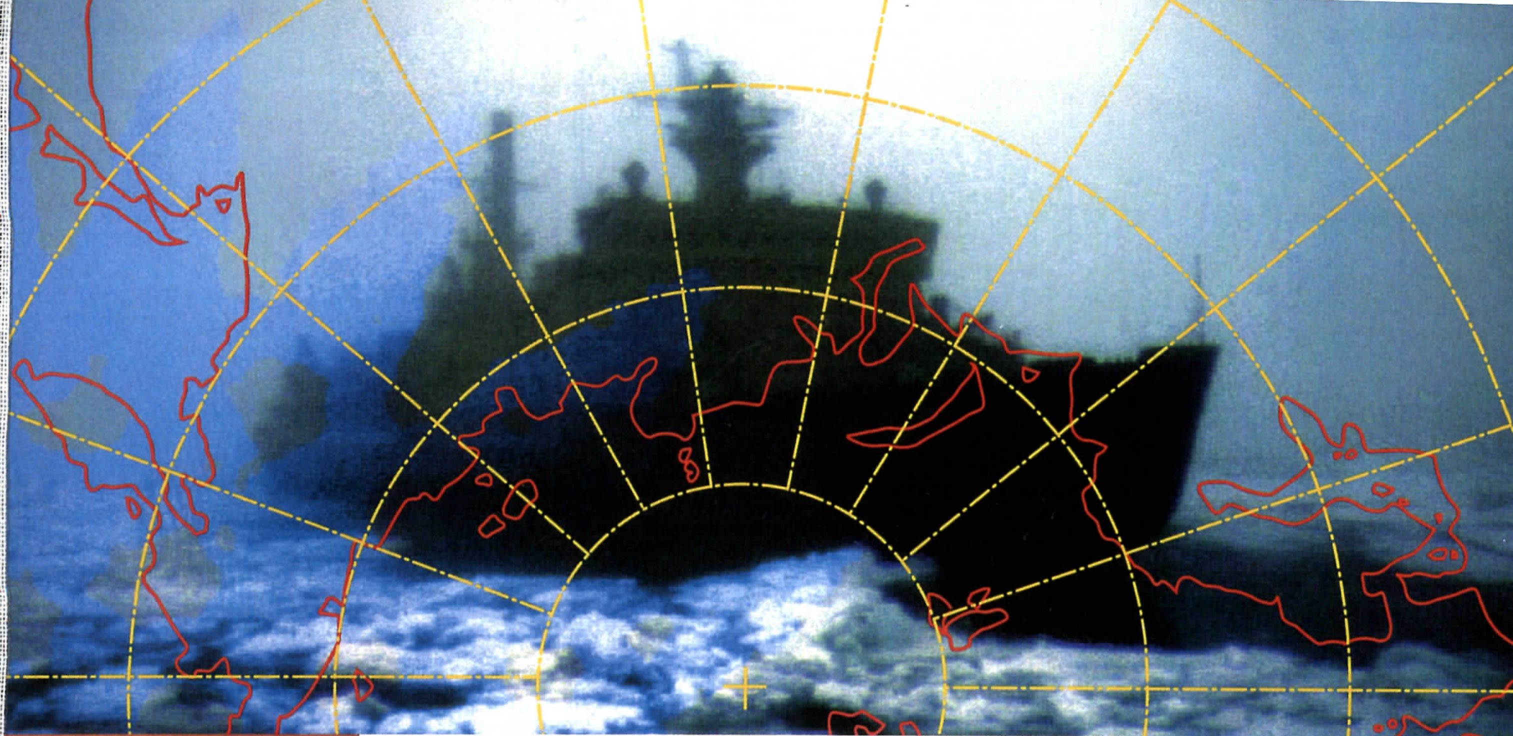

INSROP WORKING PAPER NO. 14 - 1995, I.1.1

Routing, Communication and IT-Customizing
Volume 2

Norvald Kjerstad

INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia

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INSROP - WORKING PAPER NO. 14-1995

Sub-programme I: Natural Conditions and Ice Navigation

Project: 1.1. Routing, Communication and IT-customizing. Volume 2.

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Date: 31 July 1995

Reviewed by: Captain Lawson W. Brigham, US Coast Guard, USA

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FOREWORD - INSROP WORKING PAPER

INSROP is a five-year multidisciplinary and multilateral research programme, the main phase of which commenced in June 1993. The three principal cooperating partners are **Central Marine Research & Design Institute (CNIIMF)**, St. Petersburg, Russia; **Ship and Ocean Foundation (SOF)**, Tokyo, Japan; and **Fridtjof Nansen Institute (FNI)**, Lysaker, Norway. The INSROP Secretariat is shared between CNIIMF and FNI and is located at FNI.

INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

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Preface

The purpose of this report is to provide Sub-program I "Natural Conditions and Ice Navigation" with a nautical approach and operational aspects regarding navigation,routing and communication on the Northern Sea Route. This is the second of two volumes. Much of the information is gathered through practical navigation on the NSR. The last expedition was on the newest nuclear icebreaker, Yamal, where I took part as a crew member on one of the North Pole expeditions during the summer of 1994.

Vol.1 and Vol.2 will together fulfill the need of a comprehensive description of the NSR and the accessible technology and techniques for navigating, routing and navigation-training in Arctic waters. The report will be drawn up within the framework of future operational courses in Arctic navigation, which will probably become compulsory when the ongoing reform of the ice classification of ships has entered into force.

One of the tasks of this project has been to inform actual operators of vessels in Arctic waters about the opening for international shipping along the NSR. This has been done through articles published in various shipping magazines in Scandinavia and almost daily questions on telephone and fax.

I would like to thank Nikolay Matjushenko, President of Murmansk Shipping Company (MSC) who has made it possible for me to sail on MSC vessels several tours on the NSR. The Canadian Coast Guard (CCG), and the Swedish icebreaker authorities have also provided a lot of important information and cooperation.

Ålesund 28.06.95

Norvald Kjerstad
Project Manager

Contents of volume 2

Content of Volume 1
(Released June 1994)

Abbreviations

ALRS	Admiralty List of Radio Stations
AVHRR	Advanced Very High Resolution Radiometer
CCG	Canadian Coast Guard
DMSP	Defence Meteorological Satellite Program
DNMI	The Norwegian Meteorological Institute
DNV	Det Norske Veritas
ECD	Electronic Chart Display
ECDIS	Electronic Chart Display and Information System
ERS-1	European Remote Sensing satellite # 1
FESCO	Far East Shipping Company
GLONASS	Global Navigation Satellite System (Russian)
GMDSS	Global Maritime Distress and Safety System
GPS	NAVSTAR Global Positioning System (US)
HF	High Frequency
IALA	International Association of Lighthouse Authorities
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
INS	Inertial Navigation System
INSROP	International Northern Sea Route Project
JRS-1	Japanese Remote Sensing satellite # 1
LORAN-C	Long Range Navigation (Equ. to Russian Chayka)
MARPOL	Maritime Pollution Prevention Convention
MF	Medium Frequency
MSC	Murmansk Shipping Company
NOAA	National Oceanographic and Atmospheric Administration
n.m.	Nautical Mile (1852 meters)
NNF	Nordic Institute of Navigation
NP	Nautical Publications (British Admiralty)
NSR	Northern Sea Route (Northeast Passage)
SAR	Search And Rescue / Synthetic Aperture Radar
SLAR	Side Locking Airborne Radar
SOLAS	Safety Of Life At Sea (IMO-conv.)
SSM/I	Special Sensor Microwave / Imager
UHF	Ultra High Frequency
VHF	Very High Frequency

1 Planning and Operational aspects

1.1 Passage planning for the NSR

Passage planning is of importance to all kind of offshore activity to increase safety and effectivity of the operation. Different types of publication and computer based systems have been developed as tools for this purpose, but few (or no) systems provide the Arctic dimension in this important process.

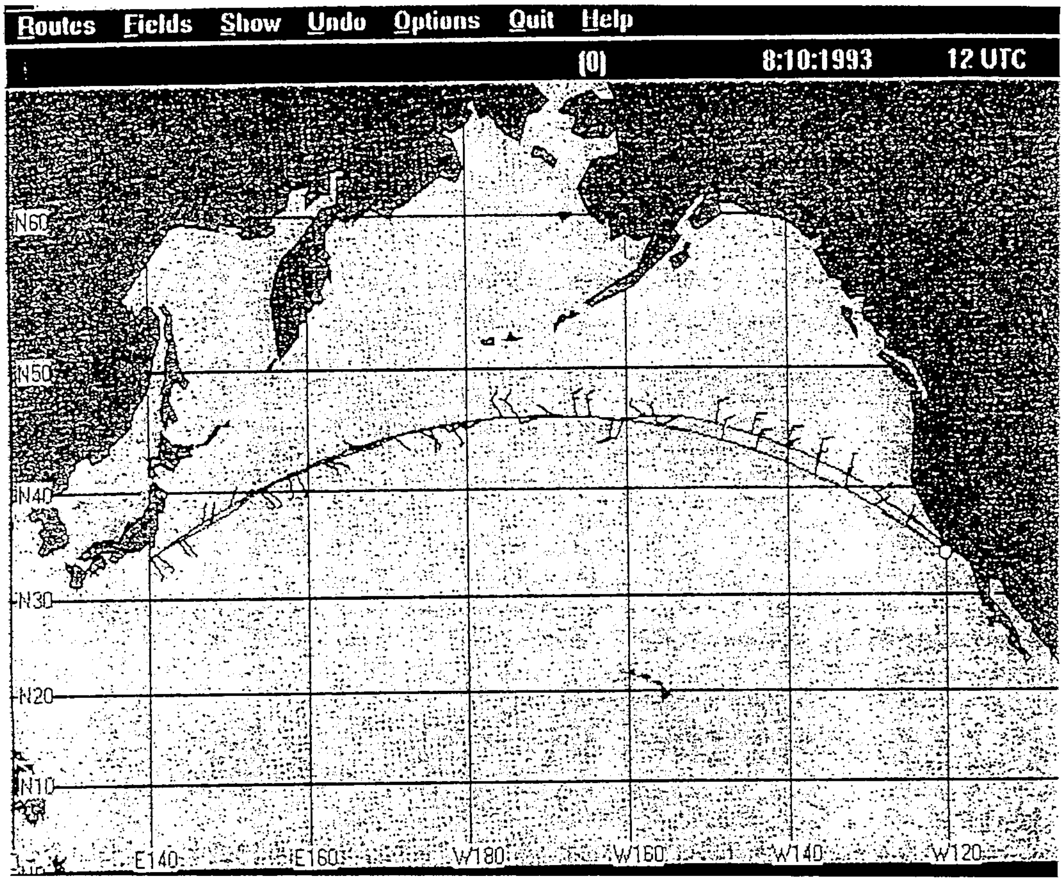


Figure 1.1 *Picture from the SeaStar system. This is a navigation and weather routing tool where the meteorological database is updated through satellite communication system (Source:DNMI).*

Passage planning can be divided into two main phases and two subdivisions in each phase:

Strategic, long term onshore planning.

- Appraisal.
- Planning.

Tactical, on board routing.

- Execution.
- Monitoring.

This process, and the need for different kinds of information is visualized in figure 1.2.

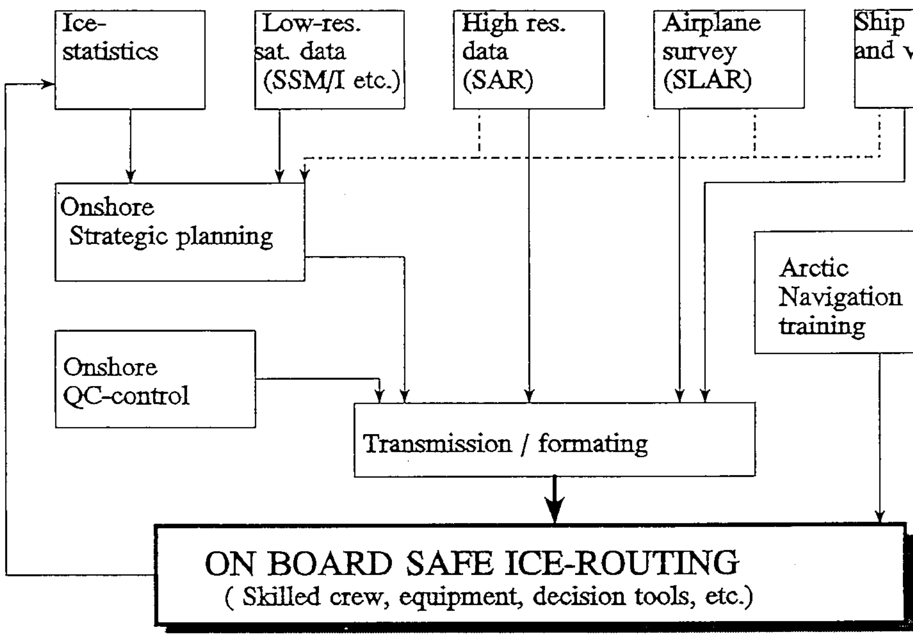
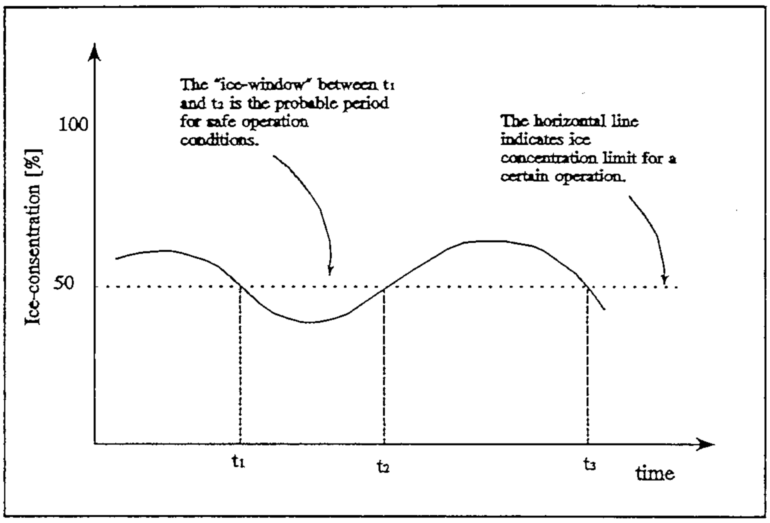


Figure 1.2 *Important elements in the routing process. Note that the need of high reselution and detailed information increases as the execution gets closer.*

1.1.1 Strategic long term planning

Based on statistical ice data the period of passage and the route can be roughly planned several months in advance. Ice statistics can be obtained from standard nautical publications (ref. Volume 1 of this report) or directly from different scientific institutes within or outside Russia. From statistical analyses a "minimum ice concentration window" (ref. figure 1.3) can be calculated. Such window can indicate the probability of encountering marginal ice situation in a given area at a given time of the year. The variables in the calculation will be the ice concentration in % or 10th's and the probability. Similar techniques are widely used for waveheight analyses when planning offshore operations. Such calculations can be important for shipowners and brokers in negotiations with insurance companies regarding the ice damage risk, and it is important when deciding the needed icestrengthening (ice-class)in the actual operation. The degree of ice strengthening will also have an economic impact.

Figure 1.3
Statistical calculations on ice concentration can be helpful for planning the most favorable time for arctic operations.



During the strategic planning phase permission must be sought to sail on the NSR

Between the first strategic planning and the tactical phase it will be possible to consider use of long term ice-forecasting which is provided by the Russian Hydrometeorological Institutions.

Ice information for the Western part of the NSR are provided by the center in Dikson, and in the East by the center in Pevek.

1.1.2 Tactical planning and Pilotage

The tactical phase will be taken care of by the shipmaster within the framework from the strategic phase and the appraisal. Integrated in the planning the margin of safety and safe speed have to be considered. Other main requirements the master plan must provide are:

- Access to necessary information on present ice situation (ref. Volume 1) and government regulations like pilotage and restrictions.

- Comprehensive briefing of personnel.

- Adapt the operational status of the ship to the actual situation.

- Close monitoring of position and hydrometeorological elements

- Cross checking.

- Contingency planning.

Pilotage is compulsory and information can be obtained from the NSR-Administration. River pilots will normally embark in the river estuaries. The regional ice centers in Dikson and Pevek will recommend a route and give information on icebreaker locations and services.

When executing the plan it will be important to have access to different ice data, from precise and high resolution ice SAR-images to wide area and statistical information.

1.2 Ice surveillance

1.2.1 Low resolution satellite data.

The categories of ice surveillance (ref. figure 1.2) are normally based on the degree of resolution. Low resolution data collected from scanning radiometers (AVHRR) and optical satellite sensors gives us access to ice data with resolution between 5 - 50 km. The reflectivity from the ice will be dependent on salinity and ice concentration, consequently we will be able to extract information on ice age and concentration. Such data is provided by the NOAA-satellites and it gives us reasonable data to determine the location of the ice edge and the marginal ice-zone, which is very relevant for offshore operations in the Eastern Barents Sea and in the Kara Sea. These satellites also give us information on the sea surface temperature which is a very important parameter to estimate the danger of being trapped in new ice. Such situations can often be quite crucial for ships with low ice-class. Wide area ice concentration like the one in figure 1.4 can be based on data from the US NOAA-satellites, METEOSAT or the Russian OSEAN and KOSMOS satellites. The coding of the wide area ice-concentration can be done by different colours, iso-lines or symbols.

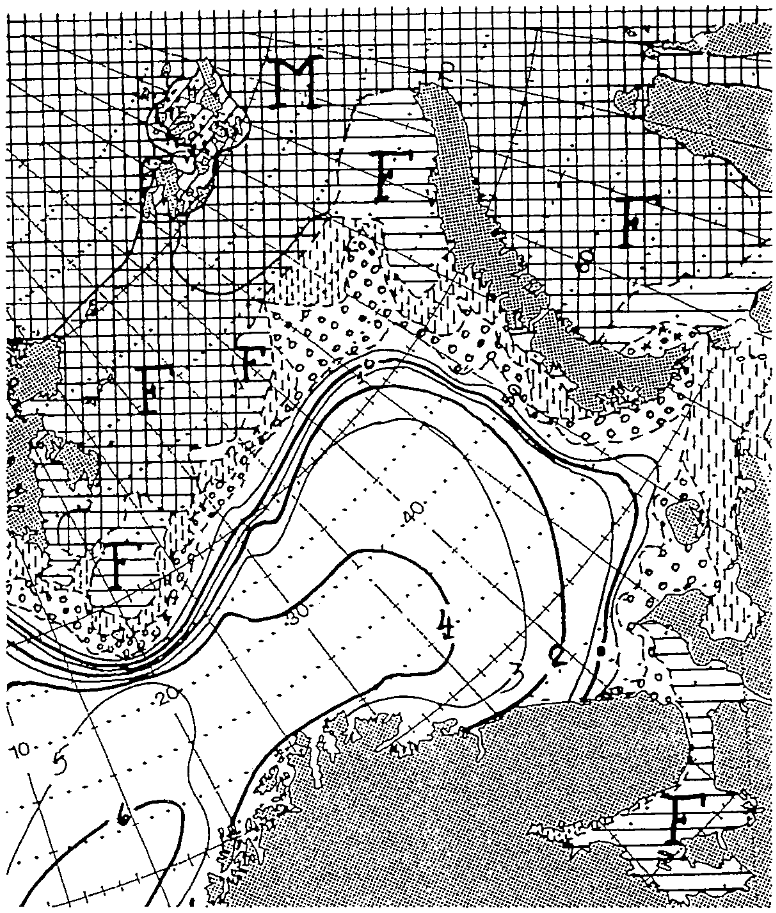


Figure 1.4
Sea-ice concentration and marginal ice-zone in the western part of NSR and Norwegian Arctic (March 1995). Isoterms indicate sea surface temperature (DNMI).

The limiting factor in remote sensing from NOAA satellites is the dependency of a clear sky. Data / images from these satellites can either be analyzed by a shore station or by special receivers on board (figure 1.5).

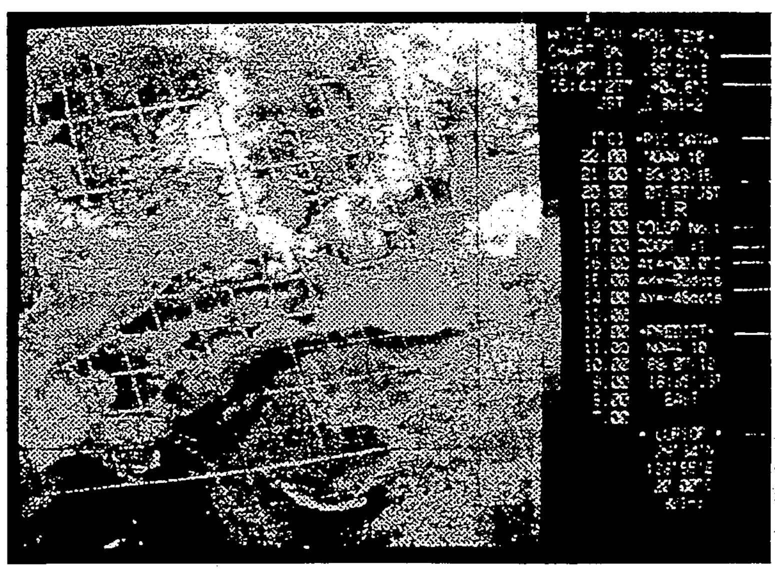


Figure 1.5
Satellite data presented on board on a Furuno receiver.

Another important tool for wide area ice surveillance is the DMSP-satellites which are equipped with Microwave sensors (SSM/I). These sensors have the advantage of penetrating clouds and are consequently almost weather independent. Unfortunately the resolution is rather coarse, approx. 25 km.

Institutes in Norway can normally cover the Barents and the Kara Seas with AVHRR and SSM/I data. Due to the complexity of the receiver and analyzing tool few ships will be able to analyze SSM/I data on board. Some icebreakers like the US "Polar Sea" will be able to provide such services (Brigham,94) At present there are no Russian icebreakers with such services operational. The remote sensing center in Fairbanks, Alaska will be able to provide data between the Laptev Sea and the Bering Strait, including US and Canadian Arctic.

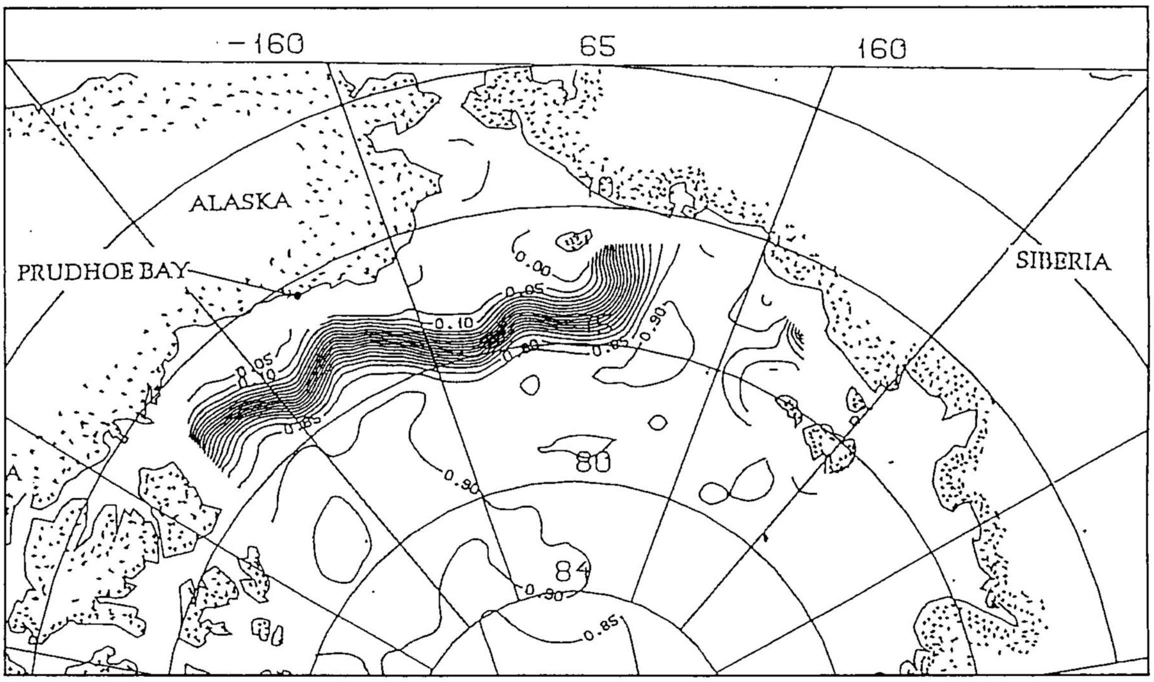


Figure 1.6 *SSM/I satellite image from the Eastern part of the NSR (September 1979). The iso-lines indicate total ice concentration (Johannessen and Olaussen, 86)*

1.2.2 High Resolution data.

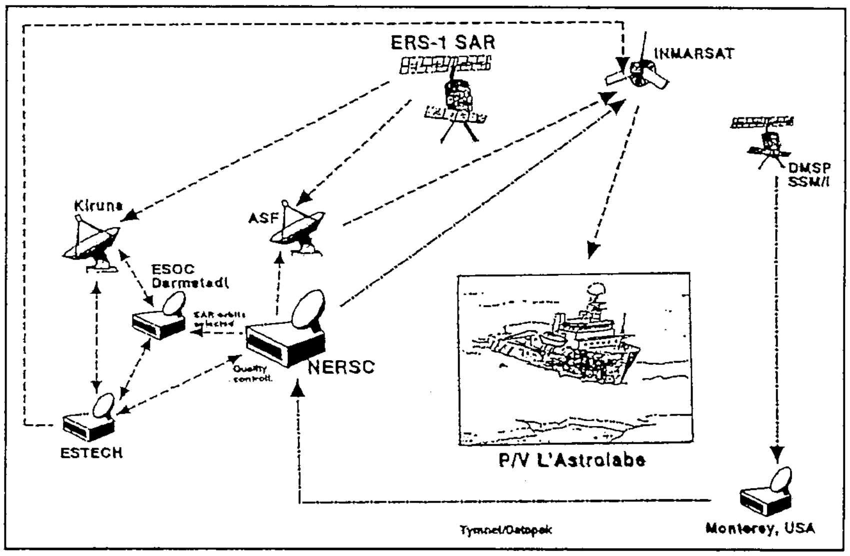
After planning the route through the most favorable ice conditions based on low resolution data it will be necessary to have additional information to take advantage of the optimum ice condition within a local area. Such conditions are:

- Open water leads.
- First year ice and polynyas in areas of old ice.
- Avoiding areas of ridging and pressure.

These elements require an ideal resolution of at least the beam of an ice-going vessel (approx. 15 - 35 meters). Remote sensed data with such qualities and high resolution can only be obtained by satellites equipped with SAR-sensors or aircraft equipped by SLAR. The fundamentals of such remote sensing are described in chapter 1.2.6.

Satellite based SAR has been commercially and scientifically accessible since the ERS-1 was launched in July 1991. The ice surveillance capability has proven to be excellent with a resolution of 25 meters, independent of clouds and darkness. Other details like ice roughness, ice age and ice thickness can be extracted from SAR data. The ERS-1 was tested along the NSR in August/September 1991 on board the L'Astrolabe (Johannessen, Sandven 92). The signal transmission concept of the L'Astrolabe expedition is shown in figure 1.7. This concept has also been proven on board the Russian nuclear icebreaker Sovetsky Soyuz with very promising results.

Figure 1.7
The communication lines for SAR ice routing on the NSR (Johannessen & Sandven 92)

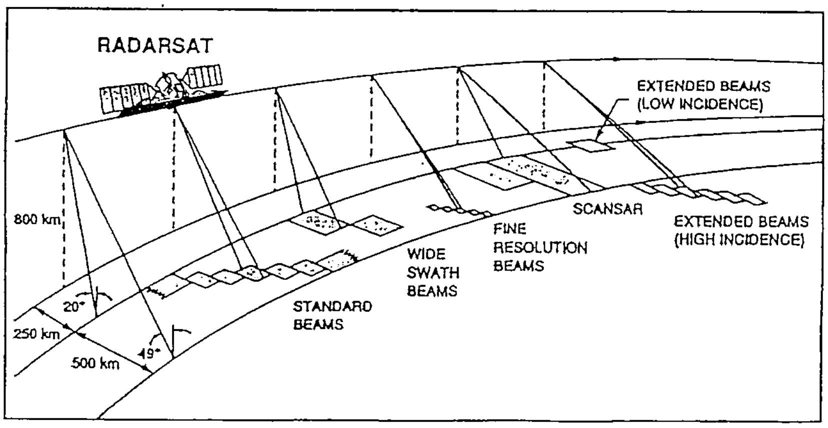


By 1995 three more SAR satellites, the Japanese JRS-1, the European ERS-2 and the Canadian RADARSAT, will be launched for scientific and commercial service. The RADARSAT will gather data essential for more efficient recourse management , ice, ocean and environmental monitoring and Arctic and offshore surveillance. Technical characteristics for the RADARSAT can be seen in table 1.1.

Table 1.1 *Technical characteristics of the Canadian SAR satellite, RADARSAT. Launch is scheduled in 1995.*

Frequency	5.3GHz	Wavelength/Band	5.6cm/C
RF Bandwidth	11-30MHz	Peak Power	5 kW
Average Power	300W	Max data rate	85Mb/s
Antenna size (m)	15 X 1.5	Polarization	HH
Launch Mass	2750 kg	Array Power	2.5 kW
Batteries	3x48 Ah	Design Lifetime	5 years
Altitude (km.)	793-821	Inclination	98.6°
Period	101 min.	Ascending node	18 hrs.
Sun-synchronous	14 orb/d	Coverage 70°North	Daily
Coverage 48°N	4.day		

Figure 1.8 *Illustration of different sensors used on the RADARSAT.*



Additional information on the RADARSAT can be obtained from:

Canadian Space Agency
RARARSAT Program
6767, route de l'Aèroport
Saint-Hubert, Quebec J3Y 8Y9
Tlf. 514-926-4406, fax. 514-926-4433

The disadvantage of satellite based SAR-images is their complexity which requires advanced receiving equipment and high interpretation skills. SAR images must therefore be interpreted by experts and transferred on faximile to the ship. The level of "external" expertise can be reduced by means of tutorial programs for the ice-navigators. Such a program is the "IceXpert", an interactive approach to instruction in interpreting sea ice information from synthetic aperture radar (SAR) imagery. One of the display modes from IceXpert is shown in figure 1.9

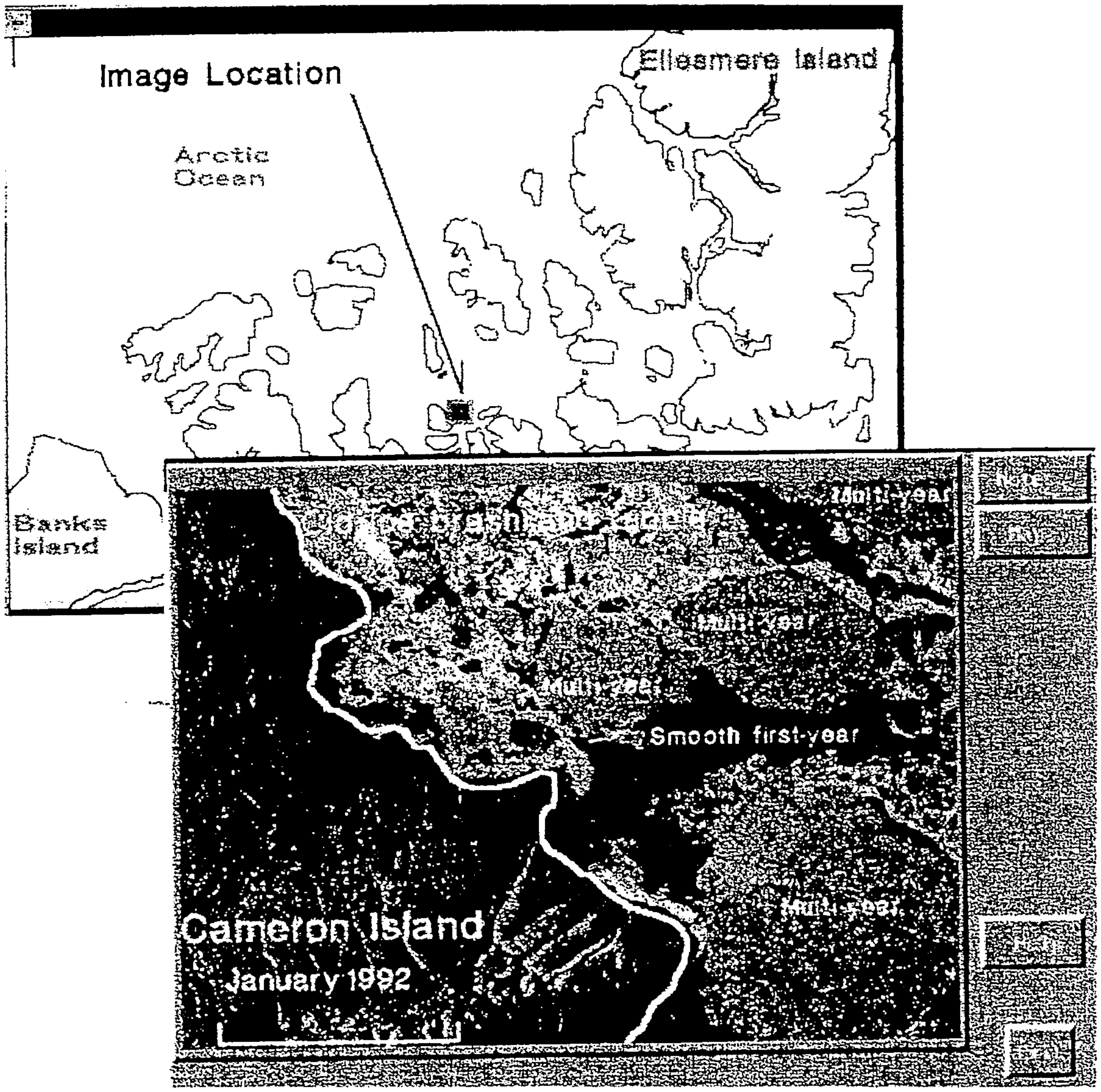


Figure 1.9 *A SAR image from the tutorial SAR-interpretation program IceXpert. Ship operators can learn basic theory and practice ice-image interpretation by means of a PC-program.*

The IceXpert program is developed by Nordland Science Ltd. and additional information can be obtained from them.

Norland Science & Engineering Ltd.
904-280 Albert Street, Ottawa
Ontario K1P 5G8, Canada.

From the description above it can be seen that sophisticated ice surveillance systems have been developed. As a matter of fact the bottleneck is to customize and transfer the capabilities to the users on the ship for near to realtime routing service. The accessible communication links are also limited in the arctic area and interphase to on board expert systems will be difficult in large parts of the NSR. Radiofaximile transmission from a few coast stations can be made (ref. volume 1) but the most flexible transmission will in the near future be to use the INMARSAT satellite communication system for transmission of ordinary telefax to the ship (Sandven & Kloster, 94). An important step to increase the availability of ice information is to transfer digital ice information directly to interfaced information systems on board. One approach to this new technology is made by a Norwegian system called HAVINFO, which is specially designed for the Norwegian fishing fleet and the Coast Guard. The ice situation is transferred from DNMI to the ship via the INMARSAT standard-C system. The information will automatically be superimposed to a simple graphic chart (fig.1.10). Information of the HAVINFO type will be an excellent tool for low resolution ice information but will be limited by the coverage of the INMARSAT system (ref. volume 1).

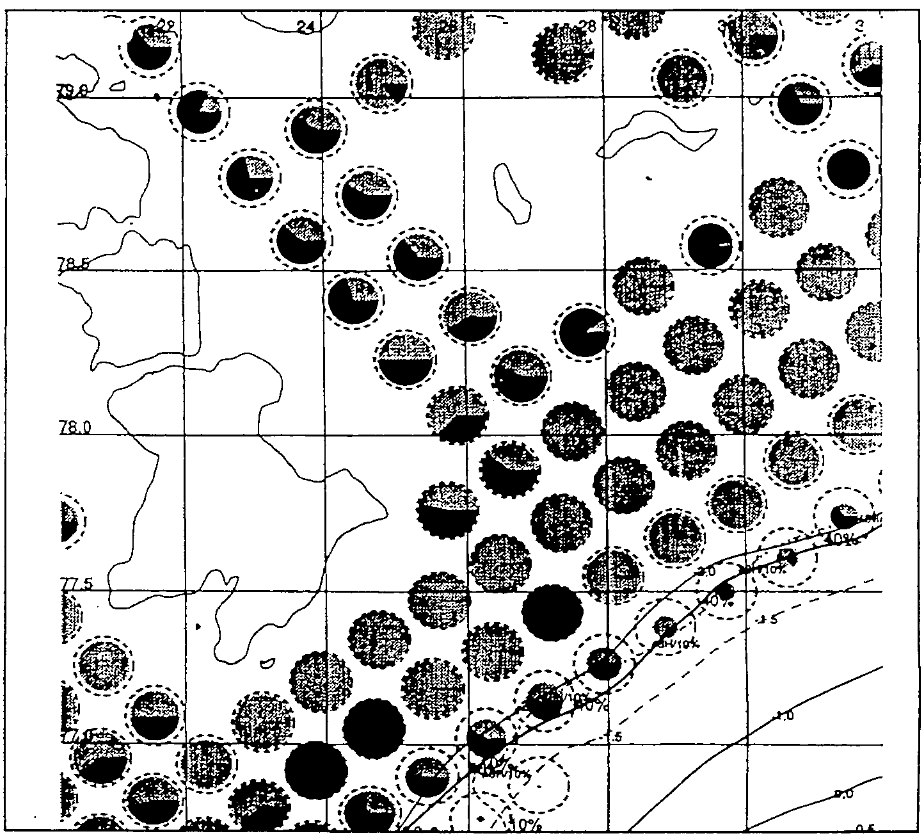


Figure 1.10 Graphic image of ice-concentration on the HAVINFO system.

More information on the HAVINFO system can be obtained from:

NIT-Nord, N-9005 Tromsø, Norway

The development of electronic charts (ECDIS / ECD) and digital updates of these opens in fact very interesting perspectives for ice routing. The ice information e.g. a SAR-image could be considered as a separate information layer in the ECDIS system and be superimposed to the chart. The critical factors will still be the communication link and the limitation of the INMARSAT system, but a future communication system will hopefully be able to provide full NSR-coverage. If such system should be usable for ice-pilotage through open leads the accuracy has to be at least equal to the SAR data resolution (e.g. 9 meters in case of the RADARSAT fine-mode). Such accuracy will be very difficult to obtain due to limitations in the chart coordinate systems (Datum) and the navigation system. A realistic accuracy will be approx. 100 meters. If differential corrections to the satellite navigation system (GPS / GLONASS) are accessible and the parameters related to the Russian coordinate system (Pulkova-42, ref. Volume 1) are released, an accuracy of approx 10 meters should be realistic.

1.2.3 Airborne Ice Surveillance

By means of Side Locking Airborne Radar (SLAR) the resolution on the ice information can be improved compared to the satellite based SAR. Airborne systems will also be more flexible regarding the area of operation. A survey can be performed on a certain route on request from a ship or from the ice surveillance headquarters. The collected ice data can relatively easily be transferred to the ship via a UHF link The imagery receiving station will normally be based on the "Polar Star" terminal - whitch is PC compatible (Fomin, 92). SLAR information is also important for the ice information centers ashore when they prepare ice-charts for faximile transmission. Since the mid 80's Russia has performed SLAR ice reconnaissance services along the NSR as a routing aid for ships. This service has been performed by an IL-24H aircraft equipped with an X-band (15GHz) radar. At the optimal operating altitude of 7200 meters the aircraft can cover a swath of 2 x 42 km., with a "dead zone" of 11.5 km. below the aircraft. The recorded data has been transmitted to icebreakers in the area and to hydrometeorological centers in Amderma, Dikson, Tiksi, Pevek and Cape Shmidt. SLAR data has still not been directly transferred to the merchant ships on the NSR but more sophisticated information technology will in the near future make it easier to take advantage of this detailed ice information. Experienced operators can easily extract important details such as:

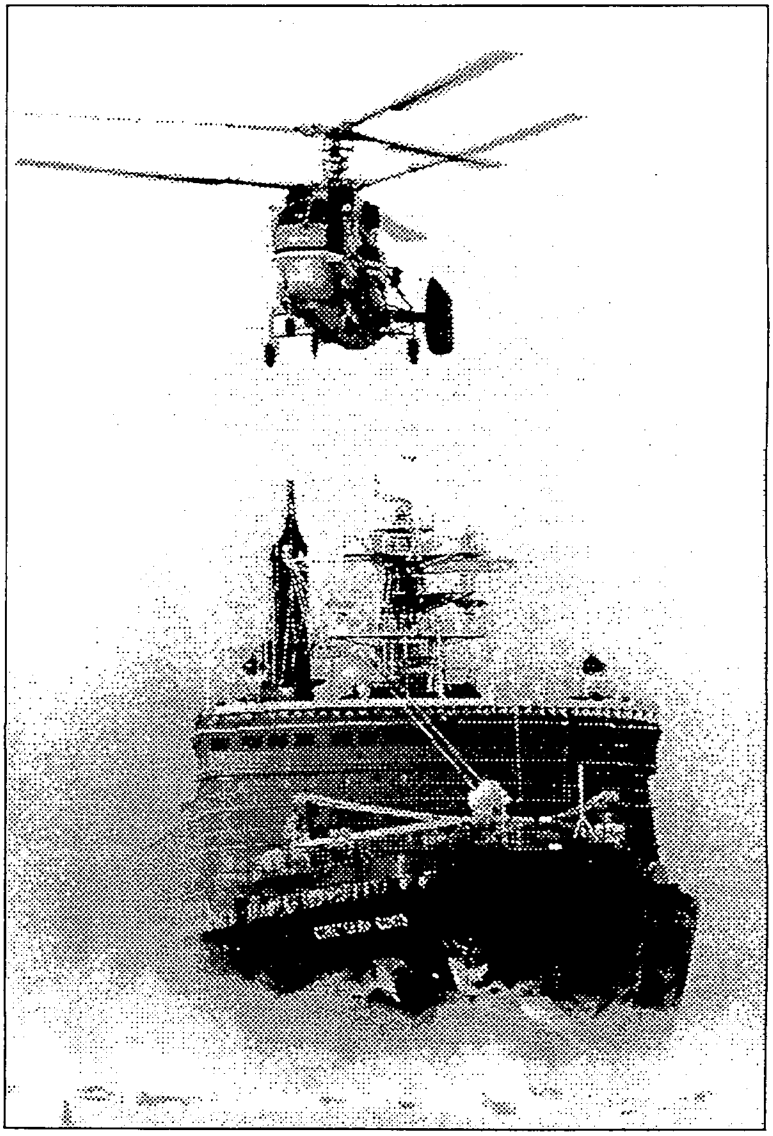
- Ice age and development stage.
- Ice concentration.
- Fast ice boundaries.
- Hummocks.
- Leads, polynyas and fractures.
- Ships and convoys in ice and open water.

Systems for determining ice thickness by airborne survey has also been developed. These techniques have proved to be very helpful for long term forecasting (strategic phase) and for selecting sites for take-off and landing on the ice.

1.2.4 Helicopter surveillance

Even with high resolution ice information from satellites and aircraft it will often be necessary to add complementary visual information from helicopters operating from the polar icebreakers. The helicopter pilot can then survey the area together with an experienced ice navigator in front of the ship and guide the icebreaker and its convoy to the easiest route. These options are often considered as the most important seen from the navigator's point of view.

Figure 1.11
The KA-32 helicopters located on board the Arctic icebreakers are important in tactical ice routing (Source: MSC)



1.2.5 Ice surveillance services along the NSR.

The NSR ice surveillance concept is based on ice analyses made in the meteorological centers in Diksen and Pevek. The analysis is based on information gathered from satellites, airplane, ships and scientific stations. The experts in the centers will work out a simplified ice map and transmit it on a radiofaximile (fig.1.12).

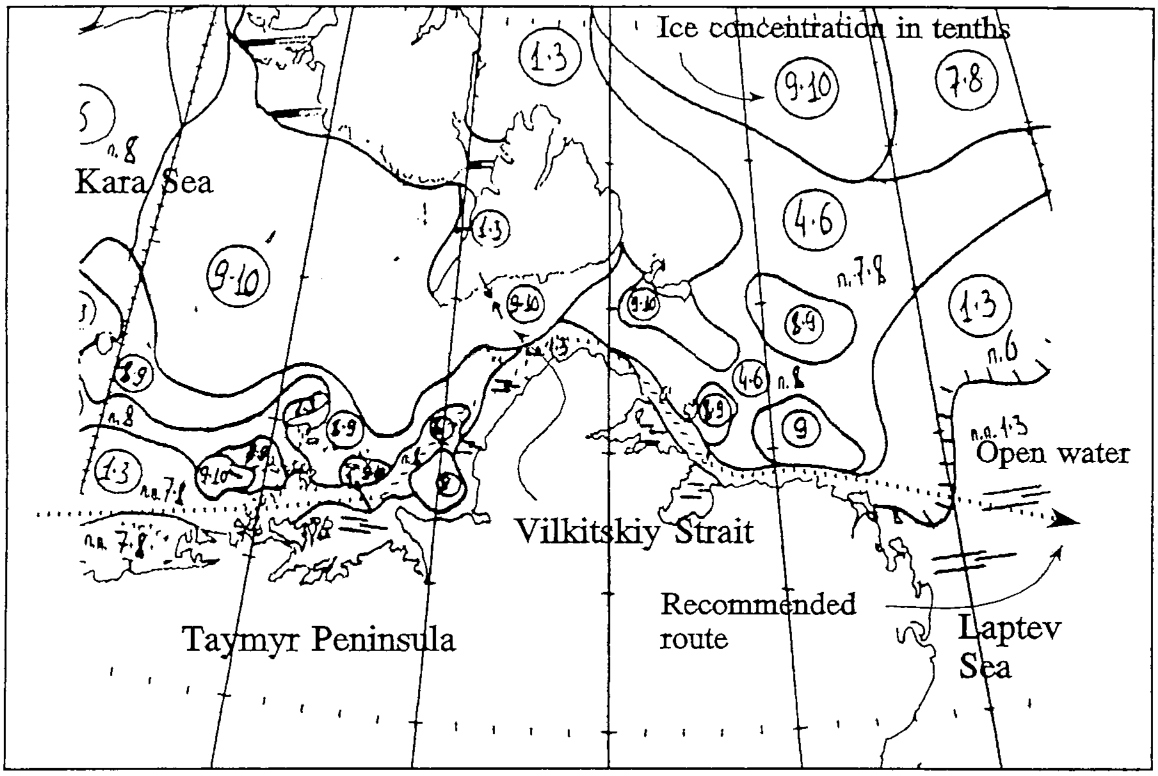


Figure 1.12 Ice concentration map transmitted from the ice center in Dikson (Kjerstad,92b).

1.2.6 SAR-satellite fundamentals.

The viewing geometry of a spaceborne SAR in comparison to an airborne SAR with a similar swath width varies only over a few degrees and thus proves a more uniform illumination geometry over the whole swath. Depending on orbit parameters a spaceborne SAR can collect data more quickly over larger areas than its airborne equivalent. The coverage frequency is set by orbit parameters like e.g. inclination and height. Overlap frequency is typically more than 3 days.

How different features can be separated within an image depends on:

- Incident angle (reflection angle)
- Surface roughness (scattering patterns)
- Conductivity and microstructure.
- Emitted wavelength (frequency)
- Polarization (horizontal or vertical)

With respect to ice this will give characteristic "signature" in polarization, absorption and backscattering. The ice signature will consequently depend on:

- Age (salinity)
- Snow cover
- Roughness and ridging
- Degree of coverage
- Extension

With a typical resolution from 10 - 100 meters the SAR will provide very important information for ships and offshore operation in ice covered waters. By comparing 2 images from the same area, taken at different times we will be able to calculate the icedrift and other significant variations (fig.1.13).

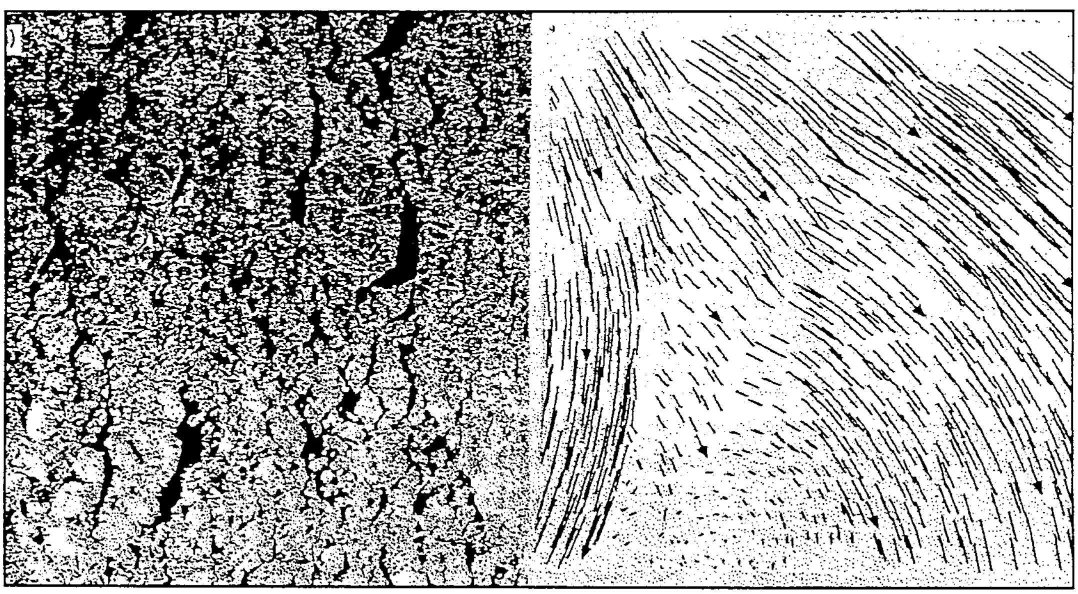


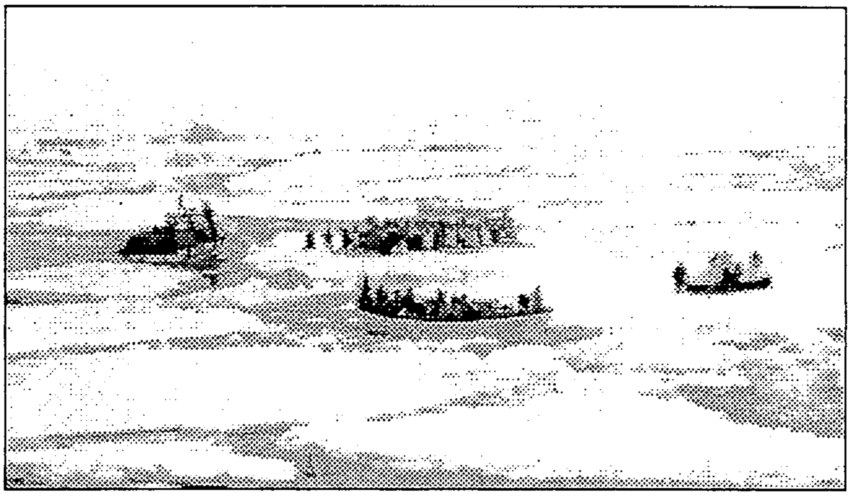
Figure 1.13 *Based on comparison of different SAR images the drift of the ice can be calculated and drift-vectors presented.*

Interpreting SAR images is substantially different from visual observation and its unique geometry and properties must be considered. Elements of interpretation are brightness (tone), texture, patterns, shape, size and association with other elements (fig.1.9). Tutorial computer programs like the IceXpet are very helpful aids for interpretation techniques.

1.2.7 Radar navigation in ice

Even if level ice normally reflects radar signals very poorly, radar will be an excellent aid for detecting drift ice in relatively open water and for ridge and lead detection in close ice and for position fixing in coastal waters. When using radar in ice-infested waters precautions and care must be taken. In open water, growlers, bergy bits and minor ice belts can easily be discriminated by the sea clutter and the ship can be dangerously damaged due to high speed ice interaction (fig.1.14)

Figure 1.14 *Lifeboats in the ice west of Svalbard. From the rescue operation of the ice-damaged passenger vessel Maksim Gorkiy in 1989 (Source: Norw. Coast Guard)*



A straight line between two points is very rarely the fastest in the arctic ice. By active use of radar controls, where gain and clutter are used in the right combination, ridges and characteristic ice features can be detected and avoided. Icebreaker channels and open leads are also possible to detect at ranges up to approximately 3 nm. Large polynyas where the ice is new and navigation is easy can easily be detected. Suitable radar range for navigation can be 3 - 6 nm.

Due to the high reflectivity on X-band radars (3-cm) these are preferable compared with the lower frequency S-band (10-cm) radars. Good resolution, in particular with respect to beam angle, is important to separate significant features. It is therefore important to use large antennas with a low beam angle. Range resolution is given by half the pulse length and the radar should therefore be operated in short pulse mode when in the ice. When in open water a long pulse could be preferred due to higher detection probability on small ice floes, growlers etc. Modern colour radars, where the colour threshold can be adjusted can contribute with helpful additional information. Features with good reflectivity like ridges, ships, etc. can be visualized in separate colors compared to the ice if the threshold, gain and clutter are adjusted properly. When using colour radars, special care must be taken when returning into open water. Accidents have happened due to inadequate threshold limit when position fixing has been performed by means of ranges to low and sloping coast line. It is also reported that some modern radars with very sophisticated picture presentation have poor ice capability in ice. These radars will not be able to separate a ship echo from the ice and the consequences can be very nasty in the arctic waters where the visibility is quite frequently limited due to fog. The only radar of this category found to have acceptable performance is Sperry and Selsmar (Swedish Maritime Adm.,94).

The use of different polarization on marine radars (ref. chapt. 1.2.5) has not been much evaluated by ships sailing in the arctic. In spite of this the Canadian bulk carrier the M/V "Arctic" has installed a radar where both vertical and horizontal polarization can be provided, so-called cross polarization. The results are very promising and it is possible to detect multi year ice in the first year ice. This is possible due to a significant difference in the polarization and the reflectivity from saline first year ice and the multi year ice with low salinity.

Position fixing by means of radar bearings and ranges can in some cases encounter peculiar difficulties in the Arctic:

- Difficult to determine where the ice ends and the land or open water begins. Proper gain setting is important.
- Disagreement between ranges, caused by inaccurate charts.
- Uncertainty as to the height and, therefore, the detection range of land masses because of a lack of topographical information on the chart.
- Gyro speed and latitude error must be considered when taking gyrostabilized radar bearings.

The use of Automatic Radar Plotting Aid (ARPA) is not recommended in the ice but can be very helpful in open water for detection and alerting on potential ice or icebergs. <u>ARPA must never be used without visual watchkeeping.</u>

1.2.8 Modern routing technology

Due to recent advancements in computer based navigation systems and PC technology we can consider the present as the treshold of a new era in routing and navigation. Integration of different information systems will be a very important tool to provide safer and more efficient navigation in the Arctic. The most important element of such systems is visualized in fig.1.15.

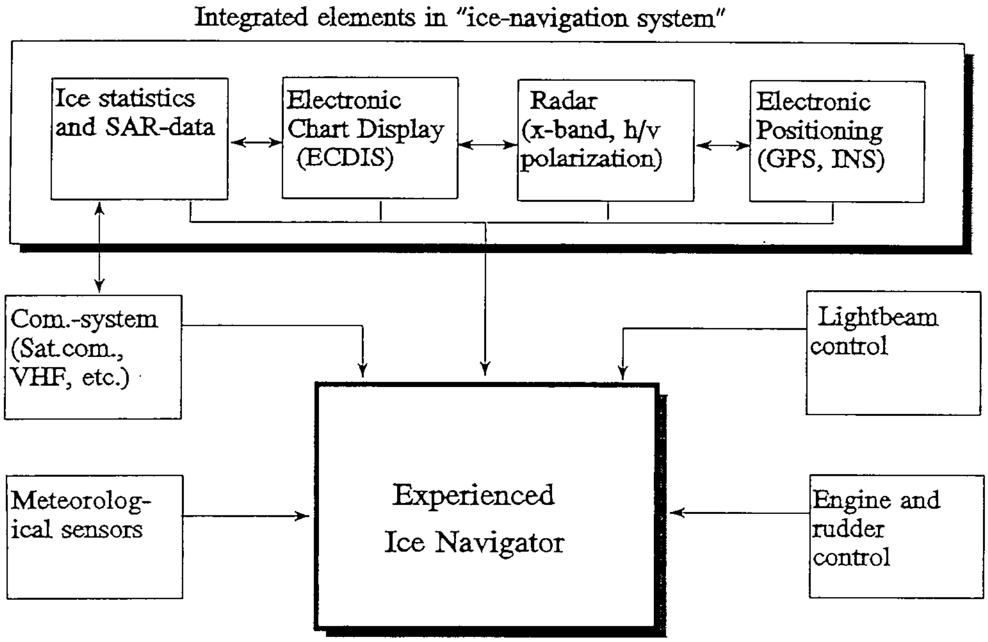


Figure 1.15 *Important elements in the routing process and planning of Arctic navigation.*

The basic element in the routing system can in general be considered as a Geographic Information System (GIS) with a seachart based geographical reference. If the system is satisfying certain demands from international organizations it can be considered as an ECDIS. If the system is provided with meteorological and oceanographical information these can be superimposed to the chart and we are able to navigate in the chart relative to important environmental obstacles like ice and hurricanes etc. As position reference, a navigation system like GPS or GLONASS must be interfaced. An important element in this process is to have the meteorological information transferred in close to real time and at a reasonable update rate from a shore based information center or directly from satellites or aircraft. If we were to consider navigating by means of ECDIS and GPS with an SAR ice-image overlay, we would experience that the ice image would not match the position given by the GPS. The mismatch would be caused by the continuous drift of the ice if the image update wasn't sufficient. In such cases the ice image has to be tied to the chart in some way. There are three approaches to solving this problem:

- Higher update rate.
- Prediction of driftvectors by means of comparison of two following images.
- Radar comparison followed by manual tie-in of the ice image.

Methods of prediction and modelling of icedrift and icegrowth have been improved and it is possible that the degree of reliability and accuracy will reach a point where they can be used directly to support strategic and tactical planning. The third approach, using the radar, is at the present time a possible way to update and compare old images.

Many companies have developed electronic chart and navigation systems with additional information options but only one system can be considered operational for ice navigation at the present time. This is the Canadian system, ICENAV, developed for CANARCTIC Shipping Company in Ottawa.

The IceNav is a PC-based system developed to provide safe operation of the bulk carrier M/V Arctic in the Canadian Arctic. The IceNav is a sophisticated ice routing system interfaced to GPS and Radar where image data files are transferred via the INMARSAT system to the ship. The user can manipulate the system design by conventional Windows philosophy, which is now also applied on some modern radar displays.

Additional information on IceNav can be obtained from:

Canarctic Shipping Company, Ottawa, Canada
tlf.: 1-613-234-8414, fax.: 1-613-234-9747

1.3 High latitude navigation problems

There is no unique method of polar navigation - the only real trick on high latitudes is to use every known method and apply them to unique polar problems.

The familiar Mercator projection will normally not be used in Arctic areas since distortion becomes significant as the poles approach. Transverse Mercator - (UTM), Lambert Conform - (fig.1.16) and Stereographic projections, are therefore often used. The common factor for these projections in the Arctic is that the rhumb line (RL) for navigation can not be drawn as a straight line on the chart. If a straight line is drawn this will be a great circle (GC), or close to a GC depending on projection.

In the case of using Lambert Conform, etc., for navigation it can be convenient to apply a grid on the chart (fig.1.17). A straight course line from position A to B will then intersect the grid at a fixed angle (G). The true course (T)

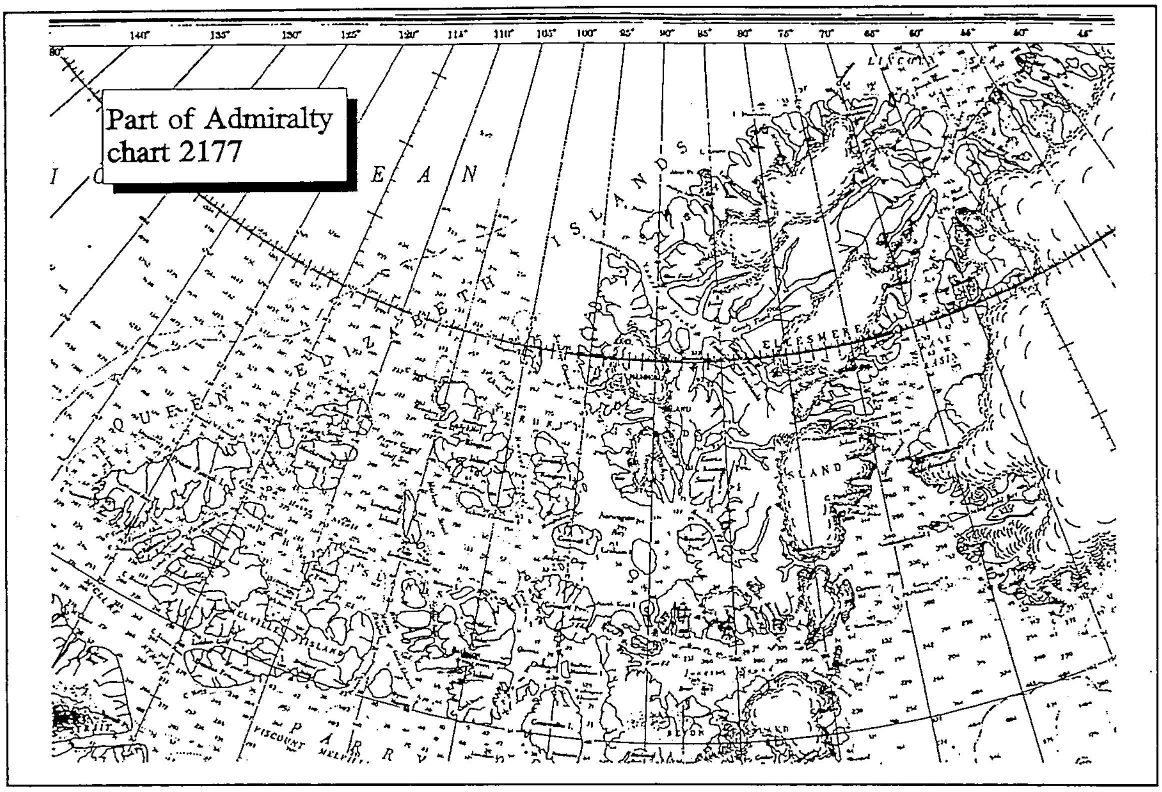


Figure 1.16 *Arctic maps are often made as Lambert Projections like this Admiralty Chart 2177 from the Canadian Arctic.*

is then easy to calculate based on the longitude as follows (northern hemisphere):

T = G - longitude West
T = G + longitude East

True course for GC can also be calculated as follows:

$$tanT=\frac{\sin\delta lon_{A-B}}{\tan lat_B\cdot\cos lat_A-\sin lat_A\cdot\cos\delta lon_{A-B}}\ [°]$$

δlon_{A-B} is the longitudinal difference between position A and B (fig.1.17).

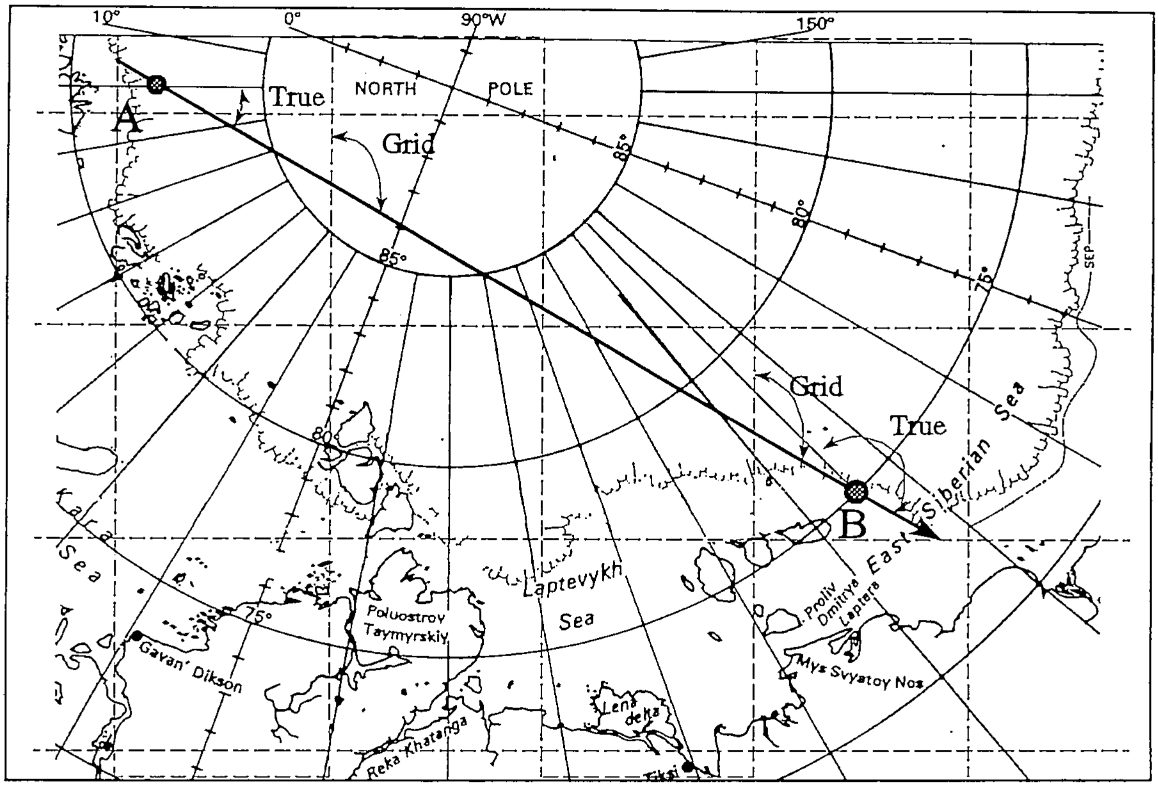


Figure 1.17 *Grid navigation makes it easy to find courses from Gnomonic and Stereographic projections.*

1.3.1 Magnetic compass

The magnetic compass has during the last years become less vital for navigation. Nevertheless, it remains one of the basic navigation instruments and some attention is necessary. The compass depends on the horizontal component of the magnetic field of the earth. In polar regions the magnetic latitude increases and the horizontal component of the magnetic field decreases rapidly and the compass will flicker.

The magnetic deviation will vary between 20 - 30° along the NSR. Effects caused by magnetic storms and local magnetic anomalies will make the situation complex and rather unpredictable. Further details on the magnetic conditions can be found in local Pilot descriptions.

Magnetic compass should not be used for direction finding and navigation in the Arctic due to instability and unpredictable errors.

1.3.2 Gyrocompass, INS and other direction-finding devices

The gyrocompass is at present the most important device for direction finding, also in the Arctic. The directing force on the gyro is dependent on latitude, course and speed. Consequently care must be taken when navigating at high latitudes, like the entire NSR. Errors, E, caused by this can be calculated as follows:

$$E = \frac{v \cdot \cos C \cdot 57.3}{901 \cdot \cos\phi + v \cdot \sin C}$$

v = ship speed [kts], C = ship course [°], ϕ = geographic latitude [°]

The size of the error can be visualized by an example:

> You are heading out the Yenisey Gulf on a nuclear icebreaker of the Arktika class. It is open water and speed is 21 kts., course is 355°. Latitude is 73°30′ N.

$$E = \frac{21 \cdot \cos 355 \cdot 57.3}{901 \cdot \cos 73.5 + 21 \cdot \sin 355} = 4.7°$$

Many gyrocompasses have a compensation device for this error but since the stabilizing force is relatively low, special attention should be taken to high latitude navigation by gyro compasses. At approximately 85° North the compass becomes unstable. When exceeding 85°, e.g. enroute to the North Pole, the Gyro must be used unstabilized as a gyroscope pointing at an astronomical point. Since this is not a normal option on gyrocompasses an inertial navigation system (INS) must be used as a direction device at latitudes above 85° north. The INS measures acceleration (north and east) on a gyro-stabilized platform. If this acceleration, a, is integrated twice we can measure the distance, s :

$$s = \iint a$$

The distance in north and east direction, found by integration, can be used in dead reckoning (DR) for position calculations.

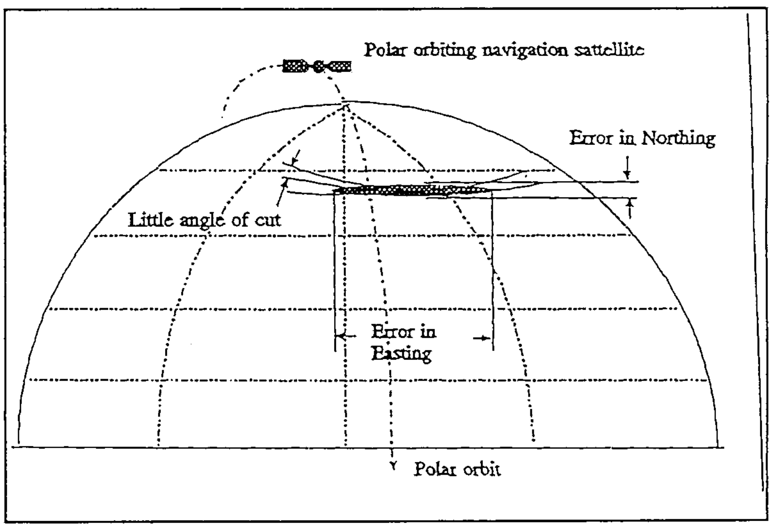
More expensive "gyro" compasses based on a LASER sensor where phase shift of the light is measured will not be affected by the errors described above. Some INS are based on LASER technology and will be important elements in an integrated high-precision navigation system.

1.3.3 Satellite navigation

Position fixing by means of satellite observations has traditionally been very helpful in polar regions since most other radionavigational aids have not covered the area. Two principally different systems are at the present time operational. The oldest are polar orbiting satellites like the Transit and the Tsikada systems where doppler measurements provides lines of positions (LOP). The other system is based on time/pseudo range measurements like the GPS and the GLONASS systems.

Using the doppler system the receiver will calculate the position each time the satellite passes in the vicinity of the ship. In polar regions this will be relatively often - usually every 30 minutes. A problem very often neglected is the fact that most of the satellite will pass the ship with a very high elevation angle since the orbits are polar. The consequence of this is LOP's with very little angle of cut, which gives very wide error ellipse in the longitudinal direction (fig.1.18)

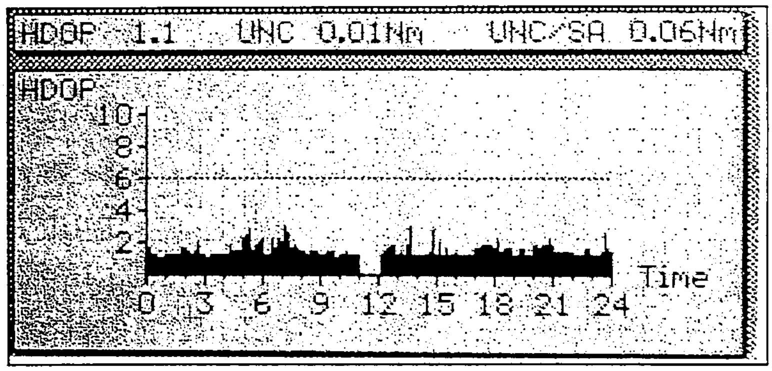
Figure 1.18
Error ellipse for line of position obtained from polar orbit satellites.



Many receivers will in such cases neglect the fix and continue DR. The fix can in fact be displayed and the latitude calculation can be used with a good degree of accuracy. The Transit system will be phased out after the GPS is declared operational in 1995. Termination will take place in 1997 (ref. US. Federal Radionavigation Plan 1992).

The U.S. GPS system is now declared fully operational and provides a global, continuous navigation service with an accuracy of 100 meters for civil users (20 - 30 meters for military users) 95 % of the time and 300 m, 99% of the time. The Russian GLONASS system which is now in the deployment phase is very like the GPS in terms of coverage and accuracy. Both systems are based on time measurements from which pseudo ranges can be calculated. The polar performance of these systems is normally no different from other parts of the world. The probability of the accuracy in the polar regions could in fact be more disputed, due to unpredictable fluctuations in the ionosphere (Håkegård, 93), Since the ionosphere refraction is one of the most important elements related to the accuracy there is reason to believe that the accuracy will be degraded a little bit in polar regions. The geometry of the satellites will give 24 hours coverage on the NSR (Kjerstad,92).

Figure 1.19
Horizontal dilution of precision (HDOP) on GPS for a period of 24 hrs. on the NSR (Kjerstad, 92)



Positions obtained by the GPS will normally be presented in the global WGS-84 datum. When used in connection with Russian charts it will therefore be necessary to apply a correction factor in latitude and longitude (ref. vol. 1). The GLONASS is at present the time operated in a local datum (Pulkova-42).

Differential satellite systems are at present not available on the NSR, but a program for equipping the NSR with differential GPS is now under development (ref.INSROP 1.2). Differential GPS will provide accuracies of approx. 10 m (95%) in the covered area.

When choosing a GPS receiver for use in cold regions it is important to examine the environment specification for the receiver architecture. Development of compact GPS receivers built in the antenna unit has become popular due to their low production costs. Consequently sensitive electronic circuitry is located in a rather tough environment. Typical specification for such receivers does not guarantee operation below - 20°C, which means we can experience serious problems when navigating in the Arctic during the winter season.

1.3.4 The GPS attitude determination

Positioning service provided by GPS is normally based on pseudo range measurements to 3 or more satellites. One new and very exciting application is to provide carrier phase technology to measure vessel attitude and heading. The wavelength on the carrier phase is respectively 19 and 24 cm on L1 and L2 frequencies. If we consider two antennas close together (fig.1.20) there will be a phase shift on the signal from a satellite. This shift will be proportional to the angle between the antenna plane and the satellite. If we extend this system and locate 4 antennas, 2 in transversal and 2 in longitudinal direction, we are able to measure ship attitude (roll and pitch) and heading.

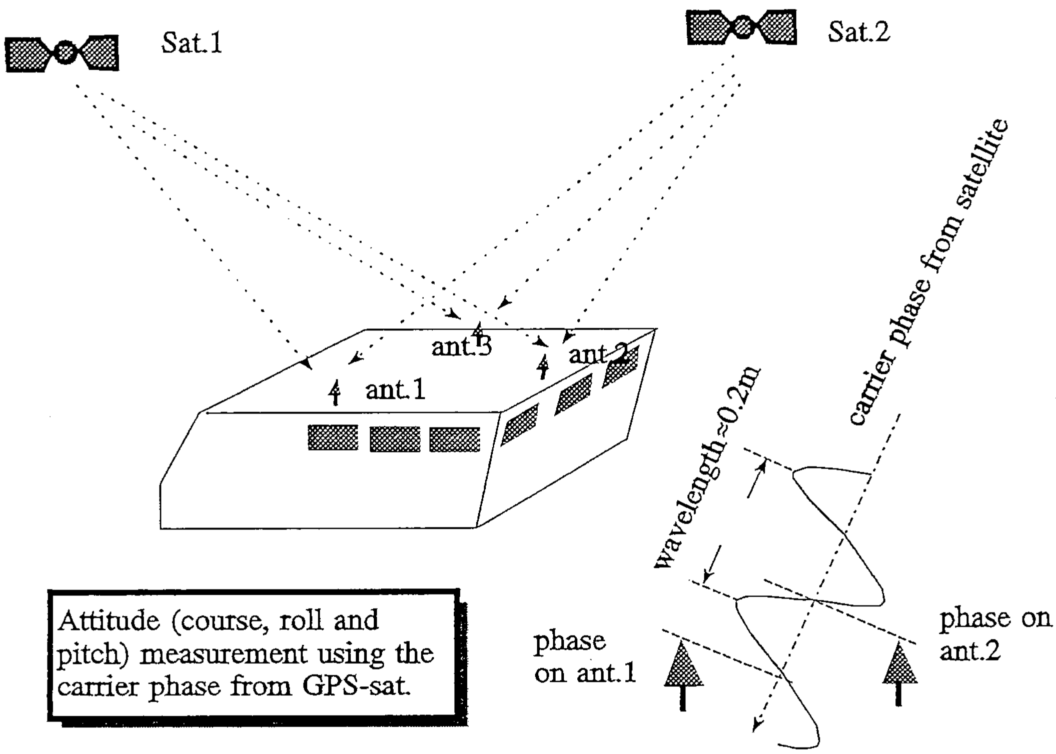


Figure 1.20 *By means of 2 or more antennas the GPS can be used for attitude determination (course, roll and pitch), important when navigating in Arctic areas where compasses often are incorrect.*

The heading will be determined to true north, without any of the errors known from magnetic and gyro compasses in the arctic areas. At the present stage of this technology the method is very sensitive to ambiguity from carrier phase reflected from obstructions close to the antennas. The system has been tested enroute to the North Pole by the U.S. icebreaker Polar Sea and the Canadian icebreaker Louis S.St. Laurant with very promising results (Brigham, 94).

1.3.5 Other radionavigation systems

Parts of the NSR are covered by the radionavigation systems MARS-75 and Chayka/Loran-C. Coverage is described in vol.1. Since these systems operate on medium - low frequencies they are affected by the transmission conditions at the given time. Compared to satellite systems these landbased systems are more sensitive to environmental conditions like magnetic storms, precipitation etc. Another crucial element when electro-magnetic waves propagate along the earth's surface is the dependency on good conductivity in the earth. Significant absorption due to low conductivity is often observed in arctic regions. Examples of poor conductivity are ice and snow covered areas and areas affected by permafrost. In addition to influencing the absorption the ice and snow covered areas will affect the velocity of propagation of radio waves, and since the signal time of arrival is the fundamental dimension for calculation of the position, the accuracy will be degraded to some extent. Some of these problems can be taken care of by modelling the receivers, but in general we can conclude that the performance of the radionavigation systems will be reduced in the Arctic compared to lower latitudes.

The recent renewal of the North Atlantic Loran-C system and a potential link to the Northwest Russian Chaika chain will probably cover the western part of the NSR by position services with an accuracy comparable to the GPS with respect to repeatability.

The very low frequency OMEGA system based on phase measurements to 8 different stations distributed around the world is considered to give global coverage. Some crucial elements are in fact associated with the system's arctic performance. The accuracy is closely tied to a complex set of corrections based on propagation conditions related to time of day, time of year and position. These corrections are not very well known in the arctic and the accuracy will be significantly degraded. When using Omega in the arctic the performance will also be reduced due to the signals from some of the stations being influenced by polar cap absorption.

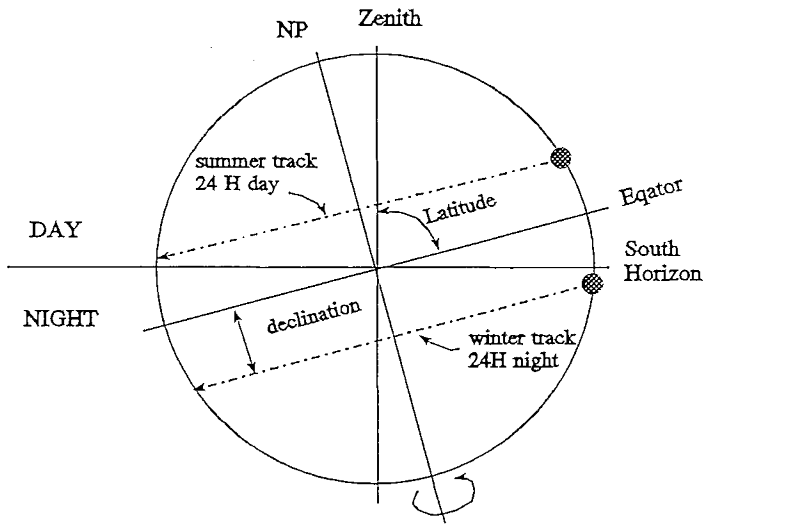
Ionospheric interference and poor conductivity in ice and snow covered areas will reduce range and performance of radionavigation systems in the Arctic.

1.3.6 Celestial navigation

Due to the many limiting factors related to electronic navigation, Arctic celestial navigation is of prime importance, although its practice may be very different from that to which the navigators are accustomed.

During the summer months with continuous daylight altitude measurements can be taken of the sun only (occasionally the moon). The navigator will therefore depend on only one line of position. At high latitudes the sun will, after the light period, cut the horizon at a very low angle (fig.1.21).

Figure 1.21 Fundamentals for celestial navigation. The figure is based on latitude 75°N.



Movement of the sun at 75° latitude.

This will be favorable with respect to celestial observations due to a rather long period of twilight which is necessary for observing both the horizon and the celestial body. At very high latitude there will be a period where the upper elevation is too low for reliable observations and the midnight elevation is too high for adequate twilight for star observations.

1.3.7 Radio Detection Finding

Due to rapid development in satellite navigation systems radiodetection finding is not an important navigation aid any more. New requirements described by GMDSS have also reduced the significance of radio detection finders. In spite of these issues I will discuss some arctic problems related to radio detection finding since radio bearings can play an important role in search and rescue operations. The NSR is well equipped with radio beacons, quite capable as serving as a secondary or back up navigation system.

As mentioned under radionavigation systems the propagation conditions for radio waves can be rather crucial in arctic regions due to ionospheric interference and low conductivity in often snow and ice covered areas. The range to where the signal can be distinguished will normally be shorter than in lower latitude conditions.

If radio bearings are to be plotted out on the chart we have to be aware of the difference between the GC bearing and the bearing to be plotted on the chart projection used. If the difference is between a GC- and a Mercator bearing it is often called "radio conversion". This conversion increases with average latitude (lat_m) and the longitudinal difference (δlon) between the ship and the radio beacon after the approximated formula:

$$Radioconversion = \frac{\delta lon \cdot \sin lat_m}{2}$$

Applied in the Arctic the significant magnitude can be visualized by the following example:

> *The ship is located close to Cape Zhelaniya (N 77° - E 70°) and takes a radiobearing to the station at Cape Chelyuskin (N 77°43′ - E 104°17′) (ref. vol. 1). Applied in the formula this will give the following conversion:*

$$r.c. = \frac{104°17' - 70° \cdot \sin(77° + 77°43'/2)}{2} \approx 17°$$

In this case, where the ship is west of the station, the conversion should be added to the observed radio bearing. In the opposite case the conversion should be subtracted from the observed bearing.

2 Navigation in ice

It is not expected that all navigators who have read this chapter can sign on a ship and sail safely through ice infested waters. Navigation in ice is first of all an art gained by long experience. The approach in this text will hopefully help the unexperienced and focus on some very important issues.

Warning: Any ship without ice strengthening should avoid ice concentrations closer than 4/10, even if the ice covers only a limited ice-belt.

The best conditions for navigating in or close to ice is when the air is clear and when the sky is covered by a thin layer of cloud. In open water the ice will then be first observed as a light image in the clouds called **ice blink** in the direction towards the ice. In the opposite case when navigating in close drift ice the direction towards open water will be seen as a darker part of the cloud called **water sky**. The optimum course will normally be in the direction of the most remote extension of the dark sky.

When the sky is absolutely clear a white/yellow fog can often be seen in the direction where ice will occur. The ice edge will often, due to light refraction, be magnified and can be seen from quite a far distance. In such cases an ice floe can give the illusion of an iceberg.

Low visibility is unfortunately the most frequent situation when navigating in or close to ice, in which case other ice observation techniques have to be used. Use of proper look-out by all available means, including radar, to make a full appraisal of the probability to meet ice will be necessary. Observation of air and water temperature will be important. A sudden drop in air temperature simultaneously as the water temperature approaches 0°C will give a good indication of presence of ice in the vicinity. At the same time the wind tends to vary less and the waves will be reduced. When the wind blows away from the ice edge, small pieces of ice can often be seen a mile or so from the edge. In such cases it is important to reduce speed and be prepared to meet the ice.

2.1 Ice terminology

Before discussing navigation techniques it is important to define the most common ice terminology used in the discussion.

Close ice	Floating ice with concentration from 7/10 - 8/10. Floes generally in contact with one another
Open ice	Floating ice with concentration from 4/10 - 6/10. Floes generally not in contact with one another
Ridged ice	A line of broken ice forced upward by pressure from surrounding ice.
Rafted ice	Type of deformed ice formed by one piece of ice overriding another.
Level ice	Ice which is unaffected by deformation
Hummock	A hillock of broken ice which has been forced upward by pressure.
Shear Zone	The contact zone between fast ice and pack ice where motion and pressure frequently result in an area of heavily ridged ice.

2.2 Dangerous ice

Based on analyses of ice damages on ships (Køhler, 86) and their cause relationship some hazardous ice conditions can be identified for Baltic classed ships sailing in the Arctic. These conditions are:

a) Open water with icebergs and growlers

b) First year ice with floes of multiyear ice

c) Pack ice consisting of floes of multiyear ice

Multiyear ice and growlers have, due to the crystal structure much higher strength and a ship/ice interaction can often be fatal. Damage caused by category a) can be avoided by reducing speed when conditions for visual and radar observations of ice become difficult. The category b) conditions will be more difficult to decide since the ice is often covered by snow. The ship will sail with rather high speed and is very likely to be damaged when striking a multiyear floe infested in the first year ice. Ice pilot descriptions from the actual region will in such cases be very helpful. High resolution SAR images will also help to identify the probability for multiyear floes. Navigation in category c) should be avoided by Baltic classed ships. The ship may become beset, and thus subject to ice loads much higher than the design criteria.

All ships sailing in the Arctic may have to sail through belts of pack ice, and should therefor be ice-strengthened for such conditions.

In large areas on the NSR we will only have first year ice, especially in the south-western part of the Kara Sea and in the river estuaries. On transit sailings from the Barents to the Bering Sea we will always have to expect interaction with multiyear ice on parts of the route. During the winter the river ice will also be extremely strong due to very low temperatures - often down to -50°C (fig.2.1).

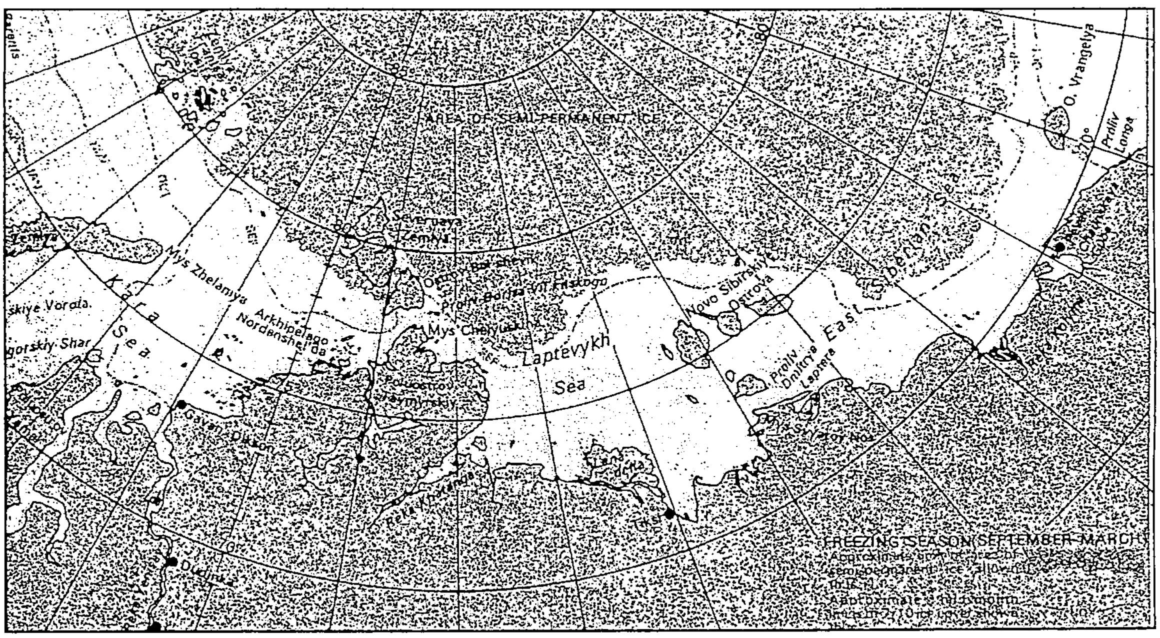


Figure 2.1 *Semi-permanent ice and limits of close drift ice during September - November along the NSR. (Source: Admiralty NP-23).*

2.3 Hull resistance

When the ship is navigating in open ice with concentration less than 5/10 we consider the ice friction negligable. As the ice becomes closer, thicker or if the strength increases the ice resistance will increase rapidly. In close ice not exposed to pressure a rough estimate of the ship's speed, v_p can be made based on the open water- and level ice performance:

$v_p = v_0 + (v - v_0) * ((m - 0.5)/0.5)$

v_0 = speed in open water
v = speed in level ice of the actual thickness
m = coverage higher than 5/10

Example:
The Russian icebreaker "Mudyug" has an open water speed of 16 kts., and a speed of 5 kts. in 0.9 m level ice. Ice coverage is 8/10.

$v_p = 16 + (5 - 16)*((0.8 - 0.5)/0.5) = \underline{9.4 \text{ kts}}$

More accurate calculations can be done where hull shape, ice type and snow cover are taken into consideration. As an example there is shown an empiric formula for resistance, R, (in metric tons) on the russian icebreaker "Kapitan Belousov" below:

$$R = 8.6 \cdot L^{0.5} \cdot B^{0.25} \cdot \left(0.4 + 8 \cdot \left(\frac{V}{\sqrt{g \cdot L}}\right)^{1.25}\right)$$

L = ship length, B=ship width, V=speed.
g = gravity acceleration constant

Numerical analyses of resistance can be done by studying the icefloes as they proceed alongside (fig.2.2). Two problems must then be solved. First the force needed to cut or break the ice, then the friction of the floes as they slide alongside.

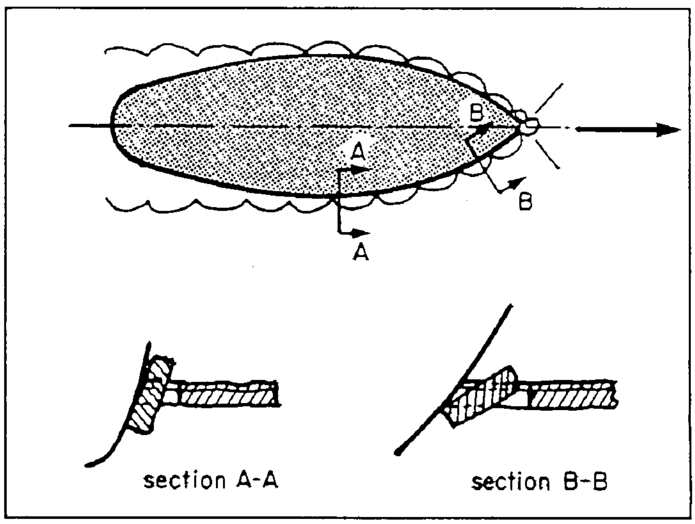


Figure 2.2
Indication of behavior of icefloes alongside in the continuous icebreaking mode (Michel, 78).

In such analyzes a significant increase in friction related to snow cover must be taken into consideration.

Different performance-enhancing systems have been developed by different ship constructors. Some of these systems are described in detail in chapter 3.3.

2.4 Ship handling techniques

Ice will always be an obstacle for the ship, even for the most powerful icebreakers. However, there are some very important techniques that can help to take the ship safely through ice covered waters. It is also important to show due respect for the strength of the ice.

Some basic rules can be applied:

Keep moving - even slowly and avoid being trapped in ice.

Never ram into solid ice if the ship isn't classed for icebreaking.

Work *with* the ice not against it.

Excessive speed leads to ice damage.

Be aware of the ship's maneuverability and the ice resistance induced in various types of maneuver.

Investigation of several ice damages has proved that even experienced navigators sometimes use too high speed and thereby damage their ship. Such a nonchalant attitude has to be focused on and avoided. Inexperienced navigators will often be too careful and stop moving and the ship can easily be trapped in the ice with the risk of being damaged by ice pressure.

2.4.1 Entering the ice

Entering the ice is often a critical phase and different conditions have to be considered.

Choose the easiest route, even if the distance is significantly longer. The fuel consumption will normally be much higher when going through ice and the gain obtained by a shorter distance will normally be lost.

Brief all involved personnel and intensify the look-out.

If possible ballast the ship to maximum draft to reduce risk of ice damage to propeller, rudder and bulbous bow.

Run engines on internal cooling system to reduce risk of fatal damage due to clogged water intake.

Reduce the speed to minimum to receive the initial ice impact.

Look for the area with the lowest ice concentration before entering the ice edge.

Normally approach the ice edge at right angles (90°). In case of heavy swell in the marginal ice zone it should be entered parallel to the swell (fig.2.3).

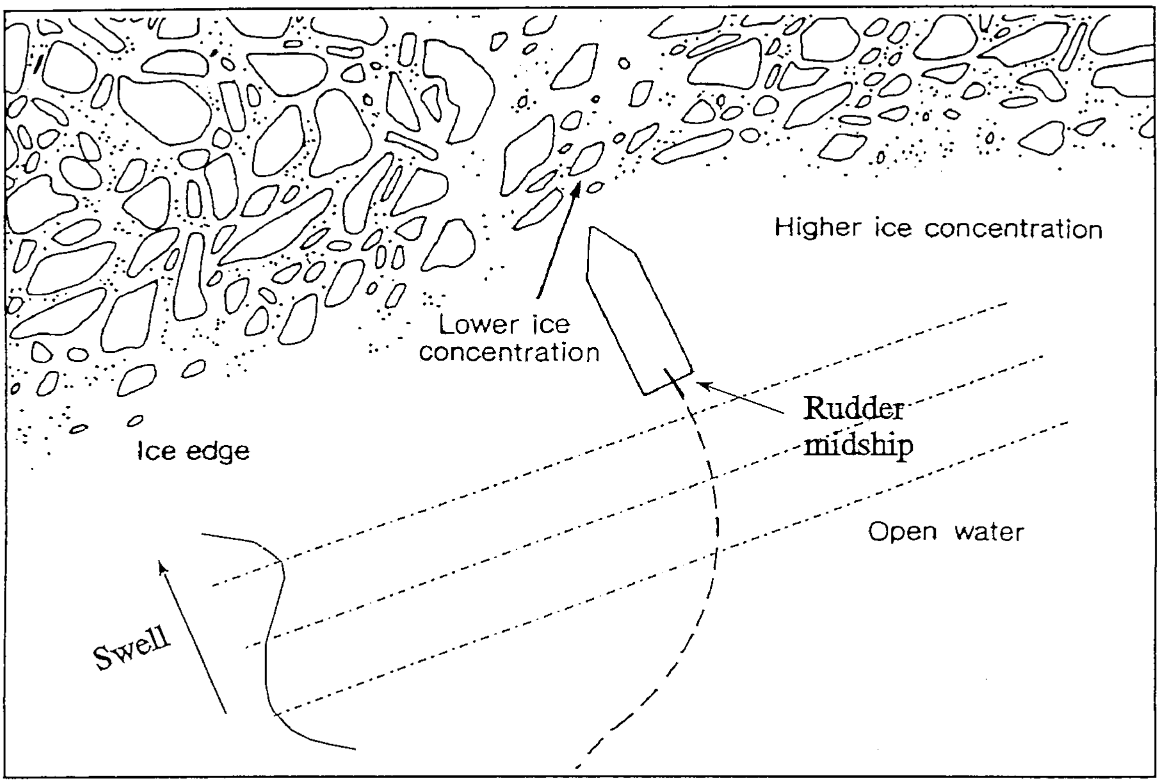


Figure 2.3 *Approach of the ice field should be done parallel to the swell and where the ice concentration is most favorable (Modified CCG, 92)*

After the initial ice impact the speed should be increased slowly according to the prevailing ice conditions and visibility. Special attention should be paid in low visibility when there are open leads - it could be the trail of an iceberg.

Always try to follow open water patches even if you have to deviate considerably off course.

In limited visibility reduce the speed to enable the ship to stop within the visible distance.

If you have to stop - keep the propeller running to prevent the stern being clogged by ice.

2.4.2 Turning, backing and ramming in ice

When navigating in ice it will be necessary to do a lot of manoeuvering to find the easiest route through. The turning phase is often critical. Due to the turning movement significant pressure will be induced on the side and stern of the ship. Considering that the side and stern plating is dimensioned for less ice pressure than the bow there can easily occur damages to plating and frames. Turns in ice must therefore be performed with a lower rate of turn than in open water.

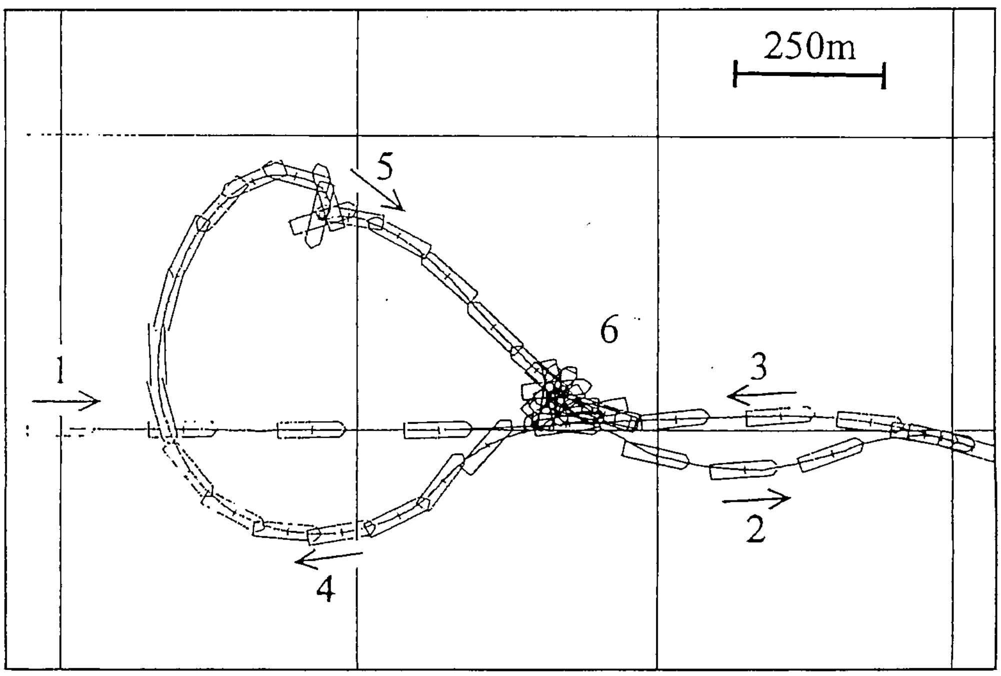


Figure 2.4 *Equipped with 2 azimuth thrusters the Finnish icebreaker "Fennica" has eminent maneuverability (Savikurki, 93).*

When the ship is proceeding at marginal speed a drag force imposed on the rudder can be enough to stop the progress. In difficult ice, ships with twin propellers should use these to assist the turn. Heeling the ship will also help turning. If the ship still has problems turning there is no alternative but to take a "star-turn" performed by backing and turning forward.

> Turning in ice will impose heavy pressure on the side and stern of the ship - damages can easily occur.

Backing in ice will expose the stern, propellers and rudders for loads that can often be critical for these vulnerable parts of the ship. Normally ice strengthened ships should only go dead slow astern and always keep the rudder midships. An effective method to protect the stern from ice is to give a burst forward on the propeller to clear away ice. A sharp lookout must be kept and ramming must never occur.

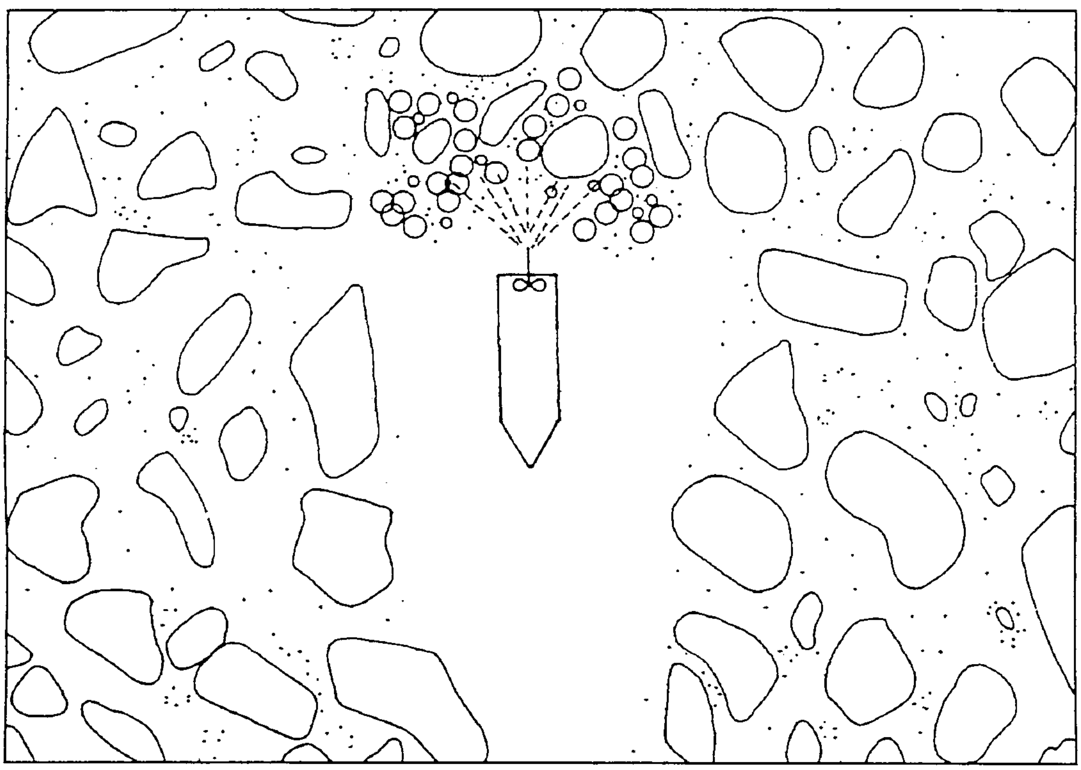


Figure 2.5 *Backing in ice: Rudder amidships, dead slow astern. Use a short burst ahead to clear ice (CCG,92).*

Ramming is effective through ice and ridges, too thick for continuous icebreaking. When the ship has stopped it has to back out and start a new run into the ice. The amount of speed necessary for breaking through will depend very much on ice conditions and the displacement of the ship. Always start with short runs to build up experience. Not all ships are designed for ramming and ships with bulbous bows must never be rammed into heavy ice and ridges. Because of extreme impact forces special caution should be taken. Also be aware of the grounding force on the keel when the ship "rafts" up on the ice. This can significantly reduce the ship's stability .

> Ships with low ice-class or bulbous bow should never attempt to ram.

2.4.3 Loading, unloading and berthing

Berthing in Arctic ice-covered ports is usually a far more time consuming process than in open water. If ice is trapped between the ship side and the pier it can easily cause damage both to the hull and the pier. It is therefore important to approach the pier at as small an angle as possible and try to slide the ice away (fig.2.6). After the springline is fastened the rudder and propeller can be used to flush away the ice. After the ship is secured it must be observed if ice is building up force between the hull and the pier, in such cases the engine must be kept in standby, ready to abandon cargo operations and leave the pier.

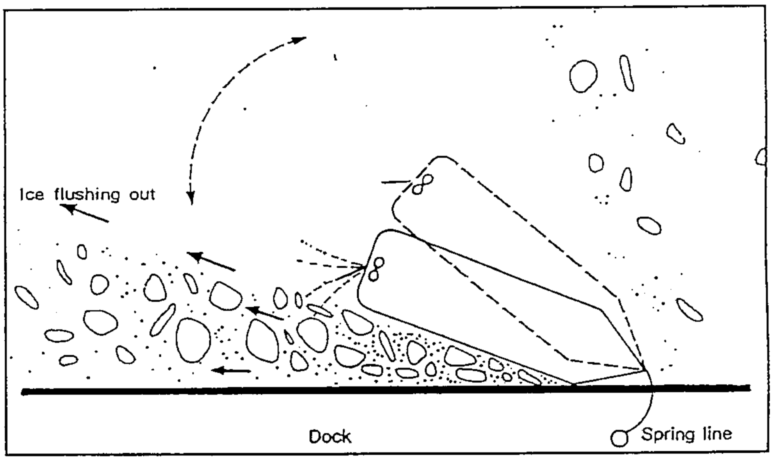


Figure 2.6
When berthing in ice infested waters the ice can be washed away while the bow is fastened by a spring line (CCG,92).

Along the NSR a lot of loading and unloading operations have been performed from the channel in the landfast ice. Specially designed ships such as the SA-15's will also be able to do roll on / roll off (RO/RO) operations onto the ice. Such operations can in many cases be convenient but attention must be paid to the risk of overloading the ice, so that the ice surface becomes flooded and cracks. The destructive load can be theoretically analyzed based on samples and calculations, but from an operator's point of view table 2.1 based on experience from the NSR can be used (Lenskiy,90).

Table 2.1 Ice strength of different ice types along the NSR (Lenskiy, 90)

Ice type	Thickness [cm.]	Strength [kg/m^2]	Destructive-load [tonn/m^2]
Thin ice	50 - 60	7.3 - 8.8	18 - 30
Medium ice	70 -120	8.8 -16.2	43 -144
Thick ice	150 -180	11.0 -13.0	247 -421
Second year	200 -250	14.5 -17.5	548 -1090
Multiyear ice	250	19.0 -22.0	1188 -1375
Old river ice	200 -250	14.6 -20.0	544 -1250

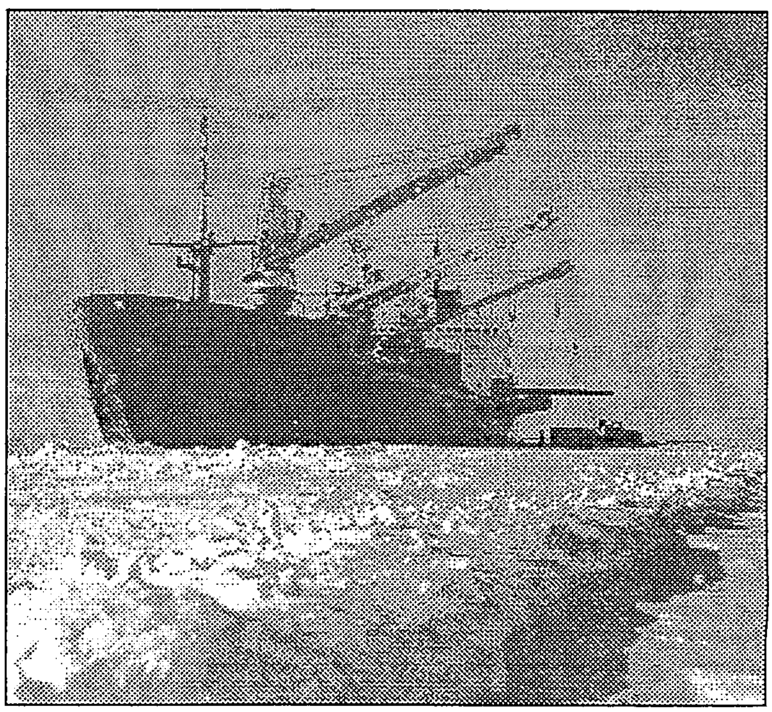


Figure 2.7
MSC ship of the Mikhail Strekalovskiy type unloads pipes on the ice off the Yamal Peninsula (Source: MSC).

2.4.4 Ice anchoring and supply of fresh water

Ice pressure imposed on an anchored ship can sometimes cause extreme loads. Ordinary anchoring in areas where there is a risk of being trapped in ice or where large floes can hit the ship should therefore be avoided. Special ice anchors can sometimes be helpful if the ship intends to berth to large ice floes. The ice anchors should be secured in the ice and a sharp lockout must be kept to avoid grounding or collision with other large ice features. Use of ice anchors can be convenient if the ship needs to fill fresh water from melt ponds. Since the salt is drained through the old ice and the surface has been covered by snow such melt ponds will contain water with salinity below 2‰

2.4.5 When the ship is trapped in difficult ice

Ice under pressure is the main reason why a ship becomes trapped in ice. Pressure normally occurs due to the prevailing winds, current and influence of river water. Pressure can be observed as a function of how fast the track behind the ship closes (fig.2.8). On-shore winds and winds blowing towards the marginal ice zone will also normally pressurize the ice and build up ridges and hummocks. Precautions to avoid pressurized ice can be taken if the route is planned in accordance to meteorological information. When sailing in pressurized ice conditions there will always be a danger of being trapped and receiving serious damages to the hull. Even for the most powerful and ice strengthened icebreakers such situations can be crucial.

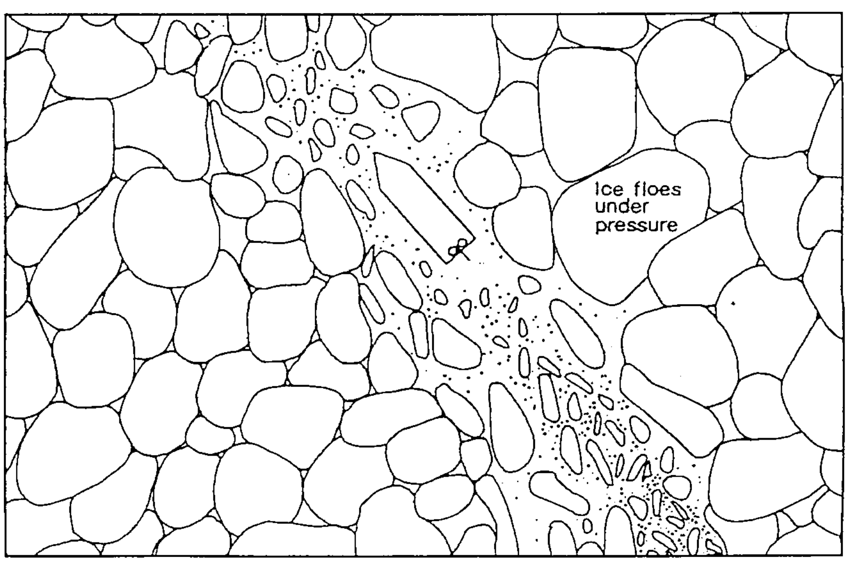


Figure 2.8
Pressure in the ice field due to wind and current will close the track behind the vessel (CCG,92).

When sailing in convoy escorted by an icebreaker the risk of being trapped can be reduced by closing in the distance between the escorted vessels or increasing the speed of the convoy. Both methods will increase the danger of collisions between the ships and a close tow operation may often be preferable (ref. chapt. 2.4.6).

If a ship is sailing without escort and becomes trapped, some methods can be used to get loose.

a) Alternate the power astern and ahead while moving the rudder from side to side.

b) Heel the ship from side to side by pumping ballast from side to side or by swing weights from side to side by the ship's crane. Be aware of the possibility of imposing pressure to parts of the hull that are below the strengthened icebelt.

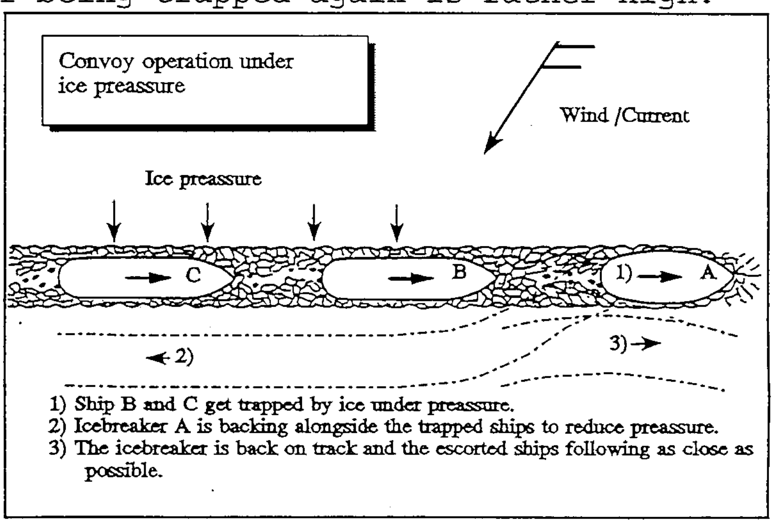
c) If the ship is rafted in the ramming process, ballast must be pumped aft to reduce the "grounding" force (ref chapt.2.6.2).

d) A lead can be opened by detonating explosives alongside and in front of the vessel. This method must be used with extreme caution to obtain experience.

e) Ships equipped with air bubbling systems alongside can use these to reduce friction between the ice and the hull (ref. chapt.3.3)

If the ship is trapped when sailing in convoy the convoy has to stop and the icebreaker has to reduce icepressure by breaking a lead parallel to the convoy (fig.2.9). In such cases many icebreaker captains prefer to tow the trapped ship since the possibility of being trapped again is rather high.

Figure 2.9
When ships are trapped behind the icebreaker the ice pressure alongside has to be reduced by breaking a parallel channel.



2.4.6 Towing and convoy operations

Most of the operations made by merchant vessels on the NSR are based on convoy sailings where 3 - 4 vessels are escorted by 1 or 2 icebreakers depending on the ice conditions. In most of the convoy operations the margins are small and to avoid collisions and damages the crew have to operate under a high level of preparedness. The speed of the convoy will depend very much on the icebreaker performance and how fast the channel will close behind. In such operations good communication is extremely important - misunderstandings can be fatal. During the dark winter period effective light beams and radars with good ice detection capability are essential.

To improve the effectivity of the convoy many convoy constellations can be used, depending on available icebreakers and ice class of the merchant vessels. Some examples of formations are shown in figure (fig.2.10).

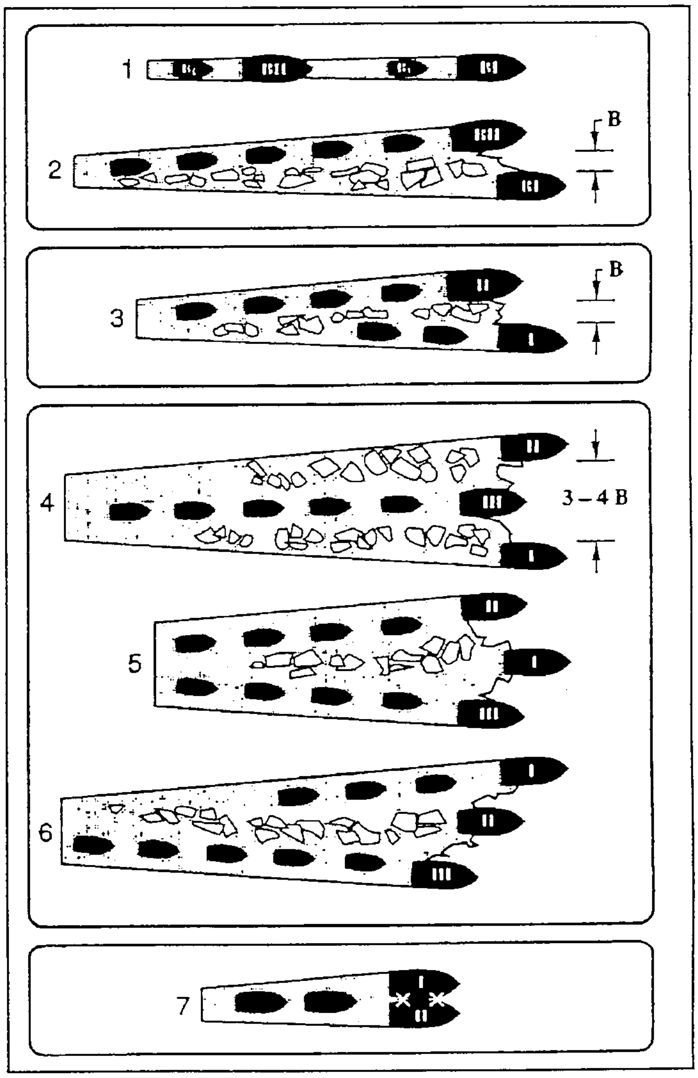


Figure 2.10
Some examples of icebreaker convoy formations (Brigham, 91).

A clean and easy navigable channel depends very much on the shape of the icebreaker. Traditionally, this has been a matter of the beam of the hull. New development on bow shape has proved that the icebreaker performance can be improved significantly. An example of this is the Thyssen Waas bow build on the icebreakers Kapitan Sorokin and Madyug. On figure 2.11 this improvement is clearly illustrated in level ice where the advantages are most significant.

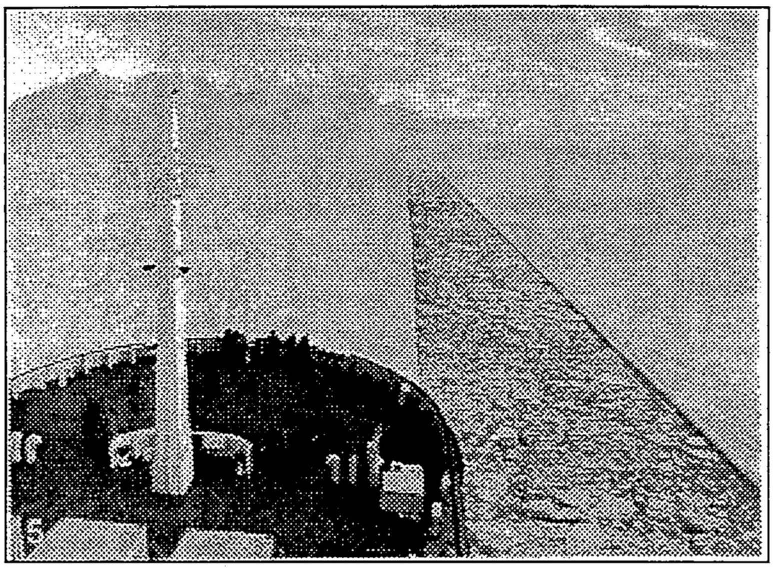


Figure 2.11
Test runs of the new bow on the icebreaker Madyug in the Svalbard area. The channel will under such conditions be much cleaner than with the old bow concept (Source: Thyssen Waas).

The merchant vessels will from time to time experience being trapped in the ice behind the icebreaker. In such situations it can be effective to arrange a short tow or a tandem tow to assist one or a few vessels through difficult ice conditions. In some areas and ice conditions towing operations can be considered the standard method of operation, e.g. in river estuaries and when the ships are taken to and from the port. How the short tow is arranged is illustrated in figure 2.12.

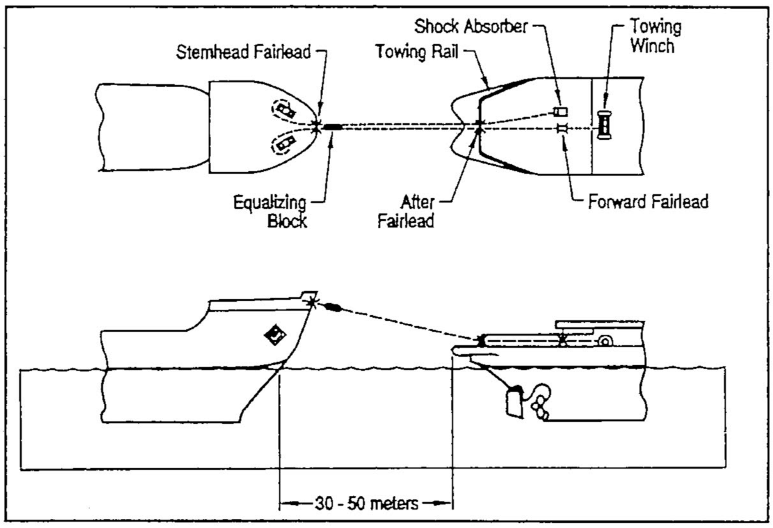
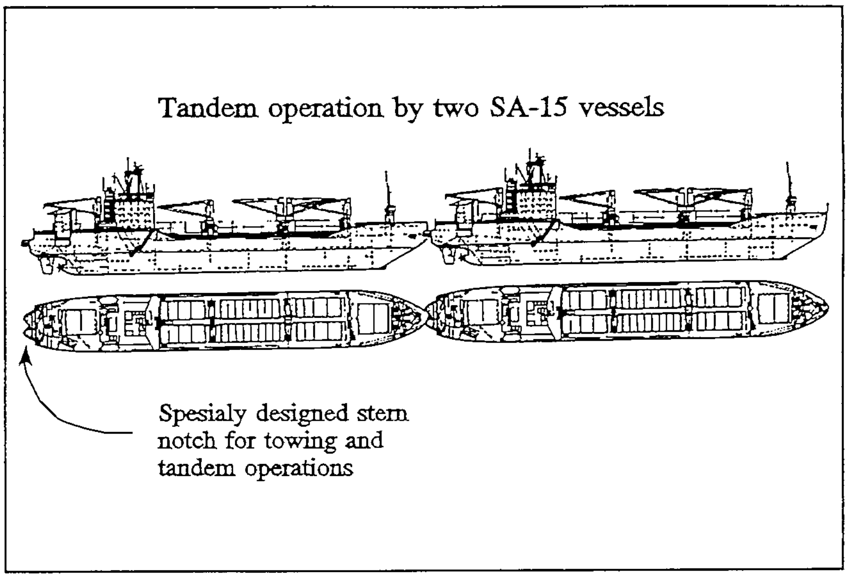


Figure 2.12
Short tow technique is often used on the NSR to improve convoy efficiency (Brigham, 91).

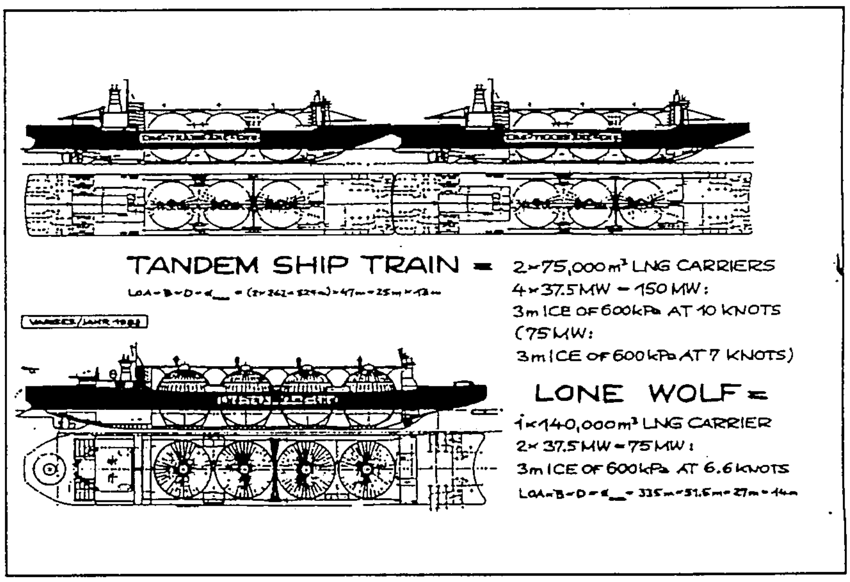
Tandem tow can be performed if the stern of the icebreakers has a stern notch and the towed vessels are sufficiently strengthened in the bow. Every icebreaker on the NSR is equipped with stern notches and the method has been much used since the early eighties. Also the SA-15 merchant vessels are equipped with a stern notch, which makes it possible to tow more than one ship after the icebreaker (fig.2.13). In such operations the towed ships can apply additional power when pushing the icebreaker from astern.

Figure 2.13
The SA-15 ships are designed with stern notch for tandem and short tow operations.



The tandem concept has been studied as a tanker project for taking petroleum resources out of the Arctic. One of these projects is shown in figure 2.14.

Figure 2.14
This Thyssen Waas Arctic tanker concept is one of many projects developed for transportation of petroleum products in Arctic areas (Source: Thyssen Waas).



In the shallow waters on the Siberian shelf and in the river estuaries it is important to be aware of the possibility of drifting channels due to the current. Such incidents can very easily result in groundings, and have actually occured both on the NSR and in the Baltic.

Drifting icebreaker channels can result in grounding if attention is not paidd to precise positioning.

2.5 Safe speed

Safe speed is one of the most important notices made in the International Regulations for Preventing Collision at Sea. In ice this notice will have two dimensions, both regarding collisions with other ships and collisions with other floating bodies like ice.

Since many factors related to the environment, the crew and the ship are elements of importance in deciding safe speed in ice it is difficult to conclude absolute figures. The elements in this process are visualized in figure 2.15.

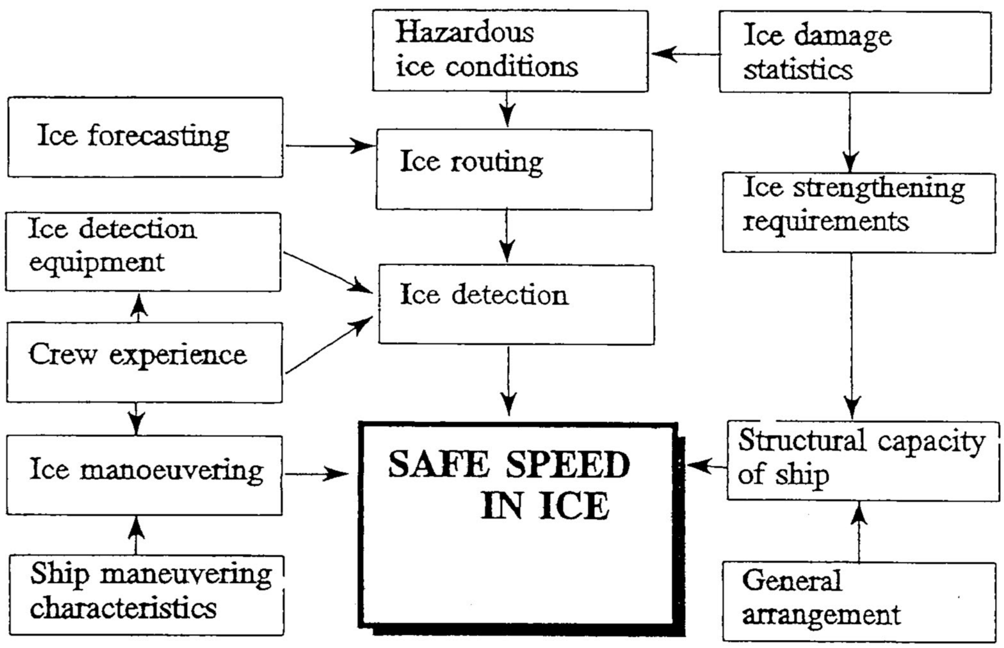
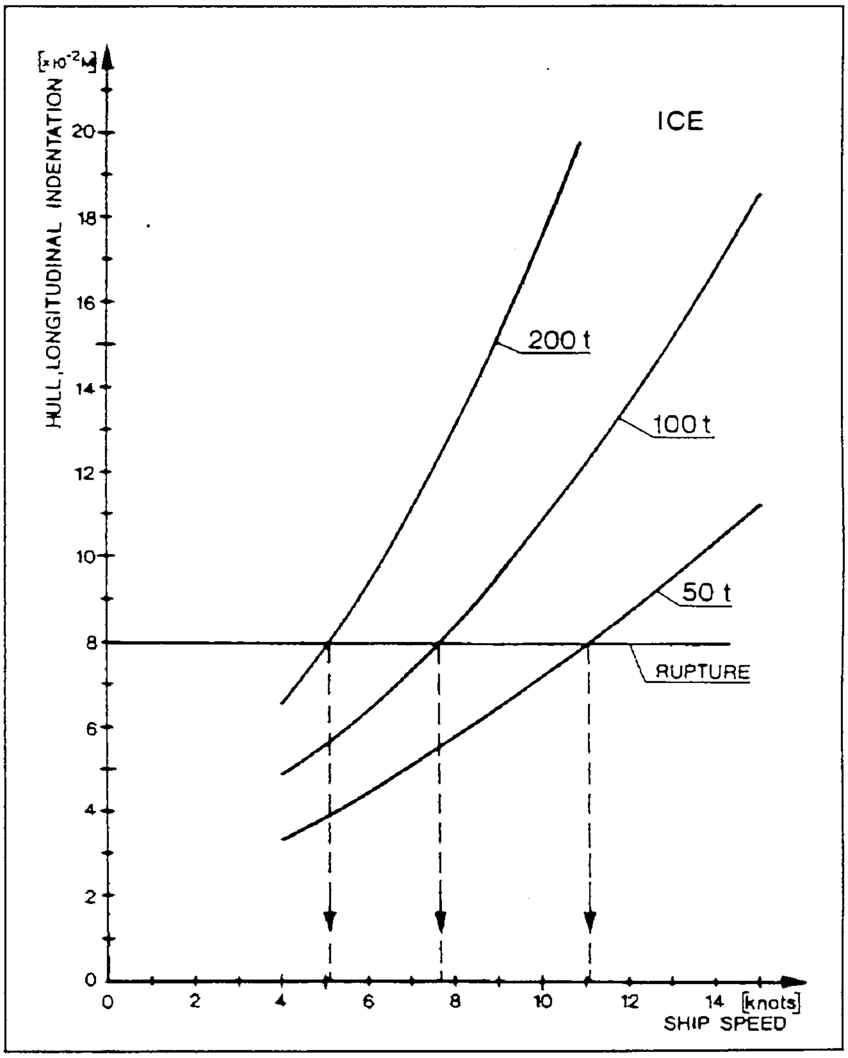


Figure 2.15 *Important elements in determining safe speed in ice (Køhler, 86)*

Based on mathematical studies of the energy imposed by a collision with ice it is possible to compute the degree of deformation or rupture on a certain part of the hull (fig.2.16). Research on hull loads has also been performed by means of electronic load sensors located in different constructions on the ship, while sailing in ice. Since such sensors are not commercially developed yet, the system can only on future ships help the navigators to decide a safe speed. When determining the safe speed it is extremely important to differentiate between Arctic and subarctic ice conditions.

Figure 2.16
Safe speed chart (Køhler, 86).

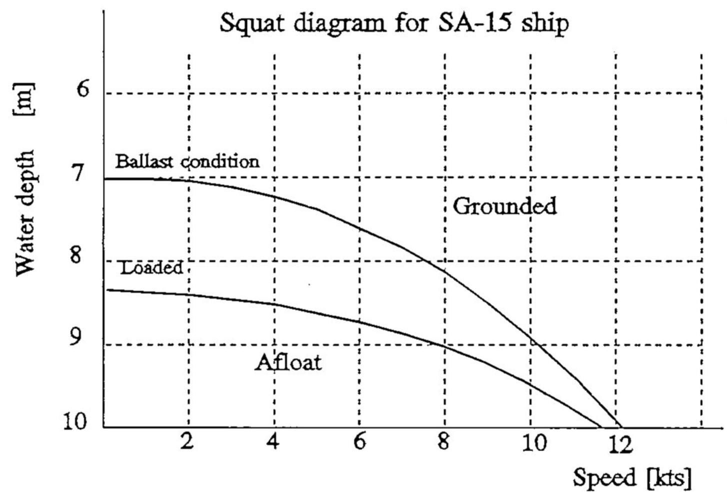


The safe speed is not only a matter of ice load. In shallow areas such as those found on most parts of the NSR the maneuverability of the ship is significantly affected by the "shallow water" or "squat" effect. The magnitude of the effect is related to the ratio between ship draft, D and height of the water, h.

$h/D < 2$	Shallow water effect can be observed
$h/D < 1.5$	Shallow water effect is significant

Under such conditions the turning diameter will be almost doubled and the draft will be increased. The degree of squat (sinkage) will depend on the h/D ratio and the speed. In figure 2.17 the possibility of grounding a SA-15 vessel is indicated as a function of the mentioned parameters.

Figure 2.17
Squat diagram for a SA-15 vessel sailing in shallow waters.



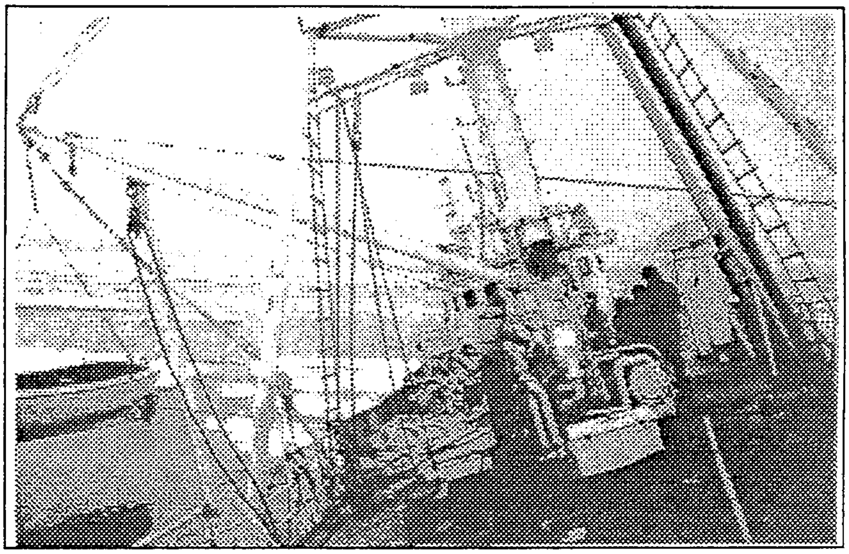
2.6 Critical situations

In all waters critical situations can occur, but due to the low temperatures in the Arctic the time factor and the importance of training and preparedness is maybe more important when critical situations occur in the Arctic. A lot of the existing life saving equipment will not be sufficient if the ship has to be abandoned in arctic waters. Depending on the ice conditions it can often be necessary to land lifeboats and life rafts. It is extremely important to protect the shipwrecked crew from water and cold winds.

2.6.1 Handling a damaged ship

If a part of the hull is damaged or ruptured the area should be protected from further loads and the flooding must be minimized. In case of a rupture deep below the waterline flooding can be reduced by covering the area with canvas. If the damage is close to the waterline the ship can be heeled or trimmed in order to raise the damage out of the water for preliminary repair (figures 2.18 and 2.19)

Figure 2.18
The crew of the sealer "Polarfangst" repair a hull rupture when the ship is heeled over by weights (Source: Capt. Paul Stark).



In case of trimming and heeling the ship, it should be borne in mind that parts which are not icestrengthened may then be exposed to ice. When damage has occurred preparations should always be made for abandoning and the Search and Rescue Center informed.

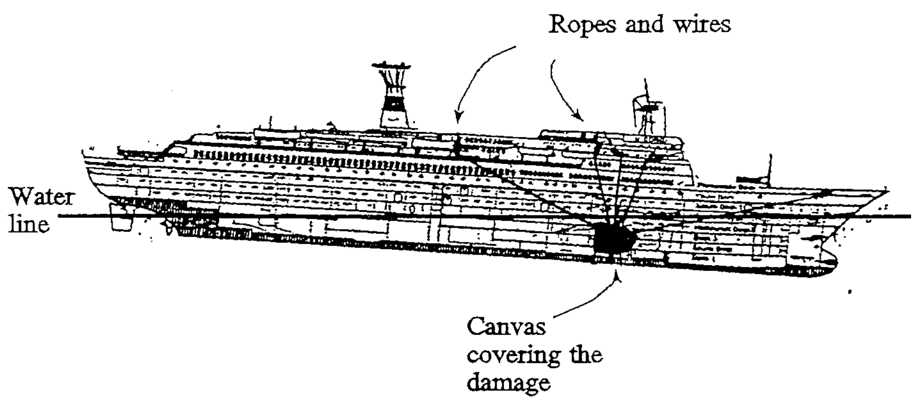


Figure 2.19 *The hull damage on the "Maxim Gorkiy" was preliminarily repaired by divers after collision with ice in the Svalbard area 1989 (Source: Norwegian Coast Guard).*

2.6.2 Ship stability

In general the stability of ships will be reduced with upward shift of center of gravity and imaginary center of gravity. Related to Arctic conditions two separate effects have to be discussed - spray icing above the water line and forces induced by ramming, grounding or icebreaking.

Spray icing will occur when the ship is exposed to certain meteorological and oceanographic conditions. The rate of ice accumulation will depend on temperatures in the air and in the water, wave height, wind speed, course relative to the wind and the construction of the ship. If we study the "Martin-diagram" (fig.2.20) we can get an indication of the significance of the different parameters involved and the rate of accumulation on a trawler type ship. The numbers indicate the following accumulation rate;

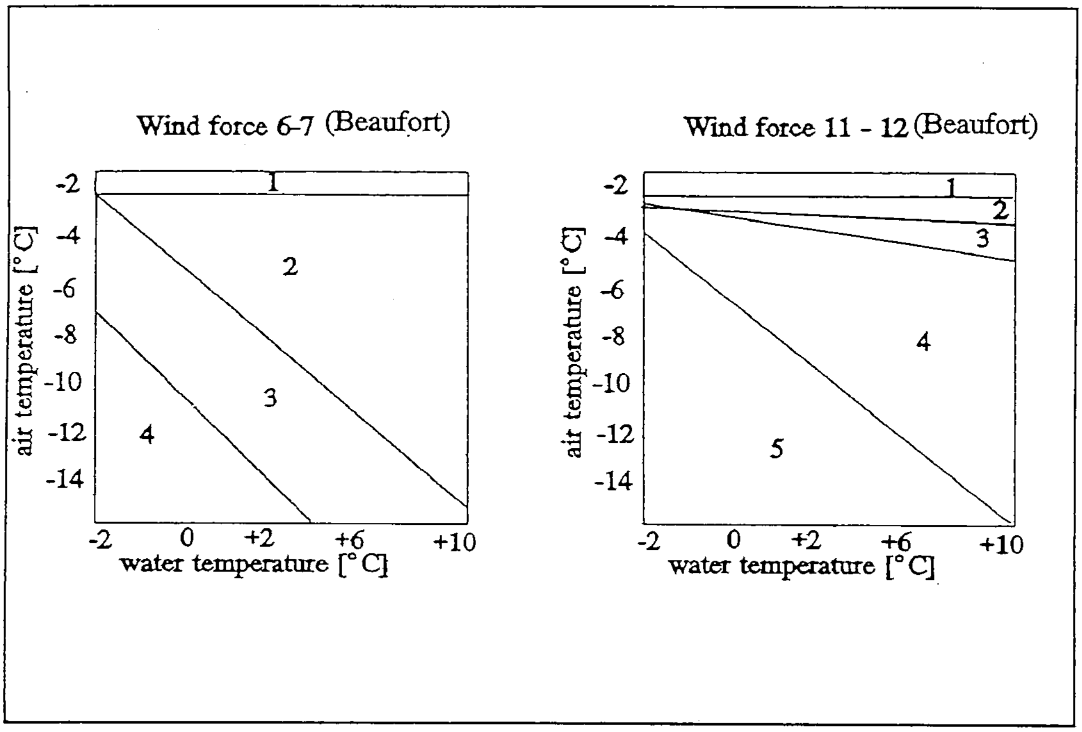


Figure 2.20 *Degree of ice accumulation on ships in different wind and temperature conditions. The diagram is developed for use on deep sea trawler type vessels.*

1 - none
2 - little (1 -3 cm/24 hrs)
3 - moderate (4 - 7 cm/24 hrs)
4 - high (7 - 14 cm/ 24 hrs)
5 - extreme (15 - 24 cm/24 hrs)

If the ship has a large accumulation area above the water line it is easy to calculate that the weight of the ice quite soon can be several hundred tons. As the ice accumulates the period of roll will increase and indicate reduced stability. If nothing is done to remove the ice the ship can suddenly roll over and sink.

The areas where most icing incidents occur are in the Barents Sea, the Northern Atlantic and in the Northern Pacific (fig.2.21).

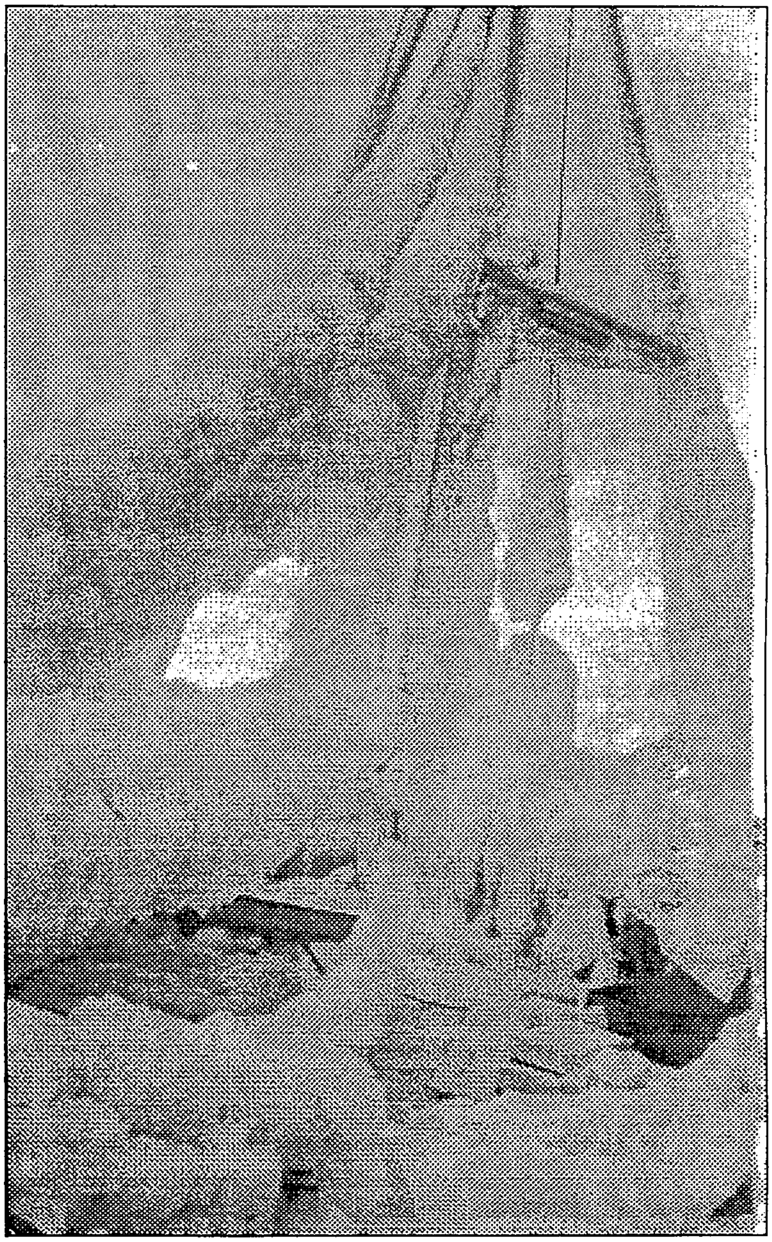


Figure 2.21
Severe spray ice on a trawler operating in Arctic areas.

Along the coast of Siberia the shallow water and ice covered surface will reduce the wave height and the exposure to ice accumulation. Stability problems due to spray icing on large vessels navigating the NSR will consequently be rather rare.

The other situation of importance to stability for ships navigating in ice is the lifting force imposed when the ship is ramming and being lifted on to the ice sheet. From a stability point of view this can be seen as a weight taken out of the bottom of the ship and consequently the resulting center of gravity will be raised - and the stability will be reduced (fig.2.22).

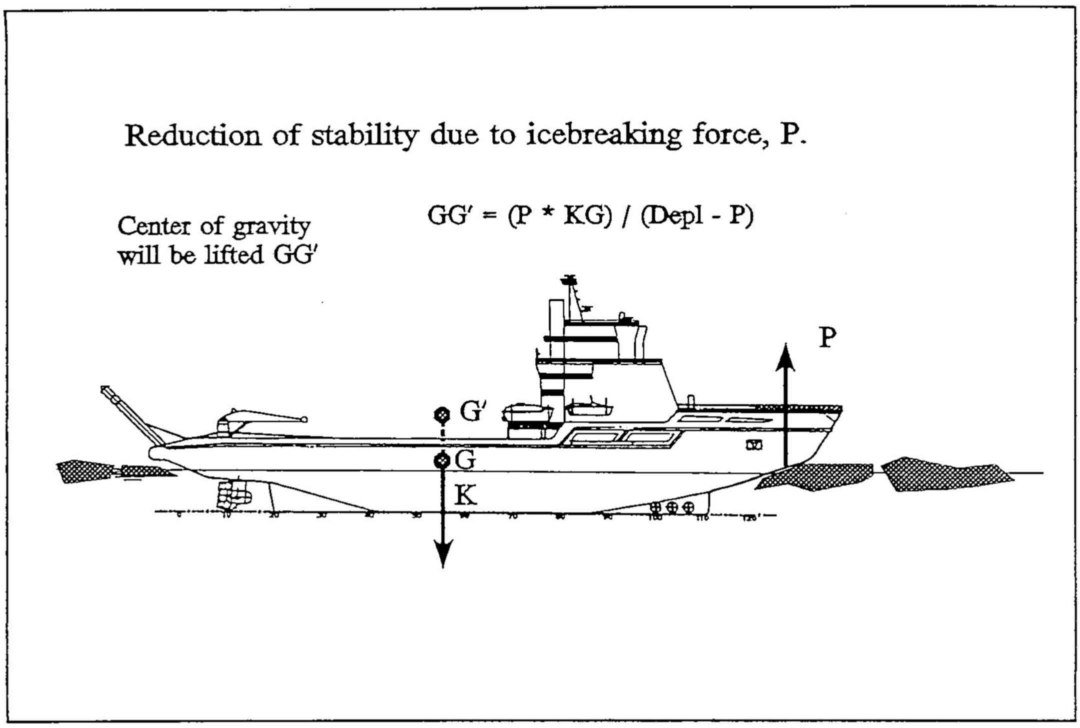


Figure 2.22 *A ship's center of gravity will be raised during icebreaking and the stability will be reduced.*

All vessels built for Arctic operations will be equipped with stability documentation where different examples of icing and ice rafting are calculated. Ship officers responsible for the safety of the ship should carefully study these examples to become familiar and confident with the stability performance of the ship.

2.6.3 Cold weather survival

Ship evacuation in cold regions may expose you to a hostile environment. Survival may depend on the available equipment and the knowledge of survival techniques. When the order comes to evacuate the ship there will very little time to think about such items as personal clothing or equipment to bring onto the ice or into the life boat / raft. A personal Arctic survival kit should therefore be prepared before an incident occurs. It is also important to train on abandoning the ship in ice and have lifeboat drills also when sailing in ice-infested waters.

When abandoning ship in low temperatures it is extremely important to stay together, keep warm and find shelter from wind. The cooling effect due to wind must not be underestimated (fig.2.23)

Wind Speed		Temperature (Celsius)									
		-8	-12	-16	-20	-24	-28	-32	-36	-40	-44
knots	km/hr	Equivalent Chill Temperature									
3	6	-8	-12	-16	-20	-24	-28	-32	-36	-40	-44
5	10	-13	-17	-22	-26	-31	-35	-40	-44	-49	-53
11	20	-21	-26	-31	-36	-42	-47	-52	-57	-63	-68
16	30	-25	-31	-37	-43	-48	-54	-60	-65	-71	-77
22	40	-29	-35	-41	-47	-53	-59	-65	-71	-77	-83
27	50	-31	-37	-43	-49	-56	-62	-68	-74	-80	-87
32	60	-32	-39	-45	-51	-58	-64	-70	-77	-83	-89
38	70	-33	-40	-46	-52	-59	-65	-72	-78	-85	-91
43	80	-34	-40	-47	-53	-60	-66	-73	-79	-86	-92
49	90	-34	-40	-47	-53	-60	-66	-73	-79	-86	-92
54	100	-34	-40	-47	-53	-60	-66	-73	-79	-86	-92
		Increasing Danger (Flesh may freeze within 60 seconds.)				Great Danger (Flesh may freeze within 30 seconds.)					

Figure 2.23 *Equivalent wind chill temperature. (Source: NOAA).*

Let us consider average February conditions at Dikson, windspeed 15 knots and temperature -21°. The equivalent chill temperature under average conditions is below -40°C, and there will be a danger of freezing within 60 seconds. It is therefore important to build a shelter as fast as possible and be aware of the polar bear, which is a real danger. Before sailing in Arctic waters the Marine Survival Handbook For Cold Regions, developed by the Canadian Coast Guard, should be studied.

If the accident occurs in the relatively open drift ice where the floes are too small to build a shelter it will be important to manoeuver the lifeboat into open water to prevent damage to the thin fiberglass hull (fig. 2.24)

> It is important to maintain the safety routines and lifeboat drills also in the Arctic.

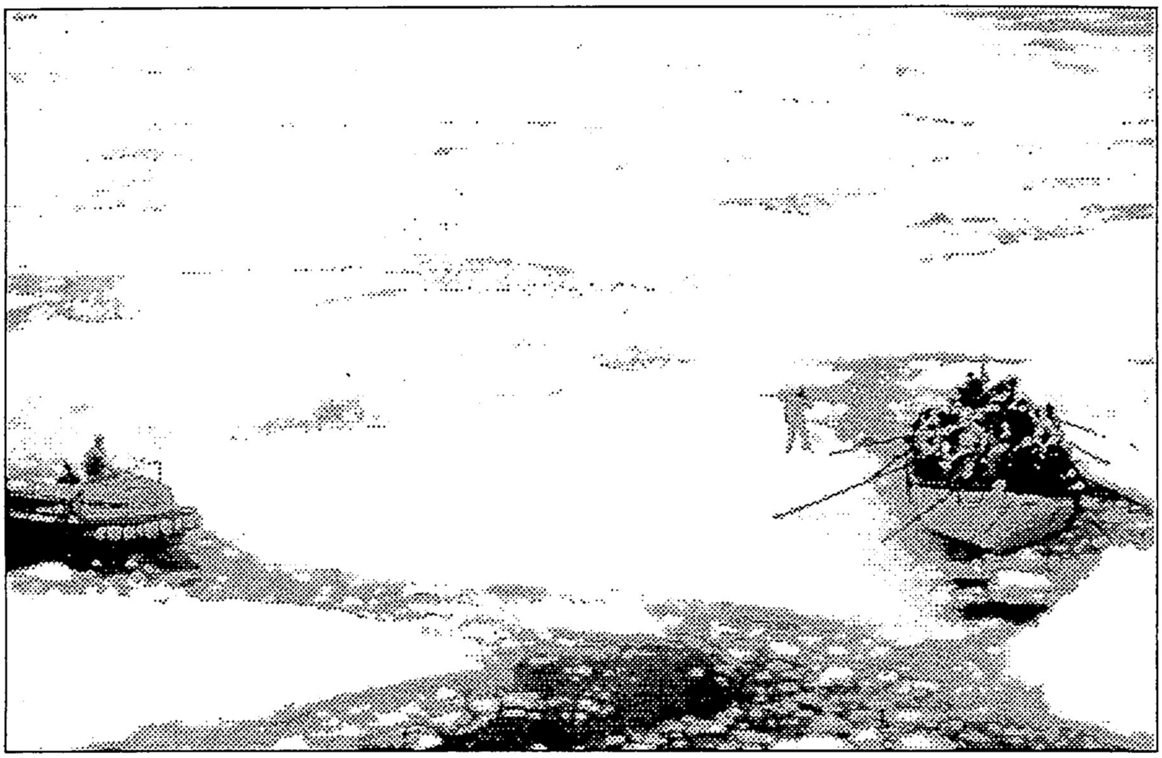


Figure 2.24 *Lifeboat from the passenger vessel Maxim Gorkiy after the accident in the drift ice west of Svalbard, June 1989 (Source: Norwegian Coast Guard)*

3 Ship Technology and classification

3.1 Classification rules

Classification of ice going vessels has been a matter of what kind of ice the ship is designed for and how the ship is intended to operate in the given conditions. The ice categories can be divided into four :

- Continuous movement in first-year level ice.
- Influence of broken first-year floes (e.g in a lead)
- Ramming against an ice edge and ridged ice.
- Exposure of ice pressure and multiyear ice.

The two first categories can be considered as moderate and make the basis requirement for strengthening of merchant vessels. These vessels are often called "Baltic" classes and will normally be assisted by icebreakers if the ice concentration is closer than 6/10 - 7/10. The third and fourth category of ice will require much more strengthening and will often be reflected as "arctic" classes or icebreakers.

Merchant ships in different classification societies and regulatory regimes will have the approximate equivalencies as shown in table 3.1

Table 3.1 Approximate equivalencies in ice class notation in different classification societies.

Rank	High			Low
Russian Register	ULA, UL	L1	L2	L3
Det Norske Veritas	1A*	1A	1B	1C
New Canadian	A	B	C	D
Lloyds Register	1AS	1A	1B	1C

According to the NSR regulations (ref. vol.1, chapt.2.1) the NSR-Administration will normally demand minimum ice class L1 in the Russian Register or equivalent. The Russian merchant ships used for year round navigation on the NSR, like the Norilsk-, and Sevmorput-class, are all classed as ULA. A significant difference between Russian regulations and other classes is the bow shape. In the Russian regulations a conventional ice bow is demanded for arctic navigation, while classification societies like DNV allow bulbous bow also on 1A and 1A* classes due to better open water performance. The main reason for not allowing bulbous bow on the NSR vessels is the enormous forces induced during a short tow after icebreakers (ref. chapt.2.4.6 and fig. 3.1).

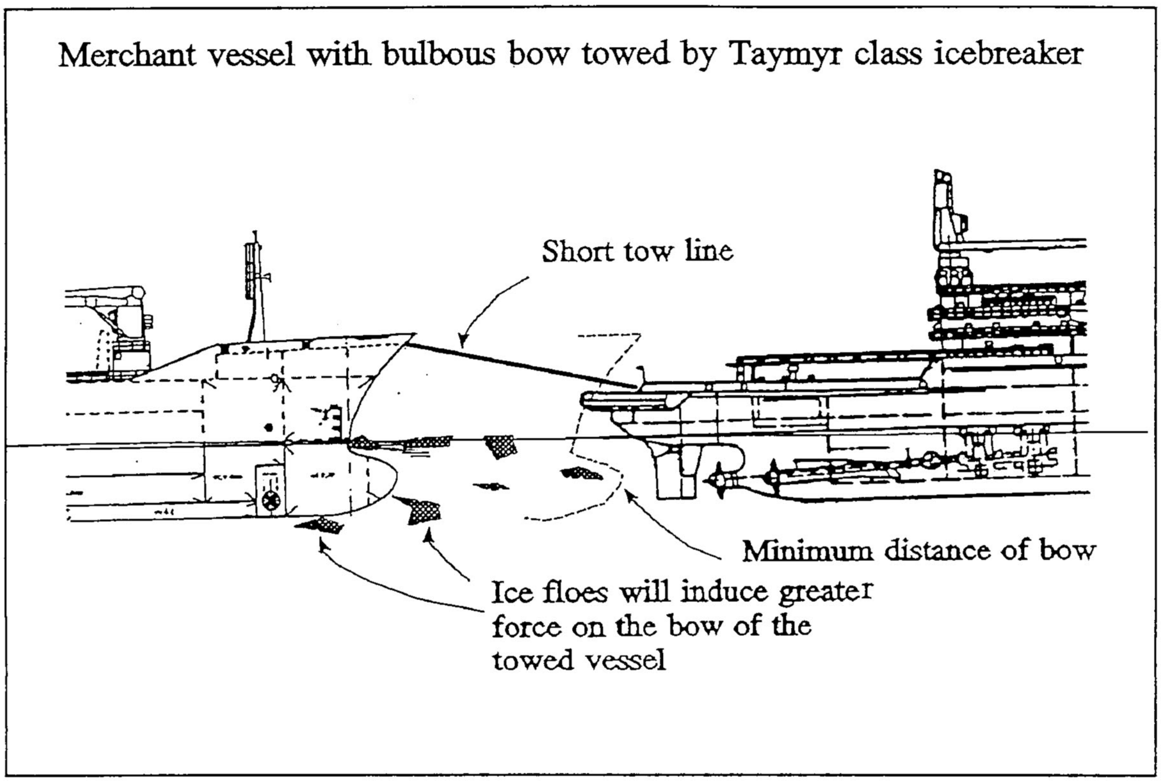


Figure 3.1 *Merchant vessels with bulbous bow will normally not be given permission to sail the NSR due to extreme loads during close tow operations after icebreakers.*

Icebreaking ships in different classification societies and regulatory regimes will have the approximate equivalencies as in table 3.2.

Table 3.2 *Approximate equivalencies in ice class notation on icebreakers in different classification societies.*

Rank	High			Low
Russian Register	LL1	LL2	LL3	LL4
Det Norske Veritas	Polar30	Polar20	Polar10 Ice-15	Ice-10
New Canadian	CAC-1	CAC-2	CAC-3	CAC-4
Lloyds Register	AC-3	AC-2	AC-1.5	AC-1

Icebreakers used on the NSR have the following class notation:

- Arktika class LL1
- Rossia class LL1
- Taymyr class LL2
- Yarmak class LL2
- Kapitan class LL3
- Moskva class LL3
- Mudyug class LL3

The design criteria for the different ice classes has traditionally been based on the following issues:

- Frame and stringer spacing and dimensions
- Shell plate dimension and steel quality
- Engine power and propeller dimension

In the different ice classes separate specifications are related to:

- Global strength (bending moment, etc.)
- Local strength (stress, shear force, etc.)
- Steel quality (low temperature)
- Engine power, propeller and rudder arrangements
- Hull design (flare, ice bow, ice knife, etc.)

The boundaries for different strengthening on a hull varies a little bit from regime to regime but the illustration below based on Det Norske Veritas rules illustrates the different areas (fig.3.2).

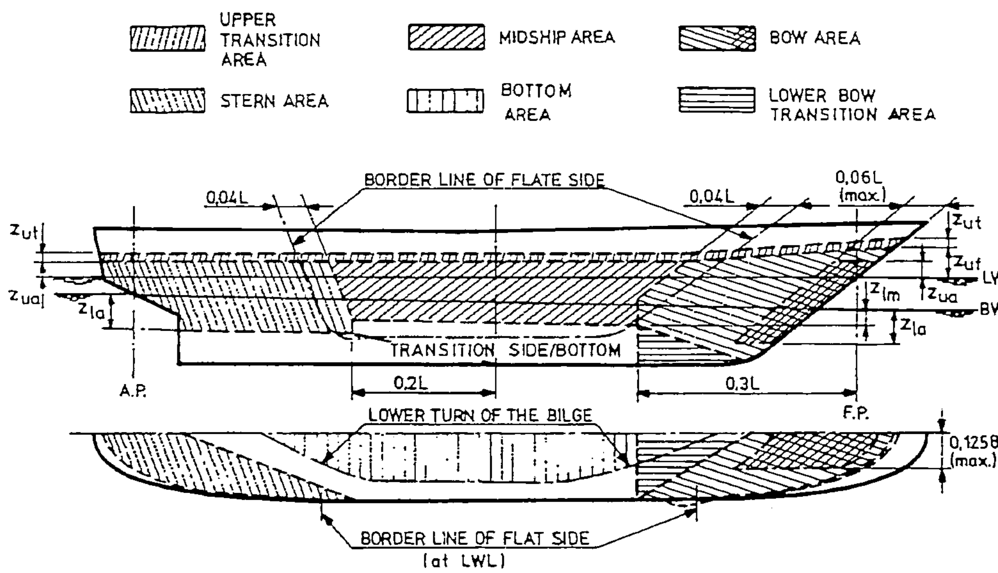


Figure 3.2 *Ice strengthening boundaries on ships classed in Det Norske Veritas (Source: DNV)*

Revision of the ice classification philosophy (ref. chapter 3.2) will also apply new and important issues related to the ice class determination. Such issues are:

- Hull design and maneuverability
- Operational aspects
- Crew capability (experience and training level)

3.2 Harmonization of ice-classes and ice regimes

Introduction

During recent decades ice classification and ice regimes have been based on local needs for safe shipping in their relevant economic zones. The main nations affected are Russia, Finland / Sweden and Canada which have all developed their own regimes. Other Arctic nations such as Norway and the United States have basically adopted the regulations from Finland and Sweden as the basis of their national ship classification.

When the USSR opened the Northeast Passage (Northern Sea Route, NSR) to international shipping in 1991 they turned into reality a new and very interesting circumpolar shipping possibility. At the same time regulations governing navigation in ice became a global rather than a local issue resulting in a significant step forward in standardization of ice classification and navigation regime. The consequence will be seen in increased safety and improved efficiency. Until today the classification societies (except the Russian Register) have based their requirements on the Finnish/Swedish rules, also called the "Baltic" classes. Technological achievements are also vital elements when discussing a new world order in Arctic shipping.

3.2.1 Present regulations for ice navigation

As mentioned in the introduction there are in general three ice-regulation regimes controlling the standard of Arctic shipping, the Canadian, the Finnish/Swedish and the Russian. There are fundamental differences in these regimes based on the fact that the rules are tailored to local needs. Responsible port states can proscribe additional requirements but are very much dependent on the class rules and the inspections provided by class surveyors.

The Canadian Model

Under the Arctic Shipping Pollution Prevention Regulation (ASPPR-72) Canada imposed restrictions on ships navigating in the Canadian Arctic. This regime is based on a rigid geographical zone / date system by which ships with a certain ice class are allowed to enter one of the 16 zones at a certain date. The date is calculated from statistical ice data in the given zone. This is generally perceived to lack flexibility since it does not take into account yearly variations in ice severity. The design conditions of that Canadian model require the ship to have capability to operate independently of icebreaker support. Icebreakers are available if needed but the icebreaker fleet is rather limited. The design criteria is divided into 9 ordinary classes and 5 lower classes.

As a consequence of the lack of flexibility of the old regime, a new regime was proposed in 1989. This regime, often referred to as the CAC regime, would permit access to any geographical zone depending on the prevailing ice conditions. Ships would be categorized according to the type of ice in which the ship could safely operate, notation on the 9 categories: CAC 1, 2, 3, 4 and A, B, C, D, E. The new regime would also include more operational aspects e.g. demand special skills of the crew. The crew would be required to use their own skills to determine the prevailing ice conditions based on mathematical calculations. The new system came into force in 1995. It is anticipated that the old and new schemes will operate concurrently, the ship operators having the choice of whether to have ships built according to the old or new standard.

The Russian model.

Based on vast experience of Russia's ice stewn waters along the Northern Sea Route and in the Baltic, the rules of the Russian Register were revised in 1982. The ordinary classes (except that of the icebreakers) are now divided into 5 categories (ULA, LA, L1, L2 and L3). The operation philosophy has been based on powerful Arctic icebreakers (many of them nuclear powered) which should escort a merchant fleet with limited ice capabilities. After implementation of new regulations for international shipping in 1991, the Russian authorities permit access of foreign vessels to Arctic waters on a "case-by-case" basis. All foreign vessels will have to carry a State ice pilot and follow a proscribed route.

The Finnish/Swedish model

All vessels calling at a Finnish or Swedish port during the winter season are assigned an ice-class as defined in the rules (1A-Super, 1A, 1B, and 1C). This assignment will be based on the ice situation at a given time and for a given area. The major classification societies reflect these "Baltic"-classes, and the authorities accept the equivalencies between them. Ice class and tonnage are reflected in the port and fairway fees.

3.2.2 New philosophy in ice classification is needed

In view of the potential for circumpolar navigation and an increased interest in passenger cruises to Arctic areas harmonization of existing ice classes is obviously needed. Such an international process was quite recently initiated by the Finnish Board of Navigation and in which the Canadian Coast Guard also played an important role. Canada's role is significant in view of their new CAC regime. Some of the aims of the harmonization process are to agree on common rules and equivalencies and prepare a proposal to IMO for a future IMO-Polar resolution or an amendment to existing IMO conventions such as MARPOL and SOLAS. Issues which will be included are :

- Environmental Protection
- Technical standards of ships
- Training program for ice navigators
- International control systems and emergency capabilities.

An Ice Navigation course could be included in the IMO list of short courses for navigators holding a navigator's or master's license. For navigators operating other special vessels such as tankers, IMO short courses are now demanded as a prerequisite to signing on such ships. The theoretical part of an ice navigator course could easily be included in the college curriculum, and in Norway the Maritime Colleges in Ålesund and Tromsø have developed such a course and are prepared to meet the new Arctic shipping challenge.

Improved safety and greater effectiveness

The implementation of a new circumpolar ice-classification standard would ensure much more effective application routines. A case-to-case evaluation of the ships would not be necessary, which means that the ice-classed tonnage could take quicker decisions. A common standard of the ice classification would also provide a higher level of safety and reliability for the operators and other parties involved in Arctic ship operations. Improved safety would hopefully also be reflected in the insurance costs and contribute to making the Arctic more lucrative for shipping. For ship insurers this new era will be a challenge. First of all they have to include the entire Arctic in their portfolio - e.g. the Northern Sea Route is not included at present. If the new ice classification results in an increase in safety, there should also be room for reduced insurance rates. Another very important issue will be IMO's attitude towards adopting the new philosophy.

We can conclude by saying that we are on the brink of a new Arctic shipping era if all new elements relating to the harmonization of ice-classes can be tied together and agreed on by all parties involved.

3.3 Icebreakers and performance enhancing systems

The many icebreakers operating on the NSR is probably the most important part of the infrastructure in the area. The quality of an icebreaker can be described by the;

- Icebreaking capacity
- Maneuverability
- Open channel
- Large operational range
- Minor environmental influence

Since the icebreaker often has the local coordination responsibility for the traffic, the ship should also have advanced communication an navigation systems.

More efficient icebreakers where the mentioned qualities have been taken care of have been developed during the last 2 decades. New low friction hulls with enhanced icebreaking performance are now operating along the NSR, in the Baltic and in the Canadian Arctic.

The bow

The bow on an icebreaker is normally designed for optimal icebreaking performance, but will also have to compromise on open water performance. The bow breaks the ice in a two step operation. First the ice will be bended down and then the floes will be pushed to both sides like illustrated on figure 3.3.

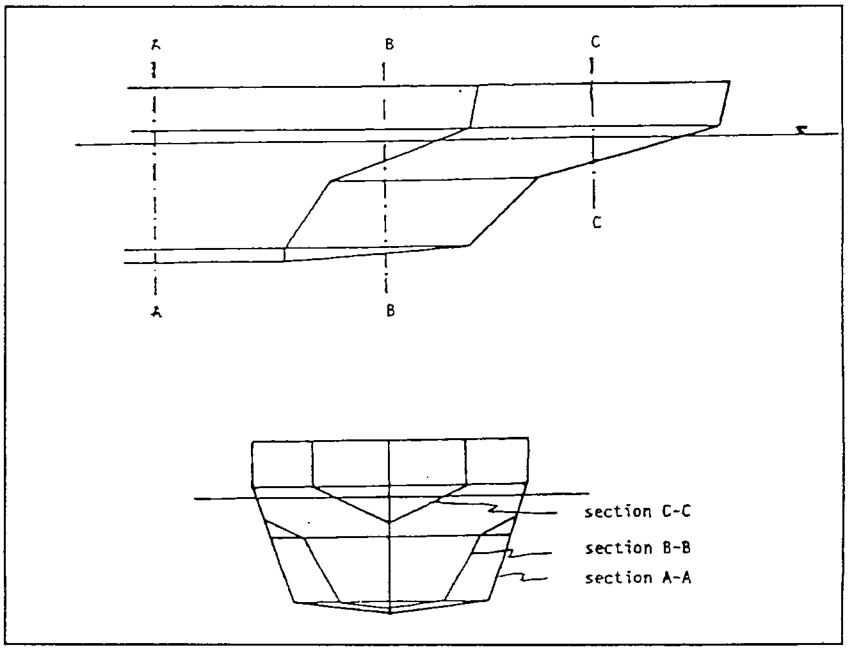


Figure 3.3
Sketch showing the principles of an idealistic , two step, bow on an icegoing vessel (Herfjord, 82).

A lot of research has been done to optimize the bow design and some icebreakers have been redesigned. Three main design groups can be considered (illustrated in figure 3.4):

- Conventional icebreaker bow
  (most Russian icebreakers)
- Spoon and semi-spoon bow
  (Taymyr-class and Kapitan Nikolayev)
- Thyssen Waas bow
  (Mudyug and Kapitan Sorokin)

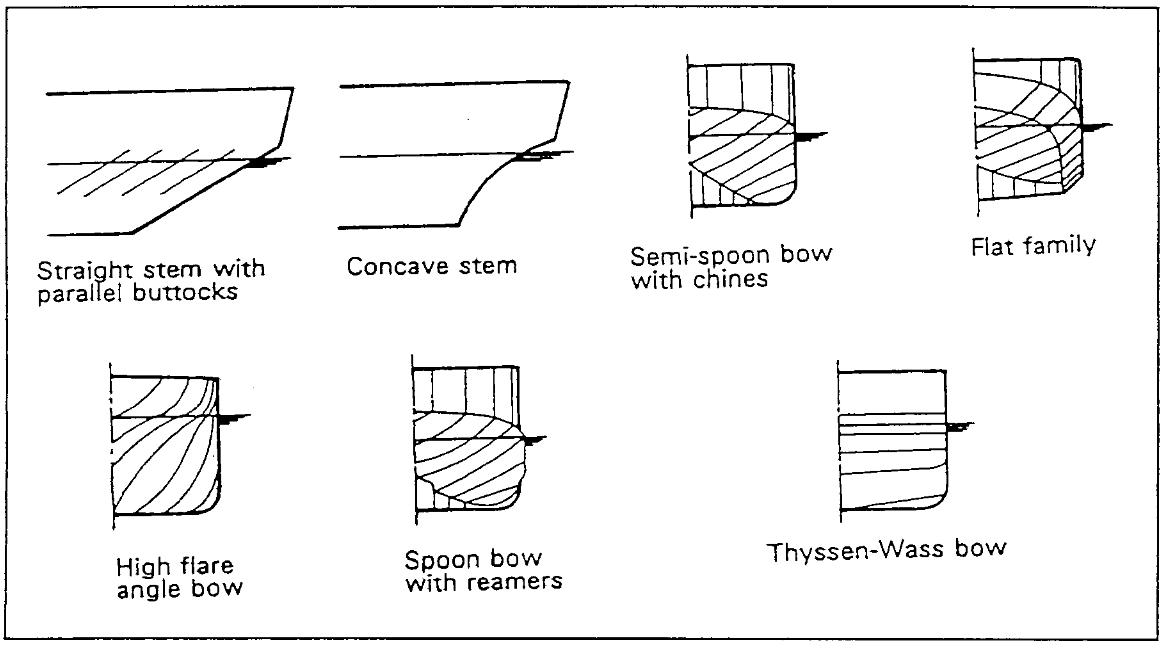
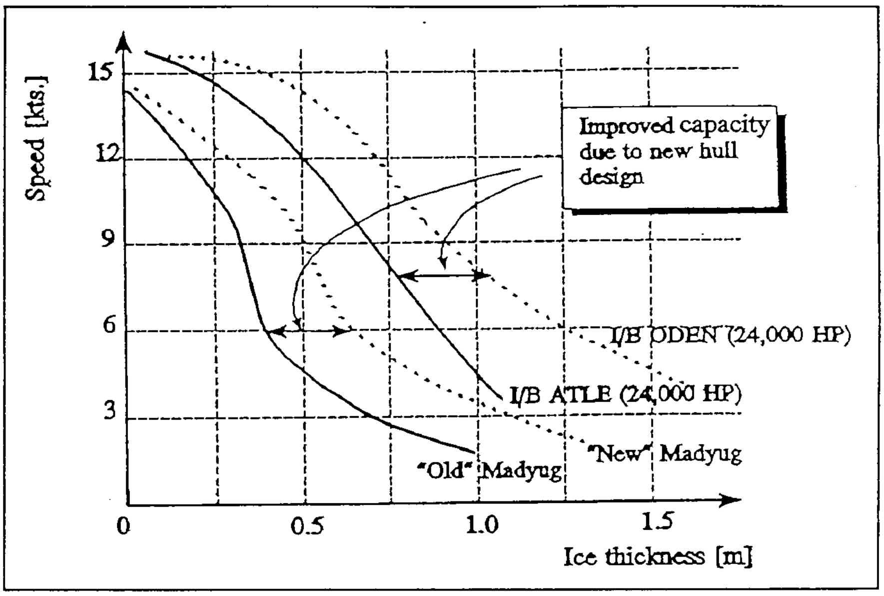


Figure 3.4 *Different bow form features on ice-going vessels (CCG,92).*

The conclusion gained from field operations with the new design is that the icebreaking capacity and clean channel quality is significantly improved in certain ice conditions by the new designs, especially in level first year ice (figure 3.5).

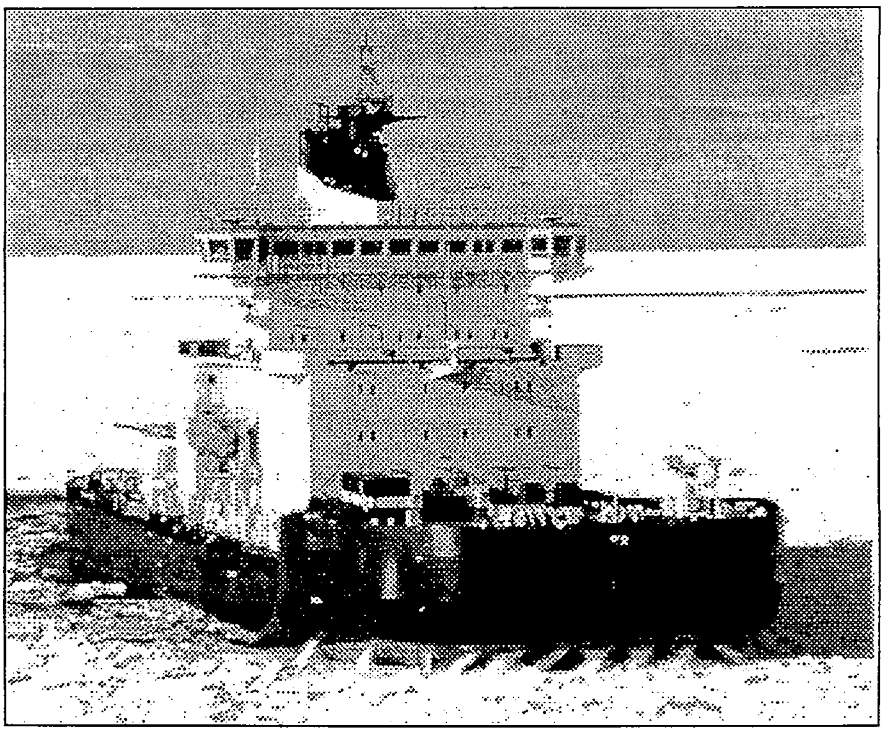
The best conventional shapes have proved to be the best in difficult ice conditions and in open water. Some of the new "effective" bows will in some cases have a negative effect on maneuverability and will increase the turning circle diameter. Heeling the ship can in such cases reduce the turning diameter.

Figure 3.5
Icebreaking performance can be significantly improved by new design.



An important factor for the friction between the ice and the bow is if the ice is covered by snow. The snow cover will increase the friction significantly, especially on the modern bow shapes. To reduce this friction some icebreakers are equipped with water jets pumping water onto the bow contact area (figure 3.6)

Figure 3.6
The Swedish icebreaker Oden is using water jets in the bow to reduce ice friction (Source: Swedish National Maritime Adm.)



The midbody
The midbody shape is an important factor for friction and maneuverability. A certain flare angle or concave shape is important in case of ice pressure (figure 3.7). While icefloes are forced alongside while the ship is moving forward the friction along a parallel midbody would be very high. Longitudinal tapper, steps or reamer construction will effectively reduce side friction.

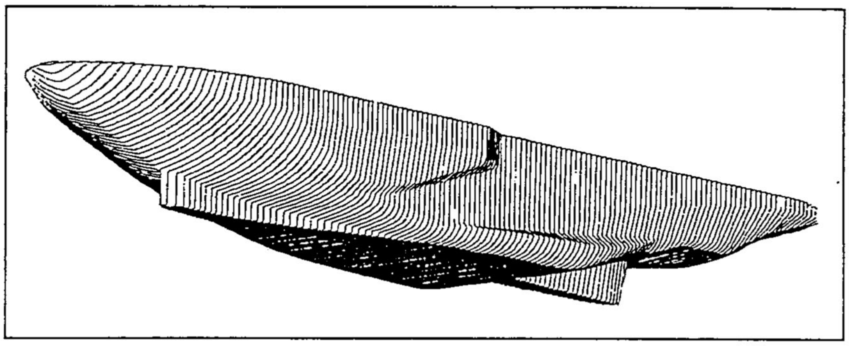


Figure 3.7
The hull of the Finnish icebreaker Fennica is designed to combine effective icebreaking and open water performance (Source: Finnyards).

Large vessels with parallel midbodies are often equipped with an air bubble system. This system will force compressed air through nozzles below the waterline and lubricate the interface between the hull and the icefloes (figure 3.8). By closing some nozzles the airbubble system can also provide side thrust for maneuvering and berthing.

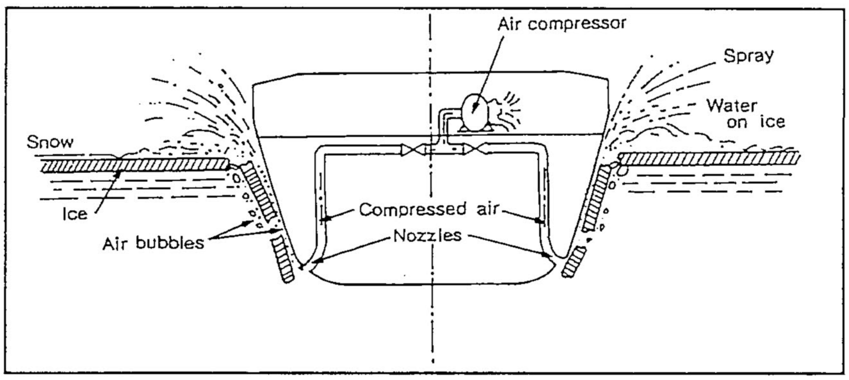


Figure 3.8
Air bubble system reducing ice friction alongside. Can also be used as side thrusters (Source: Wartsila).

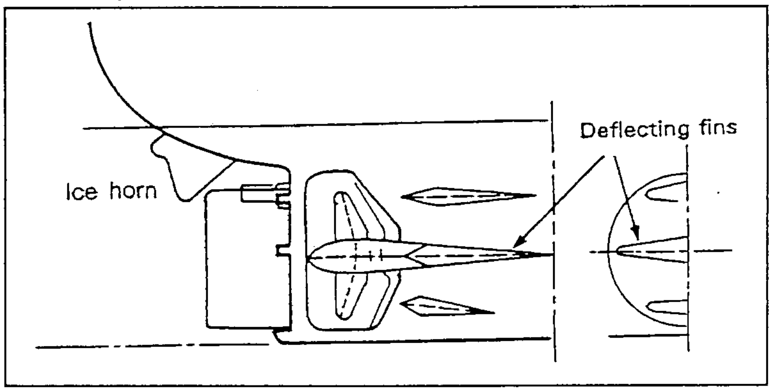
All Rossiya- and Taymyr class icebreakers and the merchant ships of the SA-15 type (Norilsk-class) are equipped with an air bubbling system.

Many of the Russian icebreakers are coated with low friction epoxy coating (Inerta-160) to reduce ice friction.

Stern shape and propeller protection
The main purpose of the stern shape is to protect the propellers and rudders from ice loads. Modern icebreakers can

be designed with a ramped stern to allow broken ice to move upward to the surface well in front of the propellers. Propeller protection like nozzles and deflecting fins are not used on Russian icebreakers. Most icebreakers have one rudder. To protect the rudder during backing, an ice horn is located behind the rudder (figure 3.9).

Figure 3.9
Stern protection devices (CCG,92).



Some icebreakers with two rudders like the Swedish Oden are equipped with rudder stops. None of the Russian Arctic icebreakers are equipped with more than 1 rudder. Ships equipped with azimuth thrusters are not equipped with rudder (fig.3.10)

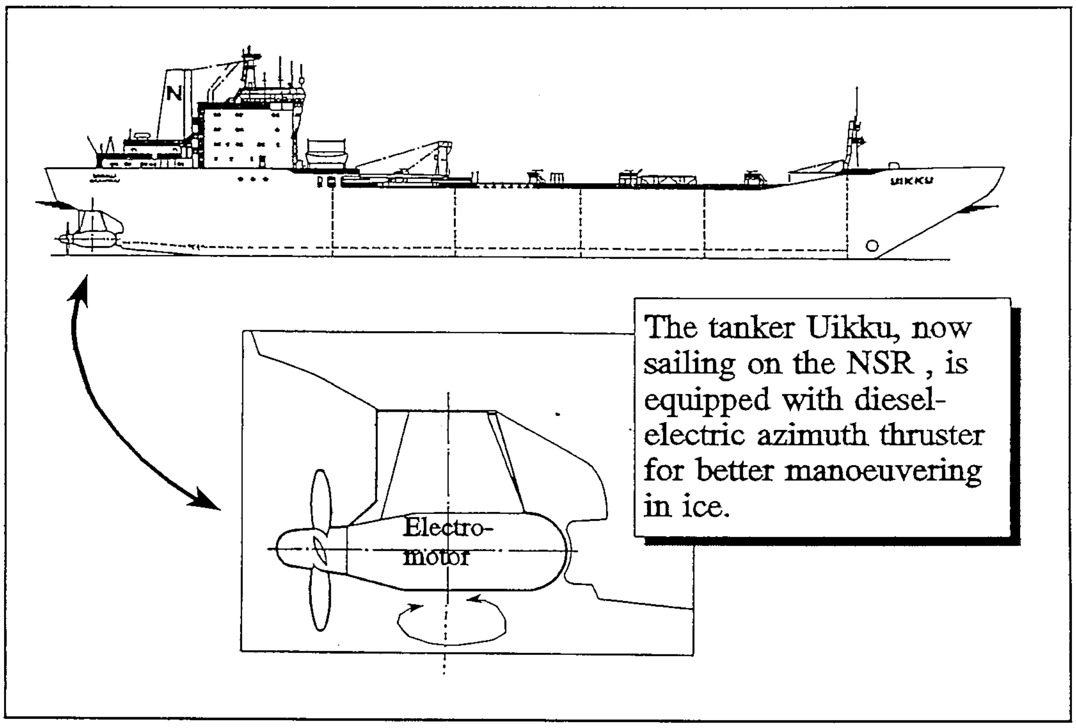


Figure 3.10 *Azimuth thrusters have shown very promising results on the new finnish icebreakers. Here shown on the tanker Uikku (Source: Kværner Masa Yard).*

On figure 3.11 all relevant factors are indicated on the shallow draft icebreaker of the Taymyr class.

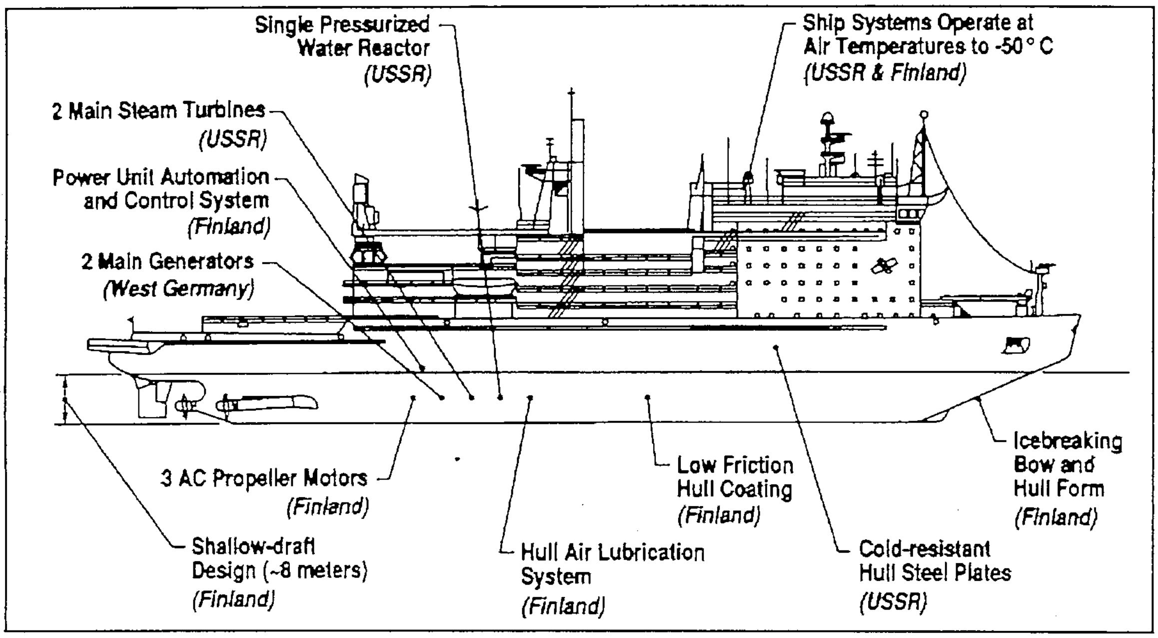


Figure 3.11 *Shallow draft nuclear icebreaker of Taymyr class with relevant system for high performance icebreaking (Brigham, 91)*

3.3.1 The Russian icebreaker fleet and future perspectives

Today the fleet of icebreakers consists of 20 polar icebreakers, of which 7 are nuclear powered. In addition there are 18 subarctic icebreakers. If we include river, harbor, salvage and research icebreakers we will end up with a total number of approximately 80. One more nuclear ship of the Rossia class, the Ural, is under construction in St.Petersburg and will probably be operational on the NSR in 1996. The Arctic icebreakers of the Moskva class, built in the sixties, is the next class to be replaced by new ships. For this purpose a new concept called the Anadyr class is under development (figure 3.12)

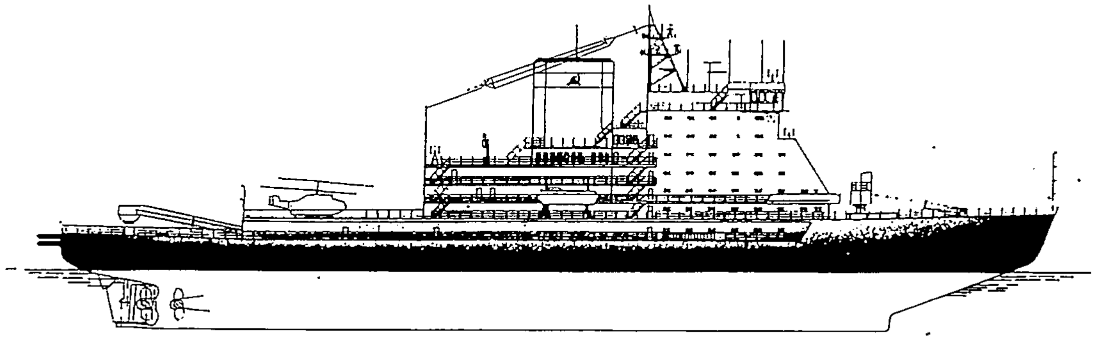


Figure 3.12 *The new diesel-electric icebreaker concept called the Anadyr type is planned to replace the Moskva- and Yarmak-type icebreakers early in the next century.*

3.4 Merchant Ships

3.4.1 Present ice classed potential

When discussing the potential for international use of the Northern Sea Route and a global approach to the ice navigation issue, it is important to survey the existing fleet with ice class in different societies. Accurate numbers of ships in each category will be difficult to find due to changing regulations and situation dependent classes, but the numbers in table 3.3 will give a fairly good idea of the situation. The information is based on data from the major classification societies / registers.

Table 3.3 *Ice class notations of the major registers (in brackets) and number of ships in each group. The column of ice class notations are considered to be approximately equivalent to the rules referred to at the top of the table. A certain degree of personal judgement has been used by the author when establishing the numbers of ships in each ice class notation, as vessels built to old rules, having old notations, etc. Some figures may therefore vary slightly from other published figures, due to interpretation of definitions (Kjerstad,94).*
Note 1) This group of DNV vessels represents vessels with the old notations "Icebreaker" and "Sealer".

Finnish/ Swedish rules		1A Super	1A	1B	1C
Canadian ASPPR regulations	CAC-4	A	B	C	D
Det Norske Veritas	9 see 1)	55 (1A*)	191 (1A)	116 (1B)	1293 (1C)
Lloyds Register of Shipping	-	65 (1AS)	312 (1A)	154 (1B)	725 (1C)
Germanischer Lloyds	1	13 (E4)	291 (E3)	277 (E2)	421 (E1)
American Bureau of Shipping	-	7 (IAA)	21 (IA)	8 (IB)	293 (IC)
Russian Register of Shipping	40 (ULA)	580 (UL)	928 (L1)	1427 (L2)	3774 (L3)
Bureau Veritas	-	9 (IA-S)	114 (IA)	157 (IB)	670 (IC)
Nippon Kaiji Kyokai	1 (1A-S+	1 (1A-S)	2 (1A)	- (1B)	4 (1C)

If we take a closer look at the kind of ships which are considered capable of providing ice-going capability by the different societies, this will vary a little bit between the societies. For shipping in the Arctic regions the "1A super" and the "1A" category are of special interest. If we consider the numbers from Det norske Veritas as representative we find the following fleet structure:

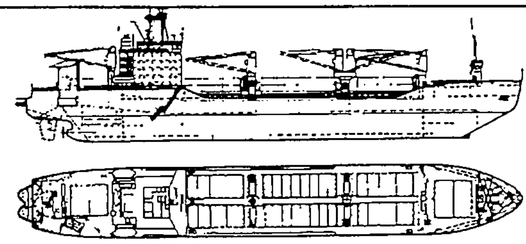
General Cargo vessels	87 ships
Bulker / Tanker vessels.............	61 "
Passenger / Ferries	40 "
Offshore / Research / Tugs	21 "
Fishing / Catching	32 "
Other	5 "
Total class 1A* and 1A in DNV	246 ships

In general it can be concluded that the majority of ships are small and medium-sized general cargo vessels. The range of categories is quite similar in the other societies (with the exception of the fishing /catching category). Consequently most of the ships in the ice-classed fleet of the world will have a draft suitable for the limited depths found on the Northern Russian Shelf.

The number of ships classed for Arctic icebreaking is considerably lower and consists of less than 20 ships outside Russia. In Russia there are 23 polar icebreakers and 40 cargo vessels in the ULA category, which have been strengthened to bring them close up to the icebreaker category.

3.4.2 Details on some NSR cargo vessels

Main specification on the NSR workhorse, the SA-15. Since 1982 19 ships of the SA-15 vessels (Norilsk-class) have been built in Finland. The ships are specially designed for multi purpose operations on the NSR. The ships have since then become the most important vessels for transportation of bulk and general cargo on the NSR. The majority of vessels have been operated by Murmansk Shipping Co., but also the Far East- and the Sakhalin Shipping Company operates SA-15 vessels. The notation SA-15 indicates that the ship can be operated in 1.5 meter thick Sub Arctic ice.



Sisterships: Archangelsk · Kapitan Danilkin · Kandalaksha · Kola · Monchegorsk · Nikel · Tiksi · Yuri Arshenevsky

Built at the Shipbuilding Yard Wärtsilä, Turku, Finland, 1982	Ship's type The single-screw, double-deck motor ship with long forecastle, long poop, intermediate engine room and house, corner ramp, ice-breaker bow and transom stem

General				Main particulars			
Classification KM ✳Y ^ A I A2				Length o.a.		m	173.5
Register tonnage	gross	g.r.t.	17,910	Length b.p.		m	159.6
	net	n.r.t.	9,484	Breadth moulded		m	24.0
Service speed	full-loaded	knots	17.0	Depth moulded		m	15.2
	in ballast	knots	17.6	Summer load-line draft		m	10.5
Navigating range		miles	16,000	Loaded displacement		t	30,758
Crew		pers.	39	Deadweight		t	19,942
Height of mast above the base-line		m	51.0	Loading capacity		t	15,648
Capacity	bale	m³	25,200	Light draft	forward	m	1.10
	grain	m³	3*.185		aft	m	7.45
	containers	TEU	576	Loading capacity per 1 cm draft		tpcm	
				Type of hatch-covers	Upper deck end-rolling	Tweendecks hinged to ends	

Description, dimensions and capacities of cargo spaces

Space No.	Holds: Dimensions, m: Length	Breadth	Height	Capacity, m³: grain	bale	containers, TEU	Tweendecks: Dimensions, m: Length	Height	Capacity, m³: bale / grain	containers, TEU	Deep-tanks: Capac., m³: grain	Cargo hatches: Dimensions, m: Length	Breadth
1	12.25	20.5	4.50	978	800	4	19.0	5.0	3,100 / 2,799	40	900	12.8	13.0
2	27.0	18.0	8.50	3,637	2,900	96	27.0	5.0	2,900 / 3,793	48	2	19.2	2 × 8.0
3	33.25	18.0	8.50	4,257	3,900	144	33.25	5.0	3,800 / 4,760	64	2	25.6	8.0
4	23.75	18.0	8.50	3,255	2,300	108	23.75	5.0	2,200 / 3,431	44	2	19.2	
5	*1.0	22.0	2.25	502	500	4	21.25	5.25	2,000 / 2,746	24		12.8	11.0
5	–	–	–	–	–	–	–	–	– / 607	–			
Total				13,409	10,400	356	Total		14,000 / 18,136	220	900		

Ship stores: Description		Mass, t	Daily consumption, t/day: Under way	in port: cargo operation	no cargo operation
Fuel	diesel oil	783	2.0	2.0	1.0
Fuel	high viscosity fuel	3,743	76	7.0	5.0
Lubricating oil		185	0.6	0.1	0.1
Boiler water		44.4	–	–	–
Fresh water		457	13.2	13.2	10.0
Fuel heating		provided			
Water ballast heating		provided			

Deck cranes: Type	Outreach, m	Number and capacity
electro-hydraulic	22	3 x 20
electro-hydraulic	20	2 x 40

Ventilation	
Cargo spaces	naturally and mechanically
Service spaces	naturally and mechanically
Accommodation	

Main machinery		
Two geared diesel engine of 14ZV 40/48 Wärtsilä-Sulzer type		
Built in Finland, 1982		
output	kW	2 x 7,700
	b.h.p.	2 x 10,500
Recommended fuel	cSt 50°C	180
	secR1 100°F	1,500
Type number and diameter of propellers	unit x m	VPP 1 x 5.6

Supplementary data

1 The ship is provided with a corner ramp 18 m long and 5.0 m wide

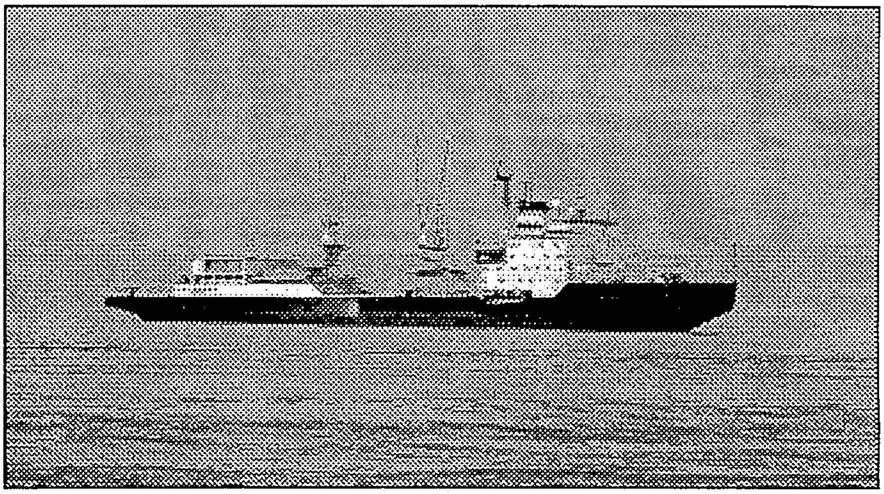
Figure 3.13
Main specification on the SA-15 vessel (Source: MSC)

Since the start of operation many impressive operations have been made - like transit sailings on NSR during the winter.

The Vitus Bering class

After the completion of the SA-15 ships, Russian shipowners started a new building program, sometimes called the SA-10 series. These ships are also called the Vitus Bering- and Ivan Papanin class, all built at the Kherson shipyard by the Black Sea. The ships are specially designed for Arctic station supply operations, where loading and unloading can be carried out by helicopter. A total of 7 ships have been built and they have the highest ice class, ULA (fig.3.14).

Figure 3.14
Vitus Bering type vessel (Source: FESCO).



3.5 Damage statistics and accident analysis

Obtaining a reliable statistical analysis of damages caused by ice has always been a problem due to tactical insurance strategy. A lot of ice damage has therefore been reported caused by other incidents in other regions. For the NSR unreliable statistics are no exception - when an incident has been registered it can be a result of many minor events.

In the period between 1954 and 1990 a total number of 800 damages have been reported on the NSR (Lenskiy, 93). Many statistical parameters are missing but some important information can be extracted from the figures. The reported damages can be categorized to have occurred in the following 5 different ice conditions:

- Ice pressure not caused by collision with ice
- Impact with ice when sailing unescorted
- Impact with ice while following an icebreaker
- Damage due to pressure from an icebreaker when towed
- Damage caused by an icebreaker trying to free a trapped ship

It is believed that many of the damages are caused by icebreakers in close-tow towing relatively old ships not designed for this type of operations. In the actual period many relatively old ships classed as L1 have been involved in damage incidents. Due to generally more difficult ice in the eastern part of the NSR there is a higher frequency of damages there compared to the western part. How the summer navigation damages are distributed is visualized in table 3.4

Table 3.4 *Percentage of ice damages in the eastern and western part of the NSR during the entire summer season (Lenskiy, 92)*

Month	Western area	Eastern area
June	5	7
July	16	20
August	25	38
September	35	26
October	19	9

To prevent damages and make good passage plans it is important to have information about the areas where damages most frequently occur. From the reported damages it is possible to conclude that some routes are more risky than others (table. 3.5).

Table 3.5 *Percentage of 800 ice accidents on different sections of different routes of the NSR (Lenskiy, 92).*

Route	Section of route	% of ice accidents
Novaya Yemlya -	Novaya Zemlya - Beliy Isl.	28
Yenisey ports	Beliy Isl. - Dikson	46
	Dikson - C.Sopochnaya Karga	17
	C.Sopochnaya Karga - Dudinka	9
Dikson - Tiksi	Dikson - West Vilkitsky St.	18
	In Vilkitsky Strait	38
	E. Vilkitsky - Tiksi	52
Tiksi - Pevek	Tiksi - Indigirka (Laptev St)	15
	Tiksi - Indigirka (Sannikova)	46
	Indigirka - Pevek	39
Pevek - Bering	Pevek - Cape Billings	30
Strait	Cape Billings - Cape Schmidta	53
	Cape Schmidta - Bering Strait	17

Since the early 70-s the navigation season has been extended. In table 3.6 the number of ice damages is related to ship class and ship age. From the table it can be seen that the highest ice class is not as exposed to ice damage as lower classed ships.

Table 3.6 *Number of ice-damages on cargo vessels and icebreakers during the extended navigation season (October - December) (Lenskiy, 92).*

Ice-class	Numbers of damages	Age of ships (years) 0 - 4	5 - 8	9 - 12	13 - 16	16
Icebreakers:						
LL2	2	-	1	1	-	-
LL3	3	1	-	-	1	1
LL4	3	-	-	-	3	-
Cargo ships:						
ULA	5	2	-	-	-	3
UL	11	2	9	-	-	-
L1	12	-	2	3	7	1
L3	1	-	-	1	-	-

Many of the damages reflected in table 3.6 must be considered as a result of experimental voyages in extremely difficult conditions. The majority of damages are located in the bow section and below the waterline (table 3.7)

Table 3.7 *Percentage distribution of ice damages related to ship section and vertical location (Lenskiy, 92).*

Section	% damages
Bow	67
Midship	23
Stern	10

As a concluding remark it can be said that the impact of damage could be reduced by:

- Higher ice class
- More effective icebreakers
- Reduced convoy speed
- More training and experience of the crew
- Better look out

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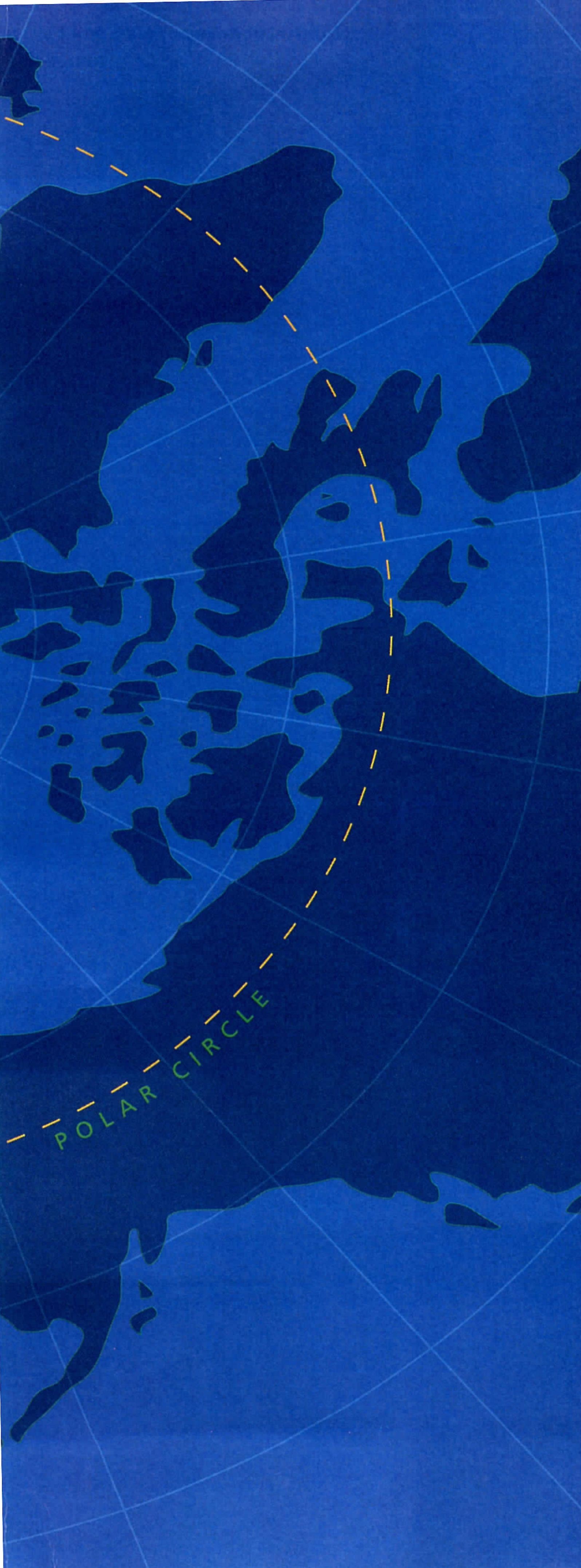

The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.
SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Sasakawa Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.
CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; shipping safety; technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stock-holding company.

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.
FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multi-disciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.