

# CANADA'S ARCTIC MARINE ATLAS



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Inside cover: Topographic relief of the Canadian Arctic



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## PHYSICAL OCEANOGRAPHY OF THE ARCTIC

### PHYSICAL OCEANOGRAPHY

- Landscape of the Seabed
- Seawater Sources and Surface Currents
- Sea Ice and Its Variation
- Tides and Their Effects
- Storms and Their Effects
- "Big Arctic" vs. "Little Arctic"

### Introduction

Ultimately, physical factors determine the characteristics of the marine environment. To start, the ocean is salt water bounded either by the coast or, in estuaries, by the interface between sea water and fresh water. Marine influences can extend inland as salt wedges (where salt water intrudes into fresh water) along river beds or as maritime air masses carried by wind. The marine environment forms habitat for marine life such as birds, mammals, fishes, invertebrates, algae, and micro-organisms at the bottom of the food web. Such life forms may spend their entire lives in the Arctic marine environment, live between fresh water and salt water, or migrate north for the short summer season and return south again as winter sets in. The Arctic marine environment is an important element of the Inuit world, providing food through the harvesting of many of the animals that live at sea, providing ease of travel over water and ice, and playing a critical role in Indigenous culture and well-being. The habitats of the ocean are constrained by physical factors such as water temperature, salinity, depth, currents, tides, the presence or absence of sea ice, seabed topography, seabed geology, and more. This section describes some of these influences and why they matter in the Arctic.

### Ecological significance

The Arctic marine environment can usefully be defined as waters affected by the presence of sea ice, either seasonally or year-round. A hard cap of ice on top of the water column has far-reaching effects on biology and climate in the Arctic. Marine mammals must get through the ice to breathe. Certain algae flourish on the underside of the ice, forming the bottom of the Arctic food web. Inuit use sea ice as a platform for travel and for hunting, relying on traditional knowledge to stay safe and to find and harvest seals and other animals. Sea ice reflects much more sunlight than does open water, helping keep the polar regions cool and thereby regulating Earth's climate. As summer sea ice continues to retreat, Canada's High Arctic is expected to be the last region where it is found.

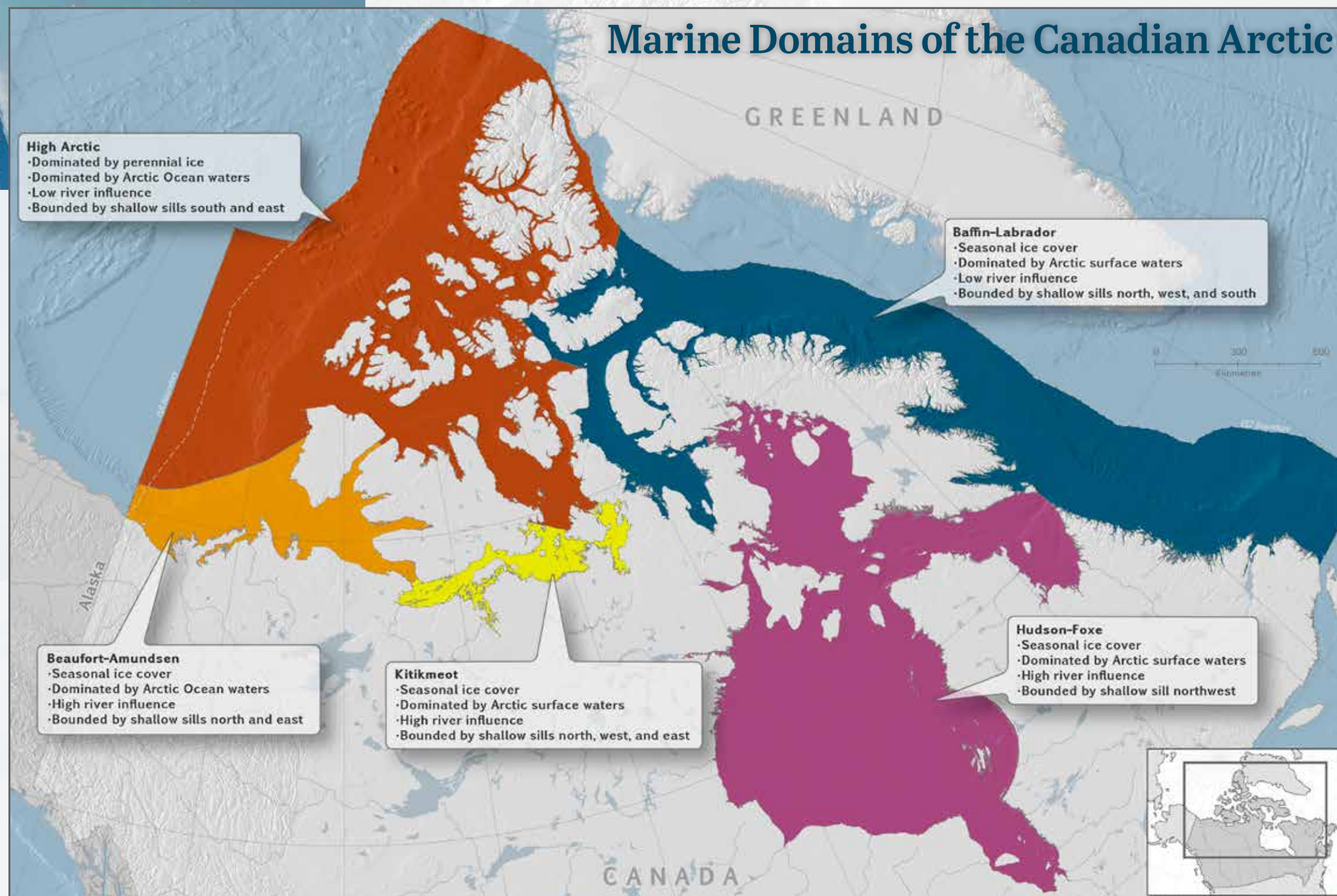
The Canadian Arctic marine environment varies regionally, and local differences are important. Sea water that flows into, through, and out of the Canadian Arctic creates a range of conditions for living things. Rivers add fresh water, and in some places heat, to the seas into which they flow, creating specialized brackish habitat that varies with the seasons. Some fishes and marine mammals flourish in these mixed waters, whereas other organisms must avoid them to survive. Other factors such as ice cover and oceanic water masses allow the identification of five broad oceanic domains in the Canadian marine Arctic, as illustrated on this page.

### Gaps in current knowledge

As outlined in this chapter, we have a general knowledge of the physical oceanography of the Canadian Arctic, but much remains to be discovered and understood. One challenge is the difficulty of reaching much of the area. Another is the current rate of environmental change, which may limit the application of past knowledge to the present and future. Constant factors are the region's landforms and tides, which are driven by the moon and the sun, but factors that are changing, such as summer sea ice and river flow, affect sea water temperature and chemistry. This atlas provides a snapshot, but ocean monitoring and further research is essential to document how change is affecting marine life and those who depend upon it.

Facing page: Meltwater pool at base of iceberg with crack in the ocean sea ice in spring, Baffin Island, Nunavut. (photo: Louise Murray)

## Marine Domains of the Canadian Arctic



### Rationale for the features included

The sea is shaped by many influences small and large. For this atlas, we have chosen to present some of the most prominent of these influences and also ones for which we have relevant data. These include the landscape of the seabed, which shapes the ocean in extent and depth; sea ice, the defining characteristic of Arctic marine waters; the sources of sea water, which determine much of its chemical and physical properties; surface currents, which affect how water, ice, and planktonic organisms move; tides, which in some areas are important local energy sources; and storms, the dominant energy source driving ocean currents, ice drift, and mixing. We also consider how local and regional conditions create unique conditions on a small scale.

For further reading, see p. 106.

DATA SOURCES  
– Domains: H. Melling pers. comm. 2017.  
– Basemap Data: Atlas of Canada 1:1M, ESRI,  
Flanders Marine Institute, Natural Earth.





## LANDSCAPE OF THE SEABED

### PHYSICAL OCEANOGRAPHY

#### ➔ Landscape of the Seabed

- Seawater Sources and Surface Currents
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**TWO MAIN FACTORS MAKE SEAWATER** more or less dense: temperature and the salinity. The seawater of greatest density at any place in the ocean eventually sinks to the seabed. There, ridges called sills tend to block the flow of the densest water, and valleys tend to channel it. For this reason, the shape and geography of the seabed determine where sea water can move and what path it takes. Knowledge of the seabed landscape is therefore critical to understanding the oceanography of any region.

#### Ecological significance

Because seabed landforms constrain the movement of ocean water, they also influence the characteristics of sea water and planktonic life that can reach any particular area of the ocean.

The main features of the seabed are the coastline, where water depth is zero; the relatively shallow continental shelves; banks, which are shallow shelf areas surrounded by deeper water; the shelf break, where the continental shelf ends and the seabed slopes steeply downward; basins, which are many times deeper than shelves or banks; and sills, which are the marine equivalent of mountain passes. Just as climbers find it easiest to cross mountains through passes, so deep ocean waters most easily cross between basins at sills.

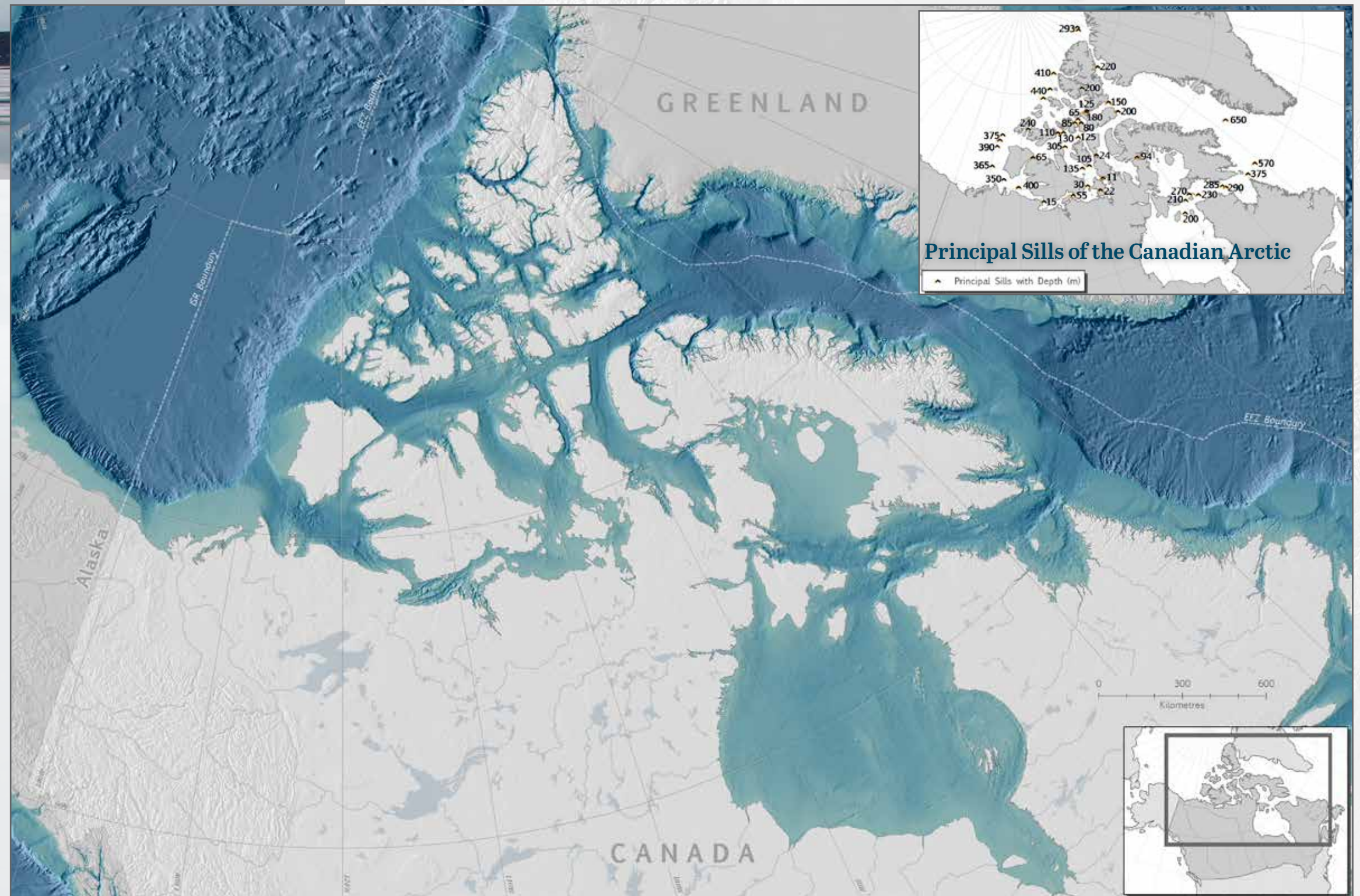
The Canadian marine Arctic encompasses two deep basins—Canada Basin and Baffin Bay—separated by a broad, shallow continental shelf—the Canadian Polar Shelf. In the southeast, Baffin Bay is separated from a third basin—Labrador Basin—by a broad and relatively deep sill. Hudson Bay and James Bay, which are commonly overlooked as areas of the Canadian marine Arctic, actually occupy an appreciable fraction of the Canadian Polar Shelf. If we consider just the sills of the Canadian Arctic, it is clear that the Canadian Polar Shelf is a complicated place. Its glacial history has rendered it studded with both islands and sills. The most obvious seabed landforms are a necklace of sills along the northwestern edge of the Canadian Polar Shelf that rise to within 300 to 400 m of the sea surface and a cluster of sills near the centre of the shelf that rise even higher, within 15 to 220 m of the sea surface.

#### Major concerns

Changes in seabed landforms of the Canadian marine Arctic occur via geological processes that operate slowly by human standards. The principal factor in play is the slow uplift of the seabed that began when the huge burden of ice sheets vanished at the end of the most recent ice age. Continuing uplift causes water depth to decrease and relative sea level to drop by as much as 1 m per century in some areas.

Facing page: A shallow bay on the coastline of the Inuvialuit Settlement Region. (photo: Jennie Knopp)

## Landscape of the Seabed



#### Gaps in current knowledge

Even preliminary seabed surveys are lacking over wide areas of the Canadian marine Arctic. This is particularly so in remote icebound northern areas and in coastal areas—nearshore regions, estuaries, bays, fjords—which are of great importance to people whose livelihood comes from the sea. Incomplete knowledge of seabed landforms restricts scientists' understanding of the functioning and vulnerability of Canadian Arctic marine ecosystems. Marine ecology is also influenced strongly by seabed sediments, but information on Arctic sediments is very sparse.

**LANDSCAPE OF SEABED DATA SOURCES**  
- Bathymetry: The GEBCO\_2014 Grid, version 20150318, Retrieved from: [www.gebco.net](http://www.gebco.net).  
- Basemap Data: Atlas of Canada 1:1M, ESRI, Flanders Marine Institute, Natural Earth.

**PRINCIPAL SILLS OF THE CANADIAN ARCTIC DATA SOURCES**  
- Sills: H. Melling pers. comm. 2017.  
- Bathymetry: The GEBCO\_2014 Grid, version 20150318, Retrieved from: [www.gebco.net](http://www.gebco.net).  
- Basemap Data: Atlas of Canada 1:1M, ESRI, Flanders Marine Institute, Natural Earth.





## SEAWATER SOURCES AND SURFACE CURRENTS

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**THERE ARE THREE MAIN TYPES OF WATER** within Canada's Arctic seas: (1) fresh water originating as snowfall, rainfall, or inflow from rivers; (2) sea water from the North Pacific Ocean; (3) sea water from the North Atlantic Ocean. These waters are identifiable by their salinity, temperature, and concentration of dissolved nutrients, all characteristics that are essential to the functioning of marine ecosystems. In places where all three types are present, as in Canada's Arctic seas, the fresh water floats on top, the Atlantic water sinks down deep, and the Pacific water slips in between.

The depths where each of these waters resides in the Arctic depend on how much of each type is present. In the Canadian Arctic, waters vary with depth from low salinity (0‰ to 2.8‰) at the surface, warm (0°C to 10°C) in summer and cold (-1.8°C to 0°C) in winter; through a thick layer of increasing salinity (the halocline) which is warmer (-0.5°C) near the top (Pacific Summer Water) and colder (1.5°C) and nutrient rich lower down (Pacific Winter Water); and continuing into a thick, warm (0.3°C to 1°C) layer of high salinity (3.4‰ to 3.5‰) that is relatively poor in nutrients (Atlantic Water).

There is a net flow from west to east through the islands of the Canadian Arctic, as Arctic and Pacific waters travel east toward the Atlantic, driven by the Pacific's higher sea level. In the west, the average pattern of wind maintains the Beaufort Gyre, which moves water and ice clockwise around the Beaufort Sea, forcing ice against the western islands of the archipelago in the north and dragging it westward in the south. Arctic and Pacific waters moving onto the Canadian Polar Shelf in this area flow through the narrow channels between islands and enter Baffin Bay through Smith, Jones, and Lancaster Sounds, or enter Hudson Bay through Foxe Basin. In Baffin Bay, as almost everywhere else on the Canadian Polar Shelf, shore-hugging currents flow in opposite directions on opposite sides. The north-flowing West Greenland Current meets Arctic Ocean and Pacific waters emerging through Smith, Jones, and Lancaster Sounds. The combined flow turns southward along the east coast of Baffin Island as the Baffin Current. Currents in Hudson Bay circulate counter-clockwise, with a net outflow of water through Hudson Strait into the Labrador Sea.

### Ecological significance

Phytoplankton (single-celled marine plants) bloom under sea ice and in surface waters when the sun returns to the Arctic in spring, but quickly consume the nutrients available there. Later renewed blooms during summer and autumn require fresh deliveries of dissolved nutrients to the photic zone (waters that sunlight can reach) from the underlying Pacific Water layer. These can occur over wide areas by the mixing action of storms, in shallow narrow channels by the action of tides, and in areas of steep sloping seabed through the process of upwelling, caused by storm winds from certain directions.

Sills on the seabed block the flow of water that resides below the depth of their crests. Water of a specific type can only flow to a given location if its entire path is at least as deep as the shallowest depth of that type. Because of the high nutrient concentrations of Pacific water, the areas isolated from its inflow are of particular interest. Where sills are shallower than the layer of Pacific Water, the seas behind those sills may never receive nutrient-rich inflowing water, as is the case for the Kitikmeot Sea (Coronation Gulf, Dease Strait, Queen Maud Gulf).

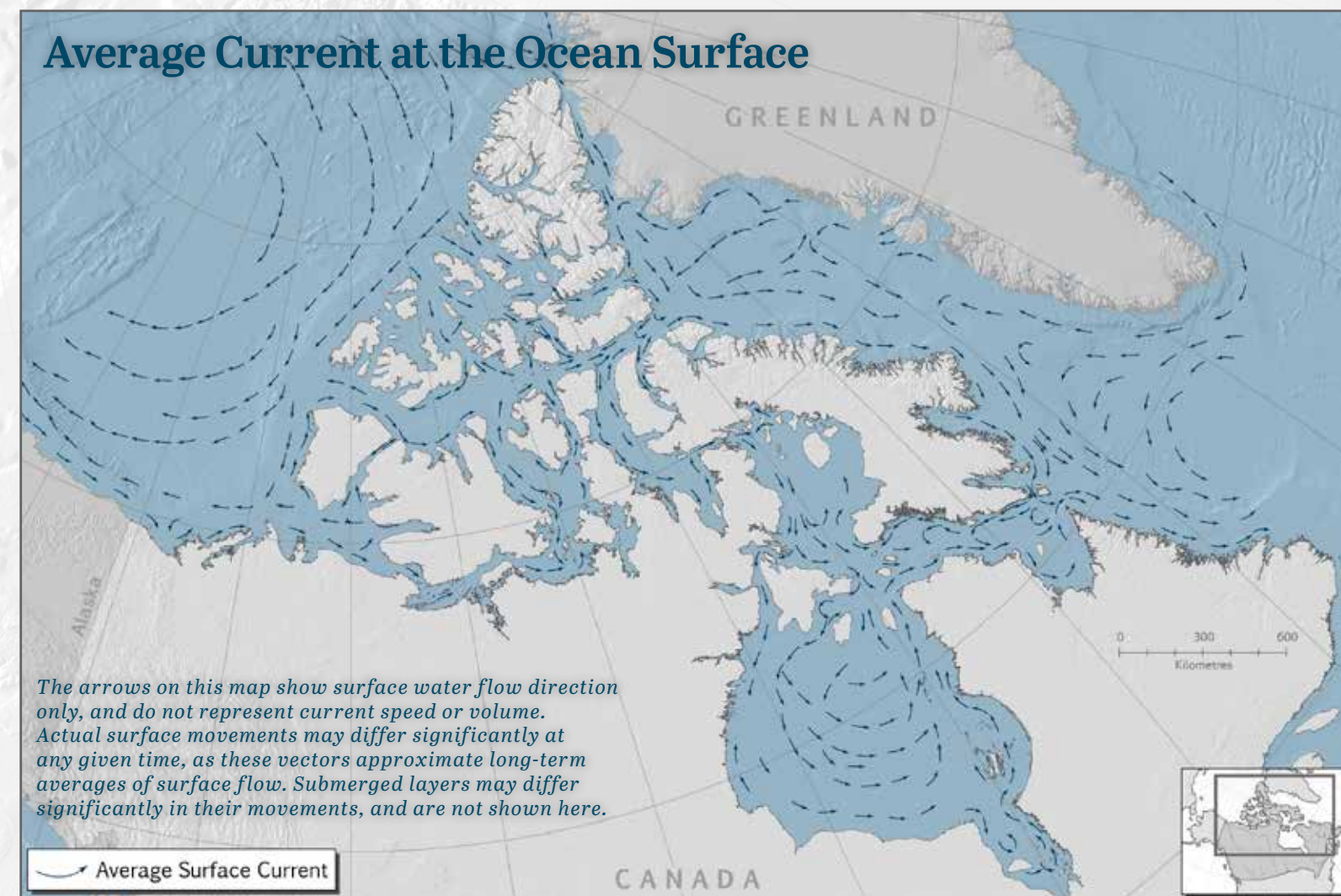
### Major concerns

We lack the knowledge to predict how global change might affect a large range of factors related to water masses in the Arctic. These factors include future wind patterns across the Arctic that drive ice and ocean movements; inflow/outflow rates of the three principal water types and their "choice" of outflow pathways; stored volumes of each water type, which affect their depths of occurrence and therefore the influence of sills on their movements across the shelf; and ice cover, which influences mixing of waters, as well as others.

Facing page: Grinnell Glacier, Baffin Island. (photo: David Henry)

DATA SOURCES  
- Average Surface Current: Modified from Environment and Climate Change Canada 2015, Arctic average water currents. Retrieved from: <https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/climatology/arctic-average-water-currents.html>; H. Melling, pers. comm. 2017.  
- Basemap Data: Atlas of Canada 1:1M, ESRI, Natural Earth.

## Average Current at the Ocean Surface



## Areas of Pacific Water Influence



## Areas of Atlantic Water Influence



## Areas of Arctic Water Influence



AREAS OF PACIFIC, ATLANTIC AND ARCTIC WATER INFLUENCE DATA SOURCES  
- Seawater Extents: H. Melling pers. comm., 2017, based on depth thresholds using GEBCO\_2014 Grid, version 20150318, [www.gebco.net](http://www.gebco.net).  
- Basemap Data: Atlas of Canada 1:1M, ESRI, Natural Earth.





## SEA ICE AND ITS VARIATION

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**EXTENSIVE ICE COVER** during at least part of the year is the defining characteristic of the Canadian Arctic seas. The ice forms as sea water freezes during cold winter temperatures. In Canada's extreme North it reaches more than 2 m thick between September and early June. Ice colliding with shorelines or other ice can break into fragments, which become stacked into thick meandering piles known as ridges. Ridges can attain a thickness of 10 m even very early in winter and may reach 30 m or more by winter's end. Along coastlines, ice that is thick and strong enough to resist the forces of winds and currents can stop drifting and become fast ice. The channels among islands on the Canadian Polar Shelf are unique in harbouring vast expanses of fast ice every winter. Broadly speaking, ice that remains adrift moves southwest on the Arctic side of the Canadian Polar Shelf and southeast on the Atlantic side. Around Hudson Bay, ice circulates counter-clockwise with some exiting via Hudson Strait, through which ice also enters intermittently. Sea ice that does not melt in summer thickens during subsequent winters and is known as multi-year ice. Most of the Arctic's multi-year ice is found in Canadian waters.

### Ecological significance

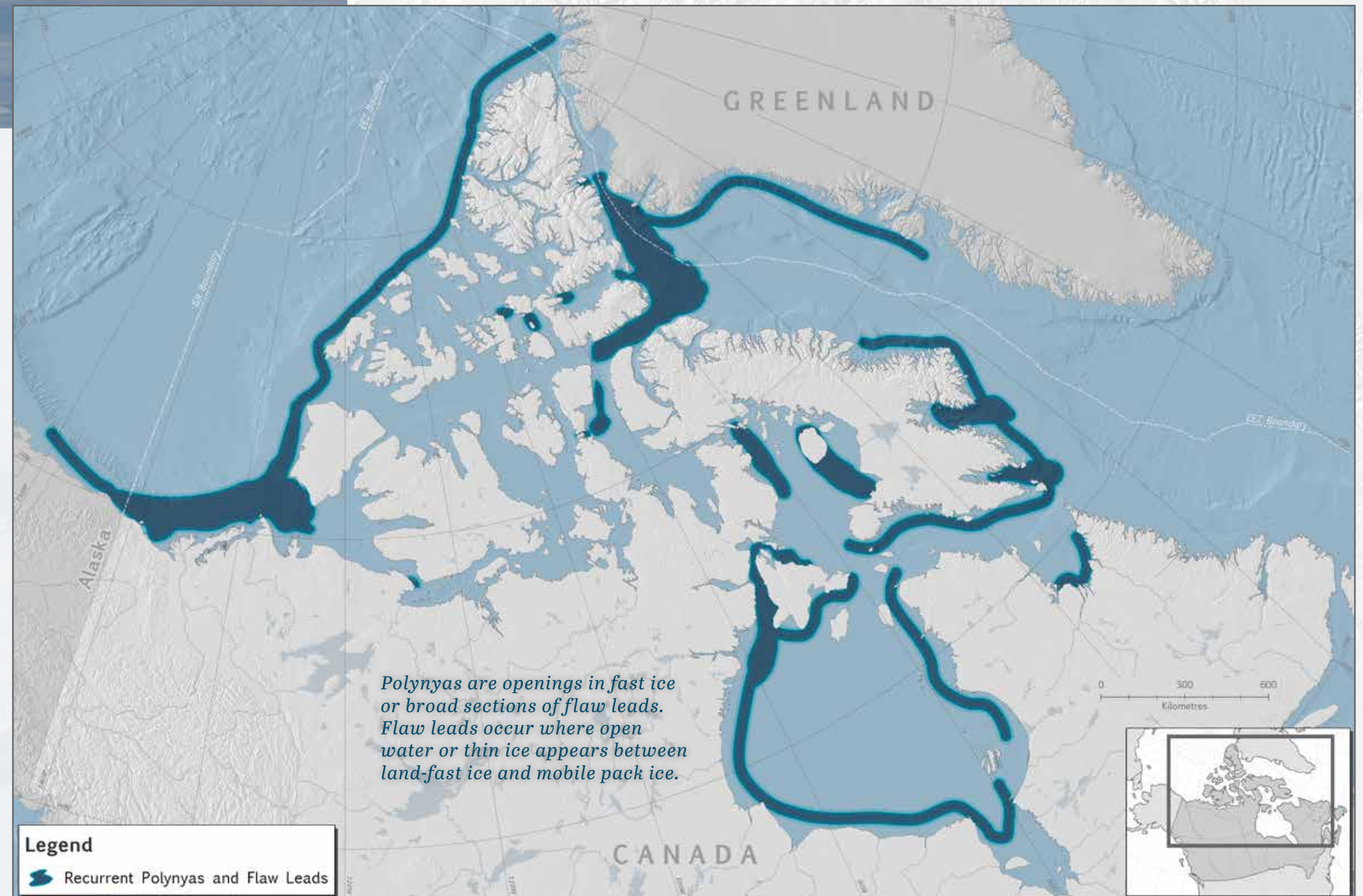
Sea ice has a dominant impact on all aspects of Arctic marine ecosystems. It is itself a habitat for life—bacteria, phytoplankton, zooplankton, fish, seals, walrus, birds, whales, foxes, polar bears, and Inuit. Its presence reduces the penetration of life-giving sunlight into ocean water. As it moves, its rough texture helps mix dissolved nutrients into the surface photic zone from deeper in the ocean. However, melting ice in summer impedes such mixing by forming a layer of brackish surface water. The solidity of ice provides support for mammals that walk (bears, foxes) and seabirds, but at the same time it impedes easy access to marine food sources. Its presence protects marine mammals from topside predators but may also isolate these same creatures from life-giving air. When winds are favourable in winter and spring, polynyas or flaw leads form along the edge of fast ice. These areas of thin ice or open water foster blooms of plankton early in spring and provide sanctuary for creatures needing both ocean and atmosphere to survive.

### Major concerns

Because sea ice has such a controlling influence on Arctic marine ecosystems, it is safe to state that these ecosystems will be strongly influenced by observed and expected changes in sea ice conditions. However, statistically significant trends in ecosystem characteristics are elusive, and computer simulations of coupled ocean/ecology systems are only now under development.

Facing page: Seasonal sea ice in the Inuvialuit Settlement Region. (photo: Jennie Knopp)

## Areas of Recurrent Polynyas and Flaw Leads of the Canadian Arctic



### Gaps in current knowledge

Accurate estimates of trends in sea ice conditions require accurate observations sustained over decades. Existing ice monitoring programs should be continued to provide the needed level of confidence. Knowledge of ice-linked trends in marine ecosystems lags far behind that of trends in the ice itself. There is a strong rationale for initiating strategic long-term monitoring of key ecosystem elements in the Canadian marine Arctic.

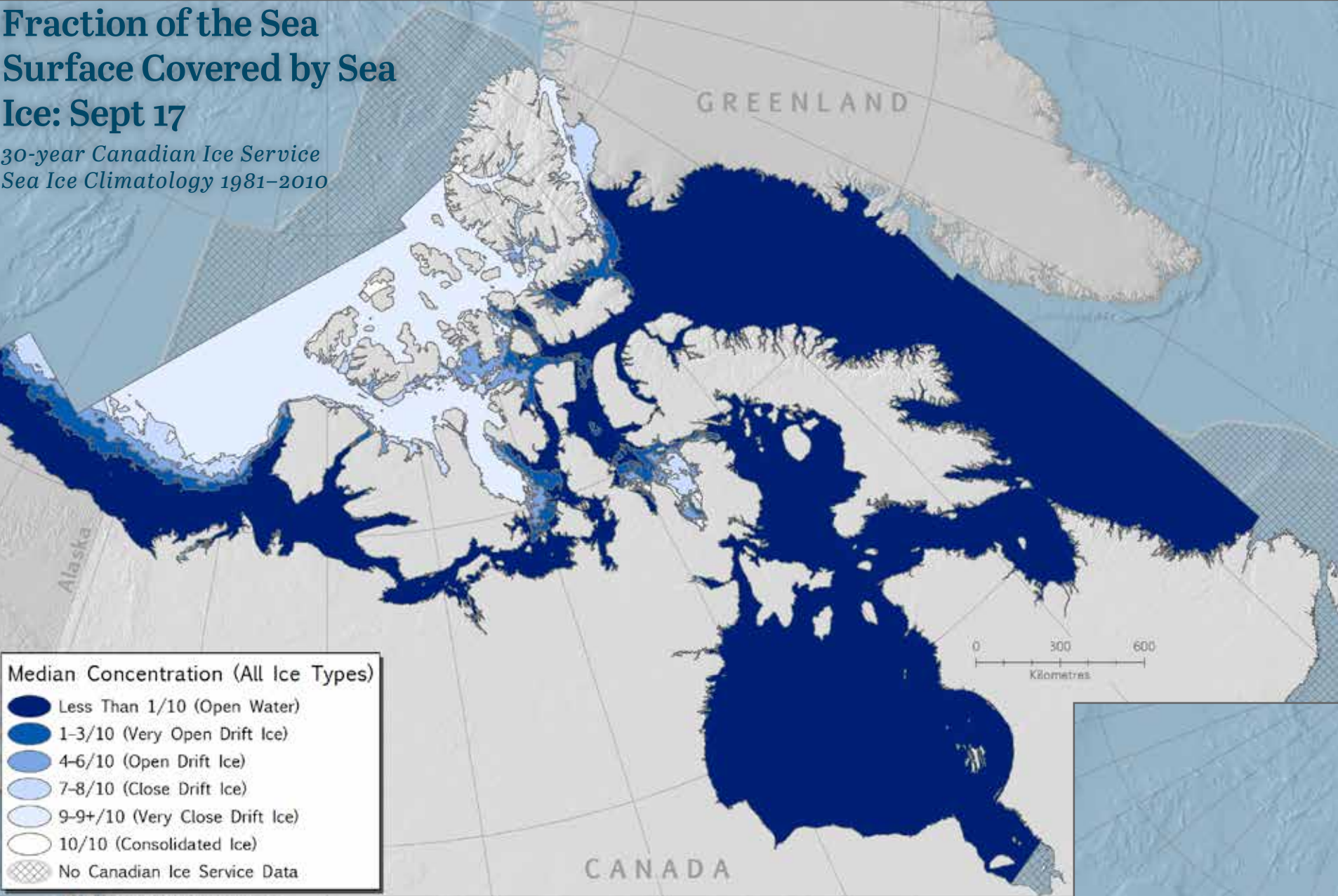
**DATA SOURCES**

- Polynyas and Flaw leads: Modified by Melling and Camack, 2017, based on maps from: Hannah, Charles G., et al. 2009. Polynyas and Tidal Currents in the Canadian Arctic Archipelago. *Arctic* 62(1): 83-95; Meltofte, H. (ed.) 2013. Arctic Biodiversity Assessment. Status and trends in Arctic biodiversity. Conservation of Arctic Flora and Fauna, Akureyri; Barber, D.G. and Massom, R.A. 2007. The Role of Sea Ice in Arctic and Antarctic Polynyas. In Smith, W. and Barber, D. (eds). *Polynyas: Windows to the World*. Elsevier Oceanography Series: The Netherlands; Melling and Camack 2017, pers. Comm.
- Basemap Data: Atlas of Canada 1:1M, ESRI, Flanders Marine Institute, Natural Earth.



# Fraction of the Sea Surface Covered by Sea Ice: Sept 17

30-year Canadian Ice Service Sea Ice Climatology 1981–2010



**Fraction of the Sea Surface Covered by Sea Ice: Sept 17 (Above)**  
The date of least annual Arctic sea ice extent is typically mid-September but the minimum extent varies from year to year.

**Fraction of the Sea Surface Covered by Sea Ice: March 5 (Right)**  
The date of greatest Arctic sea ice extent is typically late March, but that extent can vary from year to year. White areas denote fast ice that is immobile for much of the winter. Other areas are pack ice which remains mobile.

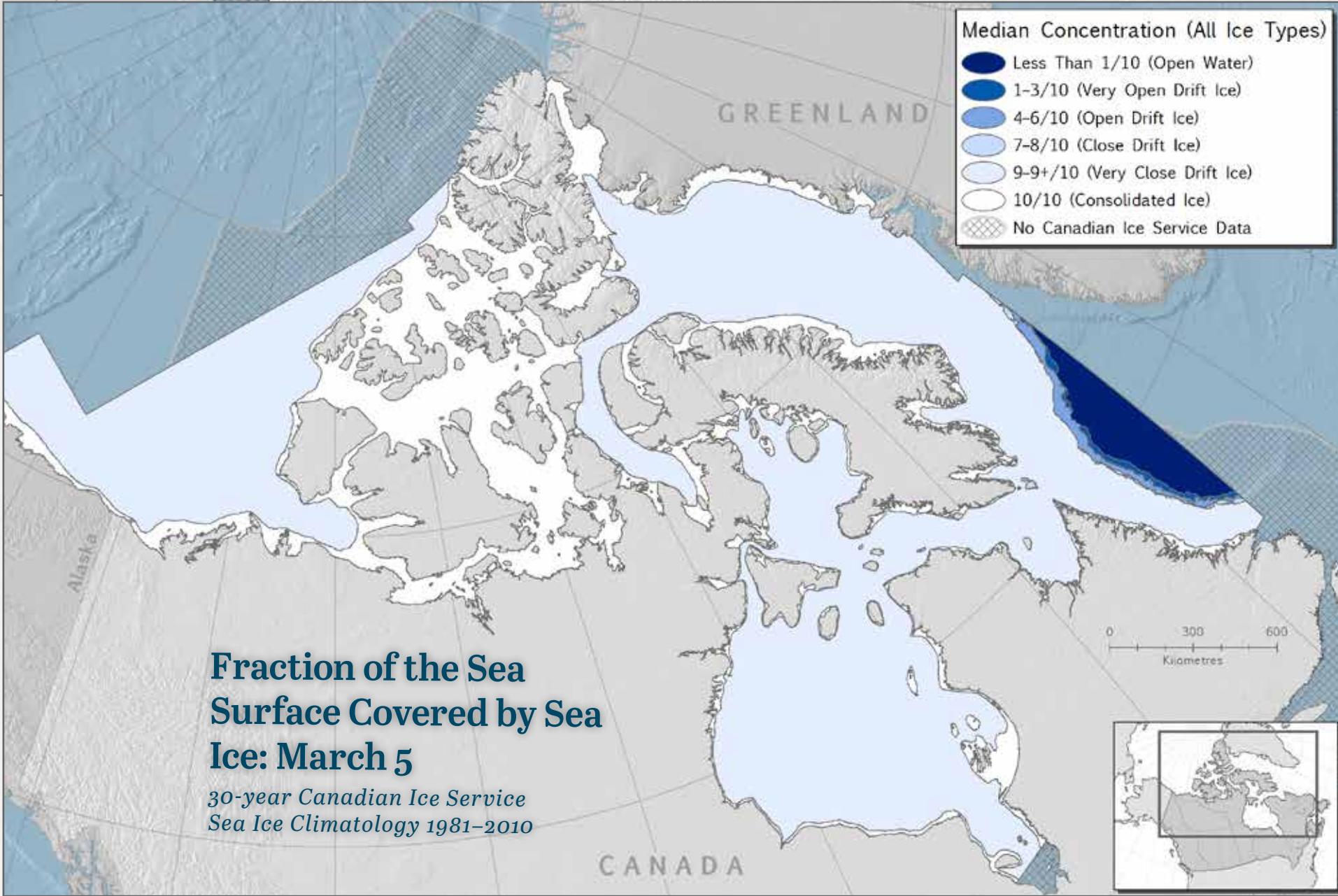
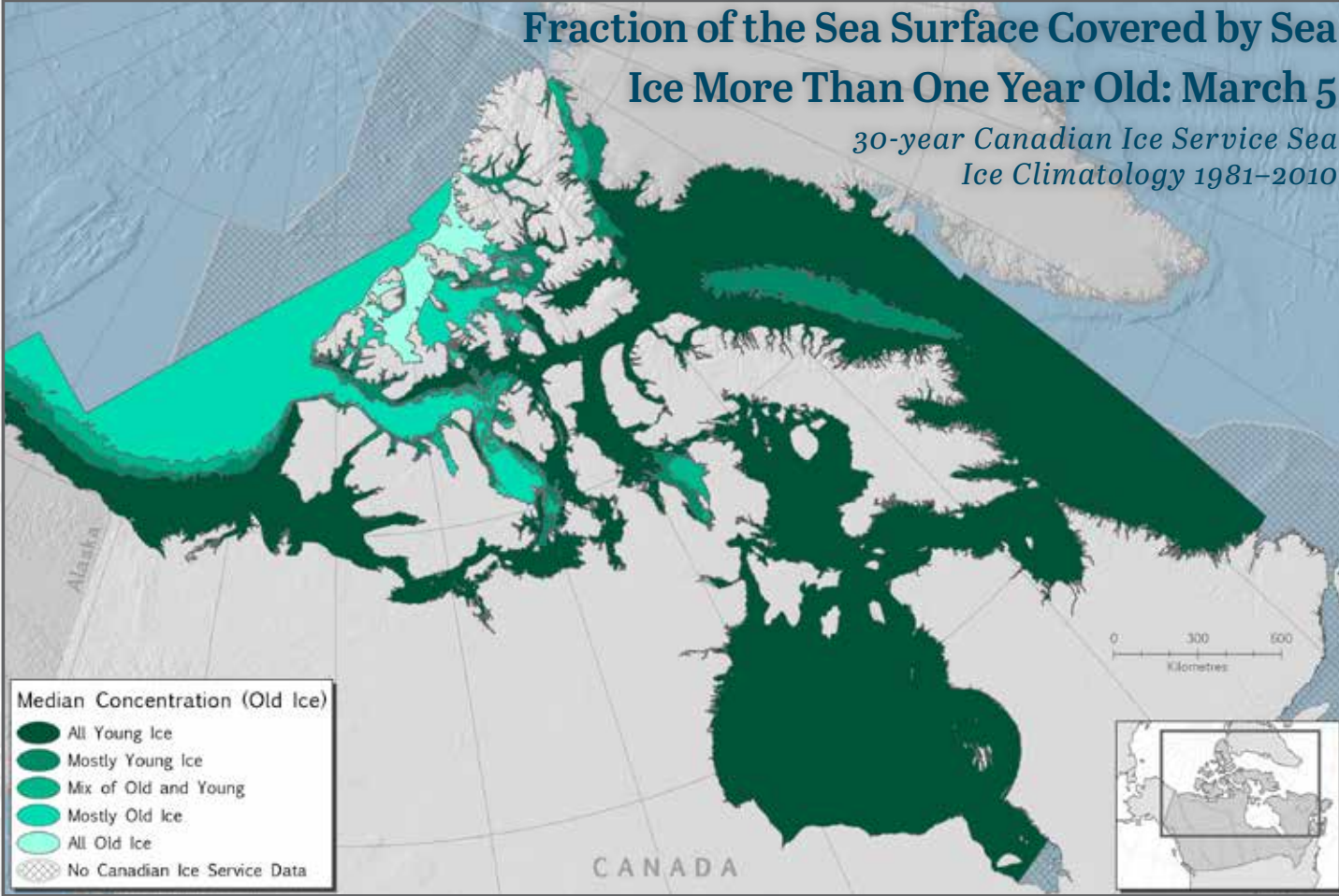
**Fraction of the Sea Surface Covered by Sea Ice More Than One Year Old: March 5 (Facing Page, Above)**  
Some sea ice lasts through the summer melt and persists for years. This ice provides travel routes for some animals through the summer but is also very hazardous to ships travelling through Arctic waters because it is harder than younger ice.

**Note:** Median summer ice minimum is the middle minimum extent, where the annual minimum ice coverage has been greater than this extent in half of past years and less than in the other half.

SEA ICE DATA SOURCES  
– Sea Ice: Canadian Ice Service (CIS), 2011.  
Climatic Ice Atlas (1981–2010). <http://iceweb1.cis.ec.gc.ca/30Atlas/>  
– Basemap Data: Atlas of Canada 1:1M, ESRI, Flanders Marine Institute, Natural Earth.

# Fraction of the Sea Surface Covered by Sea Ice More Than One Year Old: March 5

30-year Canadian Ice Service Sea Ice Climatology 1981–2010



# Fraction of the Sea Surface Covered by Sea Ice: March 5

30-year Canadian Ice Service Sea Ice Climatology 1981–2010



# Median Date When the Sea Surface Becomes Ice-Free in Spring or Summer

30-year Canadian Ice Service Sea Ice Climatology 1981–2010



**Date When the Sea Surface Becomes Ice-Free in Spring or Summer (Above)**  
The clearance of ice in the spring and summer is an event of significance for seabirds and large marine mammals since these organisms need open seas to feed or to breathe.

**Date When the Sea Surface Becomes Ice-Covered in Autumn (Right)**  
As the sea surface progressively freezes after the sea ice minimum in September, areas accessible to large marine mammals shrink and less sunlight reaches the ocean water.

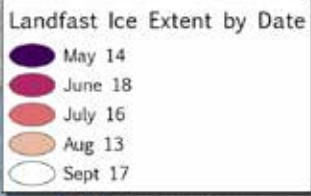
**Date When Land-Fast Sea Ice Fractures and Starts to Move (Facing Page, Above)**  
The fracture and renewed movement of fast ice in the spring re-opens marine areas that were inaccessible to some creatures during winter months. On the other hand, it reduces opportunities for travel over sea ice and releases heavy ice into Arctic shipping lanes.

**Note:** Dates of these events have been earlier than the median in half of all past years and later in the other half.

SEA ICE DATA SOURCES  
– Sea Ice: Canadian Ice Service (CIS).  
2011. Climatic Ice Atlas (1981–2010).  
<http://iceweb1.cis-ic.gc.ca/30Atlas/>  
– Basemap Data: Atlas of Canada 1:1M,  
ESRI, Flanders Marine Institute,  
Natural Earth.

# Median Date When Land-Fast Sea Ice Fractures and Starts to Move

30-year Canadian Ice Service Sea Ice Climatology 1981–2010



# Median Date When the Sea Surface Becomes Ice-Covered in Autumn

30-year Canadian Ice Service Sea Ice Climatology 1981–2010





## TIDES AND THEIR EFFECTS

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Aerial view of iceberg grounded in shallow rapids during tidal rip in Wager Bay, Ukkusiksalik National Park. (photo: Paul Souders)

**TIDES ARE THE REGULAR VARIATIONS OF SEA LEVEL** related to the positions of the sun and the moon, their gravitational pulls, and the rotation of the Earth. The gravity of the sun and the moon pulls Earth's sea water toward them, creating bulges that move around the Earth as the planet rotates beneath them. In a tidal cycle, sea level varies from low to high and back again. Cycles with the largest tidal range occur over approximate intervals of either 12 or 24 hours. Other, more subtle astronomical influences create weaker tides at longer periods—half-monthly, monthly, every six months, or every 12 months.

Irregularities in the depth and shape of ocean basins modify the bulges, so that tidal ranges (differences between high and low tides) are larger in some areas than in others. In the Arctic, changes in the ice cover between winter and summer cause changes in the tidal range and arrival time.

The rapid movement of the tidal bulges of sea water around the Earth creates tidal currents. These flow back and forth over the same intervals as the sea level changes that drive them.

### Ecological significance

Tides are responsible for the intertidal zone, one of the marine habitats of the coastal ocean, alternately exposed and flooded by changing sea level twice each day. The width of the intertidal zone depends upon the tidal range and upon the slope of the seabed. It is narrow on steep shores and wide on gentle ones.

Tidal variation raises and lowers sea ice near shorelines, maintaining cracks between ground ice (near-shore) and floating ice (on deeper water). These cracks provide breathing opportunities for seals and hunting opportunities for polar bears.

The flow of tidal currents over the seabed and under the ice generates swirls and eddies in the water that mix possibly warmer and more nutrient-rich water from deep down into the surface layer, where life-giving sunlight can reach it. An upward mixing of nutrients can restore the productive capacity of surface waters in summer and sustain biological hotspots nearby. An upward mixing of heat can reduce the thickness of winter ice and create small polynyas providing better winter habitat for walrus and seals and facilitating earlier break-up in spring. This can occur even under fast ice because wind action is not required.

### Major concerns

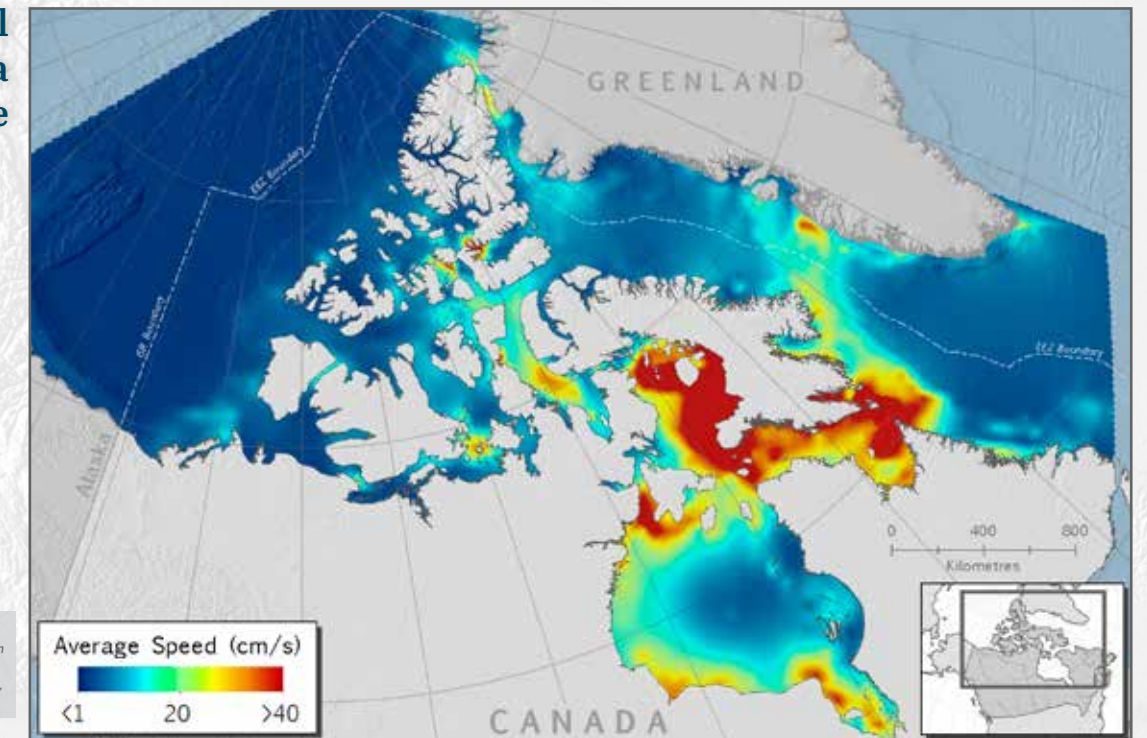
Because tides are driven by astronomy, not climate or human activity, there is no concern about change in tides. However, the ecological effects of tides are focused in small polynyas in fast ice and on biological hotspots; thus the impact of tides could possibly change as sea ice thins (polynyas could become larger and open earlier) or as the locally stored heat and dissolved nutrients in the water column change in amount or depth. It is difficult to predict how such things might change.

### Gaps in current knowledge

The principal missing element in current knowledge is the detailed landscape of the seafloor, namely its depth and topography. Existing survey coverage is spotty and sparse in navigable waters and generally missing where tides are strongest—nearshore areas and in bays, inlets, fjords, and narrow channels.

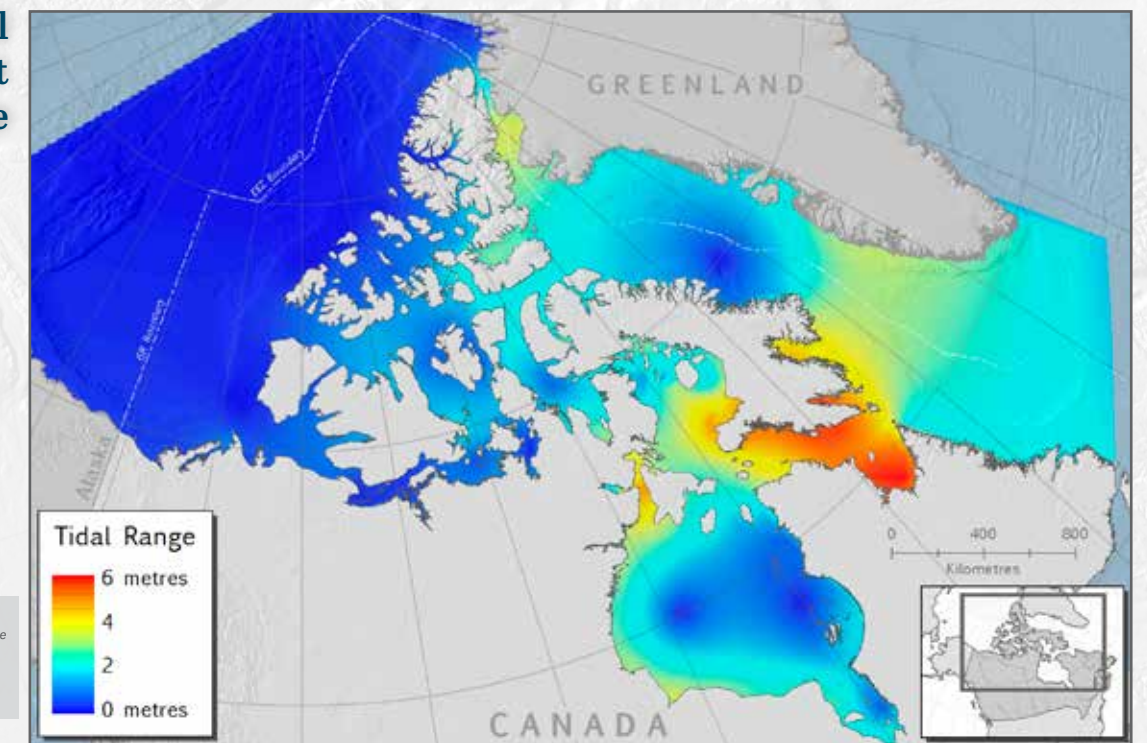
## Energy in the Tidal Current, Averaged over a Lunar Cycle

DATA SOURCES  
- Average Tidal Current Speed: Derived from WebTide Tidal Prediction Model (v0.7.1).  
- Basemap Data: Atlas of Canada 1:1M, ESRI, Flanders Marine Institute, Natural Earth.



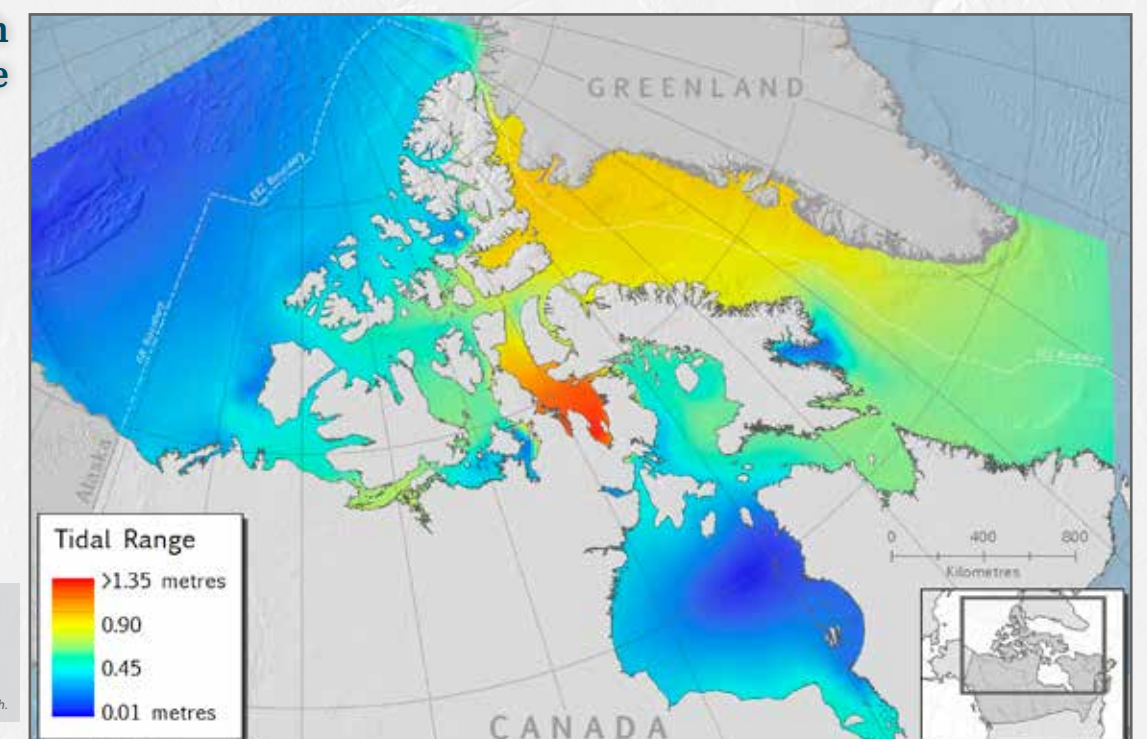
## Change in Sea Level with the Dominant Half-Daily Tide

DATA SOURCES  
- Tidal Range: Derived from WebTide Tidal Prediction Model (v0.7.1).  
- Basemap Data: Atlas of Canada 1:1M, ESRI, Flanders Marine Institute, Natural Earth.



## Change in Sea Level with the Dominant Daily Tide

DATA SOURCES  
- Tidal Range: Derived from WebTide Tidal Prediction Model (v0.7.1).  
- Basemap Data: Atlas of Canada 1:1M, ESRI, Flanders Marine Institute, Natural Earth.







## STORMS AND THEIR EFFECTS

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**VARIABILITY AND CHANGE IN THE OCEAN** are driven by inputs and losses of energy. Arctic waters receive heat energy from the sun when available, kinetic (motion-associated) energy from tides and winds. The fact that the Arctic is distinctively cold and ice covered is primarily a consequence of inequalities between equatorial and polar regions in the inputs and losses of heat energy. Whereas the equator is generously provided with solar energy year-round, the poles receive modest solar input only during summer and radiate appreciable heat to space under clear skies during winter. The ocean's uptake of wind energy is almost entirely from strong winds. For this reason, information on storm winds is more useful to oceanographers than information on average wind.

### Ecological significance

The ecological impacts of episodes of strong wind in Arctic marine areas are wide ranging. Such events in succession drive the movements of sea water and sea ice into, around, and out of the Arctic, which in turn maintain the conditions to which Arctic organisms have adapted. Strong wind events facilitate the annual cycle of freeze-up, icescape development, breakup, and decay. Their impact on the recurrent opening and closing of leads and polynyas and on the formation of ice ridges creates the unique ice habitat which is the most obvious feature of Arctic marine ecosystems. Strong winds generate rapid ice drift, powerful currents, and storm waves, all of which accelerate the mixing of surface waters with those beneath, thereby bringing dissolved nutrients from deeper layers into the photic zone. A nutrient-rich photic zone supports the primary production that is the basis of a diverse, productive ocean food web.

### Major concerns

Possible changes over time in the Arctic-wide distribution of strong winds, their strength, and their prevalent directions are likely to bring change to the characteristics of ocean and sea ice habitats and to the productivity of the ecosystems that they support. Our understanding of the future storm climate of the Canadian marine Arctic is in its infancy.

### Gaps in current knowledge

Scientific knowledge of atmospheric storm systems and the winds that they generate is well-established. Moreover, a worldwide atmospheric monitoring system already exists for forecasting weather. However, the geographic coverage of this system is poorer over oceans than over land, and the Arctic has been monitored for far fewer years than other regions. Knowledge of the attributes of strong winds across the Arctic could therefore be improved.

### Rubbled Sea Ice

Storm winds can jam ice floes together, creating bands of rubble ice that can be many kilometres wide.



An eye-level view of grounded rubble, Beaufort Sea, Spring 2006.



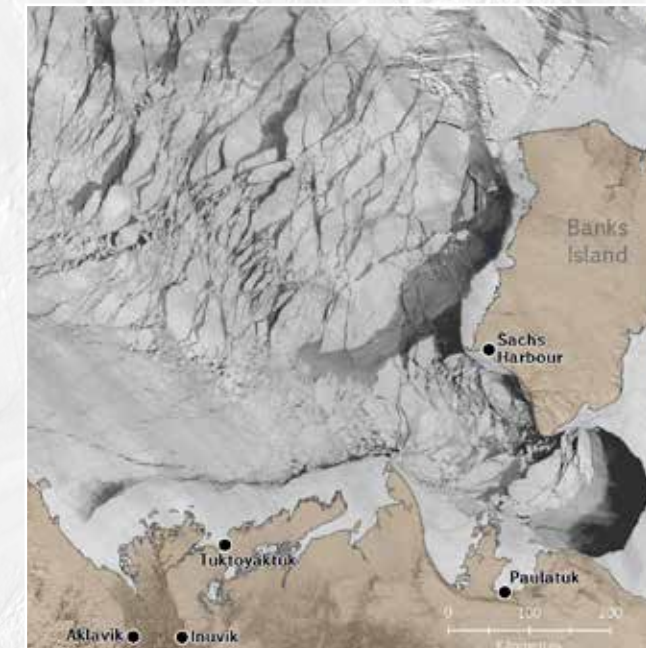
Summertime remnant of the network of ice rubble that stabilized a wide band of fast ice along the Beaufort coast during the preceding winter. (photos: H. Melling)

Facing page: A storm event, Churchill, Manitoba.  
(photo: All Canada Photos)

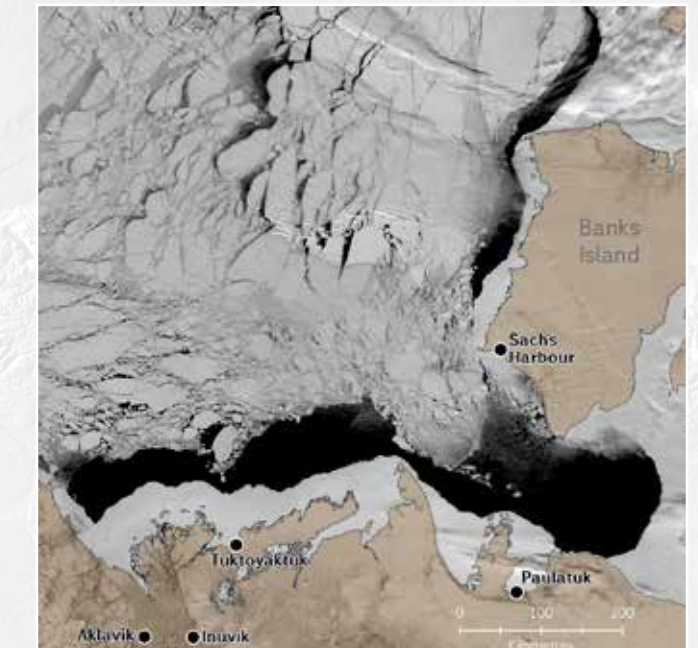
## Storm Effects on Sea Ice Cover

Winds blowing seaward during a four-day storm event in April 2015 (seen in graphic at bottom of the page) opened a vast polynya in the eastern Beaufort Sea as seen by satellite imagery from that time (top of the page).

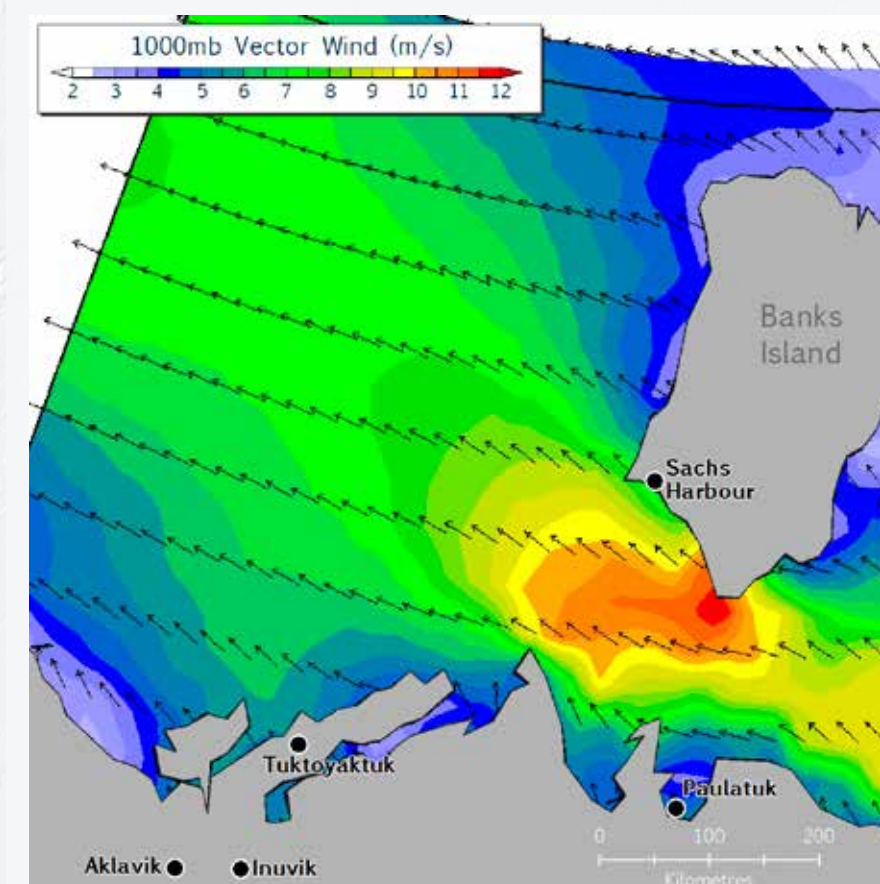
Before Storm Event: 4/19/2015



After Storm Event: 4/27/2015



Black areas are open water or ice free.



WIND DIRECTION AND SPEED DURING STORM EVENT, APRIL 19-22, 2015

### NCEP North American Regional Reanalysis 1000mb Vector Wind (m/s) Composite Mean

Strongest winds in red.

DATA SOURCES  
- Satellite Images: Enhanced imagery from NASA Worldview.  
- Graphic provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado from their website at <https://www.esrl.noaa.gov/psd/>; Kalnay et al., The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc., 77, 437-470, 1996.





## BIG ARCTIC, LITTLE ARCTIC

### PHYSICAL OCEANOGRAPHY

- Landscape of the Seabed
  - Seawater Sources and Surface Currents
  - Sea Ice and Its Variation
  - Tides and Their Effects
  - Storms and Their Effects
- ➡ “Big Arctic” vs. “Little Arctic”

**THE PREVIOUS MAPS** have illustrated the physical factors that influence the Canadian marine Arctic environment on a scale of hundreds to thousands of kilometres, including seabed landforms, ice conditions, currents, water masses, tides, and storms. The interaction of these factors has allowed the delineation of the five broad oceanic domains shown on the map at the beginning of this chapter. However, local intensification of these influences creates unique ocean conditions and marine habitat on scales too small to be seen on the maps presented so far in this chapter. Three of many possible examples are provided here.

#### Penny Strait

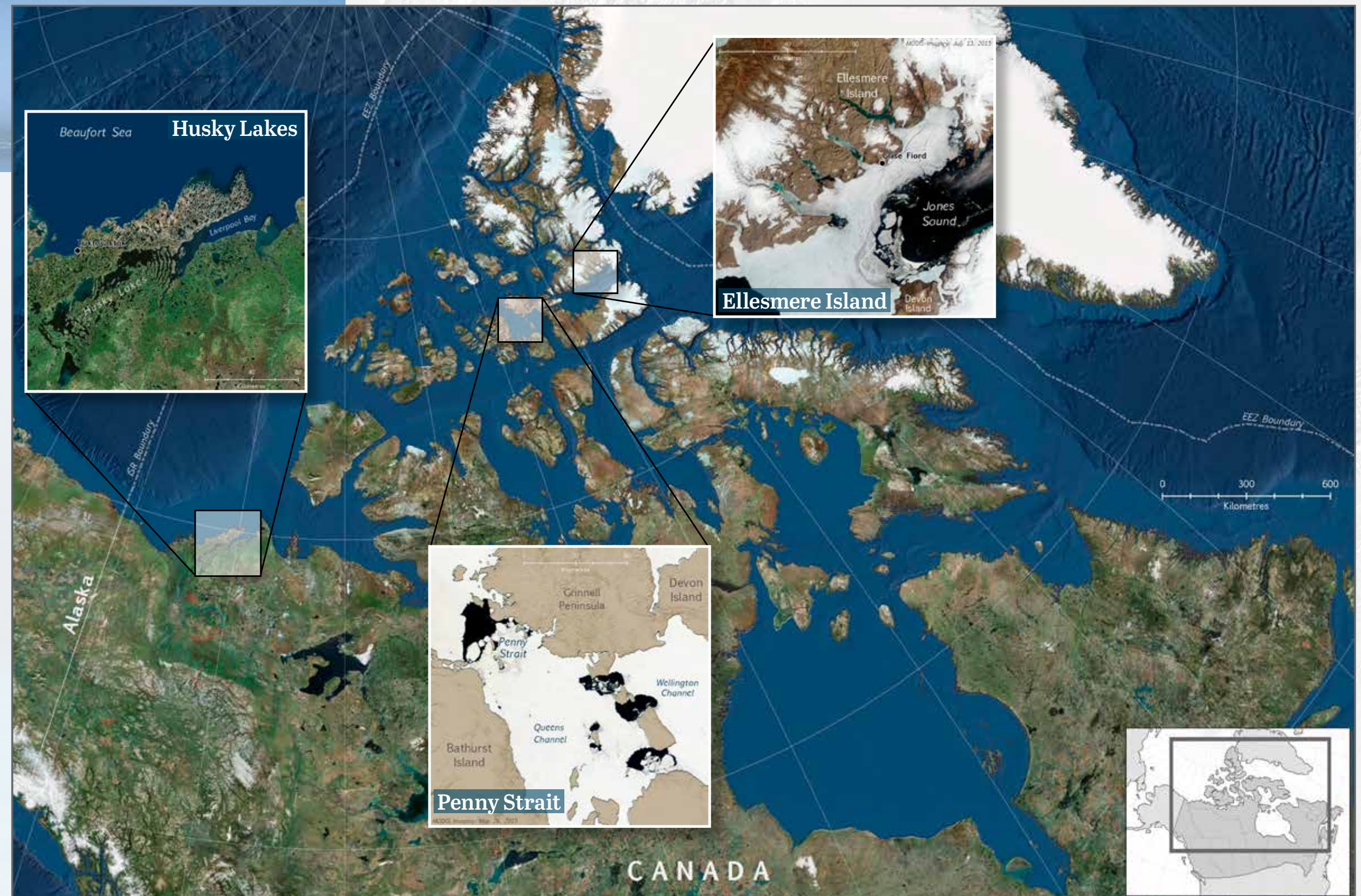
Penny Strait is a 30-km-wide channel northwest of the central sills of the Canadian Polar Shelf. Currents generated by the tide here and in shallower straits to its southwest are strong (1 to 2 m/s). Whereas Atlantic water that reaches the slopes of the sills from the southeast and the northwest is too deep to flow over the sills, the energy of the tidal current forces it to mix with overlying Pacific and Arctic waters which are shallow enough to cross the sills. The mixing effectively lifts some of the warmth in Atlantic water to the surface, heating the underside of sea ice. The ocean heat reduces ice growth during cold months and accelerates the ice's disappearance months before surrounding ice breaks up. Light ice conditions allow walrus to overwinter here—small patches are almost always ice free—and make living easier for seals, bears, and seabirds. The area of strong tides near Penny Strait is less than 1,000 km<sup>2</sup>, tiny on the scale of the Canadian marine Arctic, yet ecologically important far beyond its size. Similar conditions occur in a handful of other straits on the eastern Canadian Polar Shelf.

#### Fjords of southern Ellesmere Island

The fjords of southern Ellesmere Island mark the paths of glaciers that formerly flowed into Jones Sound. The Inuit of Grise Fjord regard one of these, South Cape Fjord, to be an excellent place to hunt seals. Narwhal and seabirds are reportedly common here too. Locally enhanced productivity—the base of the food web—is the usual reason for such aggregations, and the reason for enhanced productivity is frequently an increased supply of ocean nutrients to surface waters. The likely source of nutrients is deeper waters because algae rapidly consume near-surface supplies. Scientists use ice as convenient indicator of nutrient upwelling because deeper water in the Arctic is generally warmer and richer in nutrients than surface water. Surveys have revealed warm water pushed up to the surface within South Cape Fjord, producing anomalously thin ice in winter here and in two other fjords. Research suggests that the interaction of tidal current with a shoal (sill) across the fjord's mouth is the cause of the upwelling, but that not all fjords will be affected in this way.

Facing page: The high hills and glaciers of Ellesmere Island flow into the sea. (photo: David Noton Photography)

DATA SOURCES  
- Basemap Data and Husky Lake Imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.  
Penny Strait, Ellesmere Island  
- NASA Worldview



#### Husky Lakes

The Husky Lakes estuary is a series of five linked basins that drain into Liverpool Bay in the Beaufort Sea, near the communities of Tuktoyaktuk and Inuvik. The Husky Lakes are separated from the Beaufort Sea by a shallow sill just 4 m deep, and they are ice covered about eight months of the year. The lakes are a unique ecosystem, defined by the mixing of freshwater runoff and the intrusions of salt water from the sea. Due to their varied salinity conditions, the lakes are home to a

diverse fish population, including marine, anadromous, and even some freshwater species. Fish use the lakes for spawning, overwintering, and foraging. Beluga whales feed there during the summer. At times, beluga perish in the lakes during autumn when growing ice in connecting waterways blocks their escape to the open sea. The region is economically and culturally important to the Inuvialuit, who use it extensively for hunting, fishing, trapping, and travel.



# FURTHER READING

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