop on the surface of the ice. The puddles are much more effective at capturing incoming short-wave radiation than ice and snow, hastening the melt process. Similarly, where there is open water, such as a polynya or a shore or flaw lead, there is also greatly enhanced absorption of incoming radiation. This warmed water moves with the tides and currents and the heat energy also transfers to the bottom surface of adjacent ice. Thus, polynyas act as centres around which the break-up process spreads. Once the ice has warmed up to the melting point, it too can begin to melt. The temperature of the ice and the water beneath it essentially remains at the melting point until the ice is gone. Also, as the ice warms up, it begins to shrink, and internal stresses develop within the ice. This process is amplified wherever there are discontinuities in the ice, and cracks and openings are created which can be acted on by waves, currents, winds and tides to initiate further break-up of the ice sheet.

Oceanographic factors

As noted above under atmospheric factors, ice can begin to form once sufficient thermal energy is removed from the water. How much cooling is necessary before ice can form depends on the characteristics of the water column. As long as the water being cooled at the surface is denser than the water below it, there will be upward mixing of warmer water, and ice does not form, barring exceptional circumstances.

Similarly, the ice melts if the wind pushes it into warmer waters. The ice cools the surface water then convective overturning in the water column brings warmer water back in contact with the ice, and melt continues. If ice incursions into the warmer water continue, and the water is shallow enough, the whole water column becomes cooled and a new edge will become established.

Currents in the ocean are very important in understanding where ice may form, and then how it moves. Because of the small (about 10%) difference in density between ice and water, ice will respond very quickly to a change in the current. Water movements near shore are strongly affected by tidal motions and surface water runoff variations, as well as local winds.

The principal driving force for the circulation of water in the area covered by this atlas is the North Atlantic current system. Density and wind driven, the Gulf Stream and its extension, the North Atlantic Drift, moves vast quantities of water between Iceland and Scandinavia into the Arctic Basin. After circulating in the Arctic Ocean, most of this excess water exits the Arctic Ocean via the East Greenland current, aptly named, which also moves heavy Arctic pack ice southward between Greenland and Iceland. Much of this ice melts but some of it continues westward past Cape Farewell and then northward again in the north-flowing West Greenland Current before melting completely. Some of this current turns westward in Davis Strait and some of it continues northward, into Baffin Bay, making a large counterclockwise gyre moving at about 10 to 20 km per day. In northwestern Baffin Bay, this gyre is joined by almost all of the remaining volume of outflow from the Arctic Basin, which has filtered through amongst the islands of the Canadian Arctic Archipelago or through Nares Strait. The augmented southward flowing portion of the Baffin Bay gyre reaches Davis Strait, making as much as 20 to 30 km per day and accepts some West Greenland waters as described above before becoming the Labrador Current. The main Labrador Current has two branches, the current from Baffin Island which is the most fresh and close to shore at about 10 km per day, and the outer portion from West Greenland. At about 100 km from the coast its rate is about 20 to 30 km per day.

From northern Baffin Bay to southern Labrador Sea, the long term average ice motion may be generally described as following the shoreline at about 10 to 15 km/day. Variations in wind speed may increase this motion or stop it entirely for short periods. If an average speed of 15 km/day is maintained, multiyear ice off Devon Island at the beginning of October would arrive near the mouth of Hamilton Inlet about mid-February. This agrees with dates of aerial ice reconnaissance reporting older ice in the area.

Offshore to the northwest of the Canadian Arctic Archipelago, there is a slow, broad southward-setting current, which gradually turns westward across the northern portions of the Beaufort Sea. However within and adjacent to the Archipelago, it could be said that each major island or island group has a clockwise current around it. Because of the net transport southward through the Archipelago, and for dynamic reasons, the southward and eastward- portions of these currents are both broader and stronger than the other portions.

In the shallow waters of Hudson Bay, there is a counterclockwise gyre, driven partly by winds, partly by runoff, which flows out along the south side of Hudson Strait and joins the inner section of the Labrador Current.

Along most coastlines, the ice can become attached to the land (shore fast) and can become extensive. However, the seaward extent of fast ice will be limited if tidal action is strong, and fast ice is generally within the shallower areas. Unless a body of water is very wide, or water motions strong, ice can form a continuous cover from shore to shore, such as amongst the islands of the Canadian Arctic Archipelago. In the broader or more dynamically active channels, the location of the edge of the shore fast ice can differ markedly from month to month and vary from year to year. In most of the channels the shore to shore fast ice breaks in the summer but the northern section of Nansen Sound remains fast for most years.

Land Geography

The topography of the land has an impact on the ice since it affects the behaviour of surface winds, and in some cases even causes winds. During the colder season, over higher terrain or glaciers, very strong drainage winds can develop, affecting near shore ice. For certain atmospheric stability conditions, funnelling can cause severe wind events, and in some cases even break up a consolidated ice area.

Bathymetry

The continental shelf is the most significant single feature of the ocean bottom that affects Canadian ice regimes. Off eastern Canada the shelf extends out to about 300 km off the coast abeam the Strait of Belle Isle and gradually narrows northward to 130 km wide at approximately 56 N, and then expands to about 200 km off Cape Chidley and Cape Dyer. A submerged ridge extends from the coast of Baffin Island to Greenland at about latitude 66 N. Seaward of this line, the deep waters provide a reservoir of heat energy which can readily reach the surface and melt any ice incursions. Such a large heat energy reservoir is not available in any of the other waters depicted in this atlas.

However, waters are fairly shallow in eastern Foxe Basin and in much of the western waterways. The continental shelf in the southern Beaufort Sea is 100 km wide, except near Barter Island and Herschel Island where the shelf break is less than 50 km from shore. Very shallow waters extend as much as 20 km offshore and sea ice is often grounded.

In the Canadian Arctic Archipelago, depths are generally in excess of 100 m. However, the waters around King William Island are well known for being shallow.

General Description of the Ice Regime

Break-up

The following is a general description of the ice breakup season for a typical year. During the winter, frigid air masses develop over continental areas, then weather systems move the cold air over the adjacent seas. In spring, as the sun’s elevation in the sky increases, and the land warms up, the cold winter blasts diminish rapidly in intensity. In southern portions of the area of this atlas, ice formation stops, but on average, winds continue to drift the existing ice towards warmer waters where convection in the water column can always bring a supply of warmer water to melt the ice. So the first signs of break-up appear in southern Labrador waters and in James Bay near the end of April. Break-up gradually spread northward during May and June. At the same time in areas of consolidated ice, puddling of the melted snow cover begins while the thin ice in polynyas disappears. In June, decay has begun throughout the atlas area. Because of absorption of solar heat by polynyas, particularly the North Water, and also the northwestern portions of Hudson Bay and Foxe Basin, decay and break-up also spread southward and eastward from these areas in June and July. At the end of the typical melt season, usually early September, high concentrations of ice are present in Nares Strait, Norwegian Bay, Queens Channel, Viscount Melville Sound, M’Clintock Channel and Victoria Strait. The Arctic Ocean pack lies 50 to 100 km off the coast in the Beaufort. Also ice usually remains in Committee Bay and southern Gulf of Boothia.

However, it is worth emphasising that in many years, not all the ice will melt in other areas, notably Foxe Basin and northwestern Davis Strait. Only James Bay, the southern two thirds of Hudson Bay, and the Labrador Sea always clear completely of sea ice.

Freeze-up

In August, summer comes swiftly to an end in the areas north of Parry Channel. Around the lingering floes from previous winters, new ice is able to form almost as soon as air temperatures drop below the freezing point. This new ice thickens rapidly so by early October, first-year ice from the new ice season is mixed with first-year ice remaining from the previous winter. On the 1st of October, first-year ice remaining from the previous winter is reclassified as second-year ice. It will be nearly salt free, and much harder than the recently formed ice. In December, the first-year ice normally becomes a consolidated sheet with embedded multi year and second year ice. This old ice is often predominant in the Canadian Arctic Archipelago except around Baffin Island. The rest of the Atlas area becomes encumbered with ice moving with weather systems and currents, except for offshore portions of the Labrador Sea.

Fast ice becomes well established along the Baffin Island, Greenland and Labrador coasts. The width of this fast ice may reach 50 km at times in some areas. Offshore, the pack remains mobile throughout the winter and floes ranging from small to vast in size are repeatedly frozen together and broken apart.

Arctic sea ice carried by the east Greenland current rounds Cape Farewell (southern tip of Greenland) in January, reaches its maximum extent near 63N in May, but disappears from waters west of Cape Farewell in August. This sea ice is normally located within 100 km of the Greenland coast.

Variations

Wide variations in ice conditions can occur from one year to the next for the same date, and in some areas, from week to week. Furthermore, the entire nature of the ice cover may differ from year to year. For example, Amundsen Gulf ice remains light and mobile in some years: in others it consolidates, sometimes with embedded old ice. A warm summer in the High Arctic results in greater old ice break-up in the Sverdrup Basin, giving heavier ice the following spring and summer in Parry Channel. Parry Channel consistently develops a consolidated ice cover in western Barrow Strait, but the eastern edge may lie at Bylot Island or at Somerset Island, or most anywhere in between, and break up and re-form more than once during the winter season. Similar variations occur in the timing of consolidation in Nares Strait, but the extent of consolidation there is remarkably consistent. The width of the pack off Labrador and in Davis Strait is sensitive to extended periods of on-shore or off-shore winds.

The Total Accumulated Coverage (TAC) is defined as the geographical area multiplied by the ice concentration and is an index used to compare ice severity. For this atlas we compare the Total Accumulated Coverage (or ice conditions) for each year of the atlas for the period June 25^{th} to October 15^{th}. 2010 was the year with the minimal ice coverage for the Northern Canadian waters as a whole while 1983 was the year with the maximal ice coverage. The graphic depicting the variations of the Total Accumulated Coverage over the 30 year period is included in this atlas.

Ice Thickness

During the course of a single winter in northern portions of the Canadian Arctic Archipelago, undisturbed bare ice can grow to a maximum of about 240 cm. In the central and western Arctic, maximum thickness is about 200 cm. Farther south, in James Bay and along the Labrador coast, the thickness of locally developed ice can reach about 120 cm.

Multi-year ice found in the Archipelago reaches a thickness of 300 to 450 cm. However Ice Shelf fragments can be as thick as 2000 cm. The ice shelves consist of fresh-water and sea-water ice, formed over many years along the northwestern shore of Ellesmere Island. Some pieces of the shelf there have broken off in recent years, and these very distinctive ice features are occasionally found far from their point of origin. They are much like tabular icebergs, except not formed from snow.

Old Ice

The presence of old floes within an area of predominantly first-year ice has a direct impact on the penetrability of an ice area even for the most powerful ships. For this reason, charts examining the concentration and frequency of occurrence of old floes are included in this atlas.

In September, there may be some old ice present from earlier years, some first-year ice from the previous winter, which has failed to melt, and also recently formed ice, which is at the first-year stage of development by the end of the month. Although second and multi-year ice are difficult to identify separately at any time, it is useful to separate these three ice types which have different hardness. For this reason any first-year ice which survives to October 1^{st} is promoted to second-year ice on that date. Thus, there is an increase in the amount of old ice in the October charts due to this promotion.

In May, the median concentration of old ice indicates an elongated area of 1 to 3 tenths of old ice in south-western Baffin Bay extending southward to western Davis Strait. This pattern doesn’t change much through June to mid-July. This old ice melts after mid-July and the area is for the most part free of old ice in August through the fall.

At first, one might think that increasing old ice amounts during the melt season is not correct, but what occurs here is a melting of the thinner forms of ice, allowing the old floes to accumulate in an area rather than being dispersed through the pack.

Two series of charts show the percent frequency of presence of old ice: in the 4 to 10 tenths range; and in the 1 to 10 tenths range. Note that traces are not considered in these charts. There is always a small chance of 1 tenth or more of old ice in western Davis Strait and almost all of Baffin Bay at all times of year

In Foxe Basin, the median amount of old ice never rises above zero except in the Igloolik-Fury and Hecla Strait area, but it is evident from our climate data that old floes do infest many sectors of the Basin. The increase in the frequency of old ice in October (but not its amount) identifies areas where clearing did not occur by the end of September.

Both the amounts and frequency of occurrence of old ice are notable in southern Gulf of Boothia and Committee Bay, as well as in M'Clintock Channel, Larsen Sound and Victoria Strait.

The median old ice concentration in western Barrow Strait lies in the 1 to 3 tenths range, but bumps up to the 4 to 6 tenths range with the October 1st ice promotion. The charts depict the heavier concentrations generally present along the south side of Parry Channel in the summer months.

In Sverdrup Basin, old ice is usually predominant. However in warm summers, break-up can leave large areas where first year ice will predominate in the following year. In Norwegian Bay, old ice concentrations and frequencies are lower in eastern sections, as low as the 1 to 3 tenths range. In Eureka sound, small amounts of old ice usually persist through the melt season.

In the Beaufort Sea the Arctic Pack of the Arctic Ocean is a dominating feature. As might be expected, both the amount and frequency of occurrence of old ice increases with the distance from the coast. Except within the shallows of the Mackenzie Delta there is always a small percentage frequency of old ice. In fact, as the first-year pack near the coast melts out in the summer, incursions of old ice increase the percentages near the coast.

Regional Details

Some of the regions below do not have clearly defined boundaries. For purposes of this document, the Labrador coast includes the waters between the Strait of Belle Isle and the approaches to Frobisher Bay. To its north, Davis Strait has a northern boundary to the north of Home Bay, and Baffin Bay lies to the north of Davis Strait. Other areas referred to are fairly clear geographical entities.

Labrador Coast

As spring temperatures rise, melting normally begins in southern Labrador waters around the end of April, reaching the Resolution Island area about mid-June. The pack slowly narrows and loosens, and the southern ice edge retreats from the Strait of Belle Isle to north of the approaches to Hamilton Inlet in June and the approaches to Hudson Strait and Frobisher Bay in July, although patches of ice may linger through August.

A small percentage of old ice is usually present within the Labrador pack. After all of the level first-year ice has melted at the end of the ice season, there is nothing but ridge remnants and old ice, and the latter may in fact be predominant. The offshore ice drifting in from Davis Strait may be over 150 cm thick. Many storms affect the area, and ice ridges up to 5 metres high can easily develop under pressure caused by winds and currents. As a rule of thumb, ice keels are in the order of three times the vertical extent of associated ice ridges. Westerly winds are frequent so a flaw lead develops, while along the outer edge the ice organises into strips and patches. In periods of persistent east to northeast winds, the ice compacts near the coast and ice deformation processes can be very intense. Because of incoming swells and wave action the ice breaks up into small floes near the ice edge.

In December, first-year ice begins to appear off northern Labrador and new ice off southern Labrador. For the rest of the winter the pack is mostly first-year ice and an equilibrium edge establishes some 150 km off the Labrador Coast. Ice condition comparisons between years can be largely related to the mean wind-flow experienced during the winter and spring months. Whenever low pressure weather systems persistently track across the Newfoundland area, easterly winds along the Labrador coast can compress all the ice into a 100 km wide belt against the coast. However when the low pressure systems track north of the area, westerly winds spread the ice up to 500 km seaward.

Freeze-up on the Labrador coast has started as early as the second half of October and as late as the second week of December. The Labrador coast has completely cleared of sea ice as early as the end of June but can persist until August.

Hudson Bay

Ice melt starts in May, as an open water area develops along the northwestern shore, and a narrow coastal lead develops around the rest of the Bay. In June and July, open water leads expand around the shoreline so that at the end of July, only large patches remain in southern portions of the Bay. In August the last vestiges disappear. Intrusions of ice from Foxe Basin may occur in the northeastern part of the bay in some years.

In late October, the ice begins to form along the northwestern shores of the Bay. Some years there may also be a simultaneous development in the cold waters near Foxe Channel. In November, the ice thickens as prevailing winds move it east and southeast. In December the Bay becomes covered with thickening first-year ice. During the winter, a 10 to 15 km wide fringe of shore-fast ice develops along most of the coastline and in many years a distinctive consolidated ice area develops between the Belcher islands and the Quebec coast. Meanwhile, the pack responds to winds and the slow counterclockwise current gyre in the bay.

In Hudson Bay, freeze-up has commenced as early as the first week of October and as late as the first week of November, while complete melting has occurred as early as mid- July and as late as the first week of September, except for incursions from Foxe Basin.

James Bay

Ice melt begins in late April. By mid-July much of the Bay is open water. Complete clearing normally occurs in early August but the northwest portion may receive occasional intrusions of ice from Hudson Bay until late August. Freeze-up is usually quick beginning after mid November. However, freeze-up has begun as early as the first week of November and as late as early December. Complete clearing has occurred as early as late June and as late as late August.

James Bay ice is noted for its discoloration, caused by freezing of shallow muddy water, or by run-off concentrating sediments on the surface of the ice. A sizable open water area often develops south of Akimiski Island. Old ice does not reach James Bay.

Foxe Basin

Ice normally forms in northern and western portions near mid-October, thickening rapidly and spreading southward and seaward to cover the Basin and Foxe Channel early in November. The ice becomes predominantly first-year ice by December.

Melting starts by June. The polynya near Hall Beach slowly enlarges. Open water leads expand around the shoreline in July. In the central Basin, the ice very gradually decreases in amount but more rapid disintegration occurs in August. Patches of ice persist during September.

In Foxe Basin shallow water combines with large tidal ranges and strong winds to keep a large amount of bottom sediments in suspension. Thus the ice is very rough, much of it in small floes and muddy in appearance. In northern and southwestern sectors there are large areas of shore-fast ice. In some years, all the ice will melt throughout Foxe Basin and Foxe Channel, while in other years with a cold summer, significant concentrations of ice will remain as freeze-up begins again. Thus second year ice may affect Foxe Basin and adjacent waters through the following winter and spring.

In Foxe Basin, freeze-up has started as early as late September and as late as the third week of October. Complete clearing does not occur every year but has occurred as early as the first week of September.

Hudson Strait and Ungava Bay

Freeze-up usually begins near the shore in western Hudson strait in November, then ice formation progresses to cover the entire area by early December, and by mid December the first-year stage predominates. Except for quite extensive shore-fast ice among the islands from Big Island to Cape Dorset, the ice is in constant motion because of strong currents and frequent gale force winds. Ridging, rafting and hummocking are continually taking place, and ice congestion often affects Ungava Bay and the south side of Hudson Strait. Conversely, a shore or flaw lead is frequently present on the north side of the Strait. At times small concentrations of second year ice drift into the area from Foxe Basin. Multi Year ice also enters eastern portions from Davis Strait.

Open water leads develop in May, slowly expand in June. Clearing becomes extensive during July but Ungava Bay often remains encumbered with heavy deformed ice, with some embedded old ice in July. Complete clearing has taken place as early as mid-July and as late as the end of August. However it is worth noting that incursions of second year ice from Foxe Channel occur in some years.

In Hudson Strait, freeze-up has started as early as mid October and as late as the first week of December, while complete clearing has occurred as early as late July and as late as early September. Freeze-up in Ungava Bay has begun as early as late October and has been delayed until the second week of December.

Baffin Bay and Davis Strait

In late May and June, any thin ice in the North Water polynya in northern Baffin Bay disintegrates, and then clearing extends southward across the approach to Lancaster Sound. The pack deteriorates more quickly around the eastern shores than it does in the centre of the bay. Thus at the beginning of August ice remains near the coast from Cape Dyer to Clyde River and in central parts of the Bay northward to near latitude 74ºN. The pack is finally reduced to offshore patches between Cape Dyer and Home Bay late in August. Clearing occurs on the average by late August.

The north-flowing current along the Greenland coast is relatively warm, and the south-flowing current along the east Baffin Island is relatively cold. Thus ice formation along the west side of the Bay begins earlier than on the Greenland side. In September, new ice begins to form in the northwestern reaches of Baffin Bay. By the end of the month a fringe forms all along the Baffin Island coast. Ice formation accelerates through October and November, such that first-year ice becomes predominant north of Cape Dyer near mid-November. On average, the southern extent of sea ice achieves equilibrium near a line from the Greenland Coast near latitude 68N generally southwestward to a point some 200 km off Resolution Island.

First-year ice predominates in Baffin Bay and Davis Strait throughout the winter. Because an area of low pressure is often centered in Baffin Bay, winds may develop a flaw lead along the Baffin Island coast. A percentage of multi-year ice originating mainly from Smith Sound and sometimes Lancaster Sound infests the western side. This ice is mostly in the range of 240 to 320 cm thick. Ridging, rafting and hummocking are significant, and icebergs abound.

An open water route across northern Baffin Bay has occurred as early as the third week of June and has been as late as the last week of August. Frobisher Bay has cleared of sea ice as early as late June and as late as early October. Baffin Bay and Davis Strait have cleared of all sea ice as early as mid-August, in other years some ice has remained until freeze-up began. In the latter situation the floes remaining are usually well dispersed throughout the area by autumn storms. Freeze-up in northwestern Baffin Bay has developed as early as the last week of August and been delayed until the middle of October. In Frobisher Bay, new ice formation has begun as early as mid October, and as late as the second week of November.

Arctic Archipelago

As temperatures move above freezing in the high Arctic, polynyas and open areas start to expand slowly. Then during June, the mobile ice in Lancaster Sound clears from the west followed by break-up of its consolidated ice. On the consolidated ice in the Archipelago, puddling begins, becoming extensive in early July. Fracturing in much of the Archipelago usually occurs in July, but often waits until August in Barrow Strait, Norwegian Bay, Viscount Melville Sound, Peel Sound, Larsen Sound and M’Clintock Channel.

In Dolphin and Union Strait, Coronation Gulf and Dease Strait clearing usually comes before the end of July. Complete clearing in Admiralty Inlet and in Pond Inlet usually occurs in early August and in Queen Maud Gulf and south and east of King William Island during the second week of August. Wellington Channel and Jones Sound normally clear by late August, but incursions from the north may occur. Peel Sound, Prince Regent Inlet and the Gulf of Boothia will often clear in early September. However, the southern end of the Gulf of Boothia as well as Committee Bay usually remains encumbered with old ice throughout the summer. In Sverdrup Basin, the area of fracturing is quite variable, and ice is usually present as freeze-up begins in the fall.

In Parry Channel, and in central portions of the Archipelago, new ice begins to form in September, and thickens rapidly to first-year ice in October, and then most of the area consolidates. However, in Lancaster Sound, freeze-up events may be delayed by a month because of strong winds and tidal activity. New ice begins to form around King William Island during the first week of October, consolidating in early November. Freeze-up spreads to Coronation Gulf, and consolidation is usually complete in mid November.

In central portions of Viscount Melville Sound, and M’Clintock Channel the ice may remain in restricted motion during December. Small tidal openings are common in Penny Strait and Bellot Strait while a significant polynya exists in Hell Gate all winter. In eastern Parry Channel, the rate of consolidation varies considerably from year to year. Some years, consolidation reaches almost to the eastern entrance to Lancaster Sound, while in other years, consolidation only reaches Barrow Strait, but the median consolidation edge is at Prince Leopold Island.

East and south of a line from King William Island to Bathurst Island to southern Ellesmere Island, first-year ice predominates, with a small percentage of multi-year ice floes here and there. Committee Bay is an exception, where much of the ice is of the multi-year variety. West and north of this line, the predominant ice type is multi-year and the concentration of first-year ice depends upon the extent of break-up during the previous melting season.

The area of Larsen Sound and surrounding waters, and also the Committee Bay area noted above acts as a trap for old ice that periodically invades from more northern areas, because there is no effective exit for the ice. Incoming heat energy during the summer is sufficient to reduce the thickness of the old floes by more than the normal winter growth of this ice. The cycle may take several years before melt of an old floe is complete, but a "new" supply of old ice invades the area every few years.

Ice conditions can vary greatly from one year to the next. During colder winters, Lancaster Sound and Prince Regent Inlet can develop a consolidated ice cover and Lancaster Sound may still have loose ice as freeze-up begins. During easy years, Lancaster Sound can become bergy water by the end of May and remain open until new ice forms in October. During colder summers, many of the channels remain consolidated, or retain close pack ice leading to early freeze-up. On the other hand, during a warmer summer, most channels break up, with extensive clearing ensuing. This may allow old ice broken from the ice cover in the Queen Elizabeth Islands to drift south in the fall into Parry Channel, contributing to difficult ice conditions there the following year.

Beaufort Sea

Old or multi-year ice up to 450 cm thick - the Arctic Pack - continuously circulates with currents and winds in the Arctic Ocean, and it is present year round. Its degree of penetration into the Beaufort Sea at any given time is dependent on the wind regime of the year. On average, the boundary of the Arctic Pack lies from near Cape Prince Alfred southwestward to some 200 km north of Herschel Island and then westward some 200 km off the Alaska North Coast. Between the Arctic Pack and the coastal shore-fast ice, mobile first year ice is predominant through the winter.

The edge of consolidation in Amundsen Gulf can be quite different from year to year, but commonly it lies near Cape Baring or Cape Lambton, or less frequently at Cape Kellett. In spring, northwest winds die off, and east and southeast winds become predominant, so that a polynya develops there. In June, melt begins in the Mackenzie Delta and an open water area also develops quickly. Typically, Amundsen Gulf fractures in late June and the ice drifts out and decays. The fast ice along the Tuktoyaktuk Peninsula fractures in late June or early July, and by the end July an open water route usually develops from Mackenzie Bay to Cape Bathurst. Amundsen Gulf usually clears before August.

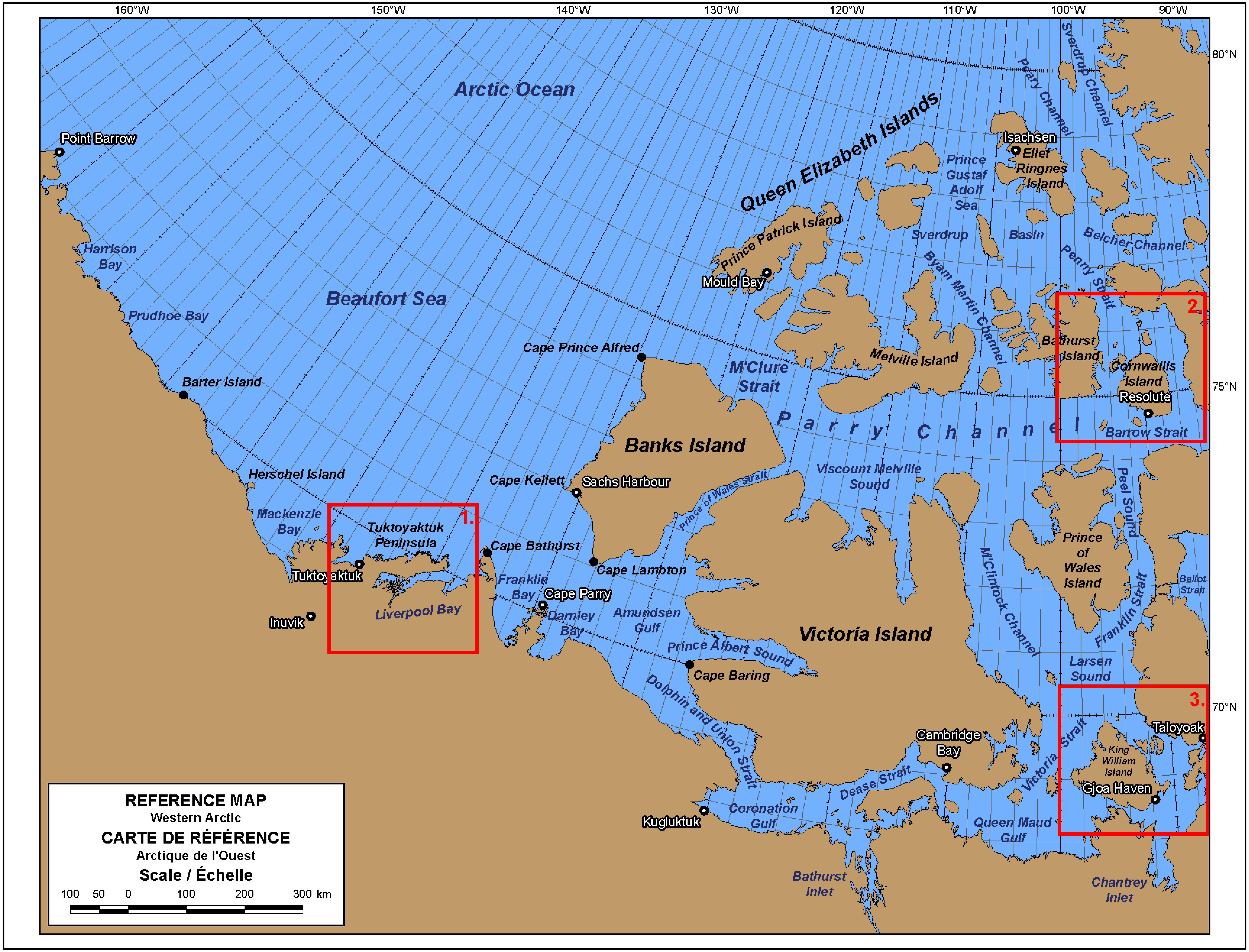
West of the Mackenzie Delta to Point Barrow, a narrow shore or flaw lead develops in July. Open drift ice conditions do not develop along the coast until the first week of August and an open water route not until the first week of September.

Freeze-up in the Beaufort depends to a very great extent upon the location of the southern limit of the Arctic Pack. New ice formation starts among the multi-year floes in late September and spreads southward while it also spreads seaward from the coast. By late October much of the ice is at the first-year stage right out to the Arctic Pack. Shore-fast ice is extensive and grows seaward to the vicinity of the 20 metre water depth. Onshore winds during the winter months hold the mobile pack ice tight to shore-fast ice.

During a cold summer, the shore-fast ice along the Tuktoyaktuk peninsula may not completely break until mid July. These cold summers occur when northwesterly winds keep the Arctic Pack close to shore. Open water along the Alaskan coast can develop as early as the third week of July.

Supporting Maps and Graphs

Environment Canada Environnement Canada



Canada

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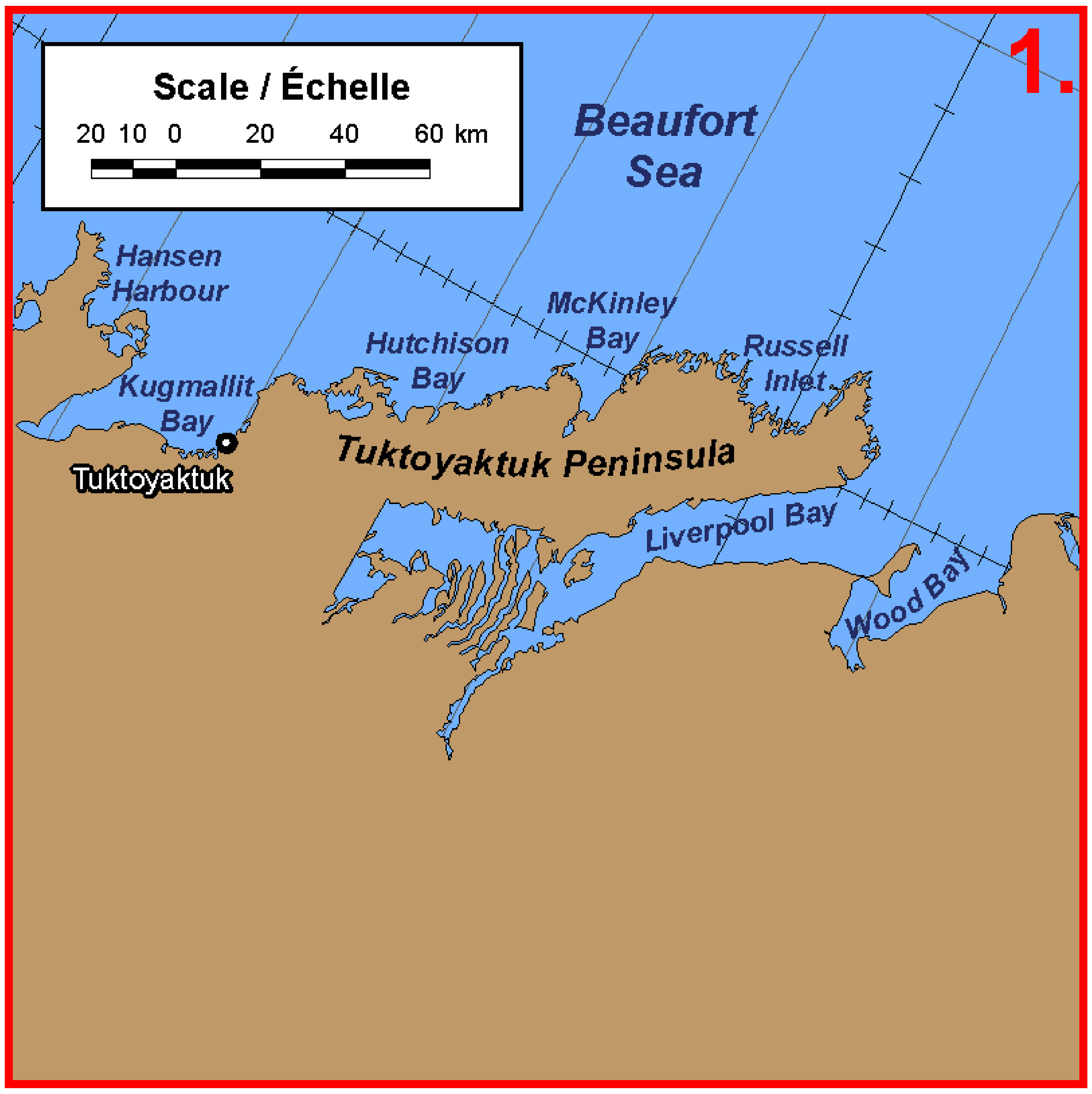
Map Insets 1
CARTE DE RÉFÉRENCE
Cartes en médaillon 1



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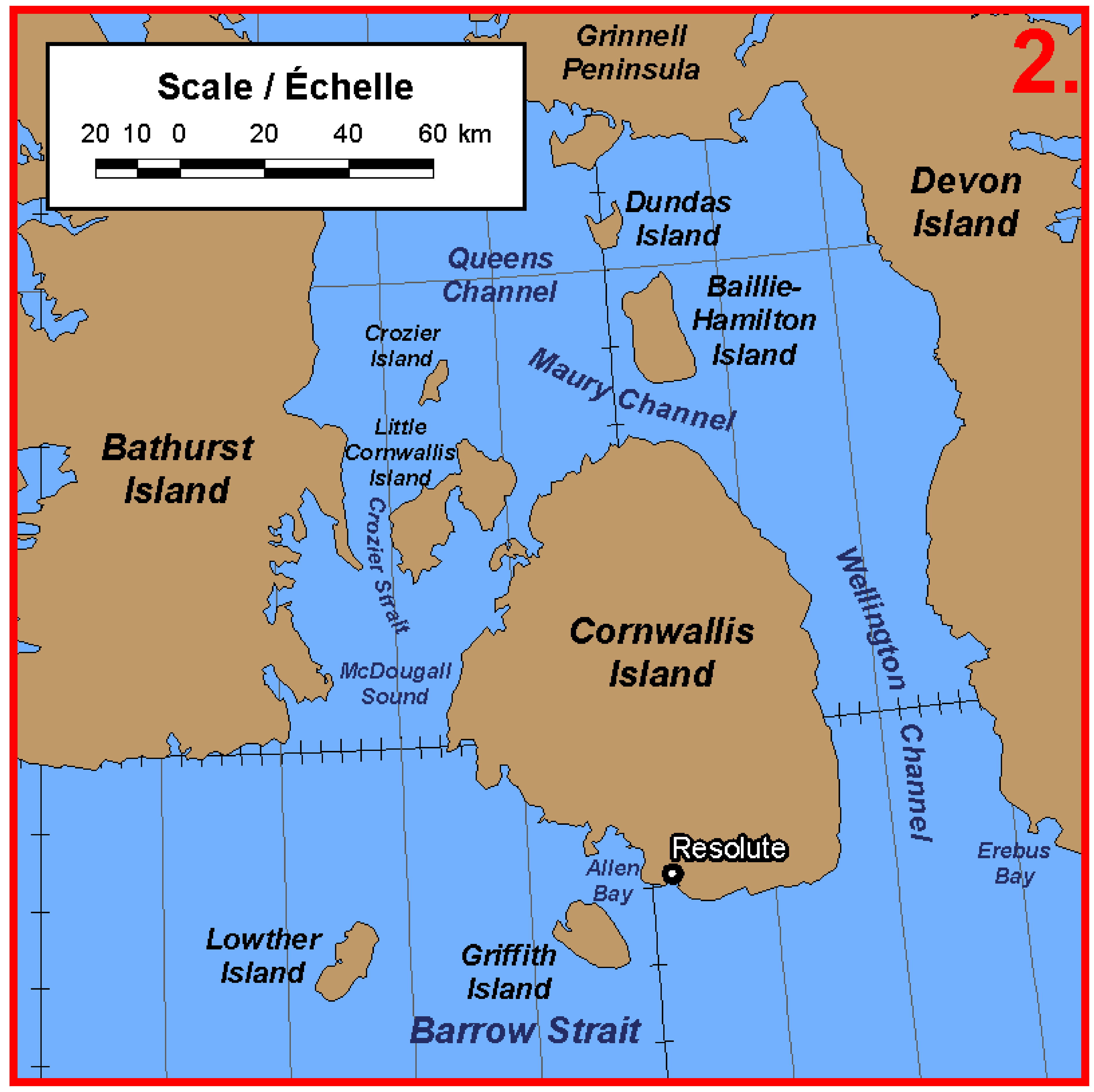

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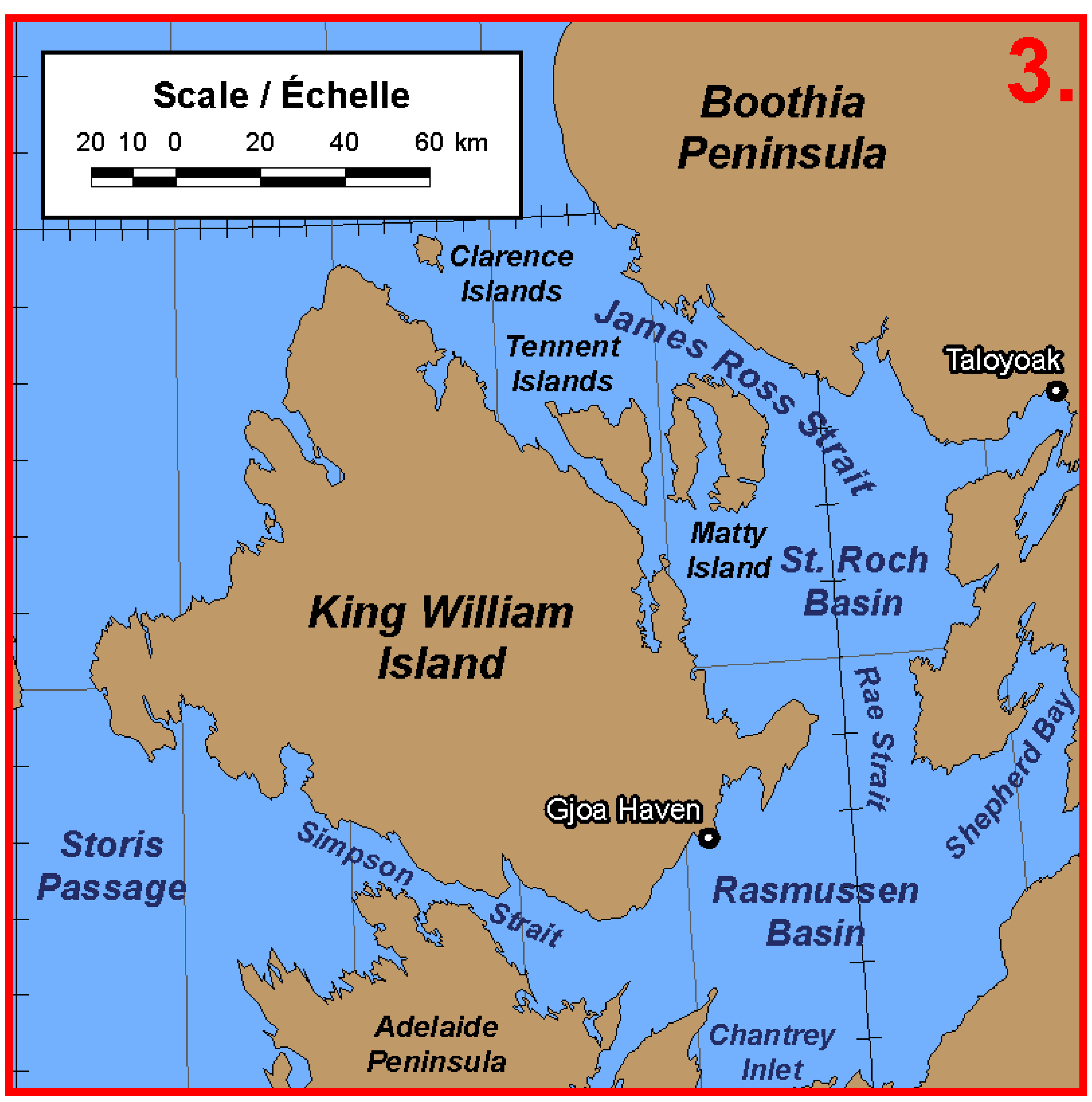
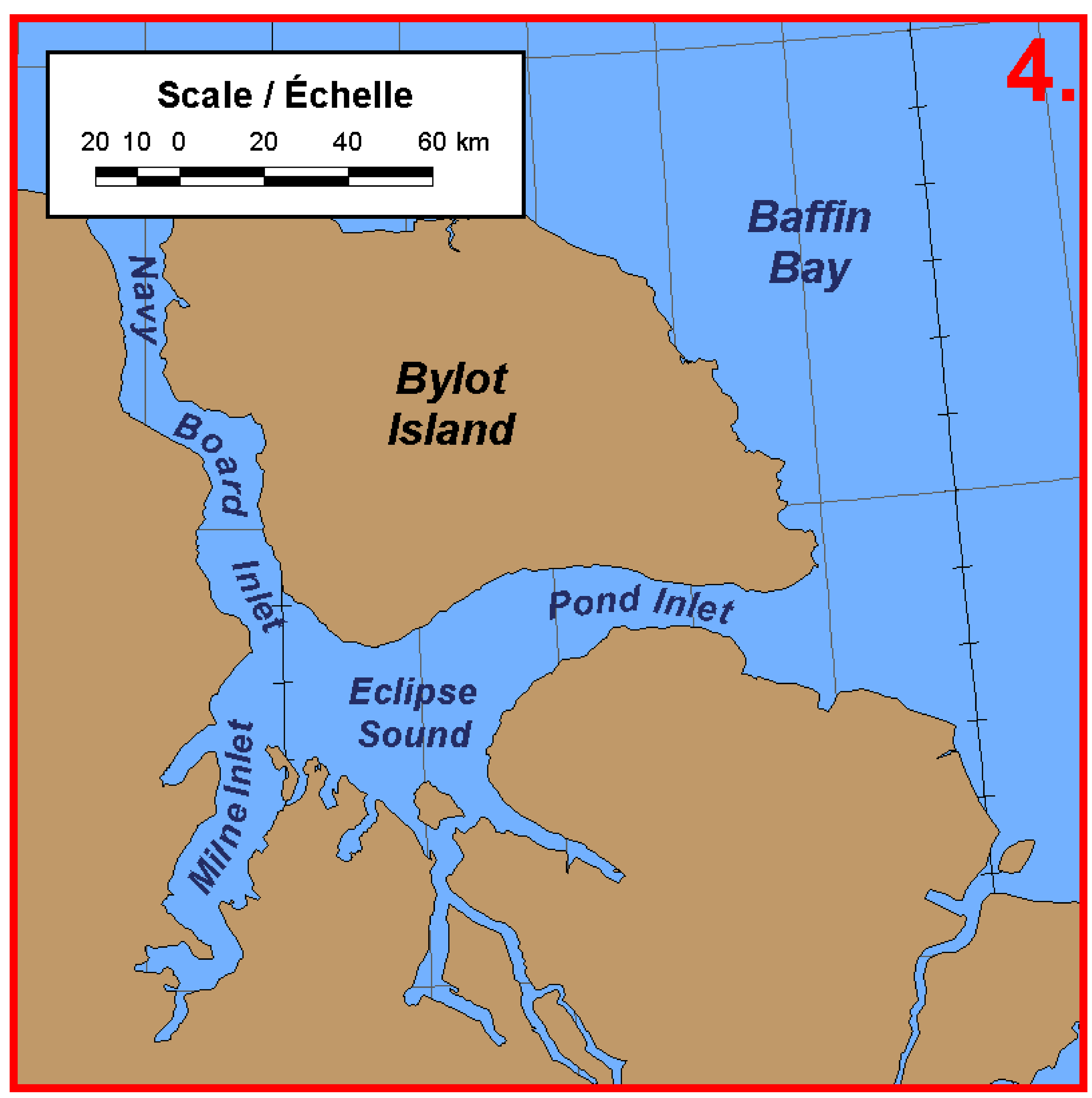


3. Taloyoak / Taloyoak



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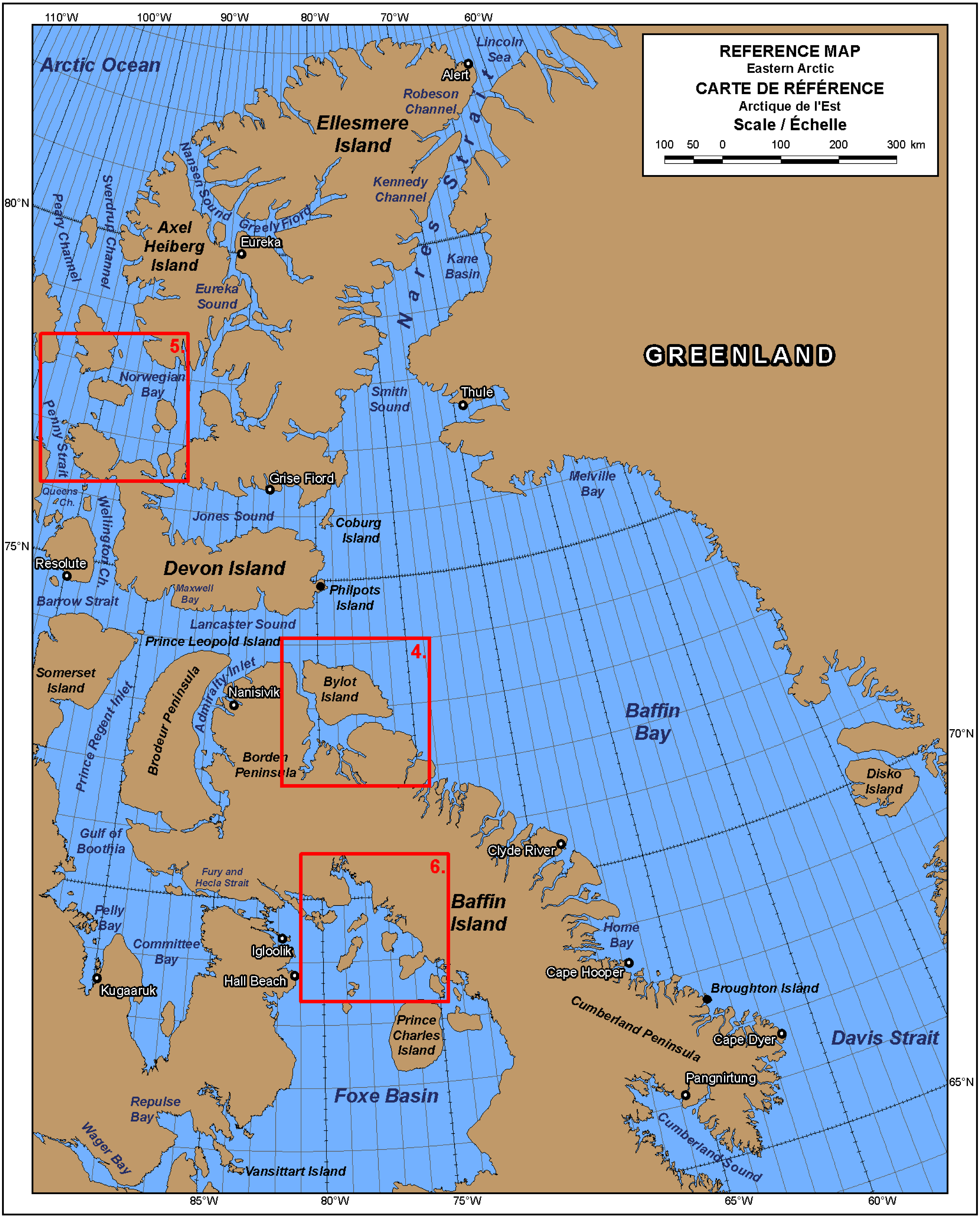
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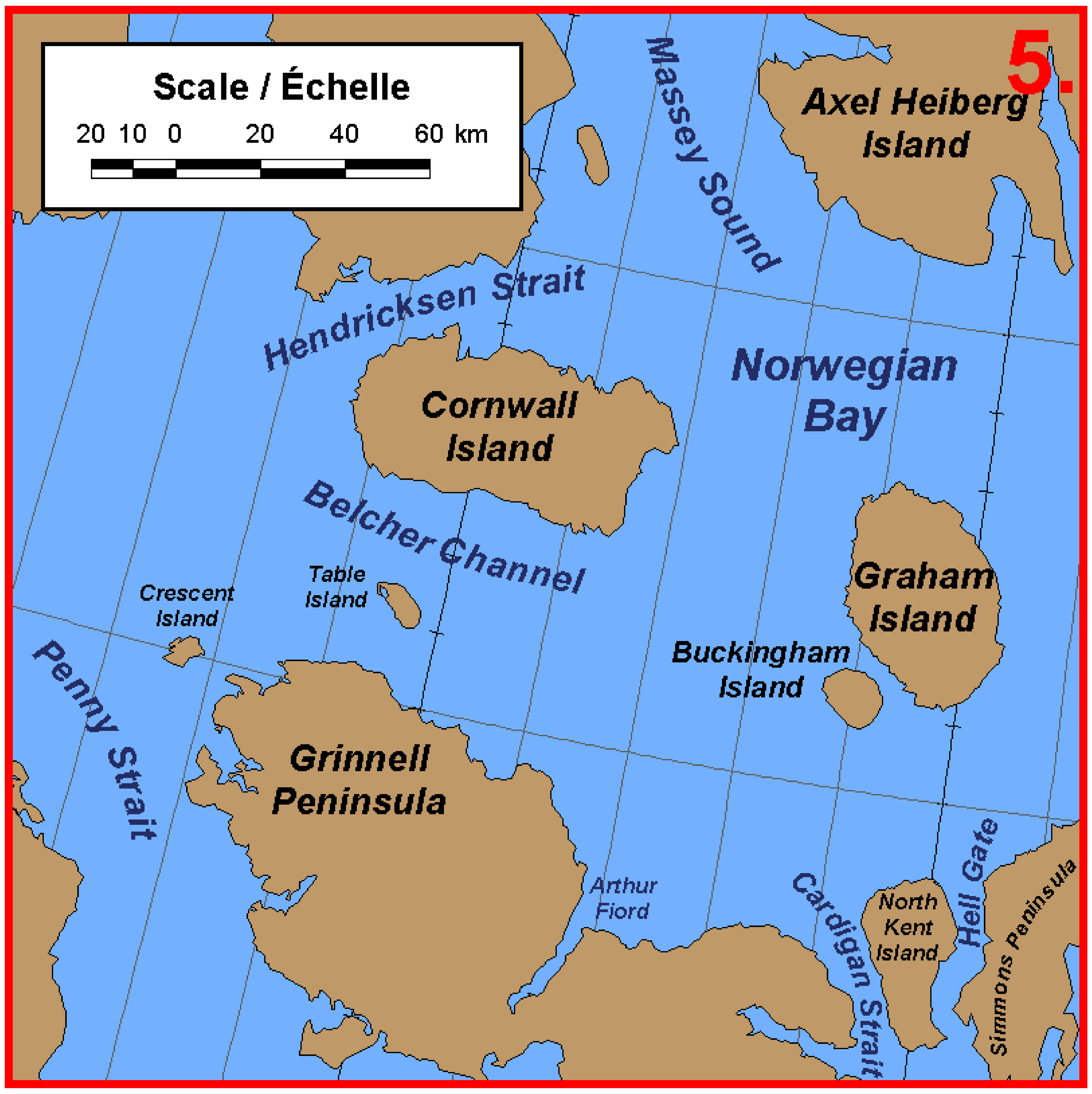
Eastern Arctic
CARTE DE RÉFÉRENCE
Arctique de l'Est
Scale / Échelle
100 50 0 100 200 300 km
110°W
100°W
90°W
80°W
70°W
60°W
85°W
80°W
75°W
65°W
60°W
80°N
75°N
70°N
65°N
Arctic Ocean
Lincoln Sea
Alert
Robeson Channel
Ellesmere Island
Nares Strait
Kennedy Channel
Nansen Sound
Sverdrup Channel
Peary Channel
Axel Heiberg Island
Greely Fiord
Eureka
Kane Basin
Eureka Sound
GREENLAND
5.
Norwegian Bay
Penny Strait
Smith Sound
Thule
Grise Fiord
Melville Bay
Queens Ch.
Wellington Ch.
Jones Sound
Coburg Island
Resolute
Devon Island
Maxwell Bay
Philpots Island
Barrow Strait
Lancaster Sound
Prince Leopold Island
4.
Somerset Island
Admiralty Inlet
Bylot Island
Nanisivik
Prince Regent Inlet
Brodeur Peninsula
Baffin Bay
Borden Peninsula
Disko Island
Gulf of Boothia
Clyde River
Fury and Hecla Strait
6.
Baffin Island
Pelly Bay
Committee Bay
Igloolik
Home Bay
Cape Hooper
Kugaaruk
Hall Beach
Broughton Island
Cumberland Peninsula
Prince Charles Island
Cape Dyer
Davis Strait
Pangnirtung
Foxe Basin
Repulse Bay
Wager Bay
Cumberland Sound
Vansittart Island

REFERENCE MAP
Map Insets 2
CARTE DE RÉFÉRENCE
Cartes en médaillon 2



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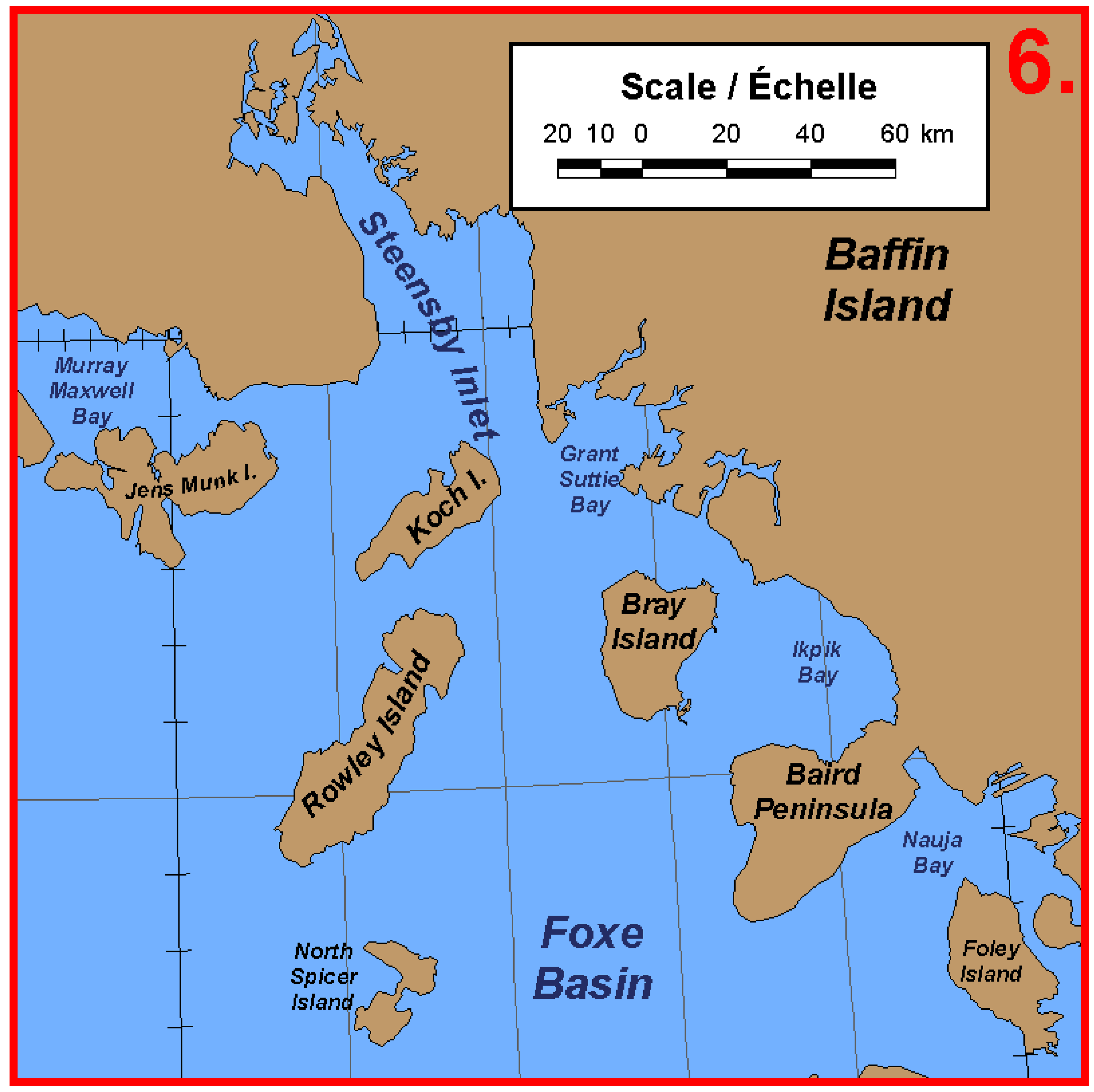

6. Foxe Basin / Bassin Foxe

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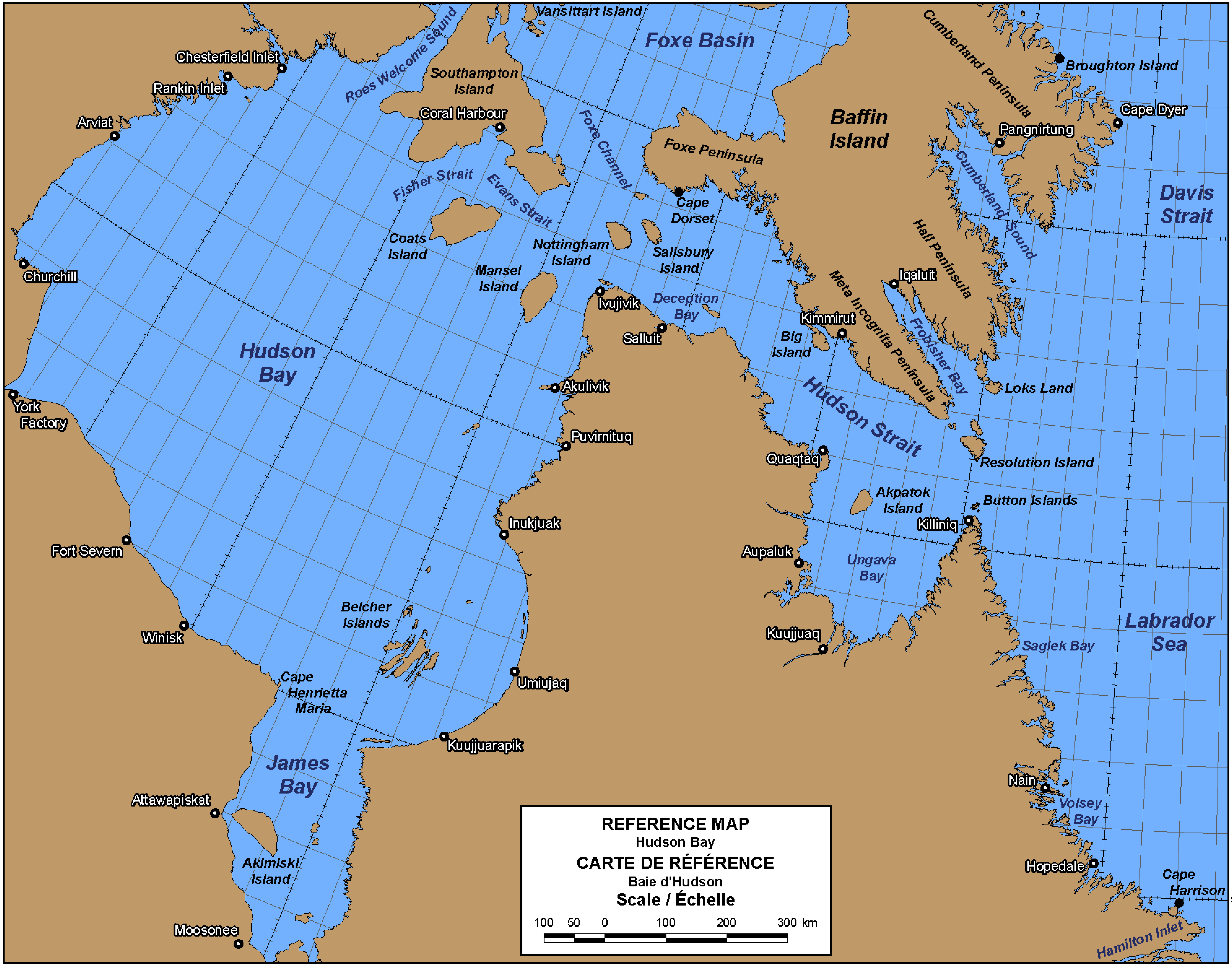
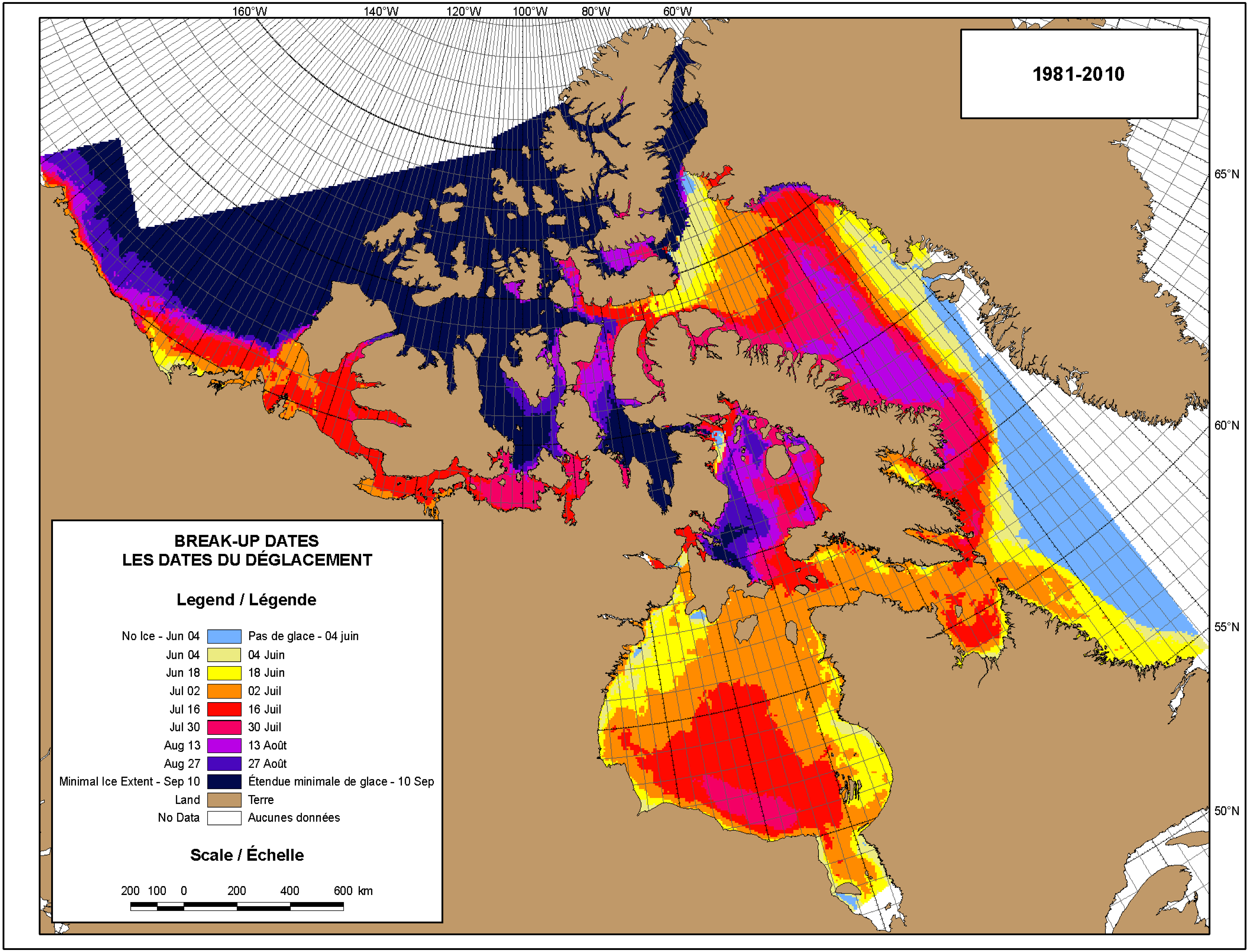


REFERENCE MAP
Hudson Bay
CARTE DE RÉFÉRENCE
Baie d'Hudson
Scale / Échelle
100 50 0 100 200 300 km

Canada

Environment Canada Environnement Canada
160°W
140°W
120°W
100°W
80°W
60°W
65°N
60°N
55°N
50°N
1981-2010
FREEZE-UP DATES
LES DATES DE L'ENGLACEMENT
Legend / Légende
Minimal Ice Extent - Sep 10 Étendue minimale de glace - 10 Sep
Sep 24 24 Sep
Oct 08 08 Oct
Oct 22 22 Oct
Nov 05 05 Nov
Nov 19 19 Nov
Dec 04 04 Déc
No Ice - Dec 04 Pas de glace - 04 Déc
Land Terre
No Data Aucunes données
Scale / Échelle
200 100 0 200 400 600 km
Canada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140°W
120°W
100°W
80°W
60°W
65°N
60°N
55°N
50°N
1981-2010
BREAK-UP DATES
LES DATES DU DÉGLACEMENT
Legend / Légende
No Ice - Jun 04 Pas de glace - 04 juin
Jun 04 04 Juin
Jun 18 18 Juin
Jul 02 02 Juil
Jul 16 16 Juil
Jul 30 30 Juil
Aug 13 13 Août
Aug 27 27 Août
Minimal Ice Extent - Sep 10 Étendue minimale de glace - 10 Sep
Land Terre
No Data Aucunes données
Scale / Échelle
200 100 0 200 400 600 km

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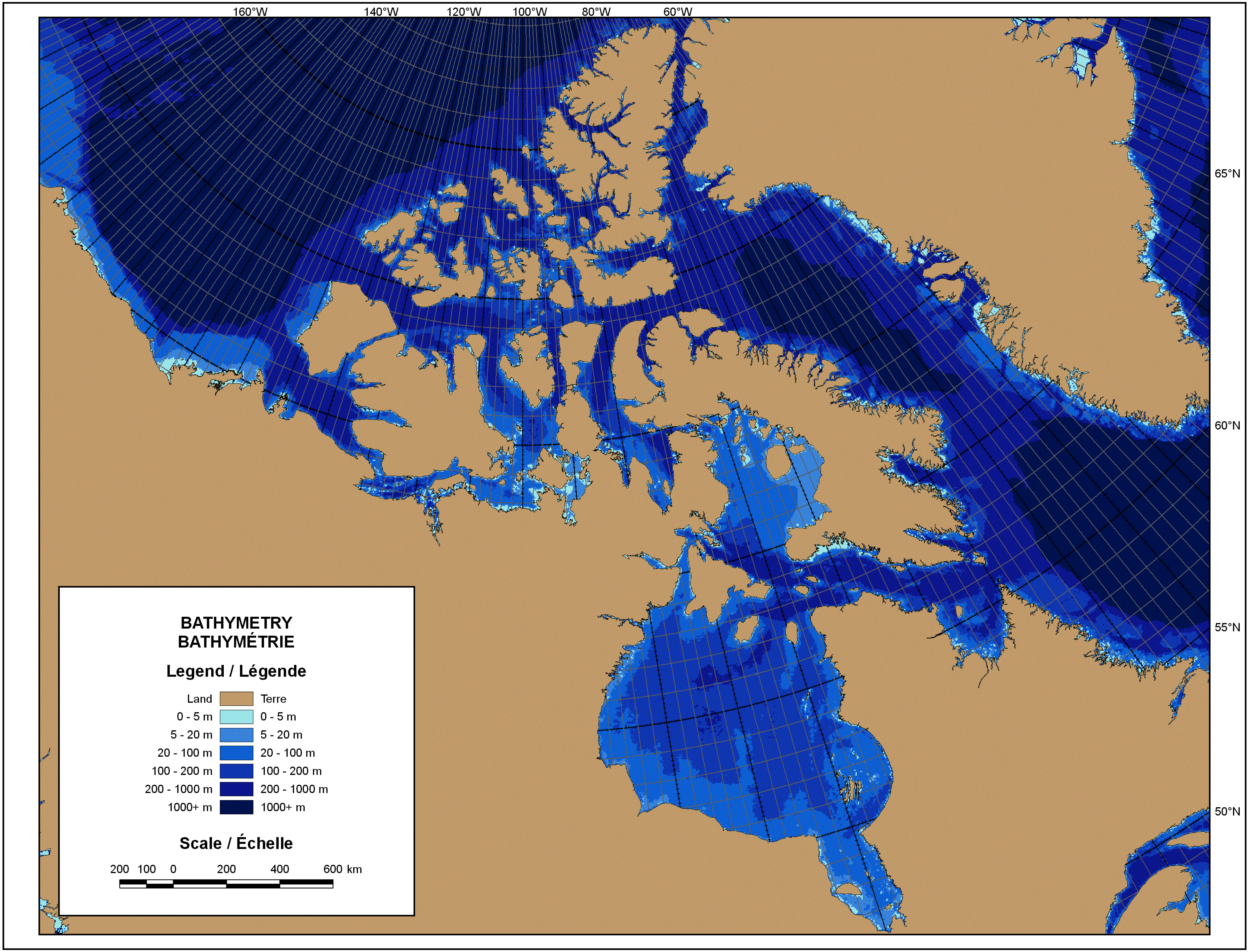

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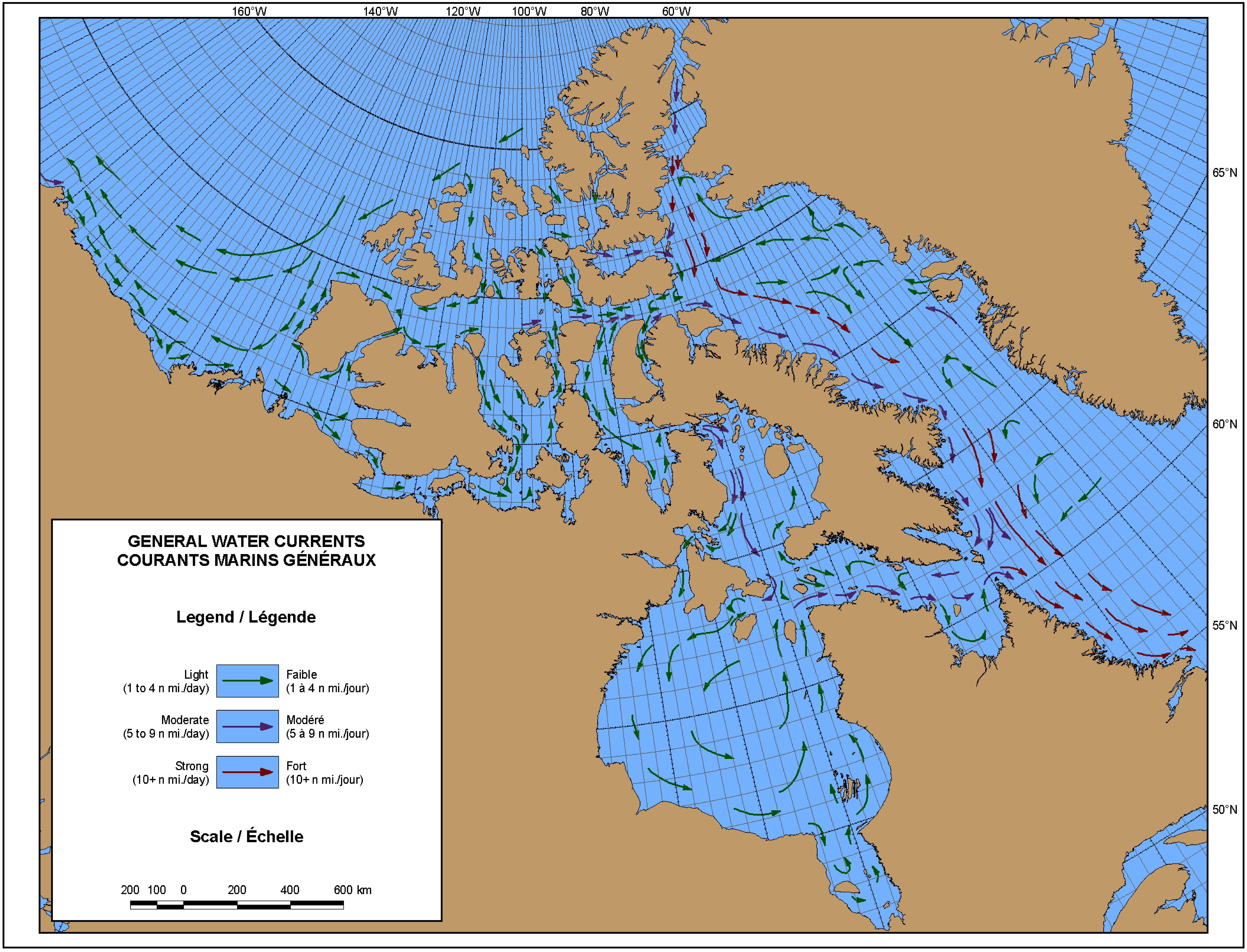
Environment Canada / Environnement Canada

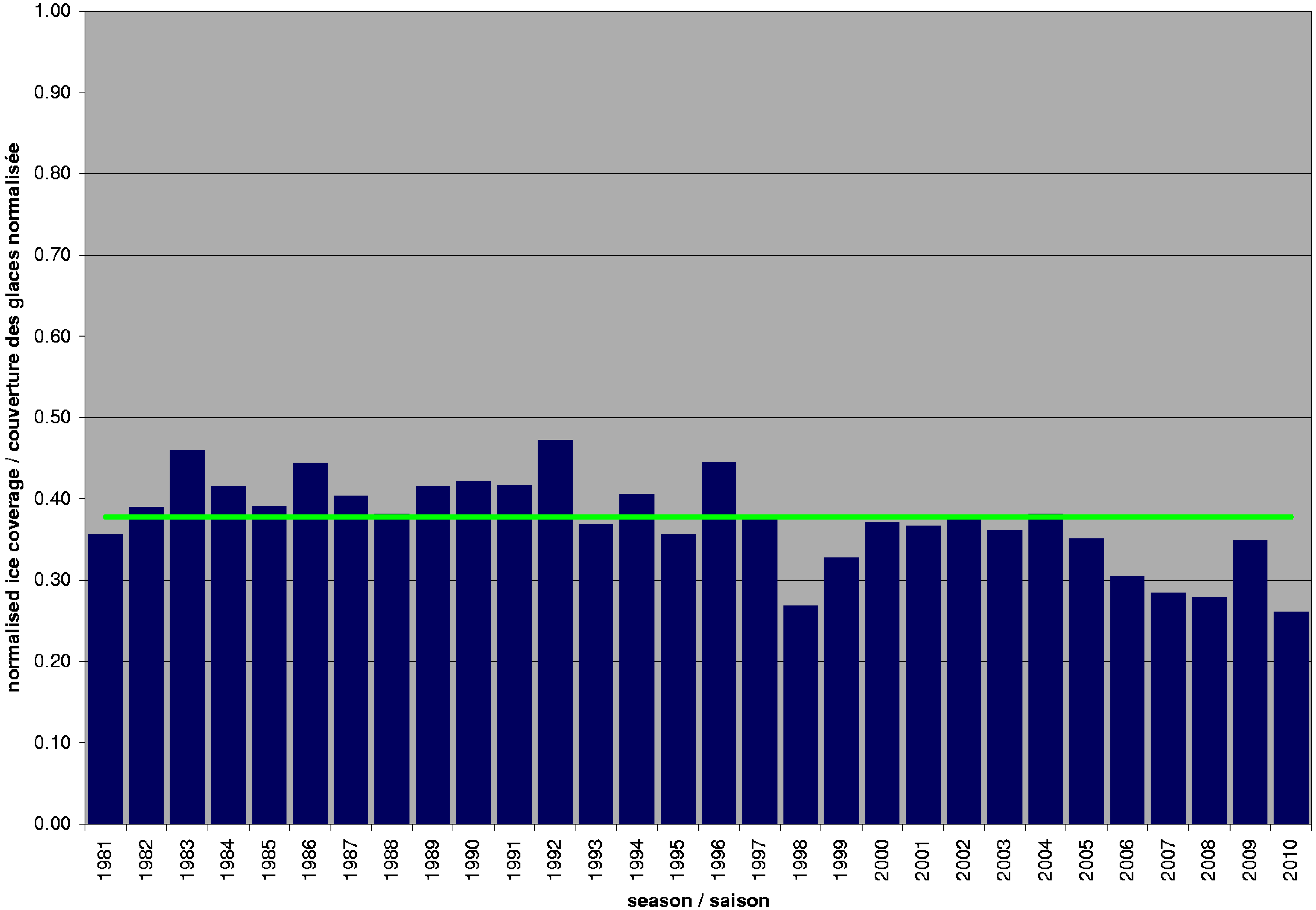


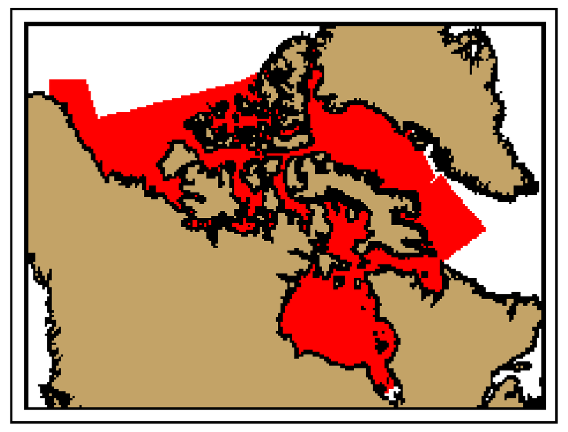
Canada

Environment Canada / Environnement Canada

Historical Total Accumulated Ice Coverage 0625 - 1015 /
Total accumulé de la couverture des glaces historique 0625 - 1015

Northern Canadian Waters: All Regions / Eaux du nord canadien: Toutes les régions





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ice season (mmdd) / saison des glaces (mmdd):
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statistics based upon / les statistiques basées sur:
1981-2010

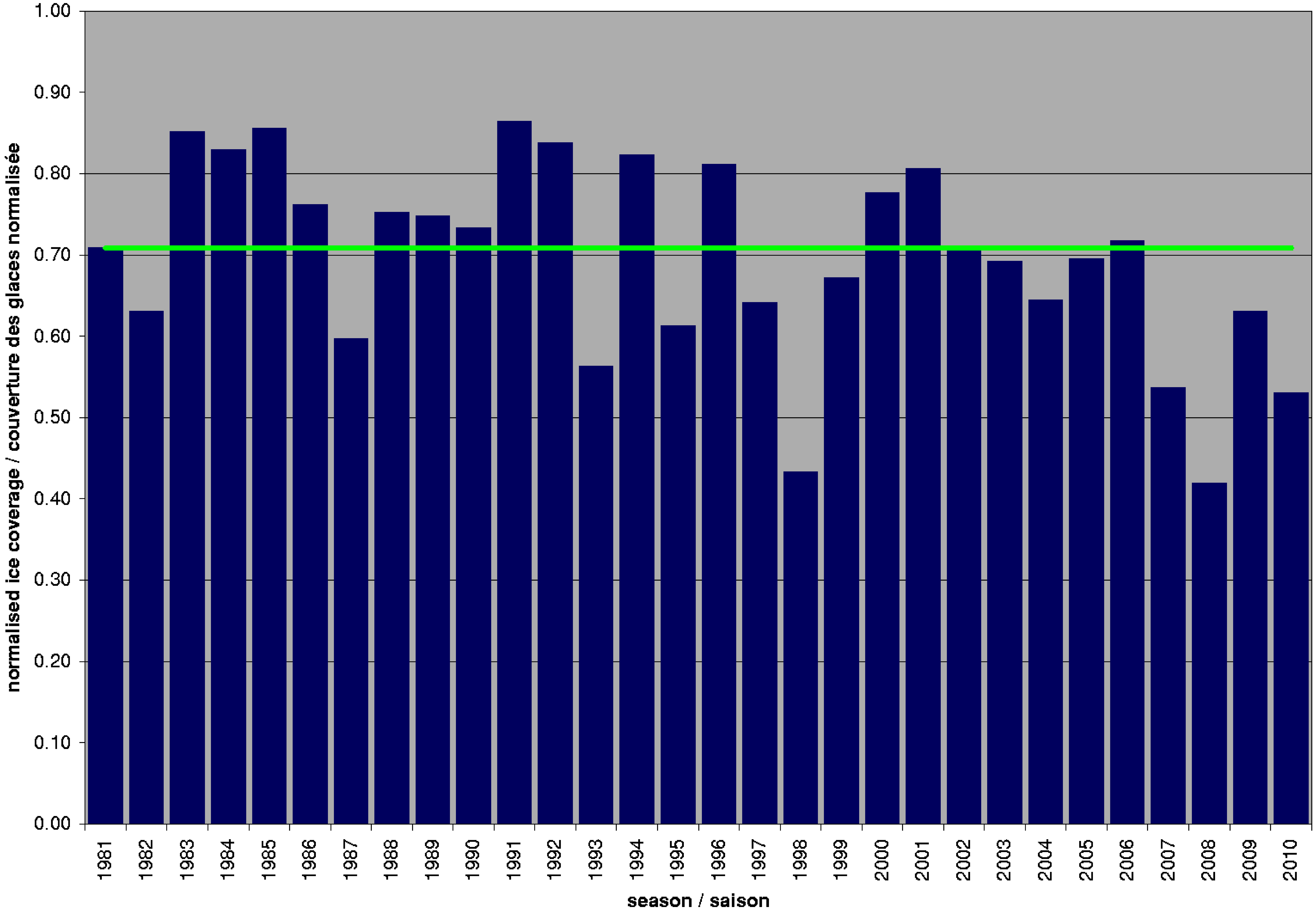
by / par:
CIS / SCG

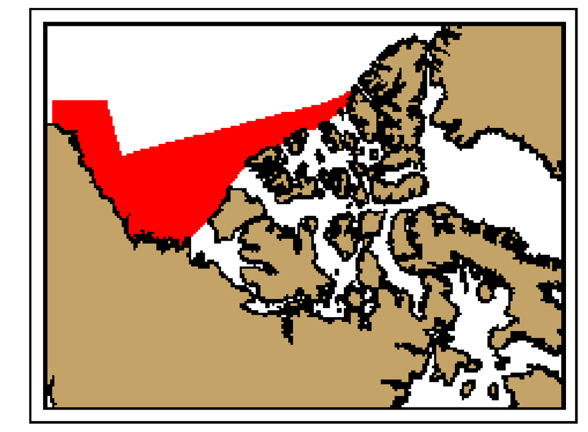
Canada

Environment Canada Environnement Canada

Historical Total Accumulated Ice Coverage 0625 - 1015 / Total accumulé de la couverture des glaces historique 0625 - 1015

Northern Canadian Waters: Beaufort / Eaux du nord canadien: Beaufort





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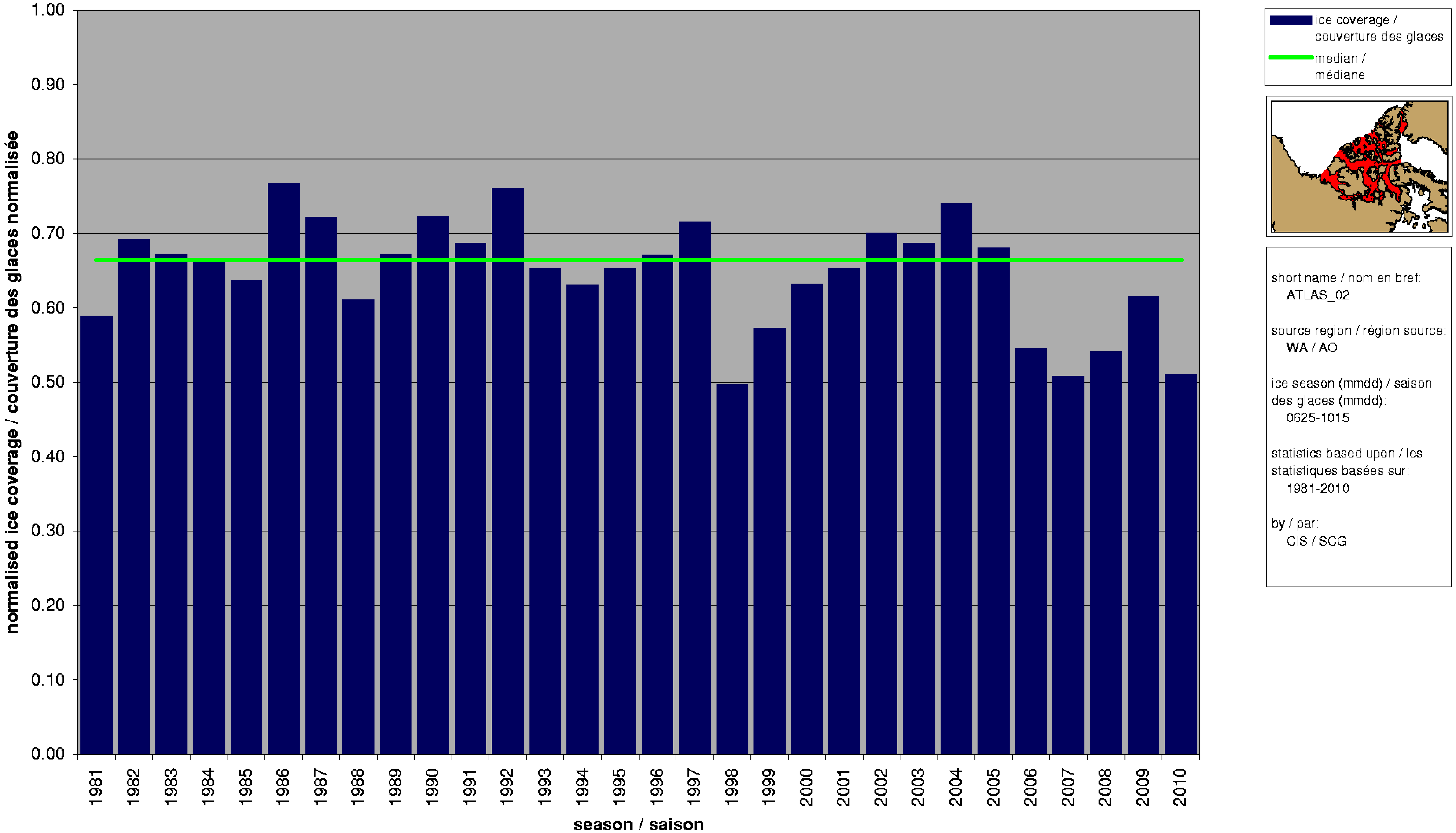
by / par:
CIS / SCG

Canada

Environment Canada / Environnement Canada

Historical Total Accumulated Ice Coverage 0625 - 1015 / Total accumulé de la couverture des glaces historique 0625 - 1015

Northern Canadian Waters: Arctic Archipelago / Eaux du nord canadien: Archipel Arctique



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1981-2010

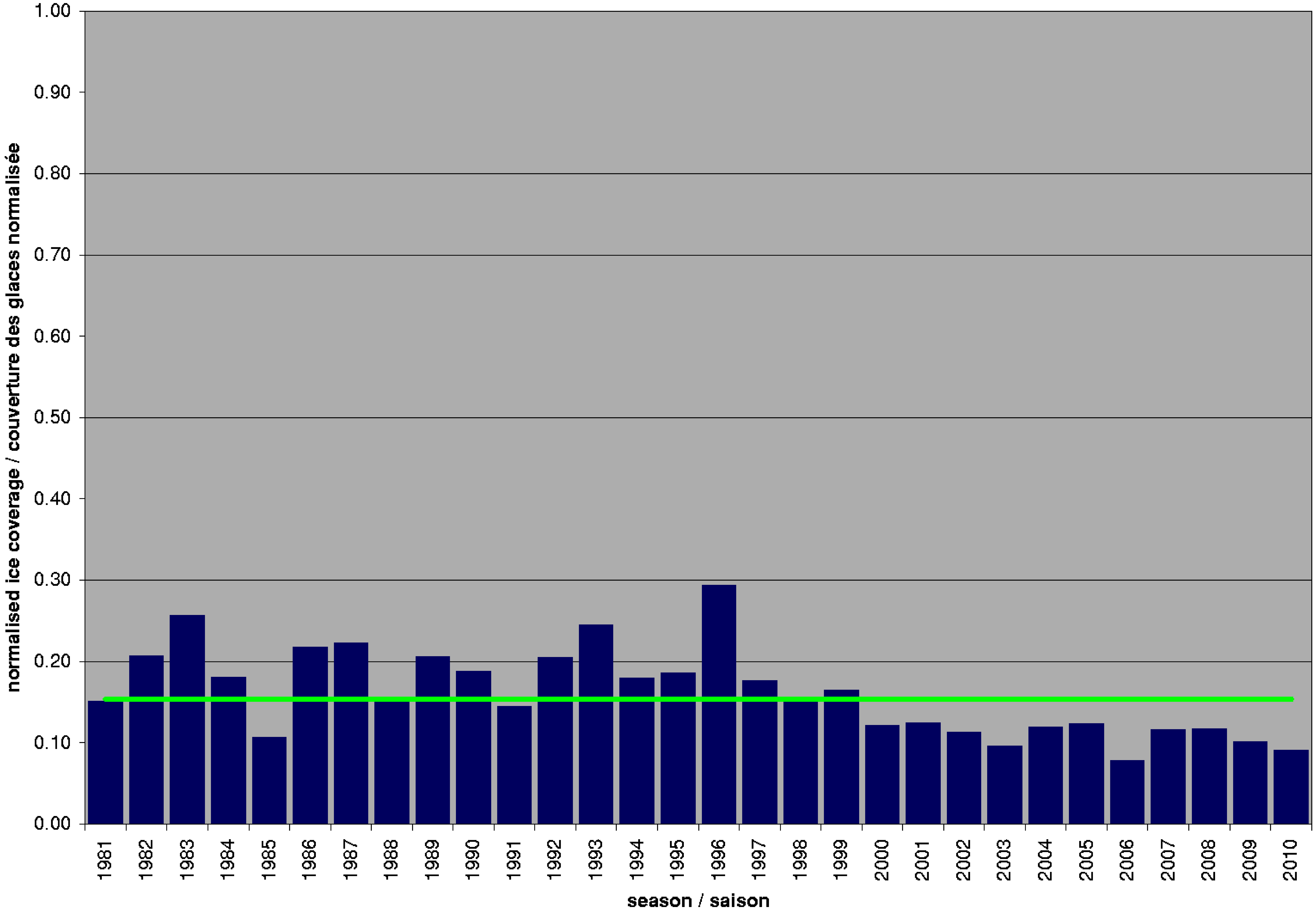
by / par:
CIS / SCG

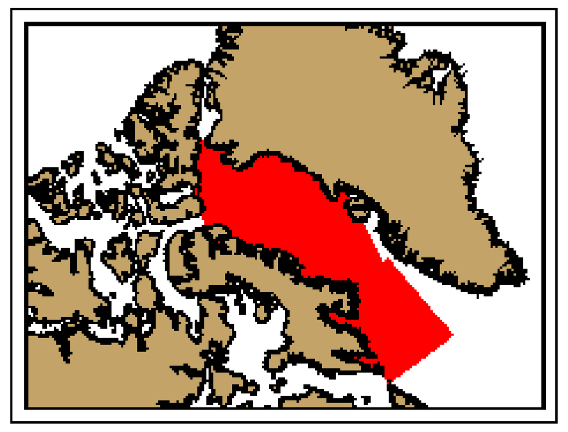
Canada

Environment Canada Environnement Canada

Historical Total Accumulated Ice Coverage 0625 - 1015 / Total accumulé de la couverture des glaces historique 0625 - 1015

Northern Canadian Waters: Baffin - Davis / Eaux du nord canadien: Baffin - Davis





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ice season (mmdd) / saison des glaces (mmdd):
0625-1015

statistics based upon / les statistiques basées sur:
1981-2010

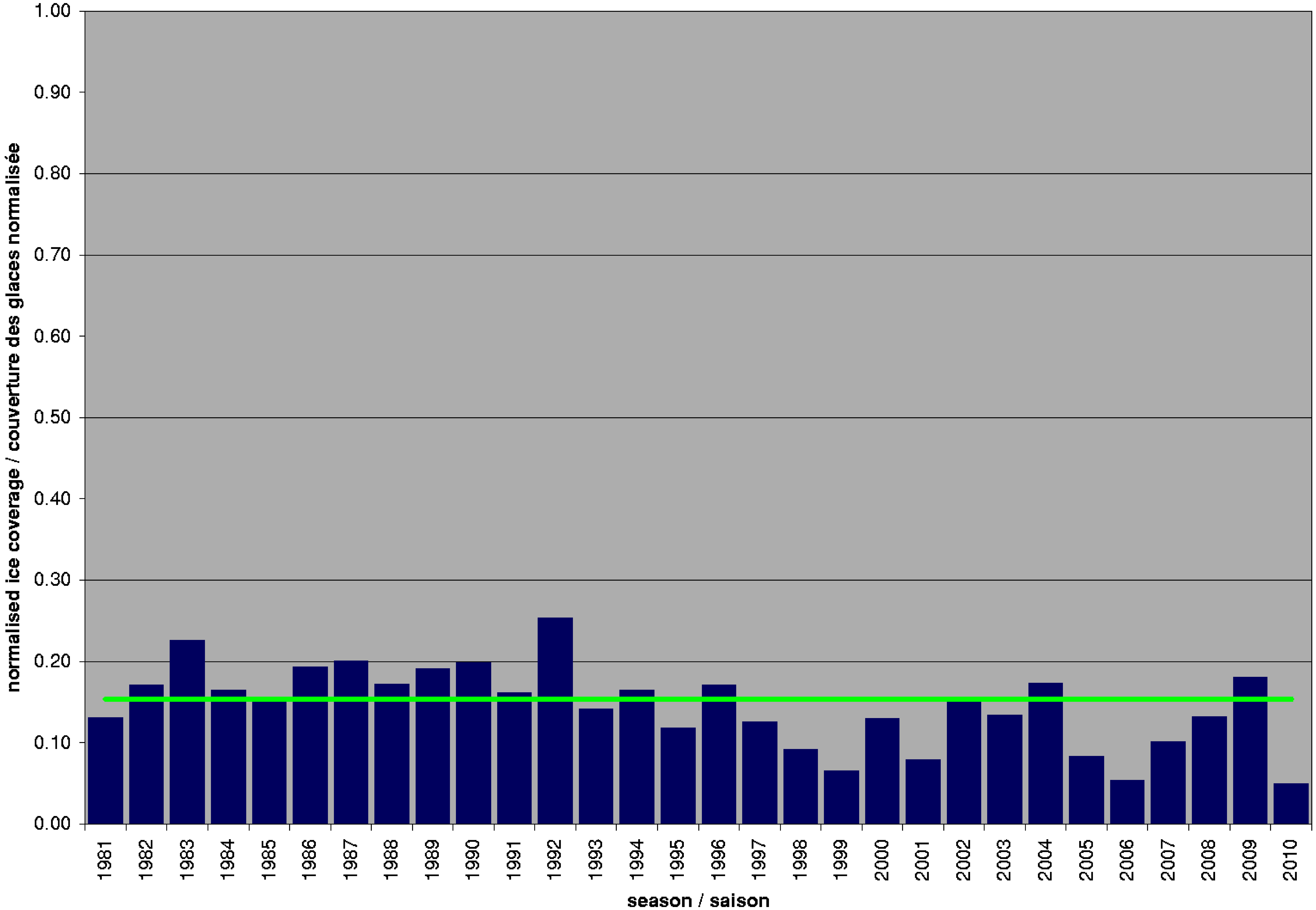
by / par:
CIS / SCG

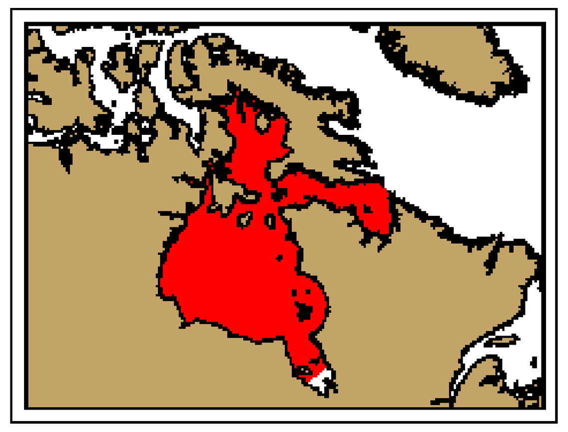
Canada

Environment Canada / Environnement Canada

Historical Total Accumulated Ice Coverage 0625 - 1015 /
Total accumulé de la couverture des glaces historique 0625 - 1015

Northern Canadian Waters: Hudson - Foxe / Eaux du nord canadien: Hudson - Foxe





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ice season (mmdd) / saison des glaces (mmdd):
0625-1015

statistics based upon / les statistiques basées sur:
1981-2010

by / par:
CIS / SCG

Canada