Fisheries and Oceans Canada
Coast Guard

Pêches et Océans Canada
Garde côtière

Canada

Canadian Coast Guard

Ice Navigation In Canadian Waters

SALUTI PRIMUM AUXILIO SEMPER

Published by:
Icebreaking Program, Navigational Services Directorate
Fisheries and Oceans Canada
Canadian Coast Guard
Ottawa, Ontario
K1A 0E6

Cat. No. T31-73/199E
ISBN 0-660-17873-7

Revised September 1999

Printed on recycled paper

Record of Amendments

#	Date	Subject	Initials

Foreword

This manual is an updated and augmented Ice Navigation in Canadian Waters, published by the Canadian Coast Guard, Fisheries and Oceans. The manual has been modified to assist ships operating in ice in all Canadian waters, including the Arctic. This document will provide Masters and watchkeeping crew of vessels transiting Canadian ice-covered waters with the necessary information to achieve an understanding of the hazards, navigation techniques, and response of the vessel.

To accommodate both the operational and educational requirements, the manual has been organised in two parts. Part I, Operating in Ice, pertains to operational considerations, such as communications, reporting, advisories, marine radar requirements, and icebreaker support, reflecting closely the original version of **Ice Navigation in Canadian Waters**. Part II, Additional Information for Navigation in Ice-Covered Waters, is instructional in nature, with information provided to help familiarise inexperienced personnel with the Canadian ice environment, navigation procedures in ice, and vessel performance in ice.

Throughout Part II, important points are emphasised in boxes as warnings and notes. Warnings highlight information which has a direct bearing on vessel safety in ice whereas notes bring attention to information which does not necessarily have immediate relevance to operational procedures but is a key element of the topic being discussed. In addition, terms which may be unfamiliar are listed in italics at the start of sections or subsections with their definitions.

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

Table of Contents

Part 1 – Operating In Ice

Part 2 – Additional Information for Navigation in Ice Covered Waters

List of Figures

List of Tables

Part 1 – Operating In Ice

CHAPTER 1 ICE ADVISORY AND SHIPPING SUPPORT SERVICES

1.1 GENERAL

A very extensive service is available throughout the areas referred to in this manual to provide varying degrees of assistance to ships transitting ice-covered waters. The service provided by the Canadian Coast Guard Ice Offices of Fisheries and Oceans Canada ranges from radio and radio facsimile broadcasts of up-to-date general information and forecasts on ice conditions, to detailed advice on routing to ships proceeding independently, and to the provision of icebreaker escort, if available and considered necessary.

Each area is under the surveillance of the Marine Communications and Traffic Services System (MCTS), which the Master may contact for advice and assistance. MCTS Centres in conjunction with the Coast Guard ice operations officers have a complete and current picture of the ice conditions prevailing 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 Masters report to the Canadian Coast Guard before their ships enter waters where ice may be encountered. These initial reports and subsequent position reports from ships will ensure a continuing watch on the ship's progress by Ice Officers and, in the event icebreaker support becomes necessary, this can be provided with a minimum of delay compatible with the normal heavy commitments of these icebreakers. Masters are urged to assist and support this Ice Advisory Service by providing reports on the ice they encounter, either in plain language or in the simple code contained in Annex A.1 and A.2.

1.1.1 Icebreaking Service Fee

In 1995, the federal government announced that it would begin recovering a portion of the cost of providing marine services. The Coast Guard engaged its stakeholders in extensive consultations regarding the form such user fees should take. Prior to the implementation of fees various fee options were examined by the Coast Guard and discussed with shipping industry representatives. Consequently, commercial ships became subject to the Marine Navigation Services Fee in 1996 and the Icebreaking Services Fee (ISF) in 1998.

The ISF recovers a portion of the cost to the federal government of providing Coast Guard ice route assistance, ice routing and information services, and marine facility and port maintenance services in support of commercial shipping. As of 21 December 1998, all commercial ships arriving at or departing from Canadian ports located in the ice zone during the ice season are subject to a transit fee. Details regarding the application of the ISF and explanations of the ice zone and ice season are available on the Coast Guard's web site (www.ccg-gcc.gc.ca) or by calling 1-800-563-6295.

1.2 COMMUNICATIONS

> ***NOTE:*** *The Canadian Coast Guard has amalgamated its Vessel Traffic Services (VTS) and Coast Guard Radio Stations (CGRS) programs into a new organization called Marine Communications and Traffic Services (MCTS)*

Communications play a key role in successful ice navigation. The Master 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 Canadian Coast Guard icebreakers is provided in subsection 2.7.1 of Part I of this manual.

The MCTS Centres and respective frequencies listed in sections 1.4 to 1.7 are those normally used for transmission of ice information. For full details on MCTS Centres and their services, the appropriate national publications on Radio Aids to Marine Navigation should be consulted. These are listed in Annex B.

Masters are advised that the following messages are handled without charge by MCTS Centres:

- messages pertaining to weather or ice conditions and forecasts;
- messages concerning aids to navigation;
- ECAREG and NORDREG messages;
- messages from MCTS Centres to ships (no ship charge); and
- reports from ships requested in this manual.

> ***NOTE:*** *In order to keep a current and accurate picture of the conditions vessels may encounter in transit it is highly recommended that vessels participating in the ECAREG or NORDREG traffic systems where ice is present provide position, ice and weather information at 1200, 1600 (the routine reporting time) and 2000 UTC.*

1.3 REPORTS FROM SHIPS

The Eastern Canada Vessel Traffic Services System, known as ECAREG CANADA, is a mandatory system providing the mariner with a single contact for government services. The Eastern Canada Vessel Traffic Services Zone Regulations apply to every ship of 500 tonnes gross tonnage or more. They are also mandatory for ships engaged in towing or pushing one or more vessels with combined tonnage of 500 tonnes, or when either vessel is carrying a pollutant or dangerous goods, as defined in Canadian and international regulations.

Inbound ships 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; and
- type of propulsion system.

A traffic clearance is issued by ECAREG CANADA which authorizes a vessel to proceed subject to any conditions issued in the clearance. Routine reports are also required for arriving at and departing a berth and exiting the ECAREG CANADA zone. The procedures and information required for these reports is contained in the latest edition of the Canadian Coast Guard publication Notice to Mariners -Annual Edition. The procedural reports described in detail in the following pages may be passed free of charge through any MCTS Centre.

ECAREG CANADA operations are spread through several offices which have jurisdiction over parts of eastern Canadian ice-covered waters, including the St. Lawrence Seaway and Great Lakes.

NOTE: *Contact must be made with ECAREG CANADA before entering Canadian Waters, to obtain traffice clearance for the Eastern Canada Vessel Traffic Services zone.*

1.4 NEWFOUNDLAND, MARITIMES, ST. LAWRENCE RIVER, AND GREAT LAKES

This area is divided into four areas (see Figure 1 for Areas A, B and C, and Figure 2 for Area D) for the purposes of provision of up-to-date information on ice conditions, routing advice, the provision of icebreaker support where available and considered necessary, and the organization of convoys if required.

The Canadian Coast Guard Ice Operations Centres are in operation seasonally as ice conditions dictate within their area of responsibility. During the winter season they are in operation 24 hours a day and are staffed with professional Ice Officers who have experience in the operation of icebreakers and ships in ice. The Centres work in conjunction with ECAREG CANADA, to provide up-to-date ice information, to suggest routes for ships to follow through or around ice, and to co-ordinate icebreaker assistance to shipping.

The Ice Operations Centres are in contact with icebreakers at all times and maintain contact with, and monitor progress of, shipping through Canadian Coast Guard MCTS Centres. All radio traffic for Ice Operations is directed through ECAREG CANADA via the appropriate MCTS Centre. Radio traffic for the Great Lakes should be addressed to Ice Sarnia.

The Ice Operations Centres are also in direct contact with shipping agents, shipowners, charterers, and port authorities on an as-required basis. In addition, the Ice Patrol aircraft and Canadian Ice Service (CIS) in Ottawa are both involved with Ice Operations Centres on a full-time basis and fully qualified Ice Specialists are stationed in the Ice Operations Centres throughout the ice navigation season.

For vessels operating on the East Coast of Canada, requests for ice services may be forwarded via the nearest MCTS Centre, free of charge, to ECAREG CANADA. 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 to ECAREG CANADA any requests for ice services received by them.

Vessels transitting 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 by contacting Vessel Traffic Services in their area of operation on the appropriate sector channel frequency if transit of the St. Lawrence River has commenced.

Ice Information Services are provided during the period in which the presence of ice constitutes a hazard to marine traffic in the ECAREG CANADA zone.

Area A - Newfoundland

All waters south and east of Cape Chidley, including Hamilton Inlet and Strait of Belle Isle north of a line drawn from Flower's Cove, Newfoundland (51°18’N, 56°44’W) west to the Quebec/Labrador border (51°25’N, 57°07’W) and east of a line drawn from Rose Blanche, Newfoundland, through position 43°25’N, 55°05’W. (See Figure 1.)

Address:	St John’s MCTS Centre Fisheries and Oceans, Canadian Coast Guard P.O. Box 5667 St. John’s, Newfoundland A1C 5X1
Radiogram:	ECAREG CANADA
MCTS Centre:	St. John’s, Newfoundland (or via any MCTS Centre)
Call Sign:	VON
Telephone:	(709) 772-4580 or (709) 772-2078
Fax:	(709) 772-5369
Reporting:	Ships inbound from sea to a port in Area A should report to ECAREG CANADA 24 hours before arrival. Ships outbound should report to ECAREG CANADA 2 hours before departure.

Figure 1 Area A (East Coast), B (Gulf of St. Lawrence), and C (St. Lawrence River)

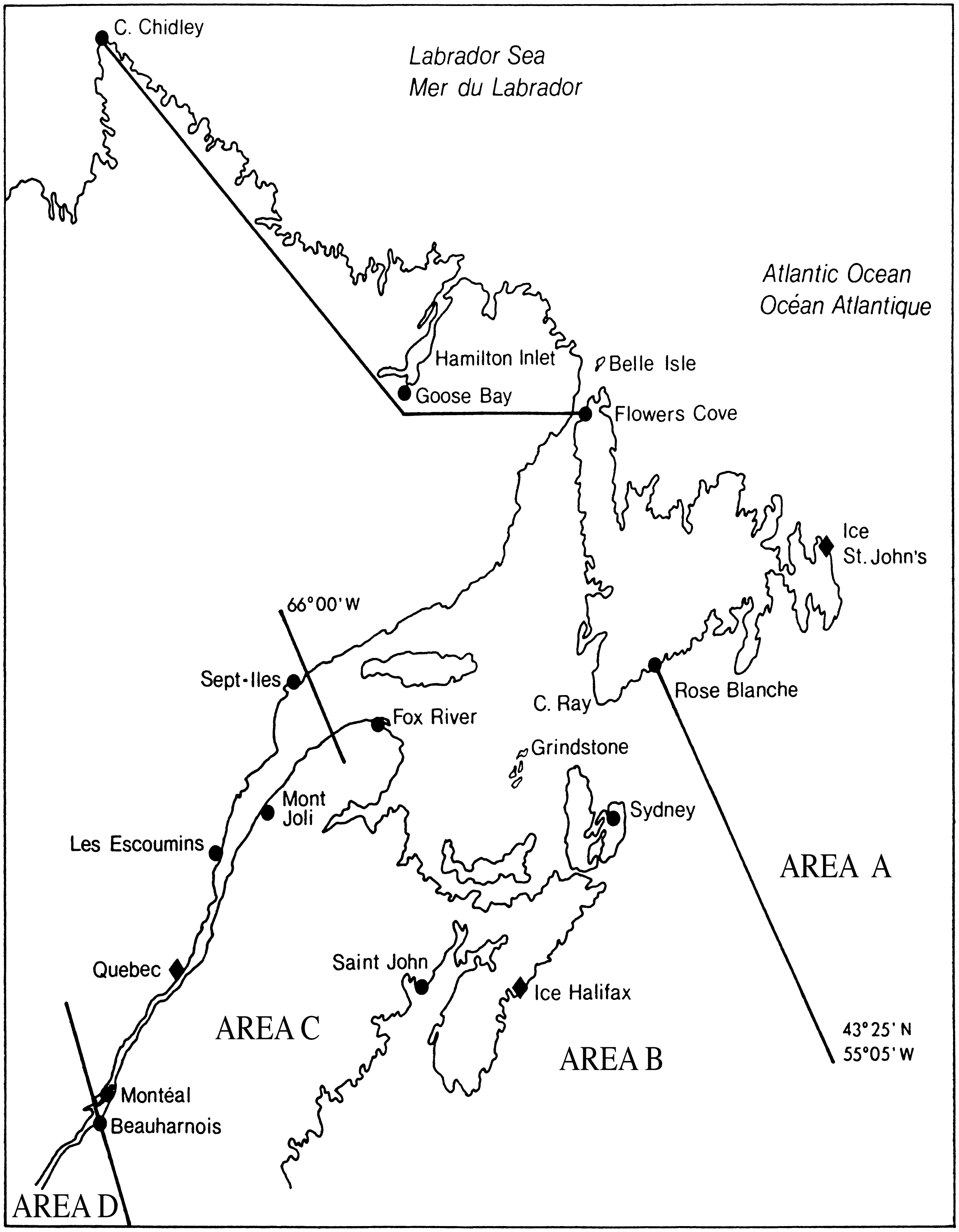
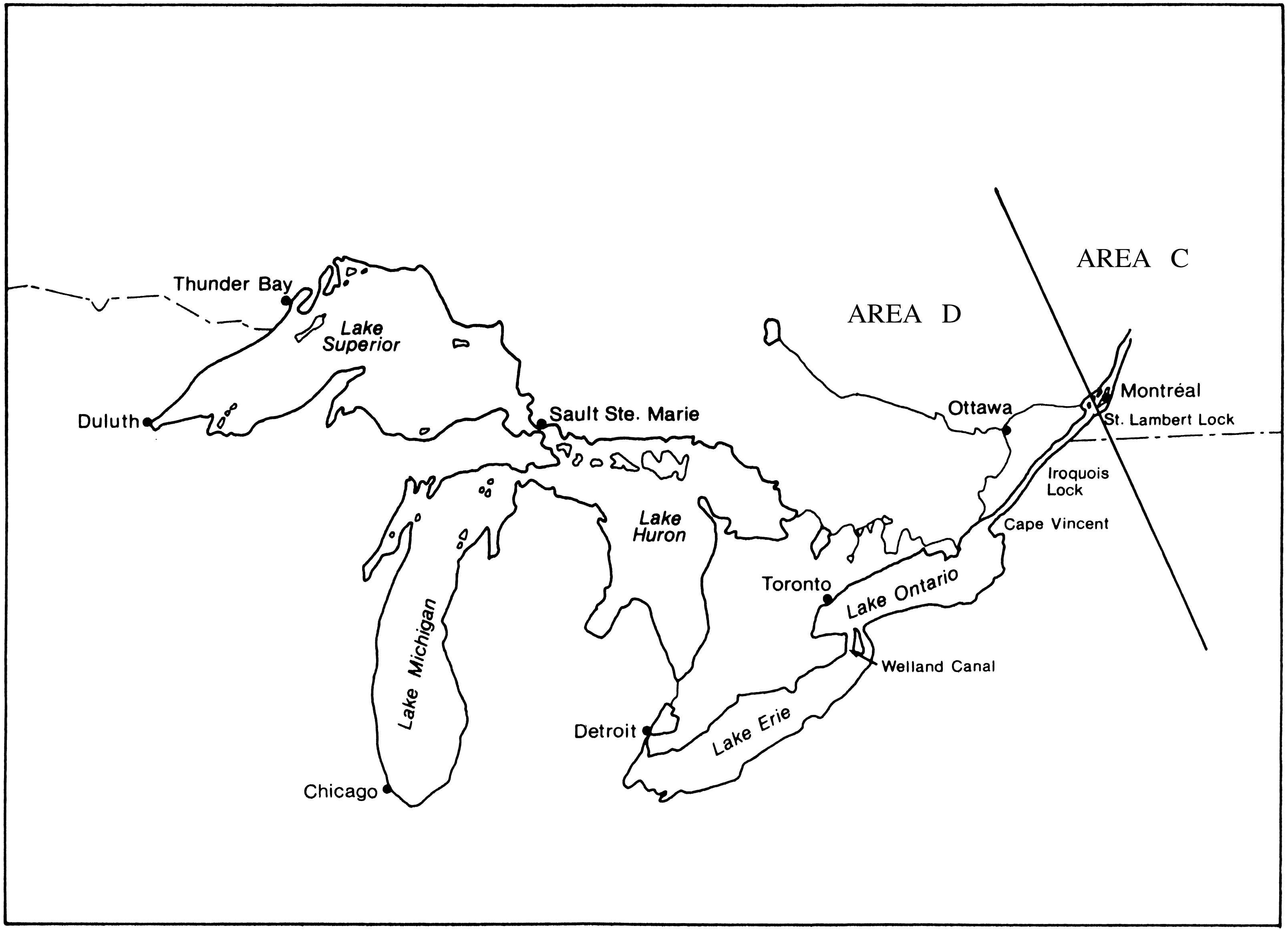


Figure 2 Area D (Great Lakes)



Area B - Maritimes

All waters east of Longitude 66°00'W including the Strait of Belle Isle south of a line drawn from Flower's Cove, Newfoundland, (51°18’N, 56°44’W) and west to the Quebec/Labrador border (51°25’N,57°07’W) line and all waters west of a line drawn from Rose Blanche through position 43°25’N, 55°05’W. (See Figure 1.)

Address:	Halifax MCTS Centre Fisheries and Oceans Canadian Coast Guard 2nd Floor Shannon Hill P.O. Box 1000 Dartmouth, N.S. B2Y 3Z8
Radiogram:	ECAREG CANADA
MCTS Centre:	Halifax, Nova Scotia (or via any Canadian Coast Guard MCTS Centre)
Call Sign:	VCS 2118/2514 kHz or 2206/2582 kHz 161.9 kHz RT VHF Ch 26
Telephone:	(902) 426-5664, or (902) 426-5665
Fax:	(902) 426-6444
Reporting:	Ships inbound from sea to a port in Area B should report to ECAREG CANADA 24 hours before passing Cape Ray. Ships outbound should report to ECAREG CANADA 2 hours before departure.
Independent Shipping Position and Progress Reports:	Ships proceeding independently throughout the Gulf of St. Lawrence when ice is present should report their positions and progress to ECAREG CANADA at 1600 UTC.

Area C - St. Lawrence River

The St. Lawrence River from 66°00'W to upper Beauharnois Lock. All ships' movements in this area are under the general control of the St. Lawrence Waterway MCTS System and ice information/advisory services are handled through this system as follows:

(a) For general information on ice conditions:

Address:	Marine Communications and Traffic Services Fisheries and Oceans Canadian Coast Guard 101 Champlain Boulevard Quebec, Quebec G1K 7Y7
Telephone:	(418) 648-4427
Fax:	(418) 648-7244

(b) For detailed information on routing, ice information and icebreaker support:

Address:	ICE QUEBEC Fisheries and Oceans Canadian Coast Guard Laurentian Region 101 Champlain Boulevard Quebec City, Quebec G1K 7Y7	
For Icebreaker Support	***Telephone:***	(418) 648-7290
	Fax	(418) 648-3614
For Ice and Routing Information	***Telephone:***	(418) 648-2214
	Fax	(418) 648-7305
Reporting:	Ships inbound for a port in Area C should report to ECAREG CANADA 24 hours before passing Cape Ray. Inbound shipping should also establish communications with Les Escoumins Traffic on passing from Area B to Area C, to obtain the latest ice conditions between Sept Iles and Montreal and for recommended routing advice to reach Les Escoumins Pilot Station. Ships outbound should report to the MCTS Centre, Montreal, 2 hours before departure.	

Area D - Great Lakes

The Great Lakes, from upper Beauharnois Lock to Thunder Bay, including the main connecting navigable waterways, Georgian Bay, and the upper St. Lawrence River. (See Figure 2)

The Canadian Coast Guard has established an ice operations centre in Sarnia, Ontario, known as ICE SARNIA. ICE SARNIA operates in concert with the United States Coast Guard Ice Navigation Centre and, between the two, they co-ordinate ice operations in the Great Lakes. ICE SARNIA normally commences operation on December 1 each year and terminates when ice conditions permit unrestricted navigation.

Ships operating in this zone may obtain the latest ice information by contacting ICE SARNIA directly or by sending messages, free of charge, via any Canadian Coast Guard MCTS Centre, to ICE SARNIA.

Address:	ICE SARNIA Canadian Coast Guard 105 Christina Street South Sarnia, Ontario N7T 7W1
Telephone:	(519) 383-1855
Fax:	(519) 337-2498
Operation:	24 hours
Office Hours:	0800 - 1600 (local time)

1.5 ST. LAWRENCE RIVER - SHIP CHANNEL

Special conditions exist in the St. Lawrence River between Quebec and Montreal where broken ice brought down by the current is apt to consolidate, forming extensive jams and ice dams which can cause a rapid rise in the water level to dangerous heights. To help prevent the development of this situation, icebreakers operate in the river throughout the winter to keep a channel open for the unobstructed movement of broken ice downstream. This channel also permits the passage of ships.

The ship 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 ships. 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 Canadian Coast Guard 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 ships. However, this procedure, which is the only way to clear the channel, is in itself the best way of freeing any beset ships 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 ships in the area of the jam. It may, therefore, be necessary to delay sailings or to curtail movement in that part of the river.

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.

1.6 St. Lawrence Seaway

The St. Lawrence Seaway extends from Montreal to Lake Erie. (See Figure 2). 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 upbound entrance of the Seaway), to Iriquois Lock and beyond to Lake Ontario.

The navigation season on the waterway now extends from early April 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 transitting 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 latest edition of the Seaway Handbook, as listed in Annex B of this manual, for complete regulations governing the St. Lawrence Seaway.

1.7 Arctic Waters including Hudson Bay and Hudson Strait

During the summer navigation season in the Arctic, a service for the support of ships navigating in ice is provided by the Arctic Canada Traffic System (NORDREG CANADA). NORDREG CANADA is a voluntary ship reporting system which operates in a similar manner to ECAREG CANADA in terms of ship reporting procedures and provision of ice information, vessel routing, and icebreaker assistance.

Mariners may obtain these ice services by sending a message, free of charge, via the nearest Canadian Coast Guard Marine Traffic and Communications Service Centre to NORDREG CANADA. The NORDREG CANADA Zone comprises all Canadian waters north of 60°00'N, those areas of Hudson and Ungava Bays south of 60°00'N, and all waters to which the Arctic Waters Pollution Prevention Act apply, excluding Mackenzie Bay and Kugmullit Bay south of 70°00'N and east of 139°00'W (See Figure 3.)

The provisions of NORDREG CANADA apply to every ship of 300 tonnes gross tonnage or more. Participation is voluntary, but mariners are encouraged to participate fully to receive the maximum benefit. NORDREG CANADA has similar application as ECAREG CANADA concerning vessels towing other vessels and in the transport of pollutants or dangerous goods.

The NORDREG CANADA office is located in Iqaluit, Baffin Island, Nunavut and is supported by the Canadian Coast Guard Ice Office in Sarnia, Ontario.

The information and reporting requirements for NORDREG CANADA are contained in the Canadian Annual Edition, Notices to Mariners.

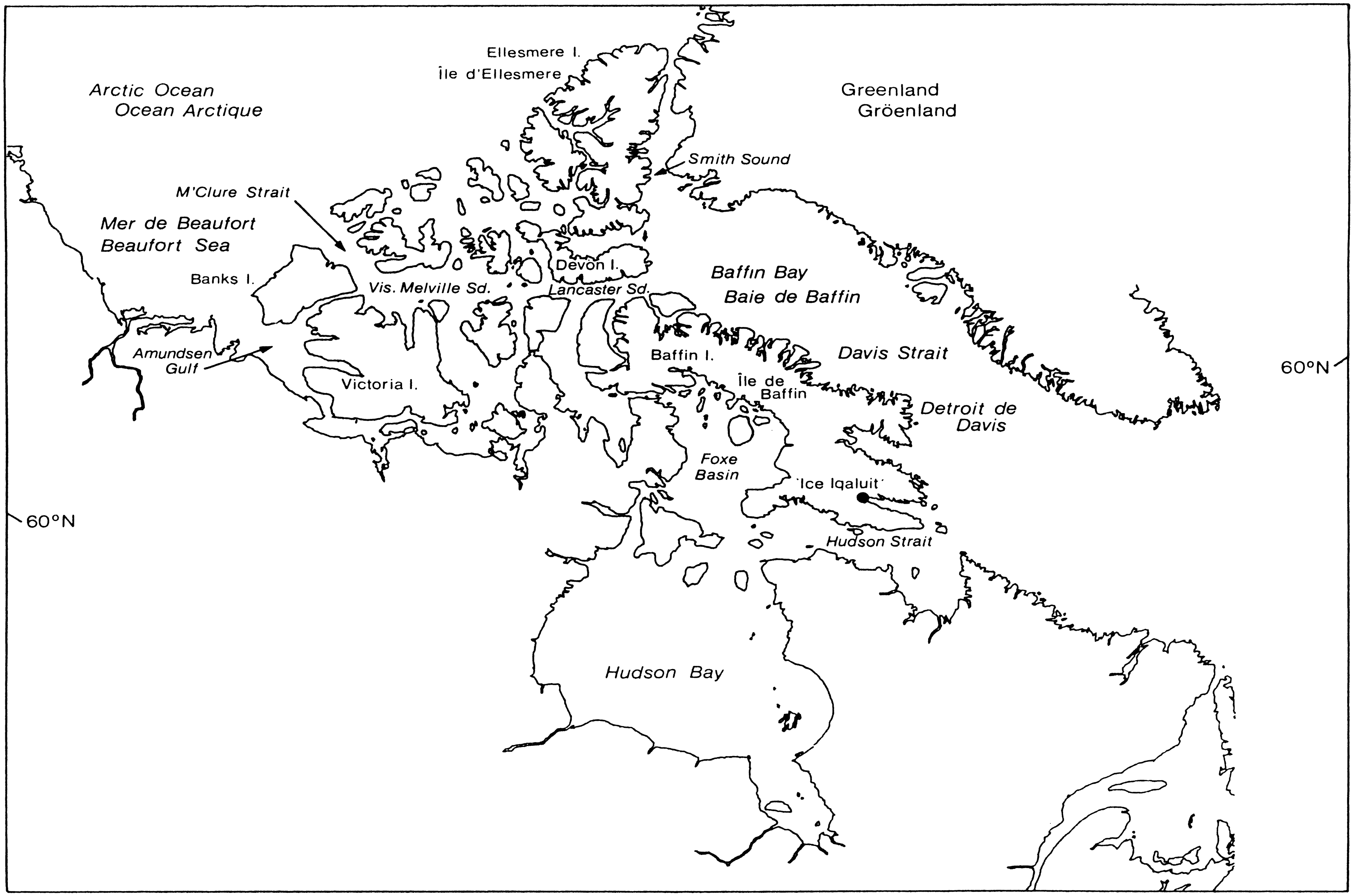
> ***NOTE**: Contact NORDREG CANADA before entering NORDREG CANADA zone*

(a) For detailed ice information, routing advice, and information on icebreaker support:

Address:	Fisheries and Oceans Canadian Coast Guard NORDREG Operations P.O. Box 189 Iqaluit, Nunavut X0A 0H0
Radiogram:	NORDREG CANADA
Radio Station:	Iqaluit - or via any MCTS centre
Call Sign:	VFF 2582 kHz RT
Telephone:	(867) 979-5724
Fax:	(867) 979-4236
Reporting:	Ships inbound to ports in Arctic waters should report (see Section 1.3) to NORDREG CANADA 24 hours before entering the NORDREG CANADA Zone. Ships outbound from Arctic ports should report to NORDREG CANADA as soon as the sailing date is known.

To make the best use of available icebreaker resources, it is essential that NORDREG CANADA be kept informed of the positions and progress of shipping proceeding independently in this area. Vessels which are proceeding independently should report their positions daily at 1600 UTC to NORDREG CANADA.

Figure 3 NORDREG CANADA Zone: Arctic Waters, including Hudson Bay and Hudson Strait



(b) For Hudson Bay area:

The Port Warden, through NORDREG CANADA, will provide ice information for Churchill. However, requests for information on local ice conditions at other Hudson Bay ports should be passed directly to NORDREG CANADA.

Address:	Ice Information Office Fisheries and Oceans Port Warden National Harbours Board Building Churchill, Manitoba R0B 0E0
Radiogram:	"Ice Info. Churchill"
MCTS Station:	Churchill (or via any MCTS centre)
Call Sign:	VAP 2582 kHz RT
Telephone:	***Office:*** (204) 675-2263 ***Evening:*** Contact Port Warden via Churchill Radio
Fax:	(204) 675-2611

1.8 COAST GUARD ICE OFFICES

The Canadian Coast Guard maintains Ice Offices to service regions where ship operations are conducted in sea-ice conditions. These offices are located with ECAREG CANADA and NORDREG CANADA offices, and requests from ships for ice information, routing advice, and requests for icebreaker support which are received are passed to Canadian Coast Guard Ice Officers.

The following list gives the locations of the four Coast Guard Ice Offices and their area of responsibility:

- **St. John's, Newfoundland**, for Newfoundland Waters and Labrador Sea in winter;
- **Dartmouth, Nova Scotia**, for the southern and western Gulf of St. Lawrence south of the main shipping corridor between Cabot Strait and the St. Lawrence River, Port of Gaspe, Chaleur Bay, New Brunswick and Prince Edward Island waters and the approaches to Sydney Harbour;
- **Quebec City, Quebec**, for the St. Lawrence River east of Montreal, including Saguenay River and the main shipping corridor between the St. Lawrence River and Cabot Strait;
- **Sarnia, Ontario**, for the Great Lakes and St. Lawrence Seaway to Montreal during the winter navigation season; and **Sarnia, Ontario and Iqaluit, Nunavut** jointly for eastern, high, and central Arctic, Foxe Basin, Hudson Strait, and Hudson Bay.

Contact with all Ice Offices can be made through ECAREG CANADA and NORDREG CANADA (for Arctic waters) through any MCTS centre as described in Part I, Chapter 1, Section 1.7.

The duties of each Ice Office are many and varied. One purpose is to maintain an update on current ice conditions, acquired from information supplied by Canadian Ice Service, as well as from ship and shore ice reports. This update is available for ships requesting it 24 hours a day. The Ice Offices also maintain a status on Canadian Coast Guard icebreakers, and plan daily activities and tasks for icebreakers stationed in the Great Lakes, Gulf of St. Lawrence and East Newfoundland and the eastern, central, and high Arctic. These daily plans are based on the ice conditions and daily requests for support. In the Gulf and east coast, the Canadian Coast Guard Ice Officers plan detailed routes for ships, which are updated on a daily basis or as required. All routing is provided in terms of waypoints.

1.9 ICE ADVISORY SERVICES

Throughout the year, ice information services for Canadian navigable waters are provided by Canadian Ice Service, Environment Canada, in Ottawa. Ice forecasts and ice charts are issued daily for areas of known marine activity and where ice is a navigational hazard; they are distributed to the Coast Guard Ice Operations Offices and are also broadcast by radio and radio facsimile. Particulars of these broadcasts are contained in the Canadian Coast Guard publication, Radio Aids to Marine Navigation - Atlantic and Great Lakes, referred to in Annex B. Canadian Coast Guard Marine Traffic and Communications Service stations will also provide ice information on request. Pre-departure ice information is available through the appropriate Area Ice Operations office. Information for longer term planning, extended period ice forecasts, and ice consultation services are available directly from the Canadian Ice Service, Ottawa.

Telephone: (613) 996-1550

Fax: (613) 563-8483

1.10 CANADIAN ICE SERVICE - ENVIRONMENT CANADA

Ice information is collected and collated by the Canadian Ice Service (CIS), Environment Canada on behalf of the Canadian Coast Guard. Canadian Ice Service responds to the needs of the Canadian Coast Guard, which funds an aircraft reconnaissance program to support the collection of ice data for use in the preparation of charts and forecasts.

Canadian Ice Service also deploys Ice Services Specialists on the larger Canadian Coast Guard icebreakers, who provide services including the reception of airborne radar and satellite imagery and carrying out tactical ice reconnaissance on helicopters for the icebreaker and Ice Operations Officers.

1.10.1 Canadian Ice Service (CIS)

Canadian Ice Service maintains a central operating facility in Ottawa for collating all ice data. CIS is responsible for the preparation of ice analysis charts and written ice forecasts, warnings, and bulletins for all ice-covered waters in Canada.

Address:	Canadian Ice Service – Environment Canada Lasalle Academy, Block E, 373 Sussex Drive Ottawa, Ontario K1A 0H3
Telephone:	(613) 996-5236
Fax:	(613) 563-8480

CIS supplies ice information to the Canadian Coast Guard Ice Offices which maintain a complete and current picture of ice conditions in their area for dissemination to vessels through ECAREG /NORDREG.

1.10.2 Ice Reconnaissance Aircraft

The Canadian Ice Service reconnaissance aircraft transmit ice charts of actual ice conditions observed during the flight to facilities and vessels equipped to receive them. Particulars of airborne facsimile transmissions from ice reconnaissance aircraft are contained in Radio Aids to Marine Navigation - Atlantic and Great Lakes, referred to in Annex B.

CIS manages the operation of one dedicated aircraft equipped for ice reconnaissance missions in the Gulf of St. Lawrence, East Newfoundland Waters, the Great Lakes and the Canadian Arctic. The aircraft is equipped with radar remote sensing systems that are able to penetrate cloud cover to obtain a view of the surface below.

The aircraft, a Dash 7, is owned by Transport Canada, and is operated and staffed by Ice Reconnaissance personnel. Known as CAN-ICE 3, this aircraft often flies combined visual and radar reconnaissance missions. Charts of actual ice conditions may be transmitted by facsimile during flight by line-of-sight communication. Details of these facsimile transmissions are provided in Radio Aids to Marine Navigation referred to in Annex B.

Ice reconnaissance missions are conducted for strategic, tactical and climatological uses. Most flights are tactical in nature to support detailed routing of Coast Guard icebreakers and merchant ships. Customized ice reconnaissance services are available, subject to normal programme constraints, on a cost-recovery basis. Radarsat provides daily information during the shipping season in the Arctic and southern waters and provides images of the ice in the high Arctic in the winter to provide information on the general ice conditions and distribution of old ice before the start of the navigation season. CAN-ICE 3 is also used to carry out ground truthing flights of satellite imagery in order to visually identify the presence of small floe multi-year ice.

1.10.3 Ice Observations from Vessels

Observations from vessels on weather, sea, and ice conditions are important sources of information for the Canadian Ice Service. Direct observations from vessels are useful in preparing ice maps and analyses.

Observations can be passed to Canadian Ice Service (information listed in section 1.10.1), or to the local Coast Guard Office which will forward the information to the Ice Centre. No cost is involved. Weather, sea, and ice observations can be added to any position report given; for instance, all vessels participating in the NORDREG CANADA system in Arctic waters are to provide a once daily 1600 UTC position report.

Additional position and ice reports are encouraged and recommended at 1200 and 2000 UTC. The provision of this supplemental information ensures that all participants benefit from the most complete and up to date ice information possible.

1.11 ENVIRONMENT CANADA WEATHER CENTRES

Weather forecasts and warnings are issued for Canadian marine areas by Environment Canada from regional Weather Centres. Meteorologists at these Centres provide 24-hour services in the form of forecasts and consultation.

Weather Centres providing forecasts and warnings are:

- Ontario Weather Centre - Thunder Bay, for the Great Lakes

  Telephone: (807) 346-8022

  Fax: (807) 346-8683

- Centre Metéorologique du Quebec, for the St. Lawrence River, James Bay, and eastern sections of Hudson Bay

  Telephone: (514) 283-1114

  Fax: (514) 283-1155

- Maritimes Weather Centre, for the Gulf of St. Lawrence and waters off Nova Scotia, New Brunswick, and Prince Edward Island

  Telephone: (902) 426-9200

  Fax: (902) 426-9158

Newfoundland Weather Centre, for Newfoundland Waters and Labrador Sea

  Telephone: (709) 256-6611

  Fax: (709) 256-6604

Arctic Weather Centre, for western sections of Hudson Bay, Hudson Strait, and waters north of 60°00'N and Lake Athabasca and southwestern and central Hudson Bay

Telephone: (403) 951-8629

Fax: (403) 495-2615

1.11.1 Weather Forecasts for Marine Areas

Marine forecasts are generally prepared for distinct marine areas twice daily. The forecasts are valid for two days with a third 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 marine radio stations.

For example, most of the Weather Centres provide four scheduled forecasts each day for their area of responsibility. The Arctic Weather Centre provides twice daily scheduled forecasts for the Arctic and northern/western Hudson Bay waters.

All of the Weather Centres listed above have produced manuals, videos, or guides which outline local conditions and forecasts. A specific example is the East Coast Marine Weather Manual. These manuals or guides are available to the mariner by contacting the appropriate Weather Centre.

1.11.2 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 annual edition of Radio Aids to Marine Navigation - Atlantic and Great Lakes, or Radio Aids to Marine Navigation - Pacific for a listing of charts available and their transmission times.

The Arctic Weather Centre provides weather charts for Arctic areas for broadcast by Coast Guard Iqaluit and Coast Guard Resolute during the active shipping season. Numerous charts are transmitted by the Canadian Meteorological and Oceanographic Centre in Halifax, Nova Scotia, including sea condition charts, throughout the year.

1.11.3 Marine Observations from Vessels

Observations from vessels on weather, sea, and ice conditions are important sources of information for the Weather Centres. 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; and
- 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 transitting 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 Climate Centre in Toronto 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 Weather Centre, listed in section 1.11, or to the local Coast Guard Office which will forward the information to the Weather Centres. 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.

1.12 WINTER AIDS TO NAVIGATION IN CANADIAN WATERS

During the winter months Masters 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 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.

> **WARNING: MARINERS ARE CAUTIONED NOT TO RELY SOLEY ON BUOYS OR OTHER NAVIGATION AIDS FOR NAVIGATION PURPOSES.**

(a) Loran Station

Although continuous service is maintained for Canadian coverage, Masters are cautioned that possible unpredicted interruptions may occur to transmissions because of severe icing at the shore stations. Mariners should also be aware that the Canadian Coast Guard has announced its intention to terminate LORAN C coverage after the year 2000.

(b) Global Positioning Systems (GPS) and Differential Global Positing System (DGPS)

Full GPS coverage is now in effect in all areas. Accuracy for the civilian Standard Positioning Service (SPS) is advertised at 100 m 95% of the time (0.06 nautical miles) from a stationary receiver. Accuracy is known to decrease 0.2 nautical miles per knot of unknown vessel speed. Solar Cycle interference may affect operation, however, this cycle occurs only approximately every 11 years. Accuracy for GPS is greater with a dual channel receiver than with a single channel receiver.

The Canadian Coast Guard is implementing a Differential Global Positioning System for southern Canadian waters. Initial Operating Service (IOS) was declared in 1996 for the first phase of the system, with Full Operating Service (FOS) for the entire system expected to be declared in 1999. When equipped with a DGPS receiver, mariners can expect accuracies of 10 metres or better, 95% of the time, when FOS is declared.

Although mariners will currently be able to use DGPS and obtain the above stated accuracies, they should be aware that the system is not yet fully operational and as such are to treat the results achieved with caution. Mariners are also encouraged to pay attention to Notices to Mariners and Notices to Shipping regarding the status of the DGPS system. For more information on the Coast Guard DGPS network, please contact any Coast Guard office in Canada.

CHAPTER 2 NAVIGATION IN ICE

2.1 GENERAL

Ice is an obstacle to any ship, 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 ships in capable hands to navigate successfully through ice-covered waters.

The first principle of successful ice navigation is to maintain freedom of manoeuvre. Once a ship 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 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.

Experience has proven that in ice of higher concentrations, three basic ship handling rules apply:

- keep moving - even very slowly, but keep moving;
- try to work with the ice movement, and not against it; and
- excessive speed means ice damage.

WARNING: EXCESSIVE SPEED IS THE MAJOR CAUSE OF DAMAGE TO SHIPS BY ICE.

A glossary of ice terminology and descriptions is contained in Annex A.

2.2 REQUIREMENTS FOR SHIPS OPERATING IN ICE

The propulsion plant and steering gear of any ship 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 ships should be ballasted as deeply as possible, but excessive stern trim is not recommended, as it cuts down manoeuvrability and increases the possibility of ice damage to the more vulnerable lower area. Suction strainers should be able to be removed easily and to be cleared of ice and snow. Good searchlights should be available to aid in visibility in the event of night navigation with or without icebreaker support.

Ships navigating in ice-covered waters may experience delays and, therefore, should be stored with sufficient fresh-water supplies and manoeuvring fuel.

2.3 ADVERSE ENVIRONMENTAL CONDITIONS

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

- low surface temperatures
- high winds
- 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
- superstructure icing when there is the great and dangerous possibility of heavy and rapid icing with consequent loss of stability.

2.3.1 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 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 ship-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 ship'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, 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.

Superstructure icing is possible whenever air temperatures are -2.2°C or less and winds are 17 knots or more, and when these conditions occur simultaneously. Generally speaking, winds of Beaufort Force 5 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.

WARNING: VESSEL ICING MAY IMPAIR THE STABILITY AND SAFETY OF A SHIP.

2.4 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.

(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.

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

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.

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.

(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.

2.5 USE OF RADAR FOR ICE DETECTION

Radar can be a great asset in ice navigation during 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. Areas of open water and smooth floes have a very similar appearance on the radar display, and can be confusing to the operator. In an ice field, the edge of a smooth floe is prominent, whereas the edge of an area of open water is not.

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 one 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 two 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.

Ridges:

Although they show up well on the radar display, it is difficult to differentiate between ridges, closed tracks of ships, and rafted ice, as all have a similar appearance on radar.

Icebergs:

Depending upon their size and attitude, icebergs may be detected at ranges between 4 and 15 nautical miles, except in fog, rain, and other conditions affecting radar. Icebergs do not appear as clearly defined targets but the sector of the radar display directly behind the iceberg will be free of clutter. A scale of less than 6 nautical miles usually gives a good display.

Growlers:

Growlers are almost impossible to detect by radar. Very little of a growler appears above the water surface because of the density 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.

> **WARNING:** **GROWLERS ARE ALMOST IMPOSSIBLE TO DETECT BY RADAR. THEY POSE AN IMMENSE THREAT TO SHIPS. KEEP A SHARP LOOKOUT.**

2.6 SHIPS NAVIGATING INDEPENDENTLY

Experience has shown that non-ice-strengthened ships with an open water speed of about 12 knots can become hopelessly beset in relatively light ice conditions, whereas ice-strengthened ships with adequate power should be able to make progress through first-year ice of 6/10 to 7/10 concentration. Such ships are often able to proceed independently without any assistance other than routing advice.

2.6.1 Entering the Ice

The route recommended by the Ice Operations Officer through the appropriate reporting system i.e. ECAREG, is based on the latest available information and Masters are advised to adjust their course accordingly. The following notes on ship-handling in ice have proven helpful:

(a) Do not enter ice if an alternative, although longer, route is available.

(b) It is very easy and extremely dangerous to underestimate the hardness of the ice.

(c) Enter the ice at low speed to receive the initial impact; once into the pack, increase speed to maintain headway and control of the ship.

(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 and keep the propeller turning slowly as it is less susceptible to ice damage than if it were completely stopped.

(f) Propellers and rudders are the most vulnerable parts of the ship; ships should go astern in ice with extreme care - always with the rudder amidships.

(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.

(h) Wherever possible, pressure ridges should be avoided and a passage through pack ice under pressure should not be attempted.

(i) When a ship navigating independently becomes beset, it usually requires icebreaker assistance to free it. However, ships 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 ship.

The Master may wish to engage the services of an Ice Pilot, Ice Advisor or Ice Navigator in the Arctic.

2.6.2 Use of Radar for Navigation in Arctic Waters

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 two 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 water-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 charted fixing aids in the area and dated survey.

2.7 ICEBREAKERS

The Canadian Coast Guard 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 or NORDREG CANADA Office or Ice Operations Office 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.

Canadian Coast Guard 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 ship or convoy (involving a number of ships) 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.

2.7.1 Communicating with Icebreakers

Once a vessel has requested icebreaker assistance, a radio watch should be kept on 2182 kHz and 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. MF and VHF remain as a proven communications tools and should be utilised to maintain contact with the icebreakers.

A continuous radio telephone watch on an agreed frequency should be maintained on the bridges of all ships working with Coast Guard icebreakers. Ships 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

Table 1 lists the letter, sound, visual, or radiotelephony signals that are for use between icebreakers and assisted ships. 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 intership VHF working frequency. It is vital to inform the Ice Offices/icebreaker of any change in the state of your vessel while awaiting an icebreaker escort.

Table 1 Operational signals to be used to supplement R/T communication between icebreaker and escort vessel(s)

Code letters or figures	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	
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	Stop. I am icebound
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 ship in an ice channel ahead of an icebreaker)	I am stopping headway
WO	Icebreaker support is finished. Proceed to your destination	
5	Attention	Attention

Code letters or figures	Icebreaker instruction	Assisted vessel(s) response
	Signals which may be used during icebreaking operations	
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

NOTES:

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

2. *If more than one vessel is assisted, 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.*

3. *The use of these signals does not relieve any vessel from complying with the International Regulations for Preventing Collisions at Sea.*

2.7.2 Report Required Before Escort Commences

Before escort or assistance commences, the icebreaker will require some or all of the following information to assess a ship'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);
- ship's length and beam;
- port of departure and destination;
- cargo type and amount (tonnage);
- ice pilots name;
- 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

- radiotelephone working frequencies, communications systems including telephone and/or fax number.

The onus is on the escorted vessel to advise of any deficiencies that exist on their vessel.

2.7.3 Icebreaking Escort Operations

The following are comments on aspects of icebreaker escort procedures:

(a) **Track width:** Progress through ice by an escorted ship depends to a great extent on the width of the track made by the icebreaker, which is directly related to the distance between the icebreaker and the ship 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 per cent 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, the track may be as much as three 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 ship(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 ship 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 should 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 should be informed at once to avoid the possibility of besetment and resulting decay.

(e) **Maintaining the escort distance:** Masters 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.

(f) **Ice concentration:** With 9+/10 concentration, 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 ship 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, and this 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.

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 the floes into as many pieces as possible, thus reducing the possibility of damage to the ship following in the track.

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

(k) **Freeing a beset vessel:** Freeing a ship 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 ship, and passing back along the vessel's side. To free a ship beset while navigating independently: the icebreaker will normally approach from astern and cross-ahead at an angle of 20 to 30 degrees to the beset ship'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 two ships 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 ship becomes beset during escort, the normal procedure is for the icebreaker to back up to free her and then proceed ahead with the escorted ship following. However, when progress is slow, the Free and Proceed system may be used, in which the beset ship is directed to proceed up the track made by the icebreaker in backing up while the icebreaker follows behind. The icebreaker then 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 ships in ice, Canadian Coast Guard icebreakers use two rotating red lights to indicate that the icebreaker has become stopped.

In most cases these lights are placed in a vertical line 1.8 m apart aft the mainmast and are visible for at least two miles. However, construction restrictions of some icebreakers necessitate that these lights be placed horizontally.

As an additional warning signal, all icebreakers are fitted with and use a zet-horn, facing aft, audible up to 5 nautical miles. 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 Master of the escorted ship should treat these signals with extreme urgency and immediately reverse engines to full speed astern. The rudder should be put hard over until all forward motion has ceased.

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

(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.

(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 should be used and the capstan 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 ship may be stopped in fast ice (when the conditions permit).

(r) **Convoys:** Convoys of ships 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 ships when there is an insufficient number of icebreakers of suitable capacity available to facilitate the escort of ships proceeding to or from similar 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 ships in the convoy are responsible for arranging and maintaining a suitable and safe distance between the vessels. The icebreaker will designate the required distance to be maintained between itself and the lead ship of the convoy.

Part 2 – Additional Information for Navigation in Ice Covered Waters

CHAPTER 3 ICE AND WEATHER ENVIRONMENT

This chapter provides an overview of environmental conditions which can be expected in areas of Canada where navigation in ice occurs. The chapter has four main sections: a summary of important meteorological and oceanographic features of the marine environment, a description of basic ice properties, a review of ice conditions which may be encountered in different regions of Canada, and information on icebergs.

3.1 CLIMATOLOGY AND ENVIRONMENT

Climate A composite or generalization of day-to-day weather conditions (such as temperature, humidity, and wind) for a region.

Glacier A slowly moving river or mass of ice formed on land by the accumulation of snow on higher ground, sometimes extending to the coastline.

Iceberg A floating mass of ice which has detached from a glacier and has been carried out to sea. Icebergs can vary in size and shape.

Sea ice Ice which forms on the ocean surface as a result of sea water freezing.

Climate is the long-term product of variability in weather and ocean conditions. In the following subsections some of the key climatological elements that can be expected in Canadian marine areas are described. Recently, concern for the influence of human activity on the environment has grown. For this reason, some important aspects of the marine environment which relate to navigation are also reviewed in this section.

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. Detailed information on weather, ocean, and environmental conditions may be obtained through other sources. A list of references is included in Annex B.

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. The length of time when air temperatures are below freezing varies considerably over Canadian waters affected by ice.

The occurrence of air temperatures lower than 0°C is an important sign of approaching winter. Figure 4 illustrates the average dates for start of winter in Canada, when average daily air temperatures fall below 0°C. Figure 5 shows the dates for end of winter, when daily mean 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.

Figure 4 **Mean dates for start of winter, when the mean daily temperature falls below 0°C**

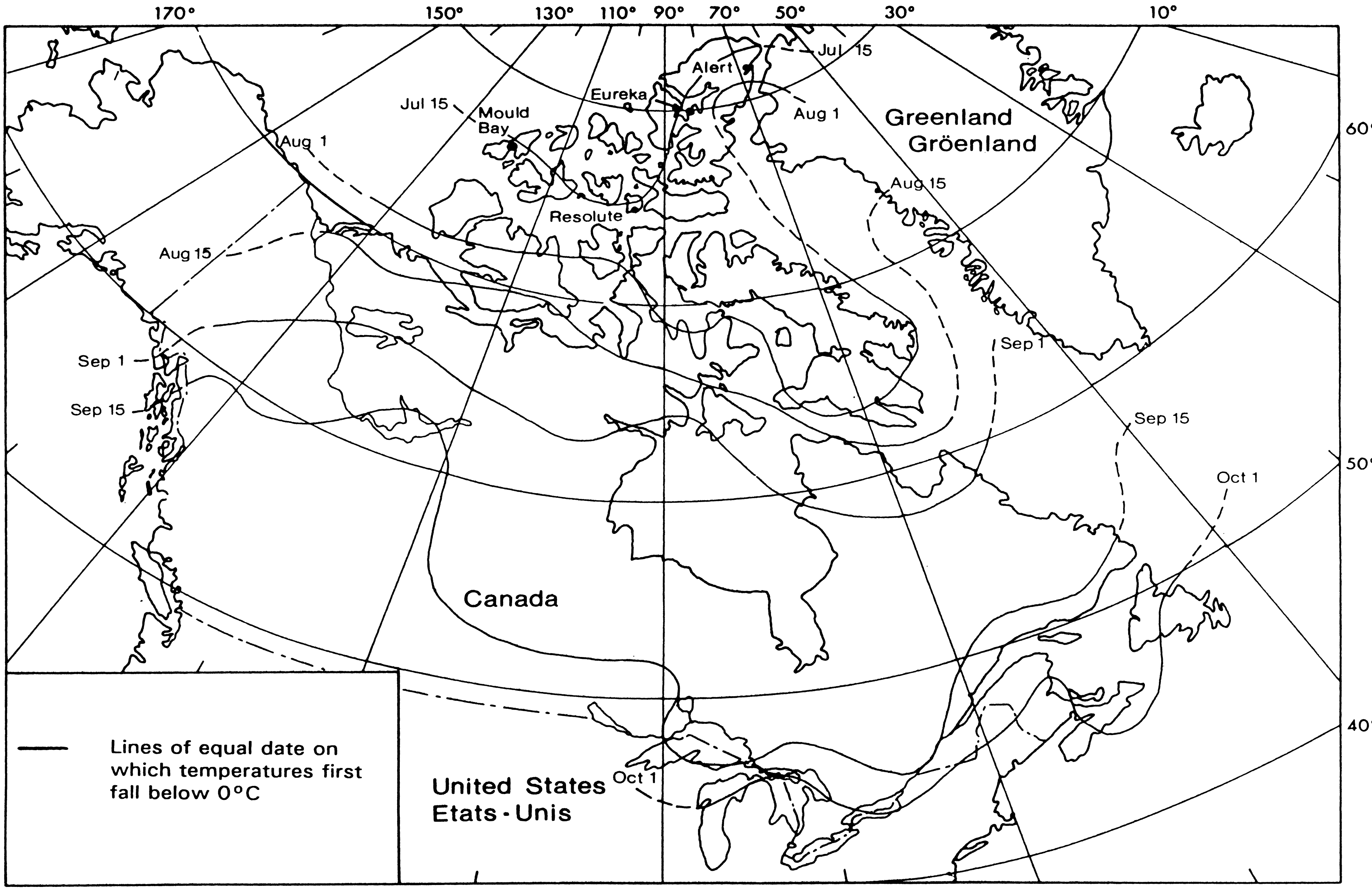
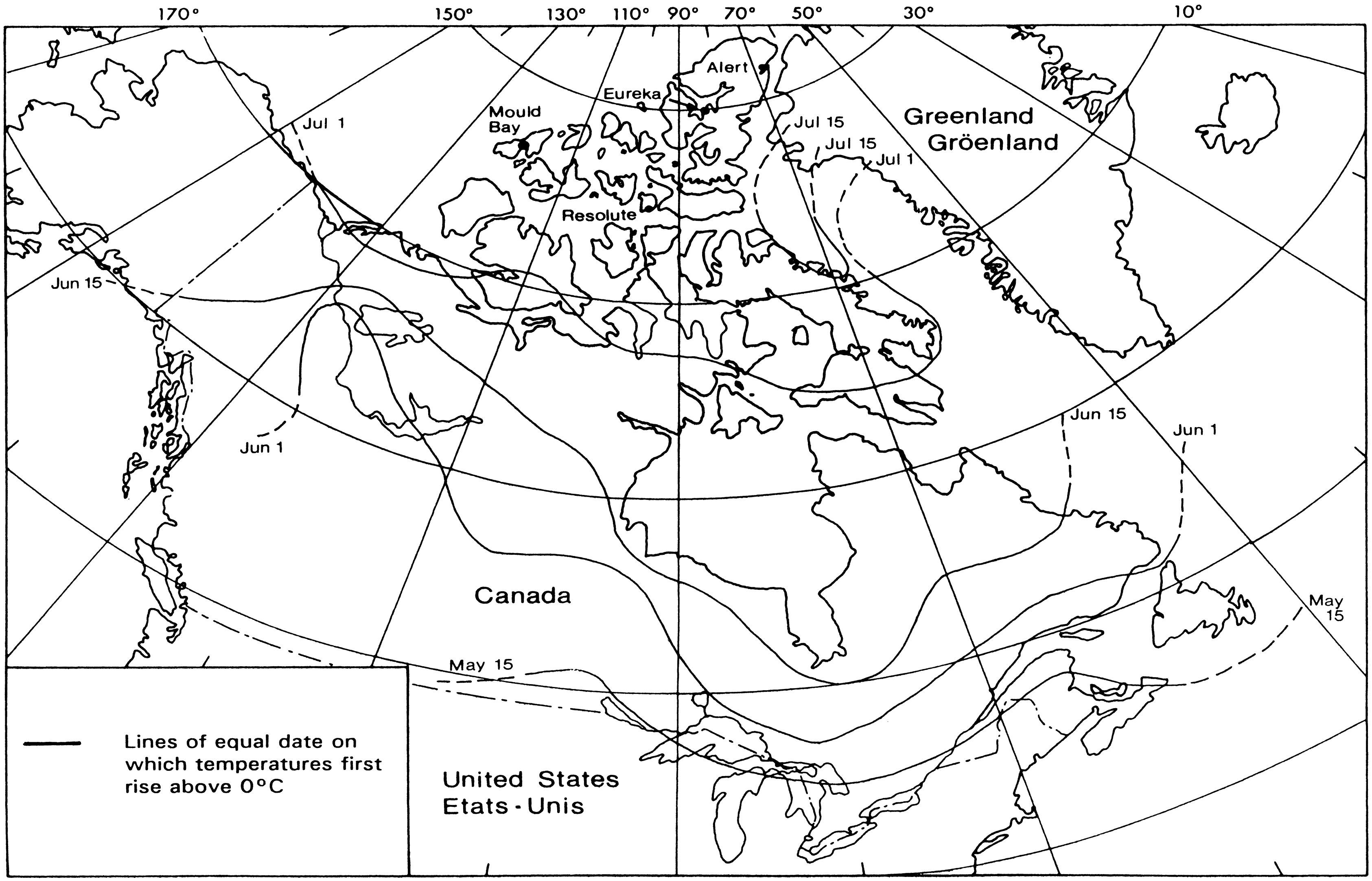


Figure 5 Mean dates for end of winter, when the mean daily temperature rises above 0°C



Sea-ice growth usually starts sometime after freezing air temperatures are achieved because the freezing point for sea water, which contains salts, is between -1.6° and -1.7°C. Also warmer water from within the ocean may reduce the effect of freezing air temperatures on the surface water, further delaying ice growth.

Table 2 shows monthly mean daily temperatures for selected coastal stations in Canada. The stations range from locations around the Great Lakes to the Arctic, providing an indication of marine temperature patterns throughout Canadian ice-covered waters. More detailed temperature and related weather information may be found in the Sailing Directions for Canadian Waters.

3.1.2 Major Storm Tracks and Wind Conditions

Weather systems tend to move along preferred paths over Canadian waters. Major storm tracks during the summer months are shown in Figure 6. Major tracks pass through the St. Lawrence Lowlands, with storms developing and moving out to sea in a northeasterly direction over the Grand Banks of Newfoundland and the Labrador Sea. Storm systems tracking toward the southern tip of Greenland may move entirely into Davis Strait or may split with a portion continuing toward Iceland. The storms which move completely into Davis Strait tend to produce the most severe weather conditions in the Arctic.

Storms in the Arctic also tend to follow preferred routes, particularly south of Parry Channel; storms follow a general west to east track, with a tendency to spiral northward. Over the Beaufort Sea and Western Arctic Islands, there are several principal storm tracks. During the summer months, there is an important west to east storm track along 75°N and a storm track following the mainland coast into northern Hudson Bay. In the fall, these patterns break down and by winter the most common storm track is through the Bering Sea eastward to Banks Island.

Figure 7 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.

Although Figures 6 and 7 show the most common storm tracks, individual storms may behave quite differently. For instance, it is not uncommon to encounter severe weather conditions resulting from low pressure systems which move northwestward across the Labrador Sea into the Arctic, or northward along the United States eastern seaboard into the Gulf of St. Lawrence and onto the Grand Banks. These variations in normal weather patterns can result in large departures from typical seasonal weather conditions, affecting wind speed and direction, air temperature, precipitation, and visibility, and can produce unseasonal ice conditions for a given region.

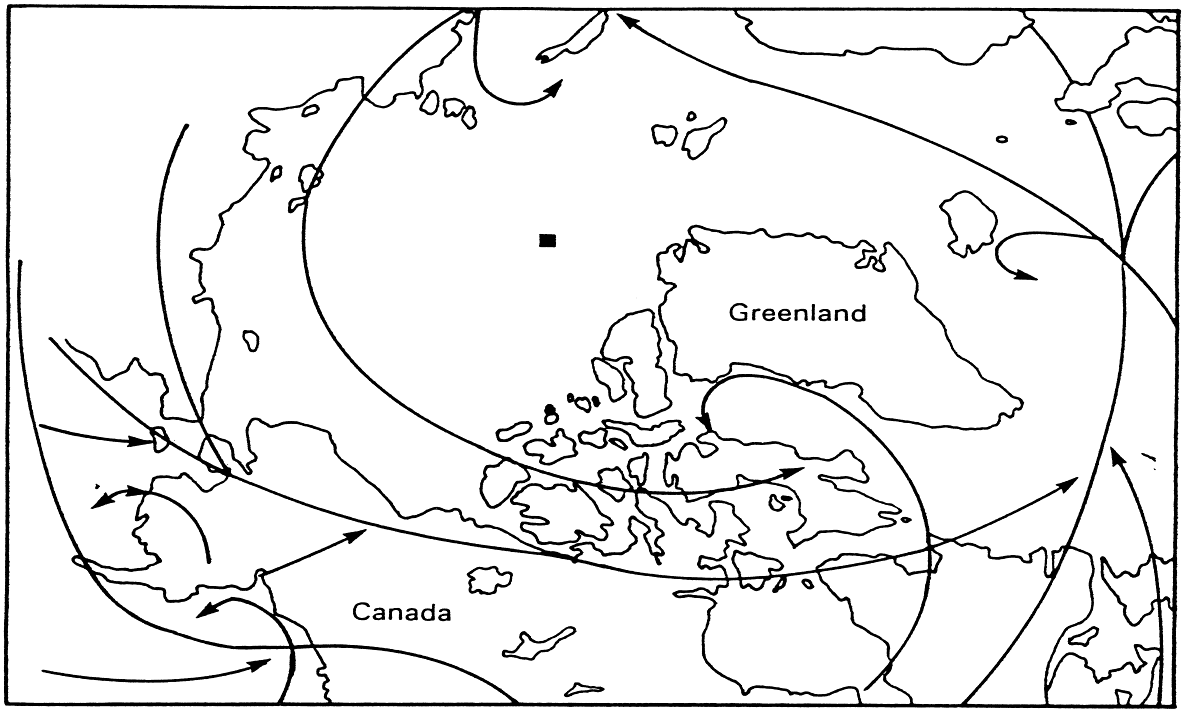
Table 2 Monthly mean daily temperatures for selected stations in Canada

Station	Monthly mean temperature (°C)												Mean temp. for year (°C)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Thunder Bay	-15.4	-13.0	-6.3	2.5	8.8	14.0	17.6	16.4	11.1	5.7	-2.6	-11.1	2.3
Sault St-Marie	-10.1	-10.0	-5.1	3.1	9.1	14.6	17.3	16.9	12.8	7.6	0.7	-6.7	4.2
Sarnia	-5.7	-4.5	0.6	7.1	12.4	18.1	20.9	20.3	16.5	10.5	4.2	-2.2	8.2
Windsor	-4.9	-3.8	1.2	8.1	14.2	19.7	22.2	21.3	17.4	11.1	4.4	-1.9	9.1
Kingston	-7.7	-7.0	-1.6	5.5	11.4	16.7	20.1	19.4	15.4	9.4	3.4	-4.2	6.7
Grindstone Island	-5.8	-7.3	-4.0	0.5	5.8	11.6	16.5	16.9	12.9	7.6	2.8	-2.7	4.6
Québec City	-11.4	-10.1	-4.1	3.6	11.1	16.9	19.4	17.8	12.8	7.0	0.1	-8.4	4.6
St. John's	-3.5	-4.0	-1.7	2.0	6.3	11.6	16.1	16.0	12.2	7.6	3.8	-1.0	5.5
Goose Bay	-16.4	-14.5	-8.6	-1.7	5.0	11.3	15.8	14.3	9.1	2.7	-3.8	-13.0	0.0
Iqaluit	-26.2	-25.2	-22.3	-14.0	-3.3	3.5	7.9	6.9	2.4	-4.7	-12.4	-20.3	-9.0
Clyde River	-26.9	-27.4	-26.3	-18.7	-6.9	0.9	4.6	4.0	-0.1	-6.6	-16.9	-24.2	-12.0
Churchill	-27.5	-25.9	-20.4	-10.1	-1.5	6.2	11.8	11.3	5.4	-1.5	-12.1	-22.2	-7.2
Longstaff Bluff	-28.4	-28.2	-26.1	-18.0	-7.2	1.0	6.9	6.4	-0.8	-9.2	-18.1	-24.8	-12.2
Arctic Bay	-29.8	-31.1	-27.7	-19.8	-7.6	2.1	5.8	4.8	-1.6	-11.1	-21.1	-26.8	-13.7
Resolute	-32.6	-33.5	-31.3	-23.1	-10.7	-0.3	4.3	2.7	-4.9	-14.7	-24.2	-28.8	-16.4
Alert	-32.1	-33.3	-33.0	-24.7	-11.2	-0.6	3.9	0.9	-10.1	-19.7	-26.1	-29.8	-18.0
Cambridge Bay	-33.7	-34.6	-30.1	-22.2	-9.6	1.5	8.2	6.9	-0.5	-11.1	-23.8	-29.6	-14.9
Mound Bay	-33.8	-35.6	-32.4	-23.6	-10.9	-0.3	3.7	1.7	-6.6	-17.8	-26.6	-31.3	-17.8
Tuktoyaktuk	-28.4	-29.1	-26.5	-17.2	-4.7	5.1	10.6	9.0	2.6	-7.7	-19.7	-25.2	-10.9

Source: Canadian Climate Normals Temperature and Precipitation - 1951-1980, Environment Canda AES

The Climate of the Canadian Arctic Islands and Adjacent Waters Volume 2, Environment Canada AES

Figure 6 Principal storm tracks in summer in Canada



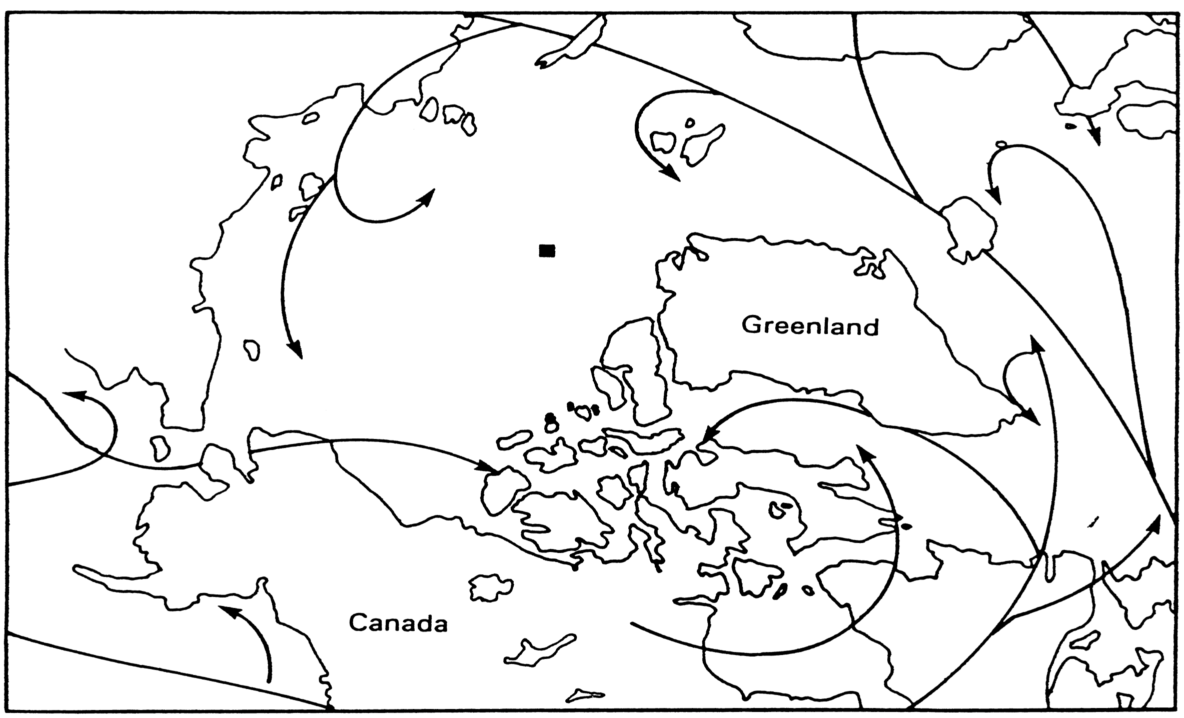


Figure 7 Principal storm tracks in winter in Canada

3.1.3 Polar Lows

Arctic instability lows or polar lows are small, intense low-pressure events that may not be detected or predicted by meteorologists. However polar low systems may be forecast before they form when conditions are favourable to support their development. Fortunately, polar lows can be seen on satellite images; and once the polar low has been flagged, the meteorologists can alert the marine community to their existence. Unfortunately, there are periods when a given area is not covered by satellites; so the first indication of a polar low may be a sudden change in pressure, rapid increase in wind, or heavy snow flurries at a ship or land station.

Polar lows are known to occur in the North Atlantic, North Pacific, Hudson Bay, Hudson Strait, Davis Strait, Baffin Bay, Labrador Sea, and Chukchi Sea. Small versions of polar lows can also exist on the Great Lakes. 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. They are low-level features, generally steered by the winds at 1200 - 2500 m. Polar lows, which get their support from upper troughs or cold upper lows, tend to move in the direction of that upper feature.

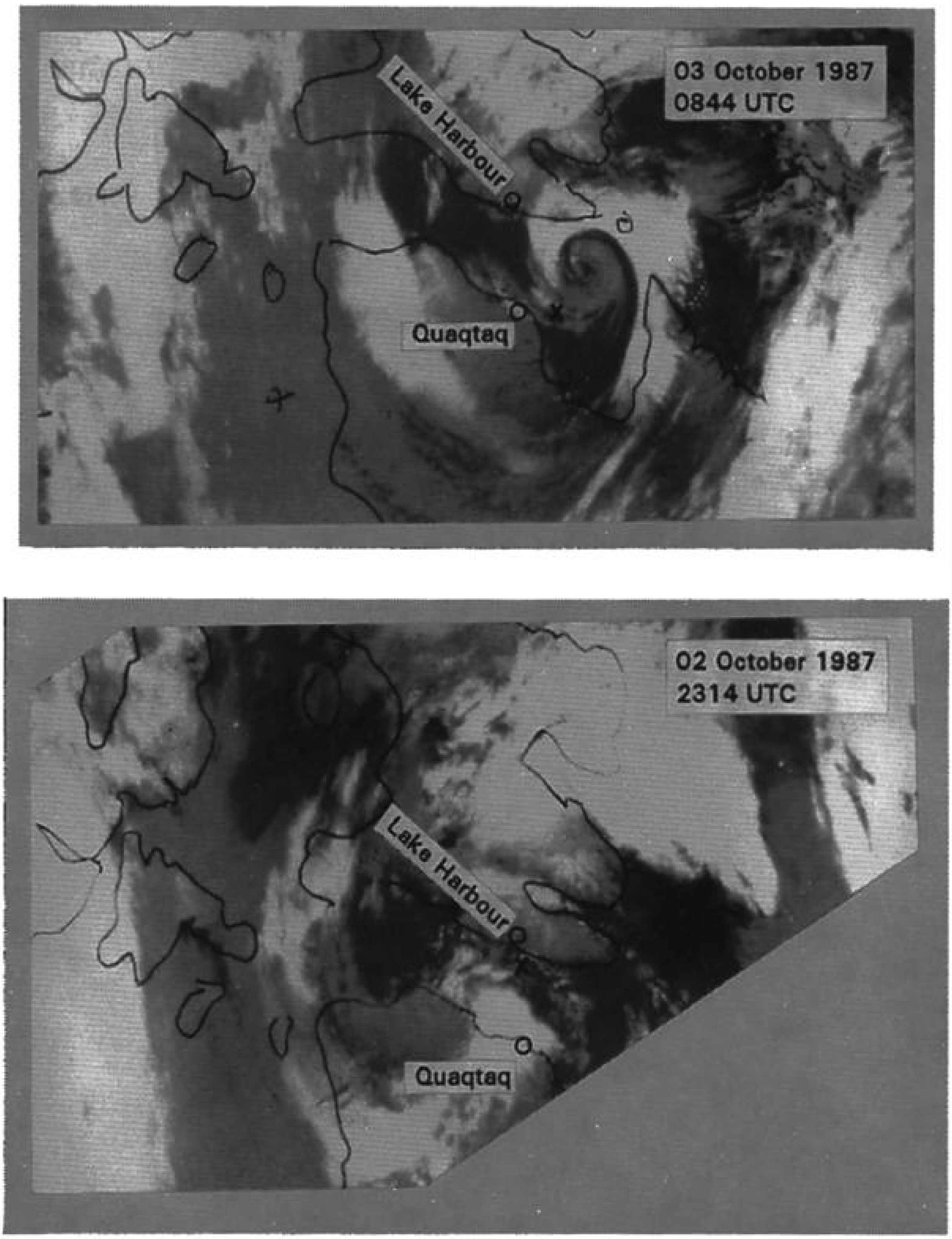
Polar lows are often accompanied by strong winds and areas of moderate to heavy precipitation. A polar low can form in as few as 12 hours and seldom lasts more than a day. However, under stagnant weather systems, polar lows or a family of polar lows can persist for several days.

Table 3 demonstrates the rapid development of a polar low. In this case the low was documented by the Canadian Coast Guard Ship Norman McLeod Rogers on October 3, 1987 while in Hudson Strait. A polar low developed rapidly and gave the vessel winds of gale strength within hours of the winds being light. The table shows the wind regime as logged at the vessel.

Table 3 Wind speed and direction during a polar low in Hudson Strait

Date October 1987	Time (UTC)	Position of CCGS Norman McLeod Rogers	Wind	
			Direction	Speed
2	2100	62.8°N 69.7°W	SSE	10
3	0000	62.4°N 69.6°W	SE	10
3	0300	61.9°N 69.3°W	ESE	22
3	0600	61.5°N 68.8°W	SSE	8
3	0900	61.0°N 68.4°W	WNW	45
3	1200	60.6°N 68.0°W	WNW	35
3	1500	60.4°N 67.8°W	WNW	22

Figure 8 Satellite images showing the development of a polar low in Hudson Strait



In Figure 8, two satellite images illustrate development of the polar low on October 3, 1987. In the lower image, taken 45 minutes prior to the ship's 03/0000 UTC report, the low is developing under the cloud shield in southern Hudson Strait. At the time, the ship was off Lake Harbour and reported winds SE at 10 knots. The upper image shows the polar low 9.5 hours later, when the CCGS Norman McLeod Rogers was then off Quataq and reported winds from WNW at 45 knots.

3.1.4 Precipitation Patterns

Precipitation patterns vary considerably between the Great Lakes in southern Canada and the Arctic islands provides an indication of rainfall patterns by showing information for selected coastal stations.

Table 5 illustrates snowfall amounts for the same stations. 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 which is reflected in lower rain and snowfall in these areas.

3.1.5 Fog and Visibility

Sea Fog or Advection Fog	Fog which forms when relatively warm, moist air moves over colder water.
Sea Smoke or Evaporation Fog	Fog resulting when the air is very much colder than the sea.

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 converse is true during the winter months. Figure 9 illustrates the seasonal variability of daylight for different latitudes.

Table 4 Mean Monthly rainfall for selected stations in Canada

Station	Mean Monthly Rainfall (mm)												Rainfall for year (mm)
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Thunder Bay	1.9	1.9	13.7	35.4	69.2	76.6	75.4	83.1	89.1	51.6	25.3	4.1	527.3
Sault St-Marie	3.2	13.0	31.8	55.7	83.6	74.2	55.6	82.7	95.2	68.1	46.8	15.6	625.5
Sarnia	22.3	21.6	41.5	75.1	69.2	81.1	65.8	55.3	68.2	54.1	61.8	38.4	654.4
Windsor	28.1	28.5	51.9	78.3	70.2	89.3	83.4	84.1	67.0	56.9	53.6	46.2	737.5
Kingston	22.0	24.7	39.3	62.0	70.7	64.0	53.2	76.2	80.9	75.8	71.2	49.8	689.8
Grindstone Island	32.6	24.6	23.5	42.0	60.1	56.4	62.9	78.9	71.7	83.1	81.9	49.9	667.6
Québec City	41.1	10.9	20.9	59.7	79.8	112.9	136.3	114.7	115.1	86.1	58.6	27.5	863.6
St. John's	77.9	69.7	67.0	78.1	89.4	83.4	75.3	121.6	116.7	145.5	162.5	161.2	1248.3
Goose Bay	2.1	3.5	4.2	14.4	44.9	88.9	105.1	103.2	84.5	51.7	21.0	5.5	529.0
Iqaluit	0.3	T[a]	T	0.3	1.8	29.2	52.8	57.9	29.5	7.1	1.0	T	179.9
Clyde River	T	T	0.0	0.0	0.3	2.3	16.3	24.6	10.9	0.3	T	0.0	54.7
Churchill	T	0.1	0.6	2.0	13.5	39.9	45.6	58.3	44.5	15.4	1.0	0.2	221.1
Longstaff Bluff	0.0	0.0	0.0	0.0	T	7.6	29.2	21.8	14.7	0.5	T	0.0	73.8
Arctic Bay	0.0	0.0	0.0	0.0	T	4.1	19.1	23.1	8.4	T	0.0	0.0	54.7
Resolute	0.0	0.0	0.0	0.0	T	5.8	23.4	25.7	3.8	T	0.0	0.0	58.7
Alert	T	0.0	0.0	0.0	0.0	3.6	7.9	7.1	0.3	0.0	0.0	0.0	18.9
Cambridge Bay	0.0	0.0	0.0	0.0	0.5	9.4	21.8	25.9	8.9	1.0	T	0.0	67.5
Mound Bay	0.0	0.0	0.0	0.0	0.3	2.8	13.0	13.5	2.0	T	0.0	0.0	31.6
Tuktoyaktuk	0.1	0.0	0.0	T	2.3	10.7	19.7	27.2	10.7	1.6	T	0.0	72.3

Source: Canadian Climate Normals Temperature and Precipitation - 1951-1980, Environment Canada AES
The Climate of the Canadian Arctic Islands and Adjacent Waters Volume 2, Environment Canada AES

[a] T = Trace of precipitation

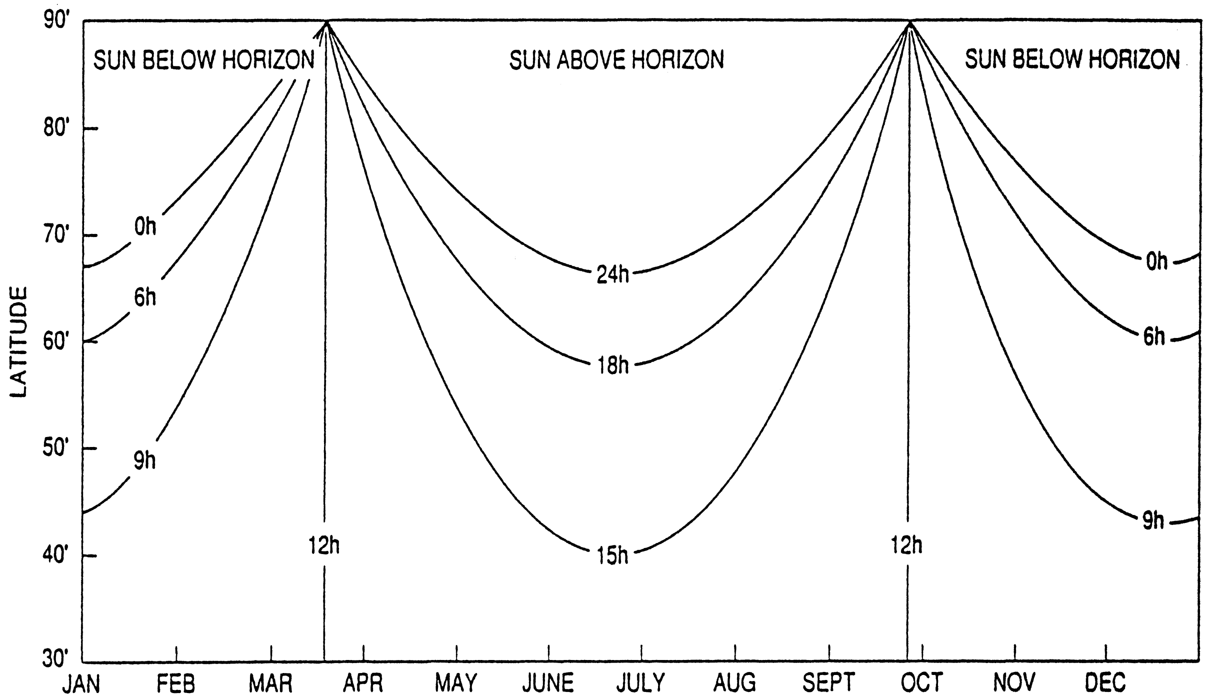
Table 5 Mean Monthly snowfall for selected stations in Canada

Station	Mean monthly rainfall (mm)												Snowfall for year (cm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Thunder Bay	48.4	30.7	34.2	16.2	4.2	0.0	0.0	0	T[a]	3.3	29.8	46.2	213.0
Sault St-Marie	76.3	63.8	30.3	10.0	1.8	0.0	0.0	0.0	0.1	6.1	41.4	75.9	305.7
Sarnia	28.8	23.7	22.0	6.1	0.4	0.0	0.0	0.0	0.0	3.8	16.1	38.0	138.9
Windsor	30.2	22.8	20.0	4.2	T	0.0	0.0	0.0	0.0	0.1	11.5	28.6	117.4
Kingston	51.7	35.7	32.4	7.6	0.3	0.0	0.0	0.0	0.0	1.0	14.4	47.9	191.0
Grindstone Island	57.6	43.6	47.8	22.6	2.9	0.0	0.0	0.0	0.0	1.3	16.1	50.3	242.2
Québec City	64.8	63.1	44.5	8.7	0.3	0.0	0.0	0.0	0.0	1.9	26.7	78.3	288.3
St. John's	81.4	74.6	65.0	34.6	11.1	2.0	0.0	0.0	T	4.4	21.2	65.1	359.4
Goose Bay	80.0	60.6	74.6	48.6	18.4	3.7	0.0	0.0	4.0	24.7	57.0	73.6	445.2
Iqaluit	25.7	29.0	21.6	23.6	21.6	8.4	0.3	0.3	14.5	36.1	37.8	28.2	247.1
Clyde River	10.9	6.6	5.1	8.4	14.0	8.4	7.1	5.6	27.9	32.8	18.5	7.6	152.9
Churchill	16.9	14.6	18.6	22.3	19.5	3.5	0.0	0.0	6.4	29.3	41.6	22.8	195.5
Longstaff Bluff	4.1	8.1	2.3	7.6	13.5	7.6	0.3	1.3	15.7	22.6	10.7	6.9	100.7
Arctic Bay	5.8	4.3	5.6	4.1	6.6	3.6	0.3	0.8	13.5	15.2	6.9	4.6	71.3
Resolute	2.8	3.3	3.3	5.8	8.9	6.6	3.0	4.8	14.2	15.5	5.6	4.8	78.6
Alert	7.4	5.3	7.4	6.6	12.4	9.9	10.2	20.3	31.2	16.8	8.6	8.6	144.7
Cambridge Bay	5.3	4.3	5.8	6.4	7.6	4.1	0.3	7.6	15.5	9.4	6.1	7.2	77.6
Mound Bay	2.5	2.3	3.0	3.0	7.6	3.8	3.8	6.6	11.7	9.4	3.0	3.0	59.7
Tuktoyaktuk	5.3	5.4	4.4	7.1	3.5	2.2	0.2	0.6	4.2	16	8.9	7.4	65.2

Source: Canadian Climate Normals Temperature and Precipitation - 1951-1980, Environment Canada AES
The Climate of the Canadian Arctic Islands and Adjacent Waters Volume 2, Environment Canada AES

[a] Trace of snowfall

Figure 9 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 sea-water. 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 sea-water. 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 snowfall 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

Accretion	The building up of ice on a ship from freezing spray, fog, freezing precipitation, or wet snow.
Freezing spray	Ice which forms on a ship's hull and topside facilities as sea spray comes in contact with cold metal.
Super-structure icing	The formation of ice on a ship's hull or deck facilities, caused by freezing sea spray, precipitation, or fog.

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 produce difficulty in manoeuvering. Icing can also cause 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 sea-water and when sea-surface temperatures are below 6°C. To get spray icing you need 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 cm/hr and ice build-up of over 25 cm is not uncommon.

In addition to air temperature and wind speed, other factors affecting freezing spray accumulation are the particular ship 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.

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.

Under severe icing conditions, manual removal of ice may be the only method of preventing a capsize. It is important for the Master 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 ship 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 ship.

Freezing spray warnings are included in marine forecasts by Environment Canada. 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 ship icing is given below for the Gulf of St. Lawrence, Labrador Sea and Hudson Bay, and Arctic waters including Baffin Bay and Davis Strait.

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 cm in thickness. Freezing precipitation and supercooled 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 January, potential spray icing conditions are encountered more than 50 per cent of the time. Freezing rain is most frequently experienced from December to April, and supercooled 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-m 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, three areas showed heavier icing accumulations: (1) the central Gulf area west of the Magdalen Islands; (2) the Strait of Belle Isle off Flowers Cove; and (3) north of the Gaspe 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.

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 cm. Icing from supercooled fog and freezing precipitation are less frequently reported, and are generally responsible for small amounts of accreted ice, about 1-2 cm. 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 per cent 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. Supercooled 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 ship 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 m waves. Typical conditions are less severe in Hudson Bay, with an air temperature of -6°C, 25-knot northwesterly winds, and 2 to 3 m 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 cm on Hamilton Bank (54°N, 55°W), whereas they are typically 4-5 cm 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.

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 cm.

3.1.7 Tides and Currents

Bathymetry	The form of the bottom of a body of water, usually shown by contour lines of depth.
Gyre	Movement of water in a circular or spiral path.
Storm surge	Movement of the sea up and down or to and fro during a strong storm.

Tides and currents are important factors in the behaviour of sea ice and icebergs. Figure 10 shows the general circulation patterns in Canadian waters and Figure 11 shows important currents and bathymetry in the Gulf of St. Lawrence, the Grand Banks of Newfoundland, and the Labrador Coast. While the circulation patterns shown in these figures are relatively constant, at local or regional scales, the circulation may vary considerably. The following paragraphs summarize key aspects of the mean surface currents, beginning with the southern regions, continuing northward. In the Great Lakes, tidal influence on water level is so small (only a few centimetres) as to be insignificant to navigation.

Gulf of St. Lawrence

The main flow of water through the Gulf of St. Lawrence comes from the St. Lawrence River, into the Gulf, and then southeastward toward Cabot Strait. There are two areas of strong outflow, the Gaspé Current, flowing at a mean speed of 0.5 to 1.0 knots, and the Cape Breton Current, with a mean speed of 0.50 to 0.75 knots. Weaker inflowing currents can be found off the southern tip of

Newfoundland (Cape Ray) and along the south coast of Anticosti Island. Weak currents are also found over the Magdalen Shallows and in the Gulf's northeastern arm. There is a variable tidal stream through the Strait of Belle Isle near the surface. At greater depths there is a net inward flow.

The mean tidal range in the Gulf of St. Lawrence is 0.6 to 2.2 m. In the St. Lawrence River, tidal ranges are higher, from 2.0 to 4.6 m.

East Coast and Labrador Sea

The Labrador Current dominates the circulation of both the Labrador Sea and Newfoundland waters. It flows north to south, drawing water from the cold Baffin Current. A portion of the West Greenland Current crosses Davis Strait to join the Baffin Current. Along the Labrador coast, the Baffin Island water remains inshore and the West Greenland water flows along the outer shelf edge.

The two portions of the Labrador Current exhibit different characteristics: the Baffin Current is fresher and colder than the West Greenland Current water. Current velocities also differ, with inshore speeds about 6 nautical miles per day compared to 10 to 20 nautical miles per day further offshore.

As the Labrador Current reaches the Grand Banks, the continental shelf widens, the current slows, and splits with one stream flowing between the western edge of the Banks and Newfoundland and the other flowing along the northern edge and eventually southward through the Flemish Pass. Currents over the Banks tend to be weak and variable in direction.

Along the east coast of Newfoundland, the mean tidal range is from 0.8 to 1.6 m and off the coast of Labrador tides vary from about 0.4 m in Lake Melville to 4.6 m off Cape Chidley at the north tip of Labrador.

Figure 10 Surface Currents in Canadian Waters

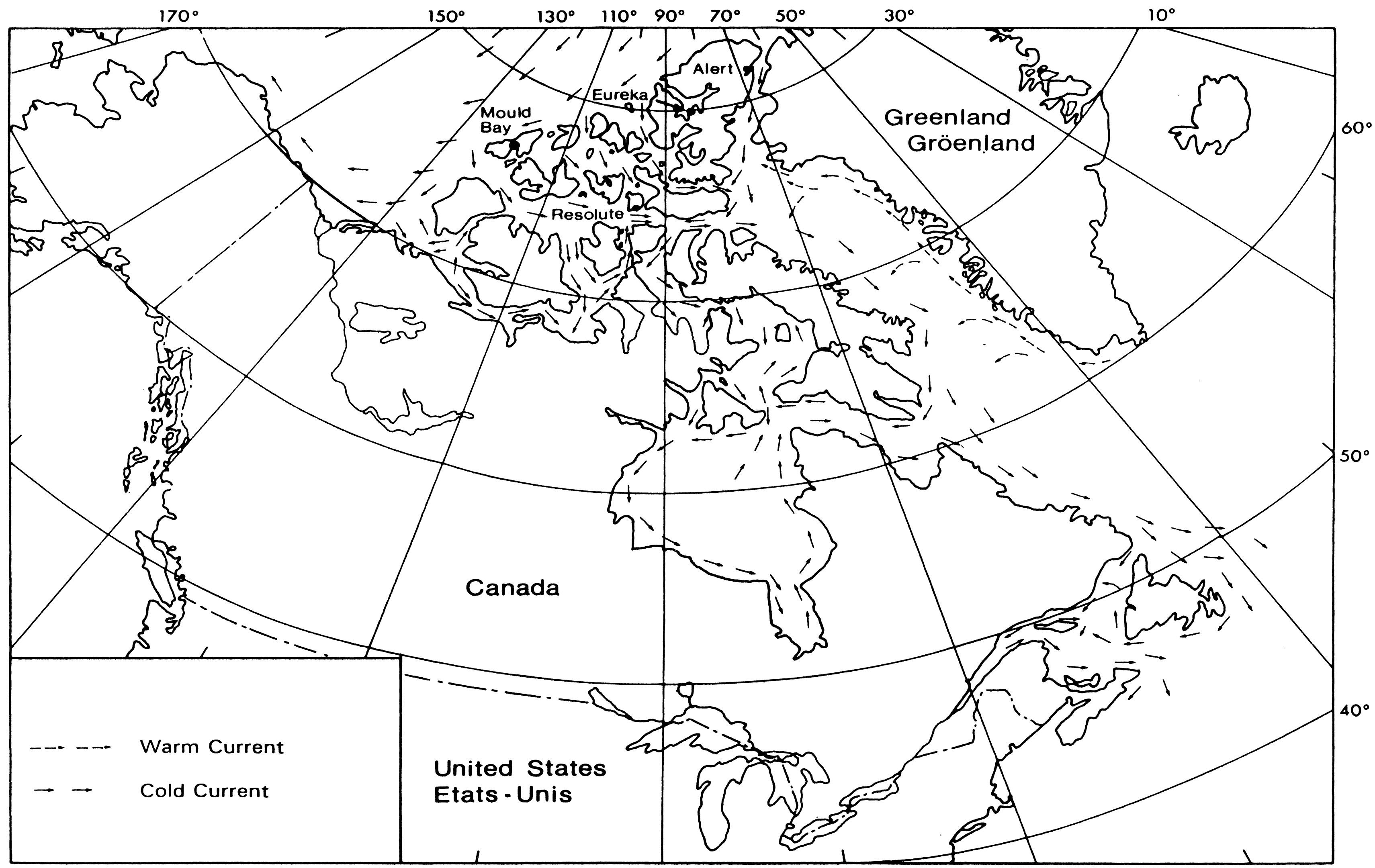
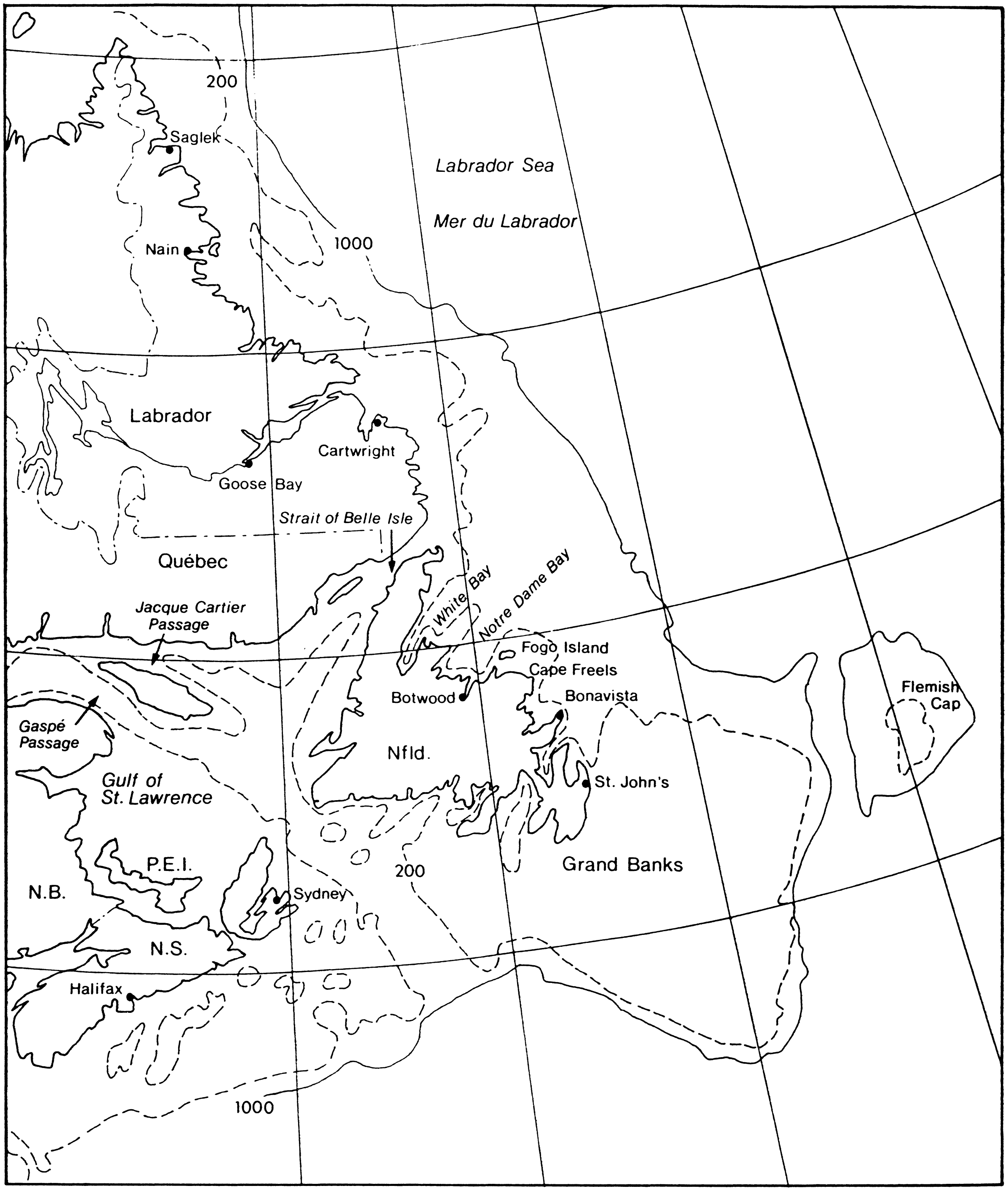


Figure 11 Gulf of St. Lawrence, Grand Banks of Newfoundland and Labrador Sea, showing bathymetry (in metres)



Arctic Waters

Although there has not been a great deal of measurement of ocean currents in the Arctic, general circulation patterns are understood. Figure 10 illustrates the surface circulation in Arctic waterways. Cold currents are shown as solid lines and warm currents as dashed lines.

The ocean circulation system in Baffin Bay is particularly important to Arctic navigation. The counter-clockwise flow carries relatively warm water northward along the west Greenland coast, across Baffin Bay at the north end, and mixes it with southward-flowing cold water from Nares Strait between Greenland and Ellesmere Island. Combined with a smaller cold water outflow from Jones Sound and a larger outflow from Lancaster Sound, the current carries cold water southward along the east Baffin Island coast. The current speed along the northeast coast of Baffin Island is about 0.8 knots in the summer. Very little is known about seasonal variability.

There are two ocean surface circulation patterns in the Arctic Ocean – the **Beaufort Gyre** and the **Trans-Polar Drift.** It is generally believed that the outflow along east Greenland is from the Trans-Polar Drift, whereas the outflow through the Canadian Arctic Archipelago is from the Beaufort Gyre. However, oceanographic studies indicate that Nares Strait water also comes from the Trans-Polar Drift, with the eastern-most outflow of the Beaufort Gyre passing through Nansen Sound. Through other parts of the Archipelago, there tends to be southeastward drift in the Queen Elizabeth Islands and eastward flow through Parry Channel.

Wind-generated currents are important in many of the smaller water bodies surrounding the Arctic islands. The nature of these currents varies with wind velocity, fetch, water depth, and local topographic relief.

In the Western Arctic, the clockwise rotation in the Arctic Ocean results in a net east to west flow in the Beaufort Sea. Current speeds are moderate, on the order of 1 to 2 knots. Wind-induced currents and discharge from the MacKenzie River can affect both the speed and direction of water currents in the Beaufort Sea.

The Eastern Arctic is affected by tides with average daily ranges of 2 to 3 m, although large ranges in excess of 6 m 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 m.

In addition to affecting vessel operations, tides may result in intermittent pressure within an ice cover, affecting navigation. Table 6 illustrates the range in tides through the Canadian Arctic. Detailed tidal information for Arctic Island waterways is available in the latest edition of the Canadian Tide and Current Tables, available through Fisheries and Oceans Canada.

Table 6 Tidal ranges at selected Arctic locations

Station	Location	Range (m)	
		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 m are common, and may persist for several hours. In some embayments, such as Tuktoyaktuk Harbour, surge levels may exceed 2 m. 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.

3.1.8 Environmental Disturbances

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; and
- cultural and socio-economic practices of local populations

There are numerous potential effects which 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. Navigators should consider how their ship might affect the environment and take measures to minimize the disturbance.

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 A. These definitions have been developed and approved by the World Meteorological Organization. For more complete information on ice terminology, refer to the Manual of Standard Procedures for Observing and Reporting Ice Condition (MANICE), produced by Canadian Ice Service, Environment Canada. Copies of MANICE are available through Environment Canada, Ottawa.

3.2.2 Ice Types

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, 7/10 or more, drift ice may be replaced by the term pack ice.

Fast Ice Ice which forms and remains fast along the coast, and it is attached to the shore, to an ice wall, to an ice front, between shoals, or grounded icebergs. If thicker than 2 m above sea-level, it is called an ice shelf.

Floe Any relatively flat piece of ice 20 m or more across.

Ice island A large piece of floating ice protruding about 5 m above sea-level, which has broken away from an Arctic ice shelf. Has a thickness of 30 to 50 m and an area of from a few thousand square metres to 500 sq. km or more. It is usually characterized by a regularly undulating surface giving it a ribbed appearance from the air.

Ice shelf A floating ice sheet of considerable thickness showing 2 - 50 m or more above sea-level, attached to the coast. Usually, an ice shelf is of great horizontal extent and has a level, or gently undulating, surface. It is nourished by annual snow accumulation and also by the seaward extension of land glaciers. Limited areas may be aground. The seaward edge is termed an ice front.

Iceberg A massive piece of ice of greatly varying shape, protruding 5m or more above sea-level, which has broken away from a glacier, and which may be afloat or aground. It may be described as tabular, domed, pinnacled, wedged, drydocked, or blocky. Sizes of icebergs are small, medium, large, and very large.

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). It has a matt surface and is up to 10 cm in thickness. May be subdivided into dark nilas and light nilas.

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; and
- glacier ice, formed on land or as an ice shelf from the accumulation and recrystallization 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 cm thick. **Thin, medium**, and **thick** lake ice range in thickness from 5-15 cm, 15-30 cm, and 30-70 cm, respectively, whereas **very thick** lake ice is greater than 70 cm 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 A. **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 cm and, as it thickens, grows progressively lighter in colour from grey to grey-white. **First-year** ice is ice of not more than one winter's growth, ranging from 30 cm to over 2 m thick. **Old ice** is sea ice which 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 ship navigation.

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

3.2.3 Ice Properties

Brine Water containing salt(s).

First-year ice Ice of not more than one winter's growth, ranging from 30 cm to 2 m thick.

Old ice Ice which 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.

Salinity Amount of salt(s) in solution in water, usually given as parts per thousand (ppt).

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 which gradually interlock. This layer may be as little as 1 to 2 cm 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 m thick off the Alaskan Coast.

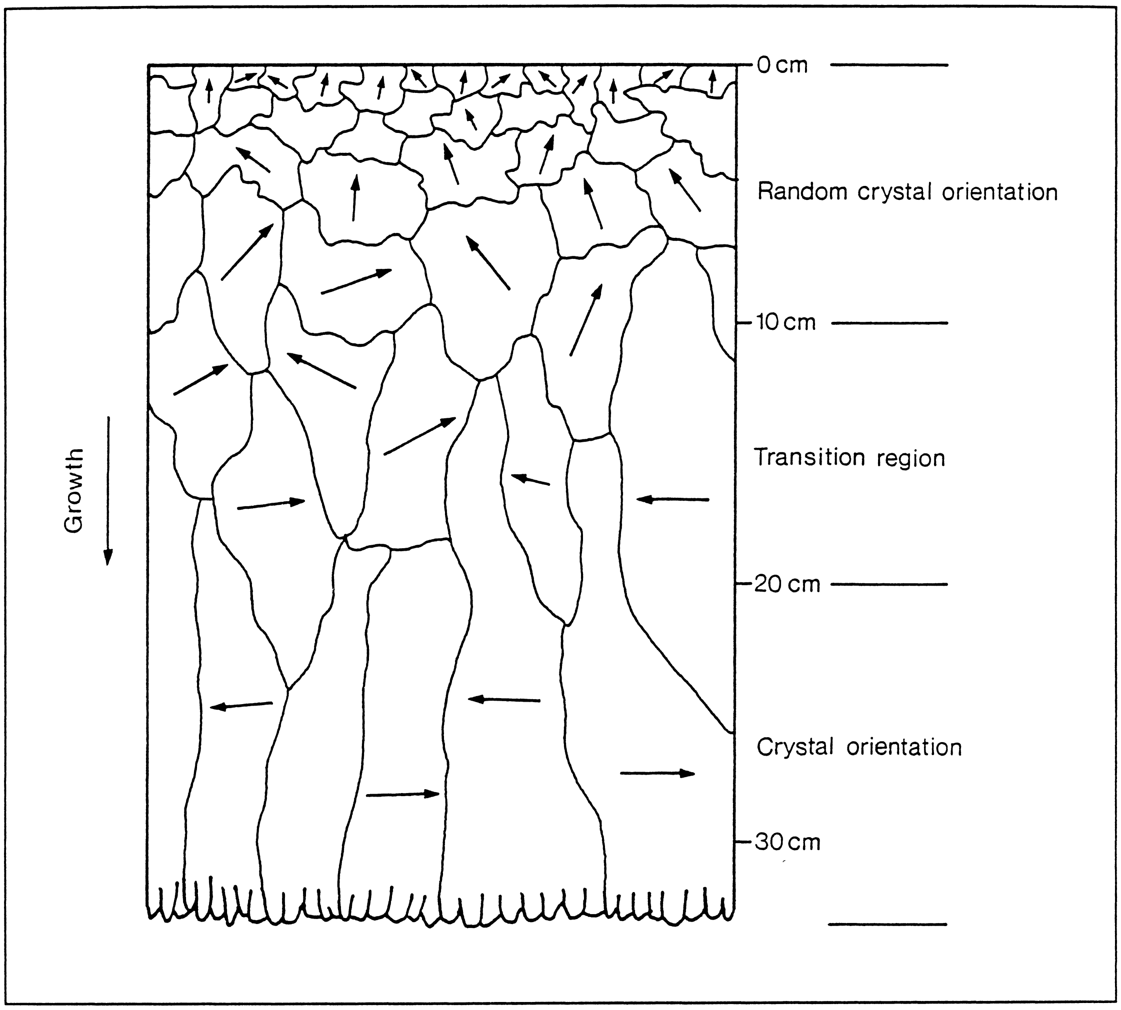
Once an initial layer of ice has formed on the surface, ice growth continues downward. Beneath a transition zone the ice is composed primarily of long columnar ice crystals. Figure 12 illustrates the characteristic crystal structure within young sea ice.

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.

Figure 12 Characteristic crystal structure of young sea ice



3.2.4 Ice Formation and Growth

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 matte appearance.
Grey ice	Young ice is usually 10-15 cm thick. It is less elastic than nilas, and breaks on swell, and usually rafts under pressure.

Pancake ice Predominantly circular pieces of ice 30 cm to 3 m in diameter, up to 10 cm in thickness, with raised rims due to the pieces striking against one another. It sometimes forms at some depth where water bodies of different physical characteristics meet, then it floats to the surface. The growth of pancake ice may rapidly cover wide areas of water.

Several forms of ice may be encountered: 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 effect 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 one 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

Deform	To change the shape; for ice this usually involves ridging and rafting.
Floe	Any relatively flat piece of ice 20 m or more across.
Hummocked ice	Ice piled haphazardly one piece over another to form an uneven surface. When weathered has the appearance of smooth hillocks
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.
Lead	Any fracture or passage-way through ice which is navigable by surface vessels.
Polynya	Any non-linear shaped opening enclosed by ice. May contain brash ice and/or be covered with new ice, nilas, or young ice; submariners refer to these as skylights.
Rafted ice	Type of deformed ice formed by one piece of ice overriding another.
Ridged ice	Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice.

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 which 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 per cent 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 m for every 120 m 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

Ablation Wasting or erosion of floating ice or iceberg, by melting, or water action, or evaporation.

Close ice Floating ice in which the concentration is 7/10 to 8/10, composed of floes mostly in contact with one another.

Open ice Floating ice in which the concentration is 4/10 to 6/10, with many leads and polynyas. Generally floes are not in contact with one another.

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.

Very close ice Floating ice in which the concentration is 9/10 to less than 10/10.

Very open ice Ice in which the concentration is 1/10 to 3/10 and water dominates over ice.

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 per cent 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 per cent 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, BERGY BITS, AND GROWLERS

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 m. Normally about 100-300 sq. m in area.

Calving The breaking away of a mass of ice from a glacier, ice wall, ice front, or iceberg.

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. It has a length of less than 5 m and normally occupies an area of about 20 sq. m.
Iceberg	A massive piece of ice of varying shape, protruding 5 m 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.
Ice island	Floating piece of ice broken from an ice shelf, often 40-50 m in thickness, with a higher freeboard than sea ice, and exhibiting undulating surface rolls.

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 14) 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. 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. They are mainly found in the Arctic Ocean, Beaufort Sea, and channels of the Archipelago. Occasionally ice islands have reached the eastern Arctic.

Almost all icebergs found along the east coast of Canada originate from the glaciers of west Greenland (Figure 14). 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 two 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 per cent of the icebergs come from west Greenland glaciers.

The size of icebergs calved varies from growler size (about 20 sq. m with 1 m above water) to icebergs 1 km long and over 200 m high. The height-to-draught ratio of an iceberg varies from 1:1 to 1:3 for pinnacled 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 m it would not be unreasonable to expect a draught of 300 to 500 m. As a result of their substantial draught, even smaller icebergs frequently become grounded in coastal waters and on shoals.

Figure 13 Photograph of a typical iceberg

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 14) 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.

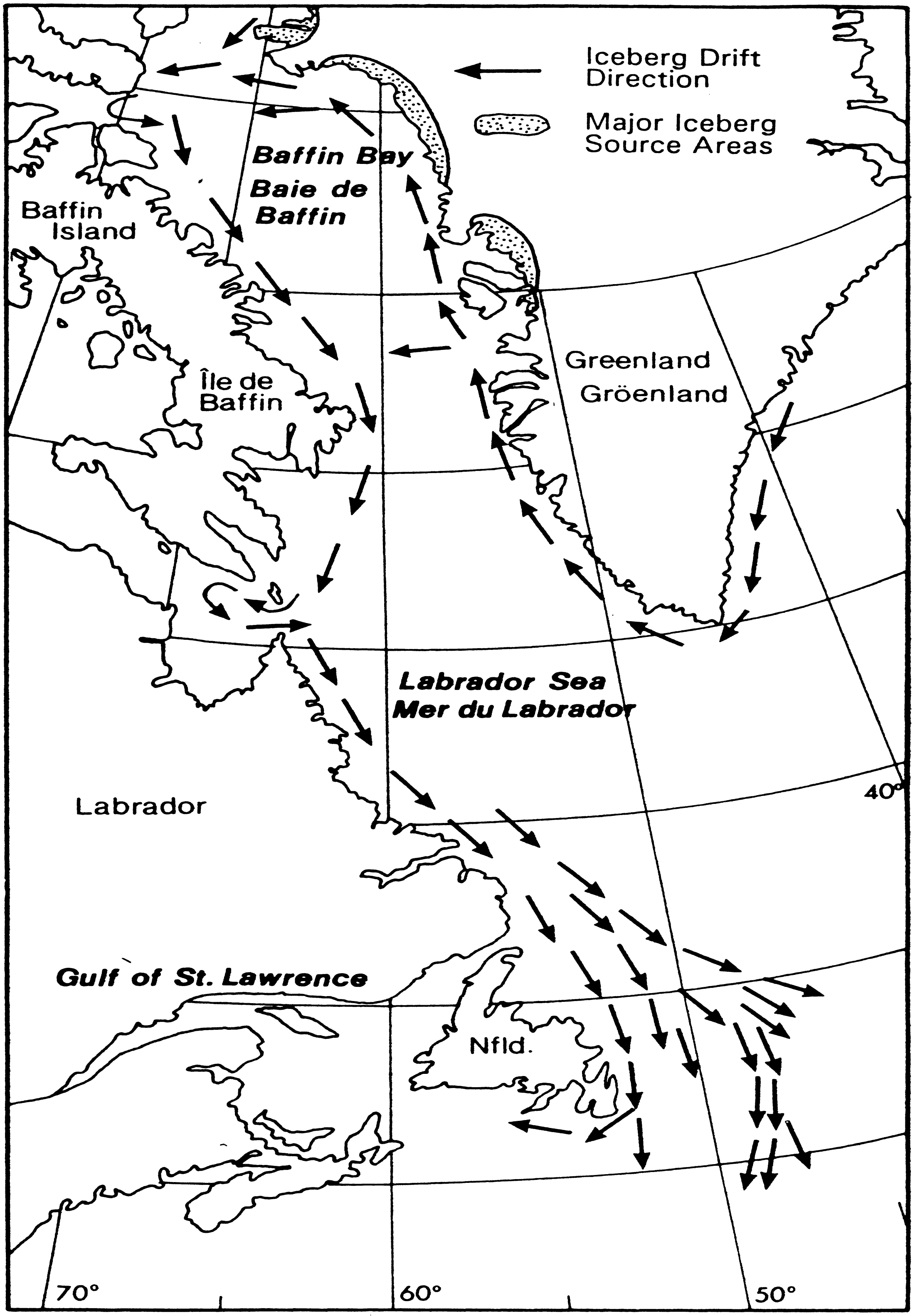
Whereas the main drift path is anticlockwise in Baffin Bay, it is not uncommon for icebergs to be carried westward across Baffin Bay by smaller current streams which branch off from the West Greenland current. Iceberg drift is seldom direct, with icebergs frequently following lesser currents into bays 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 m) 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 km 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 two to three 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. It is not uncommon for an iceberg to roll up to several times a day. Therefore, it is very important for vessels to steer a wide berth around an iceberg in case it rolls.

Figure 14 Sources and main tracks of icebergs in Canadian waters



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 7.

Table 7 Time taken for icebergs of differrent sizes to dereriorate

Surface Sea-Water Temperature (°C)	**Deterioation 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 m high, under 45 m long

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

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

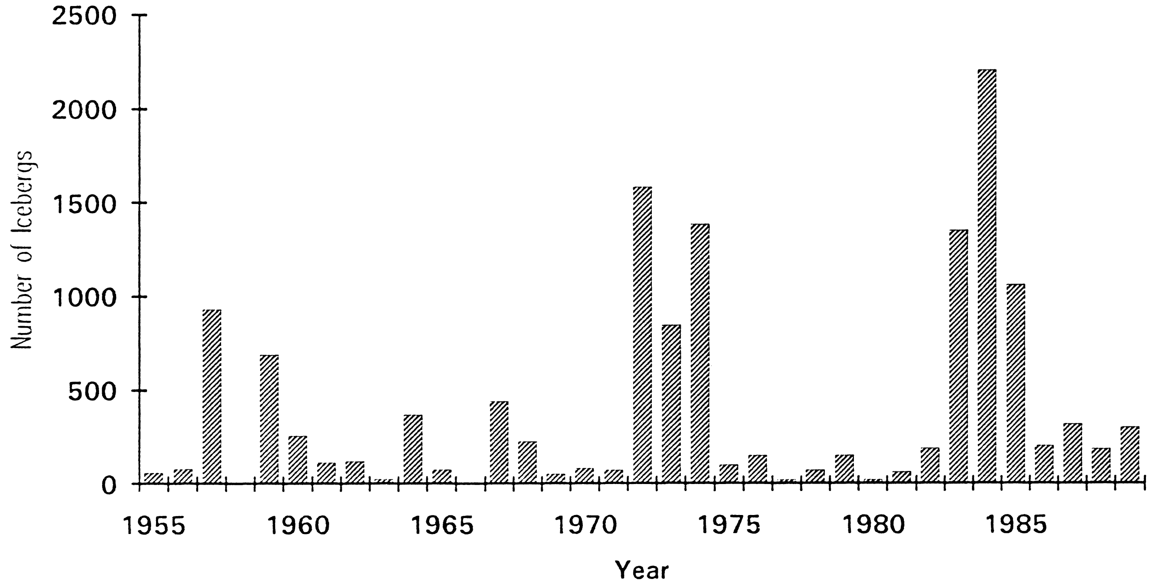
[d] **For tabular bergs the height limits differ:** less than 6 m for small, 6-15 m for medium, and more than 15 m for large icebergs.

The melt rate for icebergs in Arctic waters is slow, but, even so, it is unlikely that more than 20 to 25 per cent 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 per cent of the remainder will complete the drift to the Grand Banks.

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 International Ice Patrol observations, 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 15 shows the annual variability between 1955 and 1984.

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 in past years, almost two-thirds of the icebergs have been observed in April.

Figure 15 Annual count of icebergs crossing 48°N latitude



3.4 ICE CLIMATOLOGY

Batture floes Large, thick, uneven, and discoloured floes often up to 8 km or more across which form on the upstream side of shoals and islets in the St. Lawrence River when cold weather precedes or accompanies neap tides.

Compact ice Floating ice in which the concentration is 10/10 and no water is visible.

Consolidated ice Floating ice in which the concentration is 10/10 and the floes are frozen together.

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.

Ice keel The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an ice keel.

Regional ice conditions are described in the following subsections. It is emphasized that this information is of a very general nature, as it is beyond the scope of this manual to examine the range of possible ice conditions in detail.

Seasonal Outlook - Ice Conditions in Northern Canadian Waters is published annually by Canadian Ice Service, Environment Canada. 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.

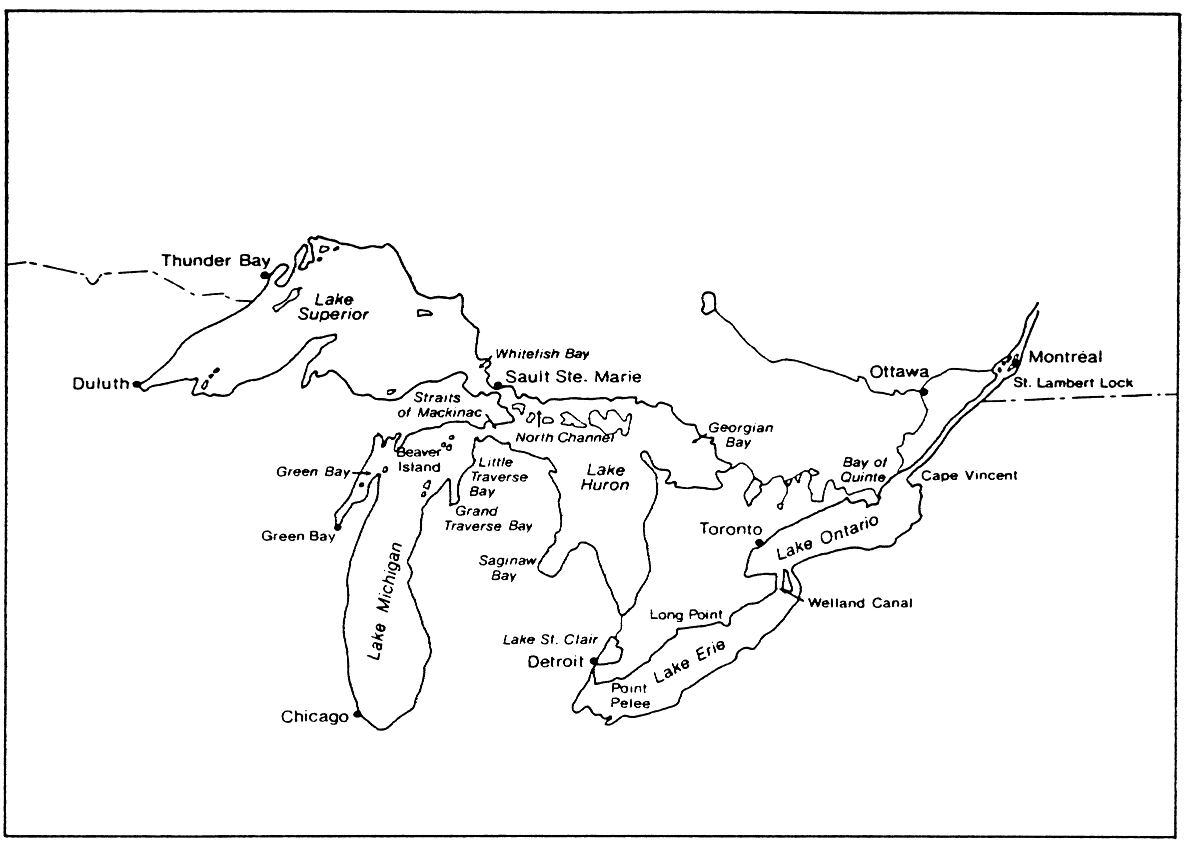
Seasonal Outlook for Ice Conditions in the Gulf of St. Lawrence and Newfoundland Waters is issued in early December, to provide a similar overview of expected winter ice conditions in southern areas.

Both seasonal outlooks are updated twice monthly during the ice-navigation season, providing 30-day ice forecasts.

3.4.1 Great Lakes and St. Lawrence River

The Great Lakes and St. Lawrence River represent an important region for Canadian and American trade and commerce and the presence of seasonal ice cover in this area has a major effect on commercial navigation. Figure 16 shows important place names for the five Great Lakes.

Figure 16 The Great Lakes



The timing of initial ice formation varies across the region, as do other characteristics of the ice cover. Table 8 compares the variation of ice cover for each of the Great Lakes and Lake St. Clair in two-week segments throughout the ice season. In addition to showing the variation between lakes, the normal, minimum, and maximum ice coverage provide an indication of variability from year to year. For clarity, ice conditions are discussed separately for each of the Lakes and the St. Lawrence River

Lake Superior

In Lake Superior, ice usually begins to form near the end of November or in early December. It first forms in bays and harbours along the north shore, in the western portion of the lake, and over the shallow waters of Whitefish Bay. Throughout January, ice continues to form and thicken in embayments around the lake, but there is little expansion of the ice cover into the central part of the lake until early February. During the first half of February, ice forms in the western basin of the Lake and, normally, the mid-lake area of the eastern basin shows first signs of an extensive ice cover during the last two weeks of February. Ice cover reaches a maximum in early March and, at that time, level fast ice ranges from 45-85 cm in thickness.

Melting usually begins by mid-March and by mid-April only about 1/10 of the lake is covered with ice. The eastern portion of the lake usually remains open throughout the winter months.

In the winter, but especially during late March and early April, the role of wind action is important in the reduction of ice extent. The wind modifies the ice extent in two ways, by compacting ice along windward shores and by mixing the water vertically, which brings warmer water to the surface where it acts to melt the ice. The combined effects of the wind are to produce open leads along leeward portions of the lake and, at the same time, to raft the ice along windward shores. Areas influenced by wind forcing can experience considerable ice deformation, in the form of ridging, rafting, and hummocking, producing deformed ice as much as 8 m thick.

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.

Lake Michigan

In Lake Michigan, the first areas to experience ice formation are the northern embayments of Green Bay, where freeze-up normally occurs during the last half of December. Ice then forms in the Straits of Mackinac and the shallow waters between the Straits and Beaver Island. Through January and early February, an ice cover begins to form on shallow waters around the perimeter of the lake, beginning first in the northern portions, gradually expanding southward. Maximum ice cover is usually reached in early March. Figure 17 shows that Lake Michigan is normally 5/10 ice covered during the last two weeks of February. With above-freezing temperatures moving progressively northward during March, ice formation ceases. This happens first in the southern two-thirds of the Lake by mid-month and in the northern one-third by the end of March. Ice persists for the longest time (until mid-April) in Green Bay, and in the northeast portion of the Lake between the Straits of Mackinac and Beaver Island.

Table 8 Ice concentration on the Great Lakes and Lake St. Clair for semi-monthly periods

Period	Ice Concentration (tenths)					
	Superior	Michigan	Huron	St. Clair	Erie	Ontario
Dec 16-31						
Maximum	2	ND[a]	5	9+	6	2
Minimum	0	ND	TR[b]	TR	0	0
Normal	TR	ND	TR	6	TR	TR
Jan 01-15						
Maximum	6	4	8	9+	10	3
Minimum	TR	TR	TR	TR	0	1
Normal	TR	2	3	9	4	TR
Jan 16-31						
Maximum	9	7	9+	10	10	5
Minimum	TR	TR	TR	TR	0	0
Normal	1	2	3	9	7	TR
Feb 01-14						
Maximum	9+	8	9+	10	10	8
Minimum	TR	TR	1	TR	TR	TR
Normal	4	2	6	9	9	2
Feb 15-28						
Maximum	10	9	9+	10	10	9
Minimum	TR	1	1	TR	TR	TR
Normal	8	5	7	9	9	2
Mar 01-15						
Maximum	10	8	9+	10	9+	5
Minimum	TR	TR	TR	0	0	TR
Normal	7	3	5	7	6	1
Mar 16-31						
Maximum	9+	6	9+	9+	9+	3
Minimum	TR	0	TR	0	0	0
Normal	5	2	4	1	3	TR
Apr 01-15						
Maximum	9+	3	9	8	8	2
Minimum	TR	0	TR	0	0	0
Normal	1	TR	2	0	1	TR
Apr 16-30						
Maximum	8	ND	4	2	2	0
Minimum	TR	ND	TR	0	0	0
Normal	TR	ND	TR	0	TR	0

Lake Huron and Georgian Bay

Lake Huron has a similar north-south orientation to that of Lake Michigan, with the result that ice cover development exhibits a similar pattern, although smaller differences in temperature between the north and south moderate this pattern somewhat.

[a] ND - insufficient data to calculate per cent of lake surface ice-covered.
[b] TR - trace of ice, less than 1/10.

Initial ice formation begins in the North Channel and along the east coast of Georgian Bay during the second week in December. Some ice also forms in Saginaw Bay at this time. Through January, the ice cover expands lakeward and, by the beginning of February, only the central portion of Lake Huron remains open. Maximum ice cover is reached during the last two weeks of February. At this time, the North Channel and Saginaw Bay have a consolidated ice cover and Georgian Bay is completely ice covered. In a normal year, about 6/10 of Lake Huron is ice covered; however, in a cold winter maximum ice cover may be 9+/10 or more. Prevailing winds can result in considerable rafting, ridging, and hummocking, particularly in the southeast portion of the Lake.

In March, the ice cover begins to decay and the area covered decreases. Ice persists in the northern portions of the Lake and in Georgian Bay but by the end of April less than 1/10 of Lake Huron and Georgian Bay remains ice covered. Georgian Bay clears by early May.

Lake Erie and Lake St. Clair

Lake Erie is relatively shallow, with the result that water temperatures respond quite rapidly to changing atmospheric conditions. From Table 8 it can be seen that of all the Great Lakes, Lake Erie and Lake St. Clair show the greatest ice cover in December. As well, maximum coverage is reached earlier in the winter season, and open water conditions appear somewhat earlier in the spring compared to the other lakes.

Initial ice formation normally begins in the third week of December in the western end of Lake Erie, in Long Point Bay, and along the western shore of Lake St. Clair. Ice is normally consolidated in Lake St. Clair from the middle of January until March, with ice thickness reaching between 15 and 70 cm during the winter.

Through the end of December and into early January, there is rapid growth of ice elsewhere. During the first half of January the western portion of Lake Erie is normally 9/10 ice covered. By this time there is also extensive ice formation in the central basin between Point Pelee and Long Point, whereas the eastern basin remains largely open water. Through the end of January, ice cover forms here as well and maximum coverage is reached in early February. There can be considerable variability in the maximum ice cover from one year to another. Normal maximum coverage is around 9/10, but in a mild winter it may only be 3/10 covered.

Breakup of the ice normally begins in early March. Prevailing westerly winds open the western end and north shore first, with this open water area gradually spreading eastward and southward. By the end of March, Lake Erie and Lake St. Clair are mostly open water, although some ice may persist in the eastern end of Lake Erie into April. These remnants are often the product of considerable wind forcing, producing rafted ice conditions which can present considerable navigation problems in spring, sometimes until early May.

Lake Ontario

Lake Ontario is the second deepest of the five Great Lakes and has the smallest surface area. The large ratio between water volume and surface area means that Lake Ontario acts as a large heat reservoir, with the result that the ice cover is generally least of the five Lakes.

Initial freeze-up normally occurs in the Bay of Quinte during the first week of December and in the bays and harbours at the western end of the Lake in the last half of December. Ice does not normally begin to form at the eastern end of the lake and the head of the St. Lawrence River until the first half of January. Maximum ice cover is normally reached by the beginning of March, with most ice concentrated in the eastern portion of the lake. Normal maximum ice cover is about 3/10; however, in a severe winter the ice cover can approach 9+/10 although this extreme is rare, occurring only three times in the last 100 years.

Ice breakup on Lake Ontario is rapid and by the end of March remaining ice is restricted to the eastern end of the Lake. The lake generally becomes ice free in early April.

St. Lawrence River

The St. Lawrence River flows from the eastern end of Lake Ontario to the Saguenay River where it becomes the Gulf of St. Lawrence (Figure 17 and 18). 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 are large, thick, uneven and discoloured floes up to 8 km 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 masters are advised to avoid them if at all 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.

In the Port of Montreal, the combined effect of an Ice Control Structure and the Rapide de Lachine serve to maintain dispersed ice conditions throughout the winter. Upstream of Montreal to Lake

WARNING: BATTURE FLOES ARE A MAJOR HAZARD TO NAVIGATION THROUGH THE ENTIRE ST. LAWRENCE RIVER. VESSELS SHOULD AVOID CONTACT WITH THEM IF AT ALL POSSIBLE.

Ontario, the shipping season is restricted and is controlled by the operation of the St. Lawrence Seaway Authority.

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.

3.4.2 Gulf of St. Lawrence

A submarine valley known as the Laurentian Channel, extends northwestward from Cabot Strait, across the central part of the Gulf of St. Lawrence, through the Gaspé Passage, and westward to the Saguenay River. The 200-m depth contour in Figure 10 shows channel orientation, depths in the channel range from 275 to 450 m. An extension of this deep water channel can be found in the northeast part of the Gulf, extending into Jacques Cartier Passage between the Quebec coast and Anticosti Island, with water depths of 175 to 275 m. In the southwestern portion of the Gulf of St. Lawrence, the water is considerably shallower with depths of 50 to 75 m. In the Strait of Belle Isle water depths are about 50 m.

Freeze-up Patterns and Timing

Table 9 provides a summary of median freeze-up dates for a few selected locations in the Gulf of St. Lawrence.

Table 9 Median freeze-up and clearing dates for Gulf of St. Lawrence stations

Station	Location	Average week of freeze-up	Average week of clearing
Cornerbrook	Newfoundland	Nov 26 - Dec 02	Apr 09 - Apr 15
Summerside	Prince Edward Island	Nov 19 - Nov 25	Apr 23 - Apr 29
Caraquet	New Brunswick	Dec 03 - Dec 09	Apr 30 - May 06
Harrington Harbour	Quebec	Dec 17 - Dec 23	Apr 23 - Apr 29

Earliest ice formation generally occurs in the lower St. Lawrence River and in the shallow waters along the New Brunswick coast in early December. However, ice is rarely a persistent navigation hazard in the Gulf of St. Lawrence until early January. By mid-December ice begins to form in Northumberland Strait, completely covering the Strait by the end of December. In the Strait of Belle Isle, new ice begins to form late in December or early in January.

Ice formed early in the St. Lawrence River is carried seaward and by the end of December the south half of the estuary, from Pointe-des-Montes eastward, is covered with ice. By the beginning of January, new ice begins to form along the north shore of the Gulf. This ice continues to grow southward and eastward at the same time that ice formed in the estuary is drifting eastward through the Gaspé Passage. Generally, the western portion of the Gulf, from Cape North on Cape Breton Island to the southern tip of Anticosti Island, is ice covered by the end of January. Also, by this time, much of the Gulf`s northern portion is ice covered, as are waters off the northwest coast of Newfoundland from the Strait of Belle Isle to Daniels Harbour.

The ice cover growth continues through February, spreading to include most of the Gulf by the end of the month. The ice cover also thickens during this time, reaching its maximum thickness by mid-March. In sheltered harbours and bays, smooth ice grows 45 to 85 cm thick during a normal winter. By comparison, level offshore pack ice is somewhat thinner, growing to 40 to 60 cm in thickness.

Fast and Mobile Ice Areas

Fast ice in the Gulf does not extend far from land, in most cases, because of the great water depths in the channel. However, large expanses of fast ice develop in southern Chaleur Bay, in the Sept-Iles area, along the north shore islands near Mingan, from Cape Whittle to Blanc Sablon, and in the Bay of Islands, along the West Newfoundland Coast.

Ice in other areas of the Gulf of St. Lawrence remains mobile throughout the winter season.

Ice Pressure and Deformation Areas

The mobility of the ice through much of the Gulf allows it to respond to the forces of wind and currents, which can result in areas of ice pressure as well as to open water leads. Ice pressure, in turn, may result in the deformation of ice through rafting and ridging. Ridge heights in the Gulf seldom exceed 2 m, with most less than 1 m.

Frequently an open water lead will persist along the southwestern coast of Newfoundland, from Cape Ray, to Cape St. George, to the Bay of Islands. However, under conditions of extreme ice pressure, this area and other windward shores may experience considerable ice deformation, with ice floes piling to heights of 10-13 m. Similar ice pile-ups may occur along the east coast of Cape Breton Island when northeast gales push ice from Cabot Strait into Sydney approaches.

Ice Breakup, Movement, and Decay

With warming air temperatures, ice breakup usually begins around mid-March in leeward and thinner ice areas. The main shipping route through the deep water portion of the Gulf normally becomes clear of ice first, usually early in April. Ice in shallower water between New Brunswick, Prince Edward Island, and Cape Breton Island decays more slowly; the area does not clear of ice until the third week in May. Similarly, clearing of ice in the northeast arm of the Gulf of St. Lawrence is delayed, progressing from the central portion of the Gulf toward the Strait of Belle Isle by the end of May. Whereas the sea ice clears in the spring, icebergs drifting south through the Strait of Belle Isle may persist in the northern-most portions of the Gulf well into summer.

Typical Versus Extreme Ice Conditions

The extent of ice cover in the Gulf can vary considerably from year to year. In a mild winter, very little ice will be found in the Gulf of St. Lawrence. For instance, in the winter of 1957-58, the only ice to form was located near Prince Edward Island, along the coast of New Brunswick and in the St. Lawrence River. Similarly, in 1968-69, an open water channel persisted throughout the winter season. On the other hand, during a particularly cold winter, initial ice formation can begin as early as mid-November and the period required to form a complete ice cover in the Gulf can be reduced to the end of January. Ice can persist well into summer, as was the case in 1974 when sea ice remained in the northeast arm between Quebec and Newfoundland until mid-July.

All ice forming in the Gulf of St. Lawrence melts during the summer, so it is classified as first-year ice or younger. However, on rare occasions, some old ice floes may enter through the Strait of Belle Isle with old floes observed as far west as Cape Whittle in April and May.

3.4.3 East Newfoundland Waters and Labrador Sea

East Newfoundland waters and the Labrador Sea, shown in Figure 11, extend seaward to the eastern edge of the continental shelf and consist of a series of banks separated by relatively deep troughs. Over the Grand Banks off Newfoundland water depths vary between 50 and 90 m. Water depths over the seven banks along the Labrador coast are somewhat greater, ranging between 60 and 190 m. Water depths over the troughs and off the northeast coast of Newfoundland are considerably greater, reaching depths of 350 m.

Freeze-up Patterns and Timing

The presence of ice off Newfoundland and Labrador is seasonal, with the season length varying with latitude. Table 10 provides an indication of the range of average freeze-up and clearing dates for selected locations along the east Newfoundland coast.

Table 10 Freeze-up and clearing dates for Labrador and Newfoundland

Station	Location	Average week of freeze-up	Average week of clearing
Hopedale	Labrador	Nov 26 - Dec 02	Jun 18 - Jun 24
Cartwright	Labrador	Nov 26 - Dec 02	Jun 11 - Jun 17
Botwood	Newfoundland	Dec 10 - Dec 16	Apr 23 - Apr 29

Ice first begins forming in the bays and inlets along the northern coast of Labrador in the last two weeks of November. As air temperatures drop, ice formation spreads rapidly southward with signs of new ice growth in the Strait of Belle Isle by the end of December. At the same time that coastal ice is forming, freeze-up expands seaward. Newly formed ice drifts southward, largely in response to the Labrador Current and winds. By the end of December the southern ice edge normally extends from the Strait of Belle Isle seaward about 50 km to 55°N. Further north, the ice pack widens to about 140 km, with the eastern ice edge running parallel to the Labrador coast as far as Cape Chidley.

Through January, the ice continues to grow in southern Labrador and to drift south toward Newfoundland. By the end of January, the ice will normally extend southward to the northern parts of Notre Dame Bay. In most years this southern advance will continue in February, past Cape Freels and often past Cape Bonavista. While ice frequently extends as far south as 48°N, 50°W by the end of March, this can vary considerably depending on the severity of winter and on prevailing winds. South and southeast winds result in the development of coastal leads and loose ice conditions, whereas north and northeast winds tend to pack the ice along the Newfoundland coast.

Fast and Mobile Ice Areas

Fast ice forms in the many bays and inlets along the Labrador coast and grows seaward as the winter season progresses. Extensive areas of fast ice can be found between 55°N and 58°N. Deeper water offshore prevents the formation of fast ice, resulting in a shear zone roughly parallel to the shore, which develops where the fast ice and mobile ice interact.

Fast ice along the Newfoundland coast is mainly confined to southern Notre Dame Bay and the area from Fogo Island to Green Bay. Some fast ice can also be found at the southern end of White Bay and the bays and harbours along the northern peninsula.

In general, the drift of ice along the Labrador coast is in a southerly direction parallel to the coast and it averages 10 to 15 km/day. Variations in wind speed and direction may alter the ice velocity and on occasion may stop it entirely for short periods. In mobile pack, ice composition varies both in terms of ice thickness and floe size.

The sea ice found along the Labrador Coast is primarily first-year or younger ice, with small concentrations of old ice reported occasionally and icebergs in all seasons.

Fast ice grows in sheltered harbours and bays to about 80-120 cm in a normal winter. Offshore, level pack ice can reach a thickness of up to 150 cm. The thickness of infrequently observed old ice has been measured up to 210 cm. Further south off Newfoundland, ice thicknesses tend to be less. Fast ice generally grows to 60-90 cm through the winter whereas level pack ice ranges from 90 to 120 cm thick. Rafting and ridging can affect the thickness of pack ice considerably, with ridging in excess of 2 m observed on occasion, especially near the ice edge where ice floe interaction is high.

Variations in floe size along the Labrador coast can be related to the distance of the ice from the pack edge. Near the ice edge, waves and swell from the open ocean cause considerable interaction between ice floes. Frequent collisions result in abrasion and cracking of ice floes into smaller pieces. Wave and swell energy is dampened with distance into the pack, resulting in less energetic floe interaction and larger floes.

> ***NOTE:*** *Icebergs can also be found in the ice pack, a formidable hazard to navigation along the Labrador Coast. While they tend to be more common in the spring and summer, it is important to watch for them at all times.*

Ice Pressure and Deformation Areas

While fast ice remains relatively stable through the winter season, pack ice moves in response to winds and ocean currents. In the Labrador Sea, a lead can often be found between the fast ice and the offshore pack ice when westerly winds are prevalent. At the same time, along the outer edge of the pack, there will tend to be diffuse ice conditions with numerous strips, patches, and belts of ice separating from the main pack. On the other hand, east to northeast winds will tend to compact the ice cover, producing a sharply defined outer edge, closing of leads between the fast and pack ice, and high ice concentrations. Under these conditions ice deformation may be severe, resulting in rafting and ridging. It is common for the ice thickness to be increased by floes piled on top of each other. Ice ridges of 3-5 m are not uncommon under these circumstances, although 1-2 m is a more likely thickness. As a rule of thumb, ice keels below the ice are in the order of three times the vertical extent of associated ice ridges.

> ***NOTE****:* *An ice ridge of 2 m can be expected to have a keel of about 6 m.*

Ice Breakup, Movement, and Decay

Off Labrador the pack ice continues to grow in thickness and extent, reaching its normal maximum limit in April. However, as early as late March, ice off Newfoundland begins to deteriorate and the ice edge begins to retreat slowly northward. Figure 17 shows average ice edge positions along the Labrador and Newfoundland coasts for the months of January, April, and July. The seasonal advance and retreat of the ice cover is apparent as is the general area covered by ice.

By the end of March the ice pack usually has retreated to 49°N latitude extending seaward from Cape Freels. As spring temperatures rise, the ice starts to melt and the rate of retreat of the ice pack increases. By late May, ice off mid-Labrador begins to decay and, by mid-June, ice off the northern tip of Labrador is also in a state of decay. Clearing of the pack ice along the Labrador coast is a gradual process as the southern ice edge retreats northward and, at the same time, the eastern edge moves shoreward. By early June, the southern ice edge clears the Strait of Belle Isle and by the end of the month it is north of the approaches to Hamilton Inlet. As the ice cover deteriorates, its composition changes from a relatively compact area of ice to one of strips and patches, particularly near the ice edge. Within these strips and patches, ice concentrations may range from 4 to 6/10. By mid-July the ice edge is normally near Nain and at the end of July it is approaching Cape Chidley, where strips and patches of ice may remain into the first week of August.

Typical Versus Extreme Ice Conditions

Ice along the Labrador and Newfoundland coasts is predominantly first-year or younger in age because the ice forms and disappears within a single year. Occasional pieces of old ice may drift into the region from Hudson Strait, Davis Strait, and Baffin Bay. The quantities of old ice to be encountered will be small, but even an infrequent piece of old ice can present a serious hazard to shipping and care should be taken to watch for old ice and to avoid it.

WARNING:	**CONCENTRATIONS OF OLD ICE ARE LOW ALONG THE LABRADOR COAST BUT THE MARINER SHOULD WATCH CAREFULLY FOR OLD ICE PIECES AND GIVE THEM A WIDE BERTH.**

The progression of a typical season has been described in earlier sections, but the timing and the extent of the ice pack can vary considerably from year to year. Figure 18 provides an indication of the variability in the coverage, showing the average, minimum, and maximum sea-ice extent during the period from 1973-1985.

In addition to overall ice extent, the timing of freeze-up and break-up may vary considerably from year to year. For example, in the harbour of Botwood, Newfoundland, new ice can form as early as the end of November or as late as early January. Along the Labrador coast freeze-up has been known to start as early as the second half of October and as late as the second week of December.

Clearing of ice from the Labrador and East Newfoundland waters is equally variable; the southern ice edge can be north of the Strait of Belle Isle by the last week of April during a mild winter but, in a cold winter, this may not be the case until the middle of July. In some years the Labrador coast has been completely free of ice as early as the end of June, whereas in other years ice has persisted as late as the last week of August.

Figure 17 January, April, and July ice edge positions off the east coast of Canada

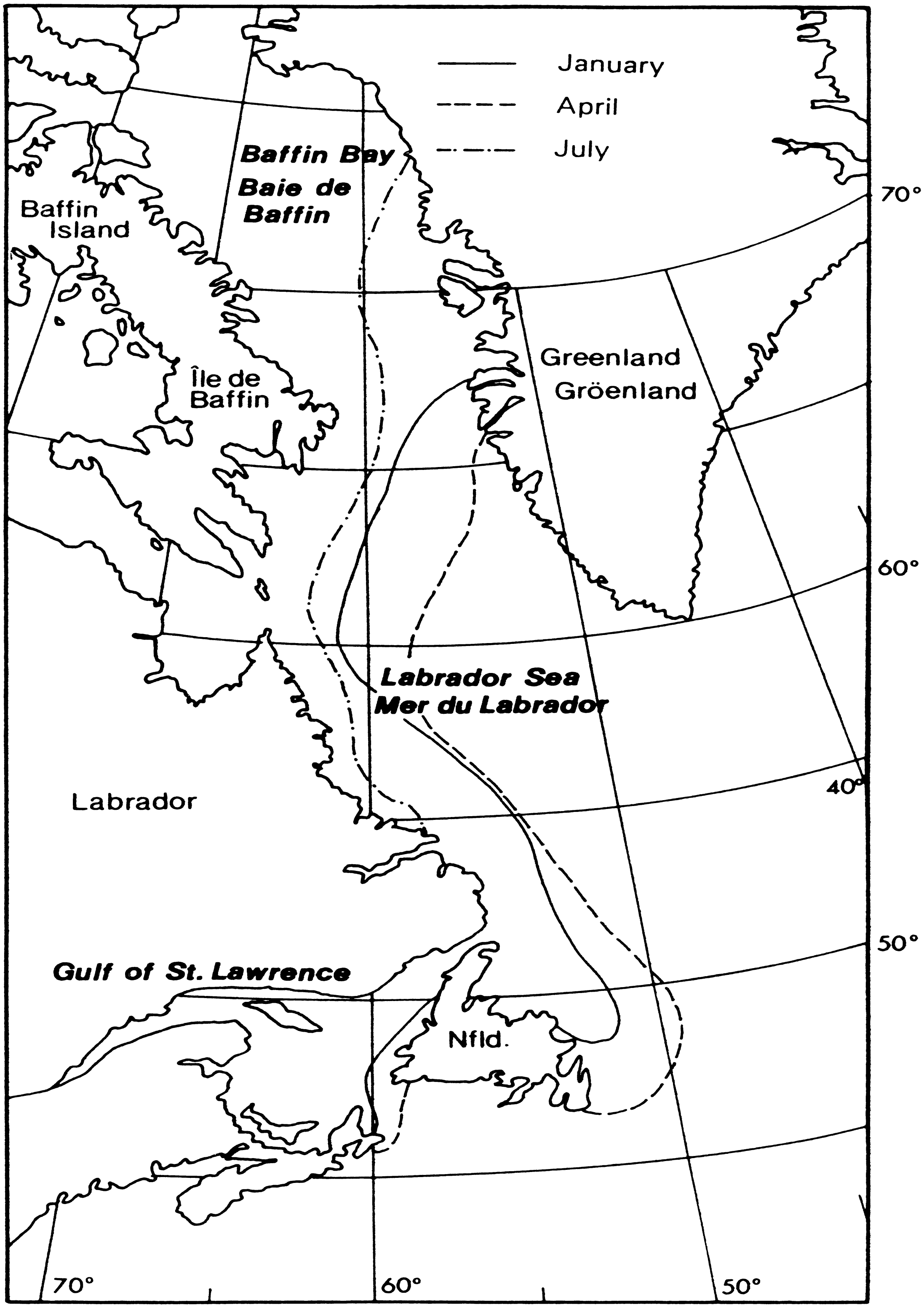
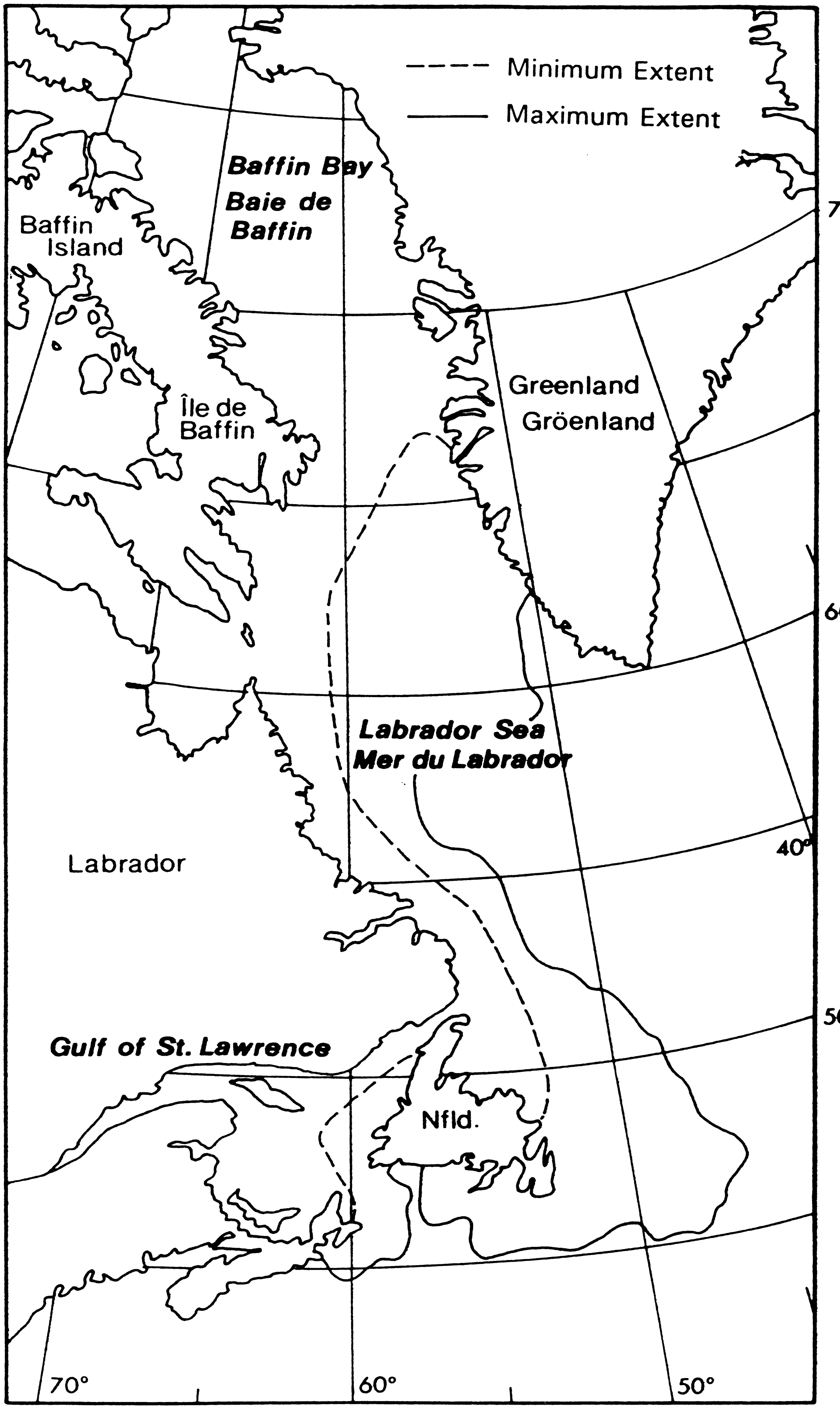


Figure 18 Variability in minimum and maximum extent of sea ice off the east coast of Canada



3.4.4 Hudson Bay, James Bay, Hudson Strait, and Foxe Basin

This region (Figure 19) is characterized by shallow water depths except for Hudson Strait. Foxe Basin averages 50-90 m depth in the central part and 15 to 45 m in the northern part. Hudson Bay and Ungava Bay are deeper, averaging 135 to 175 m in the northern half and 45 to 135 m in the southern part. James Bay ranges from 5 to 100 m deep. In contrast, Hudson Strait is a deep channel averaging 275 metres which, in combination with its southeast/northwest orientation, serves to focus the tidal effect coming from the Atlantic Ocean, producing the largest tidal ranges in the world. The western shore of Ungava Bay has a maximum tidal range of 9.3 m.

The near-surface water currents, shown in Figure 19 for Ungava Bay and Hudson Strait, indicate the general direction of flow, but the tidal effects can reverse the near surface current by 180°. The continuous reversals of flow cause the ice cover to be very rough, and often under pressure. Recent winter voyages in the area have found vast areas of rubble in Hudson Strait, and tide-induced pressure can cause ships to become beset in the ice for periods of up to several hours.

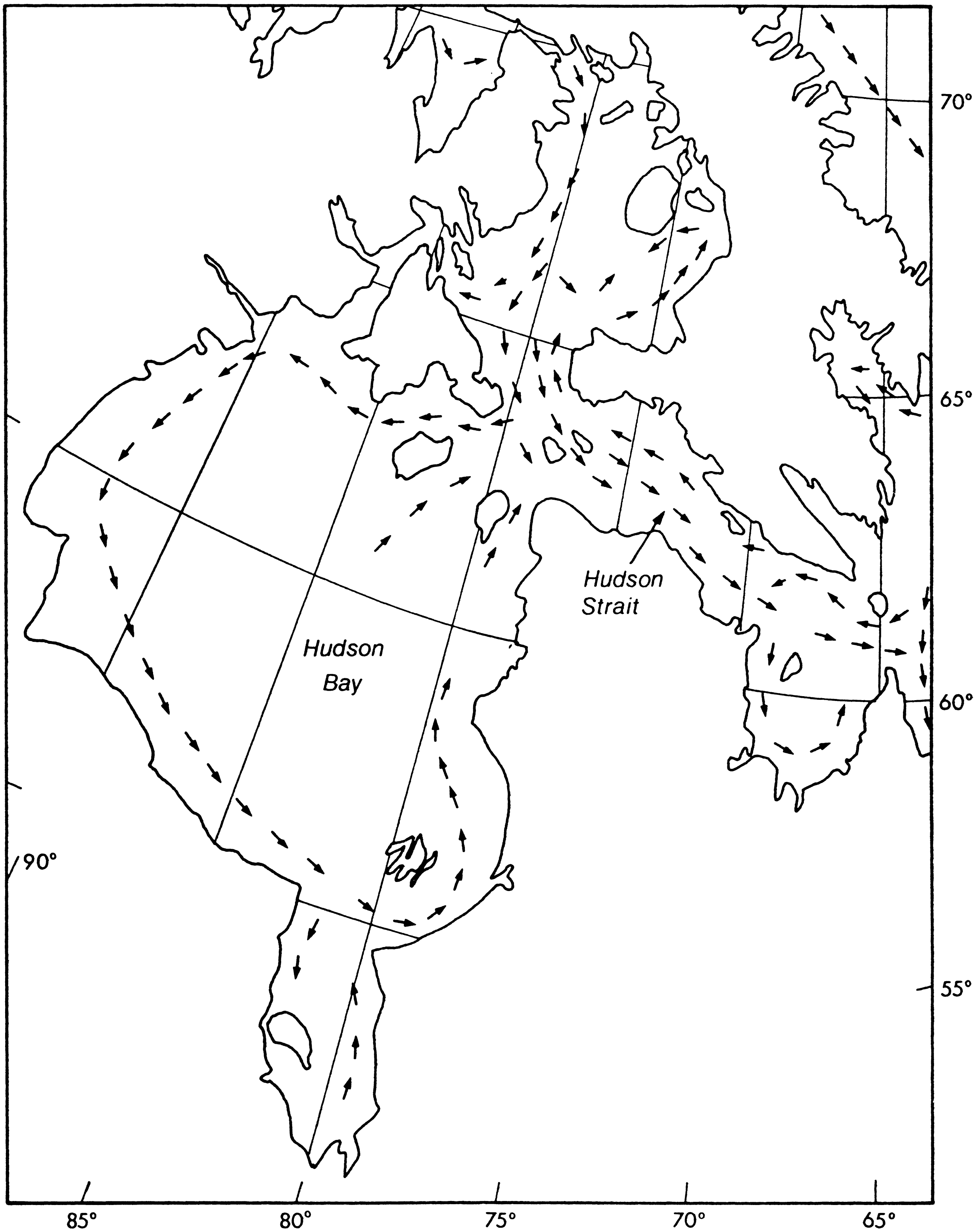
Freeze-up Patterns and Timing

The large water areas involved, and the large variation in latitude, mean that the timing of freeze-up can vary considerably in this area. The freeze-up process generally follows this pattern:

- (first two weeks of October) Northern Foxe Basin and the Churchill River begin forming new ice;
- (last two weeks of October) Western Hudson Strait and northwestern Hudson Bay begin forming new ice;
- (first two weeks of November) James Bay begins forming new ice;
- (first two weeks of November) Foxe Basin and Foxe Channel are completely ice covered;
- (last two weeks of November) Hudson Strait is completely ice covered;
- (first two weeks of December) James Bay is completely ice covered; and
- (mid-December) Hudson Bay completely ice covered.

The resultant winter ice cover in this region is composed of many different thicknesses of ice that are all very rough. Continual ice motion allows rafting, ridging, and hummocking to take place throughout the winter.

Figure 19 Mean surface water currents in the Hudson Bay area



Fast and Mobile Ice Areas

Two locations in the region are known to have extensive areas of fast ice: an area that covers the bay east of the Belcher Islands, and an area which includes the islands and shoreline in northern and eastern Foxe Basin. There is also a band of fast ice which circles most of Hudson Bay, lines both sides of Hudson Strait and Ungava Bay, and encircles each of the Islands in northeastern Hudson Bay. This band of fast ice varies in width from almost none to as much as 45 km. The thickness of the fast ice varies with latitude, James Bay late winter fast ice is 80 to 120 cm thick, whereas in Foxe Basin fast ice can be up to 230 cm thick.

Within the three main water bodies, Hudson Bay, Hudson Strait, and Foxe Basin, most ice remains mobile all winter. Although these areas become totally ice covered each winter, their size, local tides, and exposure to severe winter storms all combine to keep the ice mobile and produces a significantly rough ice surface.

Figure 20 shows an ice chart of typical ice conditions in late winter/early spring. The composite ice chart for 21 May 1991, compiled by Canadian Ice Service (CIS), shows the extent of the fast and mobile ice areas.

Ice Pressure and Deformation Areas

Large portions of this area experience ice pressure as a result of wind forcing. The predominant northwest wind causes the ice to be pressed tightly along the eastern shore of Hudson Bay from Hudson Strait to James Bay and along the southeastern shore of Foxe Basin. Tide-induced pressure also occurs in Foxe Basin. Although Hudson Strait experiences some ice pressure along its southern side during northwest winds, tides are the predominant cause of ice pressure in this area. Ice drift in Hudson Strait is generally from west to east, which causes the ice cover in eastern Hudson Strait to become very compact when the tide is rising.

Deformation of the ice cover is typically related to ice pressure and mobility. Large areas in this region remain mobile each year, thus moderate surface deformation is widespread. Extremes occur in Foxe Basin where areas in the southeast can have ridge frequencies of 24 ridges per km, average ridge heights of 1.3 to 2.0 m, and maximum ridge heights of 5.0 m.

The combination of winds, tides, and near surface water currents cause the southern shore of Hudson Strait to experience moderate intensity, but nearly continuous ice pressure and deformation during mid-winter.

Old Ice Occurrence and Distribution

This region receives old ice from three sources: Fury and Hecla Strait, non-melt in Foxe Basin, and Davis Strait and Baffin Bay. Near-surface water currents (Figure 19) moving eastward through Fury and Hecla Strait, bring small amounts of old ice from Committee Bay into northern Foxe Basin. Only small, weathered floes reach Foxe Basin during the summer and they melt quickly in the warm waters of northern Foxe Basin.

South-central Foxe Basin is an area where sea ice can remain throughout the summer. In some years an area along the north and east coasts of Southampton Island has patches of second-year ice in concentrations up to 9+/10, which re-freeze into the new ice cover in fall. This ice then drifts slowly to the east during the winter, typically dispersing and mixing with the rough ice of Hudson Strait. By the following spring second-year ice concentrations are rarely observed greater than a trace.

Old ice from the Arctic Ocean drifts south along the east Baffin Island coast all year. On those occasions when a high concentration of old floes is off the eastern end of Hudson Strait (south of Davis Strait) and an easterly wind develops, old ice can be driven into eastern Hudson Strait. However, the old ice which enters Hudson Strait in this manner does not usually reach further than 70°W before drifting to the south side of the Strait, and then it is carried eastward to the Labrador Sea.

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 which recurr in the same position every year. Figure 21 shows the distribution of recurring polynyas in the Canadian Arctic.

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. Similar to polynyas in other areas, these polynyas are focal points for the initiation of spring melt.

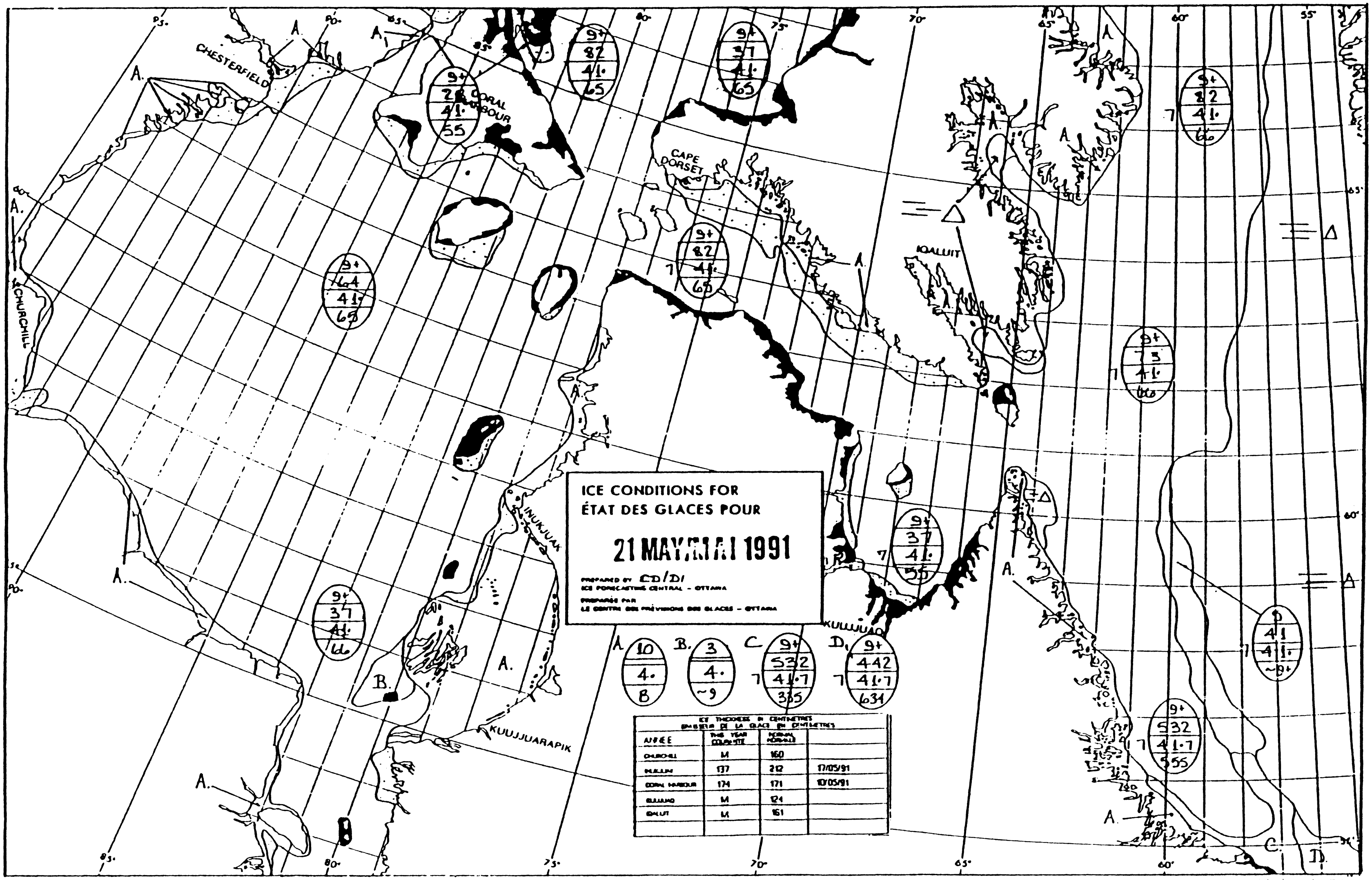
Ice Breakup, Movement, and Decay

The wide range in latitude in this region results in a melt and decay process which lasts throughout the summer. The following stages are typical of the decay process:

- initial melt in James Bay, mid-late April;
- initial melt in Hudson Strait and Ungava Bay, early May;
- initial melt in Hudson Bay, mid-May;
- initial melt in Foxe Basin, early June;
- James Bay is clear of most ice, late July;
- Hudson Strait and Ungava Bay are clear of most ice, mid-August;
- Hudson Bay is clear of most ice, late August; and
- Foxe Basin contains only a few strips of ice in most years, early September.

The near-surface water currents serve to carry both the decaying ice in Hudson Strait out to the Labrador Sea, and the decaying ice in Foxe Basin into northern Hudson Bay. Other than these two areas, most of the ice in this region melts in place. The southerly latitude of this region and the tendency for winds to shift to the south in the summer results in rapid ice melt throughout the region in July.

Figure 20   Example of a composite ice chart for Hudson Bay and Hudson Strait, May 21, 1991



Typical Versus Extreme Ice Conditions

Extreme ice conditions in this region are notable. In summers, when winds persist from the north instead of coming from the south, Foxe Basin will have significant quantities of unmelted ice all summer; Hudson Bay will begin to freeze as early as the first week of October; and James Bay will start to freeze during the first week of November. In a year when the winds shift to the south early, and remain there, Hudson Bay will clear completely by the first week of August and remain so until the first week of November, Hudson Strait will clear as early as the last week of July and remain so until the last week of November. Foxe Basin can clear as early as the first week of September and remain open until the third week of October.

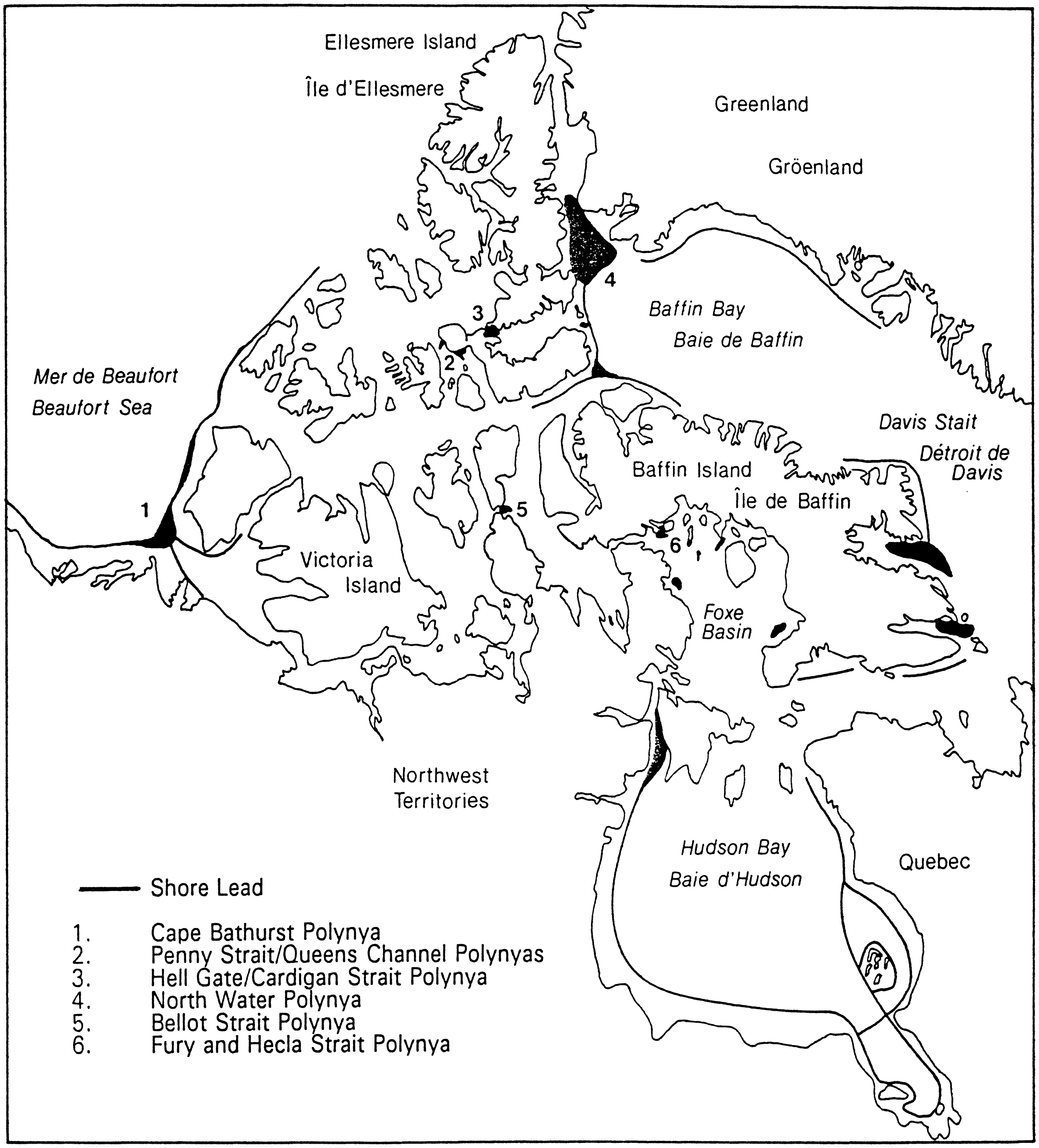
3.4.5 Baffin Bay and Davis Strait

Baffin Bay and Davis Strait together form the largest and deepest channel in the Canadian Arctic. Depths range from 3658 m in southern Davis Strait to 2396 m in the southwestern portion of Baffin Bay. Deep water is part of the reason why the area never freezes solid, even in the coldest winter months. Tidal influences from the Atlantic Ocean, as well as the warmer north-flowing current along the west coast of Greenland, combine to keep the ice cover in motion throughout the year. The relatively warm water moving along the west coast of Greenland is counteracted by a south-flowing current of cold water along the east coast of Baffin Island. These two currents have a great effect on the ice cover: the ice edge is usually far to the north along the Greenland coast and far to the south along the east coast of Baffin Island, so that navigation can be much easier in the eastern half of Baffin Bay for most of the year.

Ellesmere Island, then extends southward to cover the entrance to Jones Sound by the last week of September. Ice formation progresses southeast along the Baffin Island coast and east to cover Melville Bay by the second week of October. All of Baffin Bay and most of the Baffin Island coast is ice covered by the end of November, however, along the west coast of Greenland, the north flowing current of warmer water from the Atlantic Ocean prevents ice growth south of about 66°N.

The ice regime of northern Baffin Bay is also strongly influenced by the presence of the North Water Polynya which recurrs at the top of Smith Sound. This area remains open, or is covered with only young ice, all winter. It serves as a focal point for the initiation of spring melt, in addition to modifying the freeze-up process.

Figure 21 Distribution of recurring polynyas in the Canadian Arctic



Freeze-up Patterns and Timing

Freeze-up and breakup dates for Baffin Bay and Davis Strait, provided in Table 11, are based on observations for the past 30 years. Rarely do events occur more than a few days outside the ranges given. Freeze-up begins in the northwest of the region. Ice begins to form around

Table 11 Average freeze-up and breakup dates for areas in Baffin Bay and Davis Strait

Area	Event	Average date of occurrence	Range of occurrence
Baffin Bay	Clearing of all ice (open water)	Sep 10	Aug 20 - not at all
	Formation of 9+/10 ice cover	Oct 15	Oct 1 - Nov 15
Davis Strait	Clearing of all ice (open water)	Sep 1	Aug 15 - Sep 30
	Formation of 9+/10 ice cover on western half	Nov 15	Nov 1 - Dec 1

Fast and Mobile Ice Areas

Baffin Bay contains two large fast ice areas: in the northeast section in Melville Bay, and along the northeast coast of Baffin Island. The extent of the Melville Bay fast ice is quite variable. In some years it is only 32 km wide but, in other years, it has been observed to be 112 km wide. This fast ice halts the calving of icebergs in the winter, which is a benefit to shipping. However, in the spring the Melville Bay fast ice has been observed to be thicker than most first-year ice in Baffin Bay, which is a significant detriment to shipping once it breaks up and drifts into Baffin Bay.

The border of fast ice along east Baffin Island is not as extensive as that in Melville Bay, but is often much thicker and rougher. The continual southward movement of ice along the Baffin Island coast causes considerable shearing action along the fast ice edge, resulting in significant amounts and heights of ridged ice. The fast ice near Clyde River can be 40 km wide, decreasing in width northward towards Bylot Island and southward to Cape Dyer, where it is almost non-existent.

Beyond the fast ice, the Baffin Bay and Davis Strait ice cover remains mobile throughout the winter. The North Water Polynya defines the northern extent of mobility with an ice bridge usually forming across the mouth of Smith Sound. Lancaster Sound occasionally consolidates eastward to its entrance at Baffin Bay (81°W), however, it usually remains mobile as far west as Prince Leopold Island (90°W).

Ice Pressure and Deformation Areas

The principal area of ice pressure in Baffin Bay and Davis Strait is along the Bylot Island and Baffin Island east coasts. The southward flowing current is the dominant force causing the ice to press along the coast and shear as it moves south. The area which most commonly experiences ice pressure in this region is along northeast Bylot Island, where the southbound current and the ice is deflected to the east. In addition, ice moving east from Lancaster Sound presses along the northern Bylot Island coast. The combination of these forces results in extended periods of ice pressure around Bylot Island, particulary in the fall and winter.

Old Ice Occurrence and Distribution

Old ice enters Baffin Bay through Smith Sound, Jones Sound, and Lancaster Sound. All of these sources are on the northwestern side of the Bay, which, in combination with the east to west circulation across the north half, and southerly flow down the west side, keeps most of the old ice in the western half of Baffin Bay and Davis Strait.

In most years, by mid- to late summer Lancaster Sound and Jones Sound have fractured and begun releasing old ice which drifts into Baffin Bay, usually in strips and patches. Very late in the summer or in autumn, Nares Strait becomes a source of old ice (from the Arctic Ocean via the Kane Basin) and, in most cases, its output of old ice far exceeds that of Lancaster Sound and Jones Sound. It is not uncommon in November to have large areas in northeastern Baffin Bay reported as 5/10 old ice with patches of as much as 9/10 old ice. The outflow of old ice from Nares Strait can be highly variable, ranging from almost no old ice in a few years to large quantities in most.

During the winter the old ice moves south along the Baffin Island coast, becoming more and more spread out. The old ice continues its southward movement throughout the winter. Recent studies tracking old ice indicate that an old ice floe located in Baffin Bay off Bylot Island in early November could be off the Strait of Belle Isle between Labrador and Newfoundland by mid-April.

The probability of old ice being encountered in the central portion of Baffin Bay in the spring and summer directly corresponds to the timing of the outflow from Nares Strait the previous fall and winter. In winters, when Nares Strait consolidates by late November or December, the old ice will have a chance to clear Baffin Bay by the next spring. However, in winters where the consolidation of Nares Strait occurs in March or April, or not at all, old ice will be present in Baffin Bay throughout the ensuing spring and summer. Old ice should be expected in Baffin Bay in some summers. The timing of the consolidation of Nares Strait the previous winter can give clues to whether it will be present or not.

> *NOTE:* ***The timing of ice consolidation in Nares Strait can provide a clue as to whether old ice will be present in Baffin Bay the following summer.***

Polynyas

The Baffin Bay and Davis Strait area has five polynyas (Figure 21): 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.

During the winter months the North Water polynya has a significant influence on the ice cover of Baffin Bay. The continual production of new and young ice in the North Water polynya contributes greatly to the roughness of ice in northern Baffin Bay. The young ice produced in the North Water polynya drifts southward into the heavier ice in central Baffin Bay, where dynamic conditions deform the relatively thin ice.

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. In the spring this, in combination with the natural southward drift of the Baffin Bay pack, causes the North Water polynya to extend rapidly into Lady Ann Strait and Lancaster Sound forming a broad expanse of open water.

Ice Breakup, Movement, and Decay

In most years, by March, Baffin Bay is 9+/10 concentration of mostly thick first-year ice with giant floes and large ice fields within the pack. In some cases floes may reach 10-20 km in diameter. The southeast to northwest oriented leads are a common feature of the mid-winter pack ice of Baffin Bay. During the months of April and May these leads expand and become more pronounced. As the Baffin Bay pack disintegrates into floes of various sizes, the leads tend to disappear (usually by mid-May).

At the same time as the ice cover is fracturing, the three northern polynyas enlarge and form one large open water area. The advance of this large polynya southeastward combines with the south-flowing current along Baffin Island to clear ice in a southward direction down the Baffin Island coast, while the warmer north-flowing current along the west Greenland shore clears ice northward. The clearing of Baffin Bay from the north, east, and west leaves ice in a north-south line in the centre of Baffin Bay later in the summer. This area of ice drifts southward, usually disappearing completely along the Baffin Island coast by early September.

Typical Versus Extreme Ice Conditions

Extreme variability is seen in the amount of ice left unmelted in the fall, the amount of old ice that enters the region, and the date when the Baffin Bay ice cover has grown to predominantly young ice. In some years Baffin Bay and Davis Strait have cleared of all sea ice as early as the third week of August, whereas in other years a significant belt of ice remains in central Baffin Bay into winter.

The old ice that comes from Nares Strait into Baffin Bay is often stopped by an ice bridge, which forms anywhere between the Lincoln Sea to the north, and Smith Sound to the south. If an ice bridge forms early in the fall, only small amounts of old ice will enter Baffin Bay. However, in some years, no ice bridge forms and significant amounts of old ice are free to move southwards.

> **WARNING: HIGH VOLUMES OF OLD ICE IN NORTHERN BAFFIN BAY POSE A SIGNIFICANT RISK TO SHIPPING.**

Formation of a predominantly young ice cover in Baffin Bay can be as early as the middle of September and as late as the end of October.

3.4.6 Arctic Archipelago

Movement of ice through the numerous channels and small water bodies of the Arctic Archipelago is often restricted by bathymetry. Examples of this can be found in Victoria Strait, Belcher Channel, and

Austin Channel, which have soundings of less than 10 m in parts of the main channel, hindering both ice drift and navigation. However, most of the channels are 100 to 600 m in depth.

NOTE: *Soundings are often incomplete in some northern channels.*

Freeze-up Patterns and Timing

The freeze-up and breakup dates, shown in Table 12, clearly indicate the brevity of summer in the northern part of the Arctic Archipelago. The freeze-up process generally starts in the north and west and proceeds south and east. The first new and young ice is usually found in the channels of the High Arctic Islands; however, ice grows quickly throughout the region in the short days of fall.

Table 12 Average freeze-up and breakup dates for areas in the Arctic Archipelago

Area	Event	Average date of occurrence	Range of occurrence
Eureka Sound	Formation of 9+/10 ice cover	Sep 15	Sep 07-Sep 21
Northern Norwegian Bay	Fracture of ice in spring	Aug 15	Aug 01 not at all
Viscount Melville Sound	Fracture of ice cover in spring	Jul 31	Jul-20-Aug 31
	Formation of 9+/10 ice cover on north side	Oct 01	Sep 15-Oct 07
Lancaster Sound	Clearing of most ice	Aug 10	Jul-21-not at all
	Formation of 9+/10 ice cover	Oct 07	Oct 01-Oct 21
Admiralty Inlet	Fracture of ice in spring	Jul 15	Jul 01-Jul 30

Melt of the ice cover in this region is a highly variable event. In years when the summer is cool, melt proceeds slowly, with areas north of about 76°-78°N remaining unbroken. In most years, however, there is a steady progression of the melt from southeast to northwest. Usually the channels leading into Lancaster Sound, Barrow Strait, Viscount Melville Sound, and M'Clure Strait fracture each year and clear out to varying degrees, depending on winds and temperature.

NOTE: *The mariner should recognize that wide year-to-year variations in breakup dates are possible.*

Fast and Mobile Areas

Each winter the Arctic Archipelago becomes a vast area of consolidated, stationary ice. Exceptions to this are the polynyas (Figure 21), the Gulf of Boothia and, occasionally, Lancaster Sound. In some years Lancaster Sound consolidates as far east as Navy Board Inlet, however, the median ice edge location is from Prince Leopold Island north to the Devon Island Coast. Central Prince Regent Inlet is another area that sometimes remains unconsolidated, however, in most winters, it too will become fast.

Ice Pressure and Deformation Areas

The predominant northwesterly wind in this region is responsible for much of the recurring ice pressure. Some of the well documented ice pressure areas include southern Viscount Melville Sound, southern M'Clure Strait, the north coast of Bathurst Island, and the boundary between the Arctic Ocean and the Arctic Archipelago. Southern Lancaster Sound is an area that experiences ice pressure when ice concentrations are high.

Ice deformation is generally the result of ice pressure caused by wind and/or currents. For example, in M'Clure Strait pressure against the south shore causes massive ridging and hummocking in the ice cover. The ice then consolidates for the winter, leaving a highly deformed ice cover. In other areas deformation occurs as a result of continuous ice movement, often throughout the winter months. Such areas include the Gulf of Boothia and Committee Bay where tidal forces deform the ice cover throughout the year. As a general rule, ice pressure should be expected when winds are strong and ice concentrations are high. Ice pressure is greatest any time a fast moving ice cover comes in contact with a slower moving ice cover or with the shoreline. Eastern Lancaster Sound is a good example of this.

Old Ice Occurrence and Distribution

The weak, near-surface water currents of the region, combined with the short, cool summers, allow old ice to remain in most channels. In the area west of 100 W and north of 76°N, and also M'Clure Strait, Viscount Melville Sound, and M'Clintock Channel, old ice is the predominant ice type in most years.

Old ice drifts into Norwegian Bay in significant amounts. However, this ice typically undergoes a great deal of melt in place such that only small amounts of old ice drift into Jones Sound. Even though only small amounts of old ice are observed in Jones Sound, old ice floes still represent a hazard to navigation as they are frequently difficult to detect mixed with first-year ice. This is frequently the case near the eastern entrance to the Sound and in Lady Ann Strait.

> **WARNING: LOW CONCENTRATIONS OF OLD ICE CAN BE ENCOUNTERED WITHIN FIRST-YEAR ICE IN JONES SOUND, PRESENTING A HAZARD TO NAVIGATION.**

Much of the old ice that drifts southeastward through the Archipelago drifts from Viscount Melville Sound eastward into Barrow Strait and Lancaster Sound. Other sources of old ice export are Penny Strait, Wellington Channel, and McDougall Sound, drifting southeastward into eastern

Barrow Strait and Lancaster Sound. Generally, the eastward drift of old ice occurs along the south side of Barrow Strait and Lancaster Sound, but southerly winds in the summer months often force the ice to the north side of the channels, obstructing navigation to Resolute Bay and Little Cornwallis Island. Although the concentration of old ice is usually low, patches of high concentration may be encountered. Similarly, the annual variability is high.

In the south central Archipelago, old ice drifts southwards from Viscount Melville Sound into M'Clintock Channel, then Larsen Sound, before melting in place in Victoria Strait. The annual occurrence of old ice in this area is highly variable but usually is present in sufficient concentrations to provide a serious impediment to navigation for vessels attempting this portion of the Northwest Passage.

Later in the fall, the ice bridge in Nares Strait breaks and old ice begins to drift south. Currents in northwestern Baffin Bay are such that, in early fall, most of this old ice drifts south and somewhat west, entering Lancaster Sound along its north side. This old ice moves a short distance west in Lancaster Sound then drifts to the south shore and is carried back out to Baffin Bay. Later in the fall, this inflow disappears with the result that old ice drift into Lancaster Sound is reduced.

Polynyas

The Arctic Archipelago region has three recurring polynyas (Figure 21): Hell Gate-Cardigan Strait, Dundas Island, and Bellot Strait. These polynyas are focal points for the initiation of spring melt. As the days lengthen in spring the areas of open water associated with these polynyas quickly expand. The polynyas also represent significant ecological areas as herds of marine mammals frequent these open water areas. For this reason alone, navigators should exercise caution while moving through polynyas.

NOTE: *Marine mammals frequently gather in and around polynyas.*

Ice Breakup, Movement, and Decay

Fracture and breakup of the ice cover proceeds from southeast to northwest in the Archipelago. The Lancaster Sound fast ice edge retreats southward down into Admiralty Inlet, then west into Barrow Strait and north into the adjoining channels. As the ice cover in these areas fractures, it begins to drift out following the near-surface water currents shown in Figure 10. Currents and ice drift in the Archipelago are mainly to the southeast but larger water bodies in the region have local variations to this pattern.

In some areas decay of the ice accounts for most or all of the clearing. An example of such an area is Coronation Gulf, where all ice is melted in place and none drifts out of the area. Melting in place is also the principle clearing mechanism in Peel Sound and in Norwegian Bay and Eureka Sound. On the other hand, Lancaster Sound exports most of its ice to Baffin Bay.

Typical Versus Extreme Ice Conditions

The northern portions of the Arctic Archipelago experience extreme variation in the amount of ice cover, but only slight variation in freeze-up and breakup dates. For instance the Norwegian Bay ice cover may not fracture during the summer, but in some years it clears completely, with open water by September.

Ice conditions in Lancaster Sound are variable in terms of seaward fast ice edge location. In mild winters the ice in Lancaster Sound remains unconsolidated as far west as 97°W; but, in a severe season, Lancaster Sound can consolidate as far east as Navy Board Inlet, near 81°W.

Victoria Strait experiences considerable variability in ice cover composition: some summers the Strait can be covered with old ice, in others with first-year ice, and sometimes it is open water. In the years when M'Clintock Channel fractures, large amounts of old ice drift into Victoria Strait which severely restricts navigation. However, in years when the melt advances quickly, Victoria Strait can be clear of all but a few strips of ice.

Recent climatological studies have shown that variability of the ice cover in the Arctic Archipelago is most strongly controlled by summer, not by winter, conditions. Even after severe winters, with average temperatures much below normal, it is summer temperatures that exert the largest influence on the fracture and clearing of the various channels and water bodies. In some very warm summers, ice concentrations can actually increase along the navigable routes when the old ice, normally held immobile to the north and west, breaks up more extensively and drifts southeastward into Barrow Strait and Lancaster Sound.

3.4.7 Western Arctic

This region extends from Point Barrow in the west to Queen Maud Gulf in the east (Figure 22). The region can be divided into two main ice regimes: the channels east of Amundsen Gulf, which become fast each year, and the Beaufort Sea to the west which, with the exception of a band of fast ice, remains mobile all year. These two areas coincide with different water depths; most depths east of 117°W are less than 170 m, whereas water depths to the west of 117°W are much greater. Nevertheless, the mainland coast has an extensive continental shelf, with the 90 m depth contour about 100 km offshore (except near Barter Island and Herschel Island where it is only 18 km offshore).

Freeze-up Patterns and Timing

The timing of freeze-up in the Beaufort Sea depends to a great extent upon the location of the southern limit of the polar pack late in summer, as new ice formation occurs first among old ice floes, then spreads southward. New ice formation in the southern Beaufort Sea usually begins during the first week of October and in the coastal shallows near the Tuktoyaktuk Peninsula it usually begins in the second week of October.

Freeze-up in Queen Maud Gulf usually starts in the first week of October and a few days later in Coronation Gulf. Amundsen Gulf is the last area to freeze over completely. Average dates for a complete ice cover and for clearing of the ice in spring are given in Table 13.

Fast and Mobile Ice Areas

From south of Banks Island to the east end of King William Island, the channels east of Amundsen Gulf form a solid ice cover that is fast to the shore each winter. The fast ice is usually smooth, with an average thickness of 2 m. However, because the water bodies are land-locked, ice breakup and clearing is delayed.

Table 13 Average freeze-up and breakup dates for areas in the Western Arctic

Area	Event	Average date of occurrence	Range of occurrence
Queen Maud Gulf	Open water	Aug 21	Aug 07 - Sep 15
	Formation of 9+/10 ice cover	Oct 15	Oct 01 - Nov 01
Amundsen and Coronation Gulfs	Open water	Aug 15	Jul 15 - Aug 15
	Formation of 9+/10 ice cover on north side	Oct 21	Oct 15 - Nov 15
Beaufort Sea (coastal)	Clearing of most ice	Sep 15	Aug 15 not at all
	Formation of 9+/10 ice cover	Oct 07	Sep 30 - Nov 07

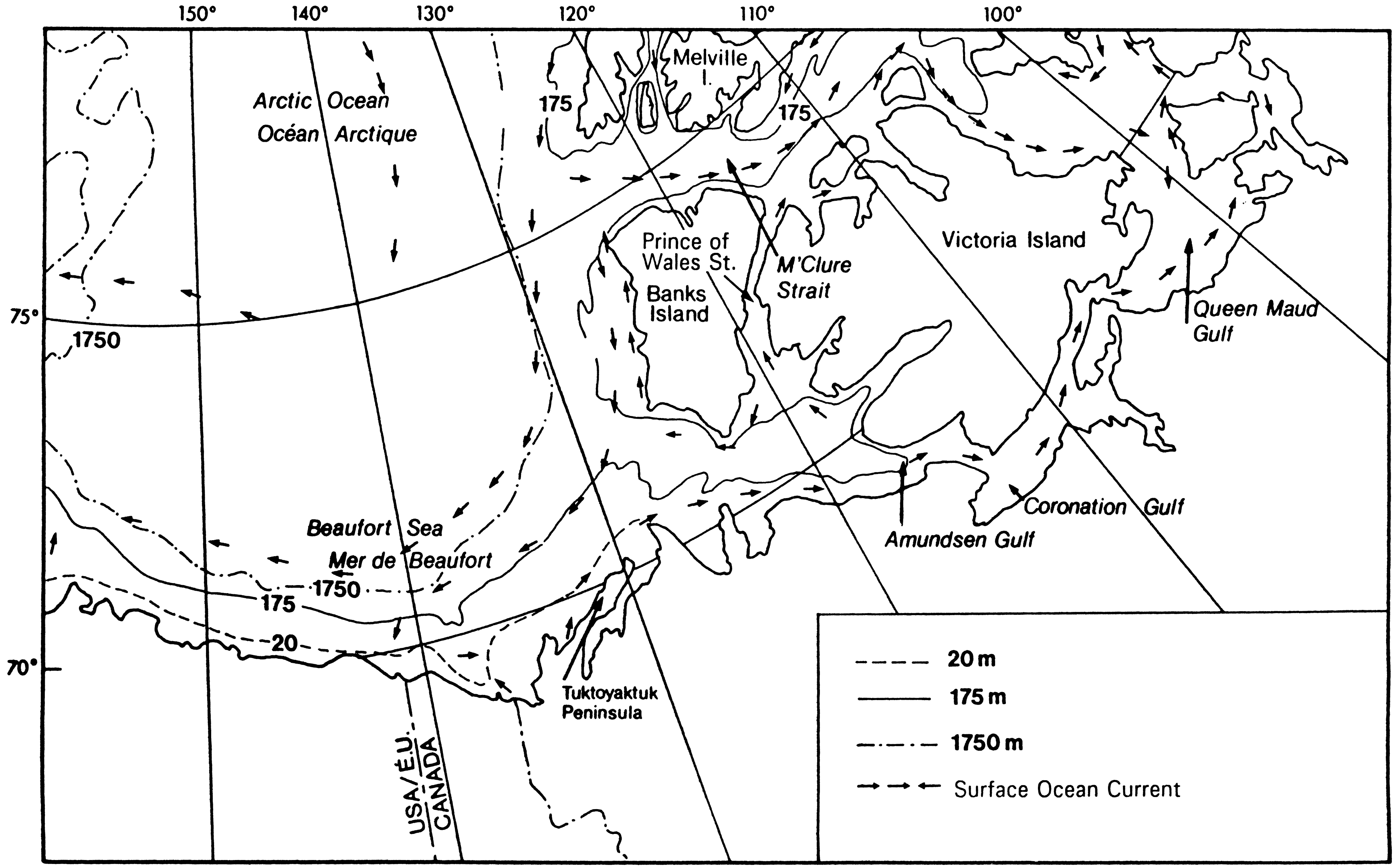
Fast ice in the Beaufort Sea area has characteristics which differ from fast ice in the eastern area. Much of the Beaufort Sea fast ice is composed of pressure ridges and rubble fields because the clockwise rotation of ice in the Arctic Ocean and Beaufort Sea, combined with predominantly northwest winds, presses the pack ice against the fast ice between Cape Parry and Point Barrow. Onshore drift of the pack ice aids in building up the fast ice along the shoreline. The typical mid-winter extent of the fast ice is shown in Figure 23. The areas reported as 7/10 to 9+/10 concentration comprise the mobile ice areas in midwinter for a median year. The extent of the fast ice can vary considerably from year to year.

Ice Pressure and Deformation

The Alaskan and Canadian coastal areas as far east as 126°W are exposed to ice pressure caused by prevailing northwest winds in the winter. The mobile pack ice of the Beaufort Sea presses along the coast, producing shear zones between the pack and fast ice. The areas of ice rubble produced by this pressure and shearing are extensive and some of the ridges produced are huge (including the sail above and the keel below). Surveys of the shear zone north of Herschel Island found ridges with total ice thickness greater than 33 m.

Along the eastern perimeter of the Beaufort Sea (Prince Patrick and Banks Islands) westerly wind events create onshore pressure. For the most part, however, the ice moves parallel to this shoreline or away from it, thus causing little deformed ice compared to conditions along the mainland coast. The general drift of the ice away from the shore is apparent from the orientation of near-surface ocean currents seen in Figure 23.

Figure 22 Western Arctic place names, bathymetry, and currents



Old Ice Occurrence and Distribution

The ice cover of the Western Arctic is composed primarily of rough old ice, except in the eastern waterway. The median location of the southern limit of ice on 21 May is shown in Figure 22. Old ice has been known to drift into Amundsen Gulf during extended periods of west and northwest winds in the summer, however, no old ice has been reported reaching as far east as Coronation Gulf.

In the eastern waterway, old ice from M'Clintock Channel and Larsen Sound drifts south into Queen Maud Gulf through Victoria Strait. The concentration of old ice in Victoria Strait is highly variable. In years when M'Clintock Channel fractures and winds are favourable, large quantities of old ice are present. During October when the ice is most mobile, Victoria Strait has been observed with as much as 9/10 old ice, but with as little as a trace of old ice in a year when ice conditions are not favourable to southward motion of old ice.

Queen Maud Gulf is a relatively shallow water body and warms significantly in the summer, with the result that old ice floes from the north melt quickly. Rarely does old ice drift west out of Queen Maud Gulf into Dease Strait and Coronation Gulf.

Polynyas

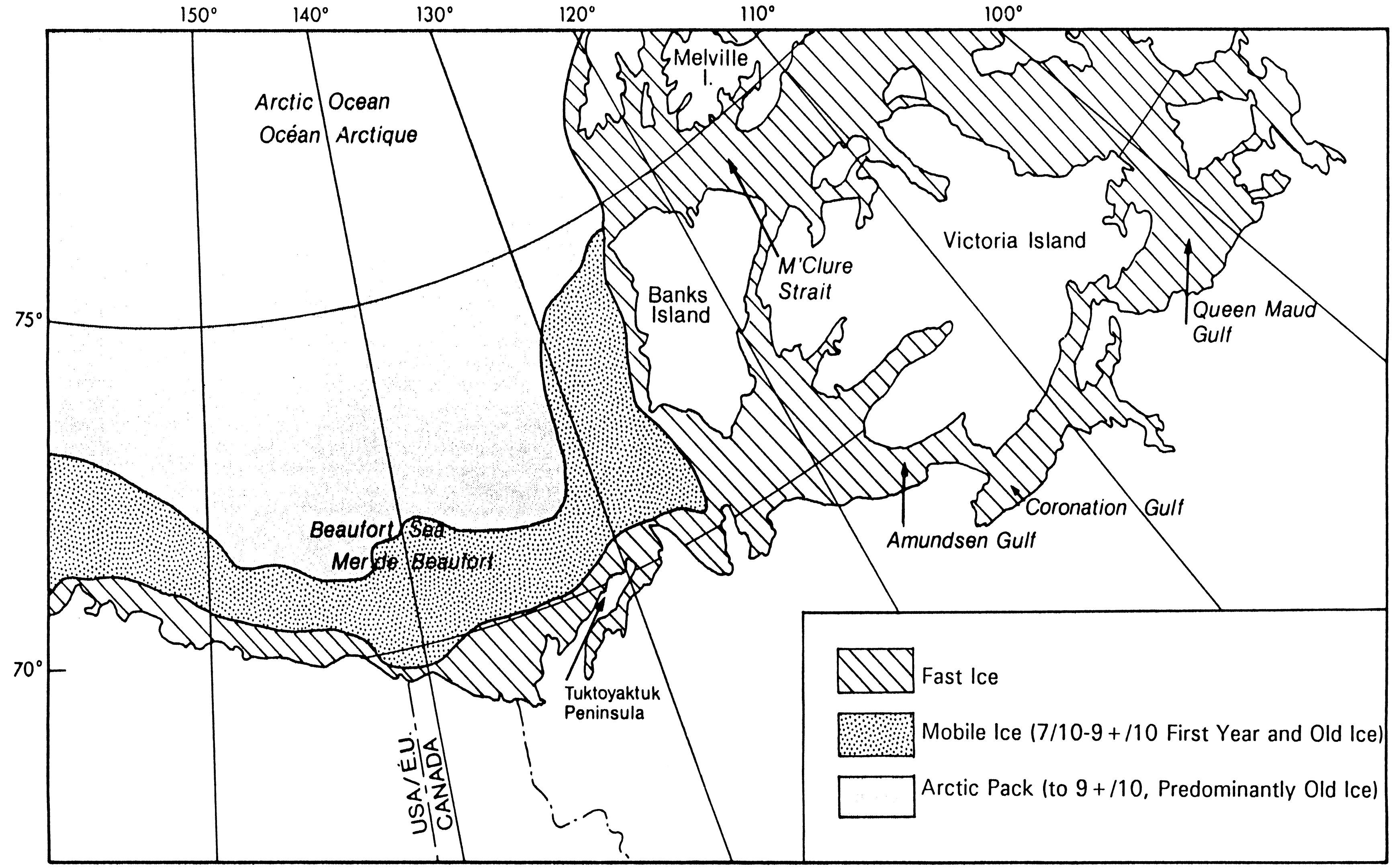
The Western Arctic has one area of recurring open water in winter, the Cape Bathurst polynya (Figure 21). Similar to other polynyas, it is a focal point for the initiation of spring melt. As temperatures rise the main polynya and its north and west arms begin to expand. The expansion of this polynya, combined with a shift to southeast winds in spring, causes the ice edge to retreat northwestward. The extent of the Cape Bathurst polynya is highly variable, as it has been known to freeze over during winters with strong westerly winds. On the other hand, during winters when winds are light or temperatures are above normal, the polynya can be very large.

Ice Breakup, Movement, and Decay

Fast ice in the Southern Beaufort Sea off the Tuktoyaktuk Peninsula is the first to begin fracturing and opening in spring. Amundsen Gulf fractures next, followed by the fast ice along the coast west of the Mackenzie Delta. About the same time as the coastal ice fractures, large areas of fast ice in Coronation Gulf and Queen Maud Gulf fracture. Ice movement is not a big factor in the deterioration of the ice cover east of the Beaufort Sea. The shallow depths and narrow channels in the area restrict movement significantly, resulting in most ice decaying in place.

In the Beaufort Sea, the continual motion of the ice accelerates decay. As soon as the ice becomes weakened it is quickly broken, thus exposing more open water between floes which accelerates decay.

Figure 23 Mid-winter extent of sea ice in the Beaufort Sea



Typical Versus Extreme Ice Conditions

The presence of polar pack ice offshore is a dominating influence in this area. In years when the winds blow predominantly onshore during the summer, severe ice conditions quickly develop. Although the pack ice is usually about 150 km offshore, in summers with adverse winds it has been known to press right down to the coast or onto the remaining fast ice. Then the onshore winds not only press the ice against shore, but greatly decrease the average air temperature, and these cooler temperatures, in turn, slow the deterioration of the ice.

Conversely, offshore winds (southerly flow) as early as late April allow for early and rapid expansion of the Cape Bathurst polynya, and push the pack ice further offshore. This regime can develop an open water route along the Alaskan Coast and Canadian mainland as early as the third week of July, and the route can be navigable until October.

CHAPTER 4 ICE NAVIGATION

NOTE:	*Ships not specifically designed and constructed for ice navigation must consider the suitability of fitted propulsion and control systems, in addition to hull strength, for navigation in ice-covered waters.*

4.1 EFFECT OF ICE AND SNOW ON SHIP PERFORMANCE

Close ice Floating ice in which the concentration is 7/10 to 8/10, floes generally in contact with one another.

Deformed ice Ice which has been squeezed together and, in places, forced upward and downward.

Hummock A hillock of broken ice which has been forced upward by pressure.

Level ice Ice which is unaffected by deformation.

Open ice Floating ice in which the concentration is 4/10 to 6/10, floes generally not in contact with one another.

Rafted ice Type of deformed ice formed by one piece of ice overriding another.

Ramming Attempting to break ice by repeatedly driving the ship as far forward as possible, backing the ship out and repeating the process.

Ridged ice A line of broken ice forced upward by pressure of the surrounding ice.

Rubbled ice Deformed ice with pieces of ice piled on top of other ice in an irregular fashion.

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.

4.1.1 Ship Resistance

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

There are several deformed or non-level ice conditions which increase resistance on the ship: rafted, ridged, rubbled, and hummocks. In general it can be said that rafted, ridged, and rubbled ice present significant impediments to the progress of a ship. Caution should also be used when navigating through level ice with occasional hummocks or rafted areas.

WARNING:	**ANY SHIP THAT IS NOT STRENGTHENED FOR OPERATING IN ICE SHOULD AVOID ICE FLOES, PARTICULARLY IF THE ICE IS DEFORMED BY RAFTS, RIDGES, OR RUBBLE.**

When the ice thickness exceeds that in which the ship can make continuous progress, (such as when the ship encounters old ice, ridges, rafts, or hummocks), the ship could resort to ramming if the ship's structure permits.

The influence of snow on ship performance varies directly with snow thickness and snow type, and greatly increases ship resistance. The friction coefficient between snow and a ship's hull varies with the consistency and wetness of the snow; wetter snow has a higher friction coefficient. 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 ice thickness and assessing performance in that increased ice 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 ship performance in snow-covered ice.

4.1.2 Ship Manoeuvring

The features of hull shape which influence manoeuvrability in ice to the greatest extent are length-to-breadth ratio, flare, midbody, 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 ship's turning circle increases as the thickness of the ice increases. Turning in the other conditions is generally influenced by the degree of confinement imposed by the surrounding ice. However, steady turns are seldom used in ice, and it is more common to use star or channel breakout manoeuvres as a faster means of turning. These manoeuvres are described in subsection 4.2.1. Heeling systems have been demonstrated to be effective for most icebreaking ships.

4.1.3 Structural Capability

A ship's performance in ice can be limited by the 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 ship encountering first-year ice will experience lower impact forces than a ship encountering old ice, or a ship which is required to ram ice features aggressively with the intention of protecting less capable ships or structures. In terms of overall magnitude, ramming operations generate the largest forces on the ship's structure.

4.1.4 Performance Enhancing Systems

Performance enhancing systems are designed to reduce the power necessary for propulsion and to increase the ship's manoeuvrability through ice. Heeling systems, which roll the ship from side to side and reduce the effect of static friction, are helpful if the ship is stuck in pressured ice, or beached on an ice feature. Such systems were incorporated on Canadian Coast Guard icebreakers until the early 1980s. 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 ships.

(b) **Air bubble system** - An air bubble system was introduced on Baltic icebreaking vessels in the 1970s. The system uses one or more air compressors to force air through nozzles at the ship's side below the water-line. The air bubbles rise to the surface together with entrained water, lubricating the interface between the ice and the ship's hull, both above and below the water-line. The conditions and operations for which the system is particularly well-suited include: low speed transitting in "sticky ice" and ice with deep snow cover, manoeuvring in pressured ice, lubricating the hull during the break-away portion of ramming, and manoeuvring alongside a dock.

(c) **Water jet/air injection system** - This system involves injecting air into water which is pumped through nozzles at the ship's side below the water-line. Few installations of this system exist, and little information is available on the system's efficiency.

(d) **Water-wash system** - The water-wash system, installed on some Canadian icebreakers, 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 ship and ice.

4.2 SHIP HANDLING TECHNIQUES IN ICE

Beset	Ship unable to move because of ice surrounding the vessel.
Ice belt	Area of ship strengthened to take ice loads at the ice draught water-line.
Ice draft	Draft at which the ship 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 downward by pressure.
Pack Ice	General term for area of sea ice in any form or concentration.
Ramming	Attempting to break ice by repeatedly driving the ship as far forward as possible, backing the ship out and repeating the process.
Ridge	A line of broken ice forced upwards by the pressure of the surrounding ice.
Rubble	Pieces of ice piled on top of other ice.
Sail	Portion of the ice in a ridge above the water-line.

4.2.1 Manoeuvres in Different Ice Conditions

Ice is an obstacle to any ship, 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 ships in capable hands to navigate successfully through ice-covered waters.

> ***NOTE***: *Experience has proven that in ice, four basic ship-handling rules apply:*
> - ***keep moving** - even very slowly, but keep moving;*
> - *try to work **with the ice movement** and not against it;*
> - *excessive speed leads to ice damage;*
> - *know your ship's **manoeuvring** characteristics.*

The first principle of successful ice navigation is to avoid stopping or becoming stuck in the ice. Once a ship 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 long way around a difficult ice area whose limits are known is often the fastest and safest way to port or to the open sea.

Before Entering the Ice

If there is an alternative route around the ice, even if it is considerably longer, it is safer for an unstrengthened ship, or for a ship whose structural capability does not match the prevailing ice conditions, to take it rather 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 going through ice, even if the distance is shorter.

> ***NOTE:*** *Do not underestimate the hardness of ice and its potential for damage.*

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

(a) Follow the route recommended by the Ice Operations Officer via the Marine Communications and Traffic Services Centre (MCTS). This route is based on the latest available information and Masters are advised to adjust their course accordingly.

(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 or the vessel must be equipped with sufficient high-powered and reliable searchlights.

(d) Reduce speed to a minimum to receive the initial impact of the ice.

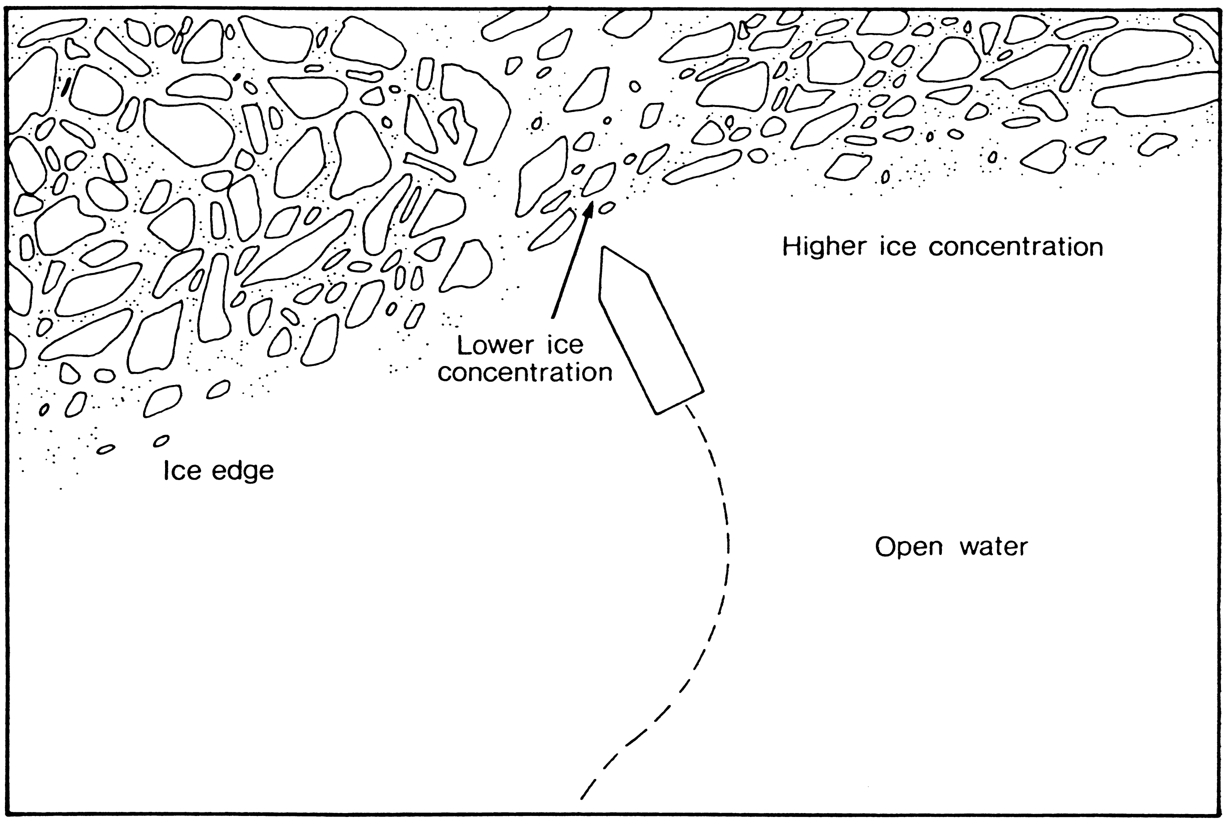
(e) The vessel should be at right angles to the edge of the pack ice to avoid glancing blows and the point of entering the ice must be chosen carefully (see Figure 24); preferably in an area of lower ice concentration.

(f) The engine room personnel have been 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.

(g) The ship has been 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 ship should be fitted with an internal cooling system to prevent the main engine cooling water intake from becoming clogged with slush ice.

Figure 24 Correct approach to ice field: reduced speed and perpendicular to edge



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 ship. 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.

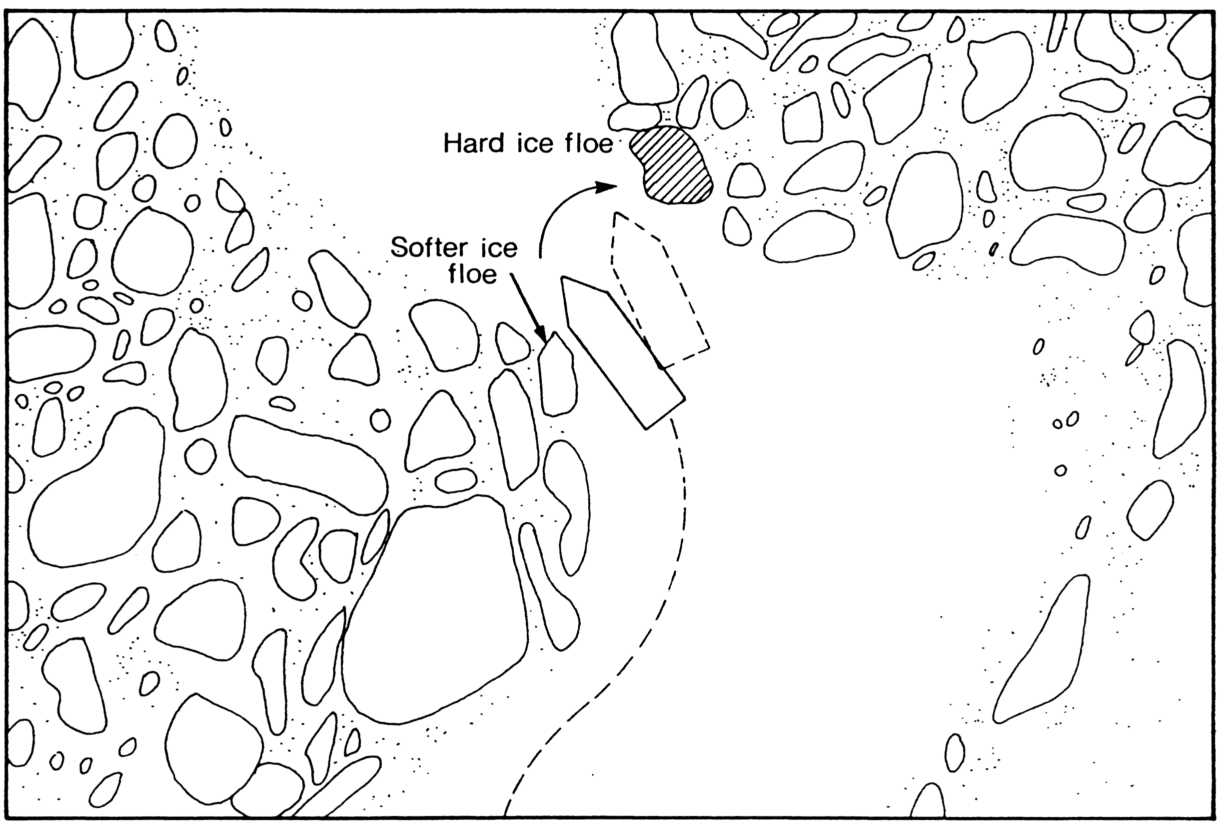
> ***NOTE:*** *Navigating in the ice is examined in detail in section 4.3, but the general rule is:*

- *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.*

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 ship is trying to break ice with its length rather than with its bow. Care must be taken even when turning in an open water area, as it is easy to underestimate the swing of the ship and to make contact with ice on the ship's side or stern: a glancing blow with a soft piece of ice may result in the ship colliding with a harder piece (see Figure 25).

Figure 25 Danger in turning in an ice channel: a glancing blow on a soft ice floe could push the ship into a harder floe



The ship will have a strong tendency to follow the path of least resistance and turning out of a channel may be difficult or even impossible. Ships that are equipped with twin propellers should use them to assist in the turn.

WARNING: AVOID TURNING IN HEAVY ICE.

If it is not possible to turn in an open water area, the Master 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 ship short round in ice by backing and filling with the engine and rudder. Masters 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.

Backing in Ice

Backing in ice is a dangerous manoeuvre as it exposes the most vulnerable parts of the ship, the rudder and propeller, to the ice. It should only be attempted when absolutely necessary and in any case the ship should never ram astern.

The ship should move at dead slow astern and the rudder must be amidships (Figure 26). 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.

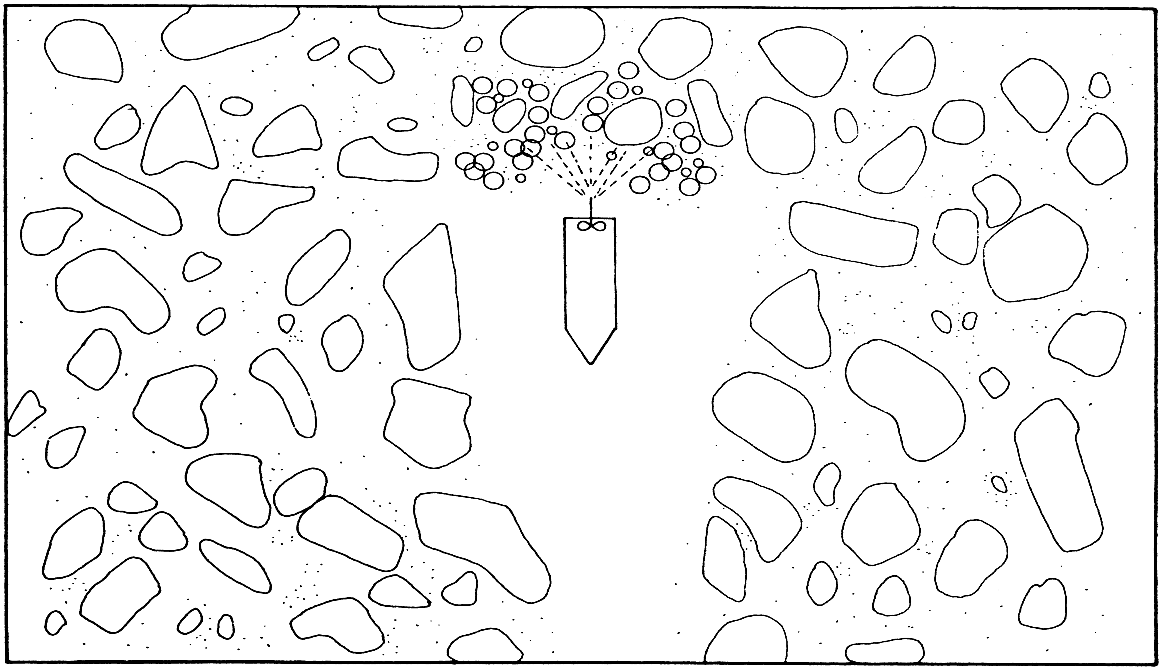
WARNING: AVOID BACKING IN ICE WHENEVER POSSIBLE. IF YOU MUST MOVE ASTERN, DO SO WITH EXTREME CAUTION AT DEAD SLOW.

Precautions Against Being 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 - 2 m above the ice cover but the keel could be several metres below. The danger from being 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 ship. Normally there will be a slight closing from the release of pressure as the ship passes through the ice, but if the ice begins to close up completely behind the ship it is a strong sign that the pressure is increasing (Figure 27).

Figure 26 Backing onto ice: rudder amidships, dead slow astern. Use a short burst of power ahead to clear ice



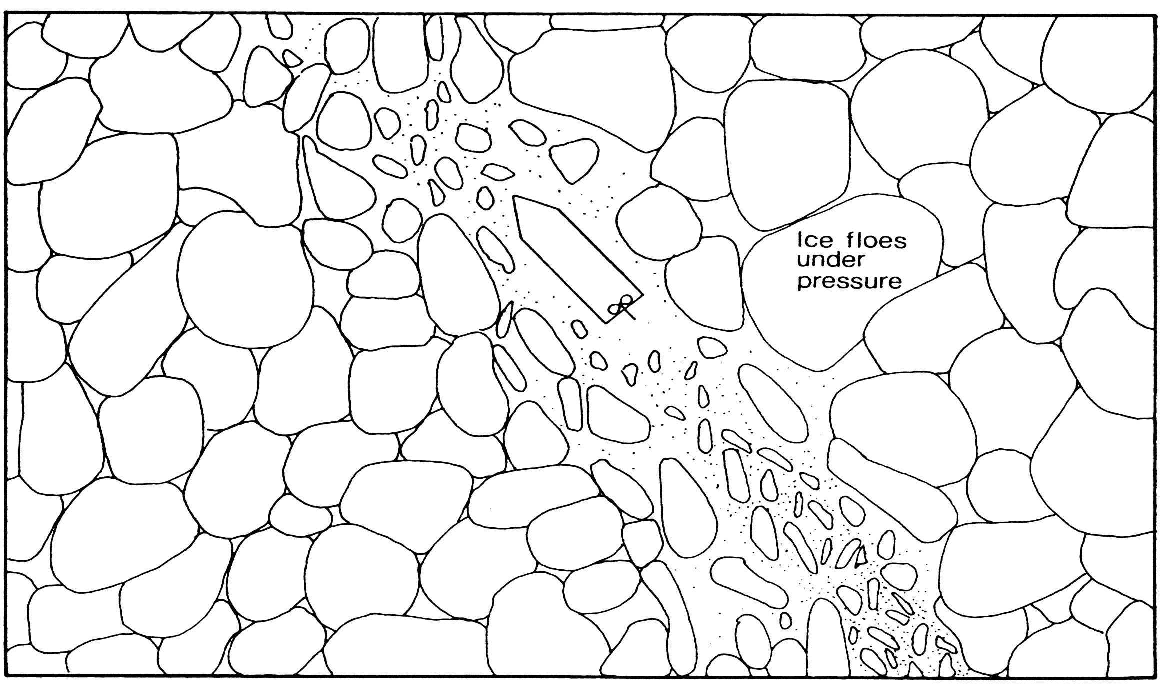


Figure 27 Pressure in ice field closes track behind vessel

> **WARNING: ANY SHIP THAT IS NOT STRENGTHENED FOR OPERATING IN ICE SHOULD AVOID FLOES THAT ARE RAFTED OR RIDGED.**

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.

Freeing a Ship Beset

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

(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 go astern into any heavy ice.

(b) Alternate the ballast to port and to starboard to list the ship and change the underwater shape. This method should only be done with knowledge of the possible consequences if the ship comes free quickly. It is more effective in older ships than in modern ships with blocky shape.

(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 less effective.

(d) In smaller ships it may be possible to swing weights over the side suspended on the ship's cranes or hooks to induce a list and break the ship free. This method should only be used with knowledge of the possible consequences if the ship comes free quickly.

Ramming

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

> **WARNING: RAMMING SHOULD NOT BE UNDERTAKEN BY VESSELS WHICH ARE NOT ICE-STRENGTHENED AND BY VESSELS WITH BULBOUS BOWS.**
>
> **ICE-STRENGTHENED VESSELS, WHEN UNDERTAKING RAMMING SHOULD DO SO WITH EXTREME CAUTION.**

For ships 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 ships must pay close attention to the ice conditions, to avoid the possibility of lodging the ship across a ridge on a large floe.

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.

4.2.2 Handling a Damaged Ship In Ice

Abandoning ship 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.

If the ship can be made sufficiently seaworthy to proceed, an assessment will have to be made of the demands that will be placed on the ship by breaking ice on 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 ships 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.

4.2.3 Berthing

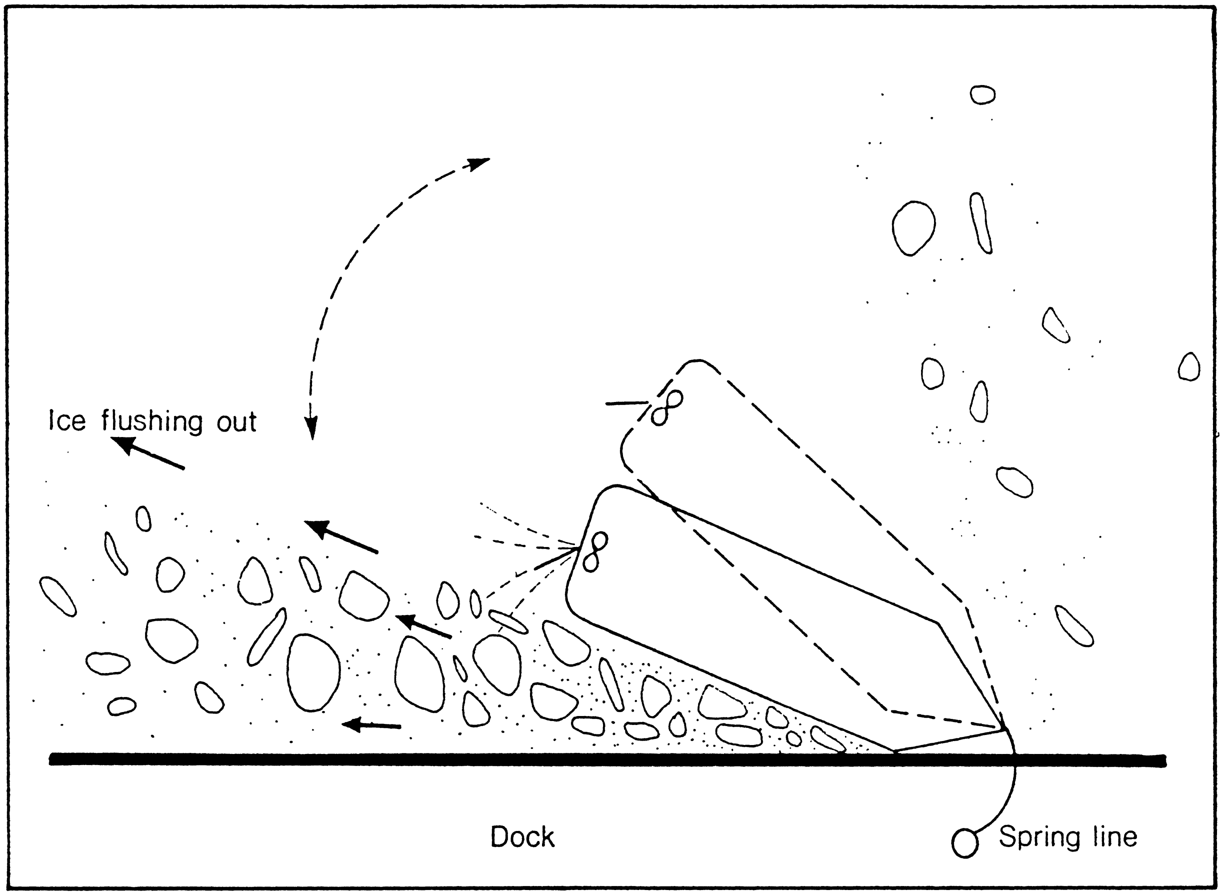
Berthing in ice-covered waters can be, and usually is, a long process, particularly in the Arctic where normally there are no tugs. When approaching a berth in ice-covered waters it is desirable (even if this is not the normal practice) to have an officer stationed on the bow to call back the distance 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 ship size and berth type, but the aim should be to bring the ship alongside with as little ice as possible trapped between the ship 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 ship (Figure 28). Frequently it is necessary to combine the two techniques (in ships 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.

Once the ship is secured, all efforts must be made to keep the ship alongside and not to allow ice to force its way between the ship and the dock. If the dock is in a river or in a strong tidal area there is nothing that will keep the ship alongside if the ice is moving. The prudent thing to do is to move the ship 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 on standby at all times.

WARNING:	**KEEP THE ENGINE(S) ON STANDBY AT RIVER BERTHS OR STRONG TIDAL AREAS WHERE ICE IS IN MOTION**

Figure 28 Berthing: flushing out ice with wash while bow is fixed with a spring line



4.2.4 Towing in Ice

Towing in ice is possible, although the strain on the tow line is that much greater if the tug or icebreaker is subject to the sudden acceleration/deceleration of icebreaking. The situation can be alleviated somewhat if there is an icebreaker ahead of the towing icebreaker. There is a long tradition of this sort of work in the Baltic, where icebreakers are specially designed with a notch in the stern and heavy winches and cables to enable the bow of the towed ship 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

There has been a good deal of towing in ice in the 1970's and early 80's in the Beaufort Sea, by anchor-handling supply boats or icebreakers when repositioning drill ships 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 tow-line 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 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.

4.2.5 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. Over the last 15 plus years 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, or push the floes out of the way. In ice management, obtaining information about the present and predicted ice conditions is very important, so as to ascertain the best deployment of the icebreakers.

4.3 Navigating in Ice-covered Waters

Bergy Bit	Piece of glacial (iceberg) ice showing from 1 m to less than 5m above sea-level, with an area of about 100-300 sq. m, and length of 5-15 m.
Calving	The breaking away of a mass of ice from an ice wall, ice front, or iceberg.
Close Ice	Floating ice of 7/10 to 8/10 concentration, composed of floes mostly in contact with one another.
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).
First-Year Ice	Sea ice of not more than one winter's growth, 30 cm to 2 m thick.
Growler	Small piece of glacial (iceberg) ice showing less than 1 m above sea-level, with an area of about 20 sq. m, and length of less than 5 m.
Old Ice	Sea ice which has survived at least one summer's melt.

4.3.1 Ships Proceeding Independently

Experience has shown that ships which are not ice-strengthened, with an open water speed of about 12 knots, often become beset in relatively light ice conditions, whereas adequately powered ice-strengthened ships should be able to make progress through 6/10 to 7/10 first-year ice concentration. Such ships are able to proceed independently without any assistance other than routing advice. Masters who are inexperienced in ice often find it useful to employ the services of an ice pilot/advisor for transitting the Gulf of St. Lawrence in winter or an Ice Navigator for voyages into the Arctic in the summer.

4.3.2 Detection and Avoidance of Ice

When steaming through open water, it may be possible to detect the approach of ice by several signs, which are listed in Part I, Section 2.4. Conversely, when in an ice field, there are several signs of approaching open water areas, which are listed in Part I, Section 2.4.

> ***NOTE:***
> *To establish 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 MCTS Centre. These messages will be passed on free of charge.*

Close-Range Ice Hazard Detection

Although a careful lookout will help the ship 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 and radar. The visual group includes searchlights and binoculars. The radar group includes both X- and S-band marine radars. SONAR has also been used to detect glacial ice, but this is still at a developmental stage.

The detection of ice hazards is dealt with in detail in following subsections, but there are some general comments to be made about the detection of ice with radar. Radar signal returns from all forms of ice (even icebergs) are much lower than from ship 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. The navigator must be careful not to become over-confident in such conditions.

> **WARNING: DO NOT RELY SOLELY ON MARINE RADAR TO DETECT ICE, PARTICULARLY GLACIAL ICE.**

For details of ice types and ice hazards see subsection 4.7.5.

Icebergs

Icebergs normally have a high freeboard and, as such, they are easy to detect visually (in clear conditions) and by ship's radar. In poor to no visibility, radar must be relied upon, and 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.

In such instances, the area of shadow on the radar behind the iceberg is the best way to detect its presence. The shadow is an area of no radar returns (with straight sides) behind a high target. Observation will reveal the shadow to increase in size on approach to the iceberg, and to swing around as the angle between the ship and the iceberg changes. However, care 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.

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 29). 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: 1) the closer the ship passes the more likely the encounter with bergy bits, and 2) 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.

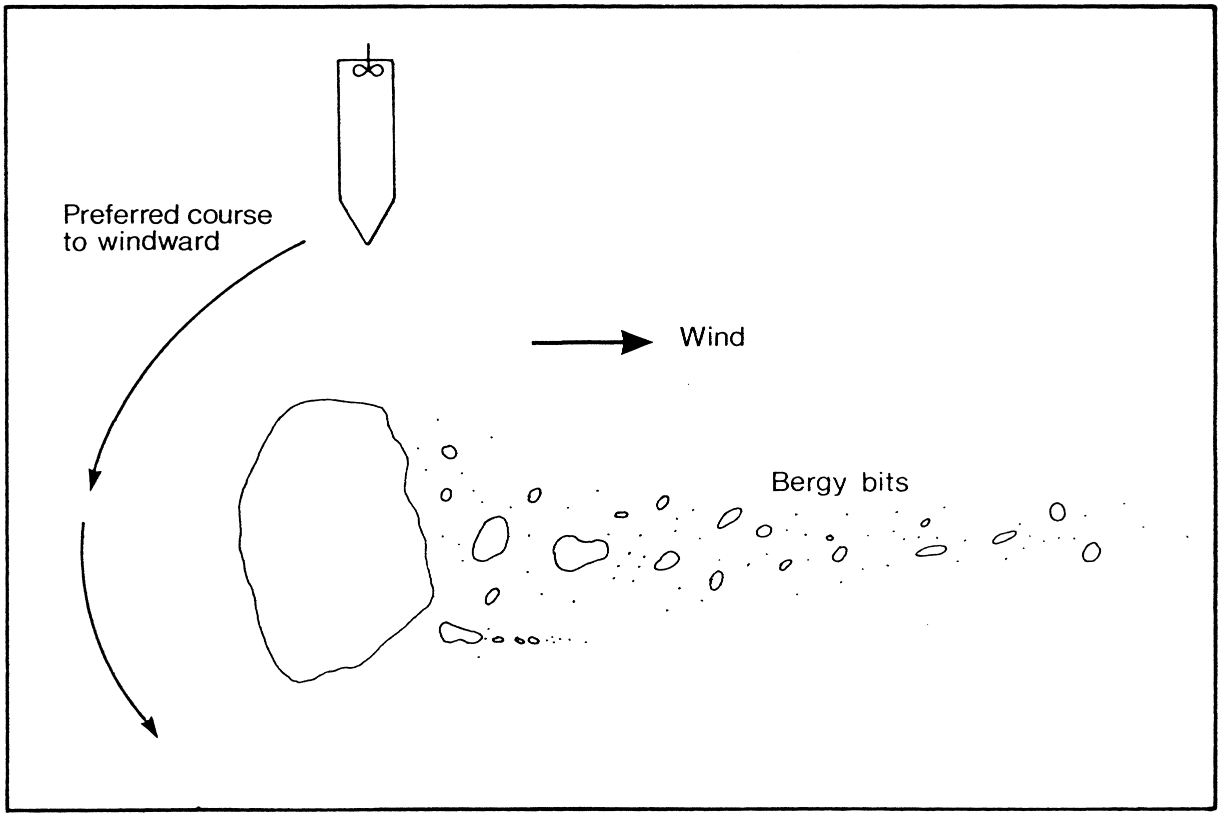
Bergy Bits

The visual sighting of bergy bits depends on good visibility, and surrounding conditions of low sea state or fairly smooth sea ice. 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 (see section 4.7 for details on ice terminology) which cause backscatter and also may produce shadows that can obscure a bergy bit. Detection is particularly difficult if the surroundings are open 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 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 29 Navigating around an iceberg and bergy bits



Growlers

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. In open or bergy water with good weather conditions visual detection of growlers is possible at 2 or 3 nautical miles from the vessel, but detection with radar is possible only to 0.5 nautical miles. In rough weather, the growler may not be seen in high seas or not be detectable in sea clutter on the radar screen. 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.

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.

WARNING: CONSTANT VISUAL AND RADAR MONITORING MUST BE MAINTAINED IN ANY AREA WHERE GROWLERS ARE EXPECTED.

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 old-ice concentration. However, mariners must watch for old ice even in areas where it is not identified on ice charts. Visual identification is possible up to 1-2 nautical miles from the ship 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 and on the Grand Banks. It is not a hazard in Cabot Strait, Gulf of St. Lawrence, or the St. Lawrence River.

4.3.3 Visibility

Operating in restricted visibility is inevitable in, or near, ice-covered waters, for instance: travel through ice may continue at night, fog 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;
- 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 ice to first-year ice indicates a significant increase in the chance of collision;
- 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 ARPA (Automatic Radar Plotting Aid);
- 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 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.

4.3.4 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 ship 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 ship (how fast it can be stopped).

4.3.5 Soundings

When in areas of old or poor surveys, 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 ship going aground. Even in areas of the high Arctic that are well surveyed, the echo-sounder should be run, as ship traffic in the area is sparse and many of the routes will not have been sailed previously by deep-draft ships.

Many of the charts in the Arctic are a combination of aerial photography and 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.

4.4 PASSAGE PLANNING

Close Ice	Floating ice in which the concentration is 7/10 to 8/10, composed of floes mostly in contact with one another.
Consolidated Ice	Floating ice in which the concentration is 10/10 and the floes are frozen together.
Lead	Any fracture or opening through ice which is navigable by vessels.
Old Ice	Sea ice which has survived at least one summer's melt.
Open Ice	Floating ice in which the concentration is 4/10 to 6/10, composed of floes generally not in contact with one another.

The purpose of this section is to provide guidance in the procedures to be followed in the acquisition and use of information for the purpose of planning passages in or near ice. Nothing in the instructions given here, or the processes that follow, either supercedes the authority of the Master 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 (see U.K. Department of Transportation publication: A Guide to the Planning and Conduct of Sea Passages). 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.

Passage planning takes place in two phases,

(a) Strategic, when in port or in open water, and

(b) Tactical, when near or in ice-covered waters.

Both Strategic and Tactical Planning involve four stages:

- Appraisal
- Planning
- Execution
- Monitoring.

The Strategic phase may be considered small-scale (large area) and the assumption is that the ship would be outside ice-covered waters, and days or weeks from encountering ice. The Strategic phase may be repeated several times before the Tactical phase is commenced. The Tactical phase may be considered large-scale (small area).

Passage planning for open water is a fixed process in which most, if not all, the information is gathered before the ship 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 ship 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. Passage planning in ice-covered waters, especially in the Arctic, is an evolving process which 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 Masters 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 so as to receive adequate rest.

4.4.1 Strategic Phase

Appraisal

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 Canadian Ice Service ice information from Canadian Coast Guard Marine Communications and Traffic Services Centres (MCTS) (Iqaluit

VFF and Resolute Bay VFR for Arctic Waters, Halifax VFH for Eastern Waters) or (potentially) facsimile via INMARSAT or MSAT.

Planning

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 ships that are not ice-strengthened, and that will be following ice instructions from the Canadian Coast Guard Ice Operations Office, the work at this point is the same as for a conventional voyage.*

The Master will develop a route to the destination based on the information obtained in the Appraisal phase, 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; and
- 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 to avoid significant concentrations of icebergs, such as off Cape Farvel and Disko Island; and
- any environmentally sensitive areas where there are limitations as to course, speed, or on-ice activities.

Execution

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.

Monitoring

Monitoring of the route should continue until the ice-covered areas are reached. As the ship approaches ice-covered waters, the quality and quantity of ice information improves (such as areas provided with Canadian Ice Service ice analyses and forecasts), which improves the accuracy of estimates for times of arrival and perhaps indicates 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 ships should monitor the updated routing instructions from the Canadian Coast Guard Ice Operations Offices.*

4.4.2 Tactical Phase

If no detailed ice information is available before reaching the ice-covered area, the ship 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 (such as Admiralty Inlet), where high concentrations of old ice are expected (such as the entrance to Lancaster Sound, early or late season) or in highly mobile ice (such as near Polaris mine on Little Cornwallis Island).

Appraisal

The gathering of tactical information is based mainly (but not exclusively) on the acquisition of Canadian Ice Service ice observation and analysis charts. The reception of these charts depends on the ship being fitted with a facsimile machine capable of being tuned, or having crystals, for the required frequencies (as per Part I, Chapter 1). Additional inputs consist of marine radar (X- and S-bands), visual observations, and (possibly) processed radar imagery.

Helicopter (visual) reconnaissance can be valuable where available, but mostly for ice pilotage (in open ice) rather than for ice navigation, because visual observations are of less value than radar aids in areas of high snow cover.

Planning

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; and
- 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 two 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.

Execution

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.

Monitoring

Progress should be monitored on the chart by conventional means and ice navigation can continue, as described in section 4.3.

4.5 PRINCIPLES OF 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 affect 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.

In high latitudes, the meridians are not the familiar parallel lines of the Mercator chart but radial lines converging at the poles. (This would appear like a bicycle wheel with the pole as the hub.) Mariners prefer using a Mercator chart, so to preserve the look of a Mercator chart a polar grid is used. A grid is printed parallel to a meridian, usually the Greenwich meridian. On a Transverse Mercator chart the fictitious meridians found on this type of chart would serve this purpose. Because the meridians cross all grid lines at the same angle they are fictitious rhumb lines.

The direction that is chosen as the reference for the grid is north, so then all parallel grid lines can be taken to be extending in the same direction. The direction relative to the grid lines is then known as the grid direction. If a magnetic compass is used to follow the grid direction then the corrections of variation and convergency can be combined to a single correction called grid variation or grivation.

4.5.1 Charts

There are two areas of concern with the use of charts in the Arctic. These are consideration of the uncommon projections used and the accuracy of the surveys.

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 high Arctic, Mercator projections suffer too much distortion in the latitude direction 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 convergency corrections.

As the Arctic becomes better surveyed there will be more Mercator charts, but other projections such as Lambert Conformal, Polyconic, and Polar Stereographic are used as well. Polar Stereographic is becoming the most popular as it provides minimum distortion over relatively large areas. The number of different projections make it important, when changing charts, to check the type 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 convergency correction may be needed even for visual bearings.

WARNING: IN THE ARCTIC, AS IN ANY OTHER AREA, CHECK THE CHART PROJECTION BEFORE USE.

Accuracy

The accuracy of charts in the Arctic can vary widely according to the date of survey. The more frequently travelled areas, such as Lancaster Sound, Barrow Strait, and the approaches to Polaris and Nanisivik mines, are well surveyed, but many charts are based on aerial photography (controlled by ground triangulation) combined with lines of reconnaissance soundings. Even new editions of charts may be misleading as some information on them may be dated. The appearance of depth contour lines on new charts does not indicate any new information. Production priorities may result in new information being added to large-scale charts only.

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

- checking the projection and its limitations,
- checking the date of survey and / or the Source Classification Diagram,
- using range and bearing to transfer positions from chart to chart,
- checking for evidence of reconnaissance soundings,
- using the larger scale map in preference to the smaller scale map; and
- checking for the method of measuring distances and taking bearings.

4.5.2 Canadian Arctic Nautical Charts and Charting Deficiencies

One of the principal problems with charts in the Arctic concerns the horizontal datum on which the actual chart is based. With more and more vessels using accurate positioning systems such as the Global Positioning System (GPS) or the Russian system (Global’naya Navigatsionnaya

Sputnikovaya Sistem - GLONASS), the greater the problem will become. Regarding GPS, the positions are referenced to the World Geodetic System (WGS 84) which is virtually equivalent to the North American Datum 1983 (NAD 83). If you are navigating on a NAD 83 chart with GPS there would be no corrections to apply. If you wanted to plot on a NAD 27 chart you must manually apply the appropriate corrections.

In 1997 there were 245 charts listed in the Arctic Chart Catalogue. Only 55 charts (22%) have sufficient accuracy or detail to facilitate accurate plotting of positions obtained by GPS, which requires a chart base relative to the NAD 83 horizontal datum. There are 49 charts that specify that positioning with GPS can lead to positioning errors up to some defined magnitude, which may be as much as 4 nautical miles. The remaining 141 charts did not have any information about the horizontal datum of the chart. For bathymetry (depth soundings, bottom composition, etc.) it is estimated by the Canadian Hydrographic Service that less than 25% of the Arctic waters are surveyed to acceptable, modern standards. Much of the data has been collected by random vessel's track soundings or over ice spot soundings.

THE VALUE OF A CHART DEPENDS TO A GREAT EXTENT ON THE ACCURACY AND DETAIL OF THE SURVEYS ON WHICH IT WAS BASED.

(Navigation Instruction, Canadian Arctic, Vol. 1, 1982, p.8)

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 Annual Edition Notices To Mariners.

4.5.3 Effect of High Latitude on Compasses and Electronic Aids

Compasses

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

> "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.

The **gyro compass** is as reliable in the Arctic as it is in more southerly latitudes, to a latitude of about 70°N. 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); and
- the gyro error should be checked whenever atmospheric conditions allow, by azimuth or amplitude.

Radar

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.

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 make 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 aerial photography. To decrease the possibility of errors, three lines (range, or less preferably bearings) should always be used for positions. Fixes using both sides of a channel or lines from two 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.

Global Positioning System (GPS)

The Global Positioning System, or GPS, is a space-based radio-navigation system which 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 24 operational satellites in six orbital planes, and an orbital radius of 26,560 kilometres (about 10,900 nautical miles above the earth). Of the 24 satellites, 21 are considered fully operable and the remaining 3 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 which is received and processed by GPS receivers to determine the user’s three-dimensional position (latitude, longitude, altitude), velocity and time.

GPS was declared initially operational in December 1993 with full operational capability being declared in July 1995. GPS provides two levels of service - a Standard Positioning Service (SPS) for general public use, and a Precise Positioning Service (PPS) primarily intended for the use of the U.S. military. The SPS point accuracies within 100 metres in the horizontal plane and 156 metres in the vertical plane, 95% of the time. However, the US Department of Defense, deliberately introduced errors in the satellite's clock oscillator frequency in a seemingly random, though controlled manner, consequently degrading the accuracy to those given for SPS. This deliberate introduction of errors is known as Selective Availability. The US president has proclaimed that the level of SA will be reduced to zero within the next seven years and when this occurs the horizontal position accuracy for stand alone civilian GPS receivers will improve from the previously stated 100 metre level to the 30 metre level.[1]

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 ship at a position 55° North or South latitude or closer to the pole, the satellites would be in a constellation around the ship 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 ship 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 ships sails because above 55°N there will not be satellites orbiting directly overhead.

Other than Selective Availability, 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 9 kilometers over the poles to over 16 kilometers 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. Sunspot activity is on an 11 year cycle and this activity is expected to peak at about the year 2000.[1]

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. [1]

If the datum used by the GPS receiver in calculating latitude and longitude is different from the 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 datums. Since 1986 the Canadian Hydrographic Service has converted some CHS charts to NAD 83. Information on the chart will describe the horizontal datum used for that chart and for those not referenced to NAD 83, corrections will be given to convert NAD 83 positions to the datum of

[1] Richard Langley, GPS World, March 1997, July 97 and Telephone Interview

A User's Guide to GPS and DGPS CCG, Marine Navigation Services, Ottawa, Canada, August, 1998 the chart. The title block of the chart will describe the horizontal datums used for the chart and will give the corrections to convert from the datum of the chart to NAD 83 and vice versa.

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.

INMARSAT

Use of INMARSAT services in the Arctic is the same as in the south, until the ship approaches the edge of the satellite reception. 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. The 1990 repositioning of the Atlantic West satellite has extended its area of coverage to include most of Lancaster Sound and Barrow Strait.

As the ship 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.

MSAT - A Regional Communications Satellite System

Early in 1996 a new telecommunications network, called MSAT, was commercially introduced. MSAT is a Canadian-owned satellite-based network targeted primarily towards mobile users operating in rural and remote areas. Currently the initial services include: voice (telephone), 4.8 kbps data, facsimile, dispatch radio, electronic mail and voice mail.

MSAT Mobile Communicators are compact, with antennas approximately 20 centimetres high and 20 centimetres in diameter and have been specifically developed for marine applications. The equipment and service costs are significantly lower than those charged by international mobile satellite service providers and due to the satellite's optimal geostationary position over the equator, excellent coverage is available over the Arctic, the Caribbean and 200 nautical miles off the east and west coasts of North America.

The MSAT equipment was successfully used from Halifax en route to Resolute, Cambridge Bay and Tuktoyaktuk during an evaluation of the satellite's coverage in the 1996 shipping season. MSAT provided a reliable, efficient and inexpensive method for the reception of ice information in the form of verbal consultation, the paper facsimile generation of ice charts, and electronic mail of text descriptions of ice conditions from the Canadian Ice Service to the ship. The only weak link has been the dissemination of large graphics files such as SLAR or RADARSAT imagery because they are just too big to be sent through the current 4.8 kbps data processors.

MSAT Network upgrades being introduced will include packet-switched communications for applications such as vessel tracking using Global Positioning System technologies.

4.6 REGULATIONS APPLIED TO NAVIGATION

The Canada Shipping Act applies to all Canadian territorial waters and fishing zones.

4.6.1 Charts and Publications Regulations

The Charts and Nautical Publications Regulations apply to Canadian ships in all waters and to all ships in waters under Canadian jurisdiction. The only exception is for the Master and owner of a ship of less than 100 tons where the person in charge of navigation has sufficient knowledge of a variety of features and hazards so that safe and efficient navigation in the area where the ship is to be navigated is not compromised.

The Charts and Nautical Publications Regulations stipulate that ships should carry the most up-to-date editions of the required charts and publications. The charts and publications used must be maintained with the latest available Notices to Mariners, Notices to Shipping or Radio Navigational Warnings before being used in the navigation of the ship. To guide mariners in acquiring appropriate charts, there is a list of charts required for travel to specific Canadian locations published in the Annual Edition, Notices to Mariners that also offers a cross-reference to approved United States, British, and Russian Federation charts. This list could also be referenced by Transport Canada Marine Safety Inspectors during spot checks of vessels.

The regulations require that ships carry the various publications that would be required normally for safe navigation, but they also require that “where the ship is making a voyage during which ice may be encountered” this manual - Ice Navigation in Canadian Waters be on board. This regulation also applies to Canadian ships in waters other than Canada's if they will be encountering ice.

Supplementary Publications

There is a vast amount of information concerning navigation in ice in this manual, and the regional Sailing Directions. Other publications that are useful for the Navigation Officer, the Ice Navigator in the Arctic or the ship’s Master are listed in Annex B, particularly MANICE and Ice Atlases for ice information, with Ice Seamanship and the Mariner's Handbook offering navigational guidance.

4.6.2 Arctic Shipping Pollution Prevention Regulations

The *Arctic Shipping Pollution Prevention Regulations* (ASPPR) are made under the authority of the *Arctic Waters Pollution Prevention Act* and applies to all ships over 100 tons, gross tonnage (Sections 28 to 30 apply to every ship) in the Canadian Arctic. The ASPPR among other things describes, the additional requirements for construction and equipping of ships for Arctic waters, the issuing of Arctic Pollution Prevention Certificates, the Zone / Date System, the Arctic Ice Regime Shipping System, the qualifications and requirements for Ice Navigators and pollution discharge limitations.

4.6.3 Arctic Ice Regime Shipping System (AIRSS)

Transport Canada has recently revised the *Arctic Shipping Pollution Prevention Regulations* to include the Arctic Ice Regime Shipping System which is intended to provide greater flexibility for the operation of vessels in the Arctic, by permitting ships to navigate outside of the current Zone / Date System when ice conditions are suitable. It is based upon a simple calculation which indicates whether or not a given set of ice conditions can be expected to be safe for a particular vessel.

The Master or Ice Navigator of an Arctic-going vessel will have the primary responsibility for applying the Ice Regime System which will be based upon 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.

Further information about the *Arctic Shipping Pollution Prevention Regulations* and the *Arctic Ice Regime Shipping System* (AIRSS) the can be found in Chapter 5.

4.7 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.

4.7.1 Levels of Ice Information

It is possible to distinguish four 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.

4.7.2 External Sources of Ice Information

External sources of ice information include archives, reports, publications, and circulars. This material often provides excellent background and synoptic level information. External sources may not be readily accessible to mariners at sea or in foreign ports, therefore appropriate material should be obtained at source in Canada prior to sailing.

The Transport Canada library, located in Ottawa, houses a number of reports and publications dealing with regional ice conditions for selected areas and time frames, many of which are written with a mariner's perspective. For further information contact:

Address:	Transport Canada Library and Information Centre Place de Ville, Tower "C" 330 Sparks Street, 15th Floor Ottawa, Ontario K1A 0N5
Telephone:	(613) 998-5127 or 998-5128
	(Hours of Service 07:30 – 17:00 EST)
Fax:	(613) 954-4731
E-mail:	library@tc.gc.ca

The Ice Climatology and Applications Division of Canadian Ice Service, Environment Canada, provides historical analyses and long-range planning support to marine activities, and maintains a library of all Ice Centre publications. For further information contact:

Address:	Canadian Ice Service Ice Climatology and Applications Division 373 Sussex Drive, 3rd Floor Lasalle Academy Block "E" Ottawa, Ontario K1A 0H3
Telephone:	(613) 947-1867
Fax:	(613) 241-8483

At the synoptic level, the Ice Forecasting Division of the Canadian Ice Service 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 km. Broadcast frequencies and schedules are listed in the Canadian Coast Guard publication "Radio Aids to Marine Navigation", issued seasonally. Taped bulletins are broadcast continuously from Canadian Coast Guard radio stations with an effective range of 60-80 km. Alternatively, these products may be obtained by prior arrangement with the Canadian Ice Service through their computer dial-in service. The most important external source of information available to the ship is the broadcast of ice analysis charts by the Canadian Ice Service. These products are described in greater detail in subsection 4.7.4.

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

Address:	Canadian Ice Service Ice Forecasting Division 373 Sussex Drive, 3rd Floor Lasalle Academy Block "E" Ottawa, Ontario K1A 0H3
Telephone:	(613) 996-1599
Fax:	(613) 241-8483

4.7.3 Shipboard Sources of Ice Information

Visual Observations

The mariner relies heavily on shipboard visual observations for close-range ice information. However, environmental conditions including darkness, precipitation, and the ice cover itself may prevent detection of dangerous ice features. Searchlights should be used to highlight ice conditions at close range. It is also recommended that high-quality binoculars be carried for use by Masters and watchkeepers when in ice-covered waters.

To a lesser extent, shipboard visual observations may be used at the route planning level, within the limits of visibility. Even with good visibility, it may be difficult to detect open water or more favourable ice conditions. This is because the low viewing angle afforded the mariner by the ship's bridge may not be sufficient to see very far beyond ice conditions in the immediate vicinity of the vessel.

The phenomenon of ice blink offers an indication of the presence of ice on the horizon. Ice blink is caused by the reflection of ice on low cloud, producing a whitish glare on the clouds near the horizon. Conversely, in ice, dark patches in low cloud may indicate the presence of open water.

For ships equipped with their own reconnaissance helicopter, aerial visual observations may provide considerably more ice information at the route planning level.

Marine Radar

Marine radar systems provide important information for short-range route planning and close-range hazard detection. In calm conditions, ice edges and many icebergs may be detected at distances of up to 10 to 15 nautical miles. In the ice, marine radar may be used to identify ice features including individual floes, ridges and rubble fields, and open water or refrozen leads at distances up to about 3 nautical miles. The effective range increases to about 6 nautical miles for larger features.

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 ships 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-cm radars provide

better ice detail while 10-cm radars 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.**

Ship and Shore Station Communications

Route planning and synoptic level information may be obtained either formally or informally via communication links to shore stations or other ships.

Radio may be used for voice communications to obtain updates on local ice conditions. Canadian Coast Guard Marine Communications and Traffic Services Centres (MCTS Centres) provide all ships with ice information and ice routing advice. Ice and weather analysis charts are issued daily and broadcast via radio facsimile (for schedules and frequencies see Canadian Coast Guard seasonal publication **Radio Aids to Marine Navigation**). Forecast charts are also available for selected areas.

On some occasions, it may be possible to receive radio facsimile copies of aerial observed charts generated on board aircraft flown by the Ice Reconnaissance Division of the Canadian Ice Service.

Ships equipped with INMARSAT satellite communication facilities may use these systems to obtain additional voice or data through special arrangements with individual sources, such as the Canadian Ice Service, Environment Canada (see subsection 4.7.2 above).

Remote Sensing Systems

With special purpose receiving and processing equipment, ships may take advantage of airborne and satelliteborne remote sensing systems for complimentary synoptic level ice information.

The Ice Reconnaissance Division of Canadian Ice Service operates one airborne imaging radar system, which is able to transmit raw data directly to suitably equipped ships at sea within line of sight. This is an all-weather system which penetrates dry snow cover to produce grey-tone images of the ice surface. The level of detail afforded by these systems depends on sensor resolution, which may vary between 25 and 400 m. The resultant images therefore, are well suited to the tactical route planning process. The higher resolution data may be used in conjunction with visual observations and marine radar at the close range hazard detection level.

The systems used to receive radar imagery from the ice reconnaissance aircraft are installed on all larger Canadian Coast Guard icebreakers. These systems are very sophisticated and expensive. In addition, their operation requires special training. For these reasons, such systems are employed only on board those ships which frequently transit difficult ice conditions.

Many commercially available systems enable ships 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 U.S. NOAA and Russian METEOR weather satellites via inexpensive personal computer hardware. Image resolution is in the range of 3 to 4 km, 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 ships transitting ice-covered waters.

4.7.4 Canadian Ice Service (CIS) Ice Charts

Ice charts issued by the Canadian Ice Service use standard World Meteorological Organization terms and symbology 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. 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 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 a daily ice analysis chart is presented in Figure 30. 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 (1994), and is outlined in this section. The use of codes and symbols varies according to the type of ice chart:

- current chart: area specific, most detailed
- composite chart: regional, less detailed.

The ice symbols are given in a Key to Ice Symbols on ice charts (Figure 30), and they are also defined in MANICE. Excerpts are given here to explain their specific use on CIS products.

Egg Code

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".

Several Egg Codes are shown in Figure 30 with a complete description of the Egg Code available in MANICE (1994). The symbols in the code are classed into four categories of ice information:

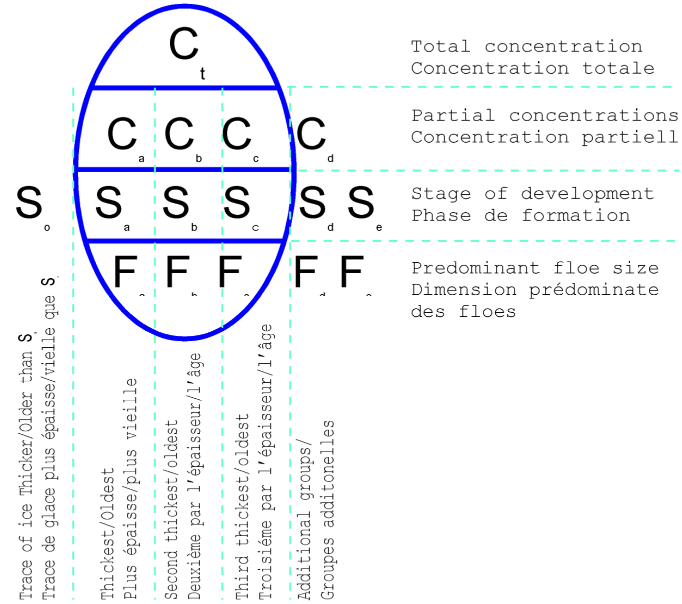
Key to ice symbols

There are a limited number of symbols used on distributed ice charts. These are illustrated as follows:

Key to Sea Ice Symbols / Clé des Symboles de la Glaces de Mer

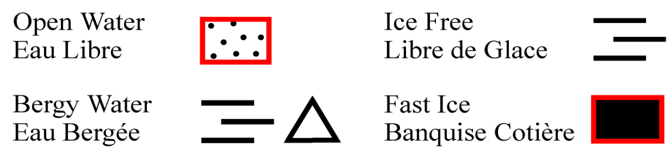
Stages of Development/Phases de Formation ($S_oS_aS_bS_cS_dS_e$)

Description/Elément	Thickness/Epaisseur	Code
New ice /Nouvelle glace	<10 cm	1
Nilas, Ice rind/Nilas, Glace vitrée	<10 cm	2
Young ice/Jeune glace	10-30 cm	3
Grey ice/Glace grise	10-15 cm	4
Grey-white ice/Glace Blanchâtre	15-30 cm	5
First-year ice /Glace première année	>30 cm	6
Thin first-year ice /Glace mince de première année	30-70 cm	7
Medium first-year ice/Glace moyenne de première année	70-120 cm	1·
Thick first-year ice /Glace epaisse de première année	>120 cm	4·
Old ice/Vieille glace		7·
Second year ice/Glace de deuxième année		8·
Multi-year ice/Glace de plusieurs année		9·
Ice of land origin/Glace d'origine terrestre		▲·
Undetermined or unknown/Indeterminée ou inconnue		X



Floe Sizes/Grandeur des floe ($F_aF_bF_c$)

Description/Elément	Width/Extension	Code
Pancake ice/Glace en crêpes		0
Brash ice/Sarrasins agglomérés	<2m	1
Ice cake/Glaçons	2-20 m	2
Small floe/Petit floes	20-100 m	3
Medium floe/Floes moyens	100-500 m	4
Big floe/Grands floes	500-2000 m	5
Vast floe/Floes immenses	2 -10 km	6
Giant floe/Floes geants	> 10 km	7
Fast ice/Banquise côtières		8
Icebergs		9
Undetermined/Indéterminée		X
Strips (concentration = C)/ Glace en cordons (concentration=C)		∾ C



1. <u>Total concentration</u> top level

   C_t - Total concentration of ice in the area, reported in tenths.

2. <u>Partial concentrations of ice types</u> second level

   $C_aC_bC_cC_d$ - Partial concentrations of thickest (Ca), second thickest (Cb), third thickest (Cc), and fourth thickest (Cd) ice, in tenths.

3. <u>Ice type corresponding to the partial concentrations on the second level</u> third 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.

4. <u>Predominant floe size category for the ice type and concentration</u> bottom level

   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).

Tables 14, 15, and 16 list the codes used within Egg Codes for sea-ice stages of development, lake- ice stages of development, and floe sizes, respectively.

Table 14 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.	

Description	Thickness	Code
Second-year ice	8.	
Multiyear ice	9.	
Ice of land origin	.	
Undetermined or unknown	X	

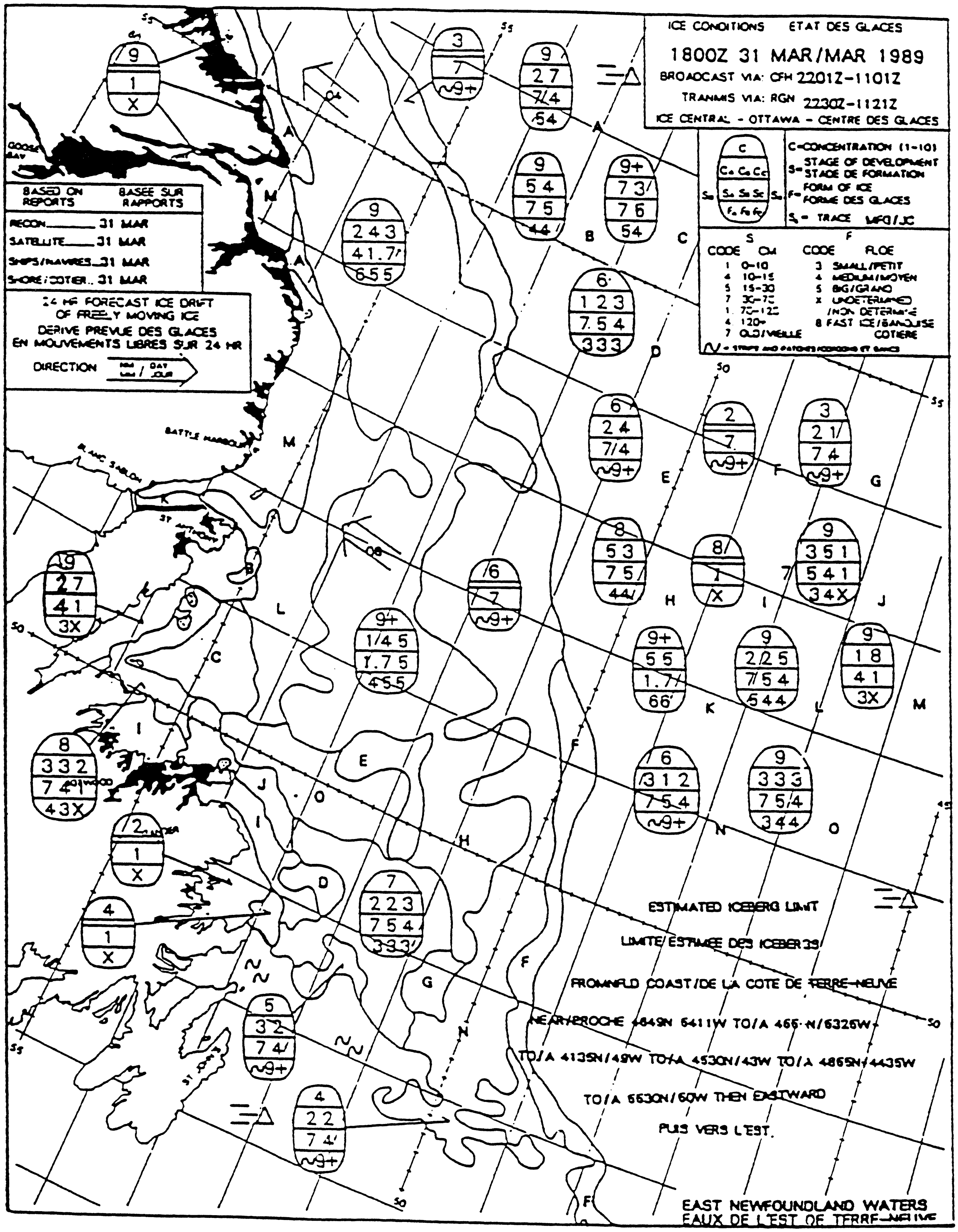
Table 15 Egg coding for lake-ice stages of development

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 16 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

Figure 30 Example of an AES Ice Analysis Chart



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 Canadian Coast Guard. In particular, these requirements address the placement of mandatory boundaries through differing ice types, concentrations, and floe size which are of significance to navigation. Mandatory boundaries are required between new, grey, grey-white, first-year, and old ice. When determining the predominant ice type a few simple rules apply.

For concentration, mandatory boundaries, shown as solid lines, are required between:

Open water:	< 1 tenth
Very open drift ice:	1 to 3 tenths
Open drift ice:	4 to 6 tenths
Close ice:	7 to 8 tenths
Very close ice:	9 to 9+ but less than 10 tenths
Compact or consolidated ice:	10 tenths

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 multiyear 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 two 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.

Other discretional boundaries are indicated by a dashed line. These are present to allow the use of several egg codes for a broad area of ice in which the overall attributes fit into one mandatory boundary, but there are subtle differences in the ice types or floe sizes. Dashed lines are also used to outline areas with lesser concentrations of especially hazardous ice. For example, when a trace of medium and thick first-year ice or old ice may be outlined in a subpolygon by using a dashed line.

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 two 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.

The daily ice analysis chart is a static picture of ice conditions at 1800 UTC. Ice is generally in some state of mobility, depending on meterological 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.

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.

4.7.5 Detection of Sea Ice from Ships

There are characteristic features and formations associated with individual ice types, which provide useful clues which 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 A.

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 m in depth, depending on sea state.

New ice may be recognized by its characteristic soupy texture and matt appearance, as illustrated in Figure 31. It may also take the form of spongy white lumps a few centimetres in diameter (termed shuga).

Figure 31 Example of new ice

Nilas

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

Nilas has unique deformation characteristics which make it easy to recognize. It bends easily on a ships wake, often without breaking, and when two sheets of nilas converge they may overlap in relatively narrow fingers. All of these characteristics can seen in the example of Figure 32.

In rougher seas, nilas may also form circular pieces up to about 3 m in diameter, with raised rims caused by pieces coming into contact with one another. An example of this pancake ice is shown in Figure 33. New ice and nilas are not a hazard to shipping.

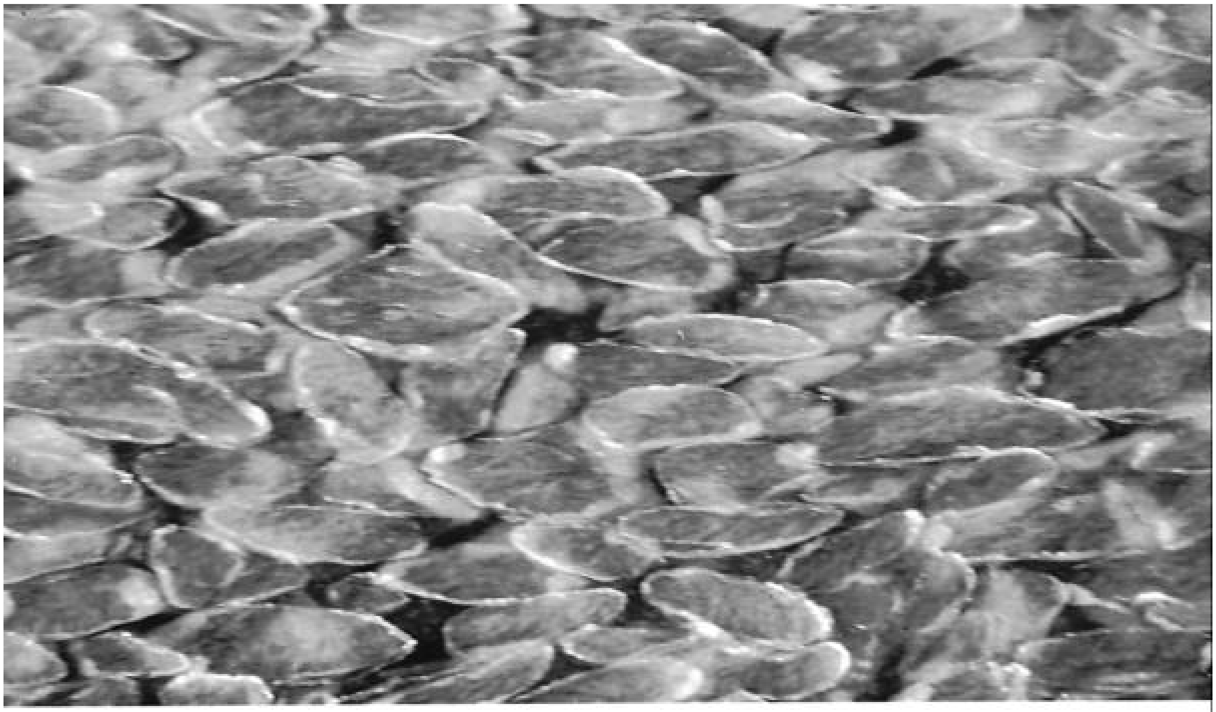
Figure 32 Example of nilas

Young Ice

Young ice is ice which is between 10 and 30 cm thick. This category includes grey ice (10-15 cm thick), and grey-white ice (15-30 cm thick). As these names suggest, young ice is most readily identified by its characteristic grey colour. Figure 34 shows an example of young ice.

Converging floes of grey ice will overlap, or raft, in wider fingers than nilas ice, which 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.

Figure 33 Example of pancake ice



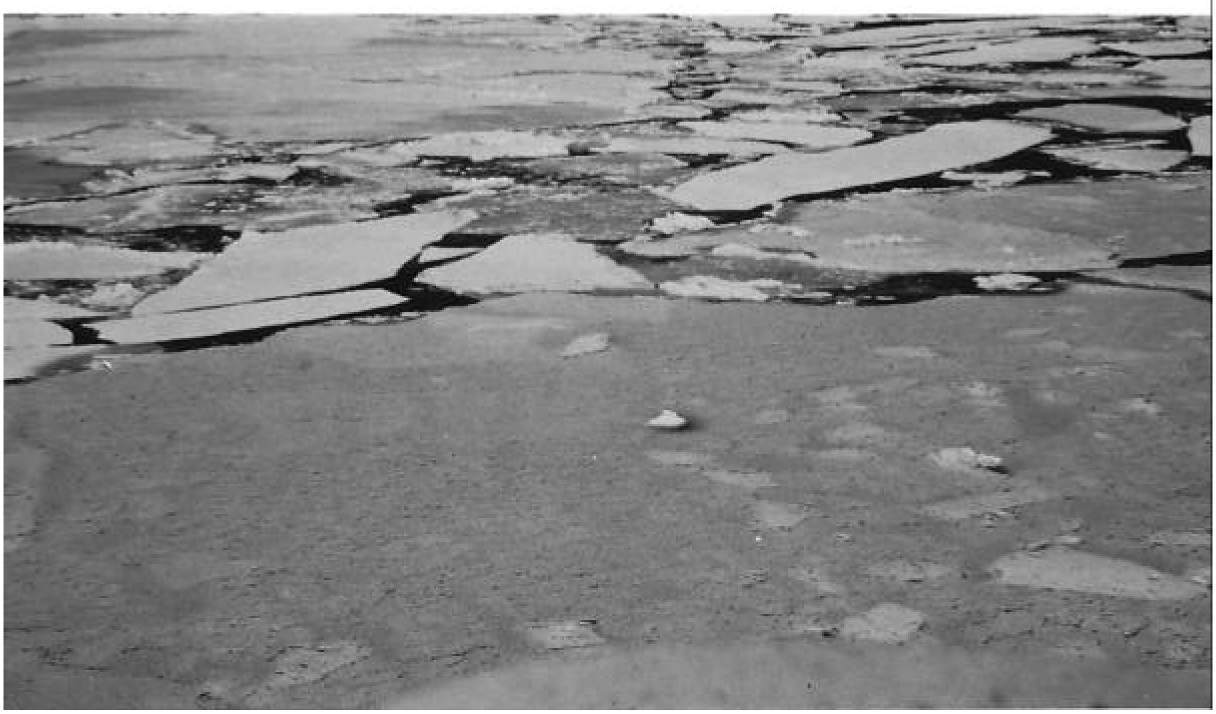


Figure 34 Example of young ice; grey and grey-white ice cakes

First-Year Ice

First-year ice (sometime called white ice) is ice which is greater than 30 cm thick, and still less than one 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. Figure 35 shows an example of first-year ice.

Figure 35 Example of First-Year Ice

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 one or two 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.

Old Ice

Old ice is ice which is more than one year old. This category includes second-year and multiyear ice. During the melt period, puddles form on the first-year ice surface which, 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 which is actually second-year ice is normally limited to the upper 50-100 cm, 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 two 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 36 shows an example of second-year ice.

Figure 36 Example of second-year ice

Multiyear 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 multiyear ice may appear more blue than first-year ice.

Multiyear 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 multiyear floe, presented as Figure 37. Multiyear ice is the strongest and hardest form of sea ice and represents a serious impediment to all ships, even the most powerful icebreakers.

Figure 37 Example of multiyear ice

4.7.6 Detection of Icebergs, Bergy Bits, and Growlers from Ships

Visual detection of glacial ice is possible for larger icebergs and bergy bits in good visibility, but marine radars are an important means of detection, especially for smaller targets. Icebergs are divided into three size categories: icebergs (more than 5 m in height), bergy bits (1-5 m in height), and growlers (less than 1 m in height).

Icebergs are relatively easy to see when visibility is good because of their large size, but in poor visibility even these large features may go unnoticed, with potentially catastrophic results.

Marine radars are generally able to pick out even small icebergs at distances in excess of 12 nautical miles. If visibility is limited for any reason, these targets should be marked and tracked, as they may be lost in sea clutter or pack ice returns as the distance closes between ship and iceberg.

Glacier ice is almost transparent to the radar: the radar return received from an iceberg is the result of scattering of the radar signal by air bubbles and other imperfections in the ice. Consequently, the strength of the radar returns from an iceberg will be much lower than the corresponding signal from a ship of similar size. The signal may be lost in sea clutter and scientific studies have shown that the signal may actually disappear completely from the radar as the iceberg approaches the ship. It cannot be emphasized enough!

WARNING: DO NOT RELY SOLELY ON MARINE RADAR TO DETECT ICEBERGS, BERGY BITS, AND GROWLERS IN FOG AND DARKNESS.

Within pack ice, icebergs may produce shadows on the marine radar display because of their large size. Often, the iceberg itself may be undetectable, but its presence is known based on its shadow. Mariners should also 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 rubbled ice, as shown in Figure 38, or by white-caps in the open sea, as shown in Figure 39. 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 so as to deflect radar energy away from the antennae. The bergy bit shown in Figure 40 was not visible on the marine radar display. It is worthwhile to reduce speed while in bergy waters and to add an extra watchkeeper to ensure that an adequate look out can be maintained. Bergy bits and growlers are the most dangerous hazards to ships in ice-covered waters.

WARNING: THE NAVIGATOR MUST WATCH FOR BERGY BITS AND GROWLERS AT ALL TIMES WHEN IN BERGY WATERS.

Figure 38 Growler hidden in ice rubble

4.7.7 Future Ice Information Systems

Shipboard Systems

Future shipboard systems could involve marine radars enhanced and optimized for ice navigation. 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, producing radar-like displays which may be colour-enhanced to distinguish between open water and various ice types.

Airborne Systems

Airborne electromagnetic sensors capable of measuring ice thickness profiles over large areas are currently under development. Such data could be used as inputs which may improve the detail, accuracy, and reliability of external ice information sources, including ice charts.

Spaceborne Systems

Canadian Ice Service has begun acquiring passive microwave radiometer data from a satellite, which provides daily updates of regional ice edge locations and total ice concentrations for areas. Although the resolution is coarser than active radar imagery, this information can provide a broad picture of ice conditions when more detailed information is unavailable.

Canada has a fully operational imaging radar satellite known as Radarsat, which provides high-resolution (100 m) global coverage of ice-covered waters on a nearly continuous basis. Systems have been developed which distributes the processed data to Canadian Coast Guard icebreakers.

Ice Forecasting

Advances are being made in the development of ice forecasting models capable of predicting ice growth and ice motion. Improvements will continue and, with the incorporation of input data such as that which will be available from Radarsat, it is possible that the degree of accuracy and reliability of these models will eventually reach a point where their synoptic level output may be used directly on board ships to support strategic and tactical planning.

Figure 39 Iceberg and growlers in the open sea

Figure 40 Example of a bergy bit not detected on marine radar

CHAPTER 5 SHIPPING IN THE CANADIAN ARCTIC

Through the Arctic Waters Pollution Prevention Act (AWPPA) of 1970, the Government of Canada through Marine Safety, a branch of Transport Canada enforces its responsibility for ensuring that navigation in Arctic waters is conducted so as to preserve and protect the sensitive northern ecosystem. Under the AWPPA there are several regulations that affect vessel navigation in the Arctic.

Each of the regulations, standards or publications mentioned in this chapter have been condensed to illustrate only the pertinent sections that may have the greatest impact on Arctic operations. Complete copies of any of the documents mentioned can be obtained by contacting:

Prairie and Northern Region, Marine (AMNS)
Transport Canada
Place de Ville, Tower C
330 Sparks St., 14th Floor
Ottawa, Ontario
K1A 0N5

Telephone: (613) 991 - 6004
Facsimile: (613) 991 - 4818
Internet: www.tc.gc.ca

5.1 ARCTIC SHIPPING POLLUTION PREVENTION REGULATIONS (ASPPR)

Application

In general, the *Arctic Shipping Pollution Prevention Regulations* do not apply to a ship of 100 tons, gross tonnage or less, however, Sections 28 and 29 referring to sewage and oil deposits apply to every ship.

The *Arctic Shipping Pollution Prevention Regulations* govern some aspects of navigation through what is commonly known as the Zone / Date System. In the Zone / Date System, 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. In response to the fact that the Zone / Date System doesn't fluctuate with ice conditions, Transport Canada introduced the *Arctic Ice Regime Shipping System* to allow ships to navigate in the Arctic when the ice conditions permit.

The Zone / Date System

To understand how to apply the Zone / Date System to vessel operations requires three different pages. The first page (Figure 41) is a map of the Canadian Arctic illustrating the sixteen *Shipping Safety Control Zones* (Schedule II of the *Shipping Safety Control Zones Order*), the second page (Table 17) is the *Date Table* (Schedule VIII, of the ASPPR) and finally Table 18 comparing the Construction Standards for Types A, B, C, D and E Ships (Schedule V, of the ASPPR).

5.1.1 Application of the Zone / Date System

Under the ASPPR regulations no ship carrying more than 453m^3 of oil shall navigate in any of the zones illustrated unless the ship itself meets prescribed construction standards as either an Arctic Class ship, a Canadian Arctic Category (CAC) ship or a Type A, B, C, D or E ship. The Type E designation refers to an open-water ship. For those ships carrying less than the 453m^3 of oil, the Zone / Date System does not apply. However, the remainder of the regulations still apply.

Operations may determine the type of their ship by referring to the table, *Schedule V of the ASPPR*, using their Classification Society's Ice Strengthening Class or open-water designation. If a vessel is built to Arctic Class or Canadian Arctic Category (CAC) requirements, the owner will have documentation to establish this fact. Using the table in Schedule VIII of the AWPPA, an operator can determine the legal periods of entry into the various Zones as depicted in the *Shipping Safety Control Zones* (figure 41).

5.1.2 Arctic Class vs CAC Vessels

A new system now exists for determining how the most highly ice-strengthened vessels are classed by Transport Canada. For new construction four Canadian Arctic Categories (CAC) have now replaced the previous Arctic Classes. Details of the new structural classifications are provided in the Transport Canada publication Equivalent Standards For The Construction Of Arctic Class Ships - TP 12260. Owners of ships built to polar standards of other Classification Societies and national authorities can apply to Transport Canada for CAC equivalency on a case-by-case basis, as may owners of vessels previously classified under the existing Canadian system for Arctic Class vessels.

CAC ships are described in more detail in Section 5.3, of this publication. One of the principal advantages of operating a CAC vessel as opposed to an Arctic Class ship is the ability to directly apply the Arctic Ice Regime Shipping System.

5.1.3 The Arctic Ice Regime Shipping System

Although simple and predictable, the Zone / Date System has one major drawback. Ice conditions vary significantly from year to year. In a severe year a ship could legally enter a zone containing ice beyond its structural capability. In a light ice year, the rigidity of the system could prevent ships from transiting areas which are completely free of ice. To address this issue, the *Arctic Shipping Pollution Prevention Regulations* (ASPPR) have been revised to allow operators increased flexibility with their operations through the introduction of the *Arctic Ice Regime Shipping System (AIRSS) Standards,* TP 12259. This system permits ships to navigate outside of the current Zone / Date System when ice conditions are suitable.

Figure 41 Shipping Safety Control Zones

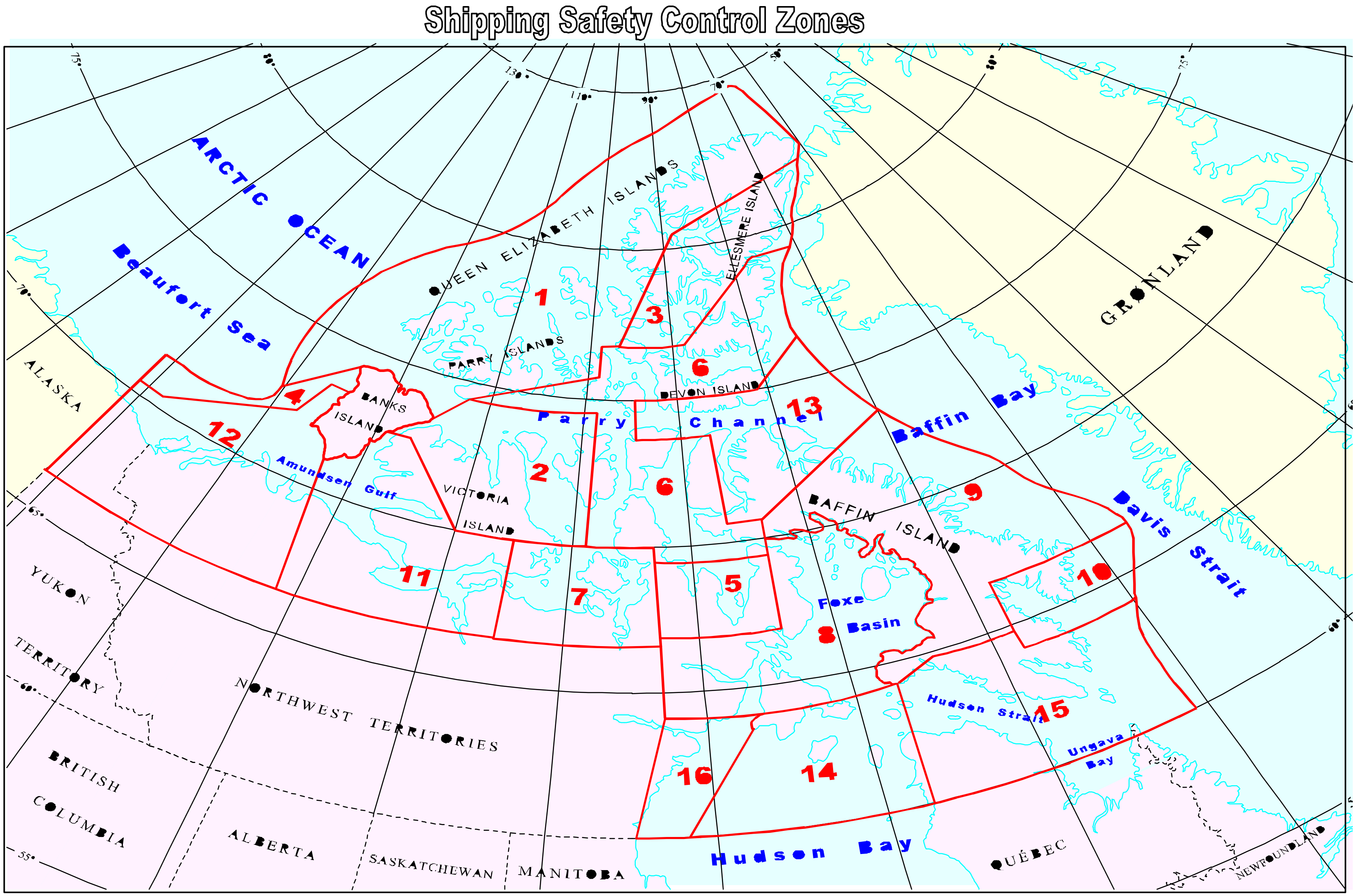


Table 17 Arctic Waters, Pollution Prevention Act, Schedule VIII (ss.6 and 26)

	Col. I	Col. II	Col. III	Col. IV	Col. V	Col. VI	Col. VII	Col. VIII	Col. IX	Col. X	Col. XI	Col. XII	Col. XIII	Col. XIV	Col. XV	Col. XVI	Col. XVII
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	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	July 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	July 1 to Dec. 31	July 1 to Dec. 15	July 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	Aug. 15 to Sept. 15	Aug. 1 to Oct. 31	July 15 to Nov. 30	July 15 to Nov. 30	Aug. 1 to Oct. 15	July 15 to Feb. 28	July 1 to Mar. 31	July 1 to Mar. 31	All Year	All Year	July 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	July 15 to Oct. 31	July 15 to Nov. 15	Aug. 15 to Sept. 30	July 20 to Dec. 31	July 15 to Jan. 15	July 15 to Jan. 15	July 10 to Mar. 31	July 10 to Feb. 28	July 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	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	July 25 to Oct. 15	July 20 to Nov. 5	Aug. 20 to Sept. 25	Aug. 1 to Nov. 30	July 20 to Dec. 15	July 20 to Dec. 31	July 20 to Jan. 20	July 15 to Jan. 25	July 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	July 25 to Dec. 20	July 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	July 15 to Nov. 10	July 1 to Nov. 10	July 15 to Oct. 31	July 1 to Nov. 30	July 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	July 15 to Oct. 20	July 1 to Oct. 31	July 15 to Oct. 15	July 1 to Nov. 30	July 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	July 25 to Nov. 20	July 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	July 15 to Oct. 20	July 1 to Oct. 25	July 15 to Oct. 15	July 1 to Nov. 30	July 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	July 15 to Oct. 15	July 1 to Oct. 25	July 15 to Oct. 10	July 1 to Nov. 25	July 1 to Nov. 25	June 20 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	July 15 to Oct. 10	July 1 to Oct. 20	July 30 to Sept. 30	July 10 to Nov. 10	July 5 to Nov. 10	July 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	July 15 to Sept. 30	July 1 to Oct. 20	Aug. 15 to Sept. 20	July 20 to Oct. 31	July 20 to Nov. 5	July 1 to Oct. 31

Table 18 Schedule V of the ASPPR Construction Standards for Types A, B, C, D and E Ships

Item	Column 1 Type of Ship	Col. II American Bureau of Shipping	Col. III Bureau Veritas	Col. IV Det Norske Veritas	Col. V Germanischer Lloyd	Col. VI Lloyd's Register of Shipping	Col. VII Nippon Kaiji Kyokai [1]	Col. VIII Polski Rejestr Statkow [1]	Col. IX Register of Shipping of the USSR	Col. X Registro Italiano Navale	Col. XI Registrul Naval Roman
1.	Type A	A1 Ⓔ Ice strengthening Class AA AMS or A1 Ⓔ Ice strengthening Class 1AA AMS	1 3/3 E glace I-super or 1 3/3 E Ice Class 1A Super	1 A 1 ICE A* or 1 A 1 ICE 1A*	100 A 4 E 4 MC	100 A1 Ice Class 1* LMC or 100A1 Ice Class 1A Super LMC	NS* (Class *1A Super* Ice strengthening) MNS* or NS* Class AA 1S MNS*	*KM YLA or *KM YL	KM ✪ ΥΛA or KM ✪ ΥΛ	100A-1.1 RG 1* or 100A-1.1 1AS	RNR ⚓ M G 60 CM O or RNR ⚓ M G 50 CM O
2.	Type B	A1 Ⓔ Ice strengthening Class A AMS or A1 Ⓔ Ice strengthening Class 1A AMS	1 3/3 E glace I or 1 3/3 E Ice Class 1A	1 A 1 ICE A or 1 A 1 ICE 1A	100 A 4 E 3 MC	100 A1 Ice Class 1 LMC or 100A1 Ice Class 1A LMC	NS* (Class *1A* Ice strengthening) MNS* or NS* Class A 1S MNS*	*KM L1	KM ✪ Λ1	100A-1.1 RG 1 or 100A-1.1 1A	RNR ⚓ M G 40 CM O
3.	Type C	A1 Ⓔ Ice strengthening Class B AMS or A1 Ⓔ Ice strengthening Class 1B AMS	1 3/3 E glace II or 1 3/3 E Ice Class 1B	1 A 1 ICE B or 1 A 1 ICE 1B	100 A 4 E 2 MC	100 A1 Ice Class 2 LMC or 100A1 Ice Class 1B LMC	NS* (Class *1B* Ice strengthening) MNS* or NS* Class B 1S MNS*	*KM L2	KM ✪ Λ2	100A-1.1 RG 2 or 100A-1.1 1B	RNR ⚓ M G 30 CM O
4.	Type D	A1 Ⓔ Ice strengthening Class C AMS or A1 Ⓔ Ice strengthening Class 1C AMS	1 3/3 E glace III or 1 3/3 E Ice Class 1C	1 A 1 ICE C or 1A1 ICE 1C	100 A 4 E 1 MC	100 A1 Ice Class 3 LMC or 100A1 Ice Class 1D LMC	NS* (Class *1C* Ice strengthening) MNS* or NS* Class C 1S MNS*	*KM L3 or KM L4	KM ✪ Λ3	100A-1.1 RG 3 or 100A-1.1 1C	RNR ⚓ M G 20 CM O
5.	Type E	A1 Ⓔ AMS	1 3/3 E	1 A 1	100 A 4 MC	100 A1 LMC	NS* MNS*	*KM	KM ✪	100A-1.1	RNR ⚓ M CM O

5.1.4 Vessel Certification - Arctic Pollution Prevention Certificates

Ships with a valid Arctic *Pollution Prevention Certificate* comply with the *Arctic Shipping Pollution Prevention Regulations*. Vessels without the certificate, which is not mandatory, may be inspected to verify their compliance with the regulations. All vessels are encouraged to have a valid Arctic Certificate issued prior to undertaking any voyage into the Shipping Safety Control Zones. The certificate may be issued outside Canada by an approved Classification Society or within Canada waters by the Administration. It should be noted that all certificates expire on March 31st following the date of issue.

The Arctic Pollution Prevention Certificate indicates the ice class of the vessel at specific drafts. Mariners intending to navigate in ice-covered waters should be aware of the ice class or type of their ship, and have a good understanding of the combinations of ice conditions and operating procedures which are likely to be safe for the voyage.

5.1.5 The Ice Navigator

The ASPPR from its conception, included a requirement for an Ice Navigator to be on board vessels in Arctic waters under particular circumstances. These requirements have recently been revised and are detailed in the following excerpt from the regulations:

26. 1. No tanker shall navigate within any zone without the aid of an ice navigator who is qualified in accordance with subsection (3).

2. No ship other than a tanker shall navigate in any zone set out in the heading to each of Columns II to XVII of Schedule VIII

   a) where the words “No Entry” are shown in that column of item 14, and

   b) where a period of time is shown in that Column of item 14, except during that period of time, without the aid of an ice navigator who is qualified in accordance with subsection (3).

3. The ice navigator on a ship shall

   a) be qualified to act as master or person in charge of the deck watch in accord-ance with regulations made pursuant to the *Canada Shipping Act;* and

   b) have served on a ship in the capacity of master, or person in charge of the deck watch for a total period of at least 50 days, of which 30 days must have been served in Arctic waters while the ship was in ice conditions that required the ship to be assisted by an icebreaker or to make manoeuvres to avoid concentrations of ice that might have endangered the ship.

4. Despite subsections (1) and (2), a tanker or ship referred to in those subsections may navigate in a zone without the aid of an ice navigator during any part of the transit in open water.

5. For the purposes of subsection (4), "open water" has the meaning assigned to that term in the *Arctic Ice Regime Shipping System* (AIRSS) *Standards* (TP 12259), published by Marine Safety, Transport Canada, in June 1996, as amended from time to time."

To summarize, an Ice Navigator is required:

i) on tankers (when carrying oil as cargo) when in a *Shipping Safety Control Zone,*

ii) when any ship, over 100 gross tons is navigating outside the Type E dates from Zone / Date Table, and

iii) while using the *Arctic Ice Regime Shipping System.*

Beyond the requirements, it is always recommended to have an experienced person guiding the ship when there is the potential for encountering sea ice. It is the shipowner's responsibility to ensure that qualified persons be on board for the intended voyage.

5.2 International Code of Safety for Ships in Polar Waters

An international initiative is developing a harmonized package of measures aimed at ensuring safety of life and protection of the environment in the world's polar waters. The initiative involves the International Maritime Organization (IMO), the International Association of Classification Societies (IACS), and the circumpolar nations in ways which best suit their respective mandates and capabilities.

A number of northern countries have established specific regulatory regimes to deal with operations in their own coastal Arctic waters, and many of the leading classification societies have developed rules for the design of ice-capable ships (in addition to the well-established 'Baltic' rules). However, none of the existing systems are really compatible with any of the others, meaning that a ship designed for one operation may have great difficulty in transferring to another, and often incurring considerable costs and delays in the process. Meanwhile, the complexity of working with multiple systems causes confusion which can itself present safety hazards. To deal with these problems, an *International Code of Safety for Ships in Polar Waters* (Polar Code) is being developed, under the auspices of the International Maritime Organization (IMO). This will represent a harmonization of existing national systems, in recognition of the increasing interest in the use of polar waters as shipping routes and areas for science and resource development.

The Polar Code's principal aim is to promote safety of navigation and to prevent pollution from ship operations in polar waters. It has been recognized in the harmonization process that this requires an integrated approach covering the design and outfitting of ships for the conditions which they will encounter, their crewing by adequate numbers of suitably trained personnel, and their operation in a planned and prudent manner. In addition, the Polar Code covers only additional requirements for polar waters, rather than providing a stand-alone document which would repeat or contradict existing requirements for other operations.

The Polar Code also takes into account that polar conditions may include both sea and glacial ice which could represent a serious structural hazard to all ships. This is the single most significant factor in polar operations and is reflected in many of the Polar Code's provisions including the application of higher levels of strengthening for Polar Class ships. The Polar Code itself does not aim to provide guidance in either structural design or machinery requirements. This will come from the parallel development of a set of unified requirements by the International Association of Classification Societies.

The Code also addresses the fact that the polar environment imposes additional demands on ship systems such as: navigation, communications, lifesaving, fire-fighting, etc. It emphasizes the need to ensure that all ship systems are capable of functioning effectively under anticipated operating conditions, notably the possibility of extreme cold. The Code stipulates that systems should provide adequate levels of safety in emergency situations. In addition, the Code recognizes that safe operation in polar conditions requires specific attention to human factors including training and operational procedures.

All ships operating under the Polar Code should carry on board a sufficient number of Ice Navigators to guide operations when ice is present. This new international Ice Navigator certification in turn requires training and experience qualification procedures, which have been agreed in general form and which will be finalized prior to the implementation of the Polar Code. The training for Ice Navigators will likely include the development of an IMO model course possibly combined with the use of an ice navigation simulator.

Polar Classes

The Polar code will establish seven Polar Classes as seen in Table 19 below. The class descriptions are deliberately general, to suit a variety of operations and their relationships are set to provide a reasonably smooth gradation of capability and cost.

Table 19 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 with Old ice inclusions
PC 4	Year-round operation in thick, First-year ice with Old ice inclusions
PC 5	Year-round operation in medium, First-year ice with Old ice inclusions
PC 6	Summer/autumn operation in medium, First-year ice with Old ice inclusions
PC 7	Summer/autumn operation in thin, First-year ice with Old ice inclusions

Certain 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, 6 and 7, can be considered as 'polarized' versions of the top two Baltic classes and the top classes represent levels of capability which have not yet been provided by commercial cargo-carrying vessels.

Not all ships operating in polar waters will be required to have a Polar Class designation. Under existing national systems some or all open water ships may be allowed to operate subject to certain constraints. Ships built, equipped and crewed according to the Polar Code requirements will be issued a certificate called a Document of Compliance. Some administrations could establish frameworks such as the Canadian Zone/Date System or the Ice Regime System which would allow any class ship to relate capacity to actual or average ice conditions.

Conclusions

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

The Polar Code will initially be adopted as a voluntary Code by IMO. Individual governments may adopt the Polar Code a mandatory requirement within their own jurisdictions. Administration of Polar Code provisions by Classification Societies should ensure widespread acceptance of its harmonized principles.

5.3 Equivalent Standards for the Construction of Arctic Class Ships - TP 12260

The purpose of the Arctic Shipping Pollution Prevention Regulations (ASPPR) is to minimize the risk of pollution in Canadian Arctic waters. The design philosophy embodied in the Standard seeks to utilize the reserve of strength in structures beyond the yield point to deal with extreme ice loads. The intention is to allow deformation of the plating while avoiding rupture. Thus the Standard which came into force on January 1st, 1996 has replaced Schedule VI. It is now the complete and stand-alone required alternative for hull construction specifications for owners wanting to build ships stronger than the typical Type E to Type A Class ships. Ships that are built to the Equivalent Standards for the Construction of Arctic Class Ships would be classified as Canadian Arctic Category (CAC) with the intent of extended operations in the Canadian Arctic.

The Standard should minimize structural failure from tripping and buckling of supporting structures. The steel used in construction must have properties that limits crack propagation at low temperatures. From an design perspective the most significant change is that CAC ships are not permitted to have oil or other pollutants against the outer shell. The subdivision and the ship's stability after damage are now more strictly controlled which results in improved pollution protection.

Equivalency with the Regulations

The categories of ships defined in the Standard are 'equivalent' to the Arctic Classes in the regulations (Schedule VI) as given in the Standard's Table of Nominal Arctic Class Equivalencies.

Vessel Operations

The Standards established four Canadian Arctic Categories (CAC) for ice strength as defined in the following table (20).

Table 20 Canadian Arctic Categories (CAC)

Category	Operating Role	Limiting Ice Type
CAC 1	Unrestricted	Multi-Year
CAC 2	Transit or controlled icebreaking	Multi-Year
CAC 3	Transit or controlled icebreaking	Second-Year
CAC 4	Transit or controlled icebreaking	Thick, First-Year

TP 12260, Page 3

The four categories described in the Standard are: CAC1, CAC2, CAC3 and CAC4 with the categories ranging from a CAC1 ship that is capable of operating in an ice management role in Multi-Year ice to a CAC4, able to do some controlled icebreaking in Thick, First-Year ice. (Specific details are contained in the Standard)

The CAC system facilitates the use of the Arctic Ice Regime Shipping System (AIRSS). The Ice Multiplier Table is used to yield an Ice Numeral for entry in particular ice regimes. Operators of heavy, icebreakers may apply to Transport Canada for a set of AIRSS Ice Multipliers on a case-by-case basis to seek the operational advantages offered by the AIRSS.

5.4 Arctic Ice Regime Shipping System (AIRSS) Standards - TP 12259

Referenced in the *Arctic Shipping Pollution Prevention Regulations* (ASPPR) the ***Arctic Ice Regime Shipping System (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 ships.

The Zone/Date System is based on rigid controls. The new AIRSS emphasizes the **responsibility of the Master** 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 Ice Regime System. The application of the AIRSS will require an Ice Navigator and the use of all available ice information.

5.4.1 Principles

- The *Arctic Ice Regime Shipping Standards* are based on the concept that ice conditions can be quantified through a simple Ice Numeral 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 be considered in applying the Ice Regime System.

5.4.2 Application Criteria

The AIRSS can only be used under the following circumstances:

- If the ship has a set of Ice Multipliers. For **Canadian Arctic Category (CAC) or Type ships**, their Ice Multipliers are listed in the Ice Multiplier Table. For all other ships, Ice Multipliers are assigned by Transport Canada on a case-by-case basis supported by the assessed ice strength of the vessel.
- If an **Ice Regime Routing Message** is sent to NORDREG Canada.
- If the vessel's calculated **Ice Numerals** are zero or **positive** for all of the ice regimes that are along the intended route.
- The final criteria for using the ice regime system is that the ship must have an **Ice Navigator** on board. The specific qualifications of an Ice Navigator are stated in Section 26 of the ASPPR and they were developed because it was recognized that navigation in Arctic ice is often a complex and dynamic process.

5.4.3 How to Apply the Arctic Ice Regime Shipping System

1. Obtain current ice information for the planned passage and select a desired route.

2. Determine the various ice regimes along the route and calculate the Ice Numerals for your vessel in each regime.

   The ice analysis charts from the Canadian Ice Service, are well suited to the 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 digital data if acquired may require more interpretation by an Ice Navigator.

3. If all the Ice Numerals are zero or greater, advise NORDREG Canada, through the submission of an Ice Regime Routing Message and proceed.

   This message does not constitute a request for permission to proceed, rather it is made for the information of the Ice Operations Superintendent at NORDREG. Based on this information, a NORDREG acknowledgement may be issued 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.

4. If the Ice Numeral 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 Ice Numerals, proceed after advising NORDREG.
5. Within 30 days of completing the voyage, send an ***After Action Report*** to Transport Canada.

5.4.4 Arctic Ice Regime Shipping System Messages:

When the Ice Regime System is used for voyages outside of the existing Zone/Date System, there will be a requirement for ships to submit the following two messages:

(a) Ice Regime Routing Message

(b) After Action Report

The following pages contain the formats of both messages.

5.4.5 Ice Regime Routing Message

The content of the *Ice Regime Routing Message* is as follows:

To: Regional Ice Operations Superintendent
NORDREG Canada Facsimile: (867) 979 - 4236

ICE REGIME ROUTING MESSAGE

a) the ship's name,

b) the ship's call sign and IMO number

c) the ice strengthening of the ship (Type / CAC / Arctic Class / etc.),

d) the date and UTC time,

e) the ship's current position, course and speed,

f) the anticipated destination,

g) the intended route,

h) a listing of the ice regimes and their associated Ice Numerals,

i) the source(s) of ice information,

j) any other pertinent information / comments

k) the name of any escorting vessel, and

l) the name(s) of the Ice Navigator(s) on board

Master

When the *Arctic Ice Regime Shipping System* is used, the *Arctic Shipping Pollution Prevention* Regulations require that an *Ice Regime Routing* Message be sent to NORDREG. This message can, in general, be very brief, however, if the vessel's route includes areas on ice analysis charts from the Canadian Ice Service with ice concentrations that may have negative Ice Numerals, the message should include additional pertinent information explaining the voyage plan e.g. expectations of changes in conditions and/or other considerations.

This message should be updated if there are any amendments to the ship's original Ice Regime Routing Message and that would include significant changes to the ice conditions. In any event, the ship should provide an update on entering any ice regime that was previously reported as having a negative Ice Numeral. These changes could for efficiency be attached to NORDREG's regular 1600 UTC Report.

5.4.6 After Action Report

When the Arctic Ice Regime Shipping System is used, in accordance with subsection 6(3) of the *Arctic Shipping Pollution Prevention Regulations,* an after action report is required to be submitted within 30 days of leaving the area. The report can be quite brief, however, in cases where the voyage has involved difficulties or unexpected occurrences, it will be valuable to include the information which the Master considers significant. This information could be useful for the future development of the system and for the overall safety of navigation in the Arctic.

To: Regional Director, Marine
Prairie & Northern Region – AMNS
Transport Canada
Place de Ville, Tower C
330 Sparks Street, 14th Floor
Ottawa, Ontario, K1A 0N

Telephone: (613) 991 – 6004
Facsimile: (613) 991 - 4818

AFTER ACTION REPORT

a) the ship's name,

b) the ice strengthening of the ship (Type / CAC / Arctic Class / etc.),

c) a description of the actual route, including the: ice regimes encountered, transit speeds and the Ice Numerals for each,

d) copies of the ice information used,

e) escort information, if applicable

1. duration of the escort,
2. the ice regime under escort, and,
3. the characteristics of the track,

f) weather conditions and visibility, and

g) any other important information.

Master

Unlike the routing message, the After Action Report is to be sent to the Regional Director, Marine, Prairie & Northern Region, who receives it on behalf of the Minister of Transport. The content of the After Action Report is as follows:

5.4.7 Ice Analysis Charts or Imagery

To fulfill the requirements of d) above "copies of the ice information used", it is suggested that copies of ice analysis charts or imagery that were used on the voyage be attached to the After Action Report and to make reporting easier for Ship's Officers, the vessel's courses could be drawn over the ice charts along with brief notations that describe the regimes or conditions of concern. This could, in essence save a lot of time and text writing.

5.5 USER ASSISTANCE PACKAGE - TP 12819

In the summer of 1998, a User Assistance Package was published by Transport Canada. The purpose of the Package is to provide ship's officers with relevant information to facilitate an introduction of the Arctic Ice Regime Shipping System which applies when vessels intend to navigate outside Canada's current Zone / Date System. It did this by:

(a) providing a **video** that introduces the Ice Regime System, and some very basic ice recognition skills,

(b) offering an Ice Regime software program that lets the operator calculate the **ship's Ice Numeral** for each ice regime, that also automatically creates both the ***Ice Regime Routing Message*** and the ***After Action Report,***

(c) combining the *Arctic Ice Regime Shipping System (AIRSS*) Standards and the *Arctic Shipping Pollution Prevention Regulations* in understandable terminology for Navigation Officers and Ice Navigators and,

(d) identifying reference material that will enable Navigation Officers to access a variety of information products linked to the ice regime concept. Part of the reference material is a **laminated card** that has a coloured Ice Multiplier Table on one side and the Canadian Ice Service egg code information of the other.

Although there is no regulatory requirement to carry the *User Assistance Package* - TP 12819, ships (both foreign and domestic) that intend to sail into Canada's Arctic are encouraged to obtain this publication and to use the system for the purpose of safe navigation. Contact Transport Canada at the following address for a free copy.

Prairie & Northern Region, Marine (AMNS)
Transport Canada, Place de Ville, Tower C
330 Sparks Street, 14th Floor
Ottawa, Ontario, Canada
K1A 0N5

Telephone: (613) 991 - 6004
Facsimile: (613) 991 - 4818

5.5.1 Principles of the Arctic Ice Regime Shipping System

- The Arctic Shipping Pollution Prevention Regulations (ASPPR) have been revised to allow operators increased flexibility and the ability to improve their efficiency. An aspect of this process is an increased emphasis on the responsibility of the mariner to ensure the safety of the ship. This was accomplished by creating the Arctic Ice Regime Shipping System which permits ships to navigate outside of the current Zone / Date System when ice conditions are suitable. It is based upon a simple calculation which indicates whether or not a given set of ice conditions can be expected to 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 be considered in applying the Ice Regime System.
- The Master or Ice Navigator of an Arctic-going vessel will have primary responsibility for applying the Ice Regime System.

5.5.2 Ice Regime Terminology

The Arctic Ice Regime Shipping System involves comparing the actual ice conditions along a route to the structural capability of the ship. This is accomplished by comparing the type of ice in a regime (thickness), the quantity of each ice type (measured in tenths) and then accounting for the ship itself.

Ice Regime

An ice regime is considered to be "any mix or combination of ice types, including open water. An ice regime occurs as a region in navigable waters covered with generally consistent ice conditions; i.e. the distribution of ice types and concentrations does not change very much from point to point in this region." (TP 9981, Page 23) Considering this definition, an ice regime could vary in size from the track of an icebreaker to Baffin Bay as long as the ice conditions are consistent. To assist with voyage planning, ice charts can be a valuable tool because the ice eggs and their regions could represent Ice Regimes.

Ice Multiplier

One of the principal concepts behind the Ice Regime System is that: "every ice type (including open water) has a numerical value which is dependent on the ice category of the vessel. This number is called an Ice Multiplier (IM). The value of the Ice Multiplier reflects the level of risk or operational constraint that the particular ice type poses to each category of vessel." (TP 12259, Page 7)

To find the applicable set Ice Multipliers for your ship, highlight the appropriate vertical column based on your ship category. This will comprise your Ice Multipliers for all the different ice types listed vertically on the left side of the table. (If you do not know your ship category refer to your Arctic Pollution Prevention Certificate or Schedule V of the ASPPR.) All the other columns can be considered irrelevant.

Ice Numeral

The Ice Numeral (IN) is an assessment of an ice regime, in mathematical terms, which is used to determine whether the ship can enter a specific ice regime. In other words, an IN is the sum of the products of the concentration, in 1/10th's, of each ice type and their respective Ice Multipliers in each regime.

Table 21 Ice Multiplier Table

WMO Ice Codes	Ice Types		Ice Multipliers for each Ship Category						
			Type **E**	Type **D**	Type **C**	Type **B**	Type **A**	CAC **4**	CAC **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 9	Thin First-Year Ice .....(FY) Thin First-Year Ice - 2nd Stage	30-70 cm 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	“	“	“	“	“	“	“
	Brash Ice		“	“	“	“	“	“	“
=∆	Bergy Water		“	“	“	“	“	“	“
¦¦¦¦	Open Water		“	“	“	“	“	“	“

Decayed Ice: For ice types: MY, SY, TFY, and MFY that are Decayed, add +1 to the Ice Multiplier.

Ridged Ice: For ice floes that are over 3/10ths ‘Ridged’ and in an overall ice concentration that is greater than 6/10ths, subtract 1 from the Ice Multiplier.

5.5.3 Factors that may affect Ice Multipliers

Decayed Ice

Currently there is no WMO or MANICE definition of Decayed Ice, however 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 which has thaw holes formed or is Rotten ice. For Decayed Ice +1 may be added to that ice type’s Ice Multiplier. As an example, if a Type B ship encounters decayed Thick First-Year ice, the Ice Multiplier changes from -2 to -1.

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 Ice Multiplier for that ice type, shall be decreased by 1. If, as an example a Type E ship finds a regime with Ridged Thin First-Year ice, the Ice Multiplier changes from -1 to -2.

Brash Ice

As a result of research, Brash Ice (not a Jammed Brash Barrier or Agglomerated Brash) has been given the same weighting as Open Water i.e. a +2 Ice Multiplier. Within the AIRSS concept this form of ice is intended to account for the ice predominately found in well defined icebreaker tracks.

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 Ice Numeral calculation. If a trace of Old Ice is encountered, caution should be exercised when navigating due to the risk that this ice creates.

Floe Size

At this time there is no direct way of quantifying the relationship of floe size within the AIRSS.

Safe Speed

The ship's speed is a critical aspect of safe ice navigation. At this time speed has not been numerically incorporated as part of the Ice Numeral calculation within the Arctic Ice Regime Shipping System, but it is an important consideration for a mariner operating with due caution in ice-infested waters. Mariners must be aware that the vessel's operating speed should cautiously be selected to avoid damaging impacts with dangerous ice, preferably by avoiding it altogether.

Figure 42 This Type D Bulk Carrier was damaged by ice in Hudson Strait

5.5.4 Ice Numeral Calculations

For any ice regime, an Ice Numeral (IN) is the sum of the products of:

(a) the concentration in tenths of each Ice Type, and

(b) the Ice Multipliers relating to the Type or Class of the ship 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 Ice Multiplier 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. Ice Numerals can be calculated from ice conditions as shown in the Canadian Ice Service's, *MANICE* / WMO ice 'eggs' or data obtained from other sources.

The Ice Numeral is therefore unique to the particular ice regime and ship operating within its boundaries. The Ice Numeral for each regime must be zero or positive for a transit to in a regime be considered and any application of the AIRSS must be indicated with an Ice Regime Routing Message and an acknowledgement from NORDREG.

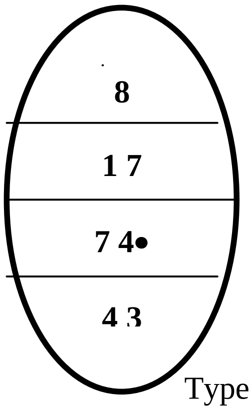
> ***NOTE:*** *While doing any Ice Numeral calculation remember that every regime is composed of an aggregate 10/10th's concentration of various ice types. As an example, if an ice "egg" shows a total concentration of 6/10th's, remember that the other 4/10th's is Open Water and should be accounted for in the IN calculation.*

5.5.5 Examples: Ice Regimes and their Ice Numeral Calculations

The following examples are of realistic Ice Numeral calculations based on ice "eggs" from Daily Ice Analysis Charts or in the case of Example 4, a Tactical Ice Reconnaissance Chart. For each case, two different ships were used to illustrate how the Ice Numerals fluctuate for the same ice with structurally different vessels.

Example 1

Ice Egg



Interpretation:

This mid-summer's Ice Regime consists of 8/10th's total ice concentration of which: 1/10th is Old ice and 7/10th's Thick First-Year ice. While doing the calculation remember to incorporate the 2/10th's of Open Water.

Ice Numeral Calculations:

Type A ship: (1 x -4) + (7 x -1) + (2 x 2 for open water) = -7 [Negative Regime]

CAC 4 ship: (1 x -4) + (7 x +1) + (2 x 2 for open water) = +7 [Positive Regime]

or If this regime happened to be Ridged:

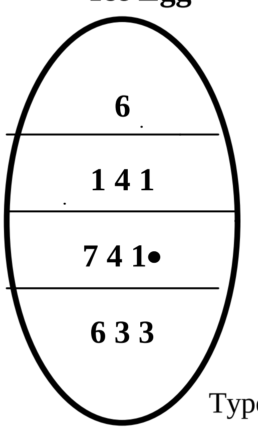
With Ridged thick first-year ice the Ice Numeral calculations are:

3 Type A ship (1 x -4) + (7 x -2) + (2 x 2 for open water) = -14 [Negative Regime]

CAC 4 ship: (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 6/10th's total concentration of ice of which 1/10th is Old ice, 4/10th's is Thick First-Year and 1/10th of Medium First-Year ice.

Ice Numeral Calculations:

Type **E** ship (1 x **-4**) + (4 x **-3**) + (1 x **-2**) + (4 x **+2**, open water) = **10** [Negative]

Type **A** ship (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:

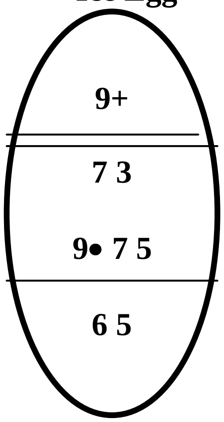
5 With **Decayed** ice (all Ice Types) the Ice Numeral calculations are:

Type **E** ship (1 x **-3**) + (4 x **-2**) + (1 x **-1**) + (4 x **+2**, open water) =**-4** [Negative]

Type **A** ship (1 x **-3**) + (4 x **0**) + (1 x **+2**) + (4 x **+2**, open water) =**+7** [Positive]

Example 3

Ice Egg



Interpretation:

This Nov. 11th Ice Regime consists of 9/10th's plus total concentration1 of ice in which there is a trace of Multi-Year ice, 7/10th's Thin First-Year and 3/10th's of Grey-White ice.

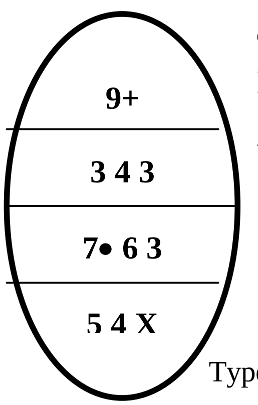
*(**NOTE**: A trace of Multi-Year or Old ice creates a high risk transit.)*

Ice Numeral Calculations:

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

Example 4

Ice Egg



Interpretation:

This data that has been interpreted from remote sensing imagery (Radar / NOAA etc.) indicates that this regime of 9/10th's plus * ice, consists of: 3/10th's Old ice, 4/10th's of First-Year (considered thick) and 3/10th's of Young ice (considered Grey-White).

Ice Numeral calculations:

Type **B** ship:	(3 x **-4**) + (4 x **-2**) + (3 x **+1**) = **-17**	[Negative Regime]
CAC **3** ship:	(3 x **-1**) + (4 x **+2)** + (3 x **+2**) = **+11**	[Positive Regime]

* [1] *"Total ice concentrations of 9/10th's plus (9+) are considered 10/10th's for the purposes of Ice Numeral calculations". (ASPPR Ice Regime Project - Case Studies of the IN Concept, TP 8890 page 5)*

5.5.6 Vessel Operations

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 Master 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, or

(d) requesting the assistance of an icebreaker by calling NORDERG.

NORDREG, 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 ship'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 ship 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, and
- the likelihood of pressure conditions, which may cause the track to close rapidly.

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 because of 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 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 Ice Numerals. 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. Following the voyage an After Action Report must be submitted even though only positive Ice Numerals 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 that there is an Ice Navigator on board, an Ice Regime Routing Message is sent to NORDREG that illustrates positive ice regimes. On late season voyages this communication with NORDREG is very important considering that the availability of Icebreaker support may be crucial if ice conditions deteriorate rapidly.

CHAPTER 6 SHIP DESIGN AND CONSTRUCTION FOR ICE OPERATIONS

6.1 HULL FORM DESIGN

Ice horn	Wedge-shaped structure above the rudder to help protect it from ice when going astern.
Type ship	A classification assigned to a ship as defined in the Arctic Shipping Pollution Regulations. Type ships are designed only for navigation in ice-covered waters, not for icebreaking.
Stem angle	Angle measured between the stem of a ship and the water-line.
Flare angle	Angle measured from the vertical to the ship's side.
Buttock angle	Angle measured between a tangent at a point on a longitudinal section through the hull and the water-line.
Water-line angle	Angle measured between a tangent at a point on a water-line and a horizontal line.
Parallel midbody	That portion of a ship's hull characterized by flat shell plating, which does not change shape over a longitudinal distance.
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.

6.1.1 Bow Shape

The bow shape of a Type ship is typical of ships designed for operation in open water. As such, it is designed only to force ice, that is, to push ice away from the ship. Therefore, operators of Type ships should not attempt to break ice. 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 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 43). Other bows can be referred to as unconventional or non-traditional, in that they are a distinct departure from smooth hull shapes (Figure 44). 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 43 Conventional bow shape

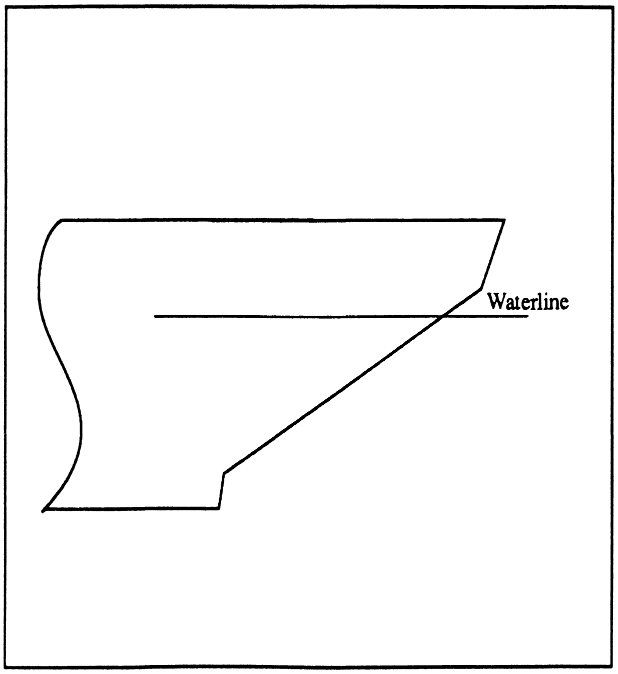
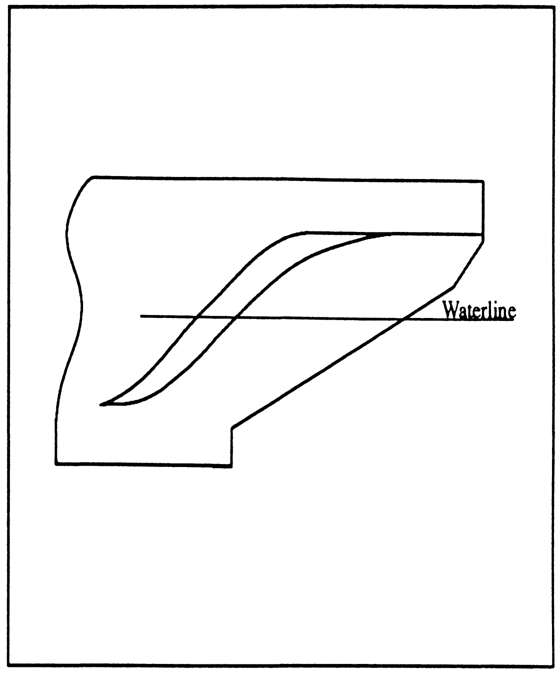


Figure 44. Unconventional bow shape



6.1.2 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.

6.1.3 Stern Shape

The stern design on icebreaking ships 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 Canadian Coast Guard 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 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;

- 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); and
- 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).

6.2 STRUCTURAL DESIGN

Arctic Class Ship	A ship designed according to the Arctic Shipping Pollution Prevention Regulations (Section 8).
Ductile	Capable of being drawn out into a wire, pliable.
Modulus	A constant that gives a ratio between the amount of physical effect and that of the force producing it.
Tripping	The collapse of a frame against the side shell.

6.2.1 Loading

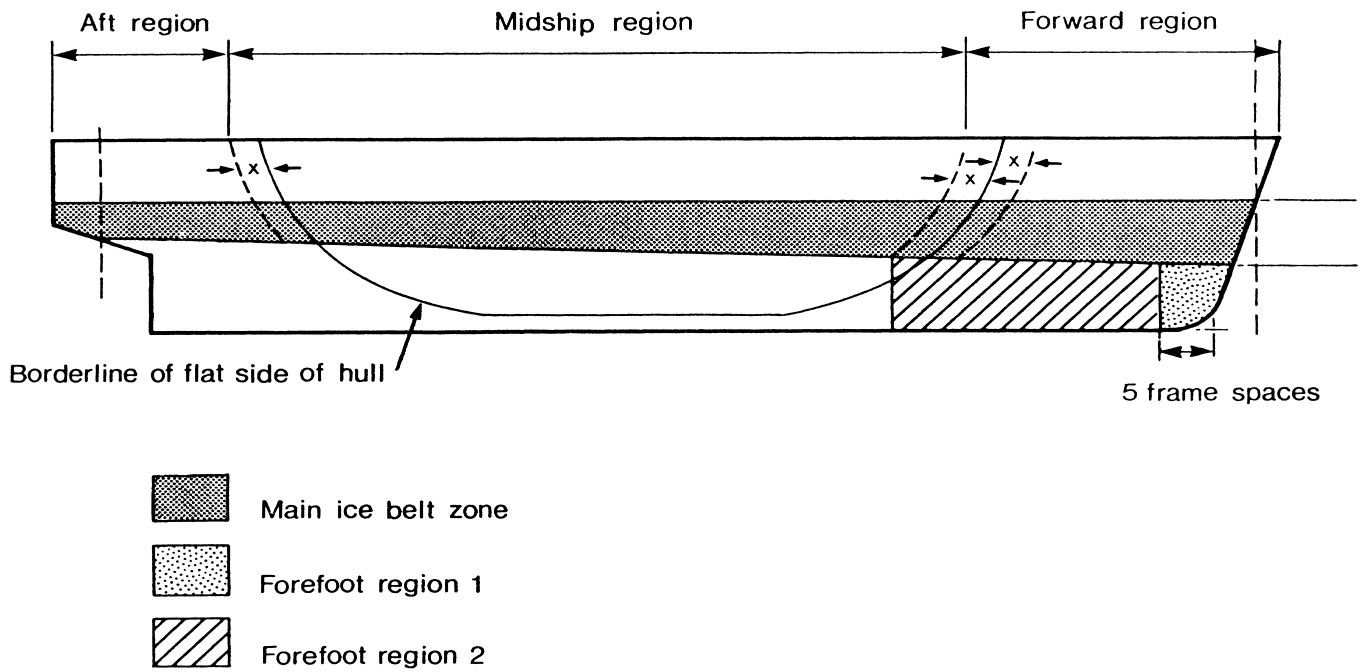
The design of structure for icebreakers and other ice-capable ships requires a knowledge of the magnitude of ice loads, which are influenced by: hull shape, displacement, power, speed, ice confinement, and ice type.

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 45 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.

6.2.2 Structural Arrangement

The ship'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 ships in a "beaching condition". This condition can occur when the ship is ramming an ice floe and the bow rises out of the water to rest on the floe. Lower Arctic Class ships, Type ships, and ships 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 ships, because bending stresses incurred during normal operations for ships 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.

Figure 45 Hull areas for a Type ship



In traditional icebreaker structure, the shell plating is supported by main frames spaced about 40 cm 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.

6.2.3 Construction Materials and Behaviour at Low Temperatures

Structural integrity requires the proper selection of hull materials. The two primary groups of steel used in ship 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 ships 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. An example of brittle failure in ship's structure is shown in Figure 46.

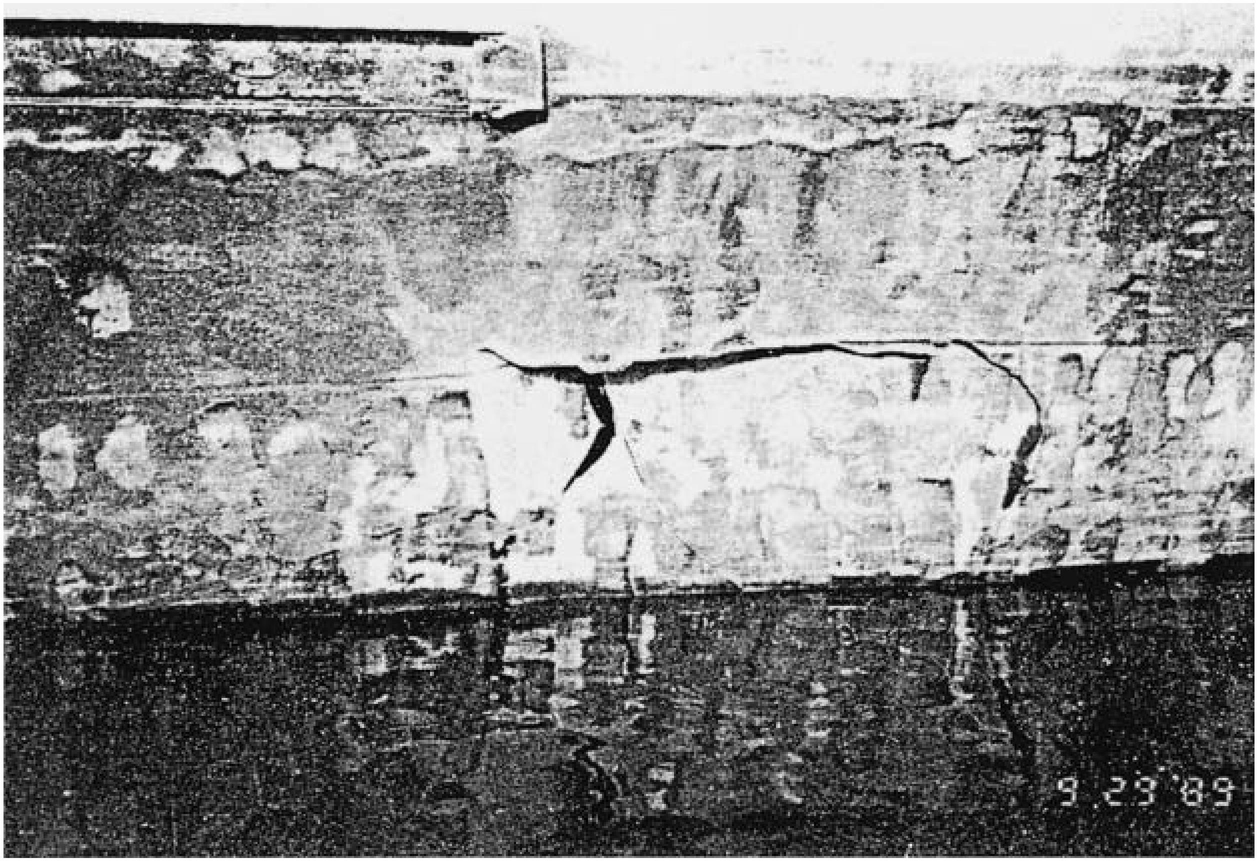
The navigating officers on board a vessel in ice must be aware of the type of steel used in the construction of their ship. The shell expansion plan will be on board and it will show clearly the steel qualities used. If a ship has no low temperature steel, it is important to avoid impacts with hard ice when the air temperatures are very low.

6.3 PROPULSION SYSTEMS

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.

Figure 46 Example of brittle fracture in ship's structure



Propulsion systems for ice-going ships must be reliable, flexible with a view to redundancy, maintainable, and have high power-to-weight and power-to-space ratios. The two dominant propulsion systems in ice-going ships are diesel-electric transmission with fixed-pitch propellers (typically installed on icebreakers), and diesel-mechanical transmission with controllable-pitch propellers. Ships not required to break ice would normally have a diesel-mechanical transmission, with or without controllable-pitch propellers.

6.3.1 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 ships.

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 ships 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 ships. Gas turbines are also unidirectional, and astern operation must be obtained from a reversing gearbox, or from a controllable-pitch propeller.

6.3.2 Electric Transmission

Canadian Coast Guard 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 ships usually have mechanical transmission systems.

6.3.3 Mechanical Transmission

Mechanical drive systems are comprised of gearboxes, clutches, and (possibly) flywheels. In ice-going ships 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.

6.3.4 Shafts and Shaft-line Components

Shaft couplings are commonly of two 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.

Traditionally, water-lubricated, rubber stave bearings have been used in Canadian Coast Guard icebreakers. Oil-lubricated, white-metal lined bearings have been used on many privately owned Arctic Class ships 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 ships than any other single cause. Radial lip seals are used extensively in Arctic Class ships with moderately sized shafts, up to about 120 cm in diameter, and small stern bearing clearances. Axial face seals are used on some icebreakers and ice-class ships and have been tested for shafts up to 160 cm in diameter.

WARNING: PROBLEMS WITH TAIL-SHAFT SEALS HAVE IMMOBILIZED MORE SHIPS THAN ANY OTHER SINGLE CAUSE.

6.3.5 Propellers

Fixed-pitch propellers are used on most icebreaking ships. However, since 1966, controllable-pitch propellers have been used on a wide range of icebreakers and icebreaking cargo ships. Stainless steel and nickel-aluminum bronze are commonly used materials for the propeller blades of ice-class ships. 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 ships 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).

6.4 STEERING SYSTEMS

A recent analysis of damage to steering systems of ice-going ships has shown that over half the failures have been to rudder stocks, about 20 per cent 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 aft of the rudder. Rudder stops can also be fitted to the hull to stop the rudder at least two degrees before the maximum steering gear travel. Baltic icebreaking vessels utilize a twin rudder arrangement with twin screw vessels. Canadian Coast Guard practice has been to use a single rudder with twin and tripple screw designs.

6.5 AUXILIARY SYSTEMS

WARNING: FREEZING OF DECK AND ENGINE ROOM SYSTEMS ARE THE MOST COMMON PROBLEMS FOR FOREIGN SHIPS NAVIGATING IN COLD CLIMATES AND ICE-COVERED WATERS.

Frazil ice Fine spicules or plates of ice suspended in water.

Sea bay 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 ship for cooling, fire, or sanitary purposes.

6.5.1 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 ships entering ice-covered waters. 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 ships which operate in ice must prevent the cooling system from becoming blocked by ice.

> **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 which can ease or eliminate these problems:

(a) High and low inlet grilles can be provided as far apart as possible.

(a) Weir-type sea inlet boxes will overcome the problem of suction pipe clogging. The principal is commonly used in Baltic icebreakers, and is shown in Figure 47. 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.

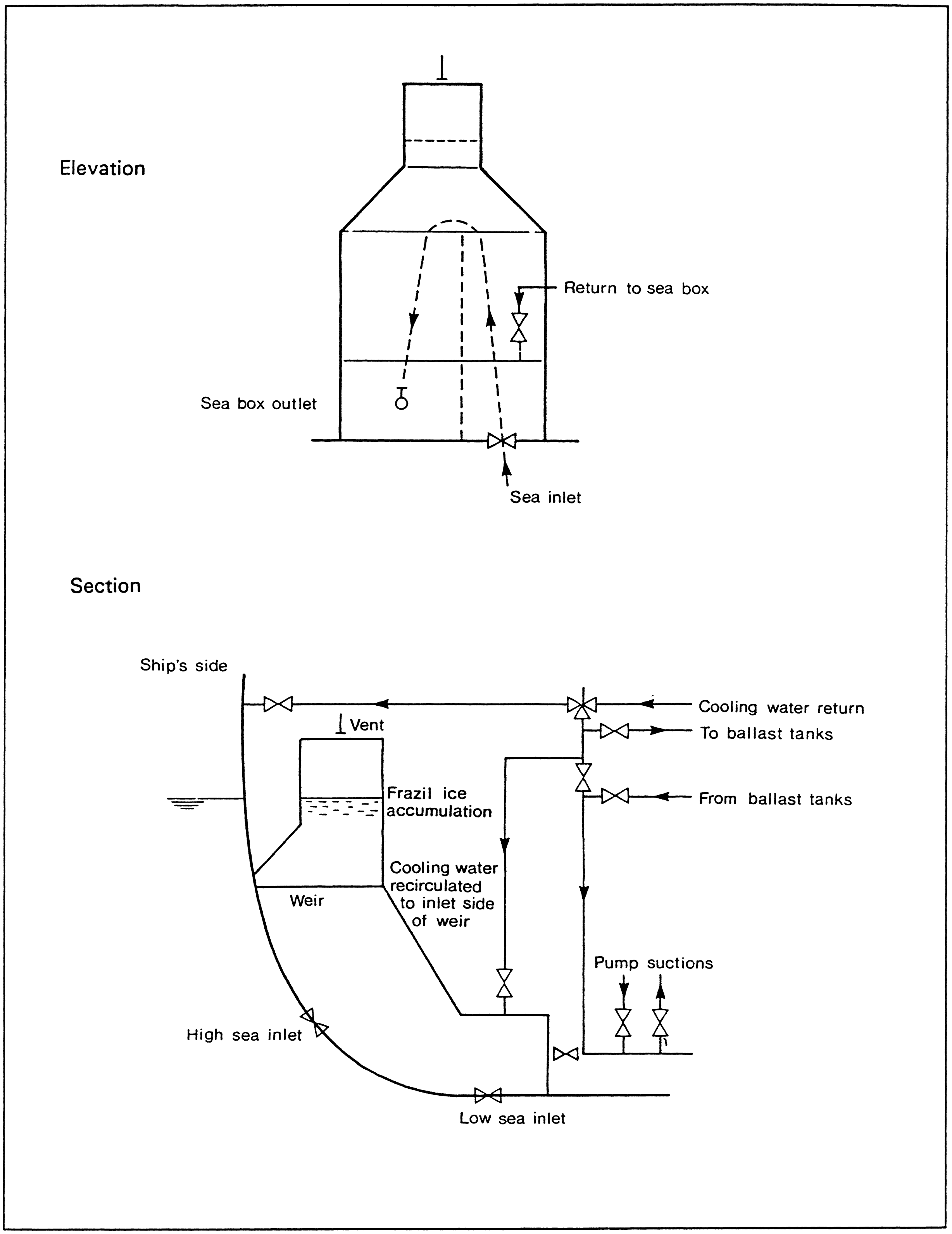
(b) De-icing return(s) can be arranged to feed steam or hot water to the sea inlet box top, where frazil ice may have accumulated, or directly to the cooling system suction where a blockage may have occurred.

(c) 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 ship is fitted with shell circulation coolers because the recirculated ballast water will become too warm for effective cooling.

(d) Means should be provided to clear the systems manually of blockage by ice.

(e) The navigators and engineers should be aware of these potential problems and the solutions available to them on their ship.

Figure 47 Alternative sea inlet arrangement



6.5.2 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. The ship 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 ship 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 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; and
- 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.

The navigators and engineers should be aware of these potential problems and the solutions available to them on their ship.

6.5.3 Waste Disposal

All ships 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.

Bilge water, dirty ballast water, tank washings, and purifier sludge are typical examples of oily water. Bilge water is discharged usually through an oily water separator, designed to limit the oil content in the discharged water to 15 parts per million. However, 15 parts per million of oil discharged into Arctic waters contravenes the Arctic Shipping Pollution Prevention Regulations. For separated oil and purifier sludge, sufficient capacity must be available for storage on board or they can be burned on board in boilers or incinerators.

WARNING: 15 PARTS PER MILLION OF OIL DISCHARGED INTO ARCTIC WATERS WILL CONTRAVENE THE ARCTIC SHIPPING POLLUTION PREVENTION REGULATIONS.

The discharge of garbage is forbidden under the Arctic Shipping Pollution Prevention Regulations. However, garbage can be separated into burnable and non-burnable types. In small ships it may be practical to install incinerators, and sufficient storage must be provided on board.

The discharge of sewage is presently permitted by the Arctic Shipping Pollution Prevention Regulations. However, sewage sludge can be burned in an incinerator or held in a storage tank.

6.5.4 Fuel Oil Heating

On ships 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 SHIP MOVES INTO MORE TEMPERATE AREAS.

ANNEX A TERMINOLOGIES FOR ICE, NAVIGATION, AND SHIP DESIGN

A.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 Services (CIS), Environment Canada, and is outlined in full in the latest edition of MANICE (1994). A list of common ice terms and definitions is given in this annex for reference with the manual.

A) SEA-ICE TYPES

Sea Ice Any form of ice found at sea which has originated from the freezing of sea water.

New Ice A general term for recently formed ice which includes frazil ice, grease ice, slush, and shuga. These types of ice are composed of ice crystals which 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.

Slush Snow which 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 cm in thickness. May be subdivided into dark nilas and light nilas.

Dark Nilas Nilas up to 5 cm in thickness and which is very dark in colour.

A) SEA-ICE TYPES

Light Nilas	Nilas which is more than 5 cm in thickness and lighter in colour than dark nilas.
Young Ice	Ice in the transition stage between nilas and first-year ice, 10-30 cm in thickness. May be subdivided into grey ice and grey-white ice.
Grey Ice	Young ice 10-15 cm thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.
Grey-White Ice	Young ice 15-30 cm thick. Under pressure it is more likely to ridge than to raft.
First-Year Ice	Sea ice of not more than one winter's growth, developing from young ice; 30 cm-2 m 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 cm thick.
Medium First-Year Ice	First-year ice 70-120 cm thick.
Thick First-Year Ice	First-year ice over 120 cm 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 multiyear 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 multiyear ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.
Multiyear Ice	Old ice which has survived at least two summer's 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.

B) LAKE-ICE TYPES

Lake Ice Ice formed on a lake, regardless of observed location.

New Lake Ice Recently formed ice less than 5 cm thick.

Thin Lake Ice Ice of varying colours, 5-15 cm thick.

Medium Lake Ice A further development of floes or fast ice, 15-30 cm thick.

Thick Lake Ice Ice 30-70 cm thick.

Very Thick Lake Ice Floes or fast ice developed to more than 70 cm thick.

C) FORMS OF ICE

Pancake Ice Predominantly circular pieces of ice 30 cm to 3 m in diameter, up to 10 cm 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 m across.

Small Ice Cake An ice cake less than 2 m across.

Floe Any relatively flat piece of ice 20 m or more across. Floes are subdivided according to horizontal extent as follows:

Small Floe A floe 20-100 m across.

Medium Floe A floe 100-500 m across.

Big Floe A floe 500-2,000 m across.

Vast Floe A floe 2-10 km across.

Giant Floe A floe over 10 km across.

C) FORMS OF ICE

Batture Floes Large, thick, uneven, and discoloured floes often up to 8 km or more across. Form on the upstream side of shoals and islets in the St. Lawrence River 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 m across, the wreckage of other forms of ice.

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. 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. May be more than one year old in which case it may be prefixed with the appropriate age category (old, second-year, or multiyear). If thicker than2 m above sea-level, it is called an ice shelf.

Grounded Ice Floating ice which is aground in shoal water.

D) 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, i.e., 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.

E) 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, 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 Ice	Floating ice in which the concentration is 9/10 to less than 10/10.
Close Ice	Floating ice in which the concentration is 7/10 to 8/10, composed of floes mostly in contact with one another.
Open Ice	Floating ice in which the concentration is 4/10 to 6/10, with many leads and polynyas. Floes generally not in contact with one another.
Very Open Ice	Ice in which the concentration is 1/10 to 3/10 and water dominates over 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 present. If ice of any kind is present, this term shall not be used.

F) Ice Distribution

Ice Field	Area of floating ice, consisting of any size of floes, and greater than 10 km across.
Large Ice Field	An ice field over 20 km across.
Medium Ice Field	An ice field 15-20 km across.
Small Ice Field	An ice field 10-15 km across.
Ice Patch	An area of ice less than 10 km across.

F) ICE DISTRIBUTION

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 km to more than 100 km in width.
Tongue	A projection of the ice edge up to several kilometres in length, caused by wind or current.
Strip	Long narrow area of drift ice, about 1 km 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.
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 m wide.
Small Fracture	50 to 200 m wide.
Medium Fracture	200 to 500 m wide.
Large Fracture	More than 500 m 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 m.
Tide Crack	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.

F) ICE DISTRIBUTION

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.

G) 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.

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.

Ridged Ice Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice.

G) ICE SURFACE FEATURES

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.

Hummocked Ice Ice piled haphazardly one piece over another to form an uneven surface. When weathered has the appearance of smooth hillocks.

H) ICE MOTION 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 one 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.

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.

I) ICE OF LAND ORIGIN

Glacier Ice	Ice in, or 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 m 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.

J) 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 m 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. Most show horizontal banding.
Domed Iceberg	An iceberg which is smooth and rounded on top.
Pinnacled Iceberg	An iceberg with a central spire, or pyramid, with one 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.
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.

J) SHAPES AND SIZES OF GLACIER ICE

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 m. Normally about 100-300 sq. m. in area.
Small Iceberg	A piece of glacier ice extending 5 to 15 m above sea level and with a length of 15 to 60 m.
Medium Iceberg	A piece of glacier ice extending 16 to 45 m above sea level and with a length of 61 to 120 m.
Large Iceberg	A piece of glacier ice extending 46 to 75 m above sea level and with a length of 121 to 200 m.
Very Large Iceberg	A piece of glacier ice extending more than 75 m above sea level and with a length of more than 200 m.
Ice Island	A large piece of floating ice protruding about 5 m above sea-level, which has broken away from an Arctic ice shelf. Has a thickness of 30-50 m and an area of from a few thousand square metres to 500 sq. km or more. Usually characterized by a regularly undulating surface giving it a ribbed appearance from the air.

K) 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.

A.2 NAVIGATION TERMINOLOGY

The following definitions pertaining to navigation in ice have been referenced in this manual.

Beset	Ship unable to move 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 Belt	Area of ship strengthened to take ice loads at the ice draught water-line.
Ice Draft	Draft at which the ship 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 ship as far forward as possible, backing the ship out and repeating the process.
Strategic Planning	Small-scale (large area) planning with the assumption that the ship 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.

A.3 SHIP DESIGN TERMINOLOGY

The following definitions pertaining to ship 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 ship designed according to the Arctic Shipping Pollution Prevention Regulations (Section 8).
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.
Ice horn	Wedge-shaped structure above the rudder to help protect it from ice when going astern.
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.
Sea bay	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 ship for cooling, fire, or sanitary purposes.
Stem angle	Angle measured between the stem of a ship and the water-line.
Tripping	The collapse of a frame against the side shell.
Type ship	A classification assigned to a ship as defined in the Arctic Shipping Pollution Regulations. Type ships are designed only for navigation in ice-covered waters, not for icebreaking.
Water-line angle	Angle measured between a tangent at a point on a water-line and a horizontal line.

ANNEX B REFERENCE MATERIALS FOR ICE NAVIGATION IN CANADIAN WATERS

B.1 NOTICES TO MARINERS, RADIO AIDS, LISTS OF LIGHTS, AND SAILING DIRECTIONS

Publication	Source
NOTICES TO MARINERS	
Notices to Mariners - Annual Edition	Hydrographic Chart Distribution Office Fisheries and Oceans Canada 1675 Russell Road P.O. Box 8080 Ottawa, Ontario Canada K1G 3H6
RADIO AIDS TO NAVIGATION	
a) British	
Admiralty List of Radio Stations	British Admiralty and Authorized Chart Agents
Vol. 1 Coast Radio Stations	
Vol. 2 Radio Beacons, Radio Direction - finding Stations, Radar Beacons	
Vol. 6 Port Operations, Pilot Services and Traffic Management	

Publication	Source
b) Canadian	
Radio Aids to Marine Navigation Atlantic - Great Lakes (includes Hudson Strait, Hudson Bay, and Arctic) Radio Aids to Marine Navigation Pacific (includes Western and Central Arctic)	Hydrographic Chart Distribution Office Fisheries and Oceans Canada 1675 Russell Road P.O. Box 8080 Ottawa, Ontario Canada K1G 3H6
c) American	
Radio Navigational Aids - Atlantic and Mediterranean, No. 117A	U.S. Naval Oceanographic Office, Washington, D.C., USA
LISTS OF LIGHTS	
a) British	
Admiralty List of Lights, Vol. H. Admiralty List of Lights, Vol. M.	British Admiralty and Authorized Chart Agents
b) Canadian	
List of Lights, Buoys and Fog Signals, Newfoundland (includes Labrador) List of Lights, Buoys and Fog Signals, Atlantic Coast (includes the Gulf and River St. Lawrence to Montreal)	Hydrographic Chart Distribution Office Fisheries and Oceans Canada 1675 Russell Road P.O. Box 8080 Ottawa, Ontario Canada K1G 3H6
c) American	
H.O. Publication No. 111A Greenland and East Greenland and East Coasts of North and South America	U.S. Naval Oceanographic Office, Washington, D.C., USA
SAILING DIRECTIONS	
a) British	
Admiralty Pilot No. 12, Arctic Pilot Vol. 3 Admiralty Pilot No. 50 A Newfoundland - Labrador Vol. 1 Admiralty Pilot No. 80 B Newfoundland - Labrador Vol. 2 Admiralty Pilot No. 65 St. Lawrence Pilot	British Admiralty and Authorized Chart Agents

Publication	Source
b) Canadian Arctic Canada Vol. I (Fourth Edition 1994)	Hydrographic Chart Distribution Office Fisheries and Oceans Canada 1675 Russell Road P.O. Box 8080 Ottawa, Ontario Canada K1G 3H6
Arctic Canada Vol. II (Fourth Edition 1985)	
Arctic Canada Vol. III (Fifth Edition 1994)	
Gulf and River St. Lawrence (Fifth Edition 1983)	
ATL 100 – General Information – Atlantic Coast, (First Edition, 1992) + Binder	
ATL 101 – Newfoundland - Northeast and East Coasts, (First Edition 1997)	
ATL 102 – Newfoundland – East and South Coasts, (First Edition 1995)	
ATL 103 – Newfoundland – Southwest Coast, (First Edition 1995)	
ATL 107 – Saint John River, (First edition 1994)	
ATL 110 – St. Lawrence River – Cap Whittle/Cap Gaspe to Les Escoumins, (First Edition 1992)	
ATL 111 – St. Lawrence river – Ile Verte to Quebec, (First Edition 1992)	
ATL 112 – St. Lawrence River – Cap-Rouge to Montreal (First Edition 1992)	
CEN 300 – General Information, Great Lakes, (First Edition 1996)	
CEN 301 – St. Lawrence River, Montreal to Kingston, (First Edition 1996)	
CEN 302 - Lake Ontario, (First Edition 1996)	
CEN 303 – Welland Canal and Lake Erie, (First Edition 1996)	

Publication	Source
CEN 304 – Detroit River, Lake St. Clair, St. Clair River, (First Edition 1996)	
CEN 306 – Georgian Bay, (First Edition 1998)	
Great Lakes - Volume 2, (Seventh Edition 1993)	
Great Slave Lake and Mackenzie River (Seventh Edition 1989)	
British Columbia – Volume 1, (Fifteenth Edition 1990)	
British Columbia - Volume 2, (Twelfth Edition 1991)	
c) American	
H.O. Publication No.13 Gulf of Lower St. Lawrence	U.S. Naval Oceanographic Office, Washington, D.C., USA
H.O. Publication No.14 Newfoundland	
H.O. Publication No.15 Labrador and Hudson Bay	
H.O. Publication No.16 West Coast of Greenland	
U.S. Coast Pilot No. 9 Pacific and Arctic Coasts	U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C., USA

B.2 ENVIRONMENT

Publication	Source
Canadian Tide and Current Tables Vol. 4 - Arctic and Hudson Bay	Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, ON, Canada, K1A 0S9
The Climate of the Canadian Arctic Islands and Adjacent Waters, by J.B. Maxwell, No. EN57-7/30-2, 1982	Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, ON, Canada, K1A 0S9

B.3 ICE

Publication	Source
Atlas of Pilot Charts N.E. Atlantic January, March, July, and September	U.S. Naval Oceanographic Office, Washington, D.C., USA
Annual Seasonal Outlook of Ice Conditions in Northern Canadian Waters (current year)	Environment Canada, Canadian Ice Service 373 Sussex Drive, E-3, Ottawa, Ontario, Canada, K1A 0H3
Canadian Arctic Marine Ice Atlas, Winter 1986-1987	Canarctic Shipping Co. Ltd., 150 Metcalfe Street, 19th Floor Ottawa, Ontario, Canada K1R 7S8
Great Lakes Ice Atlas by R. Assel, F. Quinn, G. Leshkevish and S. Bolsenga, 1983	U.S. National Oceanic and Atmospheric Administration, Washington, D.C., USA
Ice Atlas, Canadian Arctic Waterways, by W. Markham, No. EN56-54/1981, 1981	Government Publishing Centre, Supply and Services Canada, Ottawa, ON, Canada, K1A 0S9
Ice Atlas, Eastern Canadian Seaboard, by W. Markham, No. EN56-54/1981E, 1980	Government Publishing Centre, Supply and Services Canada, Ottawa, ON, Canada, K1A 0S9
Ice Atlas, Hudson Bay and Labrador Coast	Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, ON, Canada, K1A OS9
The Seaway Handbook	Information Officer, The St. Lawrence Seaway Authority, 202 Pitt Street, Cornwall, Ontario K6J 3P7
Ice Atlas of the Northern Hemisphere, H.O. No. 550	U.S. Naval Oceanographic Office, Washington, D.C., USA
Manual of Standard Procedures for Observing and Reporting Ice Conditions (MANICE), 1994	Environment Canada, Canadian Ice Service, Attn: Client Services, 373 Sussex Drive, E-3 Ottawa, Ontario K1A 0H3

Publication	Source
MANICELAKE	Environment Canada, Canadian Ice Service, Attn: Client Services, 373 Sussex Drive, E-3 Ottawa, Ontario K1A 0H3

B.4 NAVIGATION

Publication	Source
Ice Seamanship, by George Parnell, FNI, 1986	Nautical Institute, London, UK
Joint Industry - Coast Guard Guidelines for the Control of Oil Tankers and Bulk Chemical Carriers in the Ice Control Zones of Eastern Canada	
Manual of Safety and Health for Fishermen	Director, Rescue & Environmental Response, Canadian Coast Guard, Ottawa, ON, Canada, K1A 0N7
Mariner's Handbook, 1989	Hydrographer of the Navy, Ministry of Defence, London, UK

B.5 SHIP DESIGN

Publication	Source
Arctic Ship Technology (The State of the Art -1986) Volumes I and II	Melville Shipping Limited Suite 1007, 350 Sparks Street Ottawa, ON, Canada, K1R 7S8
Arctic Shipping Pollution Prevention Regulations, 1972 with amendments	Prairie and Northern Region, Marine (AMNS) Transport Canada Place de Ville, Tower C 330 Sparks Stree, 14th Floor Ottawa, Ontario K1A 0N5

ANNEX C ARCTIC SHIPPING POLLUTION PREVENTION REGULATIONS

C.1 EXISTING REGULATIONS

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 Pollution Prevention Regulations
- Shipping Safety Control Zones Order
- Arctic Waters Pollution Prevention Regulations
- Navigating Appliances and Equipment Regulations
- Ship's Deck Watch Regulations
- Ship Station Radio Regulations
- Charts and Publications Regulations
- Aids to Navigation Protection Regulations
- Public Harbours Regulations
- Quarantine Regulations
- International Convention for the Protection of Submarine Cables.

Mariners are cautioned that this list of regulations is in no way exhaustive, and that the identified regulations are subject to ongoing additions and amendments. Mariners are advised to familiarize themselves with all current regulations governing areas of interest. Copies of Canadian Government regulations are available by mail from:

Address: Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, ON
K1A 0S9