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Ice Navigation in Canadian Waters

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Ice Navigation in Canadian Waters

CCG/6120

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Inquiries

Note: Any inquiries as to the contents of this publication or reports of errors or omissions should be directed to DFO.ManagerIBProgArcticOps-ProgDECIOpsArctique.MPO@dfo-mpo.gc.ca.

Amendment register

Amendment #	Date	Description
1	1977	First revision (second edition)
2	1987	Second revision (third edition)
3	1999	Third revision (fourth edition)
4	2012	Fourth revision (fifth edition)
5	2022	Fifth revision (sixth edition)

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Abbreviations

Abbreviation	**Definition**	**Abréviation**	**Définition**
AIRSS	Arctic Ice Regime Shipping System	SRGNA	système des régimes de glaces pour la navigation dans l'Arctique
AIS	automatic identification system	SIA	système d'identification automatique
ARPA	automatic radar plotting aid	ARPA	aide de pointage radar automatique
ASPPR	Arctic Shipping Pollution Prevention Regulation (Repealed)	RPPEAN	règlement sur la prévention de la pollution des eaux arctiques par les navires
ASSPPR	Arctic Shipping Safety and Pollution Prevention Regulations	RSNPPA	règlement sur la sécurité de la navigation et la prévention de la pollution dans l'Arctique
CAC	Canadian Arctic Category	CAC	catégorie arctique canadienne
CCG	Canadian Coast Guard	GCC	Garde côtière canadienne
CHS	Canadian Hydrographic Service	SHC	Service hydrographique du Canada
CIS	Canadian Ice Service	SCG	Service canadien des glaces
DFO	Fisheries and Oceans Canada	MPO	Pêches et Océans Canada
ECCC	Environment and Climate Change Canada	ECCC	Environnement et Changement climatique Canada
ENC	electronic navigational chart	CEN	carte électronique de navigation
FDD	freezing degree-day	DJG	degré-jour de gel
GLONASS	global navigation satellite system	GLONASS	système mondial de satellites de navigation
GMDSS	Global Maritime Distress and Safety System	SMDSM	système mondial de détresse et de sécurité en mer

Abbreviation	Definition	Abréviation	Définition
GPS	global positioning system	GPS	système de localisation GPS
GRT	gross register ton	TJB	tonneau de jauge brute
HDOP	horizontal dilution of precision	HDOP	affaiblissement de la précision horizontale
IACS	International Association of Classification Societies	IACS	International Association of Classification Societies
IM	ice multiplier	MG	multiplicateur glaciel
IMO	International Maritime Organization	OMI	Organisation maritime internationale
IN	ice numeral	NG	numéral glaciel
ISF	Icebreaking Services Fee	DSD	droits de services de déglaçage
ISS	Ice Services Specialists		spécialiste des glaces
JRCC	joint rescue coordination centre	CCCOS	centre conjoint de coordination des opérations de sauvetage
LEO	low Earth orbit	LEO	orbite terrestre basse
LOS	levels of service	NS	niveaux de service
MCTS	Marine Communications and Traffic Services	SCTM	Services de communications et de trafic maritimes
MDD	melting degree-day	DJF	degré-jour de fonte
NAD	North American Datum	NAD	système de référence nord-américain
PEI	Prince Edward Island	Î.-P-É	Île-du-Prince-Édouard
RAMN	Radio Aids to Marine Navigation	ARNM	Aides radio à la navigation maritime
RNC	Raster Navigational Charts		cartes marine matricielle
SAR	Search and Rescue	SAR	Recherche et sauvetage

Abbreviation	Definition	Abréviation	Définition
SMS	safety management system	SGS	système de gestion de la sécurité
STCW	Standards for Training and Certification of Watchkeeping		Normes STCW
TC	Transport Canada	TC	Transports Canada
USCG	United States Coast Guard	USCG	United States Coast Guard
USCGIIP	U.S. Coast Guard International Ice Patrol	USCGIIP	U.S. Coast Guard International Ice Patrol
UTC	Coordinated Universal Time	UTC	temps universel coordonné
WGS	World Geodetic System	WGS	Système géodésique mondial

Preface

The CCG/6120 - Ice Navigation in Canadian Waters Manual is published by the Canadian Coast Guard (CCG) in collaboration with Transport Canada Marine Safety, the Canadian Ice Service (CIS) of Environment and Climate Change Canada (ECCC) and the Canadian Hydrographic Service of Fisheries and Oceans Canada. The publication is intended to assist vessels operating in ice in all Canadian waters, including the Arctic. This document will provide mariners of vessels transiting Canadian ice-covered waters with the necessary understanding of the regulations, shipping support services, hazards and navigation techniques in ice.

Chapter 1, Icebreaking and Shipping Support Services, pertains to operational considerations, such as communications and reporting requirements as well as ice advisories and icebreaker support within Canadian waters.

Chapter 2, Regulations and Guidelines provides a summary of information on regulations and guidelines for vessels transiting ice covered waters.

Chapter 3, Ice Climatology and Environmental Conditions covers information on the Canadian ice and weather environment.

Chapter 4, Navigation in Ice Covered Waters, is instructional in nature, with information provided to help familiarise inexperienced personnel with passage planning, navigation procedures in ice, vessel performance in ice, and other essential operating procedures.

Chapter 5,Vessel Design and Construction for Ice Operations provides the mariner with basic information on engineering, hull and auxiliary systems for vessels operating in ice.

Note: Nothing written here will have precedence over the *Canada Shipping Act, 2001* and the *Arctic Waters Pollution Prevention Act*, nor should the following material be quoted as representing them.

1 Icebreaking and Shipping Support Services

1.1 General

There are a variety of icebreaking and support services available to vessels transiting Canadian ice-covered waters. CCG Ice Operations centres are in operation seasonally as ice conditions dictate. These centres work in conjunction with Marine Communications and Traffic Services (MCTS) centres to provide up-to-date ice information, to suggest routes for vessels to follow through or around ice, and to co-ordinate icebreaker assistance to shipping.

Ice Operations centres are in contact with icebreakers at all times and monitor progress of shipping within their area of responsibility. In addition, CIS has fully qualified Ice Service Specialists with air ice reconnaissance capacity who are involved with Ice Operations centres on a full-time basis throughout the ice navigation season. The regional Coast Guard icebreaking superintendents have a complete and current picture of the prevailing ice conditions in their area and the anticipated trend of conditions and are therefore well equipped to provide reasoned advice on the best routes to pursue.

To obtain the maximum benefit from the service, it is essential that mariners report to the CCG before their vessels enter waters where ice may be encountered. These initial reports and subsequent position reports from vessels will ensure a continuing watch on the ship's progress by the CCG Ice Operations centres and, in the event icebreaker support becomes necessary, this can be provided with a minimum of delay. There are a limited number of icebreakers available to support shipping. Mariners are encouraged to follow the recommended route with which they are provided. They may also assist and support this service by providing reports on the ice they encounter, either in plain language or in the simple code contained in section 4.16.3.

1.2 Communications

Communications play a key role in successful ice navigation. The mariner relies upon the receipt of accurate ice information and advice upon which decisions can be based for their future course and progress. Effective icebreaker support and assistance to shipping also requires reliable communications. Detailed information on communications with CCG icebreakers is provided in section 4.6.1 of this manual.

The Eastern Canada Vessel Traffic Services, known as ECAREG CANADA, and the Northern Canada Vessel Traffic Services, known as NORDREG CANADA are mandatory vessel traffic services. These systems also provide the mariner with information pertaining to ice conditions, vessel routing, icebreaker assistance and other CCG services. Vessels may contact ECAREG or NORDREG CANADA via the nearest MCTS centre or refer to the latest edition of the annual publication Radio Aids to Marine Navigation (RAMN).

Note*:* Contact must be made with ECAREG or NORDREG CANADA 24 hours before entering Canadian waters, to obtain a clearance. To meet Transport Canada Marine Safety and Security requirements (Pre-Arrival Information Report). Contact must also be provided to ECAREG or NORDREG CANADA 96 hours before entering Canadian waters as per section 4.29 of the RAMN.

MCTS centres accept messages without charge, such as:

- messages pertaining to weather or ice conditions and forecasts
- messages concerning aids to navigation
- ECAREG and NORDREG messages
- messages reporting pollution
- radio-medical messages

For additional information on MCTS message services, consult the latest edition of the annual publication RAMN.

Note: In order to keep a current and accurate picture of the ice conditions it is highly recommended that vessels participating in the ECAREG or NORDREG provide position, ice and weather information at 1200, 1600 and 2000 UTC, when ice is present.

1.3 Canadian Coast Guard Ice Operations Centres

The CCG maintains Ice Operations centres to service regions where vessel operations are conducted in sea-ice conditions. Contact with all Ice Operations centres can be made through ECAREG CANADA and NORDREG CANADA (for Arctic waters) or through any MCTS Centre. Any requests from vessels for ice information, routing advice and icebreaker support that are received by ECAREG CANADA and NORDREG CANADA are passed to CCG ice superintendents.

Atlantic coast (Operating December to May)

Phone:

- For Icebreaking operations
  - (709) 772-2078
  - 1-800-565-1633 (option 7)
- For ice conditions
  - (709) 772-2078
  - 1-800-565-1633 (option 7)

Email:

- For general inquiries
  - iceatl@dfo-mpo.gc.ca
  - iceatl.cggc@dfo-mpo.gc.ca
- For 24-hour assistance
  - vts.labrador@innav.gc.ca
  - Supervisor.MCTS-Halifax@dfo-mpo.gc.ca
  - Safety.Placentia@innav.gc.ca
  - Safety.Sydney@innav.gc.ca
- For ice conditions
  - ec.ssgatlantique-issatlantic.ec@canada.ca

Mail:

- St. John’s Ice Centre
  Canadian Coast Guard PO
  Box 5667
  St. John's NL A1C 5X1

Arctic (Operating June to November)

Phone:

- For Icebreaking operations
  - (514) 283-2784
- For ice conditions
  - (514) 283-1752
  - (514) 283-2069

Email:

- For icebreaking operations
  - dfo.ccgiceopsarctic-opsglacearcticgcc.mpo@dfo-mpo.gc.ca
- For 24-hour assistance
  - vts.iqaluit@innav.gc.ca
- For ice conditions
  - ec.ssgarctique-issarctic.ec@canada.ca

Mail:

- Montréal Ice Centre
  Canadian Coast Guard
  5th floor, 105 McGill
  Montréal QC H2Y 2E7

Great Lakes (Operating December to May)

Phone:

- For Icebreaking operations
  - (514) 283-2784
- For ice conditions
  - (514) 283-1752
  - (514) 283-2069

Email:

- For icebreaking operations
  - dfo.ccgcentraliceopsgreatlakes-grandslacsopsglacescentregcc.mpo@dfo-mpo.gc.ca
- For 24-hour assistance
  - dfo.montrealops-opsmontreal.mpo@dfo-mpo.gc.ca
- For ice conditions
  - ec.ssggrandslacs-issgreatlakes.ec@canada.ca

Mail:

- Montréal Ice Centre
  Canadian Coast Guard
  5th floor, 105 McGill
  Montréal QC H2Y 2E7

St. Lawrence (Operating December to May)

Phone:

- For Icebreaking operations
  - (514) 283-1746
- For ice conditions
  - (514) 283-1752
  - (514) 283-2069

Email:

- For icebreaking operations
  - dfo.ccgcentraliceopsstlawrence-stlaurentopsglacescentregcc.mpo@dfo-mpo.gc.ca
- For 24-hour assistance
  - dfo.montrealops-opsmontreal.mpo@dfo-mpo.gc.ca
- For ice conditions
  - ec.ssgstlaurent-issstlawrence.ec@canada.ca

The CCG Ice Operations Centre operates in concert with the United States Coast Guard Ice Navigation Centres. Together they co-ordinate ice operations in the Great Lakes from upper Beauharnois Lock to Thunder Bay, including the main connecting navigable waterways, Georgian Bay, and the upper St. Lawrence River. The icebreaking season normally commences operation in December, as soon as temperature lowers and ice starts to form and terminates when ice conditions permit unrestricted navigation. Vessels operating in this zone may obtain the latest ice information by contacting the Ice Operations Centre via any CCG MCTS Centre.

One purpose of the Ice Operations centres is to maintain a current picture of ice conditions, acquired from information supplied by the CIS, as well as from vessel and shore ice reports, and ice reconnaissance flights. This update is available on request 24 hours a day through MCTS centres. The Ice Operations centres also plan daily activities and tasks for icebreakers stationed in their area. These daily plans are based on the ice conditions and requests for icebreaker support. These plans, as well as weather and ice conditions and forecast, are provided daily through a daily conference call with the industry and CCG partners, and a Power Point presentation is available through e-Navigation Portal.

The Ice Operations officers, supported by the Ice Service Specialists (ISS), prepare detailed recommended ice routes for vessels, which are updated on a daily basis or as required. All routing is provided in terms of waypoints and may also be available overlaid on an Ice Chart. Recommended ice routes for the main shipping lane through the Gulf of St. Lawrence and other ice information may be obtained from the CCG e-Navigation Portal. Figure 1 is an example of a recommended route.

The CCG has established levels of service (LOS) for Icebreaking Operations. The LOS provides a description of the various services as well as service standard targets, such as the availability of icebreakers (where and when) and how long it may take an icebreaker to arrive on scene to provide assistance.

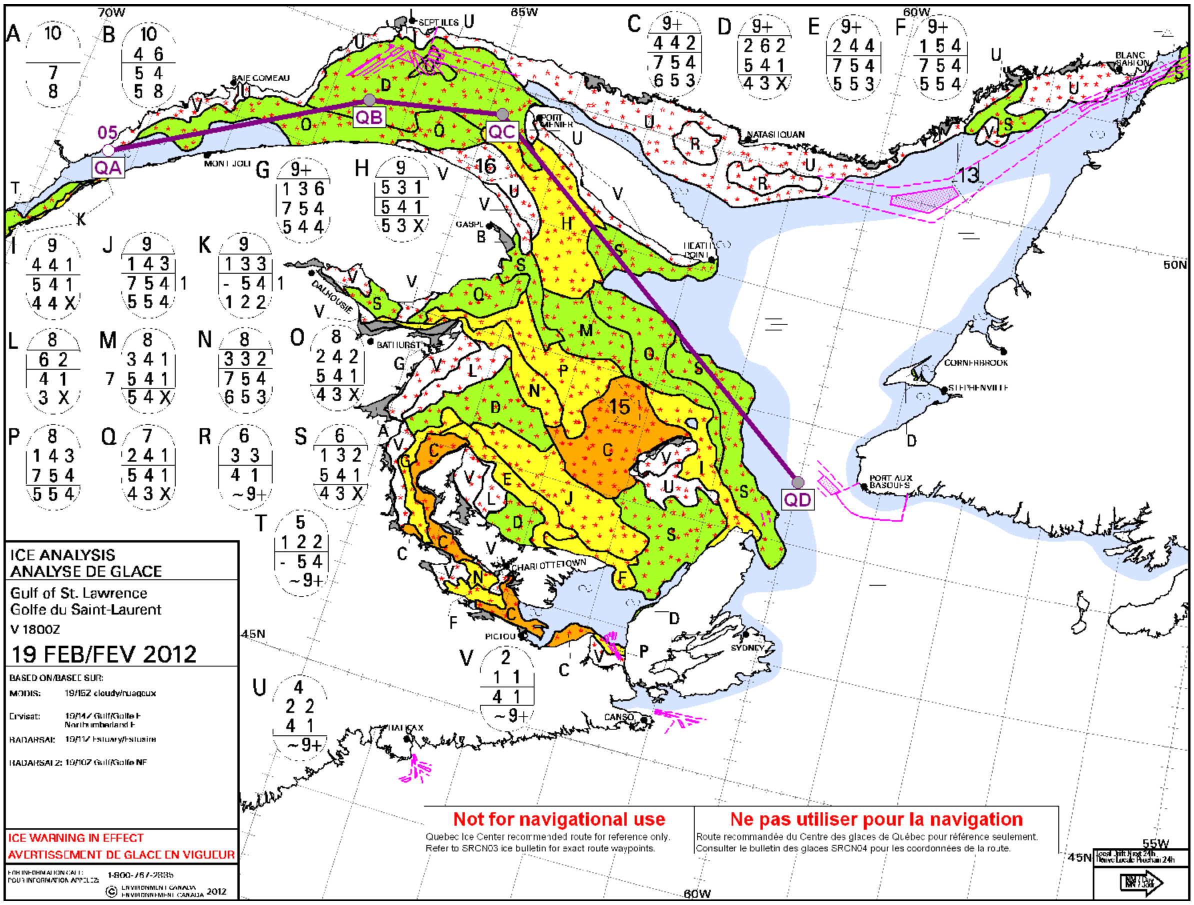


Figure 1 - Example of a Recommended Ice Route in the Gulf of St. Lawrence

1.4 Winter Navigation in Southern Canada

1.4.1 Reporting Requirements

The Eastern Canada Vessel Traffic Service System, known as ECAREG CANADA, is a mandatory vessel traffic services system providing the mariner with a single contact for Coast Guard services. The *Eastern Canada Vessel Traffic Services Zone Regulations* apply to every vessel of 500 gross register tonnage (GRT) or more. They are also mandatory for vessels engaged in towing or pushing one or more vessels with combined tonnage of 500 GRT, or when either vessel is carrying a pollutant or dangerous goods, as defined in *Transportation of Dangerous Goods Act, 1992*.

The Eastern Canada Traffic Zone comprises all Canadian East Coast Waters south of Cape Chidley (60°00'N), the Gulf of St. Lawrence and the St. Lawrence River east of 66°00'W. Local vessel traffic service zones are excluded from the ECAREG CANADA Zone but will forward any requests for ice services to ECAREG CANADA and/or the Ice Operations Centre.

Vessels transiting the St. Lawrence River west of longitude 66°W may obtain ice information for the St. Lawrence River by contacting ECAREG CANADA via a MCTS centre prior to crossing 66°W, or a MCTS Centre on the appropriate vessel traffic service’s frequency if transit of the St. Lawrence River has commenced.

Inbound vessels making their initial clearance request to ECAREG CANADA should include the following information in addition to that required by the *Eastern Canada Traffic Zone Regulations*:

- draft, forward and aft
- displacement tonnage
- open water speed
- ice class, if applicable, and classification society
- number of propellers
- shaft horsepower
- type of propulsion system

A clearance issued by ECAREG CANADA authorizes a vessel to proceed subject to any conditions issued in the clearance. Routine reports are required when arriving at and departing a berth and exiting the ECAREG CANADA zone.

For details on the reporting requirements and information on the various services, refer to the latest edition of the annual publication RAMN*.*

Vessels that have reported to ECAREG CANADA, as per reporting requirements, and are approaching the Gulf of St. Lawrence by either Belle Isle Strait or Cabot Strait will receive ice routing 24 hours prior to entering the Gulf of St. Lawrence via MCTS Halifax. Additional routing for transit areas within the Gulf and in the river West of 66°W are handled by MCTS Les Escoumins.

1.4.2 Outside Gulf

ECAREG CANADA
MCTS centre: Halifax, Nova Scotia
Call Sign: VCS
Telephone: (902) 426-4956
Fax: (902) 426-4483
E-mail*:* hlxecareg1@innav.gc.ca

1.4.3 Inside Gulf and St. Lawrence River

ECAREG CANADA
MCTS centre: Les Escoumins, Quebec
Call Sign: VCF
Telephone: (418) 233-3483
Fax: (418) 233-3299
E-mail: ecareg.escoumins@innav.gc.ca

1.4.4 Iceberg limit information

MCTS centre: Labrador, NL (located in Goose Bay, NL)
Call Sign: VOK
Telephone: (709) 896-2252
Fax: (709) 896-8455
E-mail: labrador.mcts@dfo-mpo.gc.ca and safety.labrador@innav.gc.ca

1.4.5 St. Lawrence Seaway

The St. Lawrence Seaway extends from Montreal to Lake Erie. It includes the Welland Canal, often referred to as the Western Section, and in the east, the Montreal - Lake Ontario section, which extends from the St. Lambert Lock at Montreal (the up bound entrance of the Seaway), to Iroquois Lock and beyond to Lake Ontario.

The navigation season on the waterway extends from mid March to late December. The St. Lawrence Seaway issues Seaway Notices to advise mariners of exact opening and closing dates of the navigation season and restrictions such as speed and draft and procedures for transiting the Seaway during the opening and closing. Seaway Authorities may increase or decrease the restrictions as ice and other conditions dictate. These changes will be announced as early as is practical, but in no case later than 24 hours before they go into effect. Mariners should consult the complete Regulations and Laws of the Great Lakes St. Lawrence Seaway System.

1.4.6 Great Lakes

The Great Lakes includes Lake Ontario, Erie, Huron, Michigan and Superior, as well the Georgian Bay. Detroit River connects from Lake Erie to Ste Clair River through the Lake Ste Clair. The Georgian Bay and Lake Huron are connected to Lake Superior through the North Channel, the St. Marys River and the Soo Locks extending to Whitefish Bay.

The navigation season extends from late March to late December. Close partnership exists between CCG and USCG for the services delivery of those sectors.

1.5 Arctic Waters including Hudson Bay and Hudson Strait

1.5.1 Reporting requirements

There are several Canadian authorities involved in marine shipping in the Canadian Arctic, namely, the federal government, the Government of the Northwest Territories (Yellowknife), the Government of Nunavut (Iqaluit), the Government of Yukon (Whitehorse) and the Canadian provinces of Manitoba and Québec. Vessels must contact the following relevant government organizations prior to an Arctic voyage:

1. Transport Canada, Prairie and Northern Region - Marine will have all the up-to-date information relating to marine regulations applicable to vessels operating in the region and is responsible for all vessel approval. The vessel should have a general vessel itinerary that determines whether it falls within legal entry limits for the various Shipping Safety Control Zones.
2. The CCG, Arctic Region should be provided with an itinerary early in the planning process. The CCG will use this information in combination with other submissions in the spring to plan the deployment of their icebreaking resources for the upcoming season.
3. Customs and immigration regulations need to be contacted by any cruise vessel operators as the issuing of a coasting trade licence is necessary for vessels carrying passengers from one port to another in Canada. The Canada Border Services Agency coordinates this activity with Transport Canada. Organizers are also requested to provide details of their planned itineraries to the Department of Foreign Affairs and International Trade.
4. After obtaining approval and arranging matters with the Canada Border Services Agency and Immigration, Refugees and Citizenship Canada, Transport Canada Security should be contacted to discuss security matters relating to the *Marine Transportation Security Act*.

1.5.2 Northern Canada Vessel Traffic Services Zone Regulations

The *Northern Canada Vessel Traffic Services Zone Regulations* apply to every vessel of 300 GRT or more; to vessels engaged in towing or pushing another vessel if the combined tonnage of 500 GRT or more; to vessel that are carrying as cargo, a pollutant or dangerous goods or towing or pushing a vessel that is carrying pollutant or dangerous goods.

NORDREG CANADA is a mandatory vessel traffic services system that also provides the mariner with information pertaining to ice conditions, vessel routing, icebreaker assistance and other government services. Mariners may obtain ice information and access shipping support services by sending a free message to NORDREG CANADA.

The Northern Canada Vessel Traffic Services (NORDREG) Zone (figure 2) consists of:

a) the shipping safety control zones prescribed by the Shipping Safety Control Zones Order
b) the waters of Ungava Bay, Hudson Bay and Kugmallit Bay that are not in a shipping safety control zone
c) the waters of James Bay
d) the waters of the Koksoak River from Ungava Bay to Kuujjuaq
e) the waters of Feuilles Bay from Ungava Bay to Tasiujaq
f) the waters of Chesterfield Inlet that are not within a shipping safety control zone, and the waters of Baker Lake
g) the waters of the Moose River from James Bay to Moosonee

The NORDREG CANADA office is located in the MCTS centre in Iqaluit, Baffin Island, Nunavut and is supported by a CCG Ice Operations Centre. MCTS Iqaluit is seasonally operational *from mid-May to late December* each year. The actual dates are advertised by NAVWARN and NAVAREA Warnings. Outside of MCTS Iqaluit's operational season, MCTS Prescott assumes the responsibility for NORDREG CANADA on behalf of the MCTS Iqaluit.

For NORDREG CANADA reporting requirements and information of various services, refer to the latest edition of the national publication RAMN.

Address:	NORDREG CANADA		
MCTS Centre:	Iqaluit, Nunavut	**Call Sign:**	VFF
Operational: Approximately mid-May to late December			
Email:	IQANORDREG@INNAV.GC.CA		
Telex (telefax):	063-15529	**Telegraphic address:** NORDREG CDA	
Telephone:	(867) 979-5724/5269	**Fax:** (867) 979-4264	
From late December to mid-May:			
MCTS Centre:	Prescott, Ontario	**Call sign**: VBR	
Telephone:	613-925-4471	**Fax:** 613-925-4519	

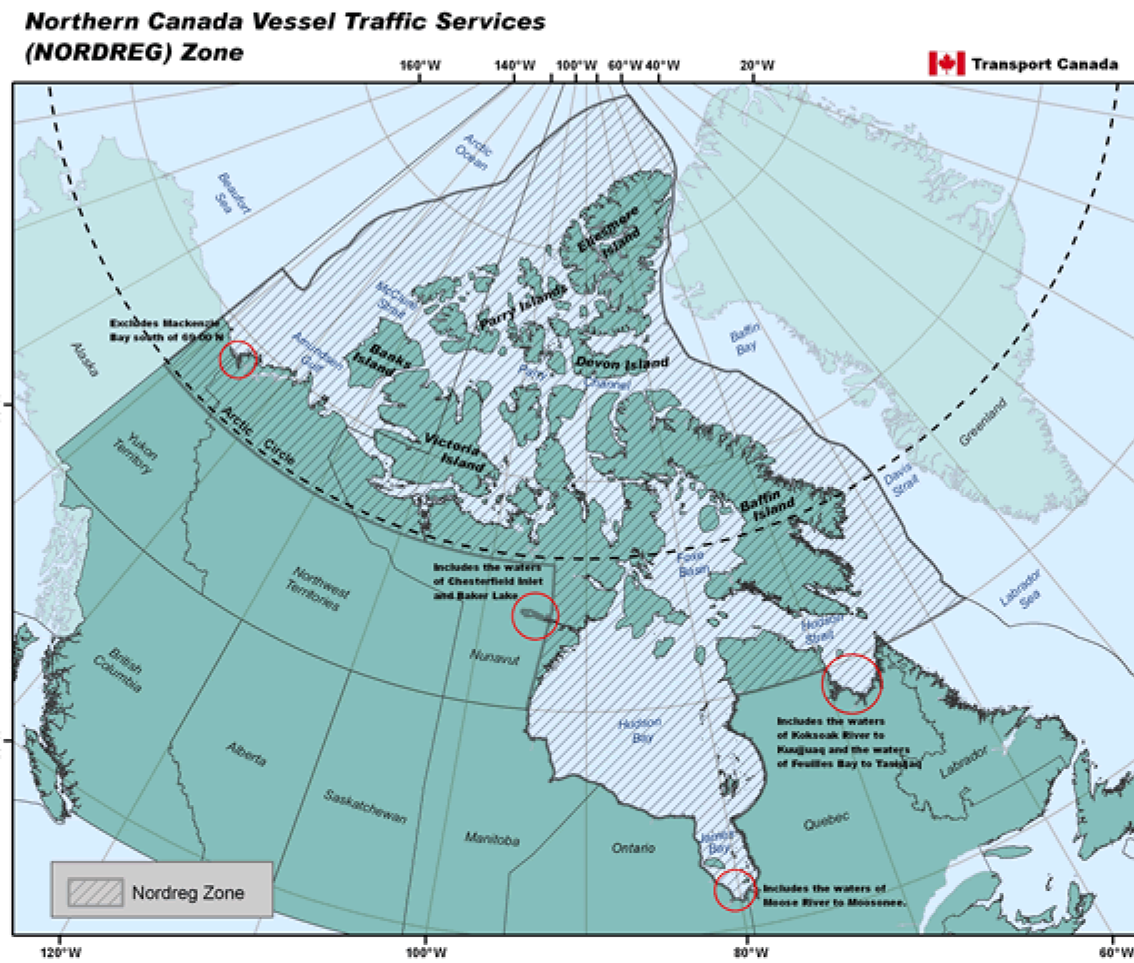


Figure 2 - Northern Canada Vessel Traffic Services Zone

1.6 Canadian Ice Service - Environment and Climate Change Canada

Throughout the year, ice information services for Canadian navigable waters are provided by CIS. The CIS maintains a central operating facility in Ottawa for assimilating all ice data and is responsible for satellite image analysis, ice charts and ice forecasts and warnings for Canada's navigable waters.

Latest ice conditions and ice charts are issued daily for areas of known marine activity and where ice is a navigational hazard. They are distributed to the CCG Ice Operations centres and are also broadcast by radio and radio facsimile via MCTS centres. Particulars of these broadcasts are contained in the CCG publication RAMN, Part 2. The MCTS centres will also provide ice information on request, including pre-departure ice information. Information for longer term planning, extended period ice forecasts, and ice consultation services are available directly from the CIS, Ottawa or by consulting the Environment and Climate Change Canada (ECCC) Ice forecasts and observations. Ice information may also be obtained from the Ice Conditions section of the CCG e-Navigation Portal.

CIS website:	Latest ice conditions
Address:	Canadian Ice Service 719 Heron Road, Annex E Sir Leonard Tilley Ottawa, Ontario K1A 0H3
Telephone	1-877-789-7733
Fax	(613) 947-9160

When required by the CCG, the CIS assigns ISSs' on the larger CCG icebreakers. The ISS are responsible for receiving and interpreting satellite imagery and carrying out tactical ice reconnaissance on helicopters for the icebreaker and Ice Operations centres.

1.7 ECCC Storm Prediction Centres

Marine weather forecasts and warnings are issued for Canadian marine areas by ECCC from several regional Storm Prediction Centres (SPC). Meteorologists at these Centres provide 24-hour services in the form of forecasts and consultation. SPCs providing forecasts and warnings are:

- **Prairie and Arctic SPC**, for inland waters (Mackenzie River, Great Slave Lake and Lake Athabasca) and all Arctic waters including Beaufort Sea to St. Roch Basin, Baffin Bay, Hudson Bay, Foxe Basin, Hudson Strait, Davis Strait, and high Arctic waters along the western Queen Elizabeth Islands. Additional marine forecasts also provided for Lake Winnipeg, Lake Manitoba and Lake Winnipegosis.
- **Ontario SPC**, for several major inland lakes and waterways, the Canadian portion of the Great Lakes and the Ontario portion of the St. Lawrence River.
- **Québec SPC**, for the St. Lawrence River and Saguenay River.
- **Atlantic SPC**, for the Gulf of St. Lawrence and waters off Nova Scotia, New Brunswick, and Prince Edward Island.
- **Newfoundland and Labrador SPC**, for Newfoundland waters and Labrador Sea.

Environmental science centres across Canada can be found at Canada.ca - Environmental science centres across Canada

Note: Information on marine weather including contact information can be found on the Weather Information of ECCC.

1.7.1 Weather forecasts for marine areas

Marine forecasts are generally prepared for distinct marine areas four times daily. The forecasts are valid for 2 days with a 3rd day outlook and provide information about wind, visibility, freezing spray, and temperature. A marine synopsis (or summary) is given with the forecast, including the movement of weather systems and warnings in effect. Special marine bulletins are issued when certain weather criteria are met. These are broadcast by MCTS centres according to schedules as published in the latest edition of the annual publication RAMN, Part 2.

For example, most of the SPCs provide 4 scheduled forecasts each day for their area of responsibility. The SPC located in Edmonton, AB provides twice daily scheduled forecasts for the Arctic and Hudson Bay waters.

1.7.2 Weather charts for marine areas

Weather information is also transmitted in facsimile chart form over high and low radio frequencies. Products include an analysis chart of existing weather conditions as well as prognosis charts. Mariners should consult the latest edition of the annual publication RAMN, part 5 for details of ECCC's programs, including the list of charts and their transmission times.

The Prairie and Arctic SPC provides weather charts for Arctic areas for broadcast by MCTS Iqaluit and repeater stations during the active shipping season. Numerous charts are transmitted by the Canadian Meteorological and Oceanographic Society centre in Halifax, Nova Scotia, including sea condition charts, throughout the year.

1.8 METAREAS and NAVAREAS

The CCG has assumed the responsibility of NAVAREA coordination for NAVAREAs XVII and XVIII as part of the World Wide Navigational Warning Service (figure 3). The service was declared to be in "Full Operational Condition" as of June 1, 2011. Mariners should consult the annual edition of RAMN for additional information.

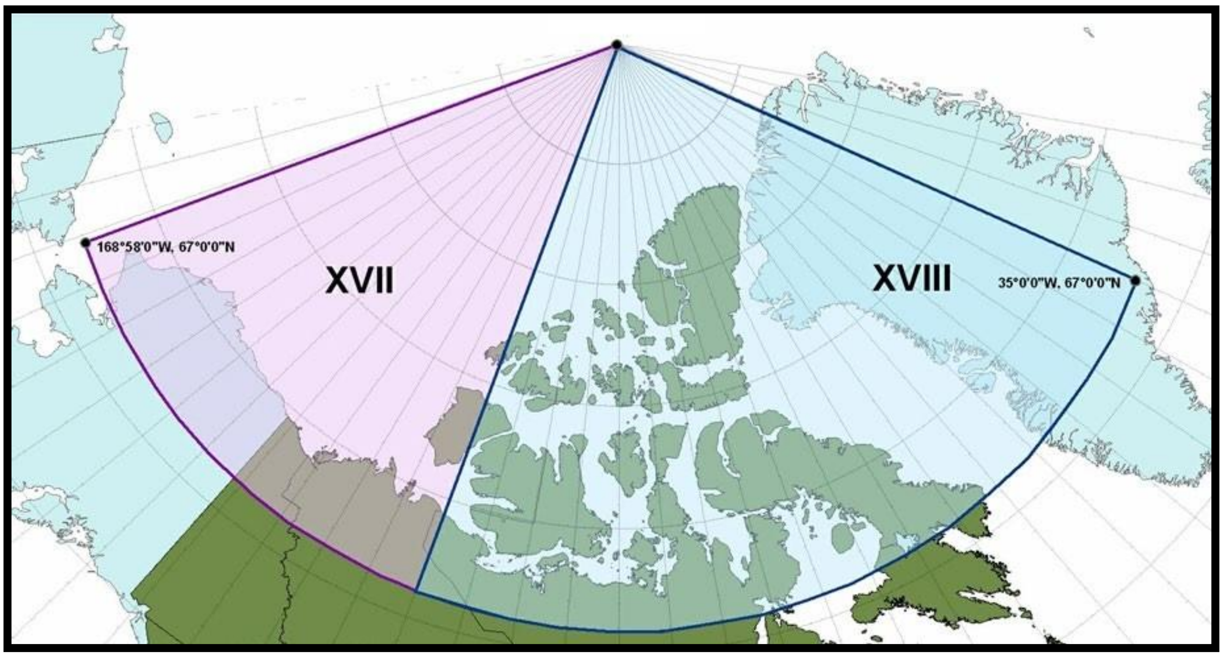


Figure 3 - METAREAS and NAVAREAS in the Canadian Arctic (photo courtesy of CCG)

During the navigation season meteorological warnings and forecasts for sections of METAREAS XVII and XVIII south of 75 degrees latitude will be broadcast via Inmarsat-C EGC SafetyNET:

METAREA	Satellite Region	Broadcast (UTC)
XVII	(POR)	0300, 1500
XVIII	(AOR-W)	0300, 1500

NAVAREA warnings for NAVAREAS XVII and XVIII south of 75 degrees latitude will be broadcast via Inmarsat-C EGC SafetyNET:

NAVAREA	Satellite Region	Broadcast (UTC)
XVII	(POR)	1130, 2330
XVIII	(AOR-W)	1100, 2300

In addition, during the navigation season meteorological warnings and forecasts and NAVAREA warnings for sections of NAVAREAS and METAREAS XVII and XVIII north of 70 degrees latitude will also be broadcast via high frequency narrow band direct printing (HF-NBDP):

Frequency	MCTS Centre	Broadcast (UTC)
8416.5 kHz	MCTS Iqaluit	0330, 1530

1.9 NAVTEX service

Under GMDSS, the NAVTEX is part of the mandatory equipment carriage requirement for SOLAS vessels. In Canada, NAVTEX service is available from various transmitting sites using the frequency 518 kHz (English) and 490 kHz (French) for the broadcast of the navigational warnings, meteorological warnings, ice bulletins and forecasts, and Search and Rescue information. Additional information on the NAVTEX service is available in the latest edition of the annual publication RAMN.

1.9.1 Transmitting sites where NAVTEX service is available

Controlled by	Site	Position	Range (NM)	ID 518 kHz (English)	ID 490 kHz (French)
Placentia MCTS	Robin Hood Bay	47º36.65'N 052º40.18'W	300	O	
Labrador MCTS	Cartwright	53º42.52'N 057º01.35'W	300	X	
Sydney MCTS	Port Caledonia	46º11.15'N 059º53.77'W	300	Q	J
Halifax MCTS	Chebogue	43º44.65'N 066º07.32'W	300	U	V
Les Escoumins MCTS	Moisie	50º11.75'N 066º06.74'W	300	C	D
Sarnia MCTS	Pass Lake	48º33.80'N 088º39.37'W	300	P	
Prescott MCTS	Ferndale	44º56.22'N 081º14.00'W	300	H	
Iqaluit MCTS	Iqaluit	63º43.82'N 068º32.70'W	300	T	S
Prince Rupert MCTS	Amphitrite Point	48º55.28'N 125º32.38'W	300	H	

Controlled by	Site	Position	Range (NM)	ID 518 kHz (English)	ID 490 kHz (French)
Prince Rupert MCTS	Digby Island	54º18.05'N 130º24.17'W	300	D	

The above noted NAVTEX services are provided on a time-shared basis for the broadcast of the following subject indicator content:

(A) Navigational Warnings
(B) Meteorological Warnings
(C) Ice Reports
(D) Search and Rescue information / tsunami
(E) Meteorological Forecasts
(G) Automatic Identification System (AIS) service messages
(J) GPS Messages

Broadcast time and content is shown in individual MCTS centre listings.

1.10 Winter aids to navigation in Canadian waters

During the winter months mariners are cautioned that most of the conventional buoys are lifted and are replaced in critical areas by unlit winter spar buoys: throughout the southwest and east coasts of Newfoundland, Cape Breton Island area, Gulf of St. Lawrence, and St. Lawrence River. It should be noted that there is a possibility that these winter spar buoys may be:

a) under the ice
b) off position
c) of a dull or misleading colour, or
d) missing from the charted position; thus, caution should be exercised accordingly when navigating in areas where they are used

Similarly, the charted or listed characteristics of these lights should not be relied upon. The current edition of Notices to Mariners should be consulted for details.

Figure 4 - Example of winter buoy (photos courtesy of the CIS)

Figure 5 - Example of winter buoy (photos courtesy of the CIS)

Warning: Mariners are cautioned not to rely solely on buoys or other aids to navigation for navigation purposes.

1.11 Icebreaking service fee

On December 21, 1998, commercial vessels became subject to the Icebreaking Services Fee (ISF). The ISF recovers a portion of the cost of providing Coast Guard ice route assistance, ice routing and information services, and marine facility and port maintenance services in support of commercial shipping. All commercial vessels arriving at or departing from Canadian ports located in the ice zone during the ice season are subject to a transit fee. Consult the Icebreaking services fees for details regarding their applications and explanations of the ice zone and ice season).

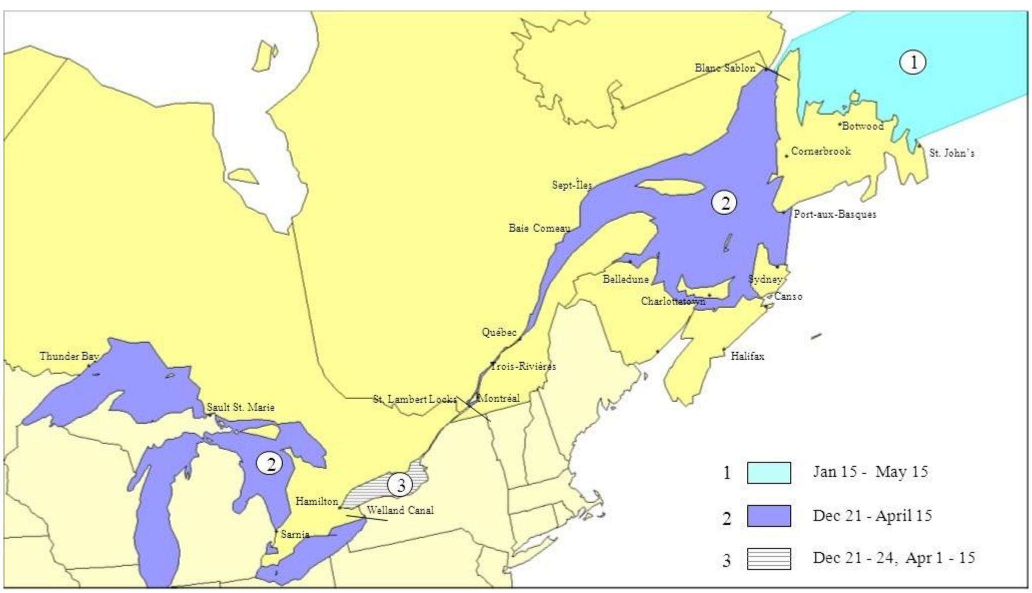


Figure 6 - Icebreaking Service Fee zones

Long description:
Icebreaking services fee zones.
Zone 1 operating from January 15 to May 15 include water from the North of St. John's up to Blanc Sablon
Zone 2 operating from December 21 to April 15 is including the Gulf of St. Lawrence and St.

Lawrence River up to Montreal.
The zones 2 is also including Lake Erie, Lakje Huron, Lake Michigan and the Lake superior
Zones 3 operating from December 21-24 to April 1 -15 include Lake Ontario

2 Regulations and guidelines

2.1 General

The *Canada Shipping Act, 2001* applies to all Canadian territorial waters and fishing zones. Arctic shipping in Canada is governed by several other pieces of legislation, such as the *Arctic Waters Pollution Prevention Act* and its regulations, the International Code for Vessels Operating in Polar Waters (the Polar Code, 2017), the *Marine Liability Act*, the *Marine Transportation Security Act,* the *Coasting Trade Act*, the *Canada Labour Code* and the *Marine Machinery Regulations*. These acts and regulations were created to enhance safety and to protect life, health, property and the marine environment. It is the responsibility of vessel owners and operators to ensure that they comply with all applicable acts and regulations.

2.2 Marine Machinery Regulations

Under the *Canada Shipping Act, 2001*, the *Marine Machinery Regulations*, Schedule VII, Part I, Division IV Shipside Components states that for vessels required to operate in ice-covered waters where ice may choke sea-water inlets, maintenance of essential seawater supply must be maintained by:

a) diversion arrangements for warmed cooling water from overboard discharges into sea- water inlet boxes
b) means to clear sea-water inlet boxes, preferably by steam that has a pressure not in excess of the design working pressure of the sea-water inlet boxes and that is vented to the upper deck by means of a valved pipe, and
c) ensuring sea-water inlet strainers have:
    i. perforations approximately 20 mm in diameter to prevent ingestion of large ice particles, and
    ii. a strainer perforated area approximately 5 times the total cross-sectional area of the inlet pipes being served to ensure full fluid flow in slush ice conditions.

Warning: Ice conditions can be treacherous on the St. Lawrence River. Fresh water, currents, tide and water depth can push frazil ice down to depths of more than 10 metres and can plug seawater cooling inlets. This is an unusual occurrence and is rarely encountered in other parts of the world.

2.3 Supplementary publications

There is a vast amount of information concerning navigation in ice in this manual and within the *Sailing Directions* published by the Canadian Hydrographic Service. Other publications that are useful for the navigation officer, the Ice Navigator in the Arctic or the ship's mariner are listed in Annex II, particularly Manual of Ice (MANICE).

Note: For a complete list of Transport Canada marine transportation acts and regulations, consult: Acts & Regulations.

Figure 7 - Heavy icebreaker CCGS *Terry Fox* (photo courtesy of the CCG)

2.4 Regulations and guidelines for southern Canadian ice covered waters

2.4.1 Joint Industry - Government Guidelines for the Control of Oil Tankers and Bulk Chemical Carriers in Ice Control Zones of Eastern Canada TP15163 B (2015)

Joint Industry – Government Guidelines for the Control of Oil Tankers and Bulk Chemical Carriers in Ice Control Zones of Eastern Canada - TP 15163 B (2015) (JIGs) apply to all laden oil tankers and to tankers carrying liquid chemicals in bulk when proceeding through an active Ice Control Zone in Eastern Canadian waters and fishing zones south of 60°north. The CCG may declare any ice control zone to be an active Ice Control Zone and promulgate this information via NAVWARN and Notices to Mariners. When proceeding through an active Ice Control Zone, all vessels to which the guidelines apply should, have on board at least one "Ice Advisor", who meets the requirements as prescribed in JIGs. Figure 8 shows the Eastern Canada Ice Control Zones.

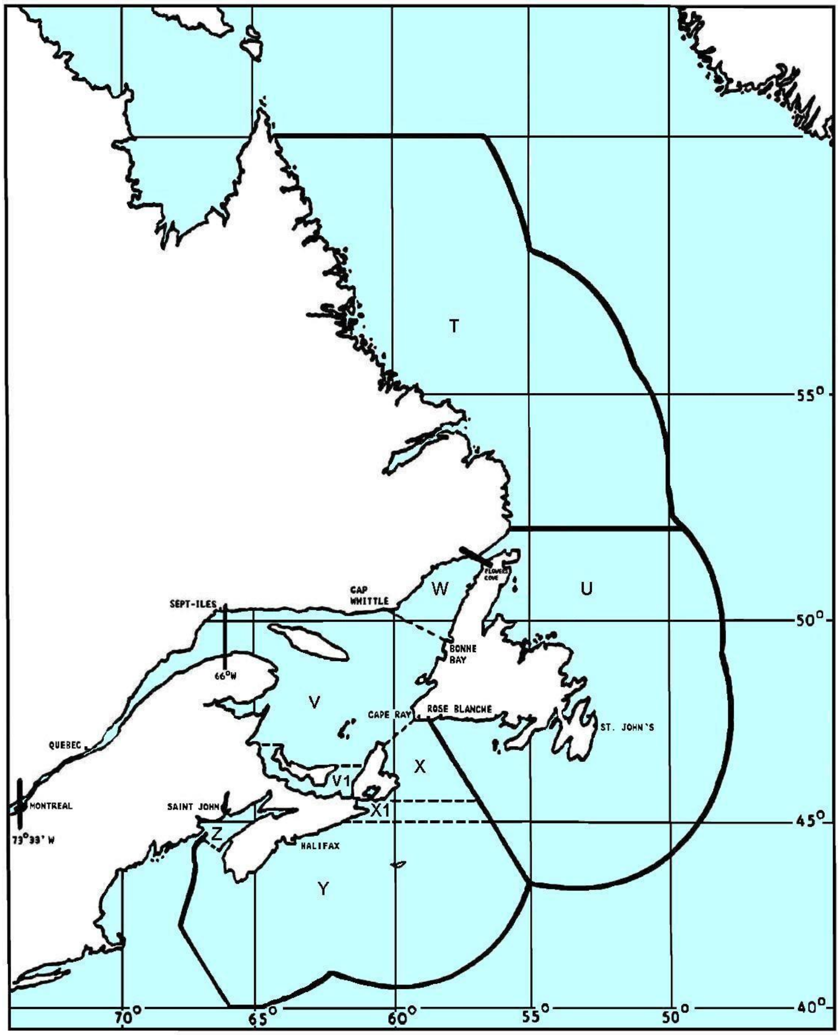


Figure 8 - Eastern Canada Ice Control Zones[1]

2.4.2 Guidelines for Navigation Under the Confederation Bridge (2009) – TP 13681E

Under Guidelines For Navigation Under The Confederation Bridge (2009) - TP 13681 E, vessels of over 1,500 GRT are required to utilize the central navigation channel, which is a compulsory pilotage zone pursuant to regulations made under the *Pilotage Act*. Traffic in the Northumberland Strait in the area of the Bridge is regulated by the *Vessel Traffic Services Zones Regulations*. When the Strait is declared an active ice zone and ice is present in the navigation channel the transiting vessel must be escorted by a suitably sized icebreaker.

2.4.3 Winter navigation on the River and the Gulf of St. Lawrence : practical notebook for marine engineers and deck workers TP 14335[2]

This publication is a complement to Ice Navigation in Canadian Waters and is intended for use by vessel owners, operators, charterers, agents and vessels' officers who seek practical information on hazards which may be encountered when transiting eastern Canadian ice

[1] Source: 12.0 Transport Canada Ship Safety Bulletins

[2] A PDF format of the publication is available at: Winter navigation on the River and the Gulf of St. Lawrence : practical notebook for marine engineers and deck workers

covered waters and in the St. Lawrence River. The publication provides advice for mariners who may be exposed to ice, freezing spray, slush ice and cold temperatures as well as the effects on machinery spaces, sea inlet boxes, deck equipment, lifesaving appliances, living quarters, the navigation bridge, cargo hold and ballast operations. This publication is available by consulting Winter navigation on the River and the Gulf of St. Lawrence : practical notebook for marine engineers and deck workers

2.4.4 Interim Standards for the Construction, Equipment & Operation of Passenger Ships in the Sea (1987) - TP 8941 E

Interim Standards for the Construction, Equipment & Operation of Passenger Ships in the Sea (1987) - TP 8941 E apply to all passenger vessels that are registered in Canada or engaged in the coasting trade of Canada when operating within a declared sea ice area within economic zones of eastern Canada.

2.5 Regulations and guidelines for the Canadian Arctic

Through the *Arctic Waters Pollution Prevention Act*, the Government of Canada through Marine Safety, a branch of Transport Canada enforces its responsibility for ensuring navigation in Arctic waters is conducted to preserve and protect the sensitive northern ecosystem. The regulations under this Act affect vessel navigation in the Arctic.

As well as the various international and Canadian regulations governing marine navigation, there are a number of regulations of specific interest to mariners which deal with shipping in the Canadian Arctic. The following are among the more important regulations:

- *Arctic Shipping Safety and Pollution Prevention Regulations*
- *Arctic Waters Pollution Prevention Regulations*
- *Governor in Council Authority Delegation Order*
- *Shipping Safety Control Zones Order*
- *Steering Appliances and Equipment Regulations*

Each of the regulations, standards or publications mentioned have been condensed to illustrate only the pertinent sections that may have the greatest impact on Arctic operations. Mariners are cautioned that this list of regulations is in no way exhaustive, and that the identified regulations are subject to ongoing amendments. Mariners are advised to familiarize themselves with all current Acts & Regulations governing areas of interest.

The *Arctic Water Pollution Prevention Act* and the *Arctic Water Pollution Prevention Regulations* provide measures to prevent pollution from vessels, and in particular, the deposit of waste into Arctic waters. The *Arctic Shipping Safety and Pollution Prevention Regulations* deal with construction and operational aspects of navigating in the Arctic, including the need for Ice Navigators. The regulations contains the Zone/Date System, which is a system dividing the Arctic into 16 Safety Control Zones, each with fixed opening and closing dates for vessels of various ice capabilities. The Arctic Ice Regime Shipping System (AIRSS) was introduced as a more flexible system that uses the actual ice conditions to determine whether entry is allowed in an ice regime. An Arctic Water Pollution Prevention Certificate may be issued to a vessel **outside of Canada** by the recognized International Association of Classification Societies (IACS).

2.5.1 Arctic Shipping Safety and Pollution Prevention Regulations

The *Arctic Shipping Safety and Pollution Prevention Regulations* govern safety and pollution prevention measures, in line with the Polar Code as of January 1st 2017.

The Arctic Shipping Safety and Pollution Prevention Regulations introduces the Zone / Date System in which the Arctic waters are divided into sixteen Shipping Safety Control Zones, with a schedule of earliest and latest entry dates for each zone corresponding to specific categories of vessels. Zone 1 has the most severe ice conditions and Zone 16 the least. Figure 9 is a map of the Canadian Arctic illustrating the sixteen Shipping Safety Control Zones. Tables 1 and 2 in the section below represent schedule 1 which identifies the permissive date for each class, as well as schedule 2 which identifies the international class equivalences.

2.5.2 Arctic Pollution Prevention Certificate

Shipowners may request an Arctic Water Pollution Prevention Certificate for vessels that carry more than 453 m^3 of pollutants (including all oil, fuel, and lubricants).

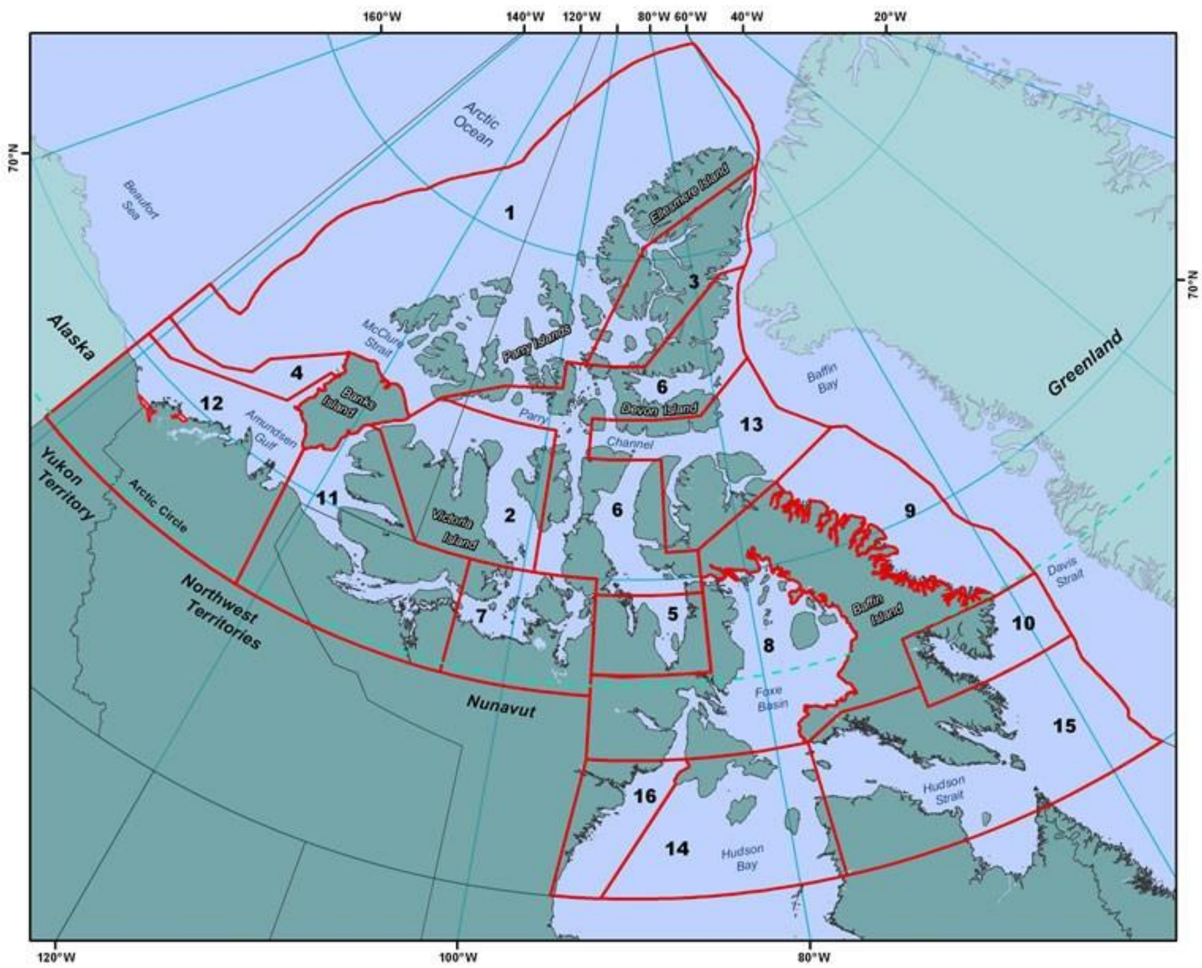


Figure 9 - Shipping Safety Control Zones (image courtesy of TC)

Table 1 - Dates of entry into Shipping Safety Control Zones[3]

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13	Column 14	Column 15	Column 16	Column 17
Item	Category	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16
1	Arctic Class 10, CAC 1	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year
2	Arctic Class 8, CAC 2	Jul. 1 to Oct. 15.	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year
3	Arctic Class 7	Aug. 1 to Sept. 30	Aug. 1 to Nov. 30	Jul. 1 to Dec. 31	Jul. 1 to Dec. 15	Jul. 1 to Dec. 15	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year	All year
4	Arctic Class 6, CAC 3	Aug. 15 to Sept. 15	Aug. 1 to Oct. 31	Jul. 15 to Nov. 30	Jul. 15 to Nov. 30	Aug. 1 to Oct. 15	Jul. 15 to Feb. 28	Jul. 1 to Mar. 31	Jul. 1 to Mar. 31	All year	All year	Jul. 1 to Mar. 31.	All year	All year	All year	All year	All year
5	Arctic Class 4	Aug. 15 to Sept. 15	Aug. 15 to Oct. 15	Jul. 15 to Oct. 31	Jul. 15 to Nov. 15	Aug. 15 to Sept. 30	Jul. 20 to Dec. 31	Jul. 15 to Jan. 15	Jul. 15 to Jan. 15	Jul. 10 to Mar. 31	Jul. 10 to Feb. 28	Jul. 5 to Jan. 15	June 1 to Jan. 31	June 1 to Feb. 15	June 15 to Feb. 15	June 15 to Mar. 15	June 1 to Feb. 15
6	Arctic Class 3, CAC 4	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	Jul. 25 to Oct. 15	Jul. 20 to Nov. 5	Aug. 20 to Sept. 25	Aug. 1 to Nov. 30	Jul. 20 to Dec. 15	Jul. 20 to Dec. 31	Jul. 20 to Jan. 20	Jul. 15 to Jan. 25	Jul. 5 to Dec. 15	June 10 to Dec. 31	June 10 to Dec. 31	June 20 to Jan. 10	June 20 to Jan. 31	June 5 to Jan. 10
7	Arctic Class 2	No Entry	No Entry	Aug. 15 to Sept. 30	Aug. 1 to Oct. 31	No Entry	Aug. 15 to Nov. 20	Aug. 1 to Nov. 20	Aug. 1 to Nov. 30	Aug. 1 to Dec. 20	Jul. 25 to Dec. 20	Jul. 10 to Nov. 20	June 15 to Dec. 5	June 25 to Nov. 22	June 25 to Dec. 10	June 25 to Dec. 20	June 10 to Dec. 10
8	Arctic Class 1A	No Entry	No Entry	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	No Entry	Aug. 25 to Oct. 31	Aug. 10 to Nov. 5	Aug. 10 to Nov. 20	Aug. 10 to Dec. 10	Aug. 1 to Dec. 10	Jul. 15 to Nov. 10	Jul. 1 to Nov. 10	Jul. 15 to Oct. 31	Jul. 1 to Nov. 30	Jul. 1 to Dec. 10	June 20 to Nov. 30
9	Arctic Class 1	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 25 to Sept. 30	Aug. 10 to Oct. 15	Aug. 10 to Oct. 31	Aug. 10 to Oct. 31	Aug. 1 to Oct. 31	15 juil. au 20 oct.	Jul. 1 to Oct. 31	Jul. 15 to Oct. 15	Jul. 1 to Nov. 30	Jul. 1 to Nov. 30	June 20 to Nov. 15
10	Type A	No Entry	No Entry	Aug. 20 to Sept. 10	Aug. 20 to Sept. 20	No Entry	Aug. 15 to Oct. 15	Aug. 1 to Oct. 25	Aug. 1 to Nov. 10	Aug. 1 to Nov. 20	Jul. 25 to Nov. 20	Jul. 10 to Oct. 31	June 15 to Nov. 10	June 25 to Oct. 22	June 25 to Nov. 30	June 25 to Dec. 5	June 20 to Nov. 20
11	Type B	No Entry	No Entry	Aug. 20 to Sept. 5	Aug. 20 to Sept. 15	No Entry	Aug. 25 to Sept. 30	Aug. 10 to Oct. 15	Aug. 10 to Oct. 31	Aug. 10 to Oct. 31	Aug. 1 to Oct. 31	Jul. 15 to Oct. 20	Jul. 1 to Oct. 25	Jul. 15 to Oct. 15	Jul. 1 to Nov. 30.	Jul. 1 to Nov. 30	June 20 to Nov. 10
12	Type C	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 25 to Sept. 25	Aug. 10 to Oct. 10	Aug. 10 to Oct. 25	Aug. 10 to Oct. 25	Aug. 1 to Oct. 25	Jul. 15 to Oct. 15	Jul. 1 to Oct. 25	Jul. 15 to Oct. 10	Jul. 1 to Nov. 25	Jul. 1 to Nov. 25	June 25 to Nov. 10
13	Type D	No Entry	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 10 to Oct. 5	Aug. 15 to Oct. 20	Aug. 15 to Oct. 20	Aug. 5 to Oct. 20	Jul. 15 to Oct. 10	Jul. 1 to Oct. 20	Jul. 30 to Sept. 30	Jul. 10 to Nov. 10	Jul. 5 to Nov. 10	Jul. 1 to Oct. 31
14	Type E	No Entry	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 10 to Sept. 30	Aug. 20 to Oct. 20	Aug. 20 to Oct. 15	Aug. 10 to Oct. 20	Jul. 15 to Sept. 30	Jul. 1 to Oct. 20	Aug. 15 to Sept. 20	Jul. 20 to Oct. 31	Jul. 20 to Nov. 5	Jul. 1 to Oct. 31

[3] Source: *Arctic Shipping Safety and Pollution Prevention Regulations*, Schedule 1

Table 2 - Construction Standards for Types A, B, C, D and E Vessels[4]

Item	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13
	Type of Vessel	American Bureau of Shipping (ABS)	Bureau Veritas (BV)	China Classification Society (CCS)	Nippon Kaiji Kyokai (ClassNK)	DNV-GL	Finnish-Swedish Ice Class Rules (FSICR)	International Association of Classification on Societies (IACS)	Korean Register of Shipping (KR)	Lloyd's Register of Shipping (LR)	Poiski Rejestr Statkow (PRS)	Rina Services (RINA)	Russian Maritime Register of Shipping
1	Type A	Ice Class A0	ICE CLASS IA SUPER	Ice Class B1*	NS (Class 1A Super Ice Strengthening)	Ice (1A*) or ICE-1A or E4	1A Super	PC1 to PC7	IA Super	Ice Class 1AS FS (+) or Ice Class 1AS FS (+)	L1A	ICE CLASS 1A SUPER	UL or LU5 or Arc5
2	Type B	Ice Class B0	ICE CLASS IA	Ice Class B1	NS (Class 1A Ice Strengthening)	Ice (1A) or ICE-1A or E3	1A		1A	Ice Class 1A FS (+) or Ice Class 1A FS	L1	ICE CLASS 1A	L1 or LU4 or Arc4
3	Type C	Ice Class C0	ICE CLASS IB	Ice Class B2	NS (Class 1B Ice Strengthening)	Ice (1B) or ICE-1B or E2	1B	–	1B	Ice Class 1B FS (+) or Ice Class 1B FS	L2	ICE CLASS 1B	L2 or LU3 or Ice 3
4	Type D	Ice Class D0	ICE CLASS IC	Ice Class B3	NS (Class 1C Ice Strengthening)	Ice (1C) or ICE-1C or E1	1C	–	1C	Ice Class 1C FS (+) or Ice Class 1C FS	L3	ICE CLASS 1C	L3 or LU2 or Ice 2
5	Type E	Ice Class E0	1D	Ice Class B	NS (Class 1D Ice Strengthening)	ICE-C or E	Category II	–	1D	Ice Class 1D or Ice Class 1E	L4	1D	L4 or LU1 or Ice 1

2.5.3 Guidelines for vessels operating in polar waters

Recognizing that certain hazards commonly found in Arctic and Antarctic waters are not adequately addressed by SOLAS and MARPOL, the IMO Guidelines for Ships Operating in Polar Waters (Polar Guidelines) aim to promote safety of navigation and to prevent pollution from vessel operations in polar waters. The Guidelines, when applied in their entirety, result in a holistic approach covering the design and outfitting of vessels for the conditions that they will encounter, their crewing by adequate numbers of suitably trained personnel, and their operation in a planned and prudent manner.

The Polar Guidelines take into account that the single most significant factor in polar operations is ice by recommending that only those vessels with a Polar Class designation or a comparable alternative standard of ice-strengthening appropriate to the anticipated ice conditions should operate in polar ice-covered waters. The Polar Guidelines provide guidance in structural design or machinery requirements through reference to a parallel set

[4] Source: *Arctic Shipping Safety and Pollution Prevention Regulations*, Schedule 2

of Unified Requirements for Polar Class Ships developed by the International Association of Classification Societies (IACS).

The Polar Guidelines also address the fact that the polar environment imposes additional demands on vessel systems such as: navigation, communications, lifesaving, fire-fighting, etc. They emphasize the need to ensure that all vessel systems are capable of functioning effectively under anticipated operating conditions, notably the possibility of extreme cold. The Polar Guidelines stipulate that systems should provide adequate levels of safety in emergencies. In addition, The Polar Guidelines recognize that safe operation in polar conditions requires specific attention to human factors including training and operational procedures.

All vessels operating under the Polar Guidelines should carry on board a sufficient number of Ice Navigators to guide operations when ice is present. The Guidelines define an **Ice Navigator** as ”any individual who, in addition to being qualified under the *Standards of Training, Certification and Watchkeeping for Seafarers* (STCW) Convention, is specially trained and otherwise qualified to direct the movement of a vessel in ice-covered waters”.

2.5.4 Seafarers’ Training, Certification and Watchkeeping Code (STCW Code)

Guidance regarding training of mariners and officers for vessels operating in polar waters is contained in the *Standards for Training, Certification and Watchkeeping* (STCW) Code. IMO has developed an internationally recognized criteria for training and experience for ice navigators as part of the mandatory Polar Code. With respect to Canadian regulations, the specific qualifications of an Ice Navigator are stated in Section 26 of the *Arctic Shipping Safety and Pollution Prevention Regulations* (ASSPPR).

Section B-V/g* of the STCW Code provides guidance for training mariners and officers for vessels operating in polar waters. It is important that mariners, officers in charge of a navigational watch and officers in charge of an engineering watch on board vessels operating in polar waters should have relevant experience and training.

Prior to being assigned duties on board such vessels, mariners and officers in charge of a navigational watch should have basic knowledge on the following subjects 2 to 11. Officers in charge of an engineering watch should have a basic knowledge of subjects 3, 6, 10 and 11. Mariners and chief engineer officers should have sufficient and appropriate experience in operating vessels in polar waters.

2. Ice characteristics – ice areas
3. Ship’s performance in ice and cold climate
4. Voyage and passage planning for a vessel in ice
5. Operating and handling a vessel in ice (operations and navigation)
6. Operating and handling a vessel in ice (propulsion, rudder and other engineering systems)
7. Regulations and recommendations
8. Equipment limitations
9. Safety precautions and emergency procedures (availability and limitations of infrastructure)
10. Safety precautions and emergency procedures (safe working procedures, common damages and limitations of fire-fighting)
11. Environmental considerations.

2.5.5 Polar Classes

From an operational perspective, the safety of the vessel will remain the ultimate responsibility of the mariner, who will be provided, directly or indirectly with the expertise and information needed to make prudent navigational decisions.

Ice strengthening appropriate for the conditions encountered is fundamental to safe operation in ice. Ice classes to indicate capability in ice have been established by many organizations. Canada supports use of the Polar Classes set out in the IACS Unified Requirements for Polar Vessels (see in table 3 below). The class descriptions are deliberately general to suit a variety of operations and their relation vessels are set to provide a reasonably smooth gradation of capability and cost.

Table 3 - Polar Class descriptions

Polar Class	General description
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Certain Polar Classes are based on existing classes for which good performance data exists. The others have been interpolated between or extrapolated from the others. The lowest classes, PC 6 and PC 7, can be considered as ‘polarized’ versions of the top two Baltic classes and the top classes represent levels of capability that have not yet been provided by commercial cargo-carrying vessels.

2.5.6 Arctic Ice Regime Shipping System

Referenced in the *Arctic Shipping Safety and Pollution Prevention Regulations*, AIRSS standards have been developed to enhance the safety and efficiency of shipping operations in the Canadian Arctic. The standards have been developed characterize the relative risk which different ice conditions pose to the structure of different vessels.

The Zone/Date System is based on rigid controls. The AIRSS emphasizes the **responsibility of the mariner** for the safety of the ship. This provides a more flexible framework to assist in decision-making. Both systems are presently working in parallel, allowing operators to navigate outside the Zone/Date limits when ice conditions permit. Operators will continue to be able to use the Zone/Date scheme to generally plan voyages to the Arctic while being encouraged to avoid dangerous ice conditions through the use of the AIRSS. The application of the AIRSS will require an Ice Navigator and the use of all available ice information.

The *AIRSS Standards* are based on the concept that ice conditions can be quantified through a simple ice numeral (IN) calculation which indicates whether or not a given set of ice conditions (regimes) will be safe for a particular vessel. A wide range of ice navigation parameters including visibility, vessel speed, manoeuvrability, the availability of an icebreaker escort and the knowledge and experience of the crew must also be considered when applying the Ice Regime System.

The AIRSS can only be used under the following circumstances:

a) If the vessel has a set of ice multipliers (IM). For **Canadian Arctic Category (CAC) or Type vessels**, their IMs are listed in the IM table. For all other vessels, IMs are assigned on a case-by-case basis supported by the assessed ice strength of the vessel. For information on application of AIRSS in relation to Polar Class vessels, refer to Ship Safety Bulletin 04/2009 IACS Unified Requirements for Polar Class Vessels - Application in Canadian Arctic Waters.
b) If an Ice Regime Routing Message is sent to NORDREG CANADA.
c) If the **ice numerals** calculated for the vessel are **zero or positive** for all of the ice regimes that are along the intended route.
d) The vessel must have an **Ice Navigator** on board. The specific qualifications of an Ice Navigator are stated in Section 26 of the ASSPPR.

There are several steps to follow in order to apply the AIRSS.

a) Obtain the most current ice information for the planned passage and select a desired route.
b) Determine the various ice regimes along the route and calculate the INs for your vessel in each regime.
The ice charts from the CIS are well suited to AIRSS and, based on their scale, they could be used directly to define ice regimes for voyage planning, strategic planning and to a limited extent, tactical navigation. Other forms of information, including satellite imagery, may require more interpretation by an Ice Navigator.
c) If all the INs are zero or greater, you must advise NORDREG CANADA, through the submission of an **Ice Regime Routing Message**.
This message does not constitute a request for permission to proceed; rather it is made for the information of the CCG Icebreaking Superintendent via NORDREG CANADA. Based on this information, the Transport Canada duty officer issue acknowledgement via NORDREG CANADA for the vessel to proceed along the projected route. This represents an acknowledgement that the planned route appears appropriate - it does not relieve Masters of their responsibility to navigate with due caution and with continuous, careful attention to the local ice conditions.
d) If the IN for any ice regime is negative, consider the alternatives, such as selecting another route, waiting for improved in ice conditions or requesting the assistance of an icebreaker. When an icebreaker or other vessel modifies a regime, or there is a change in the ice conditions, giving positive INs, you may proceed after advising NORDREG CANADA with the updated information.
e) Within 30 days of completing the voyage, you must send an **After Action Report** to Transport Canada.

Additional information is provided in section 2.5.8.

2.5.6.1 Ice Regime Routing Message

Every message required by subsection 9(1) of the *Arctic Shipping Safety and Pollution Prevention Regulations* must contain all designators listed in table 4. The update message required by subsection 9(2) of the Arctic Shipping Safety and Pollution Prevention Regulations must include designators A to K. Every message must be addressed to Transport Canada and be provided to one of the MCTS centres that is designated by the CCG to receive NORDREG CANADA reports. The intended route describe by designator G of table 4 may include more than one Shipping Safety Control Zone.

Table 4 - Ice regime routing message template

Item	Designator	Subject	Information
1	A	Vessel	The vessel's name and the name of the state whose flag the vessel is entitled to fly.
2	B	Call Sign and IMO number	The vessel's call sign and International Maritime Organization (IMO) ship identification number.
3	C	Vessel Ice Class	The Ice Class that corresponds to the Ice Class indicated on the Polar Ship Certificate. For vessels with no Polar Ship Certificate, it must correspond to the Ice Class indicated on the vessel Classification Society Certificate.
4	D	Date & UTC time	A 6-digit group followed by a Z, the first 2 digits giving the day of the month, the next 2 digits giving the hour, and the last 2 digits giving the minutes.
5	E	Final destination	The name of the final destination.
6	F	Position, course & speed	A 4-digit group giving the latitude in degrees and minutes suffixed with N, and a 5-digit group giving the longitude in degrees and minutes suffixed with W. The true course. A 3-digit group. The speed in knots. A 2-digit group.
7	G	Intended route	A series of 4-digit groups giving the latitude in degrees and minutes suffixed with N, and 5-digit groups giving the longitude in degrees and minutes suffixed with W to describe the planned route.
8	H	Ice Regime(s) to be encountered	For each regime along the planned route, a series of ice concentration in tenths (C), the corresponding ice type (IT) using the ice type symbol or the egg code, followed by the letter IN for AIRSS message or Risk Index Outcome (RIO) for POLARIS message and the resulting IN or RIO: **AIRSS** C_1, IT_1, C_2, IT_2, …, CT_n, IT_n, INxx **POLARIS** C_1, IT_1, C_2, IT_2, …, CT_n, IT_n, RIOxx

Item	Designator	Subject	Information
9	I	Source(s) of Ice Information	Indicate the source(s) used to determine the ice conditions, e.g. ice charts name/date, visual observations, reports from shore stations and from other vessels in the area, helicopter (or drone) reconnaissance, satellite radar imagery, or other means.
10	J	Other pertinent information or comments	Provide additional information that may have been considered or is pertinent to the assessment, such as limitations associated with the ice regime assessment, near regimes that are likely to drift into the proposed route, an alternate route that may be considered, or planned escorting needs.
11	K	Name of escorting vessel	Provide the name of the escorting vessel if the IN has been determined for the track of an escorting vessel.
12	L	Ice Navigator(s) and officers certified for vessels operating in polar waters	Name(s) and certification information of Ice Navigator(s) and officers certified in accordance with the STCW Convention requirements for vessels operating in polar waters.
13	M	Vessel master	Name of the aster and certification information in accordance with the STCW Convention requirement for vessels operating in polar waters.

2.5.7 Ice Navigator[5]

Vessels, other than a cargo vessel of 500 gross tonnage or more or a passenger vessel that are certified as meeting the requirements of Chapter I of SOLAS, that navigate in a shipping safety control zone set out in columns 2 to 17 of Schedule 1 during a period other than those set out in item 14 of that schedule must have an ice navigator on board.

2.5.7.1 Requirements

The ice navigator on a vessel must

a) have all of the qualifications under the *Canada Shipping Act, 2001* to act as a master or a person in charge of the deck watch; and
b) either:
   i. have served on a vessel in the capacity of master or person in charge of the deck watch for at least 50 days, of which 30 days must have been served in international Arctic waters while the vessel was in ice conditions that required the vessel to be assisted by an ice-breaker or that required manoeuvres to avoid concentrations of ice that might have endangered the vessel, or
   ii. hold a certificate in advanced training for ships operating in polar waters in accordance with regulation V/4 of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers.

[5] From Part 1, section 10 of *Arctic Shipping Safety and Pollution Prevention Regulations*

2.5.8 Arctic Ice Regime Shipping System - Pictorial Guide - TP 14044 E

Transport Canada and the Canadian Hydraulics Centre, National Research Council of Canada published the Arctic Ice Regime Shipping System - Pictorial Guide as a reference guide for the AIRSS to help explain the system and to provide images which help determine ice characteristics such as concentration and stages of development.

Ice in the Arctic is a very complex and dynamic material. It has a wide range of thickness, concentration, age and roughness. Moreover, ice conditions continually change throughout the year. There are a number of vessels that travel in Canada's Arctic and it is important that their transit through ice is safe for both personnel safety as well as preventing pollution in the Arctic. There have been over 200 reported ice damage events over the past 25 years. Approximately one-third of those events had the potential to cause pollution. AIRSS is intended to minimize the risk of damage by taking into account the actual ice conditions through which vessels sail. Because different vessels have different capabilities in ice-covered waters, each vessel is assessed and assigned to a Vessel Class. This rating reflects the strength, displacement and power of the vessel. The relative risk of damage to a vessel by different types of ice is taken into account using "weighting" factors, called IMs. In the Ice Regime System, a simple calculation relates the strength of the vessel to the danger presented by different ice regimes. The calculation gives an IN. Ice regimes that are not likely to be hazardous have zero or "positive" INs. Those regimes that could be dangerous have "negative" INs. As always however, the safety of the vessel is the responsibility of the Mariner.

2.5.8.1 Characterizing the Ice Regime

AIRSS relies upon accurately assessing the ice conditions. The CIS issues ice charts to provide an overview of the latest ice conditions in different geographic regions. Ice charts are produced using the most current available technology and give an excellent indication of the general ice conditions in an area. As such, ice charts are one of the most useful resources to provide a vessel with an overview of the ice conditions in a certain area, in advance of when it is needed. That information can be used successfully for strategic planning and are very useful when the vessel is confronted with difficult ice conditions, to help determine alternate routes.

Although ice charts have an important role for vessels traversing ice-covered regions, their importance is no substitute for real-time observations made from the bridge. AIRSS relies upon up-to-date information that is obtained directly from the bridge and integrates that real-time information with the capability of each vessel class. This results in customized routing for each vessel, depending upon its ice-worthiness.

2.5.8.2 Ice Multiplier

One of the principal concepts behind the Ice Regime System is that every ice type including open water has a numerical value that is dependent on the ice category of the vessel. This number is called the ice multiplier (IM). The value of the IM reflects the level of risk or operational constraint that the particular ice type poses to each category of vessel. To find the applicable IM for your ship, refer to the IM table and highlight the appropriate vertical column based on your vessel category. This will comprise the IM for all the different ice types listed vertically on the left side of the table. If you do not know your vessel category refer to your Arctic Pollution Prevention Certificate or Schedule II of the Arctic Shipping Safety and Pollution Prevention Regulations.

Table 5 - IM table

IMO Ice Codes	Ice Types	Thickness	**Ice Multipliers** for each **vessel category**						
			Type E	**Type D**	**Type C**	**Type B**	**Type A**	**CA C 4**	**CA C 3**
7• or 9•	Old/Multi-year ice (MY)		**-4**	**-4**	**-4**	**-4**	**-4**	**-3**	**-1**
8•	Second-year Ice (SY)		**-4**	**-4**	**-4**	**-4**	**-3**	**-2**	**1**
6 or 4•	Thick first-year ice (TFY)	> 120 cm	**-3**	**-3**	**-3**	**-2**	**-1**	**1**	**2**
1•	Medium first-year ice (MFY)	70-120 cm	**-2**	**-2**	**-2**	**-1**	**1**	**2**	**2**
7	Thin first-year ice (FY)	30-70 cm	**-1**	**-1**	**-1**	**1**	**2**	**2**	**2**
9	Thin first-year ice - 2nd stage	50-70 cm	**-1**	**-1**	**-1**	**1**	**2**	**2**	**2**
8	Thin first-year ice - 1st stage	30-50 cm	**-1**	**-1**	**1**	**1**	**2**	**2**	**2**
3 or 5	Grey-white ice (GW)	15-30 cm	**-1**	**1**	**1**	**1**	**2**	**2**	**2**
4	Grey ice (G)	10-15 cm	**1**	**2**	**2**	**2**	**2**	**2**	**2**
2	Nilas, ice rind	< 10 cm	**2**	**2**	**2**	**2**	**2**	**2**	**2**
1	New ice (N)	< 10 cm	**2**	**2**	**2**	**2**	**2**	**2**	**2**
	Brash (ice fragments < 2 m)		**2**	**2**	**2**	**2**	**2**	**2**	**2**
=Δ	Bergy water		**2**	**2**	**2**	**2**	**2**	**2**	**2**
¦ ¦ ¦ ¦	Open water		**2**	**2**	**2**	**2**	**2**	**2**	**2**

2.5.8.3 Calculating the ice numeral

The IN is an assessment of an ice regime, in mathematical terms, which is used to determine whether the vessel can enter a specific ice regime. In other words, an IN is the sum of the products of the concentration, in 1/10th increments, of each ice type and their respective IMs in each regime. For any ice regime, an IN is the sum of the products of:

a) the concentration in tenths of each ice type
b) the IMs relating to the Type or Class of the vessel in question.

Equation:	IN =	(Ca x IMa) + (Cb x IMb) + ...
where:	IN	ice numeral
	Ca	Concentration in tenths of ice type "a"
	IMa	Ice Multiplier for ice type "a" (refer to the IM table)

The term(s) on the right hand side of the equation (a, b, c, etc.) are repeated for as many ice types and each of their respective concentrations that may be present, including **open water**. Using arithmetic, the Ice Multipliers (IM) for the vessel and the Ice Concentrations (C-in tenths) of each ice type are combined in the following form:

Multi-year (MY) ice	[**CMY** x **IMMY]**
Second-year(SY)ice	+ [**CSY** x **IMSY]**
Thick first-year (TFY) ice	+ [**CTFY** x **IMTFY]**
Grey-white (GW)ice	+ [**CGW** x **IMGW]**
Grey (G) ice	+ [**CG** x **IMG]**
New (N) ice	+ [**CN** x **IMN]**
Open water (OW)	+ [**COW** x **IMOW]**
Thin first-year (FY) ice	+ [**CFY** x **IMFY]**
Medium first-year (MFY) ice	+ [**CMFY** x **IMMFY]**
IN =	**?**

The IN is therefore unique to the particular ice regime and vessel operating within its boundaries. The IN for each regime **must be zero or positive** before transiting a regime and any application of AIRSS must be indicated with an Ice Regime Routing Message and an acknowledgement from NORDREG CANADA. If the IN is NEGATIVE, the vessel must not proceed and an alternate route must be found.

2.5.8.4 Factors that may affect IMs

2.5.8.4.1 Decayed ice

For the purpose of the Ice Regime System, the definition states that decayed ice is multi-year ice, second-year ice, thick first-year ice, or medium first-year ice that has thaw holes formed or is rotten ice. For “decayed Ice” +1 may be added to that ice type’s IM. As an example, if a Type B vessel encounters decayed thick first-year ice, the IM changes from 2 to 1.

2.5.8.4.2 Ridged ice

Where the total ice concentration in a particular regime is 6/10th’s or greater, and at least 3/10th’s of the area of an ice type (other than brash ice) is deformed by ridges, rubble or hummocking, the IM for that ice type, shall be decreased by 1. If, as an example a Type E vessel finds a regime with ridged thin first-year ice, the IM changes from 1 to 2.

2.5.8.4.3 Brash ice

Brash Ice has been given the same weighting as open water i.e. a +2 IM. Within the AIRSS concept this form of ice is intended to account for the ice predominately found in well-defined icebreaker tracks.

2.5.8.4.4 Trace of old ice

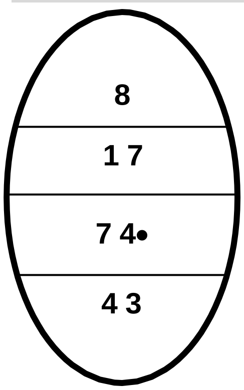
Traces of ice may be reported in forecasts or labeled on the left side of ice eggs. A trace means less than 1/10th ice concentration and is it not required to be part of the IN calculation. If a trace of Old Ice is encountered, caution should be exercised when navigating due to the risk that this ice creates.

Note: While doing any IN calculation, remember that every regime is composed of an aggregate 10/10th concentration of various ice types. As an example, if an ice “egg” shows a total concentration of 6/10th’s, remember that the other 4/10th is open water and should be accounted for in the IN calculation.

2.5.8.5 Examples of Ice Regimes and their IN calculations

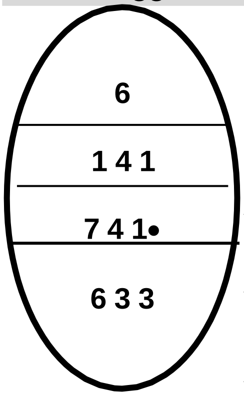
The following examples are realistic IN calculations based on ice “eggs” from the CIS Daily Ice Charts. For each case, two different vessels were used to illustrate how the INs fluctuate for the same ice with structurally different vessels.

Example 1

Ice egg	**Interpretation:**		
	The Ice Regime consists of 8/10ths total ice concentration of which: 1/10th is Old ice and 7/10ths Thick first-year ice. While doing the calculation remember to incorporate the 2/10ths of Open water.		
	Ice numeral calculations:		
	Type A vessel:	(1 x -4) + (7 x -1) + (2 x 2 for open water) = -7	Negative Regime
	CAC 4 vessel:	(1 x -4) + (7 x +1) + (2 x 2 for open water) = +7	Positive Regime
	With Ridged thick first-year ice the IN calculations would be:		
	Type A vessel	(1 x -4) + (7 x -2) + (2 x 2 for open water) = -14	Negative Regime
3	CAC 4 vessel:	(1 x -4) + (7 x 0) + (2 x 2 for open water) = 0	[Positive Regime]

Example 2

Ice Egg	Interpretation:



This July 9th Ice Regime consists of 6/10ths total concentration of ice of which 1/10th is Old ice, 4/10ths is Thick First-Year and 1/10th of Medium First-Year ice.

Ice numeral calculations:

Type **E** **vessel**	(1 x **-4**) + (4 x **-3**) + (1 x **-2**) + (4 x **+2**, open water) = **-10**	Negative
Type **A** vessel	(1 x **-4**) + (4 x **-1**) + (1 x **+1**) + (4 x **+2**, open water) =**+1**	Positive

or If this regime happened to be **Decayed** based upon data on an ice chart:

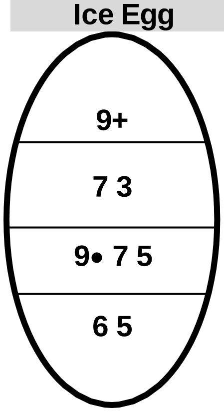
With **Decayed** ice (all Ice Types) the IN calculations are:

5

Type **E** vessel	(1 x **-3**) + (4 x **-2**) + (1 x **-1**) + (4 x **+2**, open water) =**-4**	Negative
Type **A** vessel	(1 x **-3**) + (4 x **0**) + (1 x **+2**) + (4 x **+2**, open water) =**+7**	Positive

Example 3

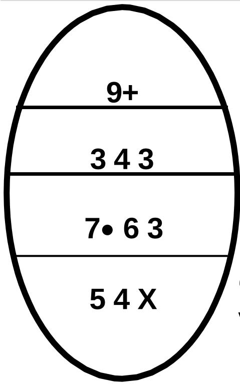
Ice Egg	Interpretation:



The Ice Regime consists of 9/10ths plus total concentration1 of ice in which there is a trace of Multi-Year ice, 7/10ths Thin First-Year and 3/10ths of Grey-White ice.
*(**NOTE**: A trace of Multi-Year or Old ice creates a high risk transit.)*
IN Calculations:

CAC **4** vessel:	(7 x **2**) + (3 x **2**) = **+20**	Positive	(Traces of ice are not factored in the calculation, i.e. under 1/10th)
Type **C** vessel:	(7 x **-1**) + (3 x **1**) = **-4**	Negative	

Example 4

Ice Egg	Interpretation:
	This data that has been interpreted from remote sensing imagery indicates that this regime of 9/10ths plus[6] ice, consists of: 3/10ths Old ice, 4/10ths of First-Year (considered thick) and 3/10ths of Young ice (considered Grey-White). IN calculations: Type **B** vessel: (3 x **-4**) + (4 x **-2**) + (3 x **+1**) = **-17** Negative Regime CAC **3** vessel: (3 x **-1**) + (4 x **+2)** + (3 x **+2**) = **+11** Positive Regime

2.5.8.6 Negative INs

While using the Ice Regime System, intentional entry into a negative ice regime outside the Zone/Date limits is prohibited. While navigating in the Arctic, the Mariner or Ice Navigator should consider several options to avoid encountering negative regimes:

a) selecting a safe route composed entirely of positive regimes
b) obtaining more recent and / or higher quality ice information
c) waiting for improved weather or ice conditions
d) requesting the assistance of an icebreaker by calling NORDERG

NORDREG CANADA and the CCG Icebreaking Superintendent will be able to provide additional information to assist in these circumstances and will have up-to-date knowledge of the positions of icebreakers.

Escorted operations

When ice conditions prevent, or significantly impede a vessel's operations, it may be desirable or necessary to work together with another vessel or be escorted. Escorted operations are specifically allowed for in the Ice Regime System, and must be considered on an individual basis while planning routes and defining local ice regimes. Under some circumstances an escort can be effective in easing the ice conditions along the route, however, if the escort's broken track is too narrow, if the ice is under pressure, the effectiveness of an escort can be severely limited.

The icebreaker will decide whether it is safe to break a track, but the Master of the escorted vessel must continue to evaluate the conditions in order to decide whether it is safe to follow, and at what speed. Communications and operating procedures must be established before any escort operation starts and maintained throughout. The following are factors to consider regarding the escort:

- the width of the broken track, in comparison with the following ship's beam
- the size, thickness, and strength of the ice pieces left in the track
- the likelihood of pressure conditions, which may cause the track to close rapidly

[6] Total ice concentrations of 9/10th's plus (9+) are considered 10/10th's for the purposes of Ice Numeral calculations".

The track of an escort and surrounding conditions should be treated as a separate Ice Regime. Extreme caution must be exercised when working in an icebreaker's track due to the confined aspect of the track.

Early season voyage

An early season voyage can be described as a voyage where the vessel intends to enter the Arctic prior to the main onset of melt and expects to enter a zone outside of the Zone / Date System. Entry could be possible under the Ice Regime System if there is an indication of positive INs. In this case it will be necessary for the vessel to have on board an Ice Navigator and send an Ice Regime Routing Message to NORDREG CANADA. Following the voyage an After Action Report must be submitted even though only positive INs may have been encountered.

Late season voyage

Late season voyages deserve special attention because of the certainty that ice conditions will worsen during the voyage, and the possibility that they will deteriorate rapidly. Severe, late season storms can cause pressure events and move large quantities of Multi-Year ice from high latitudes into the shipping channels.

With these voyages, a vessel may wish to enter a zone outside the Zone / Date System and entry is permitted provided there is an Ice Navigator on board, an Ice Regime Routing Message is sent to NORDREG CANADA that illustrates positive ice regimes. On late season voyages this communication with NORDREG CANADA is very important considering that the availability of Icebreaker support may be crucial if ice conditions deteriorate rapidly.

3.1.1 Guidelines for the Operation of Passenger Vessels in Canadian Arctic Waters - TP 13670 E

The objective of the Guidelines for the Operation of Passenger Vessels in Canadian Arctic Waters - TP 13670 E is to assist cruise operators, and their agents, in the planning of Arctic cruises and in making contact with all relevant Canadian government authorities well in advance to ensure that all the required publications are on board the vessels and have been studied before entering Canadian Arctic waters and that the operation complies with all applicable regulations.

3.1.2 Marine Environmental Handbook, Arctic Northwest Passage

The Marine Environmental Handbook for the Arctic Northwest Passage was compiled to provide information on the Arctic environment to mariners who are planning to use the busiest part of the Northwest Passage. The handbook describes the adverse environmental effects that could arise from shipping activities on the traditional use patterns on the ice surface (hunting and transportation) or on bird, animal or fish populations. It also suggests mitigating measures for vessel operations, on-ice vehicles and aircraft. It can be purchased from an authorized Canadian Hydrographic Service (CHS) chart dealer.

Examples of the environmental sensitivity to marine shipping in the Southern route of the Northwest Passage in the Autumn are shown in Figures 10 and 11.

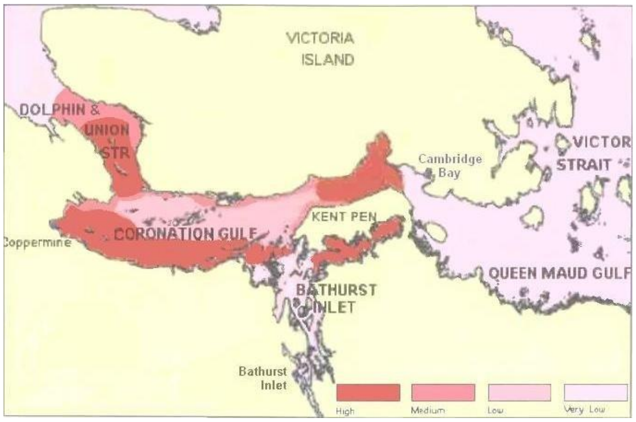


Figure 10 - Environmental sensitivity in Coronation Gulf in the Fall

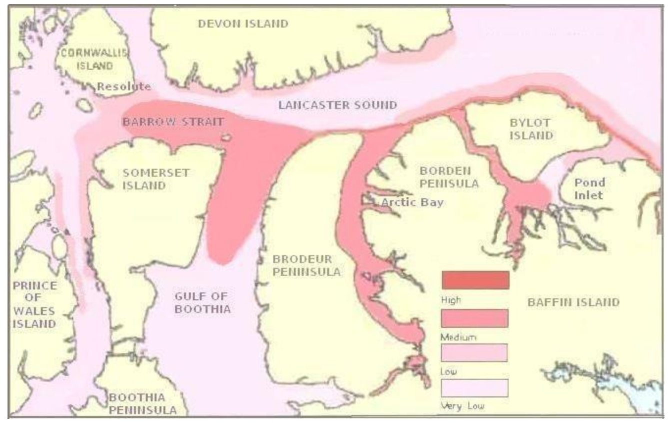
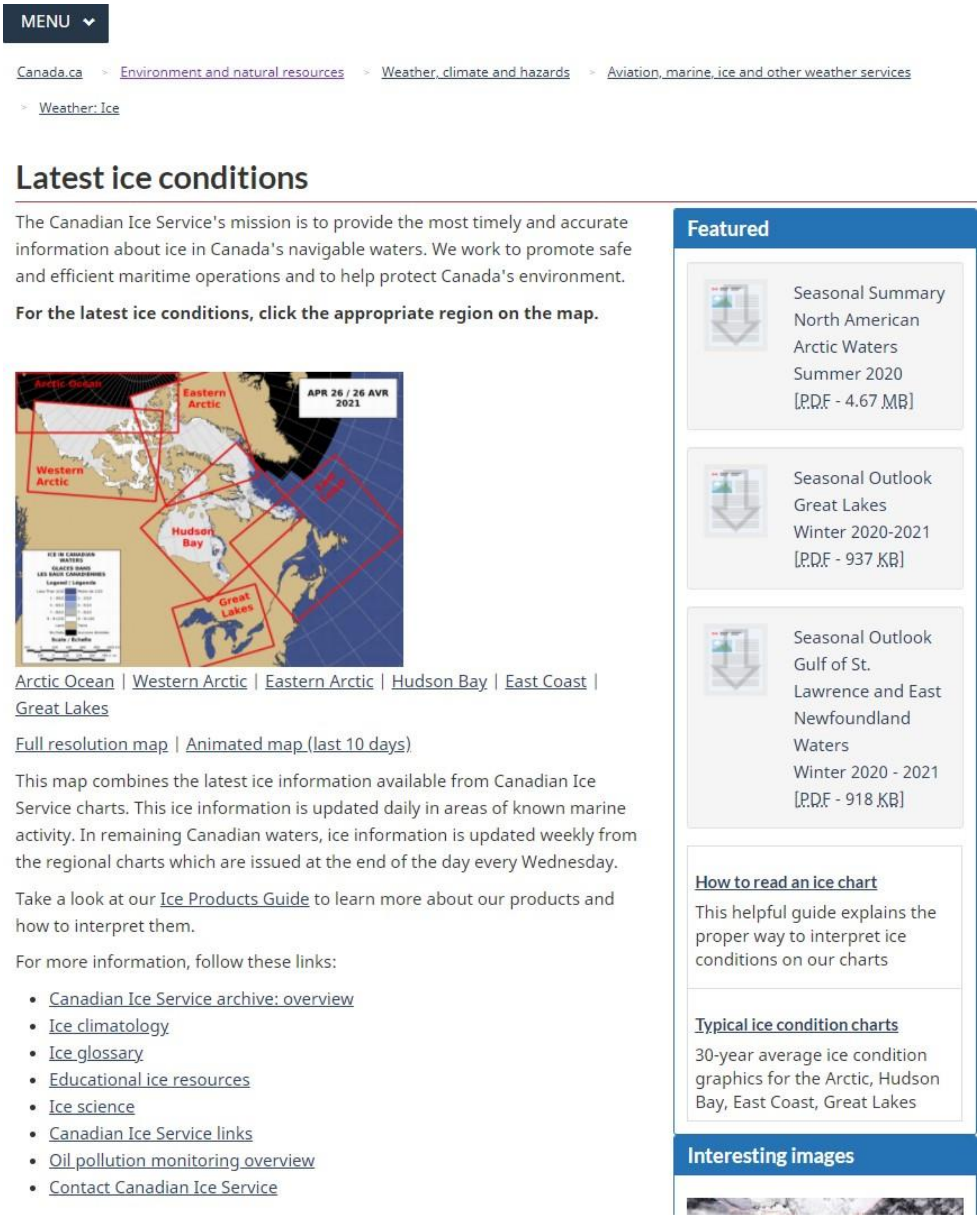


Figure 11 - Environmental sensitivity to vessels in Lancaster Sound in the Fall

3 Ice climatology and environmental conditions

3.1 Environmental conditions

This chapter provides an overview of environmental conditions that can be expected in areas of Canada where navigation in ice occurs. The chapter includes a summary of important meteorological and oceanographic features of the marine environment, a description of basic ice properties, a review of ice conditions that may be encountered in different regions of Canada and information on icebergs. Resources can be found on the ECCC Environment and natural resources website.



MENU

Canada.ca > Environment and natural resources > Weather, climate and hazards > Aviation, marine, ice and other weather services > Weather: Ice

Latest ice conditions

The Canadian Ice Service's mission is to provide the most timely and accurate information about ice in Canada's navigable waters. We work to promote safe and efficient maritime operations and to help protect Canada's environment.

For the latest ice conditions, click the appropriate region on the map.

Arctic Ocean | Western Arctic | Eastern Arctic | Hudson Bay | East Coast | Great Lakes

Full resolution map | Animated map (last 10 days)

This map combines the latest ice information available from Canadian Ice Service charts. This ice information is updated daily in areas of known marine activity. In remaining Canadian waters, ice information is updated weekly from the regional charts which are issued at the end of the day every Wednesday.

Take a look at our Ice Products Guide to learn more about our products and how to interpret them.

For more information, follow these links:

- Canadian Ice Service archive: overview
- Ice climatology
- Ice glossary
- Educational ice resources
- Ice science
- Canadian Ice Service links
- Oil pollution monitoring overview
- Contact Canadian Ice Service

Featured

Seasonal Summary North American Arctic Waters Summer 2020 [PDF - 4.67 MB]

Seasonal Outlook Great Lakes Winter 2020-2021 [PDF - 937 KB]

Seasonal Outlook Gulf of St. Lawrence and East Newfoundland Waters Winter 2020 - 2021 [PDF - 918 KB]

How to read an ice chart
This helpful guide explains the proper way to interpret ice conditions on our charts

Typical ice condition charts
30-year average ice condition graphics for the Arctic, Hudson Bay, East Coast, Great Lakes

Interesting images

Figure 12 - Canadian Ice Service website

The climatology of Canadian ice-covered waters varies widely, as the weather and ocean conditions influencing climate differ, from the Great Lakes and St. Lawrence River in the south to the waterways between the Arctic Islands in the north. Environmental considerations are also diverse. It is only possible to highlight key aspects here.

Seasonal Outlook - North American Arctic Waters is published annually by CIS. This publication incorporates the output of ice reconnaissance, analysis, and forecasting. It is issued in early June and is useful for planning voyages to all waters north of Labrador. Seasonal Outlooks - Great Lakes are issued in early December, to provide a similar overview of expected winter ice conditions in southern areas. Seasonal outlooks are updated twice monthly during the ice-navigation season, providing 30-day ice forecasts. This information is available on ECCC Latest ice conditions.

3.1.1 Air temperature patterns

Formation and growth of sea ice depends on the air temperature falling below freezing (0 °C) and subsequent lowering of sea surface temperatures. Figure 13 illustrates the average dates when the average daily air temperatures fall below 0 °C. Figure 14 shows the dates when the average air temperatures rise above 0 °C. The differences in these dates, from one part of Canada to the next, provide an indication of how widely the duration of cold temperatures may vary in Canada.

Sea-ice growth usually starts sometime after freezing air temperatures are achieved because the freezing point for sea water is near -1.8 °C. In addition, warmer water from within the ocean may reduce the effect of freezing air temperatures on the surface water, further delaying ice growth.

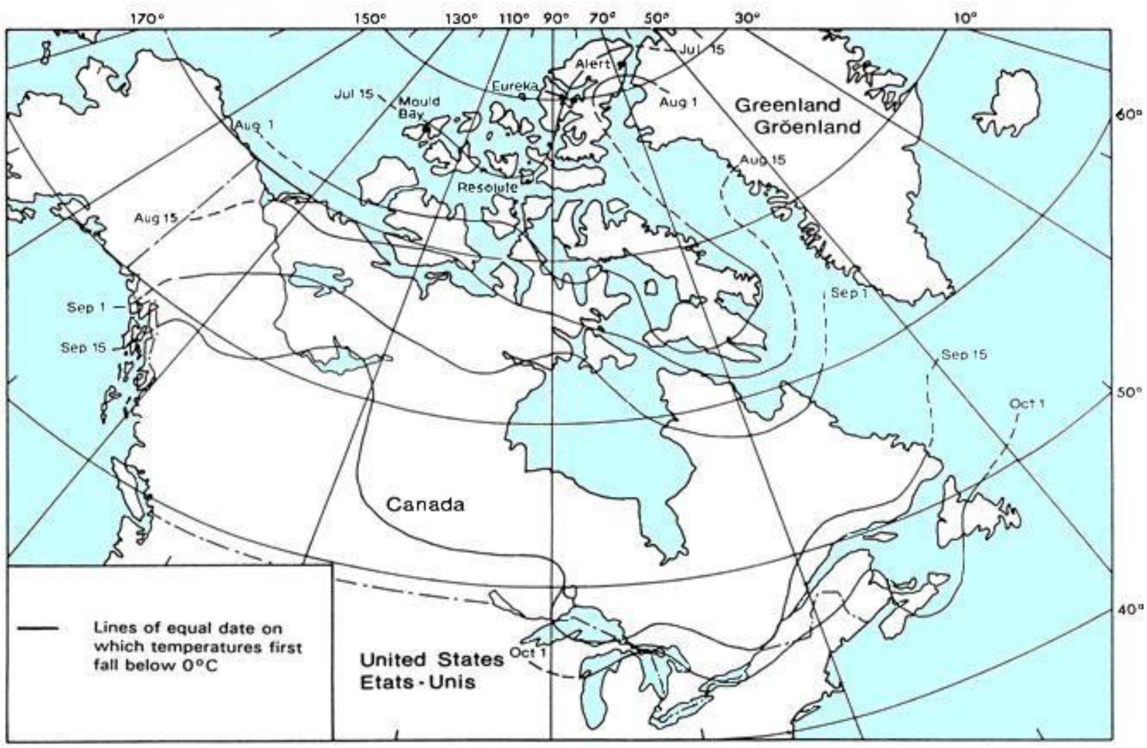


Figure 13 - Dates when the mean daily temperature falls below 0 °C

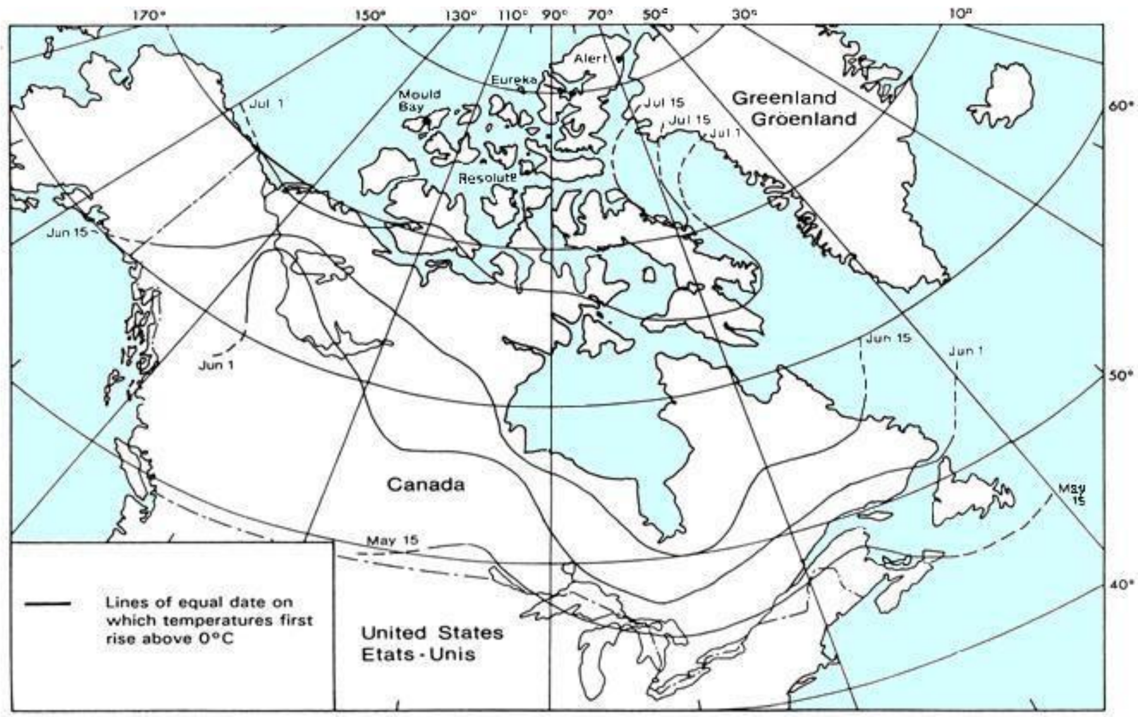


Figure 14 - Dates when the mean daily temperature rises above 0 °C

3.1.2 Major storm tracks and wind conditions

Weather systems tend to move from west to east across Canada. Major storm tracks during the summer months are shown in figure 15. Storms tend to pass through the St. Lawrence then move out to sea over the Grand Banks of Newfoundland and the Labrador Sea. Some storm systems track northward toward the southern tip of Greenland then into Davis Strait. These storms tend to produce severe weather conditions.

Storms in the Arctic also tend to follow specific tracks, particularly south of Parry Channel; storms follow a general west to east track. Figure 16 shows major winter storm tracks. The important weather features affecting the North Atlantic during winter are a low pressure area, the Icelandic Low, centred southeast of Greenland; and a continental high pressure system which develops west of Hudson Bay.

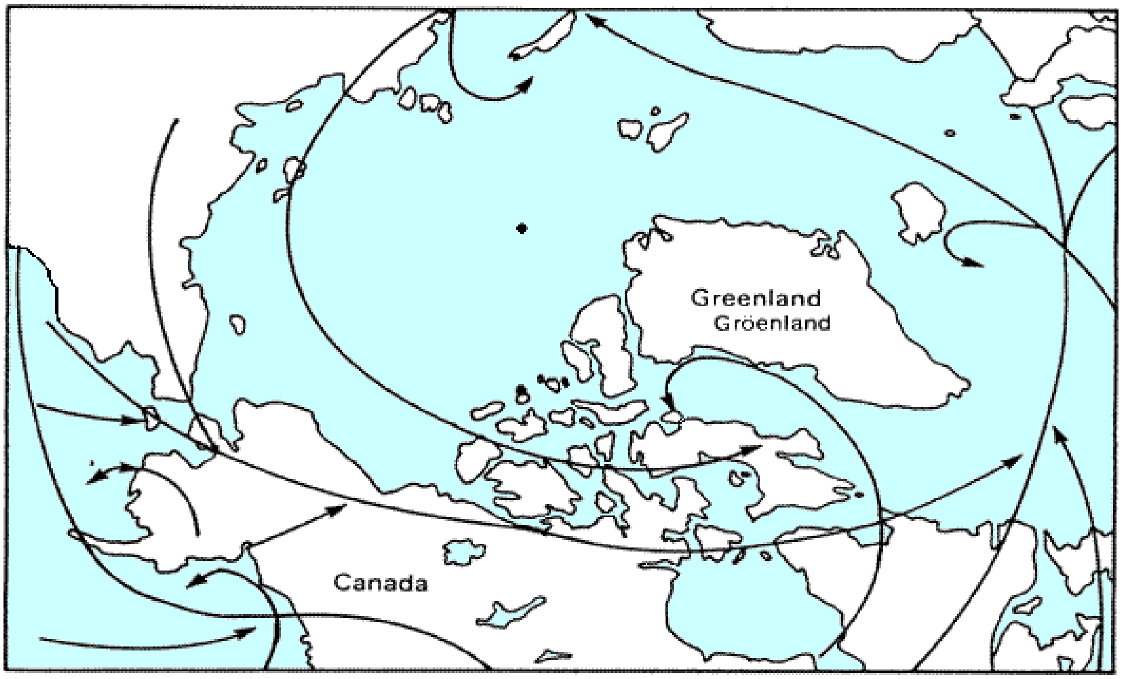


Figure 15 - Principal storm tracks in summer in Canadian Arctic

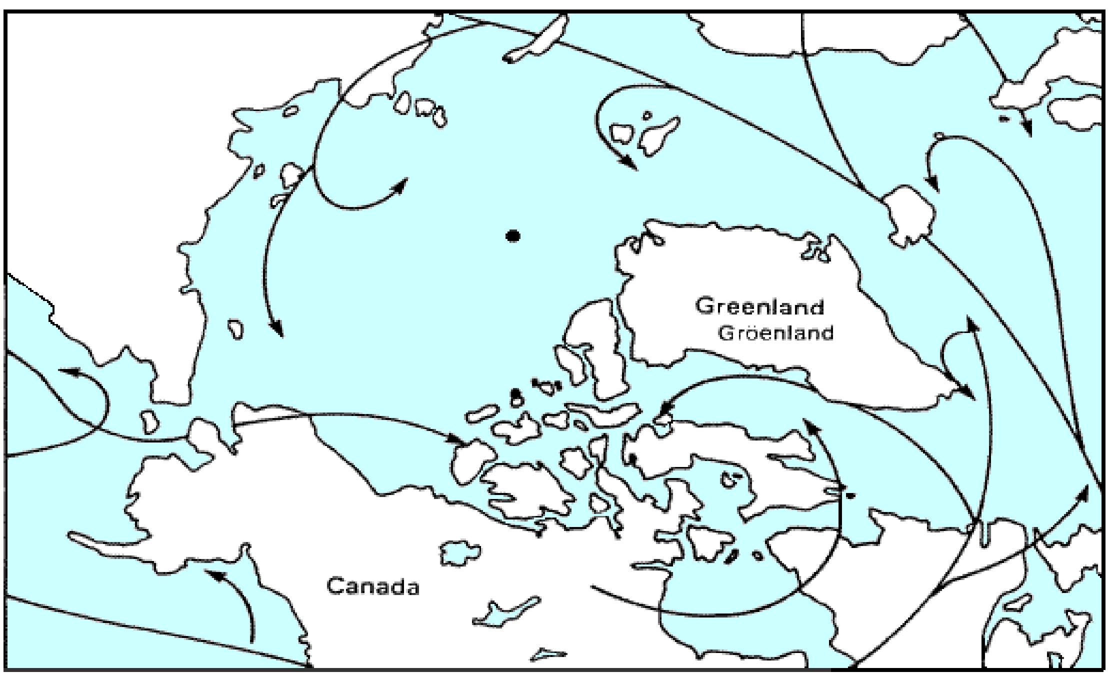


Figure 16 - Principal storm tracks in winter in the Canadian Arctic

3.1.3 Polar lows

Polar lows are small, intense low-pressure events that may not be detected or predicted by meteorologists. The first indication of a polar low may be a sudden change in pressure, rapid increase in wind, or heavy snow flurries at a vessel or station.

Polar lows form near the ice edge or coast where very cold air flows from ice or land surfaces over open water, which is warm relative to the air temperature. The cold air warms, rises, the pressure falls, a circulation evolves and, depending on other supportive factors such as cooling aloft, the polar low deepens or weakens. Polar lows usually occur during the fall, winter, and early spring.

Polar lows are often accompanied by strong winds, rapid drop in air pressure and moderate to heavy snow. A polar low can form quickly and seldom lasts more than a day. However, under stagnant weather systems, polar lows or a family of polar lows can persist for several days.

3.1.4 Precipitation

Precipitation patterns vary considerably between southern Canada and the Arctic islands. Rain and snow may be of concern to shipboard activities in Spring and Fall, when rain combined with low temperatures can result in vessel icing.

An important factor in determining precipitation amounts is the availability of moisture sources. In the high Arctic, water available for precipitation is generally low. However, areas of relatively high amounts of available water are found around southern Baffin Island in Davis Strait and in the Amundsen Gulf-Victoria Island area. The northern and central parts of the Arctic have lower moisture availability that is reflected in lower rain and snowfall in these areas.

3.1.5 Fog and visibility

Marine visibility is affected by a number of factors including daylight hours, precipitation, blowing snow, and fog. The number of daylight hours available for navigation becomes a particular concern the further north one travels. In the Arctic, extended daylight conditions occur through the summer, whereas the opposite is true during the winter months. Figure 17 illustrates the seasonal variability of daylight for different latitudes.

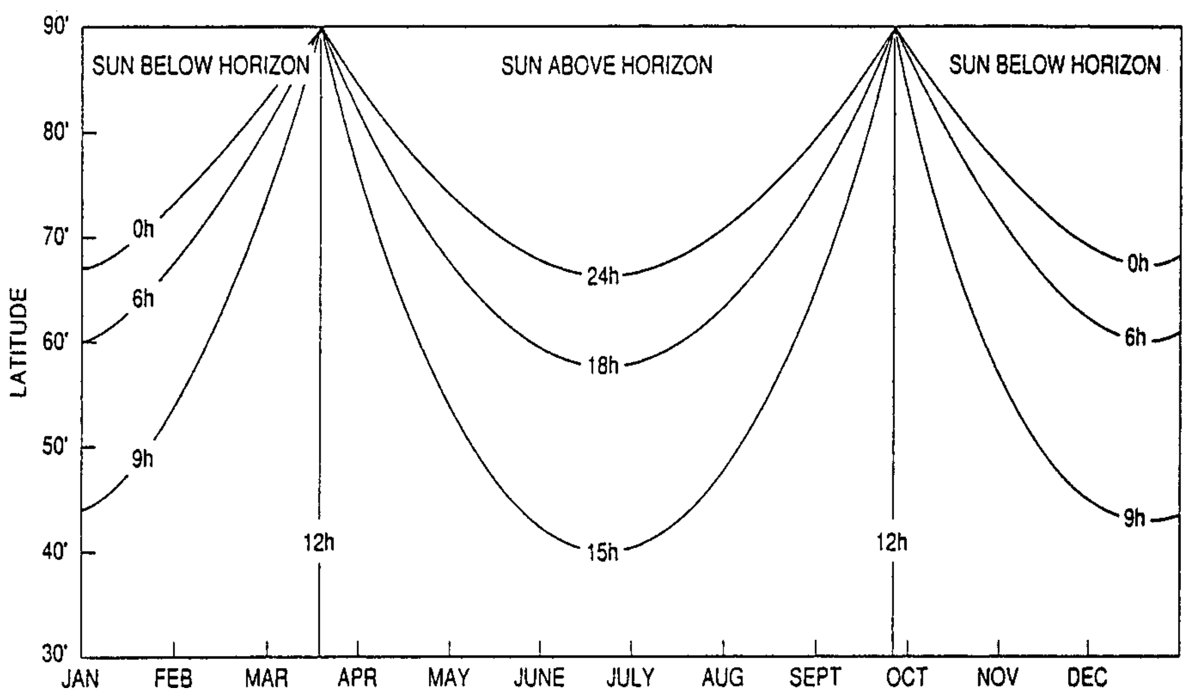


Figure 17 - Seasonal Variability of Daylight by Latitude and Month

Fog is a major cause of low visibility at sea. It is particularly common in Baffin Bay in the spring and summer and on the Grand Banks at all times of the year. **Sea fog**, or advection fog, forms when warm, moist air moves over colder seawater. As the air cools below its saturation point, excess moisture condenses to form fog. This type of fog may cover large areas and may persist for long periods, even under windy conditions, provided a continuous supply of warm moist air is available.

A second type of fog, **sea smoke**, or evaporation fog, forms when cold air moves over warmer seawater. In this case moisture evaporates from the sea surface and saturates the air. As the air is cold, excess moisture condenses to form fog. During the summer, fog often will develop over an ice pack or ice-covered waters. It is believed that this type of fog forms when melt-water on the ice surface warms, saturates the air, and condenses to produce fog.

Blowing snow is an important contributor to reduced visibility during winter months. In addition to wind strength, the time since the last snowfall affects the amount and duration of the blowing snow. Snow compacts over time and, as a result, the longer the interval between snowfalls and a strong wind event, the less likelihood there will be of significant amounts of blowing snow.

3.1.6 Freezing spray and superstructure icing conditions

Vessels operating in Canadian waters in late fall and winter are likely to experience some degree of topside icing on decks, bulwarks, rails, rigging, and spars. Icing can hinder shipboard activity and, in extreme cases, it can seriously impair vessel operations and stability. The accumulation of ice on a ship's superstructure can raise the centre of gravity, lower the speed and cause difficulty in manoeuvring. Icing can also create various problems with cargo handling equipment, hatches, anchors, winches, and the windlass. Smaller vessels are most at risk, and several fishing vessels have been lost off the Canadian east coast because of spray icing.

Icing on vessels can result from freshwater moisture such as fog, freezing rain, drizzle, and wet snow, or from salt-water including freezing spray and wave wash. Icing from advection and evaporation fog can be a problem in the fall months, but occurs rarely in winter as moisture sources are minimal once an ice cover forms. Icing arising from precipitation can occur when there is an accompanying drop in air temperature, but its occurrence is generally limited to the spring and fall months. In the Arctic, it is an infrequent phenomenon, with most areas experiencing less than 25 hours annually. Areas such as western Baffin Bay, Davis Strait, and Amundsen Gulf near Cape Parry experience 25 to 50 hours of icing annually, whereas off Brevoort and Resolution Islands icing may occur for as many as 100 hours each year.

Of the various forms of superstructure icing, freezing spray is the most common, and is the most severe cause of ice build-up. It can occur whenever the air temperature falls below the freezing temperature of seawater and when sea surface temperatures are below 6 °C. To get spray icing there must be a source of spray and enough cooling from the atmosphere so that spray freezes to an object before it has had time to run off. Freezing spray can be experienced in almost all Canadian waters, although it is more frequent and more severe in coastal waters off eastern Canada. Ice accretion rates from freezing spray can exceed 2 centimetres per hour and ice build-up of over 25 centimetres is not uncommon.

Figure 18 - Freezing Spray

In addition to air temperature and wind speed, other factors affecting freezing spray accumulation are the particular vessel characteristics including size and shape of deck fittings. Smaller vessels are exposed to more spray, and lose stability more rapidly than larger vessels. Finally, it is important to note that the presence of sea or lake ice will reduce wave generation and the potential for freezing spray. As a general rule, it can be assumed that freezing spray will not be a problem once the ice cover exceeds 6/10 concentration. Once vessels are in the ice, the potential for freezing spray is virtually zero. The preceding paragraphs describe the general process of superstructure icing, but variations in spraying and heat loss over the vessel can result in significant variations in ice accumulation rates, depending on elevation and exposure of a shipboard object. For instance, ice accumulates more rapidly on rigging and spars, increasing the potential for a vessel to capsize.

Freezing spray warnings are included in marine forecasts by ECCC. However, it is difficult to provide accurate icing forecasts as individual vessel characteristics have a significant effect on icing. Graphs assessing the rate of icing based on air temperature, wind speed, and sea-surface temperature can provide a guide to possible icing conditions, but should not be relied on to predict ice accumulation rates on a vessel. Caution should be exercised whenever gale-force winds are expected in combination with air temperatures below -2 °C.

Specific regional information concerning vessel icing is given below for the Gulf of St. Lawrence, the Labrador Sea and Hudson Bay, and Arctic waters including Baffin Bay and Davis Strait.

3.1.6.1 Gulf of St. Lawrence

In the Gulf of St. Lawrence, freezing spray is the most frequently reported cause of vessel icing. Freezing spray is also responsible for the heaviest ice accumulations, which can exceed 25 centimetres in thickness. Freezing precipitation and super-cooled fog are less frequently reported and are typically responsible for accretions of 1-2 cm thick.

Spray icing can be encountered in the Gulf area any time from November to April, although it is most frequently reported from December to February. During the month of January, potential spray icing conditions are encountered more than 50% of the time. Freezing rain is most frequently experienced from December to April, and super-cooled fog is reported from January to March.

Freezing spray conditions in the Gulf are usually produced by intense winter storms situated off the Canadian east coast. These storms set up a strong northwesterly flow of cold arctic air over the Gulf area which produces snow showers and squalls over open water. During spray icing events, the air temperature is typically around -10 °C with 30-knot northwesterly winds and 2 to 3 metre waves. Spray icing potential would be greater in the Gulf area were it not for short fetches and the presence of extensive ice cover which limit wave generation.

From an investigation of icing thickness reports in the Gulf, 3 areas showed heavier icing accumulations: the central Gulf area west of the Magdalen Islands; the Strait of Belle Isle off Flowers Cove; and north of the Gaspé Peninsula off Cap de la Madeleine. These heavier accumulations may result from more intense local icing conditions (such as shorter, steeper waves) or because the areas are visited by vessels more susceptible to spraying and consequently to icing.

3.1.6.2 Labrador Sea and Hudson Bay

In the Labrador Sea and Hudson Bay, the main cause of vessel icing is freezing spray. Freezing spray is also responsible for the heaviest ice accretions, which can exceed 20 centimetres. Icing from super-cooled fog and freezing precipitation are less frequently reported, and are generally responsible for small amounts of accreted ice, about 1-2 centimetres. Arctic sea smoke can accompany spray icing if air temperatures are very cold: vessel icing reports from east coast waters show that combined spray and fog icing conditions are more frequently experienced in the Labrador Sea.

The potential for spray icing exists from October to May in both areas. However, this is modified in Hudson Bay by the heavy ice cover which restricts vessel speed and wave growth for most of the winter. Spray icing is, therefore, most frequently encountered in October and November when temperatures are dropping, but before the ice cover has advanced significantly. In contrast, spray icing can be encountered throughout the winter off the Labrador coast, where conditions leading to spray icing exist more than 30% of the time in January and February.

In Hudson Strait and Hudson Bay, freezing precipitation is most likely in the spring and fall, whereas in the Labrador Sea, freezing precipitation is experienced over the entire winter period. Super-cooled fog is most frequently reported in February and March in the Labrador Sea, and in the fall for Hudson Bay. It should be noted that it is very difficult to obtain information about the winter marine climate of Hudson Bay because there are very few vessel reports.

Freezing spray conditions are usually produced by large, intense cyclones centred to the northeast of each area. These storms set up strong west-northwest flows of cold arctic air, which produce snow showers and squalls over open water. During spray events in the Labrador Sea, the air temperature is typically -10 °C with 30-knot westerly winds, and 4 to 5 metre waves. Typical conditions are less severe in Hudson Bay, with an air temperature of -6 °C, 25-knot northwesterly winds and 2 to 3 metre waves.

Because icing events in the Labrador Sea are most frequently associated with westerly winds, conditions can appear deceptively sheltered near shore. The danger here is that if small coastal vessels venture out in these conditions, severe icing may be encountered offshore.

From an investigation of icing thickness reports in the Labrador Sea, one area showed noticeably heavier ice accumulations: average accretion thicknesses exceed 10 centimetre on Hamilton Bank (54°N, 55°W), whereas they are typically 4-5 centimetre elsewhere. These heavier accumulations may result from more intense local icing conditions (for example shorter, steeper waves), or because this area is visited by vessels more susceptible to spraying and consequently to icing.

3.1.6.3 Arctic waters

Generally, freezing spray is less of a problem in the Arctic than in the Gulf of St. Lawrence or the southern Labrador Sea, but the likelihood of marine icing incidents is at its greatest potential (over 20% of the time) during the fall. This is the period when the air temperatures are significantly below zero and open water is still prevalent in Baffin Bay, Davis Strait and the northern portions of the Labrador Sea. Although it occurs less frequently, incidents of freezing spray in the western Arctic and Beaufort Sea have been reported, with extreme cases of ice accumulation exceeding 15 centimetres.

3.2 Ice physics

This section describes some key elements of the physical properties of ice. The intent is to provide information that will help in the interpretation of both regional ice conditions and ice charts, and that will be useful in subsequent discussions of ice navigation practices.

3.2.1 Ice terminology

The terminology used in this manual is that used by mariners and scientists who deal with ice regularly. A list of Ice Terminology is provided in Annex I. These definitions have been developed and approved by the World Meteorological Organization. For more complete information on ice terminology, refer to the MANICE.

3.2.2 Ice types

Different forms of ice can be distinguished on the basis of their place of origin and stage of development. The principal kinds of floating ice are:

- lake and river ice, formed from the freezing of fresh water
- sea ice, formed from the freezing of sea-water
- glacier ice, formed on land or as an ice shelf from the accumulation and re-crystallization of snow

Types of lake ice are identified as being new, thin, medium, thick, or very thick, on the basis of their stage of development. **New lake ice** is recently formed and is less than 5 centimetres thick. **Thin, medium**, and **thick** lake ice range in thickness from 5-15 centimetres, 15-30 centimetres, and 30-70 centimetres, respectively, whereas **very thick** lake ice is greater than 70 centimetres in thickness.

Sea ice is categorized as new ice, young ice, first-year ice, and old ice. Within each of these categories there are terms referring to more specific types of ice. Details concerning more specific ice types can be found in Annex I. **New ice** is recently formed and composed of ice crystals which are only weakly frozen together and as the ice develops it forms a thin elastic crust over the ocean surface **(nilas). Young ice** represents a transition stage between nilas and first-year ice. Young ice ranges in thickness from 10-30 centimetres and, as it thickens, grows progressively lighter in colour from grey to grey-white. **First-year** ice is ice of not more than 1 winter's growth, ranging from 30 centimetres to over 2 metres thick. **Old ice** is sea ice that has survived at least one summer's melt. It is thicker and less dense than first-year ice and generally has smoother or rounder surface features. It can be divided into **second-year** or **multi-year** ice if the history of the ice is known.

Finally, sea ice is distinguished on the basis of its mobility. Fast ice is more or less fixed to the coast. It may move slightly in response to tides but, over the course of the winter, shows little lateral motion. On the other hand, pack ice or drift ice (a mass of individual ice pieces known as floes), is mobile, drifting in response to winds and current forcing. The dynamics of pack ice may result in the ice being put under pressure, frequently leading to deformation of the ice cover. Both the pressure itself and the deformed ice can affect vessel navigation.

Glacier or ice of land origin includes icebergs and ice islands. Icebergs are further typed by size and shape, with growlers (length less than 5 metres) and bergy bits (length 5 to 15 metres) representing the smallest iceberg pieces. Larger icebergs range from small (5 to 15 metres above sea level and 15 to 60 metres in length) to very large (higher than 75 metres and longer than 200 metres). According to shape, icebergs are frequently described as being tabular, domed, pinnacled, wedged, drydocked, or blocky.

3.2.3 Ice properties

The structure of an initial ice cover is dependent on weather and sea-state conditions at the time of ice formation. Under calm conditions, large ice crystals form at the surface and gradually interlock. This layer may be as little as 1 to 2 centimetres in thickness. In more turbulent conditions, ice crystals in the surface layer will tend to be smaller, and may form quite a deep layer, for instance, up to 3 metres thick off the Alaskan coast.

Once an initial layer of ice has formed on the surface, ice growth continues downward. Beneath a transition zone the ice is composed primarily of long columnar ice crystals. As the ice grows downward, brine is frozen into the ice crystals, but through the winter the brine solution gradually drains downward with the result that, at a given level in the ice, the salinity will change as the ice cover thickens.

During the summer season, surface melt-water drains through the ice, helping to flush out additional brine from the ice. Ice which survives more than one year takes on a layered structure and horizontal layers represent ice growth during successive years.

In addition to the fact that old ice tends to be thicker than first-year ice, its lower salinity is an important consideration for ice navigation, as ice strength is closely related to brine volume. With lower salinities, old ice is much stronger than first-year ice.

Warning: Old ice is harder, stronger, and usually thicker than first-year ice. Contact with old ice should be avoided whenever possible.

3.2.4 Ice formation and growth

Several forms of ice may be encountered such as: sea ice, lake ice, river ice, icebergs, and ice islands. The freezing of fresh- and salt-water does not occur in the same manner and the following brief explanation is limited to the formation of sea ice from salt-water.

When considering the freezing process, dissolved salts are important not only because they lower the water's freezing temperature (typically around -1.8 °C for sea water of 35 parts per thousand salt), but also because they affect the density of water. The loss of heat from a body of water takes place principally from its surface to the surrounding air or water. As the surface water cools, it becomes more dense and sinks, to be replaced by warmer, less dense water from below. The cycle repeats until the water temperature reaches its freezing point. This process takes longer as the amount of salt in the water increases. As a result, the onset of ice formation will be delayed.

The first visual indication of ice formation is the appearance of spicules or plates of ice in the top few centimetres of water. These spicules are also known as frazil ice and give the sea surface an oily appearance. As cooling continues, the ice crystals grow together to form grease ice, which gives the sea surface a matt or dull appearance. Eventually, sheets of ice rind or nilas are formed, depending on the rate of cooling and on the salinity of the water. Wind and waves frequently break the ice into smaller pieces which soon become rounded as they collide with each other. The resultant ice is termed pancake ice. Individual pancakes may later freeze together, gradually thickening from below as additional sea-water cools and freezes.

The rate of freezing is controlled by the severity and duration of cold air temperatures. At -30° to -40 °C, grey ice can form from open water in 24 hours. However, the thickening ice also acts as an insulator against the cold air, and the growth rate gradually diminishes. Even at these low temperatures, it would take a month for the ice to reach the thin first-year stage. Snow cover, which has approximately 10 times greater insulating value than sea ice, will also contribute to lower growth rates.

Sometimes the amount of snow cover may be so great that its weight depresses the underlying ice to the point that its surface is below the water level. The lowest layers of the snow cover may then become waterlogged and freeze, adding to the ice thickness. This happens often on the Great Lakes and the lower St. Lawrence River.

During the initial ice formation process, as ice crystals form and existing ones grow larger, brine becomes trapped in small cells within the ice matrix. The amount of brine trapped in the ice depends on the rate at which ice forms, with greater amounts of brine retained when ice formation is rapid. Slow ice growth allows a large portion of the brine to drain away. The amount of brine in the ice has an important bearing on its strength: the greater the brine content, the weaker the ice.

A second factor affecting the strength of ice is its age. As air temperatures warm and the ice approaches its melting point, entrapped brine begins to drain away, lowering the overall salinity of the ice cover. Should temperatures drop back below the freezing point before the ice melts entirely, it will re-freeze as purer and stronger ice. For this reason, ice more than 1 year old will be stronger than first-year ice for a given thickness and temperature, an important factor to consider when navigating in regions where old ice may be found.

3.2.5 Ice motion, pressure, and deformation

Ice normally forms near coasts first and then develops seaward. A band of fairly level ice becomes fast to the coastline and is held immobile. The seaward extent of fast ice formation will be limited by factors which can contribute a stable anchor for the ice. As an example, more fast ice would be expected in shallow coastal areas, or ones with numerous islands, than in areas where water depths drop sharply from the coast. Beyond this fast ice lies the pack or drift ice, which is free to move in response to wind and water forcing.

An area of newly formed ice seldom remains unaltered for long. Winds, currents, tides, and thermal forces cause the ice to undergo various forms of deformation. Wind causes ice floes to move generally downwind at a rate that varies with wind speed, concentration of the pack ice, and the extent of ice ridging or other surface roughness. A rule of thumb which is often used to estimate pack ice motion is that the ice will move at 30° to the right of the wind direction at about 2% of the wind speed.

One effect the wind has when it blows from the open sea onto floating ice is to compact the floes into higher concentrations along the ice edge, producing a relatively well-defined boundary between ice and open water. When winds blow off the ice toward the sea, the floes near the ice edge will be dispersed, resulting in lower ice concentrations and a diffuse ice/water boundary. As sea ice is partially submerged in the sea, it will also move in response to near surface currents and tides. As a result, the net movement of the ice is a complex product of both wind and water forces and consequently is difficult to forecast.

Thermal forces cause ice deformation: as temperatures drop, ice expands. For a drop in ice temperature from -2° to -3 °C, ice with a salinity of 10 parts per thousand will expand 0.3 metre for every 120 metres of ice floe diameter. At the same temperatures, for ice with a salinity of 4 parts per thousand, the rate is about one third this amount. Below -18 °C and -10 °C respectively, 10 parts per thousand saline ice and 4 parts per thousand saline ice cease expanding and, as temperatures drop further, contraction occurs. Although the amounts of thermal expansion and contraction may seem small, they can result in pressure ridge development under some circumstances.

Atmospheric and oceanographic forces contribute additional energy to deform pack ice. As ice is subjected to pressure from winds or currents, it may fracture and buckle to produce a rough surface. In new and young ice, this results in rafting as one ice sheet overrides another. In thicker ice, pressure leads to the formation of ridges and hummocks, when large pieces of ice are piled up above the general ice surface and large quantities of ice are forced downward to support the additional weight. As a general rule, the below-water portion of ice is in the order of three to four times as deep as the above-water height.

Note: Total ice thickness below water is three to four times the ice height above the water line.

Pressure arising from strong winds can be severe and usually persists until the wind subsides or changes direction. The extent of ridging caused by pressure depends on whether or not the leeward boundary of the ice field was against land or closely packed ice when onshore winds began. In such cases, the floes within the ice field may become pressed together, eventually increasing to 10/10 concentration, with pressure developing throughout.

Pressure within an ice field can also be caused by tides. Tidal pressure is usually of short duration, lasting from one to three hours and, although less heavy than pressure from winds of longer duration, it can at times bring shipping operations to a halt. Tidal pressure can be particularly significant in restricted channels where the tidal effect is enhanced and ice movement is restricted.

Note: Onshore winds and tidal currents may cause pressure within ice fields. Pressure may be so severe as to restrict a vessel from moving.

Cracks, leads, and polynyas may form as pressure within the ice is released or tension occurs. Offshore winds may drive the ice away from the coastline and open a shore lead or push pack ice away from fast ice. In some regions where offshore winds prevail during the ice season, local shipping and vessel movement may be possible throughout much of the winter season. However, brief periods of onshore wind may cut off any leads and entrap vessels.

Warning: Mariners navigating through open water leads are urged to do so with extreme caution. The navigator should try to anticipate the effect of winds and currents on possible changes in lead conditions.

3.2.6 Ice ablation

Ice may be cleared from an area by winds and/or currents, or it may melt in place. Where the ice field is well broken (open ice or lesser concentrations), wind plays a major part as resulting wave action will cause considerable melting. Where the ice is fast or in very large floes, the melting process is primarily dependent on incoming radiation. Air and water temperatures and some types of precipitation also have a significant effect on ice melt.

Snow cover on the ice acts initially to slow ice ablation, because it reflects almost 90% of incoming radiation back to space. However, as temperatures rise above 0 °C, and the snow begins to melt, puddles form on the ice surface. These puddles absorb about 60% of incoming radiation, causing the water to warm and the puddle to enlarge rapidly. Heat from the melt-water is transferred to the ice below causing the ice to weaken. In this state, it offers little resistance to the decaying action of wind and waves. The puddling of melt-water on the ice, which usually occurs extensively in the Canadian Arctic, promotes accelerated ice decay and breakup.

3.3 Icebergs, ice islands, bergy bits, and growlers

Icebergs and ice islands differ from sea ice in that they represent extreme local hazards to navigation, rather than the limited but widespread problem offered by sea ice. Severe damage can result from hitting glacial ice.

Warning: The glacial ice of icebergs and ice islands is very hard. They should be given a wide berth.

3.3.1 Origin and nature

Icebergs are a common feature of Arctic waters, along the Labrador coast, and on the Grand Banks of Newfoundland. Icebergs (figure 19) differ from sea ice in that they are formed from fresh-water ice originally on land. They form when pieces of glacier ice break off or calve into the sea.

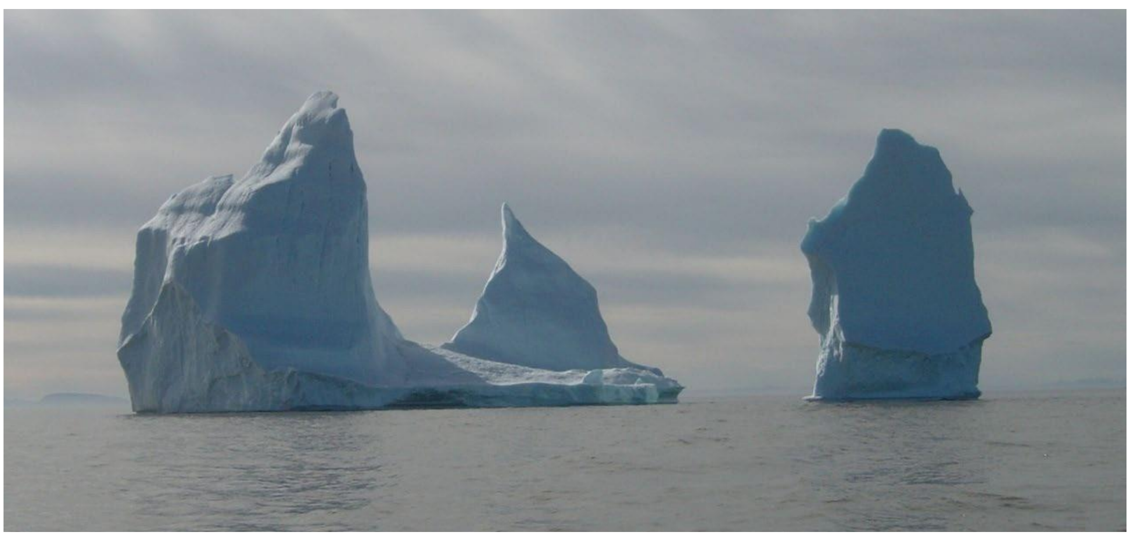


Figure 19 - Photograph of a pinnacled iceberg (photo courtesy of CIS)

A second type of floating glacial ice is created when fragments calve from ice shelves along the northern coast of Greenland and the Arctic Archipelago, particularly Ellesmere Island. The floating pieces of ice are known as ice islands (figure 20). They are mainly found in the Arctic Ocean, Beaufort Sea, and channels of the Archipelago and the eastern Arctic.

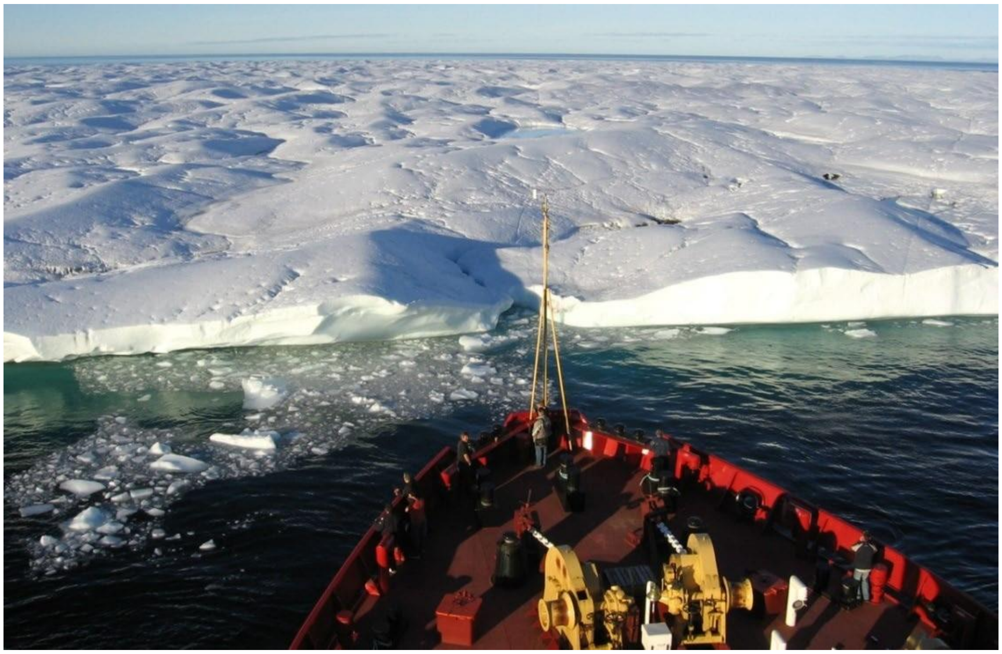


Figure 20 - Photograph of an ice island (photo courtesy of CIS)

Almost all icebergs found along the east coast of Canada originate from the glaciers of west Greenland. Most of the active glaciers along the west Greenland coast are located between Smith Sound and Disko Bay. Melville Bay, from Cape York to Upernavik, is a major source of icebergs; it is estimated that 19 active glaciers produce 10,000 icebergs annually. A second area of importance is Northeast Bay, including Karrats and Umanak Fiords, where about 5,000-8,000 icebergs are calved from 10 major glaciers each year. Disko Bay also produces a small number of icebergs from 2 glaciers.

A few Canadian glaciers on Baffin, Bylot, Devon, Coburg, and southern Ellesmere Islands calve icebergs, but only in small numbers. The annual production of icebergs from Canadian glaciers is estimated to be about 150. Total annual production of icebergs in Baffin Bay is estimated to be 25,000-30,000, although some estimates are as high as 40,000. More than 90% of the icebergs come from west Greenland glaciers.

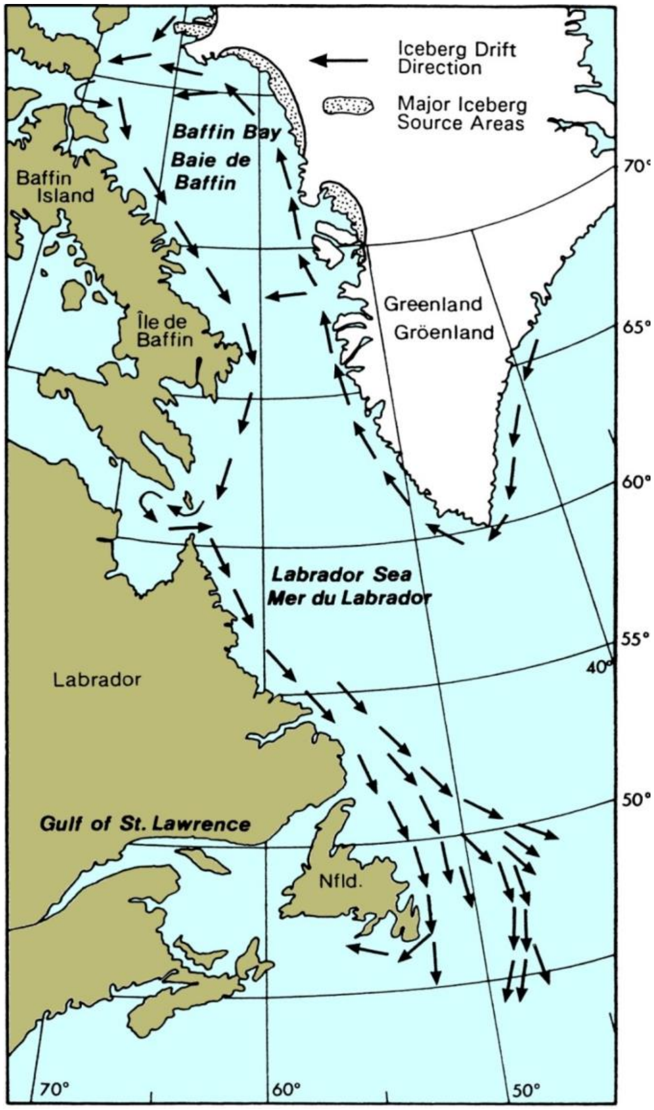


Figure 21 - Sources and main tracks of icebergs in Canadian waters

The size of icebergs calved varies from growler size (about 20 square metres with 1 metre above water) to icebergs 1 kilometres long and over 200 metres high. The height-to-draught ratio of an iceberg varies from 1:1 to 1:3 for pinnacle icebergs, to 1:5 for blocky, steep-sided tabular icebergs. A study of icebergs in Davis Strait suggested that a ratio of 1:4 was a good approximation for estimating iceberg size. If the height of an iceberg is 100 metres it would not be unreasonable to expect a draught of 300 to 500 metres. As a result of their substantial draught, even smaller icebergs frequently become grounded in coastal waters and on shoals.

3.3.2 Locations and clustering

An important consequence of the substantial draught of an iceberg is that its drift is strongly influenced by ocean currents, as well as winds. The relative importance of winds and currents on iceberg drift depends on the area and mass exposed to winds and currents and the relative strength of each. Icebergs calved from glaciers on the west Greenland coast usually drift northward (see figure 21) at a rate of 3 to 5 nautical miles per day, before being carried westward across northern Baffin Bay. From there, currents along east Baffin Island carry the icebergs south to the Labrador Sea and onto the Grand Banks of Newfoundland. Along Labrador, drift rates of 10 nautical miles per day are not uncommon.

Whereas the main drift path is anticlockwise in Baffin Bay, it is not uncommon for icebergs to be carried westward across Baffin Bay by smaller current streams which branch off from the West Greenland current. Iceberg drift is seldom direct, with icebergs frequently following lesser currents into bays and inlets. In particular, numerous icebergs are drawn into Lancaster Sound, moving westward through the Sound as far as 85°W. Icebergs also drift southward into Navy Board Inlet and eastward to Pond Inlet. Similarly, icebergs are sometimes carried into Hudson Strait south of Baffin Island. Icebergs have been observed as far west as Big Island, probably in response to strong tidal flows.

Occasionally icebergs enter the Gulf of St. Lawrence, passing through the Strait of Belle Isle. These icebergs are generally small, as the water depths in the Strait (55 metres) limit iceberg draught. Most icebergs entering the Gulf tend to go aground along the Quebec shore, east of Harrington Harbour, although a few have been observed as far west as Anticosti Island and in the Bay of Islands area along the west Newfoundland coast. A considerable number of icebergs can remain grounded in the Strait of Belle Isle.

It is estimated that an iceberg travels between 2,700 and 3,700 kilometres from its place of calving to reach the Grand Banks of Newfoundland. Based on estimated current speeds, an iceberg calved in Melville Bay could complete the trip in one year. It is more likely that it would not remain in the main current and a more realistic estimate of the travel time is 2 to 3 years.

As icebergs drift, they become smaller through melting and calving of ice fragments. Calving is frequent and, by exposing more ice surface to the water, encourages greater melting. Melting occurs both above and below the waterline. As water temperatures vary with depth, it is possible to have melting of the iceberg near the water surface, but not melting at greater depths, where temperatures may be lower than the 0 °C required to melt freshwater ice. Combined with surface melting, an iceberg's centre of buoyancy can change, resulting in unstable conditions and rolling of the iceberg. Icebergs encountered off Newfoundland are generally more deteriorated and unstable than icebergs further north. An iceberg may roll several times per day. Therefore, it is very important for vessels to steer a wide berth around an iceberg in case it rolls.

Based on studies of decaying icebergs, the U.S. Coast Guard International Ice Patrol has developed simple approximations of the deterioration times for icebergs of different sizes, under various water temperature conditions. These are shown in table 6. More information at How does IIP determine the deterioration and drift of icebergs (United States Coast Guard).

Table 6 - Time taken for icebergs of different sizes to deteriorate

Surface sea-water Temperature (°C)	Deterioration time (days)		
	Small iceberg [a]	Medium iceberg [b]	Large iceberg [c]
0	15	40	90
2.2	8	16	24
4.4	5	10	15

[a] **Small iceberg** - under 15 metres high, under 45 metres long

[b] **Medium iceberg** - 15-30 metres high, 45-90 metres long

[c] **Large iceberg** - over 30 metres high, over 90 metres long

[d] **For tabular bergs the height limits differ:** less than 6 metres for small, 6-15 metres for medium, and more than 15 metres for large icebergs.

The melt rate for icebergs in Arctic waters is slow, but, even so, it is unlikely that more than 20 to 25%of the icebergs calved from Greenland glaciers reach western Baffin Bay. It is estimated that half of these melt before entering Davis Strait, and only 20%of the remainder will complete the drift to the Grand Banks.

Figure 22 - Calving iceberg (courtesy of the CIS)

In an average year, about 300 icebergs drift south of 48°N, but there is considerable year-to-year variation in this number. Based on observations compiled from the International Ice Patrol (patrol established in 1914 by the agreement of 16 nations with shipping interests in the North Atlantic Ocean), the total, the total number of icebergs crossing 48°N has varied from a high of 1587 icebergs in 1984 to a low of no icebergs in 1966. Figure 23 shows the annual variability between 1951 and 2010. Icebergs drift all year, although when in winter pack ice their drift rate is slowed. As the sea-ice cover along the Labrador and Baffin coasts deteriorates, icebergs move more freely. Within a given year, most icebergs cross 48°N between March and June. On average, almost two-thirds of the icebergs have been observed in April.

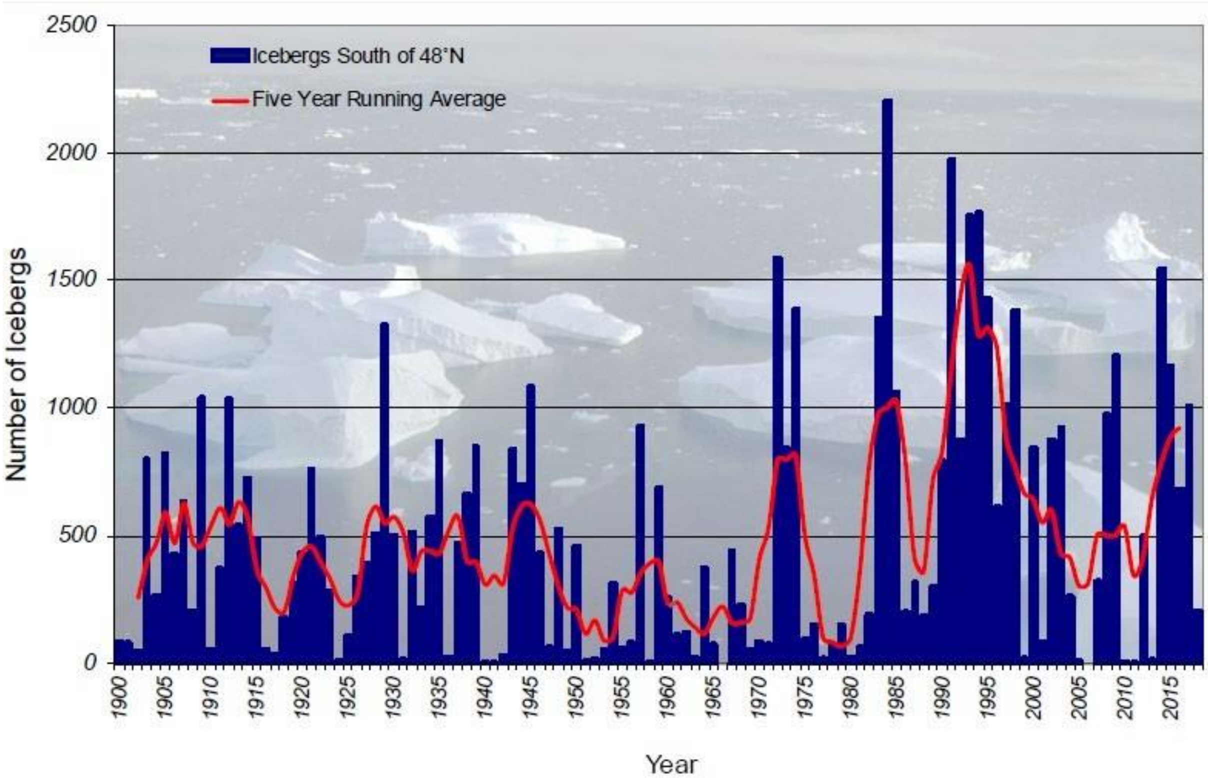


Figure 23 - Annual count of icebergs crossing 48°N latitude[7]

3.4 Ice climatology for the Great Lakes

3.4.1 Meteorological influences

Weather has a direct bearing on the planning and execution of winter navigation. Temperatures control the extent and thickness of ice that forms, and the surface winds modify its location, form and distribution. During winter, cold air from the Canadian Arctic can be carried southeastward across Canada, resulting in temperatures far below the freezing point, causing superstructure icing and rapidly increasing the volume and extent of the lake ice present. On the other hand, migratory low pressure centres may result in warm air from lower latitudes sweeping northward and creating melting conditions that last anywhere from a few hours to several weeks. The winter seasons vary considerably in severity depending upon the relative frequency and the paths of these migratory storm centres.

In considering ice formation, ice growth and ice deterioration, the amount of heat exchange between ice, water and air is of basic importance. However, due to the complexity of these processes and their measurement, air temperature is often used to quantify the effect of freezing and melting conditions. More specifically, when the mean air temperature for a day is below 0 °C, the numerical value can be expressed as the number of freezing degree-days (FDDs) and, when above 0° Celsius, expressed as melting degree-days (MDD).

Wind direction and strength during the winter have considerable effect on the ice cover for its thickness, location, and the degree of obstruction to navigation.

[7] Source: International Ice Patrol's Iceberg Counts, 1900-2011, U.S. Coast Guard Navigation Center 2011

3.4.2 Oceanographic factors

The main oceanographic factors influencing the ice regime are bathymetry, currents, and tides. There is a brief description of bathymetry and currents for each lake. Tidal ranges are generally very small.

3.4.2.1 Lake Superior

Lake Superior is the largest of the Great Lakes and is the deepest with the maximum depth of 406 metres in the southeast part of the lake. The Keweena Peninsula and Isle Royale are prominent features in Lake Superior. The Superior Shoal with a minimum water depth of 6.4 metres lies in the middle part of the lake about 85 kilometres east of Isle Royale. The waters of Lake Superior flow outward through the St. Mary’s River into Lake Huron and for the most part currents in the lake are weak. Wind-generated currents are known to produce upwelling of lake water.

3.4.2.2 Lake Michigan

This is the third largest of the Great Lakes and the second deepest with a maximum depth of 281 metres in the central part of the lake. The area to the north of Beaver Island and the Straits of Mackinac are shallow and less than 37 metres deep. Water currents are generally weak in the lake but there exists a circular pattern in southern Lake Michigan that is unique.

3.4.2.3 Lake Huron

Lake Huron is the second largest of the Great Lakes and the fourth deepest with a maximum depth of 229 metres just 27 kilometres west of the Bruce Peninsula. Generally speaking it is deep but northern and eastern shores have shoals extending 5 kilometres offshore in places. The most striking feature of the bottom of the lake is a submerged ridge which extends from Alpena, Michigan across the lake to Kincardine, Ontario. Six Fathom Bank, with a depth of 11 metres, lies on this ridge in mid-lake.

The north and east shores of Georgian Bay are bordered by many islands and shoals while the southwest portion is generally deep. A maximum depth of 168 metres lies just off the north shore of the Bruce Peninsula. Lake Huron receives the waters of Lake Michigan through the Straits of Mackinac and those of Lake Superior by way of the St. Mary's River, and in turn discharges into the St. Clair River. Water currents are generally weak in the lake and the bay.

3.4.2.4 Lake Erie

This is the most southerly of the Great Lakes and is also the shallowest of them. Its maximum depth of 64 metres lies just southeast of Long Point. West of Point Pelee the lake is very shallow with water depths less than 11 metres. Water depths in Lake St. Clair are less than 6 metres. The flow of water in the lake is generally from the Detroit River at the west end in a northeasterly direction to the main outflow through the Niagara River. Water currents in the lake are generally weak.

3.4.2.5 Lake Ontario

Lake Ontario is the smallest of the Great Lakes but is the third deepest with a maximum depth of 244 metres located in the southeastern part of the lake. The northeastern end of the lake (the approaches to the St. Lawrence River) is the shallowest area where water depths are less than 55 metres. The flow of water in Lake Ontario is mainly from the Niagara River northeastward to the St. Lawrence River. Water currents in the lake are generally weak.

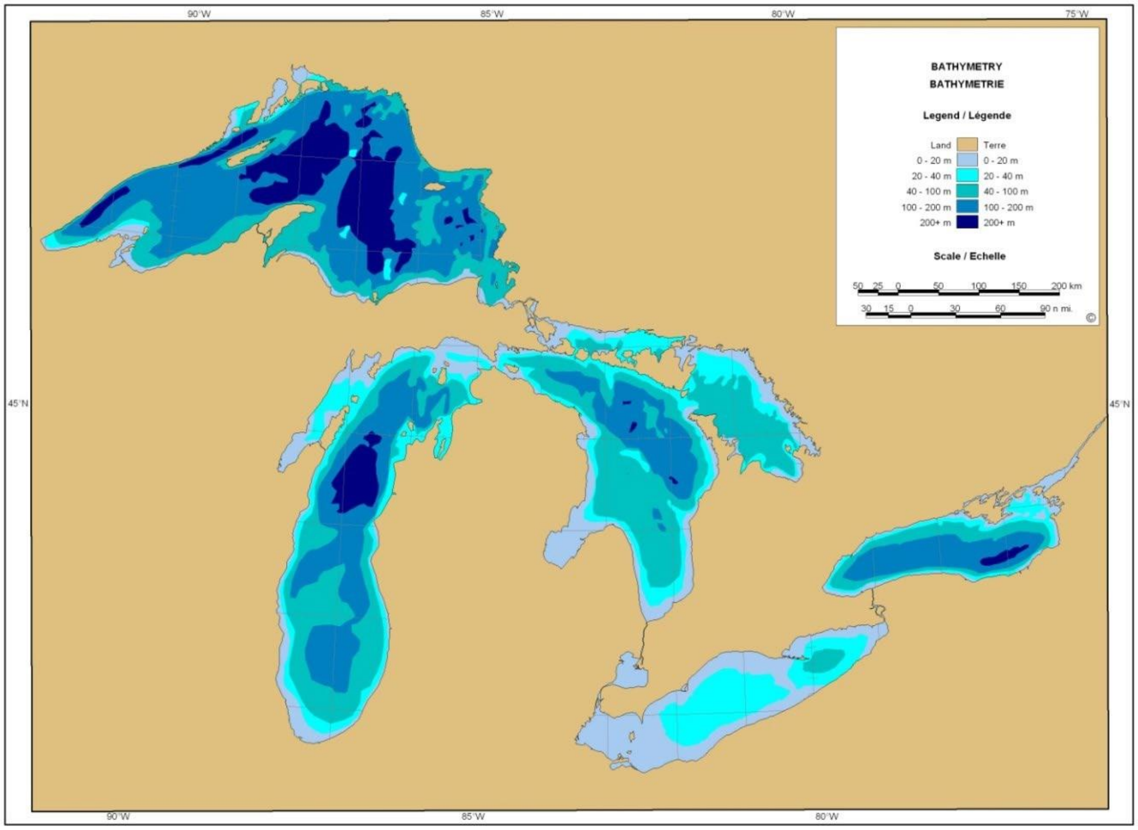


Figure 24 - Bathymetry of the Great Lakes (Chart courtesy of ECCC)

3.4.3 Ice regime for the Great Lakes

3.4.3.1 Lake Superior

Initial ice formation begins in harbours and bays along the north shore, in the western portion of the lake, and over the shallow waters of Whitefish Bay normally near the end of November to early December. The amount and thickness of ice increases so that the entire perimeter of the lake becomes covered and then extends many kilometres out into the lake by mid-winter. At the peak of the season at the last half of February, ice typically covers 75% of the lake. The eastern portion of the lake between Stannard Rock and Caribou Island will usually remain open water throughout the winter.

Break-up normally begins in March and the ice is in a state of deterioration by the end of the month. Most of the lake is open water by mid-April; however, winds and water currents can cause the ice to drift into the southeastern end of the lake.

Variations

Ice conditions can vary greatly from year to year. In a mild winter, the maximum ice coverage in Lake Superior may attain only about 12% (1997-98) while during a severe winter coverage may reach 100%. Ice has formed as early as the first week of November and persisted as late as the last week in May.

Ice thickness

In sheltered harbours and bays, ice tends to grow to 45 to 85 centimetres during a normal winter. Rafting can create ice thicknesses up to a metre or so. Windrows of grounded ice in

Whitefish Bay can pile up to 7 to 8 metres or more above lake level. Offshore ridges of ice can result in total ice thicknesses reaching 25 metres.

Warning: Shipping lanes in whitefish bay and entrances to harbours in lake superior are much affected by drift ice moving in response to forcing winds.

3.4.3.2 Lake Michigan

Lake Michigan's north-south orientation and length mean that it can have ice formation and deterioration occurring simultaneously. Initial ice formation begins in Green Bay normally during the first half of December. The next areas to become ice covered are the Straits of Mackinac and the shallow areas north of Beaver Island. In these areas ice starts to develop in the first week of January. The ice forms and accumulates in a southerly direction with a rapid build-up along the Fox Islands and a slower growth rate around the southern perimeter. Maximum ice cover occurs about the middle of February with usual maximum coverage around 25%. The central portion of the lake south of 45º North latitude usually remains open water throughout the winter.

Break-up normally begins the second half of February and progresses from south to north. Most of the lake is open water by the first half of April. The strait and island areas of Mackinac usually produce formidable ice ridges which linger into late in the season.

Variations

Ice conditions can vary greatly from year to year. In a mild winter, maximum ice coverage in Lake Michigan may be only 12% while during a severe winter it may increase to near 85%. Ice has formed as early as the last week of November and persisted as late as the second week of May.

Ice thickness

In sheltered harbours and bays, ice typically grows to 45 to 75 centimetres over winter. Rafting can create ice thicknesses up to a metre or more. Areas of ridges of ice in the Straits of Mackinac can reach up to nine metres above sea level with depth up to 2 or 3 times greater.

3.4.3.3 Lake Huron and Georgian Bay

The orientation and patterns of ice formation of Lake Huron are similar to those of Lake Michigan; however, temperature differences between north and south are not as great. Initial ice formation begins in North Channel and along the east coast of Georgian Bay during the second half of December. As the winter progresses, ice expands around the coastal areas and then extends out into the lake. Maximum ice cover occurs around the middle of February with about 50% coverage in Lake Huron and 90% coverage in Georgian Bay. The deep central and north portion of Lake Huron usually remain open water throughout the winter.

Break-up normally begins in March with the entire lake clearing by the second week of April. Large volumes of ice can drift into the southern portion of Lake Huron resulting in a heavy concentration of ice at the entrance to the St. Clair River.

Variations

Ice conditions can vary greatly from year to year. In a mild winter, the maximum ice coverage on Lake Huron and Georgian Bay may be as low as 26% (winter 2001-02) while during a severe winter, the coverage on Lake Huron and Georgian Bay can be more than

95%. Ice has formed as early as the last week of November and has persisted as late as the third week of May.

Ice thickness

In sheltered harbours and bays, lake ice typically grows to 45 to 75 centimetres during a normal winter. Areas of ridging can contain ice thicknesses of up to 18 metres.

3.4.3.4 Lake Erie and Lake St. Clair

Ice formation begins in the western end of the lake and in Long Point Bay normally during the second week of December. Elsewhere the amount of ice cover begins to accelerate in early January and is usually at its maximum extent (70%) in February. Lake St. Clair is normally completely ice covered or consolidated from the middle of January until March.

Break-up for Lake Erie normally begins near the end of February with the lake becoming mostly open water by the first week of April. The eastern end of the lake is usually the last area to clear.

Variations

In a mild year, the maximum extent of the ice cover could be as little as 8% of the lake's surface. During severe winters, 100% coverage can occur. Ice has formed as early as the first week of December and has persisted in the Buffalo area as late as the middle of May.

Ice thickness

In sheltered bays, ice typically grows to 25 to 45 centimetres over winter. Rafting and ridging of ice can create aggregate ice thicknesses in excess of 20 metres during a single winter storm.

3.4.3.5 Lake Ontario

Ice formation begins in the Bay of Quinte normally during the third week of December. Ice begins to form in the bays at the eastern end of the lake and in the approaches to the St. Lawrence River during the first week of January. An extensive ice cover does not appear until the last week of January and is usually confined to the eastern end of the lake. Maximum ice cover which usually occurs during the first half of February totals about 17%. Break-up normally starts late in February with the lake becoming generally open water in late March. Ice may be found below Niagara Falls, in protected bays and in the approach to the St. Lawrence River somewhat later.

Variation

In a mild winter, ice coverage on Lake Ontario is only about 10% while in a severe winter it can increase to 65%. Lake Ontario will rarely reach complete ice cover; one year this happened was in 1979. Ice has formed as early as the third week of November and has persisted as late as the last week of April.

Ice thickness

In the sheltered bays, ice typically grows to 20 to 60 centimetres over winter. Ridging, rafting and hummocking can significantly increase these thicknesses.

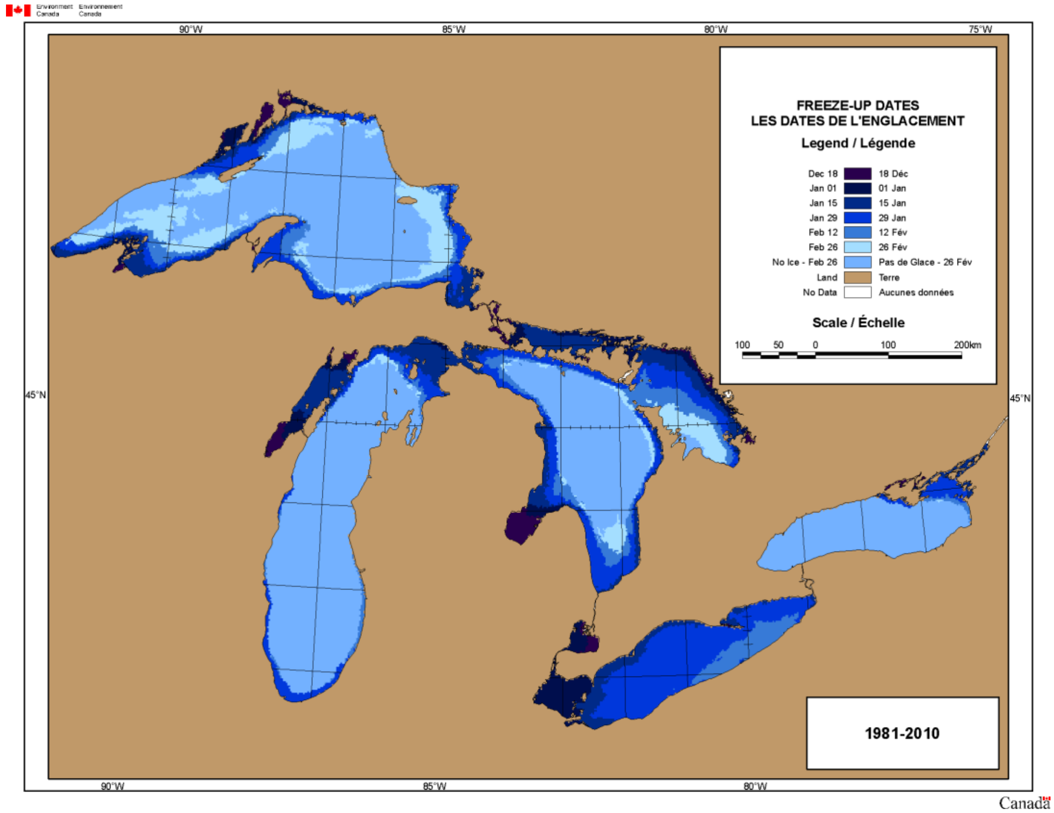


Figure 25 - Freeze-up dates for the Great Lakes (Chart courtesy of ECCC)

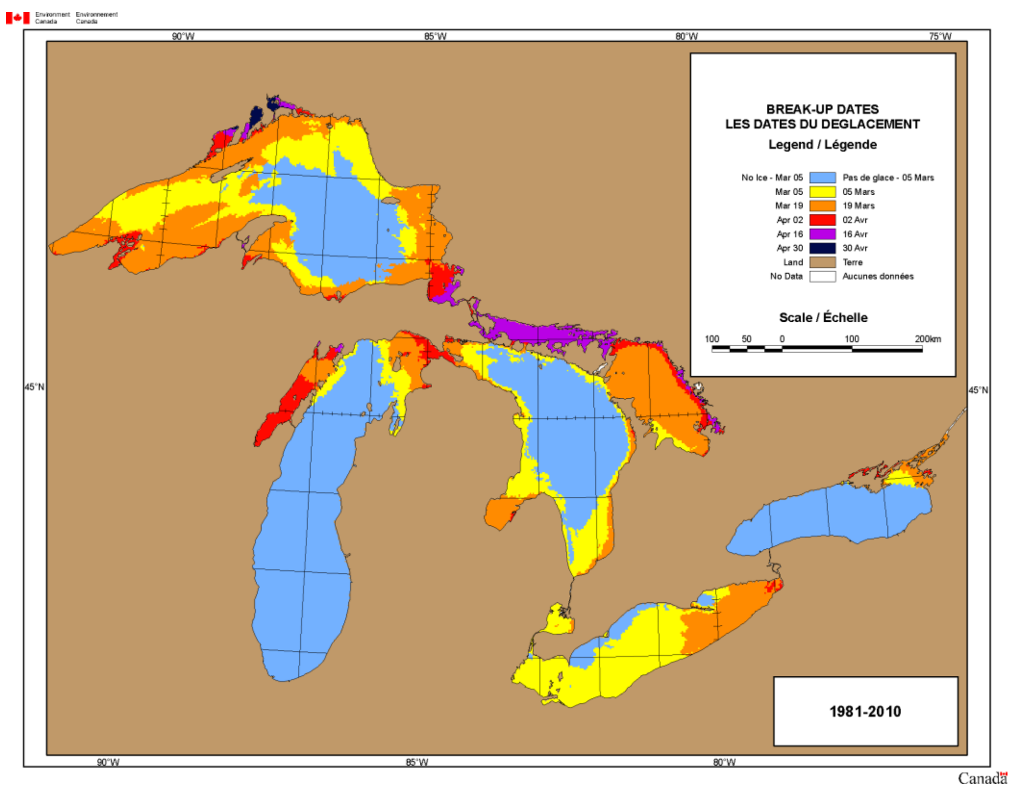


Figure 26 - Break-up dates for the Great Lakes (Chart courtesy of ECCC)

3.5 Ice climatology for the St. Lawrence River

The St. Lawrence River flows from the eastern end of Lake Ontario to the Saguenay River and estuary where it flows into the Gulf of St. Lawrence. Ice initially forms during the first half of December between Montreal and Quebec City. The combination of river currents and winds causes new ice to grow and spread along the River's south shore. By the end of December, the south half of the estuary, west of a line from Pointe-des-Monts to Marsoui, is ice covered. Normally, freeze-up in the remainder of the river begins in early January. Particularly extensive areas of fast ice are found in Lac Saint-Pierre, in sections of the river between Lac Saint-Pierre and Montreal where islands hold the ice fast, and in the non-navigable channels between Montreal and Sorel.

Through the winter, ice drift continues above Quebec City. Icebreaker maintenance supports this drift and, because of the continual movement, large ice floes are seldom formed and year-round shipping is maintained between Quebec City and Montreal. Prevailing northwest winds tend to force the drifting ice along the south shore, resulting in low ice concentrations, or open water, along the north shore.

Tidal flows can modify these conditions, with flood tides causing ice congestion in narrow areas of the shipping channel. Under ebb tides, congestion can result in Quebec harbour between Lauzon and the west point of Isle d'Orleans, when ice floes broken away from fast ice block the normal drift of ice near the harbour.

Batture ice floes (figure 27) are large, thick, uneven and discoloured floes up to 8 kilometres or more across. They form in the shallows along the entire length of the St. Lawrence River. Batture ice floes are composed of ice of different thicknesses formed under pressure during ebb tides, the whole mass freezing together and gradually increasing in size with each successive tide. As the tidal range increases between neaps and springs, large sections of grounded ice break away and drift down the river. These floes present a formidable hazard to shipping and mariners are advised to avoid them if possible. They are quite easy to identify as the ice is discoloured and the floes appear much higher above the water than the surrounding ice.

Figure 27 - Batture ice drifting down towards the Quebec City Bridge (Photo courtesy of CIS)[8]

[8] Copyright granted by Lucie Thériault

Warning: Batture floes are a major hazard to navigation through the entire St. Lawrence river. Vessels should avoid contact with them if possible.

The vessel channel is easily blocked if the ice on each side of it is dislodged from the banks and shoals to which it is attached, either through natural causes or by the wash of passing vessels. When the ice does break away, it is liable to do so in very large sheets that move across the channel and initiate the formation of a jam. At certain times this batture ice is particularly liable to be dislodged and it may then be necessary for the CCG to impose speed restrictions in certain sections of the river.

When this happens, it is of overriding importance that the jam be broken and the channel restored as quickly as possible to stop the rise in the river level. This can only be done by attacking the jam from downstream, so that ice loosened by the icebreakers may be carried away by the current. In order to do this, all available icebreakers must be concentrated at the jam and will not be available to assist individual vessels. However, this procedure, which is the only way to clear the channel, is in itself the best way of freeing any beset vessels and restoring the movement of traffic. At such times it is vital that the operation of the icebreakers not be hampered by the avoidable presence of other vessels in the area of the jam. It may, therefore, be necessary to delay sailings or to curtail movement in that part of the river.

Figure 28 - The vessel channel can be easily blocked if ice is dislodged from the banks (Photo courtesy of CIS)

Night navigation in the St. Lawrence River between Les Escoumins and Montreal should not be attempted without a thorough knowledge of the ice conditions ahead of the ship.

In the Port of Montreal, the combined effect of an ice control structure and the rapides de Lachine serve to maintain dispersed ice conditions throughout the winter. Upstream of Montreal to Lake Ontario, the shipping season is restricted and is controlled by the operation of the St. Lawrence Seaway Authority.

Even light ice conditions can be treacherous on the St. Lawrence River. Fresh water, currents, tide and the water depth can push frazil ice down to depths of more than 10 metres and enter sea bays, plugging seawater cooling inlets. If water cannot be obtained for the cooling system, the engines will not perform properly and may eventually overheat, causing engines to shut down or become seriously damaged. The design of vessels operating in ice must prevent the cooling system from becoming blocked by slush ice. This is an unusual occurrence and is rarely encountered in other parts of the world. section 5.5.1 has additional information.

Breakup on the St. Lawrence River usually begins near the middle of March in leeward and thinner ice areas. The River is normally clear of all ice by the first week of April.

3.5.1 Ice Regime of the Gulf of St. Lawrence

The Gulf of St. Lawrence area covers the St. Lawrence Estuary eastward from Québec, the entire Gulf of St. Lawrence, the waters south of Nova Scotia and the waters south of Newfoundland eastward to the Islands of Saint-Pierre-et-Miquelon.

3.5.1.1 Normal pattern of development

The first ice formation in this area occurs in the St. Lawrence River itself normally during the second week of December and the floes are carried downstream to the Québec City area shortly after the middle of the month. This ice is thin and it is primarily a freshwater type but it spreads downstream gradually, aided by wind and ebb tides. During the fourth week of December, this ice reaches the mouth of the Saguenay River and mixes with the ice forming in the salt water of this part of the Estuary. The new ice formation occurs in the coastal areas first and then develops and spreads seaward. Due to the currents and prevailing west and northwest winds, ice growing in the St. Lawrence River Estuary spreads more rapidly eastward along the south side and reaches the north Gaspé Peninsula shoreline near the end of December.

In the third week of December, ice begins to form in the coastal shallows of New Brunswick. In the last week of December new ice starts to spread seaward along the New Brunswick coast and develops in coastal areas of Northumberland Strait. At the end of December Northumberland Strait is partially covered with new and grey ice. The entire Northumberland Strait becomes ice covered in the first week of January.

During the last week of December, loose areas of new ice begin to form in the Strait of Belle Isle as well as along sections of the north shore of the Gulf of St. Lawrence. At month's end, the highest concentrations can be found in Northumberland Strait, in the coastal areas of New Brunswick, along the south sides of the St. Lawrence River Estuary and Chaleur Bay, and in some of the coastal portions of the north shore of the Gulf. Most of this ice is new and grey, and coastal fast ice outlines are being established.

At the beginning of January in the southwestern portion of the Gulf, the ice cover increases more in concentrations rather than area extent. As the ice spreads away from the shore, the warmer waters tend to melt the ice. During the month of January, the growth and spread of ice proceeds eastward across the Gulf more quickly than it progresses southward from the north shore. By the middle of the month the leading edge of the ice has reached North Cape, PEI and meanders northward through Honguedo Strait to the western tip of Anticosti

Island. The ice concentrations, at that time, have reached the very close pack range in Northumberland Strait, Chaleur Bay, most of the Estuary while lower concentrations are found in the northern section of the Estuary as well as along the ice edge. Much of this ice remains as new and grey types, but grey-white has now developed in parts of Northumberland Strait, along the south sides of the St. Lawrence River Estuary and Chaleur Bay as well as in the southern section of the Belle Isle Strait. Along the north shore, the ice has spread outward only 10 to 20 kilometres except in the Northeast Arm where the seaward extent is more likely 25 to 40 kilometres. Here ice concentrations are mostly in the open to close range with very close ice conditions in the Northeast Arm.

By the end of the third week of January the ice edge has reached East Point on Prince Edward Island and extended northward to the southeast end of Anticosti Island and then northeastward to near Point Riche Peninsula on the west coast of Newfoundland. The ice concentrations within the pack is generally very close pack except looser within 20 to 50 kilometres of the ice edge. The predominant ice type is mostly grey ice with grey-white in Northumberland Strait, along the south sides of the St. Lawrence Estuary and Chaleur Bay as well in the southern half of Belle Isle Strait. Due to the prevailing northwesterly winds and the outflow of water currents which follow the Laurentian Channel, the grey-white ice from Gaspé Passage tends to drift southeastward towards the northern shore of Îles de la Madeleine. The ice reaches Cape North near the end of January and then start to move in the western section of Cabot Strait. The mild northeastward current around Cape Anguille off the west coast of Newfoundland tends to delay ice formation south of the Pointe Riche Peninsula. At the end of January, grey-white ice is beginning to show up in the western part of the Gulf, in Gaspé Passage, in the Northeast Arm, and along the west coast of Cape Breton.

Historically, during the second week of February, the ice drifting southward through Cabot Strait will reach the approaches to Sydney and linger until the first week of April. The ice cover continues to grow and thicken as it spreads to cover most of the remaining areas of the Gulf by the third week of February. The exception is a 10 to 30 kilometers coastal lead along the Newfoundland coast south of Cape Saint George. At the beginning of February grey-white and grey ice generally predominates inside the pack but thin first year ice gradually develops during the course of the month. By the end of the third week of February thin first year is found in Northumberland Strait, along the northwest coast of Cape Breton, along the north coast of les Îles de la Madeleine, along the west coast of Newfoundland as well as along the south shores of Chaleur Bay and the Estuary. Over the northern portions of the St. Lawrence Estuary and Gulf, the predominant ice type remains new and grey. The reason the ice remains thinner over these areas is that offshore winds push the ice southward.

From the later part of February until the middle of March, the ice in the Gulf has reached its maximum extent and much of the ice continues to grow to the first-year stage of development. However, because of the continuous southward drift of the pack in the Gulf, the ice remains at the grey-white stage over the northwestern portions. The lead along the west Newfoundland coast, particularly north of the Port-au-Port Peninsula, is closed and there can be ice drifting into Cabot Strait.

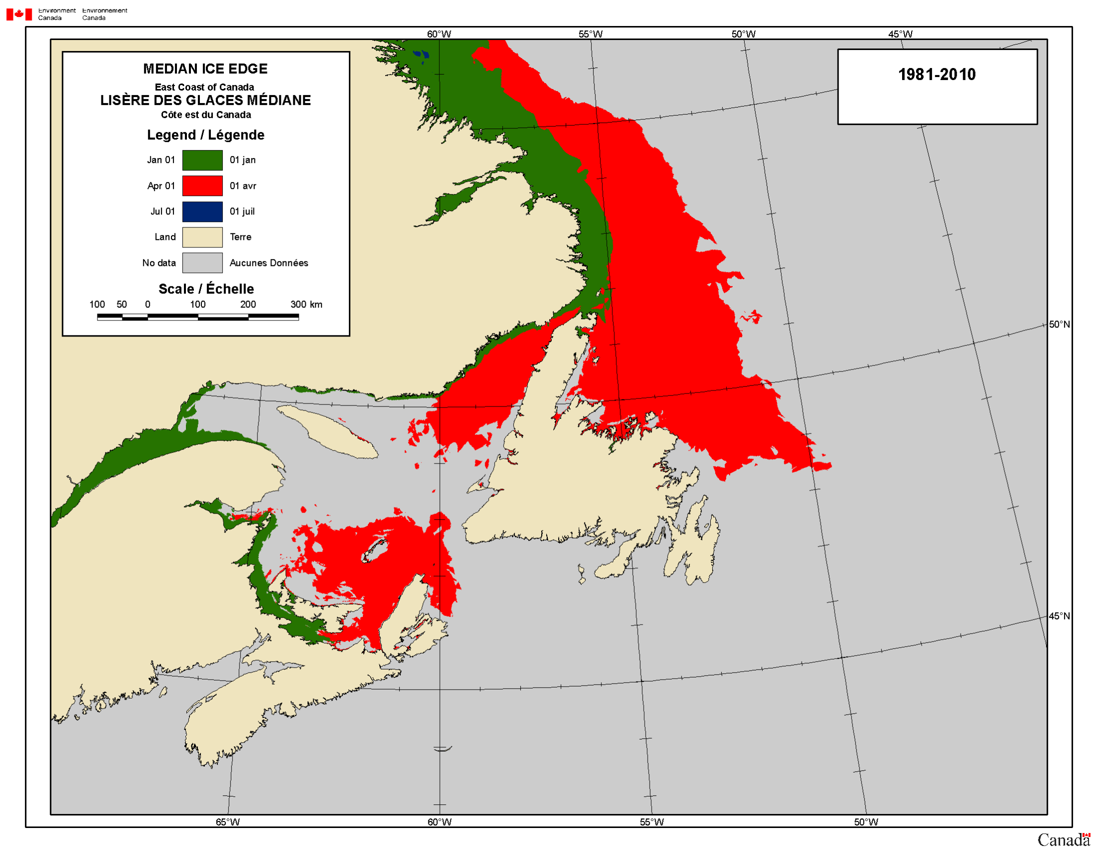


Figure 29 - January, April, and July ice edge positions off the East Coast of Canada (Chart courtesy of ECCC)

3.5.1.2 Normal pattern of dispersal and melting

Dispersal of the ice begins in late February and is first evident in the Estuary near the mouth of the Saguenay River where ice concentrations fall to very open range. Tidal upwelling of warmer water at the western limit of the deep channel through the Estuary combined with the general rise of air temperatures in the spring tend to melt the ice. The upwelling is a feature of the location and a certain amount of open water is nearly always present in this area. Snow and ice reflect a large proportion of the solar radiation; the absence of ice permits an increase in solar warming of the water. Openings in the ice cover are thus extremely important in the spring for they act as centres of ice decay. The reduction in the ice concentrations is slow until the second week in March then gradually accelerates. By the middle of March, extensive open water areas exist along the north side of the St. Lawrence Estuary and the north shore to Natashquan, and south of Anticosti Island. By this same time, ice concentrations through the remainder of the Estuary and in Gaspé Passage become reduced to very open to open range except along the north shore of the Gaspé Peninsula. The ice concentrations along the main shipping route through the central Gulf are decreasing rapidly. During the last half of March decreasing median ice concentrations are evident through the centre of the Gulf but congestion persists in the southwestern portion and in the Northeast Arm. Since the thinner forms of ice will melt and decay faster, the predominant ice types are the thicker forms of ice. Ice concentrations through Northumberland Strait begin to decrease during the third week of March in the western end and progress southeastward. In late March the Estuary is usually free of ice and the inner ice edge has passed Anticosti Island.

During the early days of April, ice in the main shipping route through the Gulf clears, separating into 2 areas: the southwestern Gulf and the waters surrounding Cape Breton, and the area from the Port-au-Port Peninsula to the Strait of Belle Isle. Once this separation has occurred, navigation into the Estuary is unhindered and re-formation of an ice barrier across the shipping route does not occur. Of these two areas, the southwestern Gulf melts first. The last of the ice in Northumberland Strait and around Cape Breton Island melts normally near mid-April. At this time, the only ice to be found is the decaying coastal fast ice and this melts by the last week of April.

The final area to lose its ice cover is the Northeast Arm. The retreating ice gradually melts northward during April and into May. By the third week in May, the sea ice has finally all melted, but icebergs can present a hazard to shipping during the summer. The date that the last ice clears can vary significantly. In 1991, sea ice persisted in the Northeast Arm into the middle of July and the following year, sea ice in the Strait of Belle Isle did not melt until the end of July.

3.5.1.3 Ice features of the area

Fast ice for most coastal areas in the Gulf has a limited extent. It forms in all the smaller bays and inlets from Gaspé to Cape North, from Pointe-des-Monts to BlancSablon and from Cape Anguille to Flower’s Cove. Melting "in situ" is the normal decay procedure in these smaller areas.

In the Estuary the tendency for an eastward motion of the ice is very apparent. Leads are common along the shore from Pointe-des-Monts to the Saguenay River, and congestion is prevalent along the Gaspé Peninsula. Wind and water motion all contribute to this pattern producing thicker, congested ice that follows the shore as it moves into the main body of the Gulf. A very difficult ice area is created across the entrance to Chaleur Bay as some of the thicker ice from the Gaspé Passage moves into the area. As the ice continues its south and southeastward progression into the central part of the Gulf it produces an ice cover of large floes of thick ice, combined with new ice formation, from Gaspé Passage to Cape Breton Island. Leads and areas of dispersed ice are created along the New Brunswick and Prince Edward Island shores in response to the wind but, in general, the southwestern section of the Gulf becomes congested with thick ice in large floes that can exert considerable pressure against Cape Breton Island and the northwestern shores of the Îles de la Madeleine.

In the northeastern Gulf the ice motion is much more restricted by the wind induced drift from west to east resulting in occasional congestion in the Bay of Islands area. Often, an area of thick and deformed ice is prevalent from the Port-au-Port Peninsula northward. Coastal leads can develop in this area when easterly winds prevail but lateral motion of the ice along the coast does not often develop.

Very large floes, locally called "battures", are sometimes encountered in the northwestern Gulf of St. Lawrence in March. These are dislodged fragments of the fast ice which forms over shoals along the south shore of the Estuary and which have been subsequently dislodged by spring tides during mild spells. Battures are noted for their size, roughness, and dirtiness, and may carry a very thick snow cover that makes them very difficult to penetrate. They constitute a severe hindrance and a hazard to navigation.

In the Gulf of St Lawrence, the ice is mobile and free to move. Floes are generally smaller when compared with those found in the Canadian Arctic. Thus, ridging can be rather extensive in area but not developed to any great height. The height of ridging seldom exceeds 2 metres and is generally less than 1 metre. However under conditions of extreme pressure along windward shores, such as the west coast of Newfoundland, ice floes may pile up to 13 metres above sea level. Puddling of the ice in the Gulf is rarely well developed. The ice is more subject to melting from below as a result of warmer water than it is to melting because of heat absorption on the surface.

When ice drifts through Cabot Strait into the Atlantic Ocean, water currents encourage its southward drift past Sydney and down to the area of Scatarie Island. The entire area of the strait only becomes covered with ice when winds hold it against the Newfoundland shore. When the winds diminish or change direction, inflowing currents around Cape Ray quickly create a lead northward towards Cape Anguille and eventually to Cape St. George. A pattern is usually established each winter for the general direction of ice drift once it leaves the Scatarie Island area. In some years, usually the colder ones, the pack continues eastward and has been known to reach as far as Saint-Pierre-et-Miquelon. In other years, when easterly winds are common it follows the Cape Breton coast, ice progresses westward towards Chedabucto Bay and sometimes along the coast of mainland Nova Scotia. In 1987, ice filled the harbour at Halifax and blocked the entrance to Bedford Basin. Weak water currents strengthened by the wind flow, are responsible for the extent of this drift. Most often the drift is generally southward but the distance it moves is not great.

Although old ice is not normally a great concern in the Gulf of St. Lawrence, old ice can drift into the Northeast Arm through the Strait of Belle Isle. Some of these old ice floes survived to drift to the north shores of Anticosti Island in early June of 1991.

Ocean swells from storms in the Atlantic Ocean can enter through Cabot Strait and cause extreme fracturing of the floes in the Iles de la Madeleine to Cabot Strait areas.

3.5.1.4 Variability of Total Ice Coverage

For the period 1981 to 2010, the most ice encountered in a single season in the Gulf of St. Lawrence occurred in 1989/90; the least amount of ice occurred in 2009/10. The ice coverage varies considerably from year to year but in general, there were above normal conditions from 1980/81 to 1994/95 and then below normal conditions from 1995/96 to 2009/10. Examples of minimum and maximum ice conditions for the entire East Coast region are provided to illustrate the spatial extent of such ice conditions.

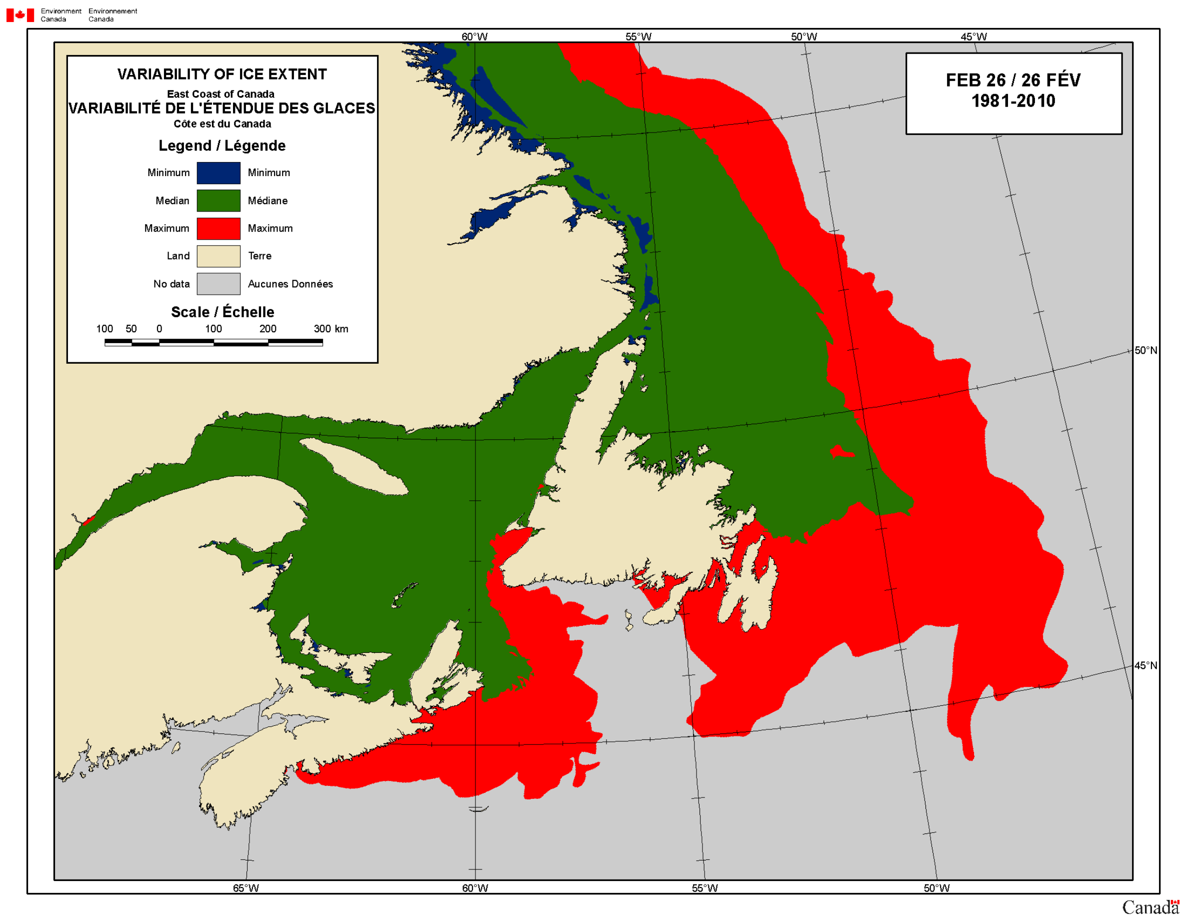


Figure 30 - Variability of ice extent on the East Coast (Chart courtesy of ECCC)

3.6 Ice climatology for the East Coast

3.6.1 Meteorological influences

Weather has a direct bearing on the planning and execution of winter navigation because temperatures control the extent and thickness of ice that forms, and the surface winds modify its location, form and distribution. Winds also play a major role in the extent of the ice cover especially at the beginning of the season; strong winds can cause ice destruction when the ice is relatively thin and temporarily suppress ice development. During winter, cold air from the Canadian Arctic can be carried seaward across Eastern Canada, resulting in temperatures far below the freezing point, causing superstructure icing and rapidly increasing the volume and extent of the sea ice. On the other hand, migratory low pressure centres from the Southeastern United States may result in mild air sweeping northward and creating melting conditions that last anywhere from a few hours to several weeks. The winter seasons vary considerably in severity depending upon the relative frequency and the paths of these migratory storm systems.

3.6.1.1 Water currents

The general water motion (figure 29) over these areas is relatively simple but the details are complicated. In the Gulf of St. LawrenceSt. Lawrence, the current is generally counterclockwise. In the Estuary of the St. Lawrence River there is a net eastward current but superimposed on it are tidal streams that alternately accelerate and decelerate the motion. The current is strongest at 2 to 12 nautical miles offshore of the Gaspé Peninsula and has a mean speed of 6 to 10 nautical miles per day. Once into the main portion of the Gulf, the water spreads over the Madeleine shallows and drifts generally towards Cabot Strait but some portions also follow the deep Laurentian Channel directly across the Gulf. After reaching the vicinity of Cape Breton Island, the current, known as the Cape Breton Current, pours around Cape North at speeds of 5 to 7 nautical miles per day, sweeps through Sydney and dissipates on the Scotian Shelf off Scatarie Island. Typical rates of motion over the Madeleine shallows (area between Prince Edward Island and Îles-de-la-Madeleine) of 3 to 5 nautical miles per day. There is a northeastwardflowing current, having a mean speed of 2 to 4 nautical miles per day, flowing along the west coast of Newfoundland past Bay of Islands and Daniel's Harbour.

The general water motion in the offshore areas of Southern Labrador and East Newfoundland is dominated by the cold Labrador Current. Off the Labrador coast, the southward motion is mainly confined to the continental shelf and the water is coldest in the upper layers near shore. After passing Hamilton Inlet, just as the continental shelf widens, so does the breadth of the current. As a result, it decelerates and floods eastward over the Grand Banks while portions of the current continue southwestward from Cape Race towards Nova Scotia. In the Belle Isle Newfoundland area, surface currents are usually less than on the Labrador coast, and the drift westward from Cape Race towards Nova Scotia waters is even slower. Through the Strait of Belle Isle is a variable tidal stream which complicates the water motion, but overall there is a significant current flowing into the Gulf of St. Lawrence with a mean speed of 6 to 8 nautical miles per day. Along the northern Labrador Coast, rates of motion are in the range of 8 to 10 nautical miles per day but these speeds can vary from one season to the next or one year to the next.

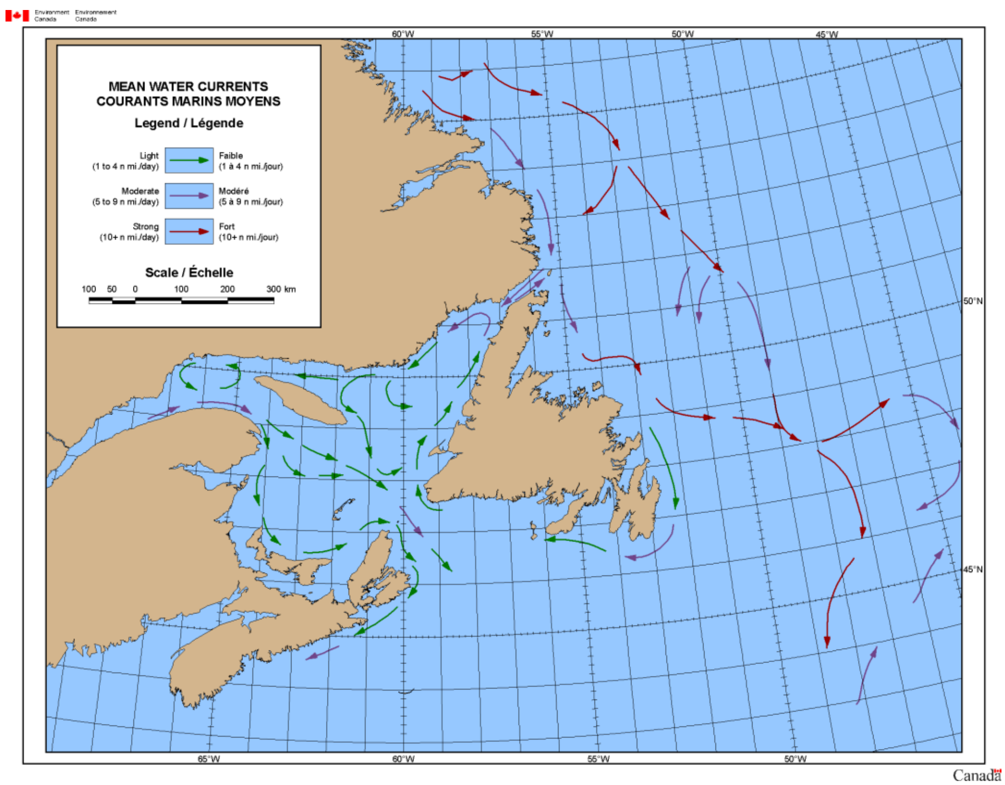


Figure 31 - Surface currents on East Coast of Canada (Chart courtesy of ECCC)

3.6.1.2 Tides

The tidal ranges on the Labrador and Newfoundland coasts are fairly small but consistent, for, at most locations the mean range is from 0.8 to 1.6 metres. In the Gulf of St. LawrenceSt. Lawrence, the situation is somewhat more complicated because the tidal surge enters from both Cabot Strait and the Strait of Belle Isle. The main tidal surge progresses in a counterclockwise manner around the Gulf after entering at Cabot Strait and mean ranges vary from 0.8 to 1.1 metres at Cape North and Cape Ray to 1.2 to 1.5 metres on the west coast of Newfoundland and along the north shore of the Gulf. In the Estuary, ranges increase progressively towards the southwest from 2.5 metres in the Pointe-des-Monts to Mont-Joli area to about 4.1 metre near Quebec City. In Chaleur Bay the tidal range is from 1.3 to 2.0 metres but in the Îles de la Madeleine only 0.7 metre. Northumberland Strait has a complicated tidal pattern. In the west end there is essentially 1 tide per day while in the eastern section there are the normal 2 with ranges of 1.2 to 1.8 metres. The Strait of Belle Isle has tides in the 0.8 to 0.9 metre range.

The major effect on the ice from these tidal forces and tidal streams is that the ice moves back and forth as the tides rise and fall. It is most apparent in the upper Estuary but is also apparent in Chaleur Bay and its approaches. Fast ice in these areas tends to be limited due to the constant motion.

3.6.1.3 Bathymetry

The bathymetry of these areas is reasonably well known. The Gulf of St. Lawrence has a deep trench, known as the Laurentian Channel, running from Cabot Strait to the Saguenay River with depths of 500 metres decreasing to 200 metres above Rivière du Loup. The Saguenay River itself has water depths of 90 to 275 metres.

There is an extension of this deep trench into Jacques Cartier Strait and the Northeast Arm of the Gulf with water depths of 175 to 275 metres. The southwestern part of the Gulf averages less than 75 metres in depth and the limiting water depth in the Strait of Belle Isle is 50 metres. Northumberland Strait also has shallow water depths running between 17 and 65 metres with the deepest waters located at each end of the strait. The fishing banks south and east of Nova Scotia are relatively shallow with water depths mostly between 50 and 90 metres.

The Grand Banks to the eastsoutheast of Newfoundland are very well known and have average depths of about 75 metres. To the northeast between Fogo Island and the Strait of Belle Isle, depths are somewhat greater averaging over 300 metres but there are a few small banks with depths less than 200 metres.

Along the Labrador coastline, 50-100 kilometres from shore there is a “marginal trough” with depths ranging from 200-800 metres. Farther offshore there are a series of broad banks with minimum depths in the 100-200 metres range. The continental shelf extends 150-175 kilometres from shore.

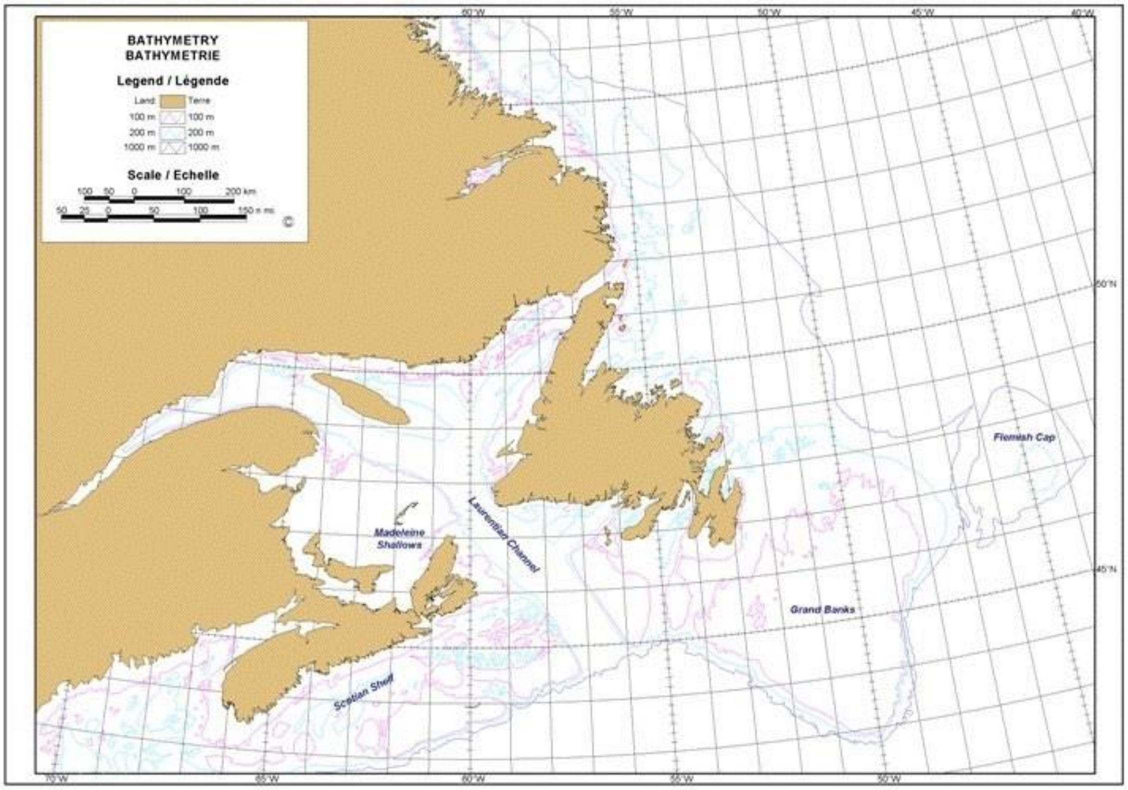


Figure 32 - Bathymetry of the East Coast (Chart courtesy of ECCC)

3.6.1.4 Climatic factors

In considering the ice regime of an area such as the Gulf of St. Lawrence or the waters surrounding Newfoundland, there are 2 major climatic factors. First, mean temperatures during the winter do not fall very far below the freezing point and as a result very cold or very mild winters have a very significant effect on the extent and severity of the ice cover. The second climatic factor is the winter winds from west through north will nearly always be cold and dry whereas those from the southwest through south to northeast will tend to be mild and moist. This has a decided effect on the location of areas of ice compaction and ice dispersal.

3.6.2 Ice regime of East Newfoundland waters and South Labrador sea

East Newfoundland and South Labrador waters cover the offshore areas south of latitude 55ºN as far as sea ice extends, along the south coast of Newfoundland as far west as the Islands of Saint-—-Pierre-et-Miquelon, and in the Strait of Belle Isle.

3.6.2.1 Normal pattern of development

Variations in the extent of ice over these waters are great because both winds and temperatures are effective in changing the location of the edge. In a cold winter, such as 1990-91, the ice could persist as late as the third week of July in the East Newfoundland waters. Conversely in a mild winter, such as 2009-10, the ice could have cleared from east Newfoundland before the end of April.

Because of its latitude, location away from the ocean, and low salinity, Goose Bay and Lake Melville are the first areas along the south Labrador Coast to freeze and both are consistently ice covered by mid-December. The initial freeze over at Goose Bay usually occurs during the third week of November but growth is slow and ice thickness by mid-December is nearly always less than 30 centimetres. Ice spreads slowly across Lake Melville, since the ice formation is slowed by strong wind conditions. It is not until mid-December that a complete cover is consistently present. Ice appears in the coastal waters during the third week of December and spreads seaward. The median ice edge spreads southward to the northern part of the Strait of Belle Isle by the fourth week of December and to the northern tip of Newfoundland before the end of the month.

During January, the mean ice edge expands seaward and spreads southward reaching White Bay and latitude 50°N in the third week of the month. Ice concentrations within about 80 kilometres of the ice edge are close pack or looser and predominant ice types are new and grey becoming grey and grey-white ice off the southern Labrador Coast. It is at this time that coastal fast ice begins to form among the islands of Notre Dame Bay and is normally established by the early days of February. The advancing ice from the north merges with the developing ice from Notre Dame Bay normally during the last week of January. By the end of the month, the pack ice begins to drift off to the southeast from Cape Freels. Ice concentrations remain looser within about 80 kilometres of the ice edge. Predominant ice types in most of the Newfoundland waters are new and grey, but have developed to the grey-white and first-year ranges north of the Northern Peninsula.

During February the ice belt broadens considerably in width. The southern limit progresses to near Cape Bonavista by mid-month and to Baccalieu Island by the end of the month. Ice concentrations remain looser near the southern and eastern ice edges with very close conditions within the pack. Grey ice predominates along the southern ice edge at the beginning of February and grey-white to first-year by the end of the month. The maximum southern extent of the ice occurs from the end of February to the middle of March.

3.6.2.2 Normal pattern of dispersal and melting

The first sign of break-up occurs in Notre Dame Bay around the middle of March when open water leads begin to slowly expand. During the last half of March, the rate of melting at the ice edge increases sufficiently to counterbalance the southward ice drift, and slow retreat of sea ice begins. It recedes only to the latitude of Cape Freels by the middle of April and then to north of Fogo Island by the end of the month. During this time the whole pack south of Hamilton Inlet becomes narrower because of melting along the eastern edge. It is only near the Labrador coast that ice concentrations remain in the very close range. Otherwise, mostly very open to close ice conditions predominate with first-year ice being the main ice type, but embedded old ice floes can also exist.

The rate of melting increases with the southern ice edge retreating north of the Strait of Belle Isle in the third week of May. It is this melting of the pack ice that exposes the icebergs that have been carried south by the Labrador Current and their numbers in the Newfoundland waters at this time of year are at their maximum.

The outflow of water from Hamilton Inlet maintains lighter ice conditions throughout the winter. By the second half of April, open water predominates in this area but does not expand appreciably until after the middle of May. Breakup of Lake Melville usually starts in the third week of May and clears about 2 weeks later. Navigation into Lake Melville may require penetration of the offshore ice pack unless offshore winds create a lead along the coast from Battle Harbour to Groswater Bay. At this stage the ice pack tends to have very variable concentrations. The southern edge of the sea ice retreats to near latitude 55°N during the third week of June.

3.6.2.3 Ice features of the area

Ice growth along the east coast of Newfoundland is relatively insignificant compared to the heavier concentrations and wide variety of ice types that drift southward into this area.

The mean wind flow in the Strait of Belle Isle area is from the northwest during the winter, but in April this shifts to a predominant northeast wind. In periods when these northeast winds develop, some of the ice from the Labrador coast, in which we can find some old ice and icebergs, can be driven through the Strait of Belle Isle and into the Northeast Arm of the Gulf. Because this ice from the Labrador area is thicker than that formed locally, clearing in the Strait is slow when these intrusions occur.

Shore-fast ice is primarily confined to the area from Fogo Island to southern Notre Dame Bay. Some fast ice also forms in southern White Bay as well as the bays and harbours along the Northern Peninsula.

Offshore winds can spread the ice seaward, concentrations are lowered in the outer portions of the pack and shore leads can develop from White Bay to Cape Bauld and from Strait of Belle Isle northward to Hamilton Inlet. In these situations the pack streams southeastward from Cape Freels leaving the coast easily accessible from Cape Freels to Cape Race. On the other hand, onshore winds may narrow the open water lead considerably along the coast creating an ice hazard for navigation. In periods such as these the major bays of East Newfoundland become filled with pack ice, the approaches to St. John's may become congested and some ice may round Cape Race and drift towards the Burin Peninsula or even Saint–Pierre-et-Miquelon Islands.

Old ice can be embedded in the main ice pack and drift southward along the Labrador coast and can arrive off Hamilton Inlet in April. It does not reach significant proportions until May when the thinner ice is melting more rapidly and average concentrations are decreasing. In cold years however, when more ice is present, these old floes can have a serious effect on navigation. Old ice has persisted in the waters off southern Labrador until August.

3.6.2.4 Variability of total ice coverage

In general, the period exhibited normal to above normal conditions from 1982/83 to 1994/95 and then dropped to below normal conditions from 1995/96 to 2012/13. The most ice encountered in a single season in the Grand Banks for the period occurred in 1984/85; the least amount of ice occurred in 2009/10. The ice coverage varies considerably from year to year but in general, there were normal to above normal conditions from 1982/83 to 1994/95 then below normal conditions from 1995/96 to 2012/13.

3.6.3 Ice regime of the 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 centimetres 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 3 times the vertical extent of associated ice ridges. Westerly winds are frequent so a flaw lead develops, while along the outer edge the ice organizes 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 kilometres 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 kilometres wide belt against the coast. However when the low pressure systems track north of the area, westerly winds spread the ice up to 500 kilometres 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.

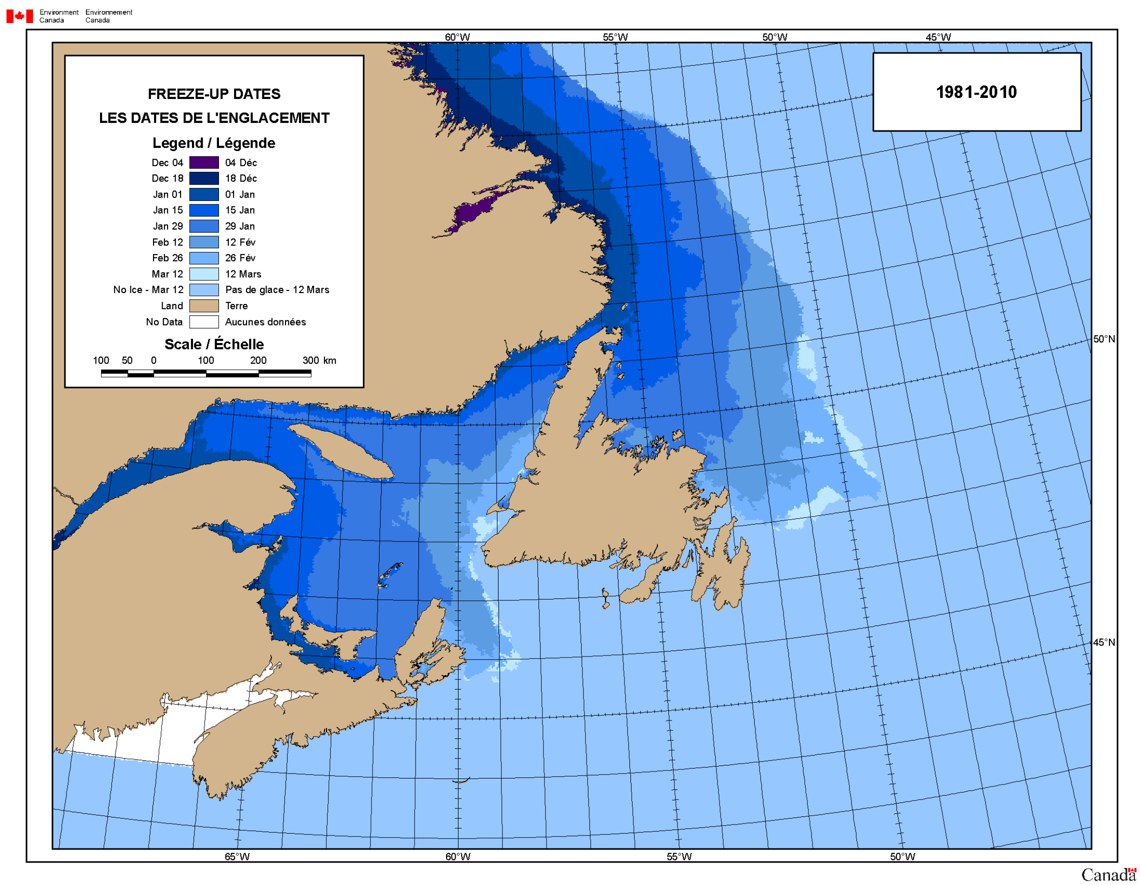


Figure 33 - Freeze-up dates on the East Coast (Chart courtesy of ECCC)

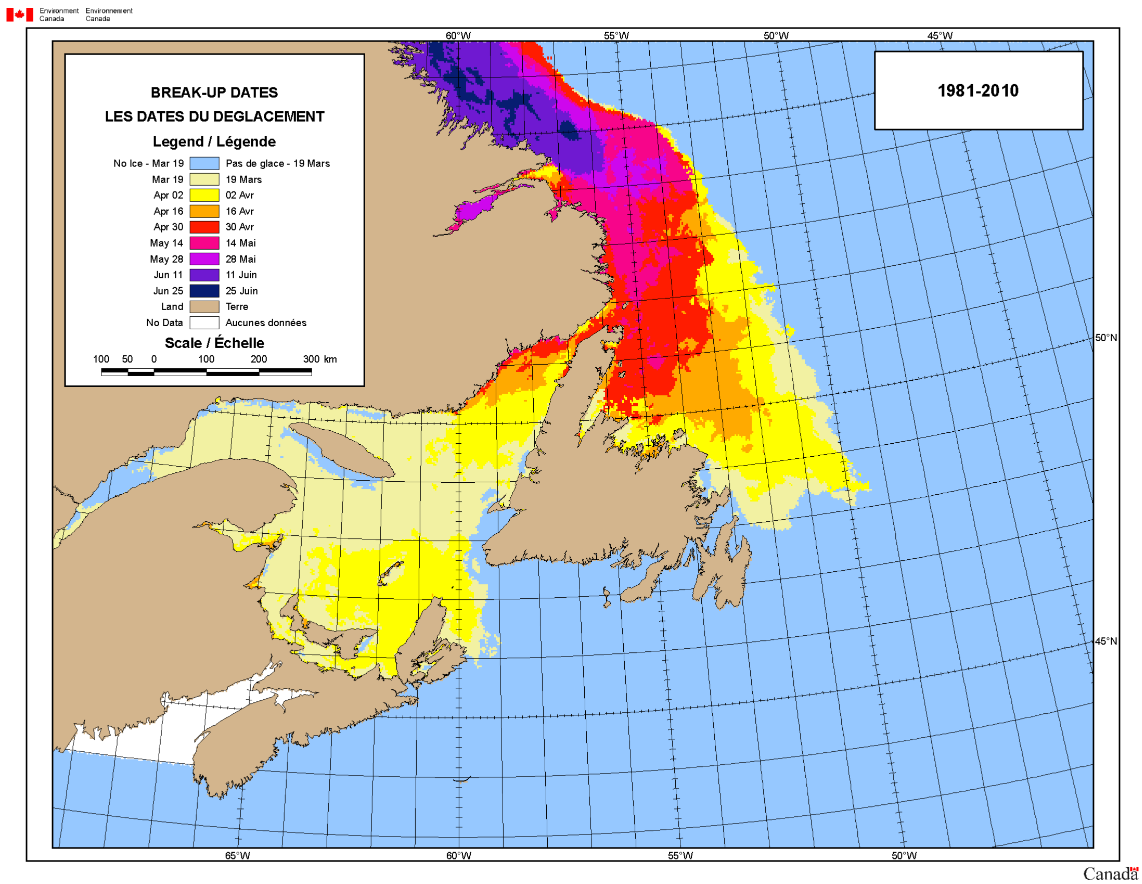


Figure 34 - Break-up dates on the East Coast (Chart courtesy of ECCC)

3.7 Ice climatology for 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.

3.7.1 Meteorological influences

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 is not 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 areas 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.

3.7.2 Oceanographic factors

As noted under meteorological influences, 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.

Tides and currents are important factors in the behaviour of sea ice and icebergs. Figure 35 shows the general circulation patterns in Canadian arctic waters. While the circulation patterns shown in these figures are relatively constant, at local or regional scales, the circulation may vary considerably. 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 is the North Atlantic current system. Dense 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 kilometres 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 kilometre per day and accepts some West Greenland waters as described above before becoming the Labrador Current. The main Labrador Current has 2 branches, the current from Baffin Island which is the most fresh and close to shore at about 10 kilometres per day, and the outer portion from West Greenland. At about 100 kilometres from the coast its rate is about 20 to 30 kilometre 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 kilometre per day. Variations in wind speed may increase this motion or stop it entirely for short periods. If an average speed of 15 kilometres per 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.

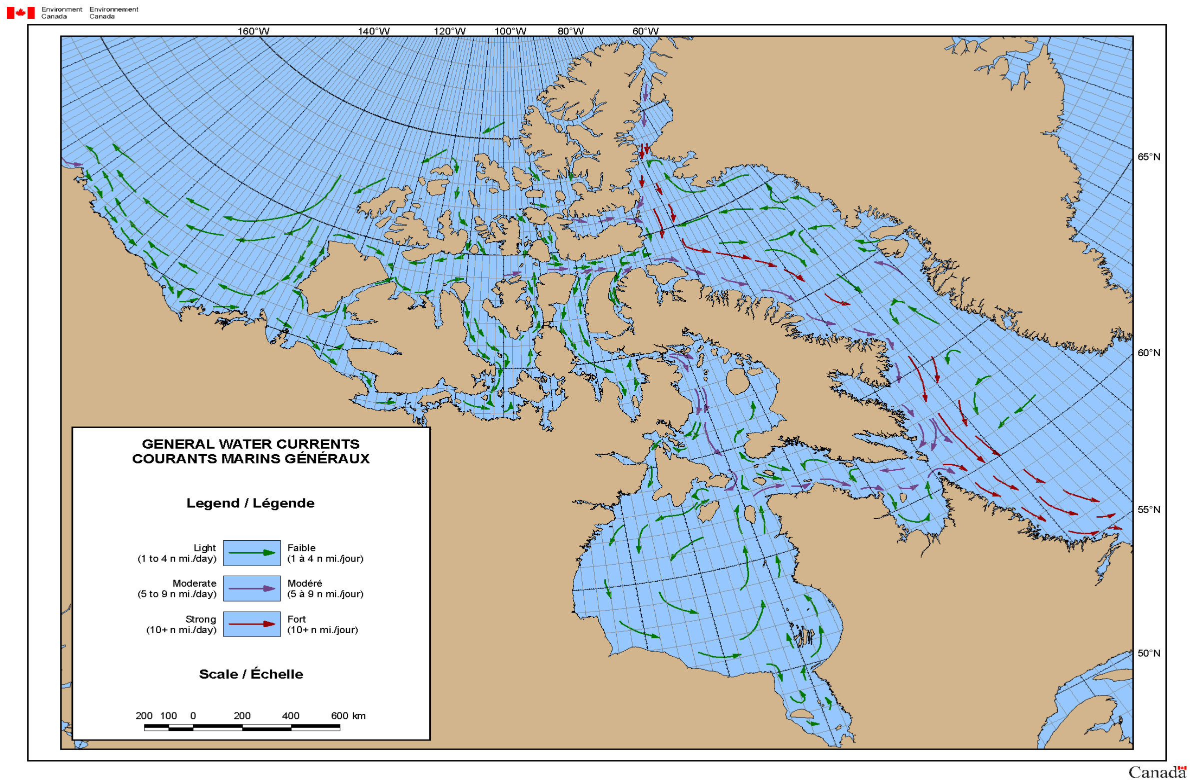


Figure 35 - General water currents in Northern waters (Chart courtesy of ECCC)

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.

The Eastern Arctic is affected by tides with average daily ranges of 2 to 3 metres, although large ranges in excess of 6 metres are sometimes observed. Local anomalies may alter these ranges between high and low tides and may result in strong tidal currents in some areas. Narrow channels such as Hell Gate, Penny Strait and, to a lesser degree, Nares Strait and Byam Channel, are examples of this. Tides in the eastern Arctic are highest in the Hudson Strait and Iqaluit areas where Atlantic tides are felt. In the western and central Arctic, including most of the Queen Elizabeth Islands west of Resolute Bay, Arctic tides predominate. The Arctic Ocean, due to its polar location, has the lowest tidal range of any of the world's oceans. Here, average daily ranges are generally less than 1 metre.

In addition to affecting vessel operations, tides may result in intermittent pressure within an ice cover, affecting navigation. Table 7 illustrates the range in tides through the Canadian

Arctic. Detailed tidal information for Arctic Island waterways is available in the latest edition of the CHS's Canadian Tide and Current Tables.

Table 7 - Tidal ranges at selected Arctic locations

Station	Location	Range (metres)	
		Large	Extreme
Diana Bay	Ungava Bay	10.2	10.8
Churchill	Hudson Bay	5.2	6.0
Hall Beach	Foxe Basin	1.3	Not available
Iqaluit	S.E. Baffin Island	11.6	12.6
Nanisivik	N.W. Baffin Island	2.8	Not available
Resolute Bay	Cornwallis Island	2.1	2.7
Cambridge Bay	Victoria Island	0.5	1.6
Tuktoyaktuk	Beaufort Sea	0.5	3.1

In some areas, particularly around the Beaufort Sea, storm surges affect sea levels as much as do tides. In ice-free summers, storm induced sea level increases of up to 1 metre are common, and may persist for several hours. In some embayments, such as Tuktoyaktuk Harbour, surge levels may exceed 2 metres. Tuktoyaktuk surge increases are associated with onshore winds, while temporary decreases in sea level occur in response to strong offshore winds. Negative surges can hinder vessel traffic in and out of Tuktoyaktuk Harbour because of relatively shallow water depths. Winter surges also occur in the Beaufort Sea but less frequently. However, even moderate high-water levels can force large pieces of ice onto beaches.

3.7.2.1 Topography and Bathymetry

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, funneling can cause severe wind events, and in some cases even break up a consolidated ice area.

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 kilometres off the coast abeam the Strait of Belle Isle and gradually narrows northward to 130 kilometres wide at approximately 56° N, and then expands to about 200 kilometres 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.

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 kilometres wide, except near Barter Island and Herschel Island where the shelf break is less than 50 kilometres from shore. Very shallow waters extend as much as 20 kilometres offshore and sea ice is often grounded. In the Canadian Arctic Archipelago, depths are generally in excess of 100 metres; however, the waters around King William Island are well known for being shallow.

3.7.2.2 Polynyas

A polynya is an irregularly shaped opening in the ice cover. Polynyas differ from leads in that they are not linear in shape. There are numerous polynyas in the Arctic that recur in the same position every year. Figure 39 shows the distribution of recurring polynyas in the Canadian Arctic.

The Arctic Archipelago region has three recurring polynyas: Hell Gate-Cardigan Strait, Dundas Island, and Bellot Strait. The Western Arctic has 1 area of recurring open water in winter, the Cape Bathurst polynya. Five polynyas exist in the Hudson Bay and Foxe Basin region. The one in southeastern Foxe Basin can disappear in adverse winds, however, the rest are present all winter. The Baffin Bay and Davis Strait area has 5 polynyas: a large polynya in Smith Sound (North Water), a small polynya in Lady Ann Strait at the entrance to Jones Sound, and others at the fast ice edge in Lancaster Sound, at the entrance to Cumberland Sound, and at the entrance to Frobisher Bay. To varying degrees, these polynyas are caused by winds, tide, currents, and bathymetry.

All the polynyas are influential in initiating fracturing and melt of the ice cover in the spring. The open water in polynyas absorbs heat, accelerating the decay of surrounding ice.

The polynyas also represent significant ecological areas as herds of marine mammals frequent these open water areas. For this reason alone, mariners should exercise caution while moving through polynyas.

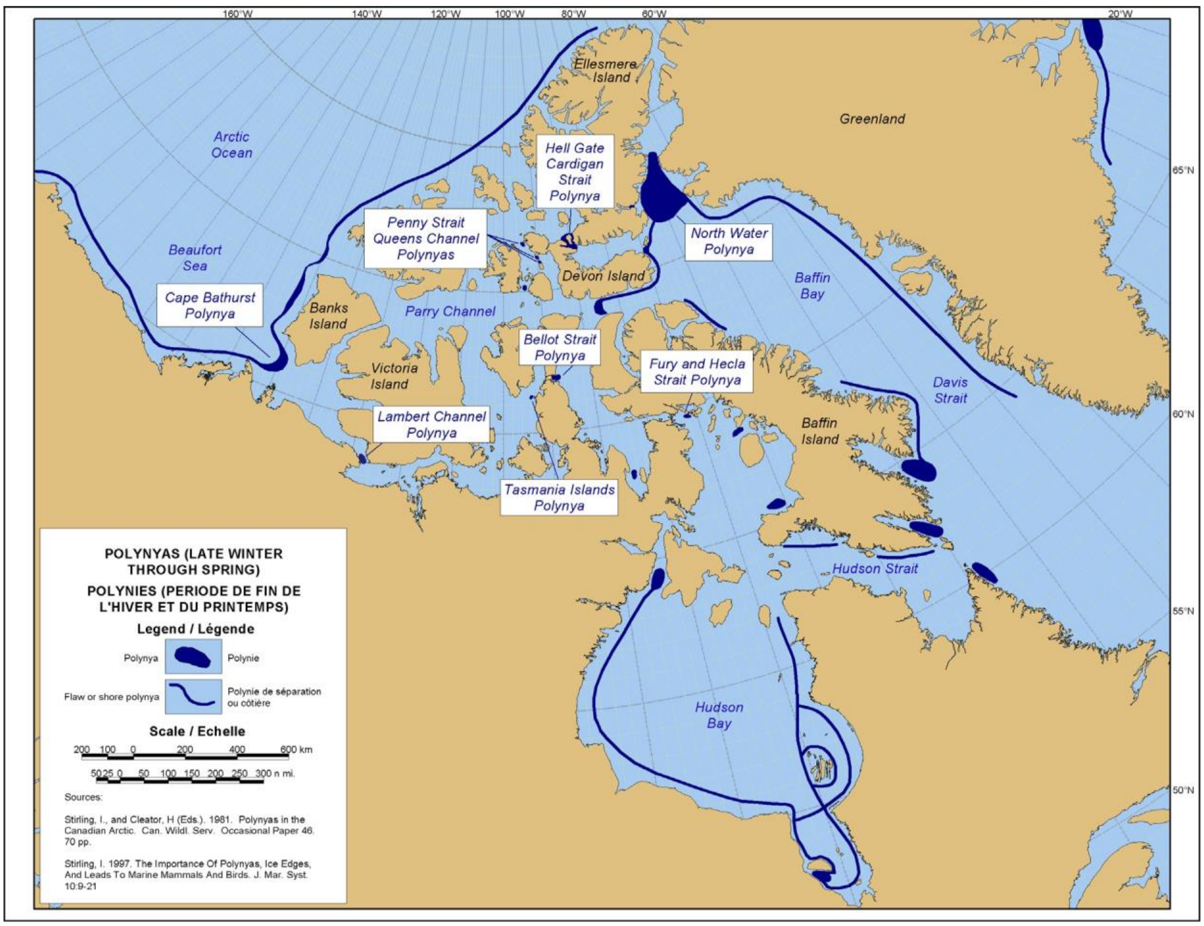


Figure 36 - Distribution of recurring polynyas in the Canadian Arctic (Chart courtesy of ECCC)

3.7.3 Ice regime of Northern Canada

3.7.3.1 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, 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 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 kilometres off the coast in the Beaufort. Also ice usually remains in Committee Bay and southern Gulf of Boothia.

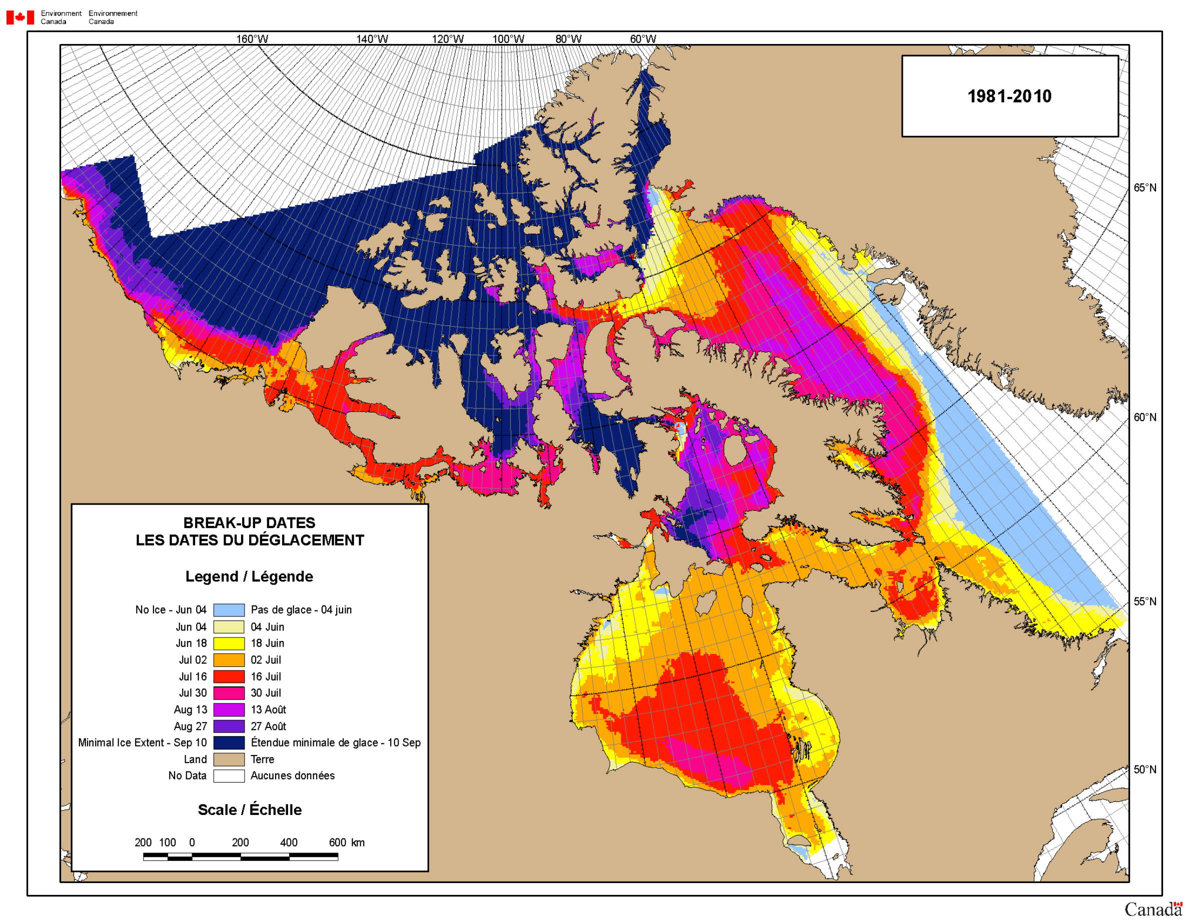


Figure 37 - Break-up dates in the Canadian Arctic (Chart courtesy of ECCC)

However, it is worth emphasizing 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.

3.7.3.2 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 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 kilometres 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 63°N in May, but disappears from waters west of Cape Farewell in August. This sea ice is normally located within 100 kilometres of the Greenland coast.

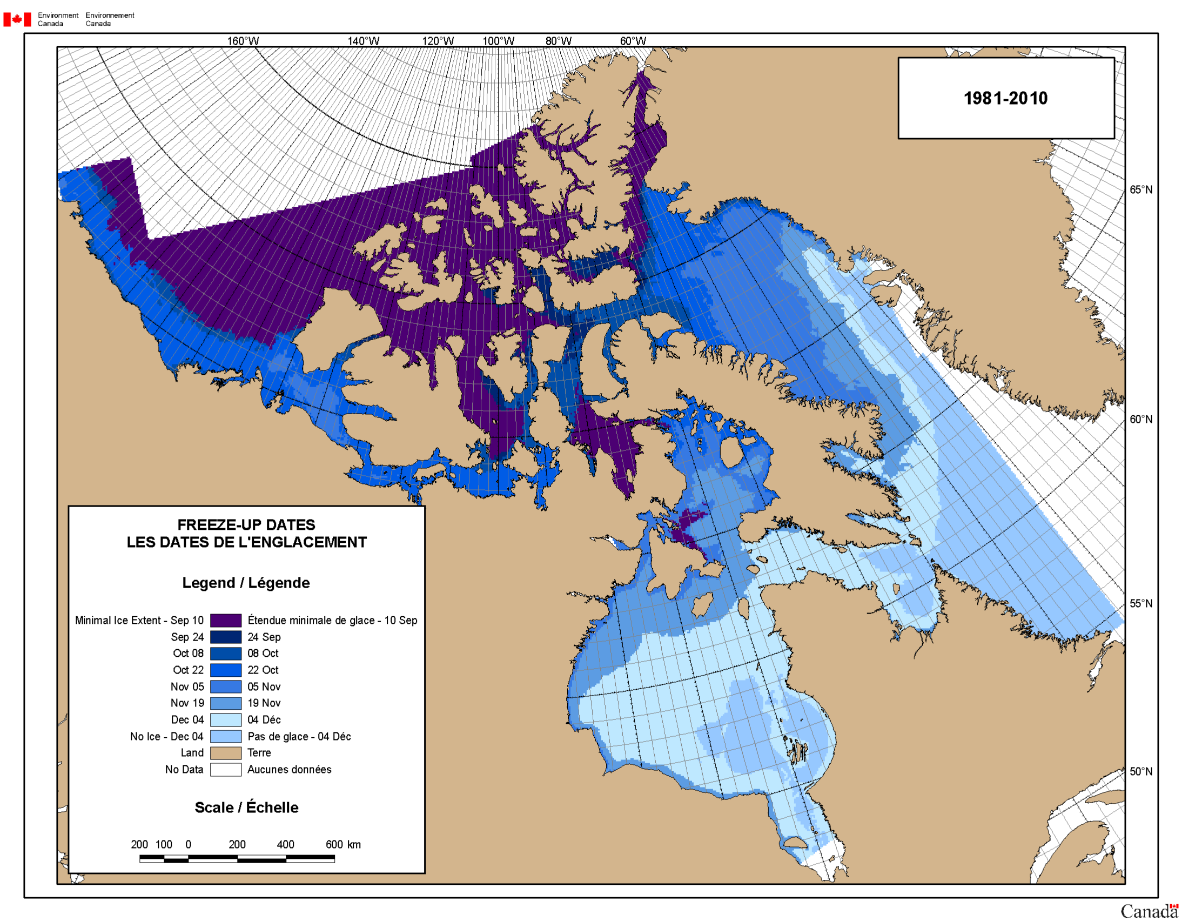


Figure 38 - Freeze-up dates in the Canadian Arctic (Chart courtesy of ECCC)

3.7.3.3 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.

3.7.3.4 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 centimetres. In the central and western Arctic, maximum thickness is about 200 centimetres. Farther south, in James Bay and along the Labrador coast, the thickness of locally developed ice can reach about 120 centimetres.

Multi-year ice found in the Archipelago reaches a thickness of 300 to 450 centimetres. However ice shelf fragments can be as thick as 2000 centimetres. 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.

3.7.3.5 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 vessels.

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 3 ice types which have different hardness. For this reason any first-year ice which survives to October 1st 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.

In Foxe Basin, the median amount of old ice never rises above zero except in the Igloolik to 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 one to three tenths range, but bumps up to the four to six tenths range with the October 1st ice promotion.

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 one to three 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.

3.7.4 Ice regime of 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 kilometres 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 counter clockwise 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.

3.7.5 Ice regime of 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.

3.7.6 Ice regime of 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.

3.7.7 Ice regime of 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. Figure 39 is a composite ice chart for 16 May 2011, compiled by CIS, showing the extent of the fast and mobile ice areas in Hudson Bay and Strait.

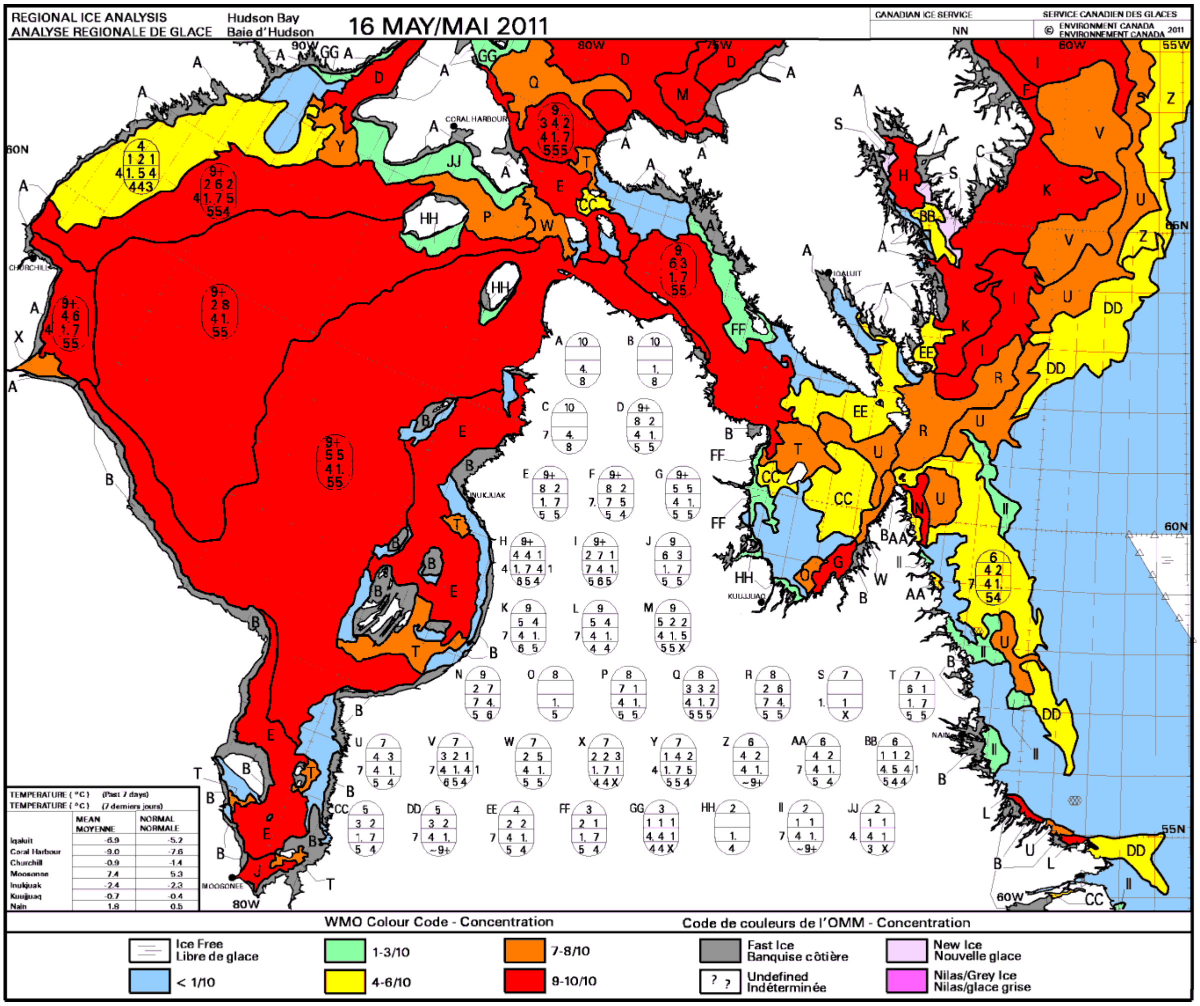


Figure 39 - Example of a regional ice chart for Hudson Bay and Hudson Strait (Chart courtesy of CIS)

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.

3.7.8 Ice regime of 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 74°N. 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 68°N generally southwestward to a point some 200 kilometres 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 centimetres thick. Ridging, rafting and hummocking are significant, and icebergs abound.

Warning: High volumes of old ice in Northern Baffin Bay pose a significant risk to shipping.

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.

3.7.9 Ice regime of the 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.

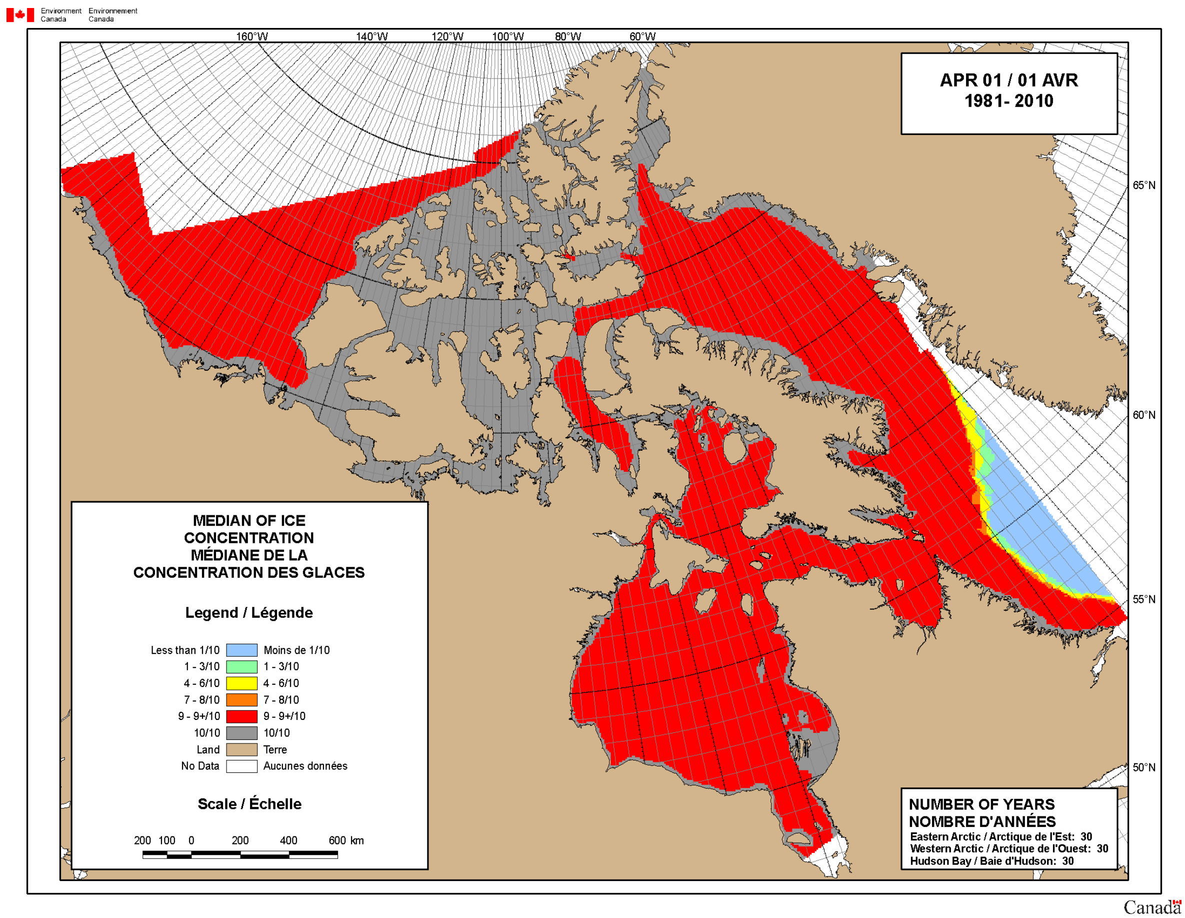


Figure 40 - Median of ice concentration in the Canadian Arctic (Chart courtesy of ECCC)

3.7.10 Ice regime of the Beaufort Sea

Old or multi-year ice up to 450 centimetres 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 kilometres north of Herschel Island and then westward some 200 kilometres 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.

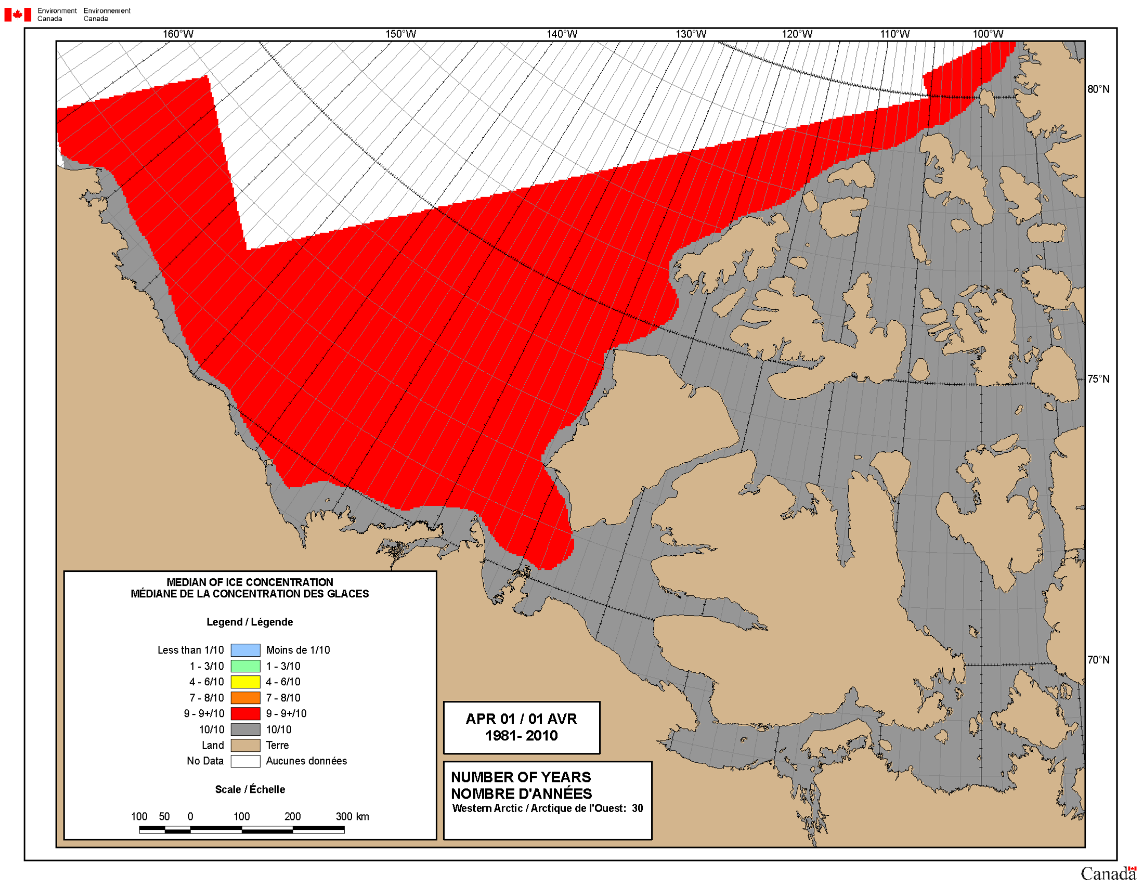


Figure 41 - Spring extent of sea ice in the Beaufort Sea (Chart courtesy of ECCC)

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.

Table 8 indicates when the extent and concentration of ice for different regions was at its record high or record low. In the north, the statistics for the season are from June 25th to

October 15th. In the south, the season begins in the fall when the ice first forms, and continues into the following spring or early summer when the ice melts.

Table 8 - Minimum and maximum ice seasons

Region name	Season of minimum ice coverage	Season of maximum ice coverage
Northern Canadian waters	2012	1983
Canadian Arctic	2012	1972
Northwest Passage (southern route)	2012	1978
Beaufort Sea	2012	1969
Gulf of St. Lawrence	2009-2010	2002-2003
East Newfoundland waters	2009-2010	1989-1990
Lake Ontario	2001-2002	1978-1979
Lake Erie	1997-1998	1977-1978
Lake Michigan	2001-2002	1976-1977
Lake Huron	2011-2012	1993-1994
Lake Superior	2011-2012	1995-1996

4 Navigation in ice covered waters

4.1 General

Ice is an obstacle to any vessel, even an icebreaker, and the inexperienced navigation officer is advised to develop a healthy respect for the latent power and strength of ice in all its forms. However, it is quite possible, and continues to be proven so, for well-found vessels in capable hands to navigate successfully through ice-covered waters.

The first principle of successful ice navigation is to maintain freedom to manoeuvre. Once a vessel becomes trapped, the vessel goes wherever the ice goes. Ice navigation requires great patience and can be a tiring business with or without icebreaker escort. The open water long way round a difficult ice area whose limits are known is often the fastest and safest way to port, or to the open sea when leaving a port.

Experience has proven that in ice of higher concentrations, 4 basic vessel handling rules apply:

1. keep moving - even very slowly, but try to keep moving
2. try to work with the ice movement and weaknesses but not against them

3. excessive speed almost always results in ice damage
4. know your vessel's manoeuvring characteristics

Warning: excessive speed is the major cause of damage to vessels by ice.

Figure 42 - Bulbous bow of M/V Zélada Desgagnés damaged by ice in Frobisher Bay July 2012[9]

4.2 Requirements for vessels operating in ice

The propulsion plant and steering gear of any vessel intending to operate in ice must be reliable and must be capable of a fast response to manoeuvring orders. The navigational and communications equipment must be equally reliable and particular attention should be paid to maintaining radar at peak performance.

Light and partly loaded vessels should be ballasted as deeply as possible, but excessive trim by the stern is not recommended, as it cuts down manoeuvrability and increases the possibility of ice damage to the more vulnerable lower area of the exposed bow. Engine room suction strainers should be able to be removed easily and to be kept clear of ice and snow. Good searchlights must be available to aid in visibility during night navigation with or without icebreaker support.

Vessels navigating in ice-covered waters may experience delays and, therefore, should carry sufficient fresh water, supplies and manoeuvring fuel, especially vessels which use heavy bunker fuel for main propulsion.

4.3 Adverse environmental conditions

Vessels and their equipment at sea in Canadian winters and in high latitudes are affected by the following:

- low surface temperatures
- high winds

[9] Source: Meridien – Bulbous bow repair

- low sea-water injection temperatures
- low humidity
- ice conditions ranging from slush ice to solid pack
- snow, sleet, and freezing rain
- fog and overcast, especially at the ice/water interface, and
- superstructure icing when there is the great and dangerous possibility of heavy and rapid icing with consequent loss of stability

4.3.1 Superstructure icing

Superstructure icing is a complicated process which depends upon meteorological conditions, condition of loading, and behaviour of the vessel in stormy weather, as well as on the size and location of the superstructure and rigging. The more common cause of ice formation is the deposit of water droplets on the vessel's structure. These droplets come from spray driven from wave crests and from vessel-generated spray. Ice formation may also occur in conditions of snowfall, sea fog, (including Arctic sea smoke) a drastic fall in ambient temperature, and from the freezing of raindrops on contact with the vessel's structure. Ice formation may sometimes be caused or accentuated by water shipped on board and retained on deck.

Vessel icing is a function of the vessel's course relative to the wind and seas and generally is most severe in the following areas: stem, bulwark and bulwark rail, windward side of the superstructure and deckhouses, hawse pipes, anchors, deck gear, forecastle deck and upper deck, freeing ports, containers, hatches, aerials, stays, shrouds, masts, spars, and associated rigging. It is important to maintain the anchor windlass free of ice so that the anchor may be dropped in case of emergency. Constant spray entering the hawse pipes may freeze solid inside the pipe, also anchors stowed in recessed pockets may freeze in place, both conditions preventing letting the anchor go. It is good practice in freezing spray to leave anchors slightly lowered in the hawse pipe in order to free them from ice accretion when needed. It is also advisable to maintain securing claws in place in case of slippery brakes, so that the anchors can be readily released in the event of a power blackout.

Figure 43 - Severe icing conditions (CCG)

Superstructure icing is possible whenever air temperatures are -2.2 °C or less and winds are 17 knots or more. It is very likely to take place when these conditions occur at the same time.

In fresh water such as the Great Lakes and St. Lawrence River superstructure icing will occur at 0 °C and below, and accumulate faster than in salt water conditions.

Generally speaking, winds of Force 5 on the Beaufort scale may produce slight icing; winds of Force 7, moderate icing; and winds of above Force 8, severe icing.

Under these conditions, the most intensive ice formation takes place when wind and sea come from ahead. In beam and quartering winds, ice accumulates more quickly on the windward side of the vessel, thus leading to a constant list which is extremely dangerous as the deck-immersion point could easily be reached with a loaded vessel.

Warning: Vessel icing may impair the stability and safety of a vessel.

The effects of freezing spray can be minimized by slowing down in heavy seas to reduce bow pounding, running with the sea, or seeking more sheltered sea conditions near-shore or in sea ice. Another option may be to head to warmer waters, although this is not possible in many Canadian marine areas.

Figure 44 - Crew removing ice from bulwarks

Figure 45 - Ice build-up on forecastle

Under severe icing conditions, manual removal of ice may be the only method of preventing a capsize. It is important for the mariner to consider the predicted duration of an icing storm and the rate at which ice is accumulating on his vessel in determining which strategy to follow.

Several tips for minimizing icing hazards on fishing vessels are:

- head for warmer water or a protected coastal area
- place all fishing gear, barrels, and deck gear below deck or fasten them to the deck as low as possible
- lower and fasten cargo booms
- cover deck machinery and boats
- fasten storm rails
- remove gratings from scuppers and move all objects which might prevent water drainage from the deck

- make the vessel as watertight as possible
- if the freeboard is high enough, fill all empty bottom tanks containing ballast piping with sea-water, and
- establish reliable two-way radio communication with either a shore station or another vessel

Freezing spray warnings are included in marine forecasts by ECCC. However, it is difficult to provide accurate icing forecasts as individual vessel characteristics have a significant effect on icing. Graphs assessing the rate of icing based on air temperature, wind speed, and sea-surface temperature can provide a guide to possible icing conditions, but should not be relied on to predict ice accumulation rates on a vessel. Caution should be exercised whenever gale-force winds are expected in combination with air temperatures below -2 °C.

4.4 Signs of ice in the vicinity

When steaming through open water, it may be possible to detect the approach of ice by the following signs:

a) **Ice blink:** this is a fairly reliable sign and may be the first indication that an ice field is in the vicinity. It can usually be seen for some time before the ice itself is visible and appears as a luminous reflection on the underside of the clouds above the ice. Its clarity is increased after a fresh snowfall. On clear days, ice blink is less apparent but may appear as a light or yellowish haze which would indicate the presence of ice. Ice blink can sometimes be detected at night, either from the reflection of moonlight, or from the ambient starlight in clear weather.
b) The sighting of small fragments of ice often indicates that larger quantities are not far away.
c) Abrupt moderation of the sea and swell occur when approaching an ice field from leeward.
d) In northern areas, and in Labrador and Newfoundland, the onset of fog often indicates the presence of ice in the vicinity.

On a clear day there may be abnormal refraction of light causing distortion in the appearance of features. Although the ice field will be seen at a greater distance than would normally be possible without refraction, its characteristics may be magnified out of all proportion – it may even appear as giant cliffs of ice in the far distance, with breaks between them where the open water lies.

The following are signs of open water:

a) **Water sky:** dark patches on low clouds, sometimes almost black in comparison with the clouds, indicate the presence of water below them. When the air is very clear this indication is less evident. When iceblink is visible at night, the absence of blink in some sectors of the horizon may indicate open water but cannot be assumed to be water sky.
b) Dark spots in fog give a similar indication, but are not visible for as great a distance as the reflection on clouds.
c) A dark bank on a cloud at high altitude indicates the presence of patches of open water below, which could lead to larger areas of open water in the immediate vicinity.

Note: To accomplish effective ice management for the Grand Banks and Canadian eastern seaboard, it is imperative that sightings of ice and icebergs be reported to ECAREG CANADA through the nearest Canadian Coast Guard MCTS Centre. These messages will be handled free of charge.

4.5 Vessels navigating independently

Experience has shown that non-ice-strengthened vessels with an open water speed of about 12 knots can become hopelessly beset in heavy concentrations of relatively light ice conditions, whereas ice-strengthened vessels with adequate power should be able to make progress through first-year ice of 6/10 to 7/10 concentrations. Such vessels are often able to proceed without any assistance other than routing advice. In concentrations of 6/10 or less, most vessels should be able to steer at slow speed around the floes in open pack ice without coming into contact with very many of them.

4.5.1 Entering the ice

The route recommended by the Ice Superintendent through the appropriate reporting system i.e. ECAREG or NORDREG CANADA, is based on the latest available information and mariners are advised to adjust their course accordingly. The following notes on vessel-handling in ice have proven helpful:

a) Do not enter ice if an alternative, although longer, open water route is available.
b) It is very easy and extremely dangerous to underestimate the hardness of ice.
c) Enter the ice at low speed to receive the initial impact; once into the pack, increase speed gradually to maintain headway and control of the vessel, but do not let the speed increase beyond the point at which she might suffer ice damage. Particular attention should be paid to applied power in areas of weak ice or open leads, pools, etc. where the speed might increase unnoticed to dangerous levels if power is not taken off.
d) Be prepared to go "Full Astern" at any time.
e) Navigation in pack ice after dark should not be attempted without high-power searchlights which can be controlled easily from the bridge; if poor visibility precludes progress, heave to in the ice and keep the propeller turning slowly as it is less susceptible to ice damage than if it were completely stopped, blocks of ice will also be prevented from jamming between the blades and the hull.
f) Propellers and rudders are the most vulnerable parts of the vessel; vessels should go astern in ice with extreme care, and always with the rudder amidships . If required to ram ice when brought to a halt, vessels should not go astern into unbroken ice, but should move astern only in the channel previously cut by their own passage.
g) All forms of glacial ice (icebergs, bergy bits, growlers) in the pack should be given a wide berth, as they are current-driven whereas the pack is wind-driven. Large features of old ice may be moving in a direction up-wind or across wind according to the direction of the current.
h) Wherever possible, pressure ridges should be avoided and a passage through pack ice under pressure should not be attempted. The vessel may have to be stopped in the ice until the pressure event is ended.
i) When a vessel navigating independently becomes beset, it usually requires icebreaker assistance to free it. However, vessels in ballast can sometimes free themselves by pumping and transferring ballast from side to side, and it may require very little change in trim or list to release the vessel, especially in high-friction areas of heavy snow-cover.

The mariner may wish to engage the services of an Ice Navigator in the Arctic.

4.6 Icebreakers

The CCG has a limited number of icebreakers available for the escort and support of shipping. These icebreakers are heavily committed and cannot always be provided on short notice when requested. Therefore, it is important for the ECAREG CANADA office or Ice Operations centre to be kept informed about the position and projected movements of vessels when ice is present. Failure to follow the reporting procedures, by vessels unsure of their ability to cope with prevailing ice conditions on their own, will only add to the difficulties of providing icebreakers and can lead to serious delays.

CCG icebreakers, many of which carry helicopters for ice reconnaissance, have operated in ice for many years, from the Great Lakes to as far north as the North Pole. Their Commanding Officers and crews are highly skilled and thoroughly experienced in the specialist fields of ice navigation, icebreaking, and ice escort. The fullest co-operation with the commanding officer of an icebreaker is, therefore, requested from a vessel or convoy under escort. For progress to be made, it is essential that escort operations be under the direction of the commanding officer of the icebreaker.

Note: No escort will be provided unless full co-operation is obtained.

4.6.1 Communicating with icebreakers

Once a vessel has requested icebreaker assistance, a radio watch should be kept on 2182 kHz and channel 16 very high frequency (VHF) (156.8 MHz). Difficulty is often experienced by icebreakers in making initial contact with these vessels, often with the result of lost time and extra fuel consumption. Medium frequency (MF) and VHF remain as proven communications tools and should be utilised to maintain contact with the icebreakers.

A continuous radiotelephone watch on an agreed frequency should also be maintained on the bridges of all vessels working with Coast Guard icebreakers. Vessels should be capable of working one or more of the following MF and VHF frequencies:

- 2237 kHz MF
- 2134 kHz MF
- 2738 kHz MF
- 156.3 MHz VHF channel 6

Table 9 lists the letter, sound, visual, or radiotelephony signals that are for use between icebreakers and assisted vessels. These signals are accepted internationally and they are restricted to the significance indicated in the table.

While under escort, continuous and close communications must be maintained. Communications normally will be by radiotelephone on a selected and mutually agreed inter-vessel VHF working frequency. It is vital to inform the Ice Operations centre and icebreaker of any change in the state of your vessel while awaiting an icebreaker escort.

Table 9 - Operational signals to be used to supplement radiotelephone communication between icebreaker and assisted vessel(s)

Code Letters	Icebreaker Instruction	Assisted Vessel(s) Response
WM	Icebreaker support is now commencing. Use special icebreaker support signals and keep continuous watch for sound, visual, or radiotelephony signals	

Code Letters	Icebreaker Instruction	Assisted Vessel(s) Response
A	Go ahead (proceed along the ice channel)	I am going ahead. (I am proceeding along the ice channel)
G	I am going ahead, follow me	I am going ahead. I am following you
J	Do not follow me. (proceed along the ice channel)	I will not follow you (I will proceed along the ice channel)
P	Slow down	I am slowing down
N	Stop your engines	I am stopping my engines
H	Reverse your engines	I am reversing my engines
L	You should stop your vessel instantly	I am stopping my vessel
4	Stop. I am icebound	I am stopping my vessel
Q	Shorten the distance between vessels	I am shortening the distance
B	Increase the distance between vessels	I am increasing the distance
Y	Be ready to take (or cast off) the tow line	I am ready to take (or cast off) the tow line
FE	Stop your headway (given only to a vessel in an ice channel ahead of an icebreaker)	I am stopping headway
WO	Icebreaker support is finished. Proceed to your destination	
5	Attention	Attention
E	I am altering my course to starboard	I am altering my course to starboard
I	I am altering my course to port	I am altering my course to port
S	My engines are going astern	My engines are going astern
M	My vessel is stopped and making no way through the water	My vessel is stopped and making no progress through the water

Note: EMERGENCY STOP SIGNAL: Icebreakers have red revolving lights placed high up at the after end of the superstructure, visible from astern, also an icebreaking siren which both will be activated when an EMERGENCY STOP is required by the escorted vessel(s).

The signal "K" by sound or light may be used by an icebreaker to remind vessels of their obligation to listen continuously on their radios.

If more than 1 vessel is assisted (convoy), the distance between vessels should be as constant as possible; watch the speed of your own vessel and of the vessel ahead. Should the speed of your own vessel go down, give an attention signal to the vessel following.

The visual signals are seldom used in practice, but are listed in case voice radio communication fails.

Note: The use of these signals does not relieve any vessel from complying with the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs).

4.6.2 Report required before escort commences

Before escort or assistance commences, the icebreaker will require some or all of the following information to assess a vessel's capabilities while under escort in ice:

- vessel name, type and call sign
- Lloyds/IMO number
- owner/agent name
- country of registry
- tonnage (gross and net)
- vessel's length and beam
- port of departure and destination
- cargo type and amount (tonnage)
- ice navigator’s name, if embarked
- open water speed
- ice class (if any) and classification society
- drafts - forward and aft
- number of propellers and rudders
- shaft horsepower
- propulsion plant (whether diesel or turbine, and astern power expressed as a percentage of full ahead power) and the type of fuel for the main propulsion (for example, heavy bunker, diesel, LNG, etc.), and
- radiotelephone working frequencies, communications systems including telephone and/or fax number

Note: The onus is on the escorted vessel to advise the icebreaker of any deficiencies or restrictions that exist on their vessel. Per example, a combination of low-sulfur fuel and engine limiter under the Environmental Ship Index (ESI) can seriously impede the vessel’s ice navigation capacity, even under escort.

4.6.3 Icebreaking escort operations

The following are comments on aspects of icebreaker escort procedures:

a) **Track width:** Progress through ice by an escorted vessel depends to a great extent on the width of the track made by the icebreaker, which is directly related to the speed of the forward progress of the icebreaker and the distance between the icebreaker and the vessel following.

b) Icebreaker beam: When an icebreaker is breaking a track through large heavy floes at slow speed, the track will be about 30 to 40% wider than the beam of the icebreaker. At high speed, and if the ice is of a type which can be broken by the action of the stern wave (wake), the track may be as much as 3 times that of the icebreaker's beam.

c) Minimum escort distance: The minimum distance will be determined by the commanding officer of the icebreaker on the basis of distance required by the escorted vessel(s) to come to a complete stop, after reversing to full astern from normal full ahead speed. Once this distance has been established, it is the responsibility of the vessel under escort to see that it is maintained. If the escorted vessel is unable to maintain the minimum escort distance and is falling back, the icebreaker must be informed at once to avoid the possibility of besetment and resulting delay.

d) Maximum escort distance: Maximum distance is determined on the basis of ice conditions and the distance at which the track will remain open or nearly so.

Increasing this distance creates the possibility of besetment, which would necessitate a freeing operation by the icebreaker. If the escorted vessel is unable to maintain the maximum escort distance, the icebreaker must be informed at once to avoid the possibility of besetment and resulting delay.

e) **Maintaining the escort distance:** Mariners are requested to maintain the required escort distance astern of the icebreaker to the best of their ability. The progress made depends to a very great extent on the correct escort distance being maintained. This distance is dictated by the existing ice conditions and the risk of collision by the escorted vessel overtaking the icebreaker.

Figure 46 - The commanding officer of the icebreaker will determine a safe escort distance (CCG)

f) **Ice concentration:** With 9+/10 concentrations, the track will have a tendency to close quickly behind the icebreaker, thus necessitating very close escort at a speed determined by the Commanding Officer of the icebreaker and the type of ice encountered.

g) **Ice pressure:** When the ice concentration is 9+/10 and under pressure, the track will close very rapidly. Progress will be almost impossible because the track, being marginally wider than the beam of the icebreaker, will close and result in the escorted vessel becoming beset.

h) **Effect of escort on width of track:** When an icebreaker makes a track, it causes outward movement of the floes. The width of the track depends on the extent of this outward movement together with the amount of open water available for floe movement. A longer escort distance allows a longer period of movement that results in a wider track.

i) **Speed:** When an icebreaker makes contact with ice floes on either side of the track, they may be forced outward with sufficient momentum to overcome the indraft at the stern; otherwise, some blocks and small floes will be drawn into the broken track. Most tracks made by icebreakers will contain ice rubble, which may also contain

floes, which could damage an escorted vessel at excessive speed.
If an icebreaker proceeds at slow speed through ice, floes will slide along her hull and remain intact, with the exception of small pieces that may break away from the leading edges. At high speeds the floes will be shattered into many pieces. The icebreaker will, therefore, proceed at a speed which will break floes into as many pieces as possible, thus reducing the possibility of damage to the vessel following in the track.

j) **Escorted vessel beset:** When a vessel under escort has stopped for any reason, the icebreaker must be notified immediately. If the vessel is beset, the engines should be kept slow ahead to keep the ice away from the propellers. The engines must be stopped only when requested by the icebreaker.

k) **Freeing a beset vessel:** Freeing a vessel that has become beset during escort is usually carried out by the icebreaker backing down the track, cutting out ice on either bow of the beset vessel, and passing astern along the vessel's side before moving both vessels ahead. To free a vessel beset while navigating independently, the icebreaker will normally approach from astern and cross close ahead at an angle of 20 to 30 degrees to the beset vessel's course. Such an approach may be made on either side in moderate winds. In strong winds at a wide angle to the track, a decision as to which side the cross-ahead is made will be determined by which of the 2 vessels is more influenced by the wind. On occasion, the icebreaker may elect to pass down one side of the beset vessel, turn astern of her and pass up on the other side, thereby releasing pressure from both sides.

l) **Systems of escort:** When a vessel becomes beset during escort, the normal procedure is for the icebreaker to back up to free her and then proceed ahead with the escorted vessel following. However, when progress is slow, the Free and Proceed system may be used, in which the beset vessel is directed to proceed up the track made by the icebreaker while backing up, the icebreaker then following behind. Before the escorted vessel reaches the end of the previously broken icebreaker track, the icebreaker proceeds at full speed to overtake and pass the escorted vessel. This cuts down the number of freeing operations and improves progress.

m) **Red warning lights and air horn:** When escorting vessels in ice, CCG icebreakers use 2 rotating red lights to indicate that the icebreaker has become stopped. In most cases these lights are placed in a vertical line 1.8 metres apart abaft the mainmast and are visible for at least 2 miles. However, construction restrictions of some icebreakers necessitate that these lights be placed horizontally in roughly the same aft-facing position.
As an additional warning signal, all icebreakers are fitted with and use a zet-horn, facing aft, audible up to 2 nautical miles, which sounds simultaneously with the red warning lights when they are activated. Prior to commencement of escort, all vessels will familiarize themselves with the positioning and operation of these red rotating lights and the zet-horn.

n) **Icebreaker stopped:** Whenever the red revolving lights are displayed and the horn sounded, either separately or simultaneously, it signifies that the icebreaker has come to a standstill and is unable to make further progress without backing up. During close escort work, a lookout shall always be kept for the flashing red light. The mariner of the escorted vessel should treat these signals with extreme urgency and immediately reverse engines to full speed astern. The rudder should be put hard over to increase ice-friction on the hull as long as headway is carried, until all forward motion has ceased, then the rudder must be returned to the amidships position.

o) **Icebreaker stopping without warning:** Mariners are cautioned that, because of unexpected ice conditions or in other emergency situations, the icebreaker may stop or otherwise manoeuvre ahead of the escorted vessel without these warning signals. Mariners must always be prepared to take prompt action to avoid overrunning the icebreaker.

Figure 47 - Icebreaker backing alongside vessel to free it from the ice (CCG)

p) **Towing in ice:** This procedure would only be undertaken in emergencies as there is an inherent risk of damage to both vessels. The commanding officer of an icebreaker who receives a request for a tow will judge whether or not the situation calls for such extreme measures. CCG icebreakers are not equipped for close-coupled towing operations.

q) **Anchoring in ice:** Anchoring in the presence of ice is not recommended except in an emergency, but if such anchoring is necessary, only the minimum amount of cable/shackle should be used and the capstan/windlass should be available for immediate use. The engines must be on standby, or kept running, if the start-up time is more than 20 minutes. If the water is too deep to let go an anchor, the vessel may be stopped in fast ice (when the conditions permit). When off-shore in deep water, a vessel can usually safely stop in the drift ice without an anchor down when darkness or poor visibility prevents further progress. The vessel will then drift with the ice and may be turned around by the ice, but will be quite safe if properly placed before shutting down.

r) **Convoys:** Convoys of vessels may be formed by the commanding officer of the icebreaker, after consultation with the appropriate shore authority. During operations in ice, this action will best aid the movement of the maximum number of vessels when there are an insufficient number of icebreakers of suitable capacity available to facilitate the escort of vessels proceeding to or from adjacent areas or ports.

The commanding officer of the icebreaker will determine the order of station within the convoy, to be arranged to expedite the movement of the convoy through the ice (not necessarily on "first come-first served" basis). The vessels in the convoy are responsible for arranging and maintaining a suitable and safe distance between individual vessels. The icebreaker will designate the required distance to be maintained between itself and the lead vessel of the convoy.

If the ice conditions should change on route, or if some vessels have difficulty in following the vessel ahead, the Commanding Officer of the icebreaker may change the order of convoy station so that vessels within the convoy can assist the progress of others less capable than themselves

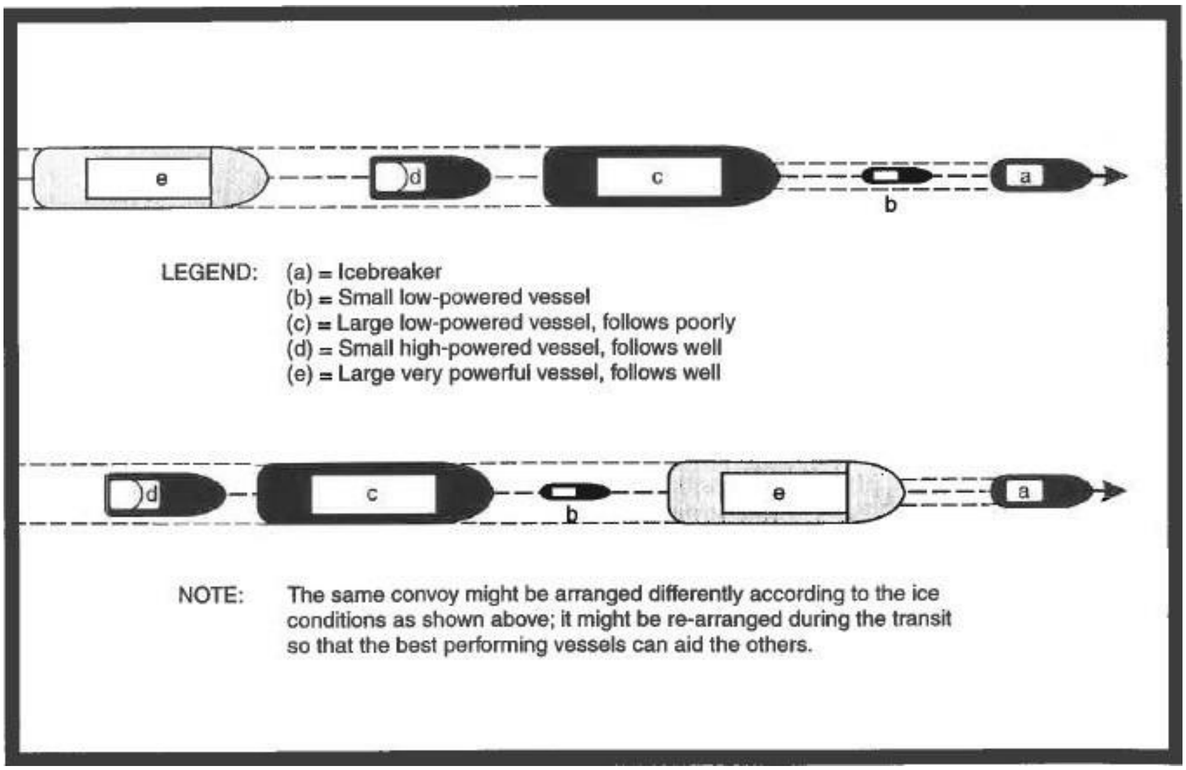


Figure 48 - Icebreaker escort – Ships in convoy (Courtesy of Marine Institute of Memorial University of Newfoundland: International Ice Navigator Course, March 31st, 1996)

4.7 Effect of ice and snow on vessel performance

Vessels not specifically designed and constructed for ice navigation must consider the suitability and best usage of their existing propulsion and control systems, in addition to hull strength, for navigation in ice-covered waters.

4.7.1 Vessel resistance

The resistance of a vessel is greater in level ice than in open water. As ice thickness and/or ice strength increases, the vessel must increase power to maintain its speed. However, even in open pack ice or in heavier ice concentrations, the navigator must use caution and avoid excessive speed.

In general it can be said that rafted, ridged, and rubbled ice present significant impediments to the progress of a vessel. Caution should also be used when navigating through level ice with occasional hummocks or rafted areas or inclusions of old ice.

Warning: Any vessel that is not strengthened for operating in ice should avoid large unbroken ice floes, particularly if the ice is deformed by rafts, ridges, or rubble.

When the ice thickness exceeds that in which the vessel can make continuous progress, (such as when the vessel encounters old ice, ridges, rafts, or hummocks), the vessel could resort to ramming if the vessel’s design and structural strength permits.

It is important that the ice navigator understands how much impact from the ice the vessel can withstand without suffering damage, and at what speed hull damage is likely to be inflicted by the ice environment currently being experienced.

The influence of snow on vessel performance varies directly with snow thickness and snow type, and greatly increases vessel resistance. The friction coefficient between snow and a vessel's hull varies with the consistency and wetness of the snow; wetter snow has a higher friction coefficient than dry snow. In certain environmental conditions the snow will be quite "sticky" whereas, in others, it will be very dry and brittle. One rule of thumb suggests that resistance from snow cover can be approximated by adding half the snow thickness to the observed ice thickness and assessing performance in ice of the increased calculated thickness. Resistance in "sticky" snow is very difficult to predict, but it can be very high: equal to, or greater than, the icebreaking resistance.

Low friction coatings and hull form are important elements in vessel performance in snow-covered ice. In ramming mode a low-friction hull coating will facilitate extraction astern after each ram, as well as permitting each ram to proceed further ahead than would be possible with a bare steel hull surface.

4.7.2 Vessel manoeuvring

The features of hull shape that influence manoeuvrability in ice to the greatest extent are length-to-breadth ratio, flare, mid-body, and bow and stern shape. Manoeuvrability is also greatly influenced by ice conditions, such as: thickness, coverage, pressure, and shear zone conditions. The diameter of a vessel's turning circle increases as the thickness of the ice increases. Turning in level ice conditions is generally influenced by the degree of confinement imposed by the surrounding ice. Steady turns are recommended for most vessels that are not as manoeuvrable as icebreakers, however it is more common for icebreakers to use star or channel breakout manoeuvres as a faster means of turning. Heeling systems have been demonstrated to be effective for most icebreaking vessels, especially in snow-covered ice situations.

4.7.3 Structural capability

A vessel's performance in ice can be limited by the hull structure's capability to withstand ice impacts. Different modes of operation and ice regimes will generate different magnitudes of ice impact forces. For example, a vessel encountering first-year ice will experience lower impact forces than a vessel encountering old ice. A vessel – usually an icebreaker - which is required to ram ice features aggressively with the intention of protecting less capable vessels or structures will, of necessity, incur higher impact forces to break ice which would damage that which they are protecting. In terms of overall magnitude, ramming operations generate the largest forces on the vessel's structure, and being repetitive, they may cause cumulative damage.

4.7.4 Performance Enhancing Systems

Performance enhancing systems are designed to reduce the power necessary for propulsion and to increase the vessel's manoeuvrability through ice. Heeling systems, which roll the vessel from side to side and reduce the effect of static friction, are helpful if the vessel is stuck in pressured ice, or beached on an ice feature. The following hull lubrication systems can also reduce resistance and aid manoeuvrability:

a) **Low friction coatings** - Low friction coatings can be used to reduce drag forces and are now used on many icebreaking vessels.
b) **Air bubble system** - The system uses 1 or more air compressors to force air through nozzles at the vessel's side below the waterline. The air bubbles rise to the surface together with entrained water, lubricating the interface between the ice and the vessel's hull, both above and below the waterline. The conditions and operations for which the system is particularly well-suited include: low speed transiting in "sticky ice" and ice with deep snow cover, manoeuvring in pressured ice, lubricating the hull during the break-away (extraction) portion of ramming, and manoeuvring alongside a dock. In open water situations the air bubblers can sometimes be used instead of thrusters.
c) **Water jet/air injection system** - This system involves injecting air into water, which is pumped through nozzles at the vessel's side below the waterline.
d) **Water-wash system** - The water-wash system pumps a large volume of water to nozzles at the bow above the water-line. The objective is to flood the ice with water, thereby lubricating the interface between vessel and ice, and to wash away any snow cover from the ice to be broken.

4.8 Vessel handling techniques in ice

4.8.1 manoeuvres in different ice conditions

Ice is an obstacle to any vessel, even an icebreaker, and the inexperienced navigator is advised to develop a healthy respect for the potential strength of ice in all its forms. However, it is quite possible, and continues to be proven so, for well-maintained and well-equipped vessels in capable hands to navigate successfully through ice-covered waters. Mariners who are inexperienced in ice often find it useful to employ the services of an Ice Advisor for transiting the Gulf of St. Lawrence in winter or an Ice Navigator for voyages into the Arctic in the summer.

The first principle of successful ice navigation is to avoid stopping or becoming stuck in the ice. Once a vessel becomes trapped, it goes wherever the ice goes. Ice navigation requires great patience and can be a tiring business, with or without icebreaker escort. The longer open water way around a difficult ice area whose limits are known is often the fastest and safest way to port or to reach the open sea.

Note: Do not underestimate the hardness of ice and its potential for inflicting damage.

4.8.1.1 Before entering the ice

For an unstrengthened vessel, or for a vessel whose structural capability does not match the prevailing ice conditions, it is preferable and safer to take any alternative open water route around the ice even if it is considerably longer. An open water route is always better than going through a large amount of ice. Any expected savings of fuel will be more than offset by the risk of damage, and the actual fuel consumption may be higher by going through ice, even if the distance is shorter.

The following conditions must be met before a vessel enters an ice field:

a) Follow the route recommended by the Ice Office via the MCTS. This route is based on the latest available information and Mariners are advised to adjust their course accordingly if changes are recommended during the passage.
b) Extra lookouts must be posted and the bridge watch may be increased, depending on the visibility.
c) There must be sufficient light to complete the transit of the ice field in daylight or the vessel must be equipped with sufficient high-powered and reliable searchlights for use after dark.
d) Reduce speed to a minimum to receive the initial impact of the ice.
e) The vessel should be at right angles to the edge of the pack ice at entry to avoid glancing blows and the point of entering the ice must be chosen carefully (see figure 49), preferably in an area of lower ice concentration.

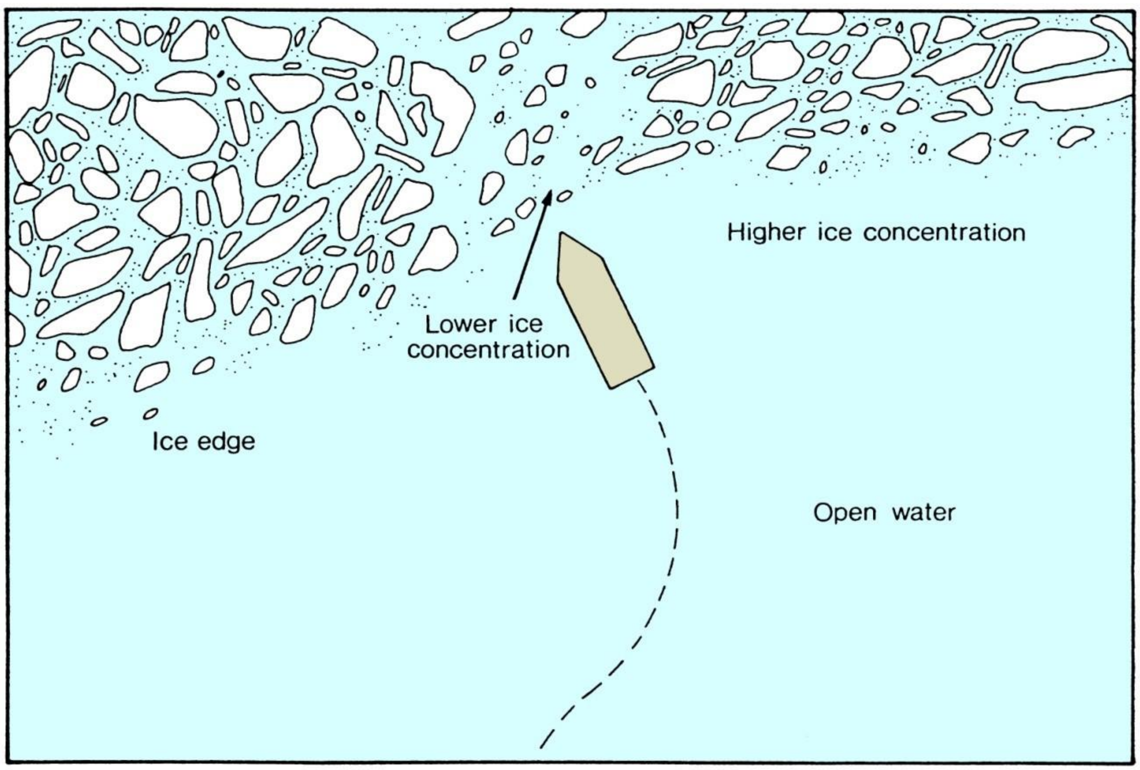


Figure 49 - Correct approach to ice field: reduced speed and perpendicular to edge (Courtesy of Capt. George Q. Parnell “Ice Seamanship”)

f) The engine room personnel must be briefed fully as to the situation and what may be required of them, as it may be necessary to go full astern at any time, and engine manoeuvres will be frequent as speed is constantly adjusted.
g) The vessel must be ballasted down to ice draft, if appropriate, or to such a draft that would offer protection to a bulbous bow, rudder, or propeller (as applicable).
h) The vessel should be fitted with an internal cooling system for use in the event that the main engine cooling water intake becomes clogged with slush ice.

4.8.1.2 After entering the ice

Once the ice is entered, speed of the vessel should be increased slowly, according to the prevailing ice conditions and the vulnerability of the vessel. If visibility decreases while the vessel is in the ice, speed should be reduced until the vessel can be stopped within the distance of visibility. If in doubt, the vessel must stop until the visibility improves. The potential of damage by ice increases with less visibility. If the vessel is stopped, the propeller(s) should be kept turning at low revolutions to prevent ice from building up around the stern.

When navigating in ice, the general rules are:

- use the pack to its best advantage. Follow open water patches and lighter ice areas even if initially it involves large deviations of course
- in limited visibility, beware following an open water lead at excessive speed, it may be the trail of an iceberg

Do not allow the speed to increase to dangerous levels when in leads or open pools within an ice field, or when navigating open pack conditions.

4.8.1.3 Turning in ice

Changes in course will be necessary when the vessel is in ice. If possible course changes should be carried out in an area of open water or in relatively light ice, as turning in ice requires substantially more power than turning in water, because the vessel is trying to break ice with its length rather than with its bow, turns should be started early and make as wide an arc as possible to achieve the new heading. Care must be taken even when turning in an open water area, as it is easy to underestimate the swing of the vessel and to make contact with ice on the vessel's side or stern: a glancing blow with a soft piece of ice may result in the vessel colliding with a harder piece (see figure 50).

The vessel will have a strong tendency to follow the path of least resistance and turning out of a channel may be difficult or even impossible. Vessels that are equipped with twin propellers should use them to assist in the turn. . In very tight ice conditions, a vessel sailing independently may make better progress by applying full power and leaving the rudder amidships This allows her to find the least resistance without any drag from the rudder in trying to maintain a straight course by steering.

Warning: Avoid turning in heavy ice – seek lighter ice or open water pools.

If it is not possible to turn in an open water area, the mariner must decide what type of turning manoeuvre will be appropriate. If the turn does not have to be sharp then it will be better to maintain progress in ice with the helm over. When ice conditions are such that the vessel's progress is marginal, the effect of the drag of the rudder being turned may be sufficient to halt the vessel's progress completely. In this case, or if the vessel must make a sharp turn, the star manoeuvre will have to be performed. This manoeuvre is the equivalent of turning the vessel short round in ice by backing and filling with the engine and rudder. Mariners will have to weigh the dangers of backing in ice to accomplish the star manoeuvre, against any navigational dangers of a long turn in ice. Care must be taken while backing on each ram that the propeller and rudder are not forced into unbroken ice astern.

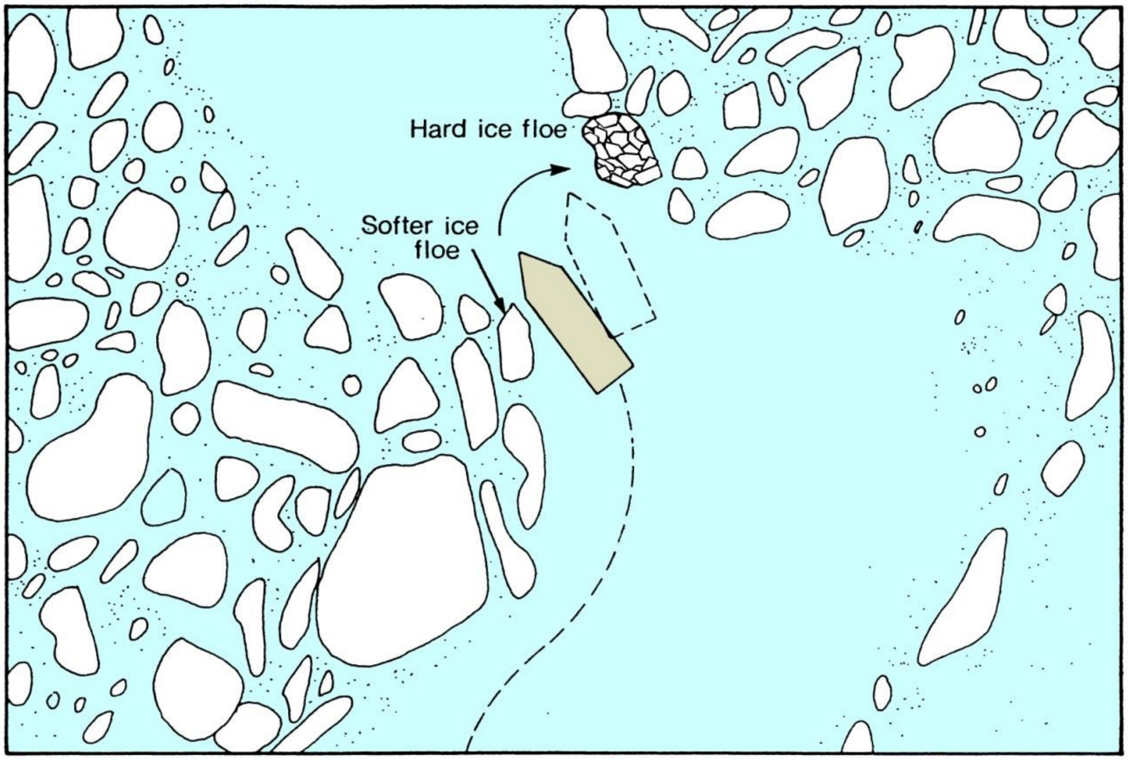


Figure 50 - Danger in turning in an ice channel (Courtesy of Capt. George Q. Parnell "Ice Seamanship")

4.8.1.4 Backing in ice

Backing in ice is a dangerous manoeuvre as it exposes the most vulnerable parts of the vessel, the rudder and propeller, to the ice. It should only be attempted when absolutely necessary and in any case the vessel should never ram astern. In recent years "double-acting" ice strengthened vessels have been developed which are designed to break ice while moving astern in order to protect their bulbous bows, but only this type of specially designed vessel should attempt such manoeuvres.

The vessel should move at dead slow astern and the rudder must be amidships (figure 51). If the rudder is off centre and it strikes a piece of ice going astern, the twisting force exerted on the rudder post will be much greater than if the rudder is centred. In the centre position, the rudder will be protected by an ice horn if fitted.

If ice starts to build up under the stern, a short burst of power ahead should be used to clear away the ice. Using this technique of backing up to the ice and using the burst ahead to clear the ice can be very effective, but a careful watch must be kept of the distance between the stern and the ice edge. If a good view of the stern is not possible from the bridge, post a reliable lookout aft with access to a radio or telephone.

Warning: Avoid backing in ice whenever possible. If you must move astern, do so with extreme caution at dead slow.

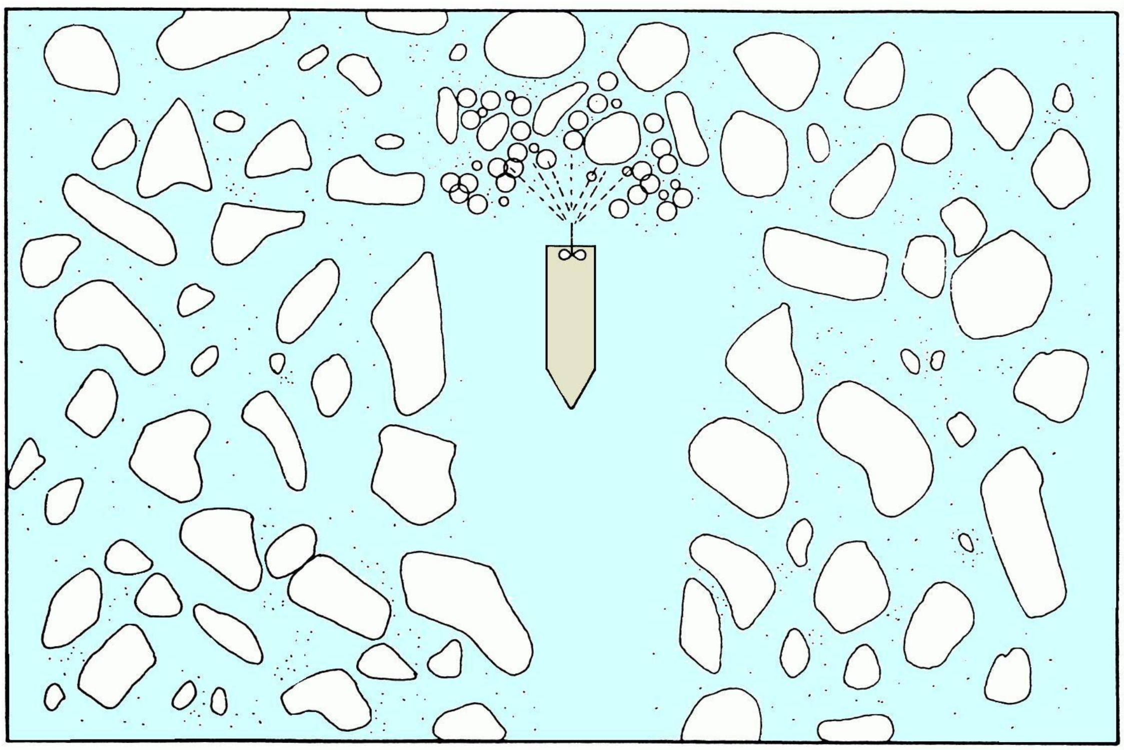


Figure 51 - Backing onto Ice: Rudder Amidships . Dead Slow Astern (Courtesy of Capt. George Q. Parnell “Ice Seamanship”)

4.8.1.5 Precautions to avoid becoming beset

The easiest way to avoid being beset is to avoid areas of ice under pressure. Ice can be put under pressure in several ways. The most common pressure situation occurs when open pack ice closes because of prevailing winds, but it may also occur when tides, currents, or on-shore breezes blow ice onto the shore.

Pack ice that has been under pressure for some time will deform, overriding as rafts or piling up as ridges or hummocks. Appearances are deceiving as the sail on a ridge or hummock may be only 1 to 2 metres above the ice cover but the keel could be several metres below.

Warning: Any vessel that is not strengthened for operating in ice should avoid floes that are rafted or ridged.

The danger from becoming beset is increased greatly in the presence of old or glacial ice, as the pressure on the hull is that much greater.

When in pack ice, a frequent check should be made for any signs of the track closing behind the vessel. Normally there will be a slight closing from the release of pressure as the vessel passes through the ice, but if the ice begins to close up completely behind the vessel it is a strong sign that the pressure is increasing (figure 52).

Similarly, if proceeding along an open water lead between ice and shore, or ice in motion and fast ice, watch for a change in the wind direction or tide as the lead can close quickly.

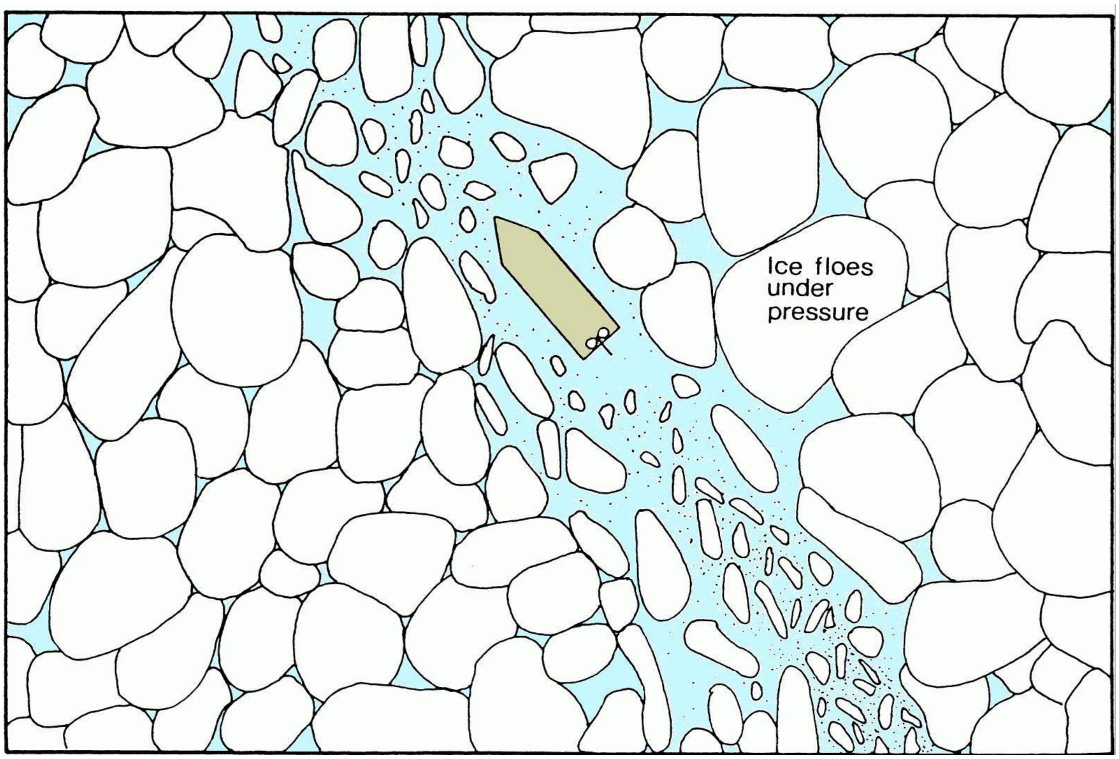


Figure 52 - Pressure in ice field closes track behind vessel (Courtesy of Capt. George Q. Parnell "Ice Seamanship")

4.8.1.6 Freeing a beset vessel

To free a beset vessel, it may be necessary to wait for conditions to improve or it is necessary to loosen the grip of ice on the hull, which may be accomplished in several ways:

a) Go ahead and astern at full power while alternating the helm from port to starboard, which has the effect of levering the ice aside. Care must be taken when going astern to ensure that no ice goes through the propeller(s), or if the vessel frees itself that it does not make sternway into any heavy ice. In vessels with twin propellers, they should be alternated with one ahead and one astern for a few minutes, then each changed to the opposite direction, slewing the stern from side to side to create a wider opening in the ice astern.
b) Alternate the ballast to port and to starboard to list the vessel and change the underwater shape. This method should only be done with knowledge of the possible consequences of an exaggerated list if the vessel comes free quickly.
c) Alternate filling and emptying of the fore and after peak tanks is a safer manoeuvre than using the ballast tanks, but it is usually only effective in changing the trim for the bow to get a better angle of attack on the ice ahead, or for the propellers to be given a better grip by greater submersion. It can also be effective in extracting from a ridge, by raising the bow so that the vessel slides backwards as the bow is raised.
d) In smaller vessels it may be possible to swing weights over the side suspended on the vessel's cranes or lifting gear to induce a list and break the vessel free. This method should only be used with knowledge of the possible consequences if the vessel comes free quickly (see (b) above).

Figure 53 - Ice under pressure will close the track behind the vessel (CCG)

4.8.1.7 Ramming

Ramming is particularly effective when attempting progress through ice that is otherwise too thick to break continuously.

Warning: Ramming should not be undertaken by vessels that are not ice-strengthened or by vessels with bulbous bows. Ice-strengthened vessels, when undertaking ramming, should do so with extreme caution.

For vessels that can ram the ice it is a process of trial and error to determine the optimum distance to back away from the ice edge to build up speed. The optimum backing distance will be that which gives the most forward progress with the least travel astern. It is always necessary to start with short rams to determine the thickness and hardness of the ice. All vessels must pay close attention to the ice conditions, to avoid the possibility of lodging the vessel across a ridge on a large floe. Floes of old ice which may be distributed throughout the pack in northern waters, must be identified and avoided while ramming.

Ramming must be undertaken with extreme caution because the impact forces caused when the vessel contacts the ice can be very high. For ice-strengthened vessels these forces may be higher than those used to design the structure and may lead to damage. However, if the ramming is restricted to low speeds, the risk of damage will be greatly reduced.

4.8.2 Handling a damaged vessel in ice

Abandoning vessel in ice-covered waters is possible, if necessary, by landing lifeboats or life rafts on the ice, if the ice is thick enough to take their weight. Vessels fitted with quick-release drop-lifeboats without davits should never attempt to launch them into ice, but should lower them gently to the ice-surface by using the recovery equipment in reverse.

If the vessel can be made sufficiently seaworthy to proceed, an assessment will have to be made of the demands that will be placed on the vessel by breaking ice during the remainder of the voyage, as opposed to any risks in waiting for escort. The damaged area should be protected from further impacts by trimming the vessel, although this will have an effect on its ability to break ice. In ice-strengthened vessels, ballasting to minimize flooding can expose the hull above or below the ice belt. Care should be taken that the change in trim does not expose the rudder and propeller(s) to the ice, but, if it is unavoidable, that any subsequent decision is made with the knowledge of this exposure.

4.8.3 Berthing

Berthing in ice-covered waters can be, and usually is, a long process, particularly in the Arctic where normally there are no tugs. When approaching a berth in ice-covered waters it is desirable (even if this is not the normal practice) to have an officer stationed on the bow to call back the distance off the wharf or pier because a variation in ice thickness (not observed from the bridge) can result in a sudden increase or decrease in the closing speed of the bow and the wharf.

There are a multitude of considerations depending on vessel size and berth type, but the aim should be to bring the vessel alongside with as little ice as possible trapped between the vessel and the dock face. It may be accomplished by landing the bow on the near end of the dock and sliding along the face (similar to landing the bow on the wall entering a lock in the Seaway), or by bringing the bow in to the desired location, passing a stout spring line, and going ahead slowly so that the wash flushes the ice out from between the dock and the vessel (figure 54). Frequently it is necessary to combine the two techniques (in vessels of sufficient manoeuvrability it is possible to clear ice away from the wharf prior to berthing). Care must be exercised not to damage the wharf by contact with the vessel, or by forcing ice against pilings. The vessel itself can be damaged by forcing unbroken floes of hard ice against the unyielding facing of a solid berth.

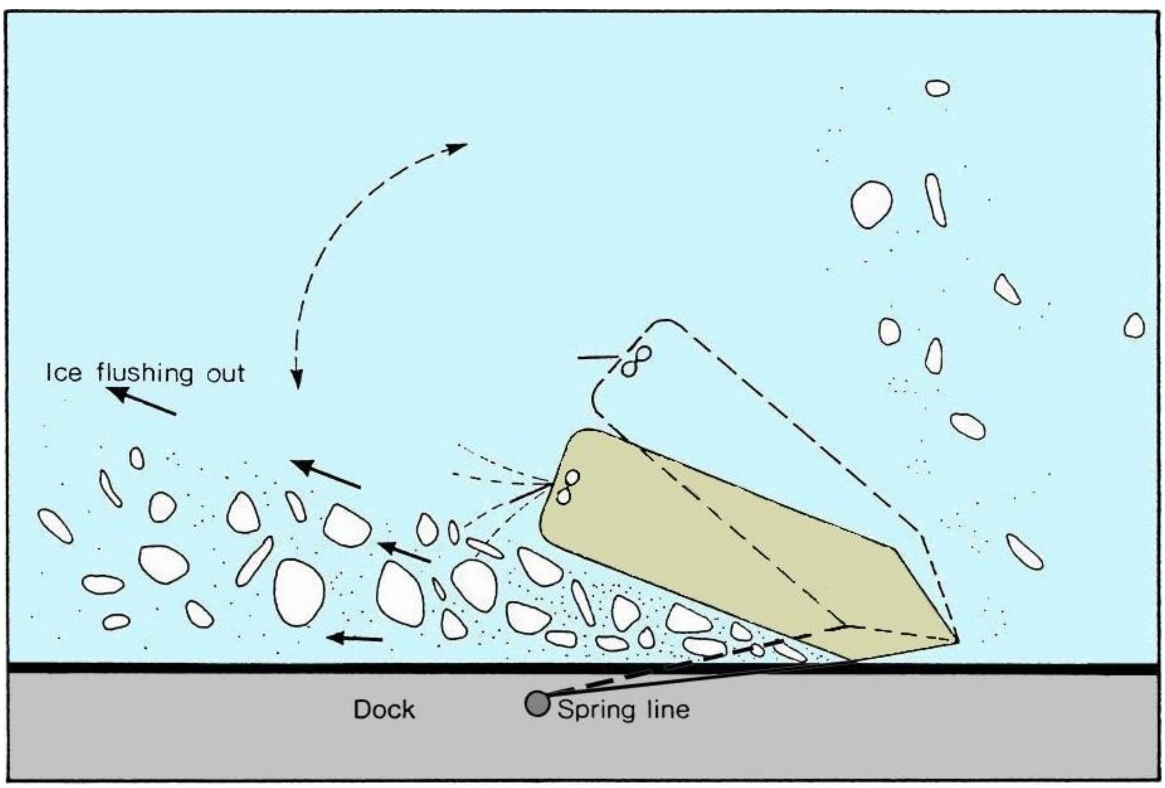


Figure 54 - Berthing: Flushing out ice with wash while bow is fixed with a spring line (Courtesy of Capt. George Q. Parnell "Ice Seamanship")

Once the vessel is secured, all efforts must be made to keep the vessel alongside and not to allow ice to force its way between the vessel and the dock. If the dock is in a river or in a strong tidal area there is nothing that will keep the vessel alongside if the ice is moving. The prudent thing to do is to move the vessel off the dock before the situation deteriorates. The ice conditions can change quickly when alongside a wharf and, for this reason, it is desirable to keep the engine(s) on standby at all times.

Warning: Keep the engine(s) on standby at river berths or strong tidal areas where ice is in motion

4.8.4 Towing in ice

Towing in ice on a long wire is possible, although the strain on the tow line is much greater than in an open water tow as the tug or icebreaker is subject to the sudden acceleration/deceleration of icebreaking. The situation can be alleviated somewhat if there is an icebreaker making a track ahead of the towing icebreaker. The CCG does not usually engage in towing operations except in emergency situations. There is a long tradition of this sort of work in the Baltic, though, where icebreakers are specially designed with a notch in the stern and heavy winches and cables to enable the bow of the towed vessel to be brought up against the stern of the icebreaker and secured. This towing method is known as close coupled towing and is considered an efficient method of towing in uniform ice conditions.

Warning: Close-coupled towing techniques which are commonly used by European icebreakers in the Baltic Sea and in Russian waters of the Northern Sea Route, are not commonly used in Canadian waters

Towing in ice was common in the 1970s and early 1980s in the Beaufort Sea, by anchor-handling supply boats or icebreakers when repositioning drill vessels and platforms. Experience has shown that towing in ice requires specialized skills in towing and ice navigation, coupled with appropriate purpose-designed equipment. The towing equipment must be robust and must allow frequent changes in towline length. The use of shock-absorbing springs or heavy surge chains is recommended. Bridle arrangements must optimise manoeuvrability to allow the towing vessel and tow to be navigated around heavy ridges and ice floes.

It is the recommended practice that the connection between vessels should incorporate a weak link, usually a lighter pendant, which will fail before the tow-line or bridle. In difficult ice conditions the towline should be kept as short as possible to avoid having the towing-wire pass under the ice floes, due to the weight of the wire and the catenary formed by a longer line. In freeing a beset tow, the towing vessel can shorten the tow-line to provide some propeller wash to lubricate the tow, but care must be exercised to avoid damaging the tow with heavy ice wash. Towing in ice is a special application not to be undertaken without the benefit of training and experience.

4.8.5 Speed

In all attempts at manoeuvring or avoiding ice, it must be remembered that the force of impact varies as the square of the speed. Thus, if the speed of the vessel is increased from 8 to 12 knots, the force of impact with any piece of ice has been more than doubled. Nevertheless, **it is most important when manoeuvring in ice to keep moving**. The prudent speed in a given ice condition is a result of the visibility, the ice type and concentration, the ice class, and the manoeuvring characteristics of the vessel (how fast it can be stopped).

4.8.6 Ice management

In situations where an icebreaker is used to prevent ice from colliding with fixed structures, such as drilling platforms, the technique of ice management comes into force. The icebreaking and offshore supply fleet in the Canadian and U.S. Arctic has been involved with work to support drilling operations. Icebreakers either try to break up drifting ice before it arrives at the structure or to push and divert the dangerous floes out of the way so that they by-pass the structure. In ice management, obtaining information about the present and predicted ice conditions is very important, to ascertain the best deployment of the icebreakers.

4.9 Close-range ice hazard detection

Although a careful lookout will help the vessel avoid large ice hazards (such as icebergs), there is still a need for the close-range detection of ice hazards, such as small icebergs and old ice floes. Close-range ice navigation is an interactive process, which does not lend itself to traditional passage planning techniques.

Two groups of equipment aid in close-range hazard detection: visual (searchlights and binoculars) and radar (both X- and S-band marine radars and the newer enhanced ice radar systems).

4.9.1 Use of radar for ice detection

Radar can be a great asset in ice navigation during periods of limited visibility, but only if the display is properly interpreted. Ice makes a poor radar target beyond 3 to 4 nautical miles and the best working scale is in the 2 to 3 nautical mile range. Radar signal returns from all forms of ice (even icebergs) are much lower than from vessel targets, because of the lower reflectivity of radar energy from ice, and especially snow, than from steel. Detection of ice targets with low or smooth profiles is even more difficult on the radar screen, although the radar information may be the deciding factor when attempting to identify the location of these targets under poor conditions, such as in high seas, fog, or in heavy snow return. For example, in close ice conditions the poor reflectivity and smooth surface of a floe may appear on the radar as a patch of open water, or signal returns from sea birds in a calm sea can give the appearance of ice floes. In an ice field, the edge of a smooth floe is prominent, whereas the edge of an area of open water is not. The navigator must be careful not to become over-confident in such conditions.

In strong winds the wave clutter in an area of open water will be distributed uniformly across the surface of the water, except for the calm area at the leeward edge.

Ice within 1 mile of, and attached to, the shore may appear on the radar display as part of the land itself. The operator should be able to differentiate between the 2 if the receiver gain is reduced. Mariners are advised not to rely solely on radar for the detection of icebergs because they may not appear as clearly defined targets. In particular, mariners should exercise prudence when navigating in the vicinity of ice or icebergs. The absence of sea clutter also may indicate that ice is present. Although ridges may show up well on the radar display, it is difficult to differentiate between ridges, closed tracks of vessels and rafted ice, as all have a similar appearance on radar.

The effectiveness of marine radar systems will vary with power and wavelength. The optimum settings for the radar will be different for navigating in ice than for open water. As the radar reflectivity of ice is much lower than for vessels or land, the gain will have to be adjusted to detect ice properly. Generally, high-power radars are preferred and it has been found that radars with 50 kW output provide much better ice detection capability than 25 kW radars. Similarly, 3-centimetre radars (x-band) provide better ice detail while 10-centimetre radars (s-band) show the presence of ice and ridging at a greater distance - it is therefore recommended that both wavelengths be used.

Warning: Marine radar provides an important tool for the detection of sea ice and icebergs. However, do not rely solely on your radar in poor visibility as it is not certain that radar will detect all types and sizes of ice and it will not differentiate old ice from first year ice.

4.9.2 Ice navigation radars

Conventional marine radars are designed for target detection and avoidance. Enhanced marine radars provide a higher definition image of the ice that the vessel is transiting through and may help the user to identify certain ice features. There are various shipboard marine radar systems enhanced and optimized for ice navigation. Figures 55 to 58 compare images from a conventional x-band radar and an enhanced x-band ice navigation radar used on board a CCG icebreaker. In the ice navigation radar, the analog signal from the x-band radar (azimuth, video, trigger) is converted by a modular radar interface and displayed as a 12-bit digital video image (1024x1024).

In the enhanced marine radar, the coastline is more clearly defined; icebergs are visible at greater distances, as are the smaller bergy bits and growlers. In the standard radar, sea clutter affects the ability to see smaller targets near the vessel. X-band radars will produce clearer images of the ice at short ranges, such as under 4 nautical miles, when set to a short pulse. The shapes of ice floes, the ridges and rafted ice and open water leads are also more distinct in an ice navigation radar, particularly when using the short radar pulse length.

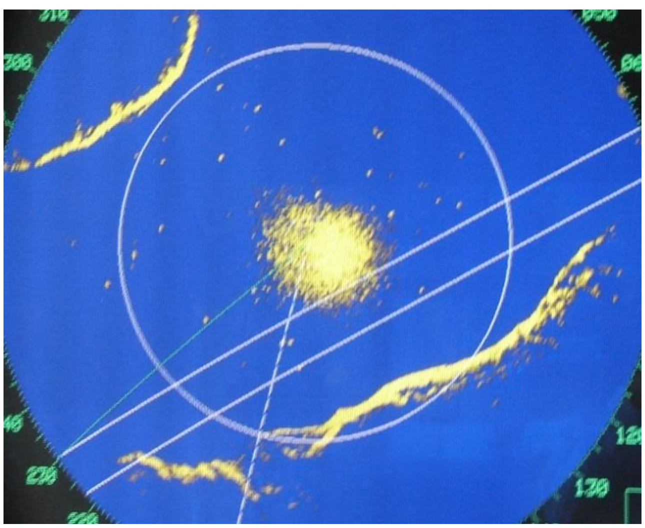


Figure 55 - Standard X-band Radar Image[10]

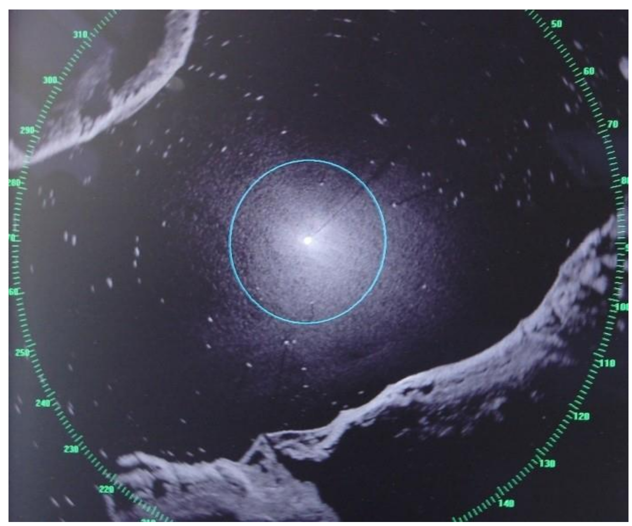


Figure 56 - Enhanced X-band Radar Image[10]

[10] Source: CCG

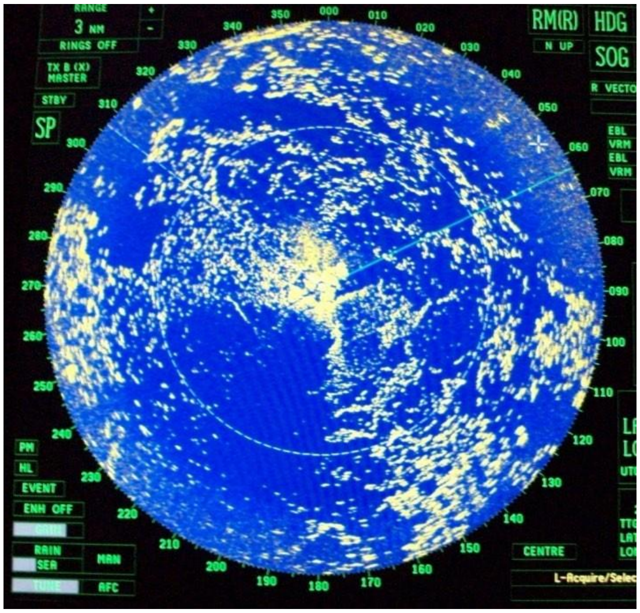


Figure 57 - Standard X-band Radar Image[11]

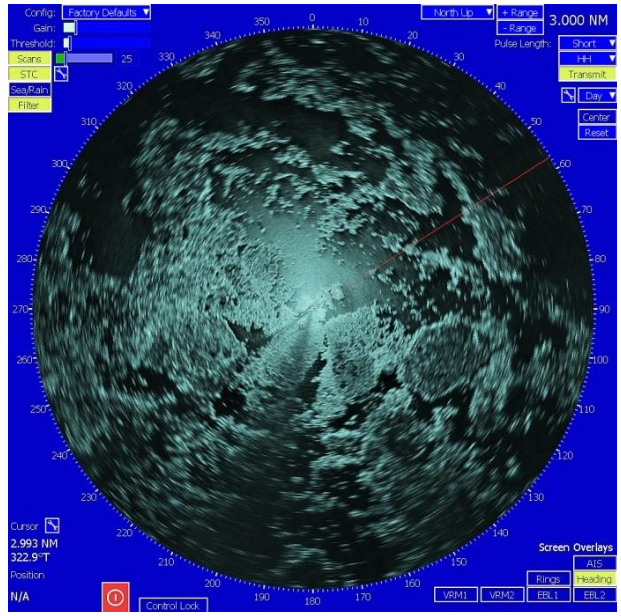


Figure 58 - Enhanced X-band Radar Image[11]

Experiments with cross-polarized radar have demonstrated that it is possible to enhance radar displays for better detection of old and glacier ice. Advances are also being made in shipboard systems which use passive microwave radiometers to measure the natural emissivity of the ice (the relative ability of its surface to emit energy by radiation), producing radar-like displays which may be colour-enhanced to distinguish between open water and various ice types.

4.9.3 Iceberg detection

Icebergs normally have a high freeboard and, as such, they are easy to detect visually (in clear conditions) and by vessel's radar. In poor to no visibility, radar must be relied upon. The radar return from an iceberg with low freeboard, smooth surface, or deep snow cover is less obvious, particularly if surrounded by bright returns from sea or ice clutter. Depending upon their size, aspect and attitude, icebergs may be detected at ranges between 4 and 15 nautical miles or even further for very large high profile icebergs, detection ranges diminishing in fog, rain, and other conditions affecting the attenuation of radar return. Icebergs may not appear as clearly defined targets but the sector of the radar display directly behind the iceberg may be free of clutter. Iceberg radar targets will sometimes cause a “radar shadow” on the far side, in which other targets will not show. It is sometimes possible to identify an iceberg target lost in the clutter by this shadow extending away from the observer. A large iceberg with a long and gently sloping aspect may not provide enough reflective surfaces to show at all on radar, so it should never be assumed that just because there are no targets in view there are no icebergs around.

Warning: Do not rely solely on marine radar to detect ice, particularly glacial ice.

Observation will reveal the shadow to increase in size on approach to the iceberg, and to swing around as the angle between the vessel and the iceberg changes. However, care

[11] Source: CCG

should be taken in using this technique as the returns from pack ice can obscure the return from the iceberg.

As the vessel gets closer to the iceberg, the size of the radar target reduces and may in fact disappear when very close to the iceberg, in which case only the shadow will remain to warn of the iceberg's presence. For this reason it is important to plot any iceberg (which has not been sighted visually) that the vessel may be approaching, until the point of nearest approach has passed.

4.9.4 Bergy bit and growler detection

From time to time pieces of ice break off, or calve, from an iceberg. The larger pieces are known as bergy bits, and the smaller pieces are known as growlers. Whereas the iceberg moves in a direction that is primarily the result of current because of its large keel area, the growlers and bergy bits are primarily wind driven, and will stream to leeward of the iceberg (figure 58). While this is the general case, the effects of strong tidal currents may alter this pattern. However, for reason of the wind influence on bergy bits and growlers it is advisable, if possible, to move to windward of icebergs to avoid bergy bits and growlers.

Passing distance from the iceberg is a function of the circumstances, but always bear in mind that:

a) the closer the vessel passes the more likely the encounter with bergy bits, and
b) a very close pass should be avoided because the underwater portion of the iceberg can protrude some distance away from the visible edge of the iceberg at the sea surface.

4.9.4.1 Bergy Bits detection

The visual sighting of bergy bits depends on good visibility, and surrounding conditions of low sea state or fairly smooth sea ice. In windy conditions, the presence of bergy bits can be indicated by spray flung upwards by the waves striking the ice, while the ice itself remains invisible as the waves break over it. The differentiation of bergy bits (in waters where they are present) from open water or from a smooth first-year ice cover is relatively easy with radar, if the height of the bergy bit is sufficient for its return to be distinguished from the ice or water returns. The radar display should be checked carefully for radar shadows which may identify bergy bits with less height differential, or when the ice or water background is more cluttered.

Detection of bergy bits by radar is difficult in pack ice, especially if there is any rafting, ridging, or hummocks which cause backscatter and also may produce shadows that can obscure a bergy bit. Detection is particularly difficult if the surroundings are open pack ice, because radar shadows behind low bergy bits are small and are difficult to discriminate from the dark returns of open water between ice floes. As with icebergs, bergy bits should be avoided, but passing distances can be relatively closer, because the underwater portion of bergy bits is unlikely to extend as far to the side as for icebergs.

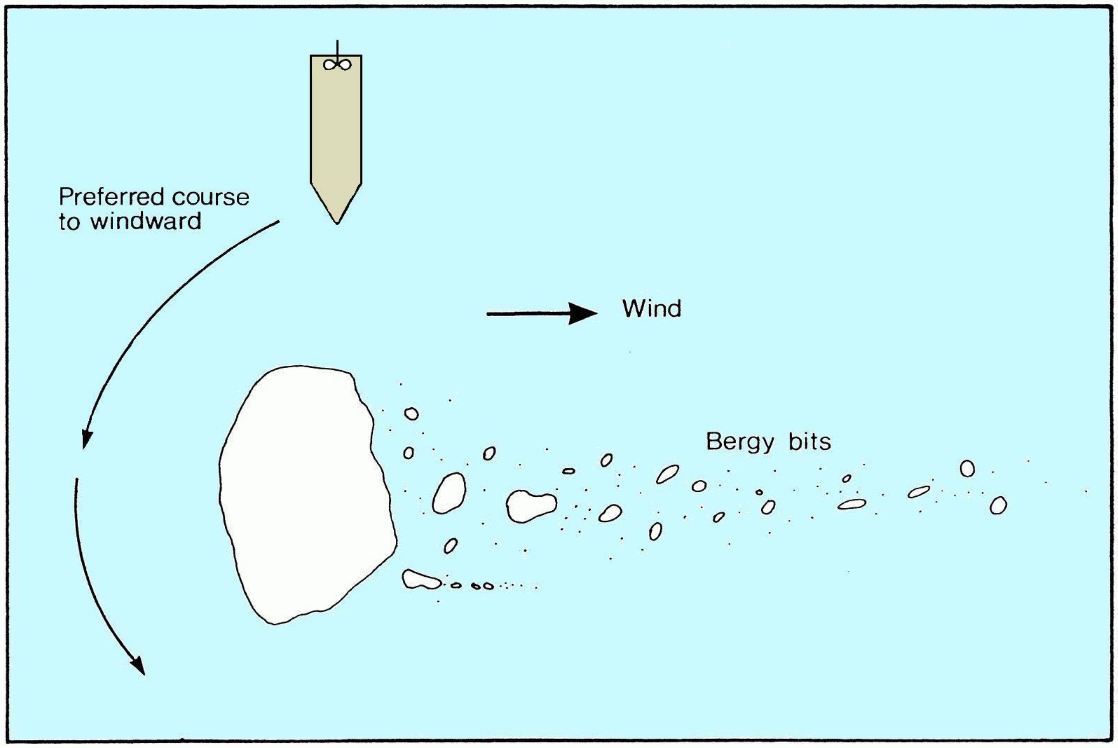


Figure 59 - Navigating around an iceberg and bergy bits (Courtesy of Capt. George Q. Parnell "Ice Seamanship")

4.9.4.2 Growler detection

Growlers, because of their low freeboard and smooth relief, are the most difficult form of glacial ice to detect (both visually and on radar) and, therefore, are the most hazardous form of ice. Very little of a growler appears above the water surface because of the low freeboard of the ice and waves may completely cover it. Unless recently calved, water erosion will have made the surface of a growler very smooth, making it a poor radar target. In open or bergy water with good weather conditions visual detection of growlers is possible at 2 or 3 nautical miles from the vessel. In rough weather and heavy swells, a growler may remain submerged through the passage of 2 or more swells passing over it, making detection by any method even more difficult. Detection (on radar or visually) can be as little as 0.5 nautical miles from the vessel, if at all. It is important to keep a constant check on radar settings, particularly the tuning control (on manually tuned radars), to ensure that the radar is operating at maximum efficiency. Varying the settings can be useful, but care must be taken to ensure that the radar is retuned after any adjustment. It sometimes helps to sight a growler visually then tune the radar for maximum return.

Warning: Growlers are almost impossible to detect by radar. They pose an immense threat to vessels. Constant visual and radar monitoring must be maintained in any area where growlers are expected.

For a growler in an ice cover, it may be possible to detect it visually in clear conditions (because it is often transparent, green, or dark in appearance), but it is often not possible to discriminate it from surrounding ice clutter on marine radar. As the exact location of each growler cannot be identified for certain amongst ice floes, care must be taken to determine a safe speed through the ice-covered area when navigating by radar.

4.9.5 Old ice floes

Detection of old ice floes is primarily visual, because differentiation between first-year and old ice on marine radar is not possible. Travel through old ice can be reduced by using ice analysis charts to avoid areas of high concentrations of old-ice. However, mariners must watch for old ice even in areas where it is not identified on ice charts. Visual identification is possible up to 1 to 2 nautical miles from the vessel in good weather. Old ice can be distinguished from first-year ice by more rounded and weathered surface, light blue colour, higher freeboard, and a well-defined system of melt-water channels. Old ice is widely encountered in the Canadian Arctic, Baffin Bay, Davis and Hudson Straits, as well as the Foxe Basin, and is occasionally found in the Labrador Sea, off the north east coast of Newfoundland and on the Grand Banks. It is not a hazard in Cabot Strait, Gulf of St. Lawrence, Great Lakes, or the St. Lawrence River.

4.9.6 Visibility

Operating in restricted visibility is inevitable in, or near, ice-covered waters, either because of precipitation, fog or darkness. Travel through ice may, however, continue at night or in fog, which is common in the Arctic during the open water period, and visibility is often reduced by blowing snow in the Gulf of St. Lawrence during the winter.

All possible effort must be made to minimize the chances of collision with ice in poor visibility and the requirements of the regulation for preventing collisions at sea also apply. These efforts should include:

- maintenance of a **constant** visual and radar lookout
- use of searchlights at night (which may be counter-productive in fog or precipitation through reflected glare)
- reduction of speed before entering any ice field in poor visibility and not increasing speed before the threat has been determined
- reduction of speed in **any ice situation** where the ratio of glacial and old ice to first-year ice indicates a significant increase in the chance of collision with hazardous ice
- location of icebergs, bergy bits, and growlers on marine radar before they are obscured by sea or ice clutter, and tracking of these targets on Automatic Radar Plotting Aid (ARPA)
- switching between ranges to optimize the radar for iceberg detection when navigating in pack ice
- use of radar to detect icebergs and bergy bits by observing their radar shadows in mixed ice cover, and
- recognition of the difficulty of detecting glacial and old ice in open pack ice with marine radar when little or no radar shadow is recognizable

Many escorts occur in fog, when the escorted vessel must follow the icebreaker and maintain the required distance by radar. If the icebreaker suddenly slows or its position is lost on the radar screen, a collision may occur. It is important in these situations to maintain VHF radio contact and constant monitoring of the radar distance between vessels.

Figure 60 - The use of searchlights when transiting ice at night is essential (CCG)

4.10 Passage planning

The purpose of this section is to provide guidance in the procedures to be followed in the acquisition and use of information for planning passages in or near ice. Nothing in the instructions given here, or the processes that follow, either supersedes the authority of the mariner or relieves the officer of the watch from their normal responsibilities and from following the principles of good seamanship.

Passage planning for routes in ice-covered waters is based on standard navigational principles for passage planning (International Maritime Organization Resolution A. 893(21) adopted on 25 November 1999, *Guidelines For Voyage Planning*). The presence of sea ice along the planned route adds importance to the traditional practice of passage planning, necessitating the continual review of the entire process throughout the voyage. Passenger ships can also follow the Guidelines on Voyage Planning for Passenger Ships Operating in Remote Areas available on IMO A 2007-09.

Passage planning takes place in 2 phases:

a) Strategic - when in port or in open water
b) Tactical - when near or in ice-covered waters

Both strategic and tactical planning involve 4 stages:

a) appraisal
b) planning
c) execution

d) monitoring

The strategic phase may be considered small-scale (large area) and the assumption is that the vessel would be outside ice-covered waters, and days or weeks from encountering ice. The strategic phase may be revised several times before the tactical phase is commenced. The tactical phase may be considered large scale (small area) and is constantly being revised as the voyage unfolds.

Passage planning for open water is a fixed process in which most, if not all, the information is gathered before the vessel leaves the dock. The localised nature of some of the information for Arctic passage planning in ice means that information may become available only as the vessel moves into Canadian waters. The amount and extent of information is a function of the voyage type, so the more difficult voyages, such as early or late season, are supported with more resources, such as icebreakers, more frequent reporting of current ice conditions, and the appropriate ice forecasts. Passage planning in ice-covered waters, especially in the Arctic, is an evolving process that demands a flexible approach to the planning and execution.

Bridge manning

It is recommended that, because of the hazards of navigating in ice-covered waters, lookouts should be increased when in or near an area of ice. Navigation in ice can be very strenuous and Mariners should be careful not to overextend themselves, even if it means doubling the Officers of the Watch on the bridge or stopping the vessel at night to receive adequate rest. This applies not only for those on the bridge, but for engine-room staff who may be called upon for long periods of manoeuvring, clearing suctions, etc.

4.10.1 Strategic phase

4.10.1.1 Appraisal stage

This procedure involves the use of all information sources used in open water passage planning, plus any others that can be obtained to give the most complete picture of the ice conditions possible. Check to determine the availability of CIS ice information from CCG MCTS, CIS, CCG MARINFO Icebreaking and Web Cameras and from the Internet web sites where ice information is freely available.

4.10.1.2 Planning stage

Strategic planning is a forward-looking exercise to assess the ice conditions that the vessel is likely to encounter along the length of its planned route. Strategic planning relies on weather forecasts and available publications on the ice climatology of the region to be encountered in addition to standard nautical publications. This exercise may be planned over a period of hours, days, or even months depending on the route, destination and the nature of the ice environment to be encountered.

Note: For vessels that are not ice-strengthened and will be following ice instructions from the CCG Ice Operations Centre, the work at this point is the same as for a conventional voyage.

The Mariner will develop a route to the destination based on the information obtained in the appraisal stage, and have this laid off on the appropriate charts. The principles involved will be the same as in open water passage planning. The plan should be developed with the following limitations of the elements of the Ice Navigation system in mind:

- availability of ice information

- diminished effectiveness of visual detection of ice hazards in late season or winter voyages
- increased difficulty of detecting ice hazards in combined conditions of open ice and reduced visibility

Additional information to be marked on the chart could include:

- the anticipated ice edge, areas of close pack ice and the fast ice edge
- any areas of open water where significant pack ice may be expected, such as east Greenland ice in the vicinity of southern Greenland
- safe clearance off areas known to have significant concentrations of icebergs, such as off Cape Farvel and Disko Island in Greenland
- any environmentally sensitive areas where there are limitations as to course, speed, or on-ice activities. For example, ice fishing in St. Lawrence and Saguenay Rivers or traditional Inuit winter ice roads in the Arctic

4.10.1.3 Execution stage

Once the planning of the passage has been completed, the tactics for its execution can be decided upon. The estimated time of arrival for the destination can be developed based on the ice conditions expected along the route. Take into account any expected reductions in speed or large deviations in course for reduced visibility, passages in consolidated ice, areas of higher concentrations of old ice, and delays in waiting for information. The point at which it is considered necessary to ballast down to ice draft and to reduce speed should also be considered.

Consider when extra lookouts will be required or when watches are likely to be doubled for entering ice or approaching areas of low visibility or high numbers of icebergs / bergy bits / growlers.

4.10.1.4 Monitoring stage

Monitoring of the route should continue until the ice-covered areas are reached. As the vessel approaches ice-covered waters, the quality and quantity of ice information improves (with CIS ice analyses and forecasts), which increases the accuracy of estimates for times of arrival and may perhaps indicate a change in route.

The strategic evaluation may be redone, once or several times, on approach to the ice, depending on the amount of new information received.

Note: All vessels should monitor the updated routing instructions from the CCG Ice Operations centres.

4.10.2 Tactical phase

If no detailed ice information is available before reaching the ice-covered area, the vessel may be limited to the strategically planned route rather than a tactical one. All efforts should be made to obtain detailed information on ice conditions, particularly when consolidated ice is likely to be encountered, where high concentrations of old ice are expected or in highly mobile ice.

4.10.2.1 Appraisal stage

The gathering of tactical information is based mainly (but not exclusively) on the acquisition of CIS ice observation and analysis charts. The reception of these charts depends on the vessel being fitted with a facsimile machine capable of being tuned to the required frequencies. Additional inputs consist of marine radar (X and S-bands), visual observations, and processed radar imagery. Ice charts can be downloaded from the CIS web site on the Internet where satellite telephone contact is available. Helicopter (visual) reconnaissance can also be valuable where available.

4.10.2.2 Planning stage

Planning may be as for open water on large-scale charts, but also, if further information has been obtained, this may involve a track planned on a small-scale chart. Planning with additional information entails laying off the route to take the best advantage of optimum ice conditions, including:

- finding open water leads
- finding first-year ice leads in close ice or old ice fields
- avoiding areas of ridging
- avoiding areas of pressure or potential pressure

Once the track has been laid out, it has to be transferred to large-scale charts and checked for adequate water depth. The 2 sources have to be reconciled so that the best route is also a safe route. Once the route has been laid out it may indicate the need for further information.

4.10.2.3 Execution stage

Once the route has been determined, estimated times of arrival can be revised. Any change in weather conditions, particularly visibility or wind direction and speed, should be considered before executing the plan, as they are important for estimating pressure areas or where open water leads may be located.

4.10.2.4 Monitoring stage

Progress should be monitored on the chart by conventional means and ice navigation can continue.

4.11 High latitude navigation

Navigating in high latitudes requires great care in the procedures and in the use of information. The remoteness of the Arctic and the proximity to the North Magnetic Pole has an effect on the charts that are supplied and the navigation instruments that are used with them. This section discusses some of the effects and limitations on charts and instruments used in the Arctic.

4.11.1 Navigational appliances

The equipment requirements for vessels navigating north of 60° North latitude in Canadian waters in a shipping safety control zone, are contained in the *Navigation Safety Regulations, 2020*. In brief the following are required:

- 2 radars
- 2 Gyro compasses
- 2 echo sounders, each with an independent transducer
- 2 searchlights with 2 spare lamps;
- a weather facsimile receiver
- a spare antenna

4.11.2 Canadian Hydrographic Service navigational charts and publications

With respect to the Arctic, due to a lack of modern hydrographic surveys, the quality of charts, including paper charts, electronic navigational charts (ENC) and Raster Navigational Charts (RNC) can be poor. Many charts contain areas that are inadequately surveyed, or are based on old surveys where only spot soundings were collected, or where data was collected only along a single track. Mariners must be aware of these limitations.

There are 2 areas of concern regarding the use of charts in the Arctic. These are consideration of the different projections used versus southern waters and the accuracy of the surveys. While up-to-date charts and nautical publications are always critical to safe navigation, the Arctic requires a special understanding and the mariner should use all sources of updates, including Notices to Mariners and broadcast NAVWARN, to be sure paper charts, electronic charts and nautical publications are up to date. The CHS provides a monthly on-line updating service for ENCs and RNCs.

4.11.2.1 Projections

To compensate for the fact that the meridians converge as they near the pole the scale of the parallels is gradually distorted. In the Arctic, Mercator projections suffer too much distortion in latitude to be used for anything but large scale charts. As the latitude increases, the use of rhumb lines for visual bearings becomes awkward, as it is necessary to add ever-larger convergence corrections.

In the Arctic, the common projections are Lambert Conformal Conic, Polyconic, and Polar Stereographic. Polar Stereographic is popular as it provides minimum distortion over relatively large areas. Roughly 30%of CHS paper navigational charts in the north use one of these projections. The number of different projections makes it important, when changing charts, to check the type of projection and any cautions concerning distances, bearings, etc. For example, the habit developed with Mercator charts is to use the latitude scale for distance, which is not possible on Polyconic charts. Particular care must also be taken when laying off bearings in high latitudes, as a convergence correction may be needed even for visual bearings. To eliminate the corrections required by the use of compass bearings for fixing positions, three radar ranges of known features can provide an accurate position.

Warning: In the arctic, as in any other area, check the chart projection before use. Be aware of different projections within the same chart.

4.11.2.2 Accuracy

The accuracy of charts in the Arctic can vary widely according to the date of survey and the survey technologies available at that time. The more frequently travelled areas, such as Lancaster Sound, Barrow Strait, and the approaches to Nanisivik, are reasonably well surveyed, but many charts are based on aerial photography (controlled by ground triangulation) combined with lines of reconnaissance soundings or spot soundings gathered as helicopters land at many discrete locations. As of March 2021, the combined modern and adequate bathymetric coverage within Canada's Arctic NORDREG Area is 15% while the same coverage in the Primary and Secondary Low-Impact Shipping Corridors is 40%. The CHS has acquired continuous bottom profiles and has recorded survey vessel positions using modern radio- or satellite-positioning systems, and meet present-day international hydrographic standards for surveying, including having conducted detailed examinations where the data indicated possible shoaling of the bottom. In general, the more recent the survey, the more reliable and accurate the results. The very latest surveys frequently, but not always, consist of 100% bottom insonification using multi-beam sonar, sweep multi-transducer systems, and airborne laser bathymetry systems.

Even new editions of charts may contain a mix of older and newer data. The appearance of depth contour lines on new charts does not necessarily indicate any new information.

Precautions to be taken when using navigational charts for Arctic areas include:

- checking the projection and understanding its limitations
- checking the date of the hydrographic survey and reviewing the Source Classification Diagram
- using range and bearing to transfer positions from chart to chart
- checking for evidence of reconnaissance soundings
- using the largest scale chart available
- checking for the method of measuring distances and taking bearings
- updating charts and nautical publications by checking for Notices to Mariners, NAVWARN and any other sources for chart corrections.

It is important to note that raster charts are electronic copies of the paper charts, and there is normally no increase in accuracy simply because a charts is digital. Most S-57 ENCs and BSB RNCs are based on the paper chart; however, in the Arctic there are some S-57 ENCs that do not have a paper chart equivalent and may be based on modern surveys. It is important to examine the meta-data in the electronic chart display to assess this information. For more details and the latest information on the status of Arctic charts please visit the CHS Website.

4.11.3 Chart horizontal datum

One of the principal problems with charts in the Arctic concerns the horizontal datum on which the chart is based. With more and more vessels using accurate positioning systems such as the global positioning system (GPS) or the Russian global navigation satellite system (GLONASS), the greater the problem will become. Regarding GPS, the positions are referenced to the World Geodetic System (WGS) which is virtually equivalent to the North American Datum (NAD). If navigating on a NAD paper chart with GPS there would be no corrections to apply. If plotting on a NAD paper chart the appropriate corrections must be manually applied. Digital charts (raster or vector) issued by the Canadian Hydrographic Service are always on NAD.

Mariners should always cross-reference positions plotted on electronic charts with the largest possible scale paper charts of the same area, as different electronic chart systems available on the market may vary greatly in the information presented on the electronic display. There can be instances where the vessel is plotted on a paper chart as being afloat in deep water, and yet is shown to be ashore on an electronic display. Conversely, a GPS position, when plotted by latitude and longitude on a paper chart, may indicate that the vessel is on the shore when 3 radar ranges from the shoreline indicate that the vessel is safely afloat.

Note: The value of a chart depends to a great extent on the accuracy and detail of the surveys on which it was based.

Mariners should proceed with due caution and prudent seamanship when navigating in the Arctic especially in poorly charted areas or when planning voyages along new routes. Additional information may be found in the Notices to Mariners, NAVWARN , Notices to Mariners Annual Edition as well as Sailing Directions.

4.11.4 Compasses

The magnetic compass can be erratic in the Arctic and is frequently of little use for navigation.

Note: The magnetic compass depends on its directive force upon the horizontal component of the magnetic field of the earth. As the north magnetic pole is approached in the Arctic, the horizontal component becomes progressively weaker until at some point the magnetic compass becomes useless as a direction measuring device.

If the compass must be used the error should be checked frequently by celestial observation and, as the rate of change of variation increases as the pole is approached, reference must be made to the variation curve or rose on the chart. In high latitudes, generally above 70°N in the Canadian Arctic, the magnetic compass will not settle unless the vessel remains on the same heading for a prolonged period, so it can be considered almost useless anywhere north of Lancaster Sound.

The **gyro compass** is as reliable in the Arctic as it is in more southerly latitudes, to a latitude of about 70°N. For navigation north of 70°N special care must be taken in checking its accuracy. Even with the compensation given by the latitude corrector on certain makes of compass, the gyro continues to lose horizontal force until, north of about 85°N, it becomes unusable. The manual for the gyro compass should be consulted before entering higher latitudes. The numerous alterations in course and speed and collisions with ice can have an adverse effect on its accuracy. Therefore, when navigating in the Arctic:

- the ship's position should be cross-checked with other navigation systems, such as electronic position fixing devices, where course history could be compared with course steered (allowing for wind and current)
- the gyro error should be checked whenever atmospheric conditions allow, by azimuth or amplitude
- in very high latitudes approaching the North Pole, the most accurate alternative to the gyro compass for steering is the GPS, which, if working as it should, can also be used as a check on “course-made-good” over the ground

4.11.5 Soundings

When in areas of old or sparse hydrographic survey data, the echo sounder should be run so as to record any rocks or shoals previously undetected, although it is doubtful that the sounder would give sufficient warning to prevent the vessel going aground. Even in areas of the high Arctic that are well surveyed, the echo-sounder should be run, as vessel traffic in the area is sparse and many of the routes will not have been sailed previously by deep-draft vessels.

Many of the navigational charts in the Arctic consist largely of reconnaissance soundings (not done as part of a survey). As a result, it is not likely that a line of soundings would be of much use in finding a position. Additionally, false echoes may be given by ice passing underneath the echo sounder or by the wash when backing or ramming in ice. In heavy concentrations of ice cover, the echo sounder may record multiple returns so that it is impossible to distinguish which one represents the actual depth beneath the keel. When soundings are lost in this manner, it may help to stop the vessel in the ice until a stable echo can be discerned amongst the random spurious echoes.

4.11.6 Position fixing

Problems encountered with position fixing arise from either mistaken identification of shore features or inaccurate surveys. Low relief in some parts of the Arctic makes it hard to identify landmarks or points of land. Additionally, ice piled up on the shore or fast ice may obscure the coastline. For this reason radar bearings or ranges should be treated with more caution than measurements in southern waters. Visual observations are always preferable. Sometimes it is possible to fix the position of grounded icebergs and then to use the iceberg for positioning further along the track, if performed with caution.

Large areas of the Arctic have not yet been surveyed to the same standards as areas further south, and even some of the more recently produced charts are based on reconnaissance data. To decrease the possibility of errors, 3 lines (range, or less preferably bearings) should always be used for positions. Fixes using both sides of a channel or lines from 2 different survey areas should be avoided. Because of potential problems, fixes in the Arctic should always be compared with other information sources, such as electronic positioning systems. Reliance on one information source should be avoided.

4.11.7 Use of radar for navigation in arctic waters

In general, Arctic or cold conditions do not affect the performance of radar systems. Occasionally weather conditions may cause ducting, which is the bending of the radar beam because of a decline in moisture content in the atmosphere. This effect may shorten or lengthen target detection ranges, depending on the severity and direction of the bending. A real problem with radar in the Arctic concerns interpretation of the screen for purposes of position fixing.

The Automatic Identification System (AIS) has now become mandatory for most large vessels likely to be encountered in Canadian waters and is a useful tool to separate echoes of vessels from icebergs on a radar display. It is also very useful to be able to identify a nearby but unseen vessel when working in ice, for the trading of ice information, details of progress and so on by voice radio or satellite communication (e-mail).

Fixing solely by a radar range and bearing, from a point of land or by the use of radar or gyro bearings, is not recommended. Fixing by 2 or more radar ranges is the best method in Arctic waters, but care is required in the correct selection and identification of prominent features on the radar screen. The following difficulties, peculiar to radar fixing in the Arctic, may be encountered:

a) Difficulty in determining where the ice ends and the shore-line begins. A reduction in receiver gain should reduce the ice return.
b) Disagreement between ranges, caused by ranging errors or chart inaccuracies. The navigator should attempt to range on the nearest land and should not range on both sides of a channel or long inlet.
c) Uncertainty as to the height and, therefore, the detection range of land masses because of a lack of topographical information on the chart.
d) Lack of fixing aids in the area and sparse, dated or non-existent hydrographic surveys.

4.11.8 Global positioning system

The GPS, is a space-based radio-navigation system that permits users with suitable receivers, on land, sea or in the air, to establish their position, speed and time at any time of the day or night, in any weather conditions.

The navigational system consists nominally of 32 operational satellites in 6 orbital planes, and an orbital radius of 26,560 kilometres (about 10,900 nautical miles above the earth). Of the 32 satellites, 31 are considered fully operable and the remaining three although functioning, deemed “spares”. The orbital planes are inclined at 55° to the plane of the equator and the orbital period is approximately 12 hours. This satellite constellation allows a receiver on earth to receive multiple signals from a number of satellites 24 hours a day. The satellites continuously transmit ranging signals, position and time data that is received and processed by GPS receivers to determine the user's three-dimensional position (latitude, longitude, and altitude), velocity and time.

Although the satellites orbit the earth in a 55° plane, the positional accuracy all over the globe is generally considered consistent at the 100-metre level. For a vessel at a position 55° north or south latitude or closer to the pole, the satellites would be in a constellation around the vessel with the receiver actually calculating the ship's Horizontal Dilution of Precision (HDOP) with satellites possibly on the other side of the pole. With a vessel at or near the North Pole all the satellites would be to the south, but well distributed in azimuth creating a strong fix. The exception to this is the vertical component of a position which will grow weaker the further north a vessels sails because above 55°N there will not be satellites orbiting directly overhead

There are a variety of sources of error which can introduce inaccuracies into GPS fixes especially in polar regions such as tropospheric delays and ionospheric refraction in the auroral zone. The troposphere varies in thickness from less than nine kilometers over the poles to over 16 kilometres on the equator which can contribute to propagation delays due to the signals being refracted be electromagnetic signal propagation. This error is minimized by accurate models and calculations performed within the GPS receiver itself. The ionospheric refraction in the auroral zone (the same belt in which the aurora borealis / aurora australis phenomena occur) caused by solar and geomagnetic storms will cause some error.

One minor advantage of the drier, polar environment is the efficiency of the receiver to process satellite data. In warmer, marine climatic conditions it is more difficult to model a wet atmosphere.

If the datum used by the GPS receiver in calculating latitude and longitude is different from the horizontal datum of the chart in use, errors will occur when GPS derived positions are plotted on the chart. GPS receivers can be programmed to output latitude and longitude based on a variety of stored datum sets.

Since 1986 the CHS has been converting CHS charts to NAD83. Electronic charts are typically on NAD83 however it is important to check the electronic chart meta-data to be certain. Information on the chart will describe the horizontal datum used for that chart and for those not referenced to NAD83, corrections will be given to convert NAD83 positions to the datum of the chart. The title block of the chart will describe the horizontal datum used for the chart and will give the corrections to convert from the datum of the chart to NAD83 and vice versa. A note of caution regarding raster charts: the title block, since it is an image taken from the paper chart, may indicate the chart is not on NAD83 however the Canadian Hydrographic Service issues all its raster charts on NAD83 therefore no correction is necessary.

4.11.9 Global navigation satellite system

The GLONASS is a radio-based satellite navigation system operated for the Russian government by the Russian Aerospace Defence Forces. It complements and provides an alternative to the United States GPS and is currently the only alternative navigational system in operation with global coverage and the same precision. The GLONASS constellation has 24 operational satellites to provide continuous navigation services worldwide, with 7 additional satellites for spares and maintenance.

4.11.10 Radios

Radio communications in the Arctic, other than line of sight, are subject to interference from ionospheric disturbances. Whenever communications are established alternative frequencies should be agreed upon before the signal degrades. Use of multiple frequencies and relays through other stations are the only methods of avoiding such interference.

4.11.11 INMARSAT

The International Mobile Satellite Organization (IMSO) owns and operates 3 global constellations of the Inmarsat 14 satellites flying in geosynchronous orbit 37,786 km (22,240 statute miles) above the Earth. Use of INMARSAT services in the Arctic is the same as in the south, until the vessel approaches the edge of the satellite reception at approximately 82°N. At high latitudes where the altitude of the satellite is only a few degrees above the horizon, signal strength is dependent on the height of the receiving dish and the surrounding land.

As the vessel leaves the satellite area of coverage the strength of the link with the satellite will become variable, gradually decline, and then become unusable. When the strength has diminished below that useable for voice communications, it may still be possible to send telexes. Upon the ship's return to the satellite area of coverage there may be problems in obtaining the satellite signal and keeping it until the elevation is well above the horizon.

4.11.12 Mobile Satellite (MSAT) / SkyTerra communications satellite system

MSAT-1 and MSAT-2 geostationary satellites have been delivering mobile satellite voice and data services to North America since 1995. The latest satellite, SkyTerra-1, was launched in orbit on November 14, 2010. The satellite phone network and local cellular networks are compatible, allowing a user to communicate over the regular cellular network, and only rely on the satellites in areas outside the range of cell phone towers. This is useful in sparsely populated areas where the construction of cell towers is not cost-effective, as well as to emergency-response services which must remain operational even when the local cellular network is out of service.

4.11.13 Iridium satellite system

The Iridium satellite constellation consists of 66 cross-linked low Earth orbit (LEO) satellites, plus spares, that orbit from pole to pole with an orbit of roughly 100 minutes. This design means that there is excellent satellite visibility and service coverage at the North and South poles.

4.12 Search and Rescue

The Canadian Armed Forces are responsible for coordinating search and rescue activities in Canada, including Arctic waters, and for providing dedicated SAR aircraft to aid in marine SAR incidents. A SAR service is defined as the performance of distress monitoring, communication, coordination, and SAR activities through the use of public and private resources. Any incident requiring assistance must be reported to an MCTS centre.

The CCG works with the Canadian Armed Forces to coordinate marine SAR activities within the Arctic. They search for and provide assistance to people, vessels, and other craft that are, or are believed to be, in imminent danger. They provide dedicated marine SAR vessels in strategic locations. There are no dedicated marine SAR units deployed in the Arctic waters on a year-round basis, however, CCG units deployed in the Arctic during the navigation season are designated for SAR activities as their secondary role. SAR aircraft are staged into the Arctic from more southerly bases in the event of a SAR incident, or may already be present on training missions.

Joint rescue coordination centres, covering all waters under Canadian jurisdiction, are staffed 24 hours a day by Canadian Armed Forces and CCG personnel. They are located in Victoria, British Columbia, Trenton, Ontario and Halifax, Nova Scotia. The joint rescue coordination centre (JRCC) in Trenton provides emergency response and alerting systems for SAR in the Great Lakes and Arctic regions.

Additional information on SAR services in Canadian waters can be found in the following publication, available from CCG:

- Annual Edition of Notices to Mariners, Section D

4.13 Reporting oil spills

Any incident involving the spillage of oil or petroleum lubricating products into the marine environment must be reported immediately to NORDREG CANADA. In addition, the operator should report the incident to the 24-hour Spill Report Centre.

Nunavut and Northwest Territories (Yellowknife)	(867) 920-8130
Yukon (Whitehorse)	(867) 667-7244
Canadian Coast Guard (Quebec City / Iqaluit) Toll free	1-800-265-0237 (24 hours)

For more information consult ECCC *Environmental emergency regulations: reporting a spill or release*.

4.14 Fuel and water

The ASSPPR requires all vessels operating in the NORDREG Zones to have sufficient fuel and water on board to complete their intended voyages and to leave all Zones. A vessel's capability of making its own fresh water will be taken into account in this regard. There are no refuelling or watering facilities in the Arctic unless the cruise operator makes special arrangements during the planning phase. Transport Canada will require an estimate of fuel consumption anticipated for the full voyage and NORDREG CANADA will need to be informed of the volume of fuel on board prior to the vessel entering the first Zone.

4.15 Environmental disturbances on ice transportation, birds, animals and fish

Environmental effects of a harmful nature are becoming an increasingly important concern in marine navigation. This concern applies to navigation in ice-covered waters where special navigational considerations may have a potential for environmental disturbance. While it is clear that accidents can have a detrimental effect on the environment, even normal marine operations have the potential to affect valued components of the environment. Valued components may include the following:

- rare or threatened species or habitats
- species or habitats which are unique to a given area

- species or habitats which are of value for aesthetic reasons
- species which may be used by local populations
- cultural and socio-economic practices of local populations

There are numerous potential effects that are not unique to ice environments; however, the presence of ice, cold temperature, and remote location, may enhance the level of disturbances over similar activities in milder environments.

Some specific environmental disturbances which are unique to ice-covered waters include the possible restriction of on-ice travel of local populations when a track is created in the ice, potential disruption of the formation or break-up process for local ice edges and, in the early spring, disruption of seal breeding on the ice.

Potential disturbances arising from normal operations are generally location specific. In most cases, avoiding sensitive areas and times of the year will mean that disturbances can be avoided. Adherence to navigation practises, as outlined in this manual, will minimize the risk of environmental disturbances from navigation in ice. Mariners should consider how their vessel might affect the environment and take measures to minimize the disturbance.

4.16 Ice information

To conduct a sea voyage safely and efficiently, a mariner must have a well-founded understanding of the operating environment. This is especially true for navigation in ice. It is the responsibility of all mariners to ensure that before entering ice-covered waters, adequate ice information is available to support the voyage from beginning to end.

The ways and means of acquiring ice information suitable for navigation vary from one source to another. Content and presentation formats also vary depending on the nature of the system used to acquire the raw data, and the degree of analysis or other form of enhancement which may be employed in generating the final product.

Many information sources are not normally or routinely available at sea, especially outside Canadian waters. In some cases prior arrangements may be necessary to receive particular products. The mariner is encouraged to consider carefully the required level of information, and to make appropriate arrangements for its delivery to the vessel.

4.16.1 Levels of ice information

It is possible to distinguish 4 levels of ice information, characterised by increasing detail and immediacy:

- background
- synoptic (summary or general survey)
- route specific
- close range

Background information is primarily historical in nature. It describes the natural variability in space and time of ice conditions for the region of intended operation. It may also describe the relationship of ice conditions to other climatological factors including winds, currents, and tides. It is applied very early in the strategic planning process, but it may also be useful at any time during the voyage.

At the synoptic level, ice conditions are defined for specific regions and time periods. The information may provide either current or forecast ice conditions but, in either case, it is not very detailed. As synoptic information is normally used days or even weeks before entering the ice, and because conditions are often dynamic, its greatest value is as a support tool for strategic planning.

Route-specific information provides a greater level of detail than synoptic information, usually for smaller areas. The detail provided may extend to the identification of individual floes and other features of the ice cover, and is most useful at the tactical planning stage.

Close-range information identifies the presence of individual hazards which lie within the immediate path of the ship. This level of information provides critical support during monitoring and execution of the tactical passage plan.

CIS, provides ice information and long-range forecasts to support marine activities. At the synoptic level, the Ice Operations Division of the CIS provides valuable strategic planning information through a series of plain language bulletins, warnings, and short-range forecasts for ice and iceberg conditions. These are broadcast live by marine radio, with a range of up to 320 kilometres. Broadcast frequencies and schedules are listed in the CCG publication RAMN, issued seasonally. Taped bulletins are broadcast continuously from CCG radio stations with an effective range of 60-80 kilometres. Alternatively, most of this information is available on the CIS website.

Extended forecasts (including seasonal outlooks and twice-monthly 30-day forecasts), and daily ice analysis charts, are available through the web, email, mail or facsimile subscription. For further information contact:

Website	Latest ice conditions - Canada.ca
Address	Canadian Ice Service 719 Heron Road, Annex E Sir Leonard Tilley Ottawa, Ontario K1A 0H3
Email	ec.cisclients-scgclients.ec@canada.ca
Telephone	1-877-789-7733

The most important external source of information available to the vessel is the broadcast of ice analysis charts by the CIS. For vessels equipped with their own reconnaissance helicopter, aerial visual observations may provide considerably more ice information at the route planning and tactical levels.

4.16.2 Remote sensing systems

With special purpose receiving and processing equipment, vessels may take advantage of airborne and satellite borne remote sensing systems for complementary synoptic level ice information.

The CIS no longer use airborne imaging radar systems for ice reconnaissance, which were able to transmit raw data directly to the CCG Ice Operations centres.

Many commercially available systems enable vessels to receive direct transmission of weather satellite imagery which may be used to assess regional ice distribution. These systems are designed to receive the VHF (137 MHz) image transmission from various weather satellites via inexpensive personal computer software. Image resolution is in the range of 3 to 4 kilometres, providing suitable information for synoptic level voyage planning. The low cost of these systems (typically in the tens of thousands of dollars) makes them suitable for a larger number of vessels transiting ice-covered waters (figure 61).

Canada has a fully operational imaging radar satellite known as RADARSAT-2, which provides high-resolution (100 metre) global coverage of ice-covered waters on a nearly continuous basis. RADARSAT-2 has the capability to send and receive data in both horizontal (H) and vertical (V) polarizations. Images acquired with the various combinations of polarizations on transmit and receive can be displayed on single channels or in various combinations including ratios and false colour composites.

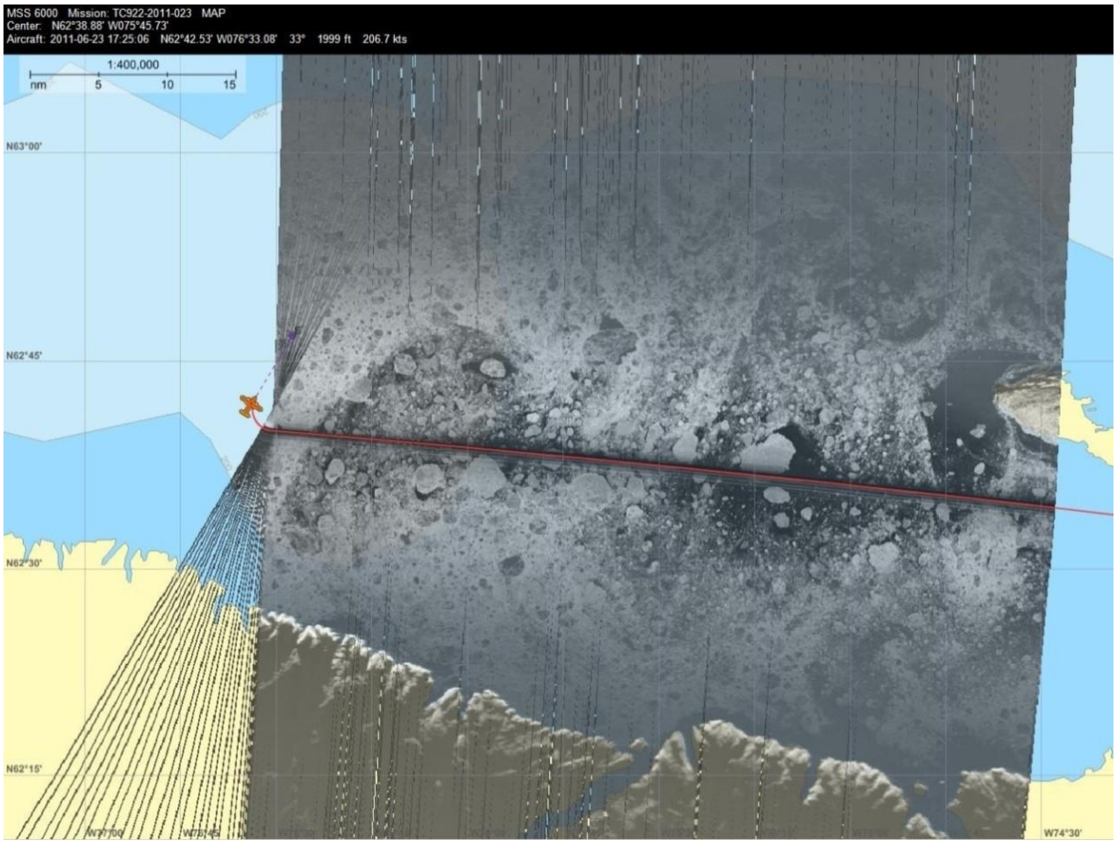


Figure 61 - Aerial ice reconnaissance image displayed in a GIS system (Courtesy of CIS)

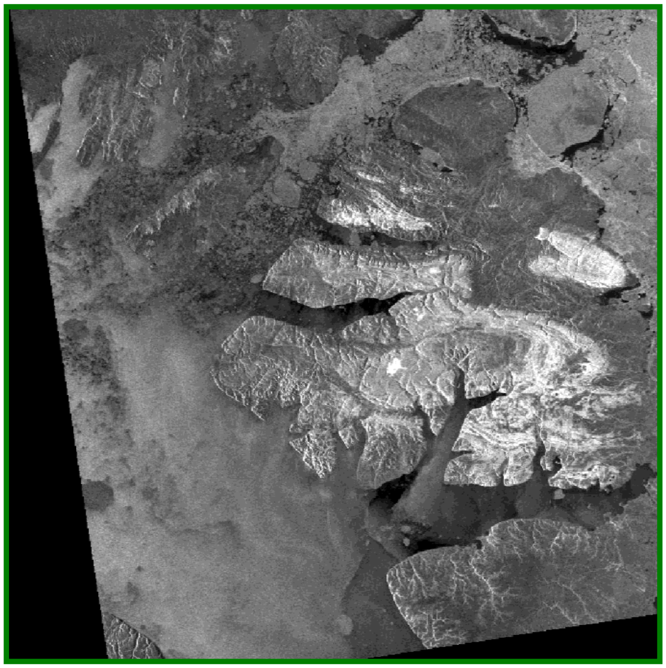


Figure 62 - RADARSAT-2 HH image of M'Clure Strait (MDA 2009)

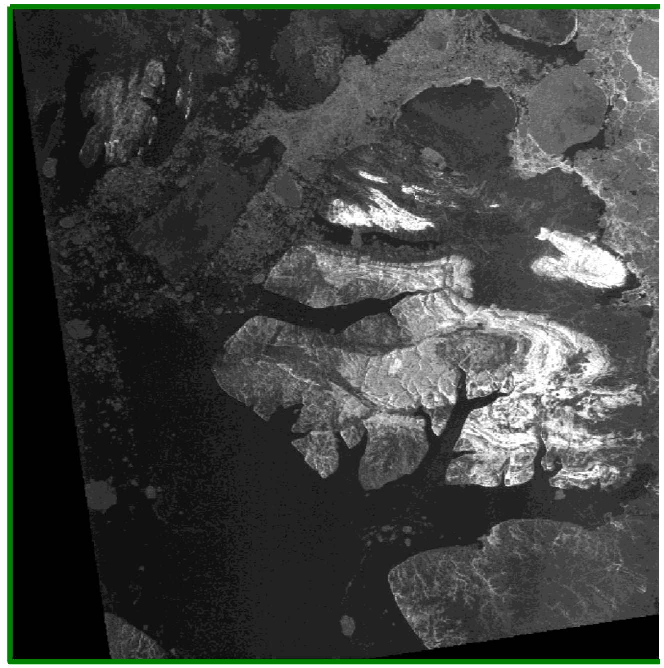


Figure 63 - RADARSAT-2 HV image of M'Clure Strait (MDA 2009)

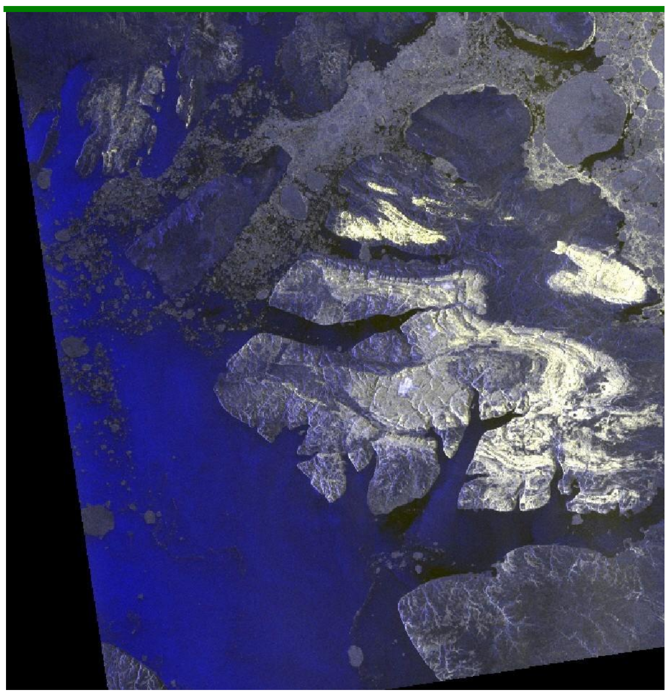


Figure 64 - RADARSAT-2 RGB221 image of M'Clure Strait (MDA 2009)

Figures 62 to 64 are RADARSAT-2 images that were taken on September 14, 2008 in M'Clure Strait.

Figure 62 is an HH polarization (horizontal send and horizontal receive). In the image, it is difficult to differentiate the multi-year ice from other ice types.

Cross-polarization modes combine horizontal send with vertical receive (HV) or vice versa (VH). In the HV image (figure 63) the multi-year ice clearly stands out but the thinner ice types are not as evident.

A combination of HH, HV and the colours red, green and blue (RGB) can help to differentiate all the ice types in satellite images.

Figure 64 is an RGB221 image with very good detection of multi-year ice, with an increased detection of strips of thinner ice when compared to the previous images.

4.16.3 Canadian Ice Service ice charts

Ice charts issued by the CIS use standard World Meteorological Organization terms and symbols to describe ice conditions at different locations. The mariner should be aware that these charts are synoptic level information sources, and the ice conditions depicted are averages for the area. There is always the possibility that local ice conditions may differ significantly from those depicted on the chart. Maintaining manoeuvrability for the avoidance of locally heavy ice conditions is an important consideration when using ice charts at the route planning level.

The ice analysis charts issued daily by CIS do not show areas of ridged ice, rubbled ice, or ice under pressure. They do, however, indicate the general drift in nautical miles per day of individual ice-fields, so that developing pressure can be deduced. In using this information, the mariner should consider at all times the potential for ice drift and changes in ice conditions, which is especially important where navigation corridors are constrained by shallow water, and where winds, currents, and/or tides may result in zones of ice convergence.

The ice analysis chart is the primary map product produced at the CIS. It is produced daily and valid at 1800 UTC during the operating season, and represents the best estimate of ice conditions at the time of issue. The chart is prepared in the afternoon so that it may be delivered to users in time for planning the next days' activities.

An example of how to read a daily ice analysis chart is presented in figure 65. The CIS uses codes and symbols to describe all ice forms, conditions, and concentrations as accepted by the World Meteorological Organization. The ice codes are depicted in oval form, known as the Egg Code, which is completely described in MANICE, and is outlined in this section. The use of codes and symbols varies according to the type of ice chart:

- current daily ice chart: area specific, most detailed
- regional weekly ice chart: smaller scale, less detailed

The basic data concerning concentrations, stages of development (age), and form (floe size) of ice are contained in a simple oval form. A maximum of three ice types are described within the oval. This oval, and the coding within it, are referred to as the "Egg Code".

The Egg Codes symbols in the code are classed into four categories of ice information:

1.	Total concentration C_t - Total concentration of ice in the area, reported in tenths.	top level
2.	Partial concentrations of ice types $C_aC_bC_cC_d$ - Partial concentrations of thickest (C_a), second thickest (C_b), third thickest (C_c), and fourth thickest (C_d) ice, in tenths.	second level
3.	Ice type corresponding to the partial concentrations on the second level Stage of development of the thickest (S_o), second thickest (S_a), third thickest (Sb), and fourth thickest (S_c) ice, and the thinner ice types (S_d and S_e), of which the concentrations are reported by C_a, C_b, C_c, and C_d, respectively.	third level
4.	Predominant floe size category for the ice type and concentration Floe size corresponding to S_a, S_b, S_c, S_d, and S_e (when S_d and S_e are greater than a trace).	bottom level

Tables 10, 11, and 12 list the codes used in the egg codes for sea ice and lake ice stages of formation and floe sizes, respectively.

Table 10 - Egg coding for sea ice stages of development (S_o S_a S_b S_c S_d S_e)

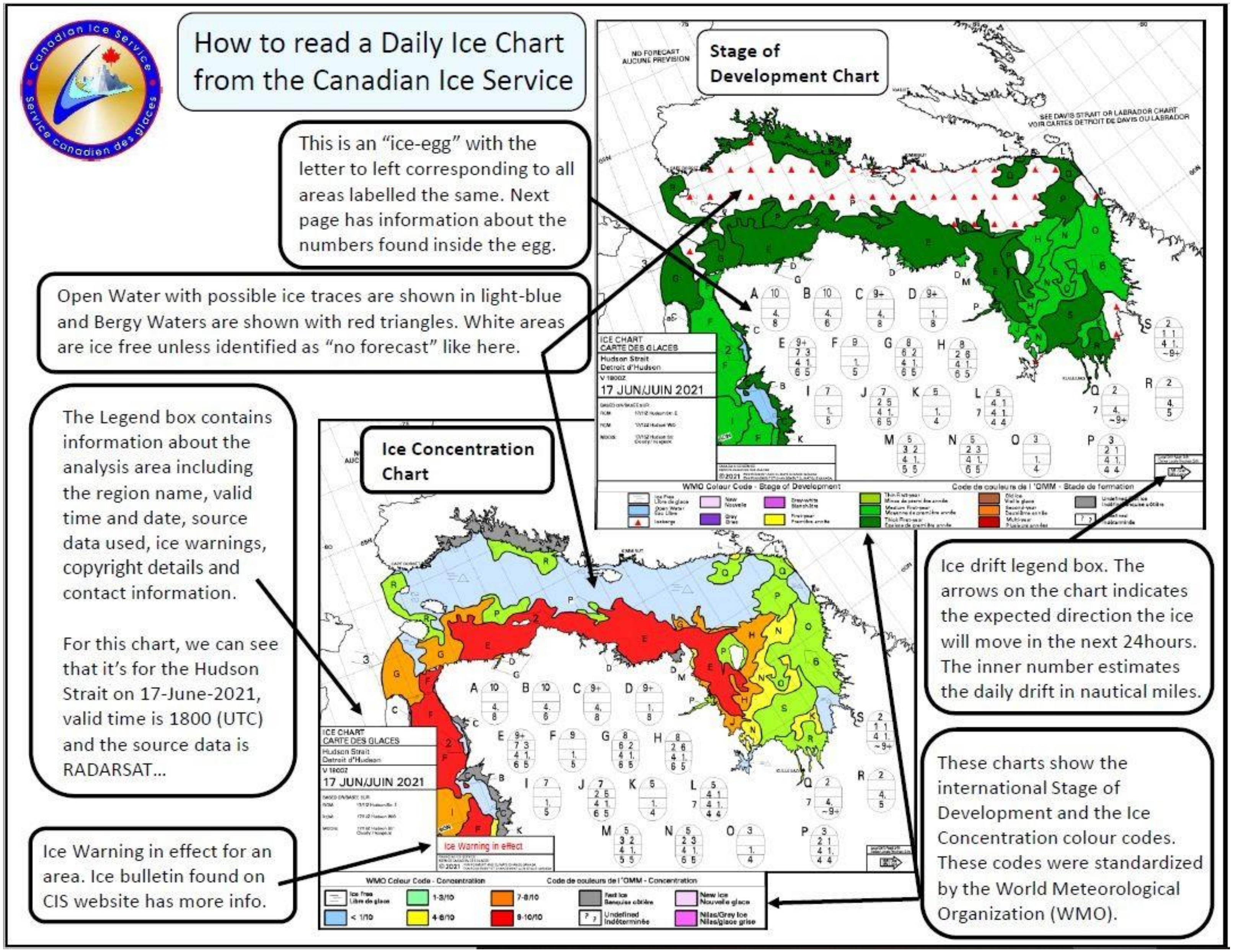
Description	Thickness	Code
New ice	<10 cm	1
Nilas; ice rind	0-10 cm	2
Young ice	10-30 cm	3
Grey ice	10-15 cm	4
Grey-white ice	15-30 cm	5
First-year ice	30-200 cm	6
Thin first-year ice	30-70 cm	7
Thin first-year ice first stage	30-50 cm	8
Thin first-year ice second stage	50-70 cm	9
Medium first-year ice	70-120 cm	1•
Thick first-year ice	120-200 cm	4•
Old ice		7•
Second-year ice		8•
Multi-year ice		9•
Ice of land origin		▲•
Undetermined or unknown		X

Table 11 - Egg coding for lake ice stages of development

Description	Thickness	Code
New lake ice	< 5 cm	1
Thin lake ice	5-15 cm	4
Medium lake ice	15-30 cm	5
Thick lake ice	30-70 cm	7
Very thick lake ice	over 70 cm	1•

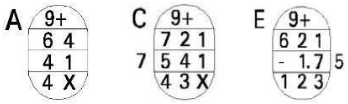
Table 12 - Egg coding for floe sizes (F_a F_b F_c F_d F_e F_p F_s)

Description	Code
Pancake ice	0
Small ice cake; brash ice	1
Ice cake	2
Small floe	3
Medium floe	4
Big floe	5
Vast floe	6
Giant floe	7
Fast ice, growlers, or floebergs	8
Icebergs	9
Undetermined or unknown	X


How to read a Daily Ice Chart from the Canadian Ice Service
Stage of Development Chart
This is an "ice-egg" with the letter to left corresponding to all areas labelled the same. Next page has information about the numbers found inside the egg.
Open Water with possible ice traces are shown in light-blue and Bergy Waters are shown with red triangles. White areas are ice free unless identified as "no forecast" like here.
The Legend box contains information about the analysis area including the region name, valid time and date, source data used, ice warnings, copyright details and contact information.
For this chart, we can see that it's for the Hudson Strait on 17-June-2021, valid time is 1800 (UTC) and the source data is RADARSAT...
Ice Concentration Chart
Ice Warning in effect for an area. Ice bulletin found on CIS website has more info.
Ice drift legend box. The arrows on the chart indicates the expected direction the ice will move in the next 24hours. The inner number estimates the daily drift in nautical miles.
These charts show the international Stage of Development and the Ice Concentration colour codes. These codes were standardized by the World Meteorological Organization (WMO).
ICE CHART
CARTE DES GLACES
Hudson Strait
Detroit d'Hudson
17 JUN/JUIN 2021
Ice Warning in effect
WMO Colour Code - Stage of Development
WMO Colour Code - Concentration
Code de couleurs de l'OMM - Concentration

Ice Egg Codes

Ice concentrations, types and floe sizes are described in a code inside an oval shape called an "ice egg" like the ones pictured below.



The **top line** of the egg gives the total concentration of ice in the area associated with the egg. The concentration is a ratio expressed in tenths describing the ice-covered area as a fraction of the entire area.
The **second line** gives partial concentrations of the ice types (stage of development). Up to 5 ice types can be reported by an egg. The 3 dominant ice types are located inside the egg. Trace amounts of the thickest ice types are displayed to the left of the egg and additional groups are written to the right. The partial concentrations add together to equal the total concentration.
The **third line** describes the ice type or "stage of development" that corresponds to the partial ice concentration immediately above it.
The **bottom line** shows the relative size of the average ice floe associated with the ice types on the third line.

Note: If a dot is present, then all numbers to the left of the dot are understood to have the dot (.) as part of their code.

Third line of Egg - Stage of development

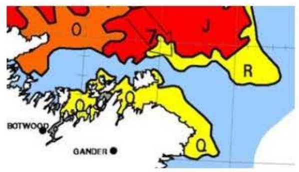
Code	Ice Type	Thickness
1	New ice	0 - 10 cm
4	Grey ice	10 - 15 cm
5	Greywhite ice	15 - 30 cm
7	Thin first-year ice	30 - 70 cm
1.	Medium first-year ice	70 - 120 cm
4.	Thick first-year ice	> 120 cm
7.	Old ice	Any
8.	Second-year ice	Any
9.	Multi-year ice	Any

Last line of Egg - Floe size

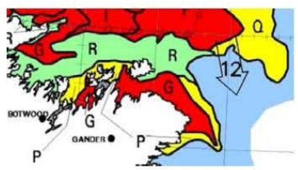
Code	Floe Size	Floe Width
1	Brash	< 2 metres
2	Ice cake	2 - 20 m
3	Small floe	20 - 100m
4	Medium floe	100 - 500m
5	Big floe	500 - 2000m
6	Vast floe	2 - 10km
7	Giant floe	> 10km
8	Land fast ice	
9	Icebergs	

Ice Motion near the Ice Edge

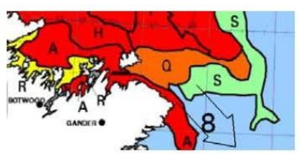
Sea ice can grow and spread very quickly when air temperatures are very low and winds are light. This typically occurs after a cold front has passed through the area.
The following ice concentration charts show the evolution of ice off Gander, Newfoundland, between Jan 24 and Jan 26, 2008.



Jan 24 2008
Daytime high temp at Gander
-5.5˚C



Jan 25 2008
Daytime high temp at Gander
-10.5˚C



Jan 26 2008
Daytime high temp at Gander
-15.2˚C

Over these three days, the ice north and east of Botwood formed and thickened. The drift arrows visible on the charts display the general velocity of the ice within 10 nautical miles of the centre of the arrow. It does not take into account the effect of landmass within the area, thus when the drift arrow points towards land this could indicate an increase of coastal ice concentration and/or pressure.
In the absence of wind, water currents move the ice. The Labrador Current, for example, moves ice southward at a rate of about 5 to 10 nautical miles per day.

Ice Concentration vs Stage of Development Ice Charts

Ice Concentration charts and Stage of Development charts have separate and distinct (WMO) colour codes that are internationally recognised. Every ice chart produced is equipped with a legend to interpret the colour code. There are no colours that are interchangeable between an Ice Concentration chart and a Stage of Development chart.

Sources of data used to make a Daily Ice Chart

RECON: Describes date and area information from aerial ice reconnaissance
RADARSAT: Describes date and area covered by RADARSAT satellite imagery. Images are not affected by clouds.
NOAA: Describes date and area covered by source NOAA AVHRR imagery. Clouds can obscure the view of the ice.

Other data sources are listed after these primary sources and could include: other satellite imagery or ship-based charts. Generally, the more source data the chart has, the more accurate the resulting ice chart will be. However, issues of image resolution and space requirements may restrict the amount of detail shown.

The Canadian Ice Service is responsible for the production and distribution of ice and iceberg information over Canadian Navigable waters as well as the Arctic METAREAS XVII and XVIII.

Ice information is available in a varying amount of detail. Large area charts are produced weekly as a climatological record of ice conditions. Daily charts are produced for areas with active marine activity. Image analysis charts are done upon request for specific requirements.

Dedicated ice observers provide valuable ice information about the ice from a ship or aircraft perspective.

Ice forecasts are text bulletins available daily for active marine areas. They provide general information about the dominant ice concentration and ice type as well as any warnings in effect.

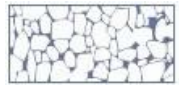
Canadian Ice Service – Meteorological Service of Canada
A division of Environment Canada
Phone: (877) 789-7733
Email: Weather.Info.Meteo@ec.gc.ca

Figure 65 - How to read a daily Ice Chart from Canadian Ice Service

4.16.3.1 Interpreting ice charts

Observed or interpreted ice charts require boundaries for all changes of ice parameters. However, the daily ice analysis chart requirements have been developed in co-ordination with the CCG. In particular, these requirements address the placement of mandatory boundaries through differing ice types, concentrations, and floe size which are of significance to navigation.

Table 13 - Concentration

 <1/10 Open water	 9/10 Very close pack
 1-3/10 Very open drift	 9+/10 Very close pack
 4-6/10 Open drift	 10/10 Compact/Consolidated ice
 7-8/10 Close pack/Drift	

A daily ice analysis chart will not normally show a boundary between ice conditions that vary by only one tenth, except when very close or compact conditions exist. Total concentration is the determining factor in defining ice boundaries, except that when first-year or thicker ice is present, any new ice which may also be present is ignored.

The **ice edge** is the boundary between open water and concentrations of 1 or more tenths of ice. This implies that traces of ice may be expected beyond the ice edge. When ice types are grey-white or thicker, an additional solid boundary between close drift/pack, 7 to 8 tenths, and very close drift/pack, 9 to 9+ tenths, is made at the discretion of the forecaster.

The user should be aware that ice types are considered to be level and undeformed. Due to rafting and ridging, there will usually be traces of thicker ice present. When present, second-year ice, code 8., and Multi-year ice, code 9., are used in the Arctic during the October to December period, and at other times when the situation is well known. A boundary is not required between these 2 ice types. Along the Labrador coast and in Newfoundland waters, old ice, code 7., is used.

Navigation through thicker ice types in larger floes is more difficult than in smaller floes. When first-year or thicker ice is present, with a concentration of 6 tenths or more, a boundary is required between areas with medium or larger floes, code 4 or greater, and areas with small floes, code 3 or less.

Strips and patches are often used on a chart in an attempt to describe ice conditions accurately when the total concentration in an area is in the very open to open drift category. In these areas, especially along ice edges, the ice is arranged by winds, currents, and tides into strips and patches of very close ice with large patches of open water in between. Similarly, the use of 2 egg codes joined by the strip symbol is often used to depict strips and patches of close or very close ice of a thicker type. In this case the patches are embedded in a broad area of thinner ice cover. A vessel which can make good progress in the average concentration of open pack ice should take care to reduce speed when encountering a strip or patch of the more heavily concentrated ice.

Figure 66 - Vessel encountering strips of multi-year ice (CCG)

The daily ice analysis chart is a static picture of ice conditions at 1800 UTC. Ice is generally in a state of mobility, depending on meteorological and oceanographic conditions. Drift arrows are included on the chart to assist the user in assessing the change in ice conditions over the next 24 hours. The arrows indicate the expected 24-hour net drift of freely moving ice, based on forecast winds and known currents. Wind-driven forces are directly proportional to the sail factor of the ice. The sail factor is directly proportional to the ice thickness and indirectly proportional to total concentration and floe size. This means that the fastest moving ice, such as very open drift, would be expected to drift at the indicated rate. There is a delay after the start of strong winds before an ice-field ice will start to drift downwind, and the ice-field will continue to drift in that direction for a period of time after the wind ceases, or changes direction.

The arrows can be used as an indication of ice pressure when placed in an area of thicker ice and directed toward even thicker ice or a coastline. Conversely, areas of easing pressure or development of leads would be indicated by an expected offshore drift.

The user should be aware that because of melt and destruction, an ice edge may not be advancing at the rate indicated. Conversely, with ice growth, the edge may be advancing at a faster rate.

4.16.4 Characteristics of sea ice

There are characteristic features and formations associated with individual ice types, which provide useful clues that the mariner can use to recognize and classify ice conditions. It must be remembered that environmental conditions such as darkness, fog, snow cover, ice roughness and surface melt may complicate ice recognition. Additional information on ice type characteristics and terminology is contained in Annex I.

4.16.4.1 New ice

New ice is recently formed ice in which individual crystals are only weakly frozen together, if at all. It is frequently found without structural form, as crystals distributed in a sea-surface layer which may exceed 1 metre in depth, depending on sea state.

It may be recognized by its characteristic soupy texture and matt appearance, as illustrated in figure 67. It may also take the form of spongy white lumps a few centimetres in diameter (termed shuga), which can also result from heavy snow falling into water at about the freezing point.

Figure 67 - Photo of new ice (courtesy of CIS)

4.16.4.2 Nilas

Nilas is ice that has developed to the stage where it forms a thin elastic crust over the sea surface. The layer may be up to 10 centimetres thick and is characterized by a dark, matt appearance.

It has unique deformation characteristics that make it easy to recognize. It bends easily on a vessels wake, often without breaking, and when two sheets of nilas converge they may overlap in relatively narrow fingers (figure 68). New ice and nilas are not a hazard to shipping.

Figure 68 - Example of nilas (image courtesy of CIS)

4.16.4.3 Young ice

Young ice is ice that is between 10 and 30 centimetres thick. This category includes grey ice (10-15 centimetres thick), and grey-white ice (15-30 centimetres thick). As these names suggest, young ice is most readily identified by its characteristic grey colour. Converging floes of grey ice will overlap, or raft, in wider fingers than nilas ice, and can extend to rafting of very large sheets. Extensive rubble fields are frequently observed, especially in grey-white ice.

Young ice achieves sufficient strength to present a potential hazard to vessels not strengthened for ice and will begin to slow down the speed of advance of low-powered vessels. Figures 69 and 70 are examples of young ice.

Figure 69 - Example of pancake ice (image courtesy of CIS)

Figure 70 - Examples of grey and grey-white ice (image courtesy of CIS)

4.16.5 First-year ice

First-year ice is ice that is greater than 30 centimetres thick and less than 1 year old. It can be classed as thin, medium, or thick. However, it is often difficult to tell by looking at the ice how thick it is, because colour and surface characteristics are relatively constant. The thickness of block edges visible in ridges will indicate a minimum thickness but the level component may be thicker than this depending on how long ago the ridge was formed. The most accurate way to estimate ice thickness is by observing the edges of pieces as they turn against the ship's side. It is useful to know the dimensions of 1 or 2 deck-level objects (such as width of deck rail) which can be viewed from the bridge at the same time as the breaking ice pieces. Figure 71 shows an example of first-year ice.

Figure 71 - Example of First-year ice

Old ice

Old ice is ice that is more than 1 year old and has survived at least one melt season. This category includes second-year and multi-year ice. During the melt period, puddles form on the first-year ice surface that because of their darker colour tend to absorb more solar radiation than the surrounding patches of white ice. Should the ice not melt completely before the onset of freeze-up, the undulating pattern will become a permanent feature of the ice surface. As the melt-freeze cycles are repeated, the ice grows progressively thicker and the difference between melt ponds and hummocks becomes more pronounced.

It is not always easy to distinguish second-year from first-year ice, as both snow cover and melt-water tend to hide the early stages of hummock growth. The component of the ice cover that is actually second-year ice is normally limited to the upper 50-100 centimetres, with the remainder being first-year ice growth. Thus second-year ice may be recognized when pieces turn on their side, by the presence of a distinct, cloudy boundary between the 2 layers which is several centimetres thick. Below the boundary, the first-year ice will usually be apparent from its slightly greener colour, and vertical structure of its columnar crystals. Figure 72 shows an example of second-year ice.

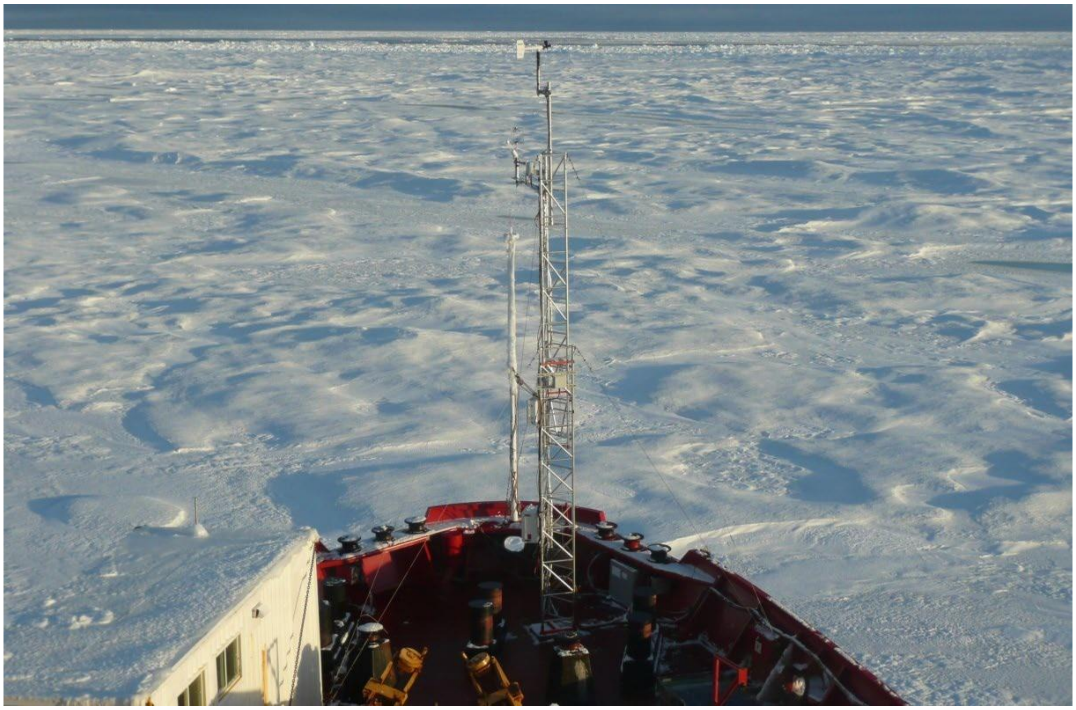


Figure 72 - Example of second-year ice (CCG)

Multi-year ice is easier to identify than second-year ice, primarily because the hummocks and melt-ponds become increasingly pronounced. In addition, there is normally a well-established drainage pattern connecting the melt ponds, and floes tend to have a higher freeboard than first-year ice. Where the ice is bare, the colour of multi-year ice may appear bluer than first-year ice.

Multi-year ice floes vary considerably in size, thickness, and roughness, depending on their growth history. Even when the surface is hidden by rubble or snow, it is frequently possible to identify these very strong floes by the first-year ice ridging which often forms around their perimeter. Many of these characteristics can be seen in the photograph of a typical multi-year floe, presented as figure 73. Multi-year ice is the strongest and hardest form of sea ice and represents a serious impediment - indeed a danger - to all vessels, as even the most powerful icebreakers will avoid contact with multi-year floes if at all possible.

Figure 73 - Example of a small floe of multi-year ice (image courtesy of CIS)

4.16.5.1 Icebergs, bergy bits and growlers

Mariners should beware of leads in pack ice, which may suddenly end at an iceberg. Because icebergs project deep into the water column, they are affected more by ocean currents and less by winds than the surrounding sea ice. This may result in differential motion and the creation by the iceberg of an open water track through the pack ice.

Generally, the same comments apply to bergy bits and growlers as to icebergs. However, the smaller size of these hazards means they are often more difficult to detect than icebergs and, therefore, are very dangerous. Special care must be taken in watching out for bergy bits and growlers. They may be well hidden by white caps in the open sea, as shown in figure 74, or by rubbled ice, as shown in figure 75. Their shape may make even larger bergy bits difficult to detect using marine radar, when the freeboard is relatively small and if the sides are oriented to deflect radar energy away from the antennae. It is worthwhile to reduce speed while in bergy waters and to add an extra watch keeper to ensure that an adequate look out can be maintained. Bergy bits and growlers are the most dangerous hazards to vessels in ice-covered waters.

Figure 74 - Iceberg and growlers in the open sea (image courtesy of CIS)

Figure 75 - Growler hidden in ice rubble (image courtesy of CIS)

Warning: The mariner must watch for bergy bits and growlers at all times when in bergy waters. Do not rely solely on marine radar to detect icebergs, bergy bits and growlers in fog and darkness.

4.16.6 Marine observations from vessels

Observations from vessels on weather, sea, and ice conditions are important sources of information for the Environmental science centres across Canada. Vessel observations allow the meteorologist:

- to know where the vessel is and to focus on that area
- to confirm a forecast with actual data during the forecast period
- to learn in real time what winds are produced by various pressure patterns in a given area
- to learn which forecasting techniques are appropriate for a given area, for example, to forecast sea conditions, vessel icing, and ice motion

Direct observations from vessels are incorporated on weather maps and analyses. There is a special need for observations from vessels transiting Hudson Strait and Hudson Bay, from fishing vessels in Davis Strait during November and December, and any vessels navigating in the Arctic.

In addition to using vessel observations in current forecasts, the information is stored by the Canadian Centre for Climate Services so that meteorologists can analyse it, for example to learn the means and extremes of wind for various marine areas. Engineers use the data to evaluate extreme events expected which could affect vessels and structures; they can develop and refine formulas to compute conditions such as sea state and vessel icing.

Observations can be passed to the appropriate SPC, listed in Section 1.7, or to the nearest MCTS centre which will forward the information to the SPC. No cost is involved. Weather, sea, and ice observations can be added to any position report given; for instance, all vessels operating in Arctic waters must provide a once daily position report. It is most useful to provide weather observations at the regular times of 0000, 0600, 1200, and 1800 UTC so that charts and forecasts can be updated.

5 Vessel design and construction for ice operations

5.1 Hull form design

5.1.1 Bow shape

The bow shape of a Type vessel is typical of vessels designed for operation in open water, typically with a bulbous bow, which is particularly vulnerable to thick first year and old ice floes. As such, it is designed only to force ice, that is, to push ice away from the ship. Therefore, operators of Type vessels should not attempt to break ice by aggressive action. The bow shapes for icebreakers may be described by the stem, flare, buttock, and water-line angles. These angles contribute to the icebreaking, submergence, and clearing efficiency. Recent trends in the design of icebreakers are to increase flare angles, to reduce water-line angles, and to reduce stem and buttock angles.

Some icebreaker bow shapes can be referred to as conventional or traditional in that they represent a progressive improvement in icebreaking resistance while retaining the smooth hull which offers least resistance in open water (figure 76). Other bows can be referred to as unconventional or non-traditional, in that they are a distinct departure from smooth hull shapes (figure 77). It would appear from past experience that the best traditional shapes have performed almost as well in level ice as the best non-traditional shapes.

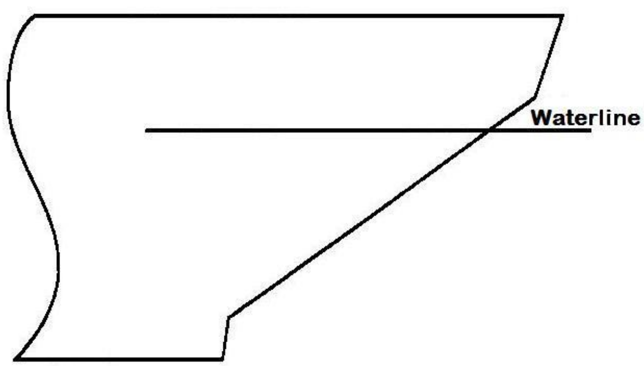


Figure 76 - Conventional icebreaker bow shape

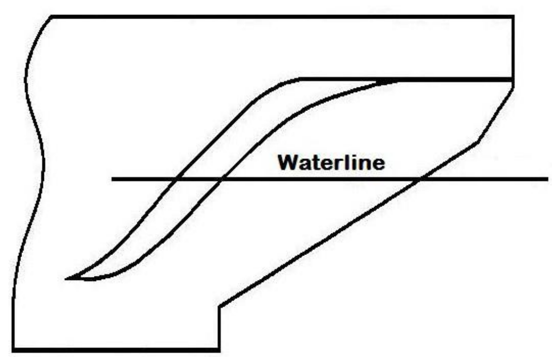


Figure 77 - Unconventional bow shape

5.1.2 Midbody shape

The selection of a midbody shape must consider its effect on resistance, manoeuvrability, construction cost, and the required deadweight. The midbody may be characterized by flare angle (over the full depth or locally), parallel midbody, and longitudinal taper.

5.1.3 Stern shape

The stern design on icebreaking vessels is controlled mainly by the number of propellers, which is a function of the required power and operational requirements. The stern must, to the greatest extent possible, provide protection to the rudder(s) and propeller(s). To provide this protection, a number of design options can be selected. The conventional stern, typical of CCG icebreakers, is rounded to provide good icebreaking astern performance, and is usually fitted with an ice horn to protect the rudder. A transom, or ramped, stern is installed on several icebreakers. The objective of this stern is to allow the broken ice pieces to move upward to the surface well ahead of the propeller(s).

There are several design features that can be added to sterns to protect the rudder(s) and propeller(s):

- an ice horn fitted to the hull immediately above and aft of the rudder provides protection to the rudder during backing operations
- rudder stops can be fitted to protect the rudder and steering gear from damage during backing operations when ice could force the rudder away from the mid vessels position
- propeller nozzles provide some protection to the propeller(s)
- deflecting fins are sometimes added to the hull in an effort to deflect ice pieces away from the propeller(s)
- the ice-clearing island (or ice skirt) is a wedge protruding below the ship's hull from the baseline forward of the propellers, and slopes up to the water-line aft of the propeller. The objective is to guide ice pieces away from the propeller(s)

5.2 Structural design

5.2.1 Loading

The design of structure for icebreakers and other ice-capable vessels requires a knowledge of the magnitude of ice loads, which are influenced by: hull shape, displacement, power, speed, ice confinement, and ice type.

The ice load experienced by a ship's hull will vary between hull areas. The bow area experiences the highest loads, while the bottom will generally experience the lowest loads. Figure 78 illustrates the hull areas for a Type ship. Research has shown that the ice load is not evenly distributed over the area of contact between the hull and the ice. The contact area shape is thought to be elliptical, with the major axis about eight times longer than the minor axis. For bow impacts, this elliptical shape is assumed to be symmetrical about either side of the stem.

In the International Association of Classification Societies concerning Unified Requirements for Polar Class Vessels, the vessel’s hull are divided into areas reflecting the magnitude of the loads that are expected to act upon them. In the longitudinal direction, there are four regions: Bow (forward region), Bow Intermediate (a transition between the forward and mid vessel regions), Midbody (mid vessel region) and Stern (aft region).

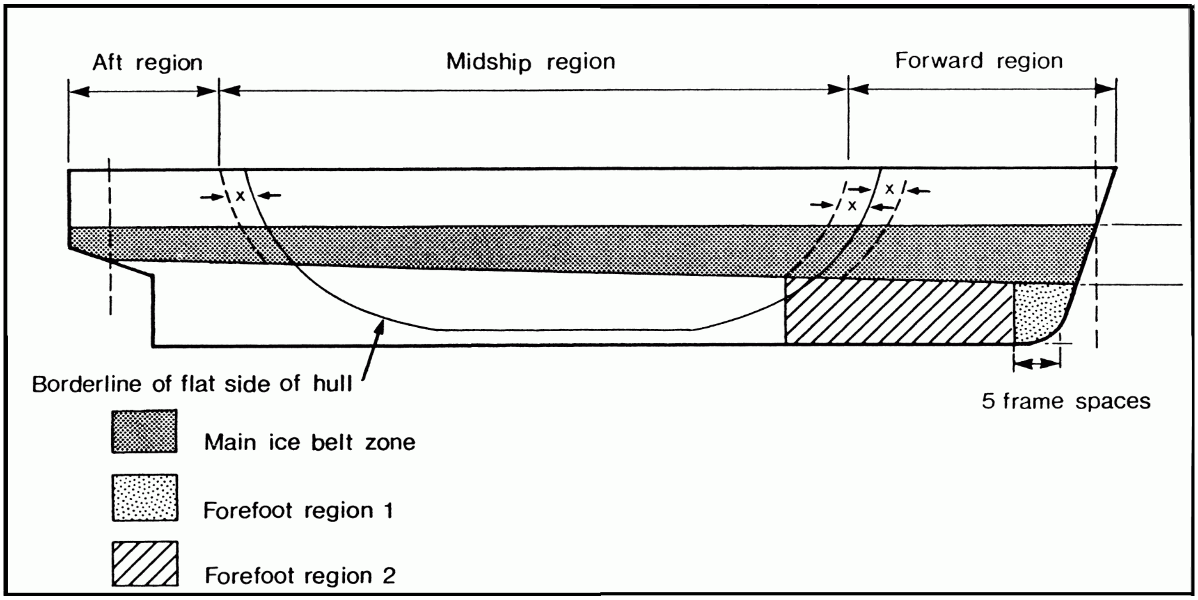


Figure 78 - Hull areas for a Type ship

5.2.2 Structural arrangement

The vessel's structure must be designed, and arranged, to withstand the loads imposed globally and locally. The most common global consideration is an adequate hull girder section modulus for the highest ice class vessels in a "beaching condition". This condition can occur when the vessel is ramming an ice floe and the bow rises out of the water to rest on the floe. Lower Arctic Class vessels, Type vessels, and vessels which are not intended solely for Arctic operations, such as those which operate in the Great Lakes or other inland waters, do not necessarily require higher section modulus than open water vessels, because bending stresses incurred during normal operations for vessels do not exceed those experienced in heavy seas. The local structure must resist failure caused by bending, shearing, buckling, and tripping. Although bending failure has traditionally been considered the most likely failure mode, experience gained from Arctic operations indicates that frame buckling and tripping are more critical failure modes. A Type vessel should never be used so aggressively in ice that the bow rises up like an icebreaker, to break the ice by the weight of the vessel, however, a Type vessel in ballast which is trimmed too far by the stern may find floes becoming wedged under the bow for a considerable distance back from the stem. Bottom damage can easily occur if heavy ice-floes are forced against the bottom plating, which is normally lighter than the plating of the ice-belt.

In a traditional icebreaker structure, the shell plating is supported by main frames spaced about 40 centimetres apart. The main frames are supported by longitudinal stringers, and the stringers are supported by web frames or bulkheads. The grillage of major structure supports the global loads and the main frames support the local loads. This arrangement is based on the assumption that initial failure will occur from the bending collapse of the main frames, and, as a result, the span of these frames need to be short, hence the position of stringers. Failure with this type of structure is usually frame buckling and tripping.

Simpler structural arrangements have evolved from the recognition that frame buckling and tripping were the critical failure modes. Typical of such arrangements, the steel plating between two decks is supported by large main frames spaced further apart than those in the traditional arrangement, and is based on the assumption that the shell plating membrane strength can also be included in the strength calculations. The frames are designed against bending, buckling, and tripping, which results in heavier frames and eliminates the need for stringers. The resultant structural arrangement has thinner plates and larger main frames but very few components and connections, which is easier to construct and has lower construction costs.

5.2.3 Construction materials and behaviour at low temperatures

Structural integrity requires the proper selection of hull materials. The 2 primary groups of steel used in vessel construction are normal strength and high strength steels (referring to their minimum yield strength). Within each of these groups, there are several grades of steel which are assigned according to their chemical composition and other mechanical properties.

Based on past experience, the critical factor associated with the properties of steel in Arctic vessels is their resistance to brittle fracture from low temperatures and high loading conditions, typical of operations in ice. Low temperature is the most important environmental factor for the selection of materials when designing against brittle fracture. At low temperatures, the ductility and fracture toughness decreases; the steel becomes brittle, increasing the likelihood of a catastrophic brittle fracture. Such fracturing is more frequent above the water-line where steel is exposed to very low air temperatures.

The mariners on board a vessel in ice must be aware of the type of steel used in the construction of their ship. The shell expansion plan will be on board and it will show clearly the steel qualities used. If a vessel has no low temperature steel, it is important to avoid impacts with hard ice when the air temperatures are very low, or the vessel has been exposed to very low temperatures for a long period prior to navigating in ice.

5.3 Propulsion systems

Propulsion systems for ice-going vessels must be reliable, flexible with a view to redundancy, maintainable, and have high power-to-weight and power-to-space ratios. The 2 dominant propulsion systems in ice-going vessels are diesel-electric transmission with fixed-pitch propellers (typically installed on icebreakers), and diesel-mechanical transmission with controllable-pitch propellers. Vessels not required to break ice would normally have a diesel-mechanical transmission, with or without controllable-pitch propellers. The most recent development for icebreaker propulsion systems includes submerged azimuthing pod propulsion motors, which are proving to be very effective for both icebreakers and icebreaking cargo vessels. By eliminating the need for a rudder, these systems make vessels more manoeuvrable at the same time as they remove the threat of rudder damage.

5.3.1 Prime movers

The choice of prime mover is a function of task to be performed, area of operation, and economics. Diesel engines, steam turbines, and gas turbines are options currently used in either icebreakers or ice-going vessels.

Medium-speed diesel engines usually are unidirectional and require a separate system for astern operation which can be provided by a controllable-pitch propeller or electric drive system. A significant disadvantage of this system is a lack of over-torque capacity. However, medium speed diesel generators have been fitted to many icebreakers in conjunction with electric propulsion motors or to drive a controllable-pitch propeller through gears. Slow speed diesel engines are usually coupled directly to a fixed-pitch propeller, although some are connected to a controllable-pitch propeller. These engines are usually fitted to vessels intended to navigate only through light or broken ice or under escort. Steam turbines are unidirectional and, on icebreakers, astern power is usually provided by an electric transmission system. There are very few icebreakers fitted with steam turbine systems other than nuclear powered vessels. Nuclear powered icebreakers use their steam turbines to generate electrical power to operate electric propulsion motors, in exactly the same way conventional diesel-electric icebreakers operate – only the prime mover is different. Gas turbines are also unidirectional, and astern operation must be obtained from a reversing gearbox, or from a controllable-pitch propeller.

5.3.2 Electric transmission

CCG icebreakers usually have electric transmission systems. In the past most systems were AC-DC, however, most recently, the AC-full frequency controllers (FFC)-AC system has been used. Commercial icebreakers and cargo vessels usually have mechanical transmission systems.

5.3.3 Mechanical transmission

Mechanical drive systems are comprised of gearboxes, clutches, and (possibly) flywheels. In ice-going vessels with medium speed diesel engines, gearboxes, and controllable-pitch propellers, it is normal to connect the engine and gearbox through a multidisc clutch, fluid coupling, or both. Flywheels add inertia to a system and have been used both between the prime mover and gearbox and aft of the gearbox.

5.3.4 Shafts and shaft-line components

Shaft couplings are commonly of 2 types. For fixed-pitch propellers, shafting with inboard flanges forged integral with the shaft is most common. When a propeller is bolted to the shaft, as with a controllable-pitch propeller, an outboard flange is provided and the inboard coupling is of the oil-injection muff type. Propeller-shafts for icebreaking vessels should be as short as possible, with the propulsion motors placed as far aft as possible, to reduce the vibration in the shaft, and to reduce the number of shaft bearings required to accomplish this.

Traditionally, water-lubricated, rubber stave bearings have been used in CCG icebreakers. Oil-lubricated, white-metal lined bearings have been used on many privately owned Arctic Class vessels in Canada. There have been no major problems with these bearings, but there is the danger of bearing failure if the oil seal is damaged, and oil is lost.

Statistics show that problems with tail-shaft seals have immobilized more vessels than any other single cause. Radial lip seals are used extensively in Arctic Class vessels with moderately sized shafts, up to about 120 centimetres in diameter, and small stern bearing clearances. Axial face seals are used on some icebreakers and ice-class vessels and have been tested for shafts up to 160 centimetres in diameter.

Warning: Problems with tail-shaft seals have immobilized more vessels than any other single cause.

5.3.5 Propellers

Fixed-pitch propellers are used on most icebreaking vessels. However, since 1966, controllable-pitch propellers have been used on a wide range of icebreakers and icebreaking cargo vessels. Stainless steel and nickel-aluminum bronze are commonly used materials for the propeller blades of ice-class vessels. Systems which use a non-reversing type of prime mover, such as medium speed diesel engines or gas turbines, will tend to use controllable-pitch propellers to obtain astern thrust. Electric drive systems and slow speed diesel engines generally use fixed-pitch propellers, achieving reverse thrust by reversing the shaft rotation.

Propeller nozzles offer increased propulsion thrust and protection and may reduce the strength requirements for propeller blades. However, shallow draft vessels which operate in the Beaufort Sea have experienced clogging of the nozzles when in thick ice or in deformed ice conditions (such as rafted or ridged ice). Much time can be lost while back-washing brash ice out of clogged nozzles and serious cavitation can result from impeded water flow through a clogged nozzle.

5.4 Steering systems

An analysis of damage to steering systems of ice-going vessels has shown that over half the failures have been to rudder stocks, about 20% to the steering gear, and another 20 per cent to items such as pintles and bushings, keys, and bearings. The highest loading on steering systems occurs during astern operations. The rate of rise of load can be so rapid that pressure relief valves for open-water operation are not sufficiently fast and allow the ice load to reach excessive levels before they become effective.

Warning: Keep rudder amidships while moving astern to avoid high local loads on the steering gear.

The stern arrangement in most icebreakers offers rudder protection with an ice horn located directly above and aft of the rudder. Rudder stops can also be fitted to the hull to stop the rudder at least 2 degrees before the maximum steering gear travel. Baltic icebreaking vessels utilize a twin rudder arrangement with twin screw vessels. CCG practice has been to use a single rudder with twin or triple screw designs.

5.5 Auxiliary systems

Warning: Freezing of deck and engine room systems are the most common problems for foreign vessels navigating in cold climates and ice-covered waters.

5.5.1 Cooling

There is potential for ice and slush to enter sea bays or sea inlet boxes, blocking sea-water flow to the cooling system. This problem is encountered by a majority of vessels entering ice-covered waters, especially when in ballast at light drafts. If water cannot be obtained for the cooling system, the main engines will not perform properly and may overheat causing the engines to shut down, or to be seriously damaged. The design of vessels that operate in ice must prevent the cooling system from becoming blocked by ice.

As a general rule, cooling systems in ice covered waters must:

a) maintain essential seawater by using inlets situated as low and as far aft as possible near the centerline
b) use sea boxes that have the following characteristics:
    i. should be fitted on each side of the ship
    ii. should be as deeply submerged as possible
    iii. should have an area open to the sea of 5 to 6 times the total area of pump suctions served by the sea bay
    iv. should be fitted with a strainer plate at the ship's side having perforations approximately 20 mm diameter to prevent ingestion of ice particles
    v. should be fitted with a low steam pressure connection to clear strainers

vi. should be vented to atmosphere by a valved pipe with a cross-sectional area at least equal to that of the cooling sections

c) use diversion arrangements to introduce warm cooling water to seawater inlets and strainers
d) provide means to manually clear sea inlets of ice blockage by introducing low compressed air or steam
e) allow ice and slush ice, introduced in the system, to float freely away from pump intakes without undue stirring
f) allow temporary or permanent use of ballast water for 2 purposes:
   i. back flushing sea boxes
   ii. cooling the engines as a short-term solution unless a large quantity is available and re-circulated

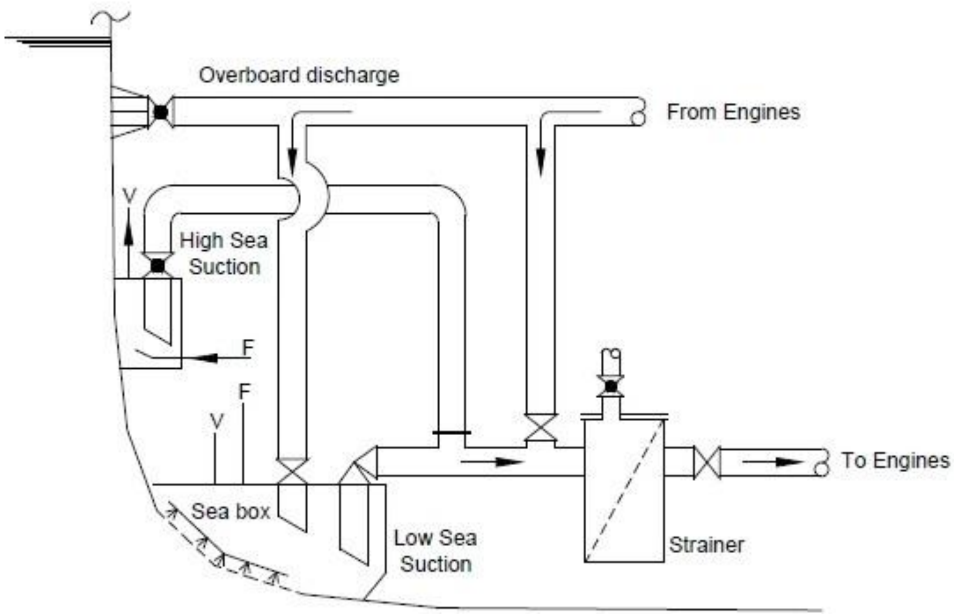


Figure 79 - De-icing returns on sea box and at strainer – section view

Warning: Blockage of the sea boxes can cause the main engine cooling system to overheat, requiring reduced power to be used or the engine to be shut down completely.

Means must be provided to clear the sea bays if they do become blocked by ice. There are several design features that can ease operation or eliminate these problems:

a) high and low inlet grilles can be provided as far apart as possible
b) weir-type sea inlet boxes will overcome the problem of suction pipe clogging. The principle is commonly used in Baltic icebreakers and is shown in figure 80. The suction is separated from the sea inlet grilles by a vertical plate weir. Any ice entering the box can float to the top and is unlikely to be drawn back down to the suction level
c) de-icing return(s) can be arranged to feed steam or hot water to the sea inlet box top, where frazil ice may have accumulated, or directly to the cooling system suction where a blockage may have occurred
d) ballast water recirculation through the cooling water system allows ballast tanks to be used as coolers, alleviating any need to use blocked sea inlet boxes. It should be noted that, while this solution is effective, it is usually a short-term solution unless vast quantities of ballast water are available or if the vessel is fitted with shell

circulation coolers because the recirculated ballast water will quickly become too warm for effective cooling

e) means should be provided to clear the systems manually of blockage by ice

The mariners should be aware of these potential problems and the solutions available to them on their ship.

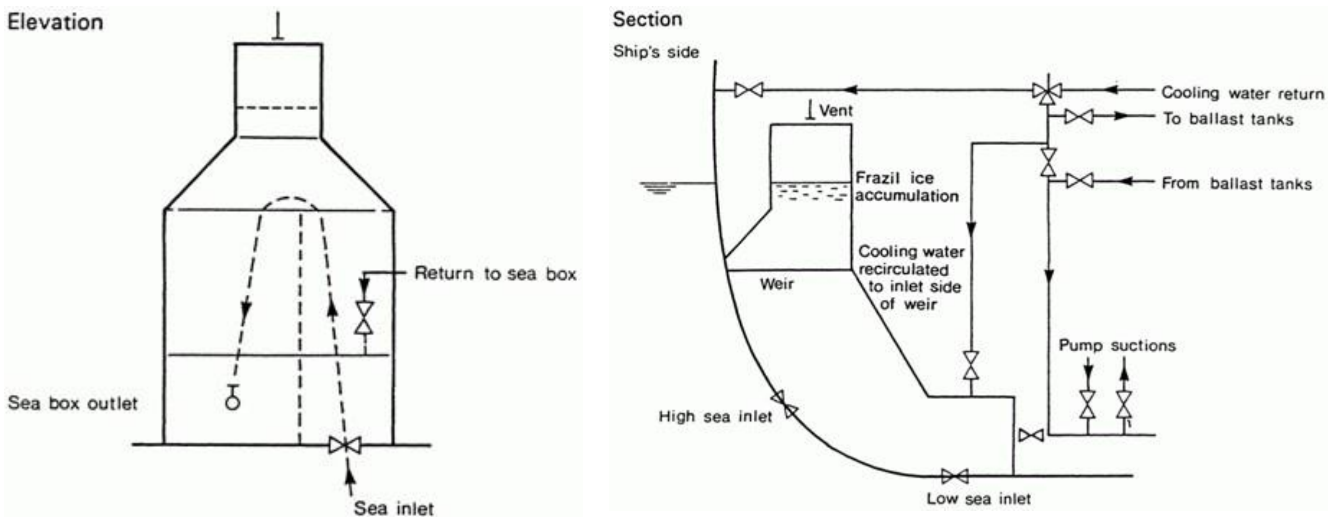


Figure 80 - Weir-type sea inlet arrangements

5.5.2 Freezing of piping, valves and tanks

Water in pipes, valves, and tanks may freeze making it impossible to empty bilges and ballast tanks, which may also result in structural damage. Fore Peak and After Peak ballast tanks are particularly vulnerable to freezing as they are often exposed to the ambient air temperature, being mostly above the waterline. Wing ballast tanks extending above the waterline are also vulnerable to freezing, and any ballast tank filled with fresh water will freeze more quickly than if containing sea water. If ballast tanks are pressed-up, with any standing water in the air vent pipes and sounding pipes, these pipes may freeze, preventing the ballast from being pumped. The vessel design should ensure that freezing is minimized or eliminated by judicious arrangement of the tanks and piping, and selection of valves and heating systems. When the vessel is scheduled to encounter very cold air temperatures every effort should be made to strip tanks and lines in which freezing may occur.

Warning: Water can freeze in bilge and ballast lines and cause structural damage in tanks.

The fire-fighting system is often exposed to the environment and must be available when required. Options to have the fire fighting system available include:

- draining the fire-main system gives the best protection from freezing, but may not always be possible
- drying the fire-main system under air pressure
- filling the fire-main system with a fluid of low freezing point (such as glycol and water); however, this is the least practical option
- allowing the fire-main to flow continuously overboard to maintain circulation; however, this is recommended only for comparatively short-term operation because of the build-up of ice at the overflow points where hydrants have been left open

Hydraulic deck machinery such as windlasses, winches, cranes, boat davits etc. can also be affected by extreme cold. The hydraulic fluid tanks, pumps and piping should be located in heated internal areas of the vessel in proximity to the machinery for which they provide the power.

The mariners must be aware of these potential problems and the solutions available to them on their ship.

5.5.3 Waste Disposal

All vessels produce waste, including: contaminated water ballast, waste oil, domestic garbage, and human wastes. These wastes must be safely and efficiently disposed of, or retained on board, until they can be discharged ashore.

Under the *Arctic Shipping Safety and Pollution Prevention Regulations*, any discharge into the sea of oil, oily mixtures, noxious liquid substances or mixtures containing such substances from any vessel is prohibited.

Discharges of sewage within polar waters are prohibited except when performed in accordance with MARPOL Annex IV at a minimal distance of 3 NM from ice shelf or fast ice and as far as practicable from areas of ice concentration exceeding 1/10. Other exceptions can be applicable.

Discharge of garbage into the Arctic sea is forbidden except under permission in accordance with regulation 4 of MARPOL Annex V.

Warning: Any discharge into the sea of oily or noxious liquid substances mixtures will contravene with the Polar Code.

5.5.4 Fuel oil heating

On vessels that use heavy or intermediate fuel for the main engine it is normal for the fuel to be heated in the main bunker tanks. Steam heating coils are conventional, but thermal fluid may also be used. These coils usually are sized to deal with the low temperatures experienced during Arctic or cold water operations and a temperature control is provided to protect against over-heating. However, great care should be taken to ensure that, when moving into more temperate areas, the fuel oil heating system is not over-heating.

Warning: Make sure that the fuel oil heating system is not over-heating when the vessel moves into more temperate areas.

Annex I Terminology for ice, navigation and vessel design

1.1 Ice terminology

There is an internationally accepted terminology for ice forms and conditions, co-ordinated by the World Meteorological Organization. This terminology is used as the basis for reporting ice conditions by the Canadian Ice Service (CIS), Environment and Climate Change Canada, and is outlined in full in the latest edition of MANICE (2005).

1.1.1 Sea-ice types

Sea ice	Any form of ice found at sea that has originated from the freezing of sea water.
New ice	A general term for recently formed ice that includes frazil ice, grease ice, slush, and shuga. These types of ice are composed of ice crystals that are only weakly frozen together (if at all) and have a definite form only while they are afloat.
Frazil ice	Fine spicules or plates of ice suspended in water.
Grease ice	A later stage of freezing than frazil ice where the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the water a matt appearance. Frequently mistaken for an oil spill as the appearance in open water is similar.
Slush	Snow that is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.
Shuga	An accumulation of spongy white ice lumps having a diameter of a few centimetres across; they are formed from grease ice or slush, and sometimes from anchor ice rising to the surface.
Nilas	A thin elastic crust of ice, easily bending on waves, and swell, and under pressure, growing in a pattern of interlocking "fingers" (finger rafting). Has a matt surface and is up to 10 centimetres in thickness. May be subdivided into dark nilas and light nilas depending on its transparency.
Dark nilas	Nilas up to 5 centimetres in thickness and which is very dark in colour.
Light nilas	Nilas which is more than 5 centimetre in thickness and lighter in colour than dark nilas.
Young ice	Ice in the transition stage between nilas and first-year ice, 10-30 centimetre in thickness. May be subdivided into grey ice and grey-white ice.
Grey ice	Young ice 10-15 centimetre thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.

Grey-white ice	Young ice 15-30 centimetre thick. Under pressure it is more likely to ridge than to raft.
First-year ice	Sea ice of not more than 1 winter's growth, developing from young ice; 30 centimetres to 2 metres thick. May be subdivided into thin first-year ice / white ice, medium first-year ice and thick first-year ice.
Thin first-year ice	First-year ice 30-70 centimetres thick.
Medium first-year ice	First-year ice 70-120 centimetres thick.
Thick first-year ice	First-year ice over 120 centimetres thick.
Old ice	Sea ice which has survived at least one summer's melt. Topographic features generally are smoother than first-year ice. May be subdivided into second-year ice and multi-year ice.
Second-year ice	Old ice which has survived only one summer's melt. Thicker and less dense than first-year ice, it stands higher out of the water. In contrast to multi-year ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.
Multi-year ice	Old ice which has survived at least 2 summers' melt. Hummocks are smoother than on second-year ice, and the ice is almost salt-free. Colour, where bare, is usually blue. Melt pattern consists of large interconnecting, irregular puddles, and a well-developed drainage system.

1.1.2 Lake-ice types

Lake ice	Ice formed on a lake, regardless of observed location.
New lake ice	Recently formed ice less than 5 centimetres thick.
Thin lake ice	Ice of varying colours, 5-15 centimetres thick.
Medium lake ice	A further development of floes or fast ice, 15-30 centimetres thick.
Thick lake ice	Ice 30-70 centimetres thick.
Very thick lake ice	Floes or fast ice developed to more than 70 centimetres thick.

1.1.3 Forms of ice

Pancake ice	Predominantly circular pieces of ice 30 centimetre to 3 metres in diameter, up to 10 centimetre in thickness, with raised rims due to the pieces striking against one another. May form on a slight swell from grease ice, shuga or slush, or as a result of the breaking of ice rind, nilas or, under severe conditions of swell or waves, of grey ice. Sometimes forms at some depth at an interface between water bodies of different physical characteristics, then floats to the surface. Its appearance may rapidly cover wide areas of water.
Ice cake	Any relatively flat piece of ice less than 20 metres across.
Small ice cake	An ice cake less than 2 metres across.
Floe	Any relatively flat piece of ice 20 metres or more across. Floes are subdivided according to horizontal extent as follows:
Small floe	A floe 20-100 metres across.
Medium floe	A floe 100-500 metres across.
Big floe	A floe 500-2,000 metres across.
Vast floe	A floe 2-10 kilometres across.
Giant floe	A floe over 10 kilometres across.
Batture floes	Large, thick, uneven, and discoloured floes often up to 8 kilometres or more across. Form on the upstream side of shoals and islets and along the tidal flats in the St. Lawrence River and Estuary when cold weather precedes or accompanies neap tides. Composed of ice of different thicknesses formed under pressure during ebb tide, the whole mass freezing together, and gradually increasing in size with each successive tide. As the tidal range increases between the neaps and springs, large sections of grounded ice break away and drift down river and into the northwest part of the Gulf of St. Lawrence. This is a Canadian description and not part of the World Meteorological Organization nomenclature.
Brash ice	Accumulation of floating ice made up of fragments not more than 2 metres across, the wreckage of other forms of ice. It can also be found in the track of an icebreaker.

Fast ice	Ice which forms and remains fast along the coast, and is attached to the shore, to an ice wall, to an ice front, between shoals, or grounded icebergs. Vertical fluctuations may be observed during changes of sea-level. It may be formed "in-situ" from water or by freezing of floating ice of any age to shore and can extend a few metres, or several hundred kilometres from the coast. Fast ice may be more than 1 year old in which case it may be prefixed with the appropriate age category (old, second-year, or Multi-year). If thicker than 2 metres above sea-level, it is called an ice shelf. In tidal areas a tide crack will occur along the shore which may contain pressure ridges and areas of open water
Grounded ice	Floating ice that is aground in shoal water.

1.1.4 Arrangement of the ice

Drift ice / Pack ice	Term used in a wide sense to include any area of ice, other than fast ice, no matter what form it takes or how it is disposed. When concentrations are high, that is, 7/10 or more, drift ice may be replaced by the term pack ice.
Ice cover	The ratio of an area of ice of any concentration to the total area of water surface within some large geographic locality. This locality may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

1.1.5 Ice concentrations

Concentration	The ratio expressed in tenths describing the amount of the water surface covered by ice as a fraction of the whole area. Total concentration includes all stages of development that are present; partial concentration refers to the amount of a particular stage or of a particular form of ice, andice and represents only a part of the total.
Consolidated ice	Floating ice in which the concentration is 10/10 and the floes are frozen together.
Compact ice	Floating ice in which the concentration is 10/10 and no water is visible.
Very close pack/drift	Floating ice in which the concentration is 9/10 to less than 10/10.
Close pack/drift	Floating ice in which the concentration is 7/10 to 8/10, composed of floes mostly in contact with one another.
Open drift	Floating ice in which the concentration is 4/10 to 6/10, with many leads and polynyas. Floes are generally not in contact with one another.

Very open drift	Ice in which the concentration is 1/10 to 3/10 and the proportion of open water dominates over the proportion of ice.
Open water	A large area of freely navigable water in which ice is present in concentrations less than 1/10. No ice of land origin is present.
Bergy water	An area of freely navigable water in which ice of land origin is present. Other ice types may be present, although the total concentration of all other ice is less than 1/10.
Ice free	No ice is present. If ice of any kind is present, this term shall not be used.

1.1.6 Ice distribution

Ice field	Area of floating ice, consisting of any size of floes, and greater than 10 kilometres across.
Large ice field	An ice field over 20 kilometres across.
Medium ice field	An ice field 15-20 kilometres across.
Small ice field	An ice field 10-15 kilometres across.
Ice patch	An area of ice less than 10 kilometres across.
Ice massif	A variable accumulation of close or very close ice covering hundreds of square kilometres and found in the same region every summer.
Belt	A large feature of drift ice arrangement. Longer than it is wide; from 1 kilometre to more than 100 kilometres in width.
Tongue	A projection of the ice edge up to several kilometres in length, caused by wind or current. The floating portion of a glacier projecting out from a coastline is also known as an ice tongue.
Strip	Long narrow area of drift ice, about 1 kilometre or less in width, usually composed of small fragments detached from the main mass of ice, which run together under the influence of wind, swell, or current.
Bight	Extensive crescent-shaped indentation in the ice edge, formed by either wind or current.
Ice jam	An accumulation of broken ice caught in a narrow channel, which may extend to the bottom in rivers and shallow waters, forming a dam.
Fracture	Any break or rupture through very close ice, compact ice, consolidated ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with nilas and/or young ice. Length may vary from a few metres to many kilometres.

Fracture zone	An area which has a great number of fractures. Fractures are subdivided as follows:
Very small fracture	0 to 50 metres wide.
Small fracture	50 to 200 metres wide.
Medium fracture	200 to 500 metres wide.
Large fracture	More than 500 metres wide.
Crack	Any fracture of fast ice, consolidated ice, or a single floe which may have been followed by separation ranging from a few centimetres to 1 metre.
Tide crack	A crack at the line of junction between an immovable ice foot, or ice wall, and fast ice, the latter subject to rise and fall of the tide.
Flaw	A narrow separation zone between floating ice and fast ice, where the pieces of ice are in a chaotic state. Forms when ice shears under the effect of a strong wind or current along the fast ice boundary.
Lead	Any fracture or passage-way through ice which is navigable by surface vessels.
Shore lead	A lead between ice and the shore or between ice and an ice front.
Flaw lead	A passage-way between ice and fast ice which is navigable by surface vessels.
Polynya	Any non-linear shaped opening enclosed in ice. May contain brash ice and/or be covered with new ice, nilas, or young ice; submariners refer to these as skylights.
Recurring polynya	A polynya which recurs in the same position every year.
Ice edge	The demarcation at any given time between the open water and sea, lake, or river ice whether fast or drifting. May be termed compacted or diffuse.
Compacted ice edge	Close, clear-cut ice edge compacted by wind or current, usually on the windward side of an area of ice.
Diffuse ice edge	Poorly-defined ice edge limiting an area of dispersed ice, usually on the leeward side of an area of ice.
Ice limit	Climatological term referring to the extreme minimum, or extreme maximum extent of the ice edge in any given month or period based on observations over a number of years. Term should be preceded by minimum or maximum.

Fast ice edge	The demarcation at any given time between fast ice and open water.
Shear zone	The contact zone between fast ice and pack ice where motion and pressure frequently result in an area of heavily ridged and rubbled ice.

1.1.7 Ice surface features

Level ice	Ice which is unaffected by deformation.
Deformed ice	A general term for ice which has been squeezed together, and in places, forced upwards and downwards. Subdivisions are rafted ice, ridged ice, and hummocked ice.
Rafted ice	Type of deformed ice formed by one piece of ice overriding another and remaining horizontal.
Finger rafted ice	Type of rafted ice in which floes thrust "fingers" alternately over and under the other. Common in nilas and grey ice.
Ridge	A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an ice keel. The portion visible on top of the ice is termed the sail.
Ridged ice	Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice.
Hummock	A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a bummock. The broken floes are frequently consolidated and almost impossible to break through.
Hummocked ice	Ice piled haphazardly one piece over another to form an uneven surface. When weathered has the appearance of smooth hillocks.

1.1.8 Ice deformation processes

Fracturing	Pressure process whereby ice is permanently deformed and rupture occurs. Most commonly used to describe breaking across very close ice, compact ice, and consolidated ice.
Hummocking	Pressure process by which ice is forced into hummocks. When the floes rotate in the process it is termed screwing.
Ridging	The pressure process by which ice is forced into ridges.

Rafting	Pressure process whereby 1 piece of ice overrides another. Most common in new and young ice.
Finger rafting	Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternately over and under the other. Common in nilas and grey ice.
Weathering	Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface. Sometimes referred to as a “landscape”, with more developed landscapes found on older ice, a means of estimating the relative age of floes.

1.1.9 Ice motion processes

Diverging	Ice fields or floes in an area that are subjected to diverging or dispersive motion, reducing ice concentration and/or relieving stresses in the ice.
Compacting	Pieces of floating ice are said to be compacting when subjected to a converging motion, which increases ice concentration and/or produces stresses which may result in ice deformation.
Shearing	An area of floating ice is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a flaw. The active ice floes under these conditions can also be described as “screwing” when under the influence of strong tides and turbulence.
Rubbled ice (not in MANICE)	Deformed ice with pieces of ice piled on top of other ice in an irregular fashion, or ice debris remaining between floes after a pressure event.

1.1.10 Ice of land origin

Glacier ice	Ice originating from a glacier, whether on land, or floating on the sea as icebergs, bergy bits, growlers, or ice islands.
Glacier	A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principal forms of glaciers are: inland ice sheets, ice shelves, ice streams, ice caps, ice piedmonts, cirque glaciers, and various types of mountain (valley) glaciers.
Ice shelf	A floating ice sheet of considerable thickness showing 2 to 50 metres or more above sea-level, attached to the coast. Usually of great horizontal extent and with a level, or gently undulating surface. Nourished by annual snow accumulation and also by the seaward extension of land glaciers. Limited areas may be aground. Seaward edge is termed an ice front.

1.1.11 Shapes and sizes of glacier ice

Calving	The breaking away of a mass of ice from an ice wall, ice front or iceberg.
Iceberg	A massive piece of ice of greatly varying shape, protruding 5 metres or more above sea-level, which has broken away from a glacier, and which may be afloat or aground. May be described as tabular, domed, pinnacled, wedged, drydocked or blocky. Sizes of icebergs are small, medium, large and very large.
Tabular iceberg	A flat-topped iceberg whose horizontal dimension is much greater than the vertical dimension. Most show horizontal banding of snow layers.
Domed iceberg	An iceberg which is smooth and rounded on top.
Pinnacled iceberg	An iceberg with a central spire, or pyramid, with 1 or more spires.
Wedged iceberg	An iceberg which is rather flat on top and with steep vertical sides on one end, sloping to lesser sides on the other end.
Drydocked iceberg	An iceberg which is eroded such that a U-shaped slot is formed near, or at water level, with twin columns or pinnacles.
Blocky iceberg	A flat-topped iceberg with steep vertical sides, usually a fragment of a tabular berg.
Growler	Smaller piece of glacier ice than a bergy bit, often transparent, but appearing green or almost black in colour, extending less than 1 m above the sea surface. Has a length of less than 5 m and normally occupying an area of about 20 sq. m.
Bergy bit	A piece of glacier ice, generally showing 1 to less than 5 m above sea-level, with a length of 5 to less than 15 metres. Normally about 100-300 square metres in area.
Small iceberg	A piece of glacier ice extending 5 to 15 metres above sea level and with a length of 15 to 60 metres.
Medium iceberg	A piece of glacier ice extending 16 to 45 metres above sea level and with a length of 61 to 120 metres.
Large iceberg	A piece of glacier ice extending 46 to 75 metres above sea level and with a length of 121 to 200 metres.
Very large iceberg	A piece of glacier ice extending more than 75 metres above sea level and with a length of more than 200 metres.

Ice island	A large piece of floating ice protruding about 5 metres above sea-level, which has broken away from an Arctic ice shelf. It has a thickness of 30-50 metres and an area of from a few thousand square metres to 500 square kilometres or more, usually characterized by a regularly undulating surface giving it a ribbed appearance from the air.

1.1.12 Iceberg concentrations and limits

Limit of all known ice	The limit at any given time between iceberg, or sea-ice infested waters and ice-free waters.
Maximum iceberg limit	Maximum limit of icebergs based on observations over a period of years.

1.2 Navigation terminology

The following definitions pertaining to navigation in ice have been referenced in this manual.

Beset	Vessel unable to move in any direction because of ice surrounding the vessel.
Clutter	Radar signal returns from a distributed target (such as sea surface or ice) which may mask a point target return (such as iceberg, bergy bit, or growler).
Ice plating belt	Area of vessel strengthened to take ice loads at the ice draught water-line.
Ice draft	Draft at which the vessel must be to take advantage of ice strengthening in the hull structure.
Ice horn	Wedge-shaped structure above the rudder intended to help protect it from ice when going astern.
Ice strengthened	Hull strengthened for operating in ice-covered waters.
Keel	Submerged portion of broken ice under a ridge, forced downwards by pressure.
Ramming	Attempting to break ice by repeatedly driving the vessel as far forward as possible, backing the vessel out and repeating the process.
Strategic planning	Small-scale (large area) planning with the assumption that the vessel would be outside of ice-covered waters, days or weeks from encountering ice.
Tactical planning	Considered large-scale (small area), short-term, planning which entails decision making while in ice-covered waters.

1.3 Vessel design terminology

The following definitions pertaining to vessel design have been referenced in this manual.

AC-DC	Type of electric transmission system in which an alternating current (AC) generator drives a direct current (DC) motor linked to the ship's propeller.
AC-FFC-AC	Type of electric transmission system in which an alternating current (AC) generator drives an alternating current (AC) motor linked to the ship's propeller. Located between the generator and motor is a full frequency controller (FFC) which controls the signals from the AC generator.
Arctic class ship	A vessel designed according to Schedule 2 of the *Arctic Shipping Safety and Pollution Prevention Regulations*.
Buttock angle	Angle measured between a tangent at a point on a longitudinal section through the hull and the water-line.
Ductile	Capable of being drawn out into a wire, pliable.
Flare angle	Angle measured from the vertical to the ship's side.
Longitudinal taper	Gradual change in hull shape along the length of the ship, from being wide in the bow region to narrow at the stern.
Modulus	A constant that gives a ratio between the amount of physical effect and that of the force producing it.
Parallel midbody	That portion of a ship's hull characterized by flat shell plating, which does not change shape over a longitudinal distance.
Polar class ship	A vessel designed according to the International Association of Classification Societies (IACS) Unified Requirements for polar class ships.
Sea chest	An enclosure attached to the inside of the underwater shell and open to the sea, fitted with a portable strainer plate. A sea valve and piping connected to the sea bay passes sea water into the vessel for cooling, fire, or sanitary purposes.
Stem angle	Angle measured between the stem of a vessel and the water-line.
Tripping	The collapse of a frame against the side shell.
Type ship	A classification assigned to a vessel as defined in the *Arctic ShippingSafety and Pollution Prevention Regulations*. Type vessels are designed only for navigation in ice-covered waters, not for icebreaking, forming a classified group of ice-strengthened vessels.

Water-line angle	Angle measured between a tangent at a point on a water-line and a horizontal line.

Annex II Reference material

2.1 Navigational charts and nautical publications

According to the *Navigation Safety Regulations, 2020*, Division 6, made under the *Canada Shipping Act, 2001*, the mariner and authorized representative of a vessel must ensure that the most recent versions of charts, documents and publications, in respect of each area where the vessel is scheduled to be navigated, are kept on board. Some exceptions apply.

For the latest information on official paper charts, S-57 vector Electronic Navigational Charts (ENC), BSB Raster Navigational Charts (RNC) and nautical publications, as well as a list of authorized Canadian Hydrographic Service dealers worldwide, please visit Canadian Hydrographic Service or contact:

Canadian Hydrographic Service
200 Kent Street (12th floor W)
Ottawa, Ontario
Canada K1A 0E6
Attention: Client Services
E-mail: CHSInfo@dfo-mpo.gc.ca
Phone: 1-866-546-3613

2.2 Ice information

For the latest information and publications related to ice conditions in Canadian waters, please visit ECCC's Latest ice conditions or contact:

Environment Canada,
Canadian Ice Service
719 Heron Rd, Annex E
Ottawa, Ontario,
Canada, K1A 0H3
E-mail: ec.cisclients-scgclients.ec@canada.ca

The following is a list of publications also providing ice information:

- MANICE is the Manual of Standard Procedures for Observing and Reporting Ice Conditions. MANICE is the authoritative document for observing all forms of ice, including sea, lake and river ice, and ice of land origin.
- Annual Arctic Ice Atlas is a continuing series prepared each year by the Canadian Ice Service since 1990. The collection of atlases documents Canadian Arctic winter sea ice conditions to provide a comparison from year to year.
- 30-year climatic ice atlases for Northern Canadian waters, East Coast and Great Lakes
- *Seasonal Outlooks* for North American Arctic Waters (Upon request. Contact : ec.cisclients-scgclients.ec@canada.ca)
- *Seasonal Summaries* for the Canadian Arctic (Upon request. Contact : ec.cisclients-scgclients.ec@canada.ca)

2.3 Navigation

For the latest TC publications on the subject, please visit the Marine Safety Publications.
An example of some publications related to navigation in ice is listed below:

- Ship Safety Bulletins:
  - TP 12259E - Arctic Ice Regime Shipping System (AIRSS) Standard
  - TP 14044 E Arctic Ice Regime Shipping System - Pictorial Guide (2003)
- Guidelines for the Operation of Passenger Vessels in Canadian Arctic Waters TP 13670 E
- Small Fishing Vessel Safety Manual - TP 10038 E (2003)
- Arctic Waters Oil Transfer Guidelines - TP 10783 E
- Survival in Cold Waters (2003) - TP 13822 E
- About the Canadian Navigable Waters Act
- National Aerial Surveillance Program