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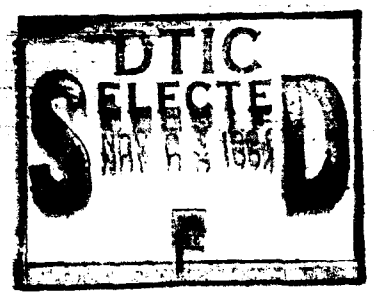
Northern Sea Route and Icebreaking Technology



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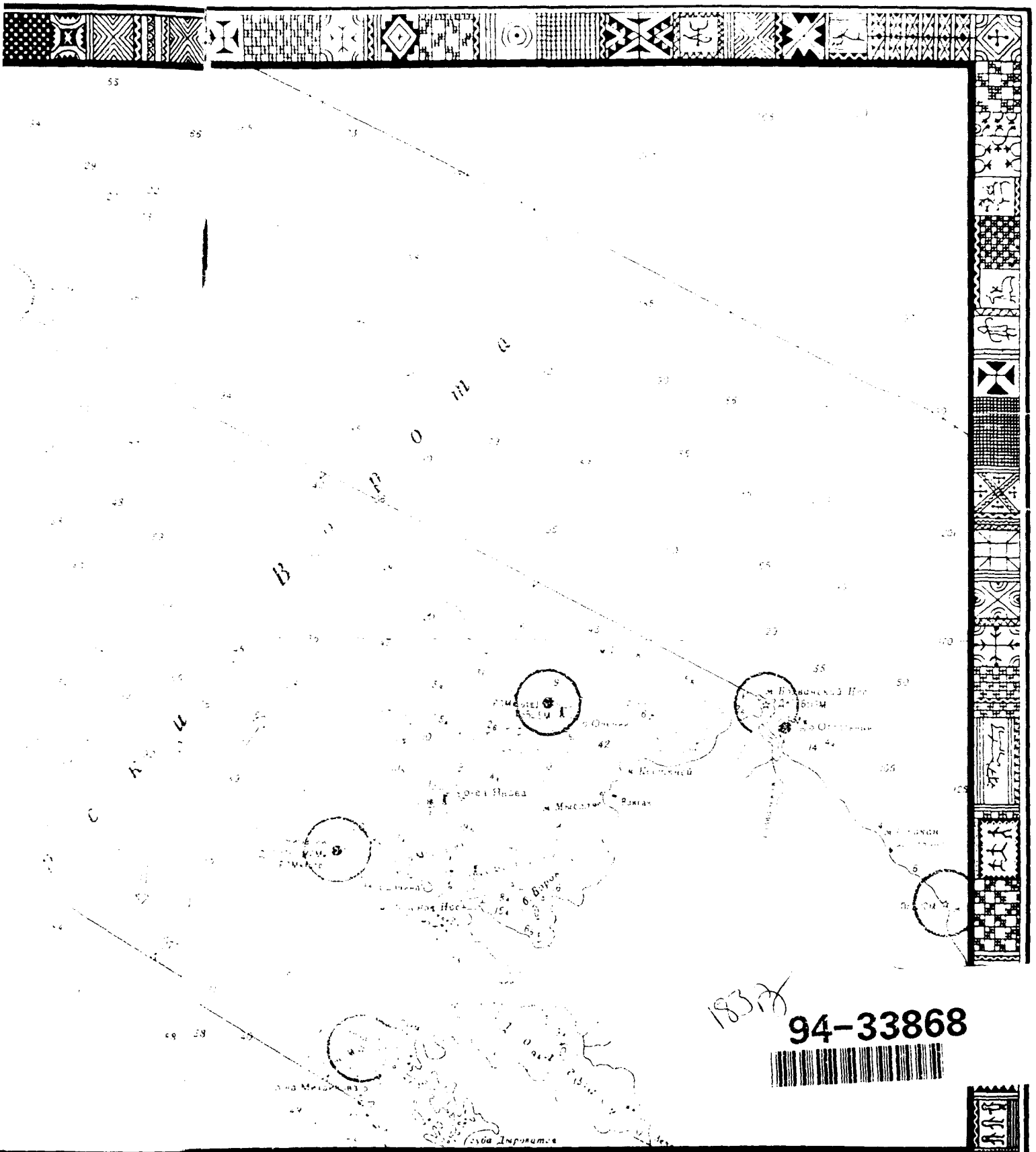

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The Northern Sea Route (NSR) follows the Eurasian coastline between the Atlantic and Pacific oceans. The USSR developed a marine transportation infrastructure along their northern coastline that includes a fleet of the world's most powerful icebreakers and ice-strengthened cargo ships, port facilities, and navigation, communication, and environmental forecasting aids. In 1987, the USSR announced it would open the NSR to foreign vessels for peaceful and commercial purposes.

Navigational difficulties are considerable, due to bitter weather conditions, the short daylight season, ice-infested waters, and isolation. However, shorter distances between north Pacific and European ports, an existing cargo base, a currently underutilized transportation infrastructure, potential stimulation and strengthening of the Russian economy, and the prospect for economic benefits from international investment in Russia make the NSR attractive. The challenging physical environment requires advances in ship design and ship operations. Modern polar ships are larger, stronger, and more powerful, their propulsion systems have been improved, and the resistance encountered during icebreaking has been reduced. The existing shallow-draft northern fleet may be undesirable for use where larger ships can move cargo more efficiently. More northerly route options would enable larger and perhaps more efficient ship passage but would also require greater icebreaking capabilities; however, it will be difficult to attract greater foreign interest unless the navigation season can be extended.

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The existing transportation network and flow of goods can serve as a springboard for establishing new international trading partners and cargoes. The world's northern-tier nations are attracted to the idea of a new trade route for opening new markets to their exports as well as for generating income from ports of call along the route, and there is a potential for western investment in the development of Russian shipping and resource extraction.

The dissolution of the USSR in 1991 added to the problems brought on by the shift to a market-driven economy. Social, economic, and political instability are fundamental obstacles to the development of the NSR. A long-term solution to Russia's economic problems may lie in her ability to stimulate domestic growth and attract foreign trade. The NSR can help attract foreign currency by selling Russia's premiere ice navigation expertise on the world market

The technological advances needed to enable year-round traffic along the NSR will occur more rapidly if the international community recognizes a demand for them. This will help promote the growth of the Russian economy and encourage a cooperative and constructive posture for that nation, both domestically and internationally. There is hope that increased foreign use of the NSR will bring about greater stability, which will, in turn, encourage increased international traffic.

NORTHERN SEA ROUTE AND ICEBREAKING TECHNOLOGY

An Overview of Current Conditions

by

Nathan Mulherin
Devinder Sodhi
Elisabeth Smallidge

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Cold Regions Research & Engineering Laboratory
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June 1994

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PREFACE

This report was written by Nathan Mulherin, Research Physical Scientist, Snow and Ice Branch, Research Division; Dr. Devinder S. Sodhi, Research Engineer, Ice Engineering Research Branch, Experimental Engineering Division; and Elisabeth Smallidge, Librarian, of the USA Cold Regions Research and Engineering Laboratory.

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CONTENTS

Page

Preface i
Foreword vi
Structure of this report viii

EXECUTIVE SUMMARY 1

NORTHERN SEA ROUTE AND ICEBREAKING TECHNOLOGY

Introduction 5
Why use the Northern Sea Route? 6
Brief history 9
The physical environment 15
- The Barents Sea 17
- The Kara Sea 17
- The Laptev Sea 18
- The East Siberian Sea 19
- The Chukchi Sea (Russia) 19
- Alaskan waters 19
- The Bering Sea 21
- The Chukchi Sea (Alaska) 21
- The Beaufort Sea 22

Icebreaking technology 22
- Polar ships 26
- Trends in icebreaking technology 26
- Sizes and dimensions 26
- Hull form 27
- Propulsion 29
- Power and performance 31
- Structural design of polar ships 32
- Future developments 34

Administration and regulations 35
Planning, logistics, and tactics 37
- The analysis phase 37
- The planning phase 39
- The operational phase 41

Obstacles and needs 47
- Social, economic, and political 47
- Infrastructural 49

Conclusions 51
Points of contact 52
References 55

MAPS OF THE RUSSIAN ARCTIC

1. The Russian Arctic 61
2. The various Northern Sea Route options 63
3. The bathymetry of the Russian Arctic 65
4. Location of recurring ice massifs 67
5. Seasonal extent of the sea-ice edge 69

BIBLIOGRAPHIES

Introduction 71
Databases searched 71
Primary sources 72

Page

The Northern Sea Route 75
Russian/Arctic waters 89
Alaskan waters, Bering, Chukchi and Beaufort seas 96
Icebreaking technology 107
Miscellaneous or nonprinted sources 119

APPENDIXES

A. Icebreaking ships of the world 123
B. Regulations for navigation on the seaways of the Northern Sea Route 136
C. Requirements for the design, equipment and supply of vessels navigating the Northern Sea Route 140
D. Letter from the Head of the Administration of the Northern Sea Route "To the Owner or Master of the Vessel" 150
E. Overview of U.S. Navy Joint Ice Center products and services for NSR operations 151
F. World Data Center products for the Arctic 153
G. Defense Mapping Agency index maps of available charts for the NSR 154
H. An adventure in ordering Russian maps of the NSR 159
I. AARI's hydrometeorological and ice forecasting products .. 161

FIGURES

1. *Noril'sk*-class SA-15 multipurpose, arctic icebreaking cargo ship 8
2. Russian nuclear-powered icebreaking LASH *Sevmorput* 8
3. Zones of environmental severity affecting marine trafficability in Alaskan waters 20
4. Significant events in the advancement of polar ship technology since 1955 24
5. Design evolution of Soviet polar icebreakers 25
6. *Taymyr*-class shallow-draft nuclear icebreaker 25
7. Dimensions of icebreakers 26
8. Main features of bow forms 27
9. Different shapes of icebreaking bows 28
10. Shaft power vs. propeller diameter for icebreaking ships 30
11. Power vs. breadth for icebreakers 31
12. Icebreaking performance: bollard pull/beam vs. ice thickness 32
13. Measured effective pressure vs. contact area 33
14. Plane strain fracture toughness vs. temperature for two grades of steel 33
15. Sample ice forecast and ship routing analysis from the Arctic and Antarctic Research Institute, for the coastal area between Dikson and Cape Chelyuskin 42
16. A portion of an Alaskan Regional Ice Analysis from the Joint Ice Center 43
17. A specialized ship routing analysis from the Joint Ice Center 44
18. Navigation charts available from the Russian State Hydrographic Department, Ministry of Transport, as of September 1992 46

Page

TABLES

1. Comparison of the distance in nautical miles for the NSR and canal alternatives 7
2. Comparison of average speed in knots of the NSR and canal alternatives 7
3. Average speed in knots for vessels on sections of the Northern Sea Route 9
4. Soviet shipping activity along the Northern Sea Route 11
5. Probability of occurrence of conditions that require icebreaker assistance through various NSR massifs 14
6. Summary of environmental conditions of the Eurasian seas along the Northern Sea Route 16
7. Selected important polar voyages in recent years 16
8. Icebreaker basis fees for leading vessels through the NSR 23
9. Recent voyages with foreign involvement 37
10. Selected atlases of the Arctic Basin 40
11. Range of safe speeds for new ships operating in drifting, 1-m-thick ice with no compaction 41

FOREWORD

It is the policy of the U.S. Department of Defense to promote activities that enhance the economic security of the nations of the former Soviet Union, the Commonwealth of Independent States. It is in the national security interests of the United States that the peoples of that region achieve economic and political stability, to reduce pressures on their leadership to adopt an aggressive military posture. In the wake of diminishing demand, Congress has also mandated that the Defense Department encourage U.S. defense industries to retool and pursue non-defense-related ventures.

The Northern Sea Route, Russia's maritime supply artery into and out of northern Siberia, is a potential international trade route between the North Atlantic and North Pacific regions. Russia is actively promoting use of the Northern Sea Route as part of its efforts to strengthen the Russian economy. The following study on the Northern Sea Route and icebreaking technology provides information on the current social, political, and economic climates for international utilization of the NSR, derived from recent, publicly available literature as well as personal communications. It identifies technological and other issues that must be addressed by the international community if the Northern Sea Route to Europe is to be developed. Passage through the territorial waters of Russia offers not only the possibility of expanded economic opportunity for the former Soviet Union, but also the creation of new markets and jobs in American shipping and shipbuilding, and expanded markets and other opportunities for our European and Asian friends and allies.

This report contains a brief history of the Northern Sea Route's development and an overview of the icebreaking technology used in today's ships. We present information on the sea, air, and ice conditions that relate to navigation along the length of the route and have included the latest information on gaining passage from the Russian NSR Administration, the support services that are available, cost considerations, and important points of contact. In addition, an extensive bibliography of relevant literature is provided.

The U.S. Army Cold Regions Research and Engineering Laboratory, located in Hanover, New Hampshire, is the only U.S. government laboratory whose mission is principally concerned with cold regions science and technology. Since it was established in 1961, CRREL has been a valuable source of information and services for universities, scientific institutions, engineering firms, independent researchers, and private corporations throughout the world. CRREL's assets include many of the world's foremost cold regions scientists and research engineers as well as a compendium of worldwide scientific literature and data.

In recognition of CRREL's unique mission, in 1974 the laboratory was chartered as the Cold Regions Science and Technology Information Analysis Center (CRSTIAC), one of the Defense Department's 24 information analysis centers (IACs). In partnership with CRREL's research mission, the CRSTIAC is an important resource by which to:

- Collect, review, analyze, summarize, and store available information within the field of cold regions science and engineering.
- Conduct research based on this information according to expressed or anticipated needs.
- Act as a catalyst for the exchange of scientific and technical information.

In a typical year, the CRSTIAC receives more than 3000 requests for information. Rapid, in-depth response to these inquiries enables timely transfer of new technology and avoids duplicate research. The need to leverage the resources of the CRSTIAC and other DoD information analysis centers for commercial applications has recently taken on increased emphasis under the present Administration's concept of dual-use technology.

In preparing this report, CRSTIAC information specialists have compiled an extensive database of literature from publicly available sources on the history of arctic marine technology and commercial activity in the Russian Arctic. This interaction and sharing of knowledge between experts in both the public and private sectors will be of increasing significance in promoting activities that encourage economic growth and stability in the territories of the former Soviet Union and in enhancing America's relations in that region of the world.

A. J. Roberto, Jr.
Chief, Technical Resources Center
USA Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire
June, 1994

STRUCTURE OF THIS REPORT

This report is presented in five parts.

The first section is an executive summary that briefly describes the goals and findings of this study.

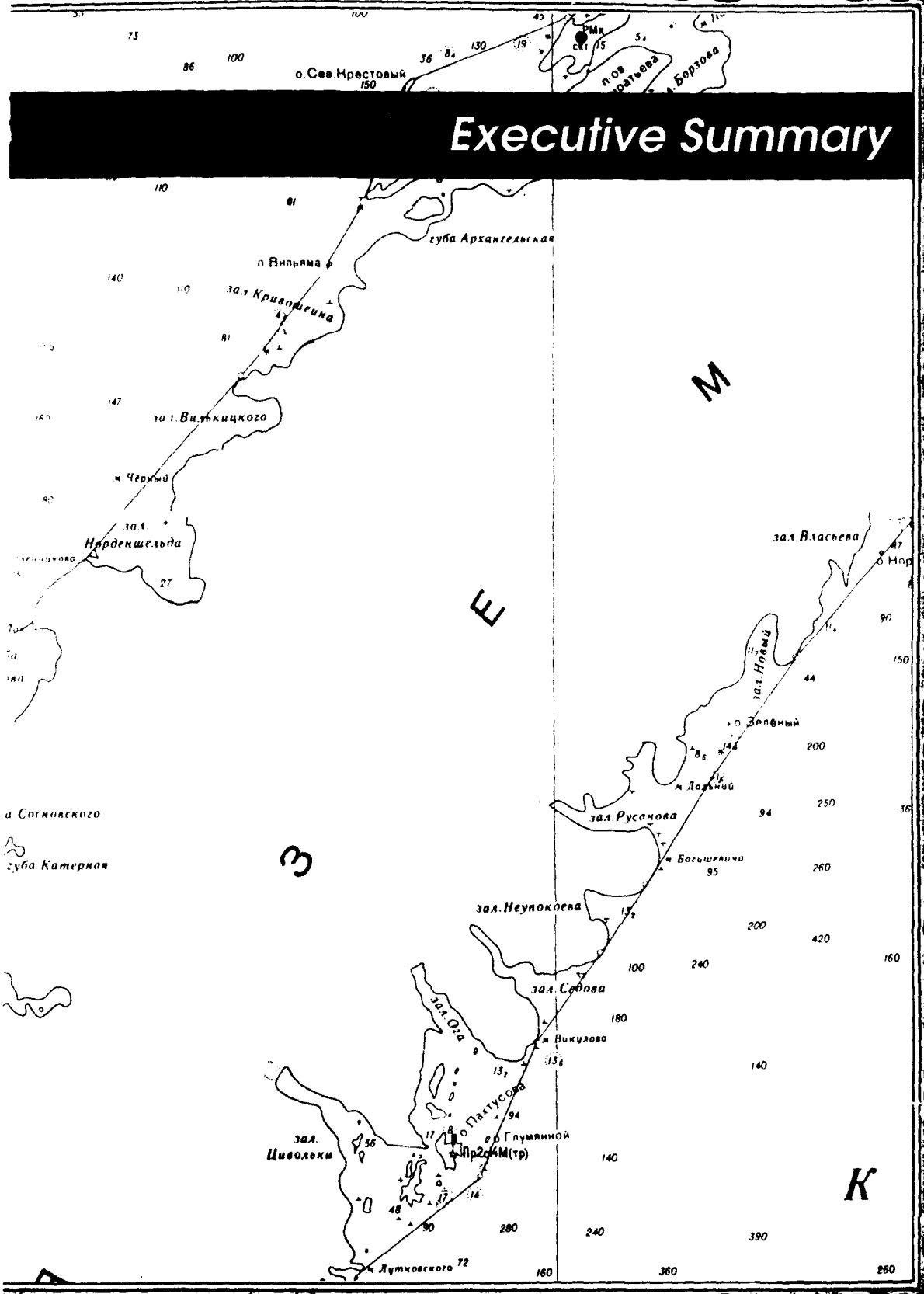
The second part is a review of the current status of Northern Sea Route activity, prepared with the intent of helping those who may be considering using the route for commercial purposes. This section includes a brief history of Northern Sea Route shipping, information on the physical environment, a review of deep-draft icebreaking technology, and an analysis of current Russian operations.

The third section provides maps of the Russian Arctic. The reader who is unfamiliar with the geography of this area may wish to fold the maps out so they are available for ready reference.

The next section contains the results of the literature search for this report. The information has been divided into five bibliographies covering the Northern Sea Route, the Russian Arctic, Alaskan waters, icebreaking technology, and miscellaneous and nonprinted sources.

The last section contains the appendixes referred to in tne text. These include a list of the world's icebreaking ships, a brief diary of our experiences in obtaining Russian navigation charts, a translation of a Russian document that describes the equipment requirements of foreign ships on the route, and descriptions of navigation aids available from U.S. and Russian sources.

Executive Summary



EXECUTIVE SUMMARY

The Northern Sea Route, a marine passage that follows the Eurasian coastline between the Atlantic and Pacific oceans, crosses four arctic seas: the Kara, the Laptev, the East Siberian, and the Chukchi. Specifically, it extends from the islands of Novaya Zemlya in the west to the Bering Strait in the east. It is from 2200 to 2900 miles long—estimates vary because the route is not a unique passageway, but is generally regarded as any and all possible routes from the Atlantic to the Pacific through the myriad straits, passages, open seas, and island groups north of the Eurasian landmass.

To extract Siberia's natural resources and supply the northern settlements with finished goods and necessities, for 50 years the Soviets invested heavily in a marine transportation infrastructure along the northern Russian coastline that includes a fleet of the world's most powerful icebreakers and ice-strengthened cargo ships, port facilities, and navigation, communication, and environmental forecasting aids.

The route offers distances between north Pacific and European ports that are 35–60% shorter than the traditional routes through the Suez and Panama canals. Transit speeds from July through October are competitive with those attained on the southerly routes, although slower speeds for the rest of the year offset the savings in distance. Ship speeds in autumn and spring will have to be increased substantially to maintain the route's economic advantage. The eastern portion of the route may in fact need to be open year-round to be economically attractive to the international community.

Historically, foreign vessels were prevented from using the NSR because certain key straits and passages were in sovereign waters of the Soviet Union, but in October of 1987 then-General Secretary Mikhail Gorbachev announced a new spirit of cooperation in the arctic regions: the Soviet Union would open the NSR, with certain restrictions, to all foreign vessels for peaceful and commercial purposes.

Although navigational difficulties are considerable in these northern waters due to bitter weather conditions, the short daylight season, ice-infested waters, and isolation, there are many reasons for using the Northern Sea Route:

- Much shorter distances between northern ports in the Pacific and Atlantic regions,
- An existing cargo base,
- A currently underutilized transportation infrastructure,
- Potential stimulation and strengthening of the Russian economy, and
- The prospect for economic benefits from international investment in Russia.

Cargo transportation routinely takes place across the entire northern Russian coast from the beginning of July to the end of October, and the western portion, as far east as Dudinka, has been kept open year-round by icebreakers since 1980. Using a highly advanced fleet of icebreaking ships, the Russians have the technological capability to move ships virtually anywhere in the Arctic during the summer months, but establishing a viable year-round cargo transportation system will require advances in several areas:

- Development of more powerful and economical icebreaking ships,
- Further development of markets for cargoes,
- Improvement of the nautical infrastructure and the opening of more Russian ports to foreign shipping, and
- Reduced risk to life, vessels, and the environment and hence, affordable insurance rates.

The continental shelf is extremely wide off Russia's north coast. The winter distribution of sea ice across the Russian Arctic is characterized by the growth of shorefast ice in vast areas where the water is less than 30 m deep. Seaward of the fast-ice, the ice cover is in constant motion due to ocean currents and winds. The moving ice region continually experiences openings, called leads, where the ice cover pulls apart, and convergence areas, where the ice crushes together to form pressure ridges and fields of broken rubble. From August to May, new ice is continually being produced in the leads, and these areas of thinner ice are obvious lines of weakness that are exploited to maximum extent by navigators.

The challenging physical environment of the Far North requires the development and further refinement of a whole series of technologies that pertain to ship design as well as to ship operations. In the last 40 years, application of modern marine technology to the design and operation of polar ships has made it possible to travel to remote polar regions that were deemed impenetrable only a few years ago. Polar ships have become larger, stronger, and more powerful, and innovative ideas have been implemented to improve propulsion systems and reduce the resistance encountered during icebreaking.

Finland and the Soviet Union have made the major contributions to the development of polar ships. The Soviet Union first used nuclear technology to power the icebreaker *Lenin* in 1959. The Finnish shipbuilder Wartsila has built many icebreakers for the Soviet Union and provided many advances in design during the development of conventionally powered icebreakers. Recently, these two technologies have merged to develop shallow-draft polar icebreakers, built in Helsinki with Soviet nuclear propulsion systems installed in St. Petersburg. Similarly, developments in the U.S. and Canada have contributed to changes in key areas of icebreaking technology, such as hull and bow form, gas turbines, and the controllable-pitch propeller.

The additional investment for building ice-class ships is considerable, and the ships are less efficient and more costly to run in open water than conventional vessels. To offset their greater construction, operating, and maintenance costs, ship owners must rely on them providing year-round service. Since depth limitations in some straits of the NSR prevent passage of ships greater than 20,000 dwt, the shallow-draft northern fleet may be undesirable for use where larger ships can move cargo more efficiently. More northerly route options would enable larger and perhaps more efficient ship passage but would also require greater icebreaking capabilities than are currently available. It will be difficult to attract greater foreign interest unless the navigation season can be extended.

In this connection, it should be noted that import and export industries depend heavily on reliable, year-round transportation of goods. Few businesses can afford the limitation of a seasonal supply of raw materials or seasonal distribution of their finished products. Attracting year-round trade along the Northern Sea Route will encourage the establishment or improvement of alternative transportation modes for the off-season, such as overland rail or air freight service. This, however, will introduce another source of competitive pressure on marine shipping.

The existing transportation network and flow of goods can serve as a springboard for establishing new international trading partners and cargoes. The world's northern-tier nations have become increasingly attracted to the idea of a new trade route for opening new markets to their exports as well as for generating income from ports of call along the route. There is a potential for western investment in the development of Russian shipping and resource extraction, and business arrangements, for example, could be formed to boost working capital for regional development of the necessary port facilities and services infrastructure.

Several international organizations have been formed since 1987 to encourage use of the NSR. The International Northern Sea Route Project (INSROP) was formed to undertake activities that would enhance international interest in the route. In November 1991, The Northern Forum, another organization committed to addressing a variety of northern territorial concerns, emphasized the support of activities that promote the NSR. Another international group, the Barents Council, also endorsed the promotion efforts and has formed a subcommittee called the Working Group for the Northern Sea Route. In the United States, there is interest in the Northern Sea Route in Alaska and Washington state. The Alaskan Department of Commerce and Economic Development has set up demonstration shipments using Russian cargo ships to transport Alaskan goods to European markets.

The shift from socialism to a market-driven free enterprise economy in the USSR, beginning around 1985, resulted in economic and social disruption, problems that were compounded in 1991 with the dissolution of the Soviet Union, including the loss of NSR carrying capacity for certain cargoes and a reduced turnover capability for its seaports. When Boris Yeltsin assumed the Russian presidency in 1991, he inherited an economy on the verge of widespread collapse. The shortage of basic goods led to social and political unrest that, in turn, produced further chaos in the supply system. Drastic emergency reforms were instituted in 1992 to stem the tide.

Social, economic, and political instability are fundamental obstacles to the development of the NSR. The Russians declare that the route is now open and the obstacles of the past are disappearing, but actual experience appears to indicate otherwise.

A long-term solution to Russia's economic problems may lie in her ability to stimulate domestic growth and attract foreign trade. It is certainly in the best interests of the United States that Russia achieve economic as well as political stability, so it can take its place among the nations of the world as an ally and a trading partner.

The Russians have proposed the following ways to raise foreign capital:

- Escort foreign ships along the route with Russian icebreakers,
- Transport foreign goods aboard Russian ice-strengthened cargo ships,
- Employ idle Russian icebreakers and cargo vessels in the U.S. and Canadian Arctic, and
- Promote arctic tourism.

The 1987 policy shift on the NSR will help attract foreign currency by "selling" Russia's premiere ice navigation expertise on the world market. The Administration for the Northern Sea Route is currently responsible for meeting the annual arctic freight transportation goals and maintaining personal and environmental safety. A primary goal is to bring in more foreign revenue to reduce the arctic fleet's dependence on state subsidy.

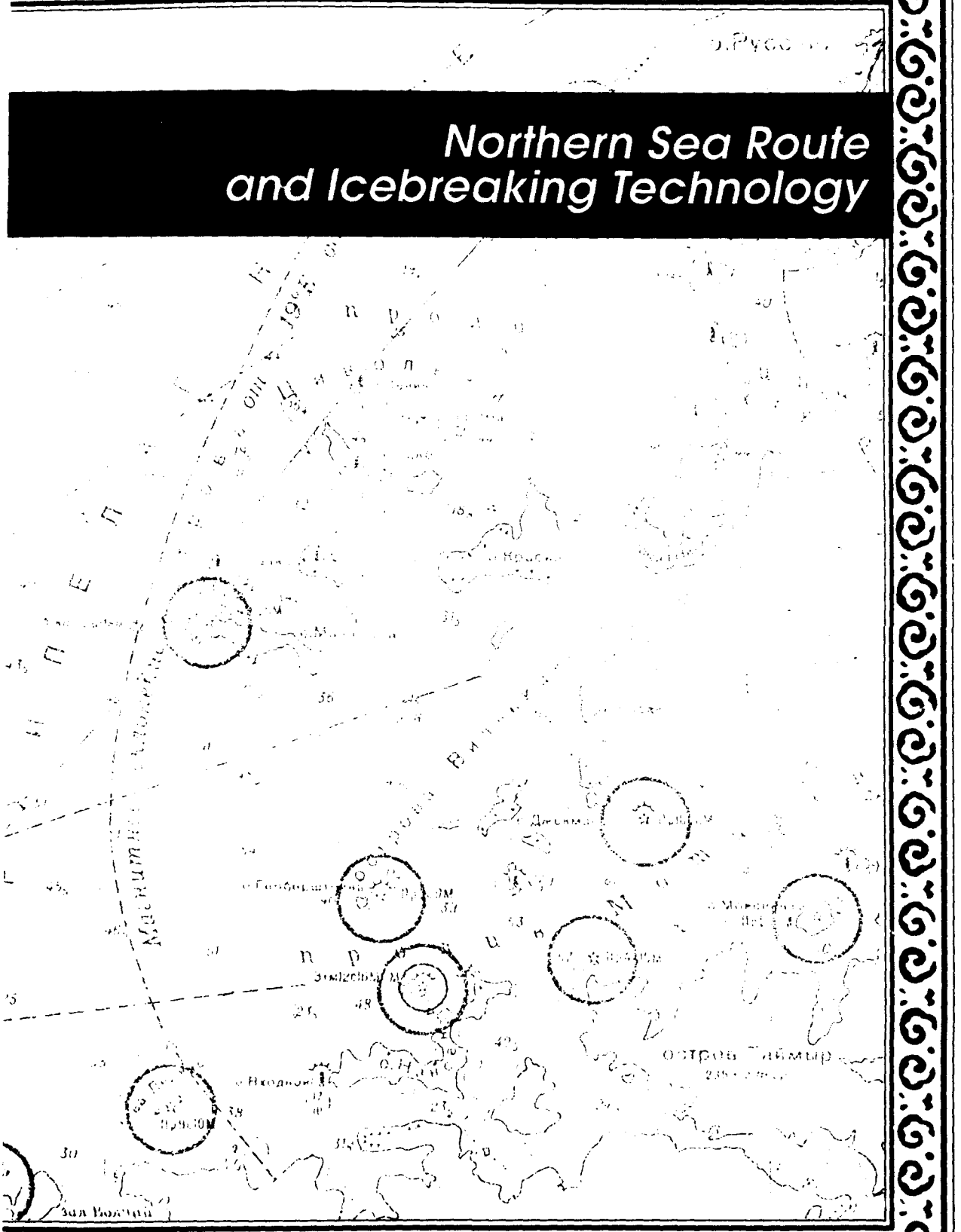
The Russians officially opened the Northern Sea Route to foreign use in July of 1991. Two shipping companies, or marine operations headquarters (MOHQs), control actual operations, such as scheduling, route assignment, navigational support, and pilotage.

The technological advances required to enable year-round traffic along the Northern Sea Route will occur more rapidly if the international community recognizes a demand for them. This would help to promote the growth of the Russian economy and encourage a cooperative and constructive posture for that nation, both domestically and internationally.

Privately, there is measured skepticism as to whether the Russians can sufficiently reorganize their operations and develop enough continuity that foreign shippers will have faith in the system. There is hope, however, that increased foreign use of the Northern Sea Route will bring about greater stability, which will, in turn, encourage increased international traffic.

In spite of the challenges, or perhaps because of them, the Northern Sea Route has been a magnet for explorers and adventurers in centuries past, and in our time calls us to the Far North with the promise of expanded trade opportunities, technological advances, increased international cooperation, and a stronger and more stable Russia as an ally and partner.

Northern Sea Route and Icebreaking Technology



NORTHERN SEA ROUTE AND ICEBREAKING TECHNOLOGY

INTRODUCTION

The Northern Sea Route is a portion of the historic Northeast Passage, the marine passage between the Atlantic and Pacific oceans that follows the Eurasian coastline. The Northeast Passage crosses five seas of the Arctic Ocean: the Barents, the Kara, the Laptev, the East Siberian, and the Chukchi. The Northern Sea Route is a more specific and modern designation, referring to that portion of the Northeast Passage that extends from the Russian islands of Novaya Zemlya to the Bering Strait. It offers a shorter distance between ports in the north Atlantic and the north Pacific relative to the routes through the Suez and Panama Canals that are currently used. Transit distances between north Pacific and European ports are some 35–60% shorter than the traditional southerly routes.

Over the last 50 years or so, the Soviet Union developed a vast marine transportation system of seaports, icebreaking ships, ice forecasting, and piloting expertise to extract the abundant natural resources of its isolated northern regions. Russian arctic shipping has developed to the point where cargo transportation routinely takes place four months of the year across the entire northern coast. Shipping traffic, both transit and local, plies the entire route from the beginning of July to the end of October. The western portion, from Murmansk to Dudinka on the Yenisey River, has been kept open year-round by icebreakers since about 1980. Using a highly advanced fleet of icebreaking ships, the Russians have the technological capability to move ships virtually anywhere in the Arctic during the summer months. This fact has been demonstrated by several trips to the North Pole that have been accomplished by Russian nuclear-powered icebreakers. Year-round maintenance of the entire route, however, is not feasible at the current time.

The challenge of the physical environment of the Northern Sea Route will require the development and exploitation of an entire series of technologies that pertain to ship design as well as to ship operations. Public policy alternatives will need to be investigated, some of which pose difficult trade-offs between technology and other considerations, such as international environmental protection vs. economic development.
Establishing a viable year-round cargo transportation system will require advances in several areas:

- Further development of markets for cargoes,
- Development of more powerful and economical icebreaking ships,
- Improvement of the nautical infrastructure and the opening of more Russian ports to foreign shipping, and
- Reduced risk to life, vessels, and the environment and hence, affordable insurance rates.

The shift from socialism to a market-driven free enterprise economy, which began around 1985, has resulted in economic and social disruption in states of the former Sovier Union. The problems were compounded in 1991 with the transformation of the old Soviet Union into the new Commonwealth of Independent States (CIS), including the loss of NSR carrying capacity for certain cargoes and a reduced turnover capability for its seaports.

A long-term solution to these problems may lie in the Commonwealth's ability to stimulate domestic growth and attract foreign trade. Historically, the USSR claimed that crucial sections of the Northern Sea Route passed through its sovereign waters and these they guarded carefully from incursion by foreign vessels, but in October of 1987, then-General Secretary Mikhail Gorbachev announced a new spirit of cooperation in the arctic regions: the Soviet Union would open the Northern Sea Route, with certain restrictions, to all foreign vessels for peaceful and commercial purposes. This landmark change of policy will enable Russia's northern fleet to bring foreign currency into the Russian economy by "selling" its premiere ice navigation expertise on the world market.

The Russians have proposed the following ways to raise foreign capital:

- Escorting foreign ships along the route with Russian icebreakers,
- Transporting foreign goods aboard Russian ice-strengthened cargo ships,
- Employing idle Russian icebreakers and cargo vessels in the U.S. and Canadian Arctic, and
- Promoting arctic tourism.

The world's northern-tier nations and territories have become increasingly attracted to the idea of a trade route that will open new markets to their exports as well as generate income as ports of call along the route.

Not incidentally, it is in the interests of the United States and our allies that Russia succeed in establishing a stable economy and political climate. The alternative, privation and instability, increases the danger of Russian aggression internationally. In addition, U.S. industries that once thrived in support of our national defense can find rich opportunities in the technological challenges of the Northern Sea Route.

This report is an overview of rapidly assembled technical information on the Northern Sea Route. We present a synopsis of the history of the NSR; the social, political and economic issues involved; and the current attitude toward promoting the route, as well as a review of Russian and American icebreaking technology. A great deal of research and analysis have already been accomplished by other organizations, and dozens of reports are readily available concerning the development of the route, as can be seen in the bibliographies.

This report is intended to serve as a logistical starting point for potential users of the Northern Sea Route and as such provides many planning and operational details in a single source. We have identified some of the current problem areas and suggested improvements that may be needed to foster greater international interest in using the route. We have identified the significant literature on arctic maritime technology with the intention of providing a foundation for supporting U.S. government and private sector activities in the Russian Arctic.

WHY USE THE NORTHERN SEA ROUTE?

The Northern Sea Route is from 2200 to 2900 miles in length (Ivanov and Ushakov, 1992). Estimates vary because the route is not a unique passageway, but is generally regarded as any and all possible routes from the Atlantic Ocean to the Pacific Ocean through the myriad straits, passages, open seas, and island groups north of the Eurasian land mass (refer to Map 1 in the *Maps* section). It is, however, legally defined by the Administration of the Northern Sea Route (ANSR) in Moscow as begin-

Table 1. Comparison of the distance in nautical miles for the NSR and canal alternatives.

Route	NSR distance	Shortest canal distance	Difference (%
Hamburg to Dutch Harbor	4,200	10,400	60
Hamburg to Vancouver	6,635	8,741	24
Hamburg to Yokohama	6,920	11,430	39
Oslo to Yokohama	7,146	12,013	41
London to Yokohama	7,323	11,655	37

Adapted from Wergeland (1991) and Mikhailichenko (1992).

ning at the "western entrance of the Novaya Semlya (sic) Straits and the meridian north through Mys Zhelaniya" and ending "by the parallel 66°N and the meridian 168°58'37"W" (ANSR, 1991). This essentially constitutes the area extending from the islands of Novaya Zemlya in the west to the Bering Strait in the east.

Navigational difficulties are considerable in these northern waters due to bitter weather conditions, ice-infested waters, the short daylight season, and isolation. So why is the NSR being considered as a possible trade route? The many reasons can be summarized as follows:

- Much shorter distances between northern ports in the Pacific and Atlantic regions,
- The presence of an existing cargo base,
- The availability of a currently under-utilized transportation infrastructure,
- Potential stimulation of the Russian economy, and
- The prospect for economic benefits from international investment in Russia.

A primary benefit of braving the Northern Sea Route's greater physical challenge is to save time and money, and distance comparisons of the world trading routes (Table 1) do favor utilization of the NSR.

Estimates of travel time, based on past performance during the summer season, are also competitive with the canal alternatives. The information presented in Table 2, supplied by the Murmansk Shipping Company (MSC) and reported by Wergeland (1991), was summarized from transit data for the 1990 and 1991 shipping season.

Computer simulations, the operational experience of Russian *Noril'sk*-type vessels (multipurpose, hull-strengthened cargo ships of the highest ice classification[1]) (Figure 1), and actual transit times for other MSC vessels were used to estimate the mean transit time through various sections of the NSR for the entire year. The latter two sources were used by Wergeland in developing the data presented in Table 3.

Table 2. Comparison of the average speed in knots of ships using the NSR and canal alternatives.

Route	Number of trips	Average speed
NSR eastbound	4	12.2
NSR westbound	3	10.3
Suez Canal westbound	3	12.9

Adapted from Wergeland (1993).

[1] The ice classification is meant to serve as a measure of a ship's reliability to navigate safely in ice-covered waters. Unfortunately, there is no single world standard, and the categories of the many national standards are somewhat difficult to compare. See Appendix C for a comparison of ice classes.

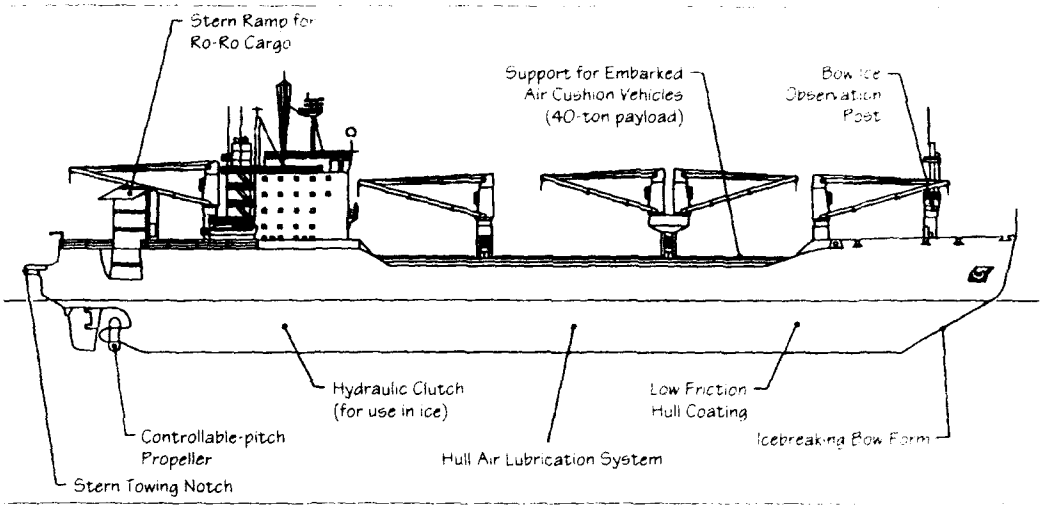


Figure 1. Noril'sk*-class SA-15 multipurpose, arctic icebreaking cargo ship (from Brigham, 1991a).*

Although the July-through-October *Noril'sk* speeds are competitive with those attained on the Suez and Panama routes, the slower speeds for the rest of the year offset the savings in distance. The estimated speeds that can be attained with the Russians' nuclear-powered LASH (lighter aboard ship) vessel show a freight transportation efficiency that may prove competitive, however. The LASH *Sevmorput* (Figure 2) is a shallow-draft, icebreaking barge/container carrier that is designed to transport up to 74 barges (lighters) or 1300 standard cargo containers. It has an open-water capability of 20 knots but, more importantly, it does not require icebreaker escort in ice less than 1 m thick. The Russians hope that the LASH, and the *Noril'sk* in convoy with *Arktika*-class icebreakers, will play a major role in opening the Northern Sea Route for year-round traffic.

The marine transportation infrastructure along the northern Russian coastline is well developed. It includes a fleet of the world's most powerful icebreakers and ice-strengthened cargo ships, as well as port facilities, navigation, communication, and environmental forecasting aids. Its purpose has been to extract the natural resources of the Siberian region and to supply the northern settlements with finished goods and necessities. Hence, there is an existing transportation net-

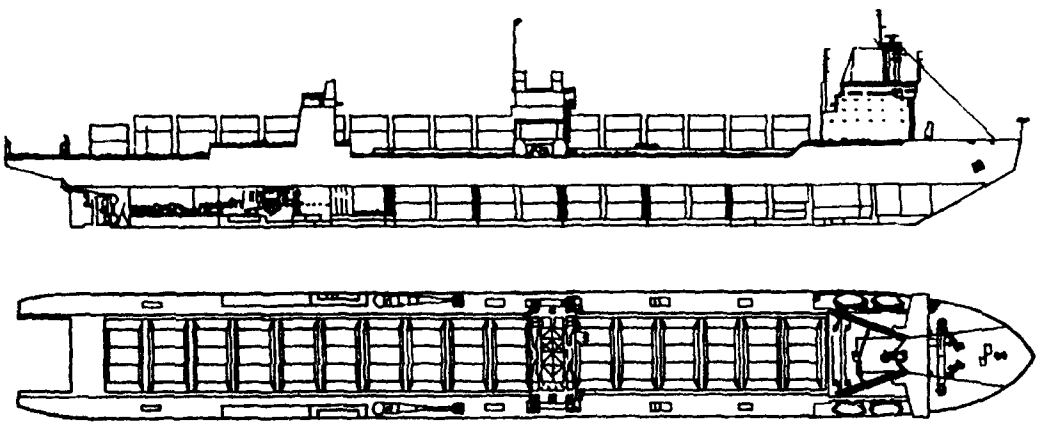


Figure 2. Russian nuclear-powered icebreaking LASH (lighter aboard ship) Sevmorput *(from Brigham, 1985).*

Table 3. Average speed in knots for vessels on sections of the NSR.

Route section (west–east)	Distance (miles)	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Noril'sk-type vessels													
Kolguyev Island to Dikson	580	8.6	8.3	8.0	7.8	7.5	7.8	11.0	13.8	14.0	12.8	9.2	8.9
Dikson to Cape Chelyuskin	440	4.9	4.8	4.6	4.4	4.3	4.5	6.0	6.7	7.0	7.3	5.3	5.1
Cape Chelyuskin to Tiksi	540	3.9	3.8	3.7	3.5	3.4	3.6	5.0	7.0	9.0	9.0	4.2	4.1
Tiksi to Provideniya	1,640	7.4	7.1	6.9	6.6	6.4	6.7	14.0	14.5	15.0	14.5	7.9	7.6
Weighted means		6.7	6.5	6.2	6.0	5.8	6.1	10.8	12.0	12.6	12.5	7.2	6.6
Nuclear-powered lighter aboard ship (LASH)													
Weighted means		7.6	9.0	9.0	8.3	7.9	8.3	12.8	14.1	15.4	15.7	10.2	9.8
Total distance	3,200												

Adapted from Wergeland (1991).

"It may appear paradoxical that at this juncture, in the midst of acute crisis at home, Russia should be actively promoting ... the Northern Sea Route.... Far from it—this is an integral part of the general strategy of stabilization and development of the NSR. The most pressing objective for the NSR today is to utilize more fully the Arctic fleet and to provide it financial support"
—Alexander Granberg, State Advisor for the Office of President of the Russian Federation (1993b)

work and a flow of goods that could serve as a springboard for establishing new international trading partners and cargoes.

The current economic difficulties in Russia have sidelined a portion of the available transport and ice-breaking capacity on the route. Cargo turnover in the region peaked at 6,578,000 tons in 1987 and has progressively declined since then to 4,903,000 tons in 1991 (Granberg, 1992). Increasing foreign use of the NSR can more fully utilize the Russian fleet and provide revenue toward its operation and maintenance.

The Russians hope that international tourism to the Arctic and Siberia can be increased to provide a source of foreign revenue. During the summer of 1990, the Russian icebreaker *Rossiya* made a voyage to the North Pole with 88 paying tourists from 12 countries aboard. Mikhailichenko and Ushakov (1992) report that ice up to 4 m thick was overcome. In 1991 and 1992, the *Sovietskiy Soyuz* repeated the North Pole voyage with 80 more tourists from 15 countries on board. The chance to visit one of the world's few remaining remote and pristine areas holds a fascination for a number of people who will gladly pay for the experience.

There is a potential for western investment in the development of Russian shipping and resource extraction. For example, western oil companies are negotiating with the Russians to supply foreign development expertise and investment dollars into the offshore Yamal and Taymyr regions for a share of the raw oil and gas products. It is conceivable that other business arrangements can be formed to boost working capital for regional development of the necessary port facilities and services infrastructure.

BRIEF HISTORY[2]

Maritime nations throughout history have sought shipping advantages in distance and time over their rivals. This rivalry spurred early exploration of new trade routes. The terms "Northwest Passage" and "Northeast Passage" came into popular usage more than 400 years ago to refer to desired corridors of travel from Europe to the East Indies via northern waters. The Northwest Passage was a proposed route from

[2] Extensive discussion of the history of the Northern Sea Route can be found in Armstrong (1988a,b, 1992a,b) and Barr (1991).

Europe westerly across the Atlantic Ocean to the Pacific, by way of the Canadian archipelago. Alternatively, the Northeast Passage accessed the Pacific Ocean from Europe by traveling northerly along Scandinavia to the Arctic Basin and then eastward along Asia's northern coastline.

In time, the idea of a northern sea route to the Orient fell out of favor as the environmental challenges of the Arctic became more apparent from successive exploratory voyages. However, the prospect of trade along the northern Asian coastline itself continued to inspire exploration in the region. The land and sea journeys of early expeditioners such as Vitus Bering, Willem Barents, Baron F.P. Wrangel, and many others were significant, and their legacy is historically noted by prominent geographical place names that honor their achievements.

Although attempts to pioneer the route began in the 16th century, it wasn't until 1879 that a west-to-east transit was finally completed by the Swede, Baron Nils Adolf Erik Nordenskiöld, after a two-year voyage. He was forced to winter-over in the ice at Kolyuchino, just 250 km short of the Bering Strait, but Armstrong (1992b) states that he most certainly could have completed the route in a single season had he not undertaken an ambitious program of scientific observations along the way.

Early in the 20th century, the Russian government commissioned two small icebreakers, *Taymyr* and *Vaygach*, to perform an extensive hydrographic survey along the entire northern coast. They worked each summer season from 1910 to 1915 and succeeded in the protracted but first east-to-west transit of the passage. Soon, however, international shipping interest shifted away from the Russian Arctic to more accessible routes not only because of the physical environment, but due to legal accessibility as well.

Claims of sovereignty over the route extend at least as far back as 1704 when an edict of Peter the Great established a Russian monopoly over commercial fishing and hunting in the western arctic seas. Similar imperial legal declarations were issued in 1753, 1799, and 1821. Russian legal claims were confirmed by conventions with the United States (1824) and Great Britain (1825). These and repeated Soviet claims following the October Revolution of 1917 have resulted in nearly universal observance of Soviet dominion over the Northern Sea Route (Kolodkin and Volosov, 1990; see also Franckx, 1988; Butler, 1991).

Isolated by a protectionist policy, the Soviets invested heavily in a marine infrastructure that allowed them to settle and develop their northern coastline and tap its abundant natural resources. The USSR sought to become independent of other nations for raw materials. The huge nickel deposits at Noril'sk in the Yenisey River basin and the tin deposits at Deputatskiy and Iul'tin were discovered during this period, and gold was discovered in the far northeast, diamonds in the Lena River basin, and apatite near Murmansk.

Granberg (1992) breaks down the modern era of Soviet development of the Northern Sea Route into four periods:

- Exploration and settlement from 1917–1932;
- Organization of regular navigation and development of the fleet and ports from 1932 to the early 1950s;
- Completion of development and establishment of regular seasonal traffic between the early 1950s and late 1970s; and
- The effort to establish year-round shipping since the late 1970s.

Some of the highlights of the modern era are presented below.

In 1920, the Soviet agency, the Committee of the Northern Sea Route (*Komseveroput*, in Russian) was established to "equip, improve, and study" the entire route from Arkhangel'sk to the Bering Strait.

[illegible] entire [illegible] and apatite and more than [illegible] and [illegible] and [illegible] western [illegible] supplied 16% and 12% respectively, of the Soviet Union's entire oil and gas production. Today, shipping of raw timber and nickel ore from the Yenisey River ports of Igarka and Dudinka, respectively, makes up the bulk of tonnage in transit along the western NSR. (Granberg, 1992)

Table 4. Soviet shipping activity along the Northern Sea Route.

Year	1935	1940	1950	1960	1963	1965	1970
Freight tonnage (000)	246	289	503	1,013	1,390	1,600	2,400
Length of season (days)	93	93	122	128	130	135	145

Adapted from Ushakov et al. (1991).

The activities of the Komseveroput were given high priority for establishing a transportation system that was regarded as vital to the nation's economy.

In 1932 a German, Otto Shmidt, completed the entire route in the small Soviet icebreaker *Sibiryakov* in just two months. The ship, however, lost its propeller in the ice just short of the Bering Strait and had to be towed by freighter after emerging from the ice under improvised sails. Still, the voyage was a remarkable achievement and underscored the advanced navigational skills and technological capability of the Russians in this severe environment. Shmidt's second attempt one year later in a Soviet cargo ship, the *Chelyuskin*, ended when the ship was beset by ice and crushed. The first damage-free transit in a single season was not accomplished until 1934: the icebreaker *Fedor Litke* claimed the title.

Soviet resolve and experience in ice navigation were unrivaled, and traffic in the Arctic continued to grow. For example, from 1917 to 1934, there were only two sinkings out of 178 round-trip voyages across the Kara Sea to import finished goods to and export timber from Igarka.

In 1932, a new and more powerful government department, the *Glavnoye Upravleniye Severnogo Morskogo Puti* (*Glavsevmorput*), or Chief Administration of the Northern Sea Route,[3] assumed the role to "develop the NSR from the White Sea to the Bering Strait, to equip it, to keep it good order, and to secure the safety of shipping along it" (Arikaynen, 1991). Otto Shmidt was installed as its first head, and for the remainder of the decade he increased freighting along the route. Under his administration, major additions were made to the arctic fleet, which moved between 100,000 and 300,000 tons of cargo annually while employing from 40 to 150 ships per year. Timber exports from Igarka accounted for as much as two-thirds of the total cargo weight; the rest was mainly supply cargo into the growing industrial areas of northern Siberia. Soviet shipments in the region grew steadily in support of Siberian development, and improving icebreaking technology produced a steady increase in the length of the navigation season (Arikaynen, 1991; Armstrong 1992). These two facts are supported by the figures in Table 4.

In 1990, 886 voyages were completed by 252 ships (Armstrong, 1993). The Igarka timber shipment amounted to approximately 1,000,000 tons. The nickel ore shipped from the Noril'sk mines near Dudinka destined for the smelters of Monchegorsk near Murmansk was estimated to be several million tons per year (Armstrong, 1988a). The importance of these two raw materials is evidenced by Russia's policy, beginning in 1980, to maintain year-round navigation from Murmansk to Dudinka (Anon., 1980, 1981).

In 1940, before the USSR became involved in World War II, a German warship was escorted through the Northern Sea Route. The *Komet*, an armed raider, was the first foreign ship in over 20 years to be granted passage, and it would be the last foreign transit for more than 50 years. Armstrong (1958) devotes an entire chapter to this historic voyage and its political significance.

When the USSR entered the war in 1941, the route became important for bringing Allied supplies into the country. Supply convoys from the west into Murmansk suffered heavy casualties from German U-boats in the Barents Sea as well as the Atlantic. Although this so-called "Murmansk Run" did not actually reach the NSR, the NSR did become an al-

[3] Various translated names for *Glavsevmorput* have appear in the literature. Arikaynen (1991) gives "Chief Northern Sea Route Agency," Armstrong (1992a) gives "Chief Administration of the Northern Sea Route," Barr (1991) gives "Directorate of the Northern Sea Route," and Ushakov et al. (1991) give "Main Department of the Northern Sea Route."

ternate supply route from West Coast ports of the U.S. through the Bering Strait to Russia's northern ports. In the four seasons of 1942–1945, 120 ships transported approximately 450,000 tons of relief supplies, which amounted to approximately half the freight turnover for the NSR during this period. Most of these voyages offloaded in Tiksi at the Lena River, but 13 were able to reach the Yenisey delta, and one even travelled as far west as Arkhangel'sk (Barr, 1991).

Post-war information on shipping figures is difficult to obtain; comprehensive annual summaries of shipping data were not published. What information there is was gleaned from a variety of sources and news coverage of the most noteworthy events, but it presents a general pattern of relatively constant growth in the marine infrastructure and activities over the next 40 years.

The Soviet offer to open the Northern Sea Route to foreign shipping and provide icebreaking support for a fee was first extended in 1967. A demonstration voyage took place that summer in which a Soviet ship transported cargo from western Europe to Yokohama. Although the transit was successfully accomplished in only 27 days, foreign shippers never seized upon this initiative. Armstrong (1972) presented the possibility that the offer was tacitly withdrawn so that the Soviets would not offend their Arab allies by proposing an alternative to the Suez Canal.

In 1977, the Soviets powered the first surface vessel to the geographic North Pole. The nuclear icebreaker *Arktika* departed Murmansk on August 9 and reached the pole on the 17th. The return to Murmansk, by way of Franz Josef Land, was completed on August 23rd. The 14-day experimental voyage, more than half of which was spent breaking through ice, covered 3852 miles at an average speed of 11.5 knots (Ivanin, 1978).

In 1978 another historic voyage occurred: the first complete high-latitude passage of surface ships, which travelled from Murmansk through the Bering Strait to Magadan (Mikhailichenko, 1986). The nuclear icebreaker *Sibir'* led the *Amguema*-class transport ship *Kapitan Myshevskiy*, which was loaded with oilfield equipment bound for the Kolyma region. They passed to the north of all the major island groups (except Wrangel Island), shaving many miles off the standard coastal route. Altogether, the convoy covered 3200 miles, of which nearly 3000 was in ice. In addition, the voyage took place in May and June, which was unusually early in the shipping season.

Since Gorbachev's 1987 Murmansk speech (see Armstrong, 1988b), several developments have occurred to increase foreign interest in using the NSR. A multinational organization, the International Northern Sea Route Program (INSROP), was formed to undertake any and all activities that would enhance international interest in the route. The lead agencies coordinating INSROP are the Fridtjof Nansen Institute of Norway, the Central Marine Research and Design Institute of Russia, and most recently, the Ship and Ocean Foundation of Japan. This project is the first credible attempt to bring together an international working group to comprehensively define problem areas and to provide a forum for solutions. INSROP participants recognized the following four areas of concern and assigned member groups to address each one in the form of pilot studies:

- Physical conditions and navigation issues,
- Ecological aspects,
- Commerce and trade studies, and
- Legal, political, and military–strategic issues.

A summary of the current state of these on-going activities was published in 1991 by Østreng and Jørgensen-Dahl.

The INSROP effort received additional impetus in November 1991 by a resolution of The Northern Forum, another organization committed to addressing a variety of northern territorial concerns. Signed by thirteen representatives of northern-tier regions in the U.S., Canada, Norway, Russia, Finland, China, Mongolia, Japan, and Korea, the resolution gives approval to the INSROP initiative and encourages a priority emphasis for supporting activities that promote the NSR. Among others, Walter J. Hickel, the current governor of the state of Alaska and chairman of The Northern Forum, is an active proponent of the Northern Sea Route.

Another international group, known as the Barents Council, has also given its endorsement to the promotion efforts and has formed a subcommittee called the Working Group for the Northern Sea Route. At their meeting in Oslo in September 1992, which was attended by representatives from eleven European, Asian, and North American countries, it was decided to formulate a plan for addressing issues relevant to promotion of the NSR. The activities of these three organizations are evidence of an international commitment toward the route's development and a widely held belief that such development might substantially benefit not only Russia, but many other countries as well.

Foreign response to Gorbachev's invitation and the international activities to promote utilization of the Northern Sea Route began with the leasing of cargo space aboard Soviet SA-15 *Noril'sk*-class icebreaking carriers (Brigham, 1993a). In 1989, there were several transits from Hamburg to Osaka. In 1990, six more voyages took place, each requiring about 25 days to complete the route. This was approximately 10 days faster than the Suez Canal route.

That same year, the nuclear icebreaker *Rossiya* (75,000 shaft horsepower) also made the third visit to the North Pole by a surface ship. (The second visit, by the *Sibir'*, was in 1987 [Frolov, 1991].) The unique feature of this nine-day cruise was the fact that the ship was adapted to accomodate 40 foreign tourists, who paid $20,000 each for the trip. The cruise was considered such a success that the *Sovietskiy Soyuz* made two similar tourist trips in 1991 and 1992. An interesting description of these polar excursions from the tourist–adventurist point of view appeared in a nationally distributed recreation magazine (Cahill, 1993). The popularity of these excursions seems assured, and tourism in the Arctic is a business opportunity that the Russians hope to capitalize on.

In August of 1991, a Russian freighter sailed from Norway to Hong Kong carrying 10,000 tons of steel. This marked the first time that Norwegian cargo had been shipped to Asia via the Northern Sea Route.

The summer of 1993 saw the commencement of sea trials of a Finnish–Russian joint venture using a foreign vessel to supply Russian fuel products to a Siberian destination.[4] A Finnish IA Super-class (the highest Finnish ice classification) tanker (16,000 deadweight tons) with a Russian ice pilot on board made three consecutive voyages. The cargo was taken on at the White Sea port of Arkhangel'sk and transported to the mouth of the Yana River in the Laptev Sea, a distance of approximately 4000 km (2485 mi). It was then offloaded to smaller vessels for delivery to an upriver destination. Each round trip required 19–23 days to complete, which included 2–3 days turnaround time. The 1993 season was estimated to be of 1-in-10-year severity in terms of ice conditions. It was necessary at times to break 3- to 5-m-thick pack ice in a 300-mile section of the Laptev Sea beginning at Vil'kitskogo Strait. Four nuclear-powered icebreakers, stationed in the area to maintain a passage, assisted the

[4] Juhani Laapio, 1993, Neste Shipping, personal communication.

Table 5. Recent voyages with foreign involvement.

Year	Ship/flag	Begin–end	Comments
1967	*Novovoronezh* USSR	No. Europe – Yokohama	Soviet ship with foreign cargo
1967	*Dubno* USSR	No. Europe – Japan	Soviet ship with foreign cargo
1967	*Ustyuzhna* USSR	No. Europe – Japan	Soviet ship with foreign cargo
1989	Several transits USSR	Hamburg – Osaka	Soviet ships with foreign cargo
1990	Six transits USSR	No. Europe – Far East	Soviet ships with foreign cargo
1990	*Rossiya* USSR	North Pole trip	Foreign tourists on Soviet icebreaker
1991	*L'Astrolabe* France	Murmansk – Provideniya	1st foreign ship transit allowed since 1940
1991	*Dagmar Aen* FRG	Nar'yan-Mar – Igarka	Foreign ship with no ice classification
1991	*Kapitan Danilkin* USSR	Norway – Hong Kong	Soviet SA-15 with Norwegian cargo
1991	*Kapitan Danilkin* USSR	Malaysia – Murmansk	Soviet SA-15 with foreign cargo
1991	*Tiksi* USSR	Hamburg – Chiba, Japan	Soviet ship with foreign cargo
1991	*Sovietskiy Soyuz* USSR	North Pole trip	Foreign tourists on Soviet icebreaker
1991	8 other voyages USSR	Various	Russian ships with foreign cargo
1992	*Sovietskiy Soyuz* Russia	North Pole trip	Foreign tourists on Russian icebreaker
1992	Freighter Russia	Vancouver – Tiksi	Russian ship with foreign cargo
1993	3 round-trip voyages Finland	Arkhangel'sk – Yana River	Foreign tankers with Russian cargo

Sources: Armstrong (1991), Kjerstad (1992), Brigham (1991a), and Matyushenko (1992).

tanker through this section. The tanker was under constant escort by Russian icebreakers only from Dikson to the Khatanga River. The trial voyages were deemed successful, and the run is expected to become regularly established in the summer of 1994. Although the Russians are seeking foreign cargo and investment to employ their own idle container ships, Finnish tankers were required for this joint venture. There are, ironically, no ice-strengthened tankers in the Russian fleet, as they were all distributed to other members of the CIS upon the breakup of the USSR. Table 5 is a summary of the recent voyages that have involved foreign participation.

In the United States, interest in the Northern Sea Route is being generated in Alaska and Washington State (Weathersby, 1990). The Department of Commerce and Economic Development for the state of Alaska has been working for the past two years to set up demonstration shipments using Russian cargo ships to transport Alaskan goods such as fish, timber, coal, and ore to European markets. The negotiations have encountered several problems, and the first trial voyage planned for the summer of 1993 failed to materialize. Optimism remains that all arrangements can be worked out for a 1994 voyage (Davies, 1993).

Although damage to the ice-strengthened fleet is commonplace even today, it is regarded more as an annoying fact of life and a necessary cost of doing business in that region. Data on 362 cases during 1986–1989 showed that minor hull damage occurred in 82% of cases. The remaining 18% included damage to propellers, shafts, and steering gear (Ushakov et al., 1991). Serious damage is rare.

Even with the technology available today, the Northern Sea Route sometimes presents unexpected challenges. As late as 1983, an early October cold spell trapped approximately 50 ships in the East Siberian Sea. Thirteen icebreakers were dispatched to the scene to effect the rescue operation. By late November, the ships were freed (except for one that was crushed by ice), but 30 suffered damage of varying degrees (Armstrong, 1984; Barr and Wilson, 1985). Each voyage into this region still presents a level of risk, which will continue to diminish with gains in operational experience.

THE PHYSICAL ENVIRONMENT

According to Batskikh and Mikhailichenko (1993), four routes through the Russian Arctic are theoretically possible (Map 2). The first is the most southerly and conventional coastal route. A second is a mid-route through ice massifs following diagonal cracks from Cape Zhelaniya (Novaya Zemlya) to Dikson and from Novaya Sibir' Island to the port of Pevek. A third route, which is useful only for through traffic, stays to the north of Cape Zhelaniya, Cape Arkticheski (Severnaya Zemlya), and Novaya Sibir' Island. A fourth route, 700 miles shorter than the coastal route, is the great circle route, by way of the Pole. This fourth course is not economically feasible at the present time, but it may in the future be viable as transportation technology improves.

The following information about the various arctic seas, from west to east, is summarized from a variety of sources (Brigham and Voelker, 1985; Barnett, 1991; Vefsnmo et al., 1991; Batskikh and Mikhailichenko, 1993).

The continental shelf is extremely wide off Russia's north coast (Map 3), and the seas overlying it are shallow. In general, the winter distribution of sea ice across the Russian Arctic is characterized by the growth of shorefast ice in vast areas where the water is less than 30 m deep. Calculations based on climatic conditions show that the maximum thickness averages 120 to 130 cm in the Kara Gates, 160 to 170 cm near Dikson and in the Longa Strait, and 190 to 200 cm in the straits of Vil'kitskogo and Dmitriya Lapteva. These mean values can vary by 30 to 50 cm depending on year-to-year conditions. The presence of snow has a large effect on the fast-ice thickness; snow acts as an insulating blanket over the growing ice and reduces its thickness.

Seaward of the fast-ice boundary, the ice cover is in constant motion due to ocean currents and winds. This region of moving ice, known as "pack ice," continually experiences openings, called leads, where the ice cover pulls apart, and convergence areas, where the ice crushes together to form pressure ridges and fields of broken rubble. During the freezing period (roughly August to May), new ice is continually being produced in the leads, and these areas of thinner ice are obvious lines of weakness that are exploited to maximum extent by ice pilots and ship captains. In the areas of convergence, rubble ice refreezes into much thicker and stronger masses. In some places, due to the presence of land barriers, prevailing winds, currents, and so forth, ice accumulates in large enough masses that it survives the summer season. These ice fields, sometimes covering hundred of square kilometers and found in the same regions every summer, are known as massifs. Map 4 shows the location of nine such massifs along the Northern Sea Route. The massifs all experience some degree of seasonal fluctuation in size. For example, the Novaya Zemlya massif nearly melts out completely, while the more resistant Taymyr, Ayon, and Wrangel massifs are more resistant and experience less ablation.

Table 6 shows the probability of occurence of ice conditions that necessitate icebreaker assistance through NSR massifs for ULA-class (highest ice classification under the Russian registry) cargo ships. The data include observations from 1970 through 1991. Even though the *Noril'sk*-class vessel has greater capability in ice, both types of ships are highly likely to need escort in all massif areas at the beginning of the season.

Table 6. Probability (%) of occurrence of conditions that require icebreaker assistance through various NSR massifs* for cargo ships of ULA-class at beginning, middle, and end of the shipping season.

	Amguema-class			Norii'sk-class		
Ice massif	Jun	Aug	Oct	Jun	Aug	Oct
Novaya Zemlya	95	0	0	95	0	0
Severnaya Zemlya	100	75	25	100	60	5
Taymyr	95	65	40	95	55	15
Novosibirskiy	95	60	20	90	45	10
Ayon	95	35	15	95	30	5
Wrangel	95	10	25	95	5	5

*Refer to Map 4.
Source: Buzuev (1992).

The summer season occurs roughly from June to September when the ice cover melts significantly, diminishing in both extent and strength. Map 5 shows how the normal ice coverage changes seasonally. It can be seen that the greatest seasonal fluctuation occurs at the east and west ends of the route. This is due to the influence of ocean currents moving northward from the warmer Atlantic Ocean in the west and the Bering Sea in the east, which accelerate ice decay in the spring and retard freezeup in the fall.

Between the freezing and melting seasons is a brief interphase described by Mikhailichenko (1992) as a period of ice pack movement from wind and ocean currents. This interphase is characterized by near-freezing air temperatures that produce little ice growth or decay. Shipping activity routinely occurs throughout the melt and the autumn interphase. The Russians would like to extend the shipping season into the freeze period and the spring interphase. Table 7 provides a summary of the environmental conditions encountered in the Eurasian seas of the Northern Sea Route.

As previously mentioned, the bathymetry of the Russian Arctic is characterized by the continental shelf lying at relatively shallow depth over vast areas. For example, the average depth of the entire East Siberian and Chukchi seas is only 58 m and 88 m, respectively (Østreng, 1991). Tidal changes range from 5 to 7 m in the Laptev Sea, from 3 to 4 m in the East Siberian Sea, and are no more than 2 to 2.5 m in the Kara Sea (Buzuev, 1991). The limiting depths for navigation are those found in the various straits. Most exceed 20 m, except the Sannikova and Dmitriya

Table 7. Summary of environmental conditions of the arctic seas along the Northern Sea Route.

	Barents	West Kara	East Kara	Laptev	E. Siberian	Chukchi
Mean air temp (°C)						
Winter	-10 to -15	-15 to -20	-25 to -30	-30	-30	-20 to -30
Summer	—	5	2	—	2 to 5	2 to 5
Mean fast ice thickness (cm)	50 to 150	120 to 200	200	200 to 250	170 to 200	130 to 180
Average date of minimum ice cover	15 Sept	24 Sept	14 Sept	17 Sept	13 Sept	12 Sept
Summer ice cover relative to winter max. extent (% of area)	10	25	48	47	57	20
Average date of complete freeze-up	Never	Mid – late Nov	Mid Nov	—	Mid Oct	Mid–late Nov
Average date of min. ice extent	15 Sept	24 Sept	14 Sept	17 Sept	13 Sept	12 Sept

Source: Barnett (1991).

Lapteva straits located south of the Novosibirskiy Islands, which are only 13 m and 8 m deep, respectively. These extreme shallows limit the size of ships that can pass safely to those under 20,000 dwt unless they are specially designed for shallow-water operations (Wergeland, 1991). The more northerly routes are deeper, but ice conditions are also more severe.

The Barents Sea

The Barents is the warmest of the Eurasian seas, and the only one not totally ice-covered in winter. During the most severe winters, only about 90% of the surface is covered with ice (70% and 50% in normal and mild winters, respectively). It experiences the greatest seasonal variation of sea-ice extent. Its ice cover is dramatically affected by the influx of warm water from the Atlantic, which moderates the ice conditions in the southern and southwestern Barents. General ocean circulation and prevailing winds in winter advect ice southwestward from the northern Barents ice pack. The southern Barents in winter, however, experiences generally southwesterly winds that introduce warm maritime air and inhibit ice growth. Winter mean air temperatures are relatively mild (–10 to –15°C). First-year ice thickness averages 50 to 100 cm in the south and 120 to 150 cm in the north. Severe winter conditions are the result of occasional shifts in the normal positioning of the Icelandic low and Siberian high pressure systems, which cause southeasterly winds to dominate. Such a shift brings in cold continental air off the Siberian plateau, which gives rise to greater ice production in the southern Barents.

The protection offered by the perimeter location of the major island groups of Svalbard, Franz Josef Land, and Novaya Zemlya prevents the influx of ice from neighboring seas where ice production is greater. In addition, weaknesses in the ice cover are prevalent on the leeward side of most island groups in the Barents. Prevailing easterly winds continually drive the ice offshore so that the ice that is present at any time is newly formed and relatively thin. These lee-side polynyas are generally evident throughout the winter off Nordaust Land, Kong Karls Land, Kvitøya, Novaya Zemlya, and especially Franz Josef Land. The spring-summer melt pattern usually initiates and expands from these areas. During summer, the polynyas typically expand southward to meet the northerly retreating main ice edge, forming vast tongues of open water. In a normal summer the ice edge retreats to about 78°N. While all the major islands have actively calving glaciers, icebergs are not a serious concern to navigators in the Barents at any time.

The Kara Sea

The other seas along the Russian coast are influenced by cold continental air masses and hence experience much colder air temperatures. Mean winter temperatures range from –15 to –20°C in the southwest Kara and from –25 to –30°C in the north and east Kara. Mean summer air temperatures range from 0 to 5°C. The sea ice cover is greatly influenced by its relatively landlocked perimeter, winds, river runoff, and shallow bathymetry. Due to Novaya Zemlya, there is little exchange of warm water from the Barents. Likewise, Severnaya Zemlya inhibits exchange with the Laptev Sea. Water and ice mass exchange is almost entirely with the Arctic Ocean to the north.

Fast ice forms along the entire Kara coastline, and it is generally narrow except in the eastern Kara where it extends outward for 150 to 200 km. Throughout fall and winter the only substantial openings in the ice cover usually occur at the boundary between this fast ice and the outer pack ice. Offshore winds tend to push the pack away from the stationary ice, creating occasional lanes of newly forming ice. This transport mecha-

nism produces thicker ice to the north. The coastline at the eastern end of the Kara is about 650 km farther north than at the western end. This obviously results in cooler air and sea conditions in the eastern sector. The ice thickness in a normal winter ranges from 120 cm in the southwest to 200 cm in the northeast.

Summer melting in the Kara typically begins at the outer edge of the fast ice when ice production ceases. A few weeks later the fast ice breaks free and drifts seaward. Rivers flowing into the Kara constitute more than half of all the runoff entering the Eurasian seas. Warm spring runoff produces early open-water areas at the major estuaries, and by midsummer, the western Kara is normally ice-free as far north as 75°N. There may be open water as far north as 82°N during a mild summer. There is, however, a cold ocean current running southward along Novaya Zemlya that piles ice into the Kara Gates. This ice will often survive through an unusually cool summer.

In the eastern Kara, summer melting is less extensive; nearly half of its area remains ice-covered throughout a normal summer. The year-to-year variability, however, ranges from zero to 80% coverage. In addition to a more northerly latitude, warm river inflow is dramatically less here than in the western Kara. There is no prevailing summer wind pattern, but in some years, westerly winds concentrate ice at its eastern barrier of Severnaya Zemlya and the Taymyr Peninsula, creating a difficult barrier to navigation.

Freeze-up begins in September in the colder northeast Kara and in October in the less saline central region where the Ob' and Yenisey Rivers enter. After that, the intervening region rapidly grows an ice cover that connects the two. The extreme southwest sector, extending 180 to 275 km eastward from the Kara Gates, normally remains open into November, but with great year-to-year variation (late October to late December).

The Laptev Sea

Sea ice distribution in the Laptev is influenced by cold winter temperatures, southerly winter winds, ocean currents, heavy river inflow, and a vast continental shelf of very shallow depth. With the extraordinarily broad continental shelf in this region, half of the entire Laptev is less than 50 m deep, and south of 76°N, its depth does not exceed 25 m. Because of these shallow waters, the Laptev and the East Siberian seas have the largest expanse of fast ice in the world from January to June. The fast- ice thickness typically reaches 200 cm due to mean midwinter air temperatures of –30°C and can grow up to 250 cm thick during severe winters.

Similar to the Kara, prevailing southerly winter winds continually push the pack northward away from the fast ice, resulting in a nearly permanent lane of weakness. The amount of old, thick ice found in the Laptev is limited not only by these winds but also by northward ocean currents. The total area of summer melt is particularly extensive due to this reduced presence of old ice. In the western Laptev, however, the ice drift is southward, and large masses of ice are deposited along the coast of Severnaya Zemlya and the Taymyr Peninsula. Along with the eastward ice deposition from the Kara, Vil'kitskogo Strait and the Taymyr coast present a serious challenge to navigation at all times of the year.

Many rivers empty into the Laptev, but the Lena accounts for more than 70% of the total inflow. The summer melt pattern is greatly influenced by this warm water influx. Large areas of open water expand outward from the deltas so that, by the end of summer, the Laptev is typically ice free as far north as 77°N (only 74°N for the western portion).

SOME RUSSIAN GEOGRAPHICAL TERMS

губа (goo-bah'), *n.* bay, inlet.
море (mo'-reh), *n.* sea.
мыс (miss), *n.* cape.
остров (os'-trov), *n., pl.* **острова** (os-tro-va'), island(s).
озеро (o'-ze-roh), *n.* lake.
полуостров (po'-loo-os'-trov), *n.* peninsula.
пролив (pro-leev'), *n.* strait.

Winds are light and variable in summer, but prolonged easterlies transport additional ice into the Taymyr ice massif.

The East Siberian Sea

Of all the Eurasian seas, the East Siberian experiences the least amount of summer melting. On average, more than 50% remains ice-covered throughout the summer season. The persistence of the ice cover is attributed to cold winter and cool summer air temperatures, prevailing winds, ocean currents, a wide continental shelf, and meager river inflow.

The East Siberian Sea is the shallowest of the Eurasian seas. The broad continental shelf allows fast ice, averaging 170 to 200 cm thick, to extend as far as 500 km outward from the coast. In winter, prevailing southerly winds bring up cold continental air, producing a winter mean air temperature of –30°C. These winds also cause weak ice conditions and potential navigation lanes at the outer edge of the fast ice as they do in the Kara and Laptev seas.

In summer, the winds shift to northerly, bringing in polar air. In addition to cool air temperatures, warming from river inflow is limited. Total river discharge into the East Siberian amounts to only 20% of the Kara's total and only 35% of the Laptev's. Ocean currents favor the influx of ice from (rather than its removal to) the Arctic Ocean, resulting in the permanence of the Ayon massif that protrudes into its eastern sector. Winter freeze-up begins in the north in September and is usually complete by mid-October.

The Chukchi Sea (Russia)

The Chukchi Sea is almost totally ice covered from early December to mid-May. It experiences a large seasonal variation in ice cover, losing about 80% of its maximum winter extent during the summer season. The extent of its summer ice melt is exceeded only by that in the Barents. Important factors that influence sea ice distribution in the Chukchi are the sea's bathymetry, winds, ocean currents, air temperatures, and the presence of Wrangel Island. Winter mean air temperatures range from –30°C in the west to –20°C in the east due to the inflow of relatively warm water from the Bering Sea. Consequently, winter mean ice thickness ranges from 130 cm in the east to 180 cm in the west. Because the continental shelf is less extensive, only a 10- to 15-km-wide band of fast ice forms along the mainland and the Wrangel Island coast. Ocean currents and winds tend to concentrate old ice from the Arctic into Longa Strait under great pressure, which can sometimes present the greatest navigational obstacle of the entire route. It was at this location that the 50-ship convoy became ice-bound in the autumn of 1983. The only midwinter area of weakness is a lee-side polynya that forms off Wrangel Island that can occasionally be 100 km wide. The prevailing onshore winds of winter normally shift around to a more offshore flow in the spring, resulting in a narrow lane of open water along the coast for the duration of the shipping season.

The summer melt pattern is primarily influenced by the influx of warmer water from the Bering Sea. Breakup initiates in the eastern end and progresses westward. At the height of summer (mid-September), the Chukchi is normally 80% free of ice. Summer air temperatures average from 2 to 5°C. Winter freezeup is usually delayed into September or October by this warmer inflow, and open water north of the Bering Strait is found into late November.

Alaskan waters

The information presented here was extracted primarily from the Arctic Marine Transportation Program (AMTP) summary report by

Voelker (1990). The program, which took place from 1979 to 1986, collected field and operational data during twelve deployments of a U.S. *Polar*-class icebreaker to the ice-infested waters surrounding Alaska. The program's purpose was three-fold:

- To assess the feasibility of commercial marine operations in ice,
- To obtain data for improving ship design for ice operations, and
- To define the environmental conditions along potential shipping routes.

Therefore, this environmental summary contains information that is more applicable to ship trafficability in the Chukchi, Beaufort, and Bering seas.

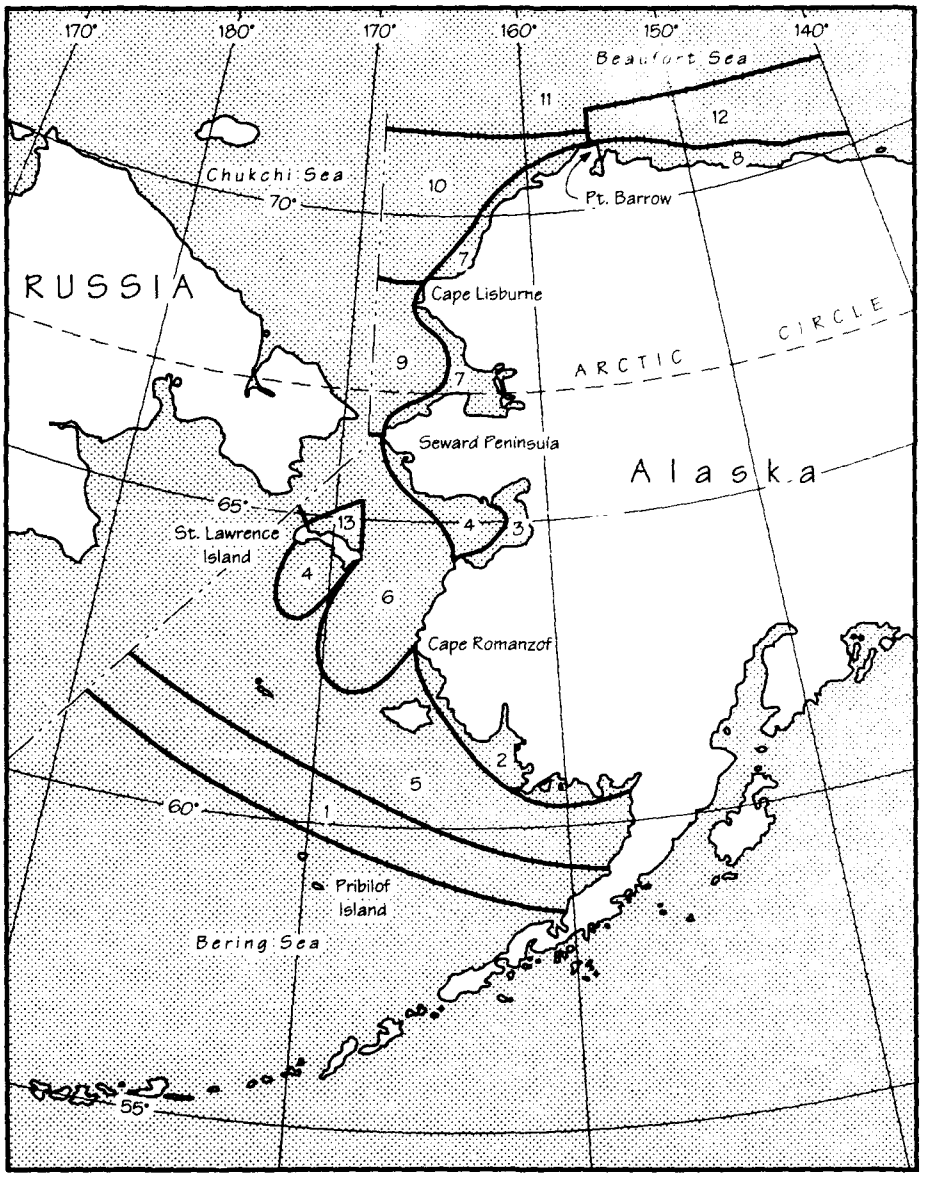


Figure 3. Zones of environmental severity affecting marine trafficability in Alaskan waters. The numbers from 1 to 13 represent increasing degrees of navigational difficulty in the areas indicated. The dashed line through the Bering Strait is the International Date Line. (Adapted from Voelker, 1990.)

Based on an analysis of meteorological and satellite imagery data and experience gained from the ship deployments, thirteen specific geographic areas were identified as having differing levels of environmental severity in terms of trafficability (Figure 3). These zones are based on representative conditions that would result during an average ice year with winds trending from the north to northeast and prevailing throughout the winter season. The winter season for the Bering Sea is considered to be 6 months long (December through May). Winter in the Chukchi is 9 months long (November through July), and in the Beaufort Sea it is 10 months long, beginning in October and ending in July.

The Bering Sea

In the Bering Sea, open water can be expected from about the Pribilof Islands southward. The southern limit of zone 1 marks the ice edge where pack ice in low concentrations is found. Zones 2 and 3 are areas of landfast ice with a level ice thickness range of 100 to 130 cm based on freezing-degree-day calculations (LaBelle et al., 1983). Areas marked as zone 4 lie in the shadow of land masses and are thus somewhat sheltered from the degree of ice movement and consolidation that occurs in more exposed locations. Ice here is usually less than 30 cm thick during periods of prevailing northerly wind. Zones 5 and 6 are regions of dynamic ice displacement, resulting in pressure ridges, rubbled floes, and open leads caused by ice drift averaging 0.3 to 0.5 knots. Ice, which is transported primarily by wind, consolidates to a thickness of between 30 and 120 cm. The most severe ice conditions in the Alaskan Arctic are found just south of the Bering Strait (zone 13). Ice becomes extremely rubbled and compacted to the windward side of St. Lawrence Island. Year-round marine traffic using current icebreaking capabilities is technically feasible throughout most of the Bering Sea, but it is usually suspended from late December to mid-May, according to the U.S. Coast Pilot manual (USDC/NOAA, 1981). Fast ice begins to form along the coast and in sheltered areas sometime in October. Pack ice formation in the more open areas begins its southward progression in November with the seasonal cooling of the water. According to Brower et al. (1988), 97% of the ice found in the Bering Sea actually forms there with very little southward influx of ice from the Chukchi Sea. Winter ice coverage in the Bering is highly variable from year to year and even month to month due to shifts in prevailing winds that produce leads and polynyas of short duration. Thick, multiyear ice is generally not found in the Bering Sea, since the ice cover melts out completely during the summer.

The Chukchi Sea (Alaska)

The Alaskan side of the Chukchi Sea is divided into three different zones of severity. Zone 7, adjacent to the Alaskan coastline, is a region of relatively stable and level shorefast ice ranging in thickness from 155 to 190 cm. Zones 9 and 10 roughly divide the Chukchi at 69°N latitude. The ice conditions in zone 9 (that is, pressure ridges, thick rubble ice, and ice pressure) are generally more serious than those found anywhere in the Bering (except zone 13). Zone 10 conditions are made more serious still by the greater concentration of drift ice that enters from the Beaufort Sea. The drifting ice ranges from 150-cm-thick first-year ice to 9-m-thick multiyear floes.

Freezeup in the northeast Chukchi begins in mid-September to early October and progresses southwestward. The Coast Pilot manual (USDC/NOAA, 1981) recommends that southbound ships be south of the Bering Strait by early November. Two winter deployments to

the north Chukchi during the Arctic Marine Transportation Program, however, concluded that year-round transits are technically—but probably not economically—feasible using current U.S. icebreaking capabilities. The study pointed out that the full 60,000-shp operational capacity of the *Polar*-class icebreakers was often required and that ice piloting and operating skills were extremely important. Average air temperatures for coastal stations in February, the coldest month, range between –18 and –30°C, while extremes of –45°C and below have been recorded. Winds can be severe and prolonged, leading to extreme ice pressures and dangerous wind-chill conditions for personnel. The 5-year return period for maximum sustained winds for both the Chukchi and Beaufort seas is 68 knots.

The disintegration of the seasonal ice cover begins, usually around mid-May, at the seaward edge of the fast ice along Alaska's northwest coast in response to strong offshore (easterly) winds that develop in March and April. However, the pack ice generally remains close in to Pt. Barrow until late July or early August.

The Beaufort Sea

The Beaufort Sea presents the most challenging navigation conditions in Alaskan waters. The narrow region along the northern coastline (zone 8) grows fairly stable landfast ice averaging 200 cm thick. The area contains not only level, first-year sea ice, but also has an abundance of pressure ridges and multiyear ice. At the seaward edge of the fast ice, at approximately the 20-m isobath, is a shearing zone marking the transition to highly dynamic pack ice that constitutes zones 11 and 12. Shear ridges in this transition zone are larger and more extensive than anywhere else on the Alaskan coastline. Both zones have an abundance of very large (several km in diameter) multiyear floes and first-year rubble that produces massive pressure ridges. Zone 12 experiences a greater frequency and intensity of pressured ice conditions because of its relative position with Alaska's north coast and prevailing northeasterly winter winds. February air temperatures along the coast average –28 to –30°C. Summertime air temperatures average 2 to 6°C. Because ice transit operations there are so demanding, refueling stops for icebreakers along the way would be required where none currently exist. The median date for opening the cargo transport season around Barrow to Prudhoe Bay is August 2, but it has varied between July 19 and September 3. The length of the navigation season also varies considerably. In 1975, the route never opened, whereas in 1958 it was considered navigable (5/10 ice concentration or less) for more than 99 days (USNOCD, 1986b).

ICEBREAKING TECHNOLOGY

In the last four decades, significant developments in icebreaking technology have taken place through the application of modern marine technology to the design and the operation of polar ships. As a result, ships can travel to remote polar regions that were deemed impenetrable only a few years ago. Basically, polar ships have become larger, stronger, and more powerful. In addition, innovative ideas have been implemented to improve propulsion systems and reduce the resistance encountered during icebreaking. Many nations have contributed to this development by designing and building polar ships and by launching voyages to various regions of the Arctic and the Antarctic. Some of the landmark voyages during the last four decades are listed in Table 8 (Brigham, 1987).

The impetus behind these technological advances has been due to:

Table 8. Selected important polar voyages in recent years.

Polar ship/flag	Time of year	Route/location	Significance
Lenin USSR	Summer 1960	Northern Sea Route	World's 1st nuclear surface ship commences icebreaking escort duties
Manhattan US	Autumn 1969	Northwest Passage	Experimental voyages to test the feasibility of commercial tankers in the Arctic
Louis S. St.Laurent & *Canmar Explorer II* Canada	Aug 1976	Northwest Passage	Successful escort of a drill ship from the Atlantic to the Canadian Beaufort Sea
Arktika USSR	Aug 1977	Murmansk to the North Pole and return	1st surface ship to reach the geographic North Pole (17 Aug)
Sibir' & *Kapitan Myshevskiy* USSR	May–Jun 1978	Northern Sea Route (north of Novosibirskiy Islands	1st high-latitude "trans-Arctic" ice escort
Polar icebreakers and icebreaking carriers USSR	Navigation season 1978–79	Barent and Kara seas	1st successful year-round navigation from Murmansk to Dudinka on the Yenisey River
Polar Star & *Polar Sea* US	1979–86	Bering, Chukchi, and Beaufort seas	Arctic marine transportation ("trafficability") studies around Alaska
Polar Sea US	Jan–Mar 1981	Bering Sea to Beaufort Sea	1st winter transit to Pt. Barrow, Alaska
Polar Star US	Dec 1982–Mar 1983	Antarctica	1st high-latitude (above 60°S) circumnavigation of Antarctica in modern times
Leonid Brezhnev and 12 other ice-breakers USSR	Oct–Nov 1983	North coast of Chukotka, Siberia	Rescue of 50 cargo ships trapped in ice
Arctic Canada	Aug 1985	Bent Horn, Cameron Island	1st cargo of crude oil from the Canadian Arctic
Vladivostok & *Somov* USSR	Jun–Sep 198?	Near Russkaya Station, Hobbs Coast, Antarctica	Rescue of Soviet Antarctic Expedition flagship drifting in heavy ice
3 SA-15 icebreaking carriers USSR	Nov–Dec 1985	Northern Sea Route	Experimental navigation season extension with sailings from Vancouver to Arkangel'sk
Icebird FRG	Fall 1985–Summer 1986	Australian Antarctic stations and Japan to Prudhoe Bay, Alaska	Bipolar resupply operations to Antarctica and Prudhoe Bay
Polarstern FRG	Jul–Aug 1986	Weddell Sea, Antarctica	Winter oceanographic operations
Sibir' USSR	May–Jun 1987	Central Arctic Basin	Evacuate drift station 27 and establish drift station 29; 2nd surface ship to reach the geographic North Pole (25 May)
SA-15 icebreaking carriers USSR	Summer 1989	Europe to Japan via the Northern Sea Route	Soviet arctic carriers under charter to Western shippers for commmercial voyages across the top of the Soviet Union
Rossiya USSR	Aug 1990	Central Arctic Basin	Transit to the North Pole (8 Aug) with Western tourists aboard
Arctic Canada	Jun 1991	Northwest Passage to the Polaris Mine, Little Cornwallis Island	Earliest seasonal surface ship transit in eastern reaches of the Northwest Passages; mine reached 23 June
Sovietskiy Soyuz USSR	Jul–Sep 1991	Central Arctic Basin and Northern Sea Route	Transit to the North Pole and along the Northern Sea Route with Western tourists
Oden & *Polarstern* Sweden & FRG	Aug 1991	Central Arctic Basin	International Arctic Ocean Expedition; reached the North Pole (7 Sep)

After Brigham (1992).

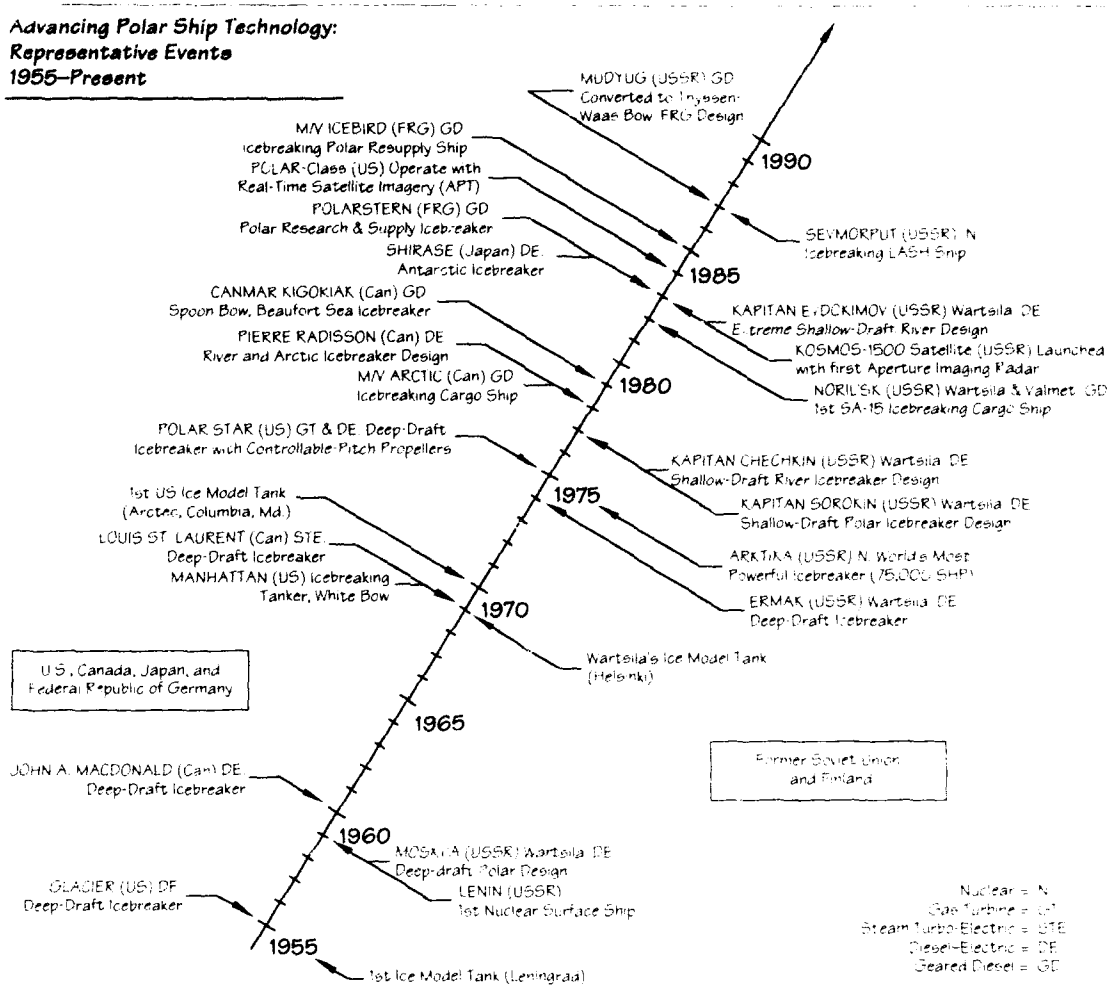


Figure 4. Significant events in the advancement of polar ship technology since 1955 (from Brigham, 1987).

- The exploration for natural resources around the Arctic basin,
- The development of the Northern Sea Route by the Soviet Union as an integral part of the development of the entire Russian Arctic, and
- The need for multi-mission ships to transport personnel, logistics, and marine research in the Antarctic.

A summary of significant advances in polar ship technology over the past four decades is shown in Figure 4. Events associated with the progress made by Finland and the former Soviet Union are shown in the figure below the timeline, and those by the U.S., Canada, Germany, and Japan are above.

Together, Finland and the Soviet Union have made major contributions to the development of polar ships. The Soviet Union first used nuclear technology to power the icebreaker *Lenin*, which was launched in 1959. The Finnish shipbuilder Wartsila built many icebreakers for the Soviet Union and provided many advances in design during the years of development of conventionally powered icebreakers. Recently, these two technologies have merged (Figure 5) to develop *Taymyr*-class, shallow-draft polar icebreakers built in Helsinki with Soviet nuclear propulsion

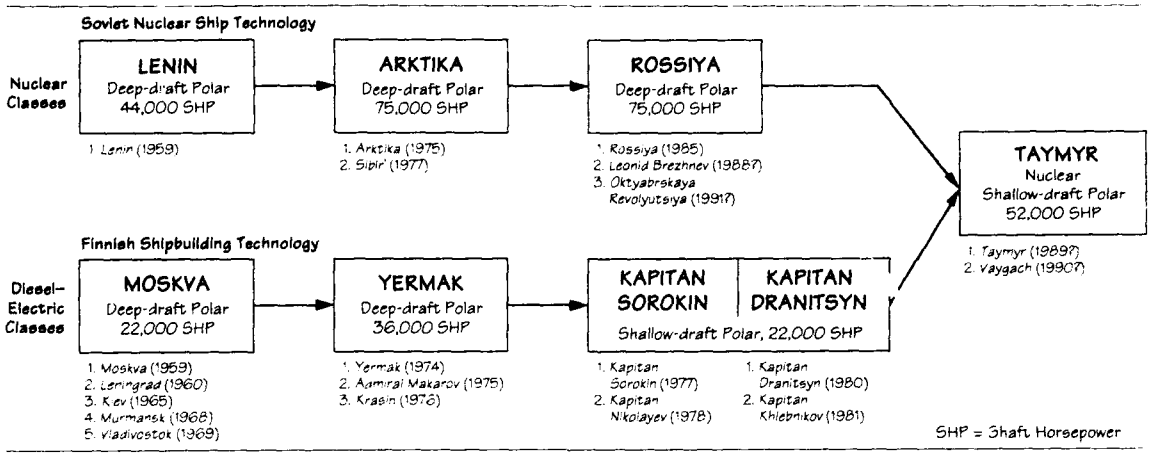


Figure 5. Design evolution of Soviet polar icebreakers (from Brigham, 1991b).

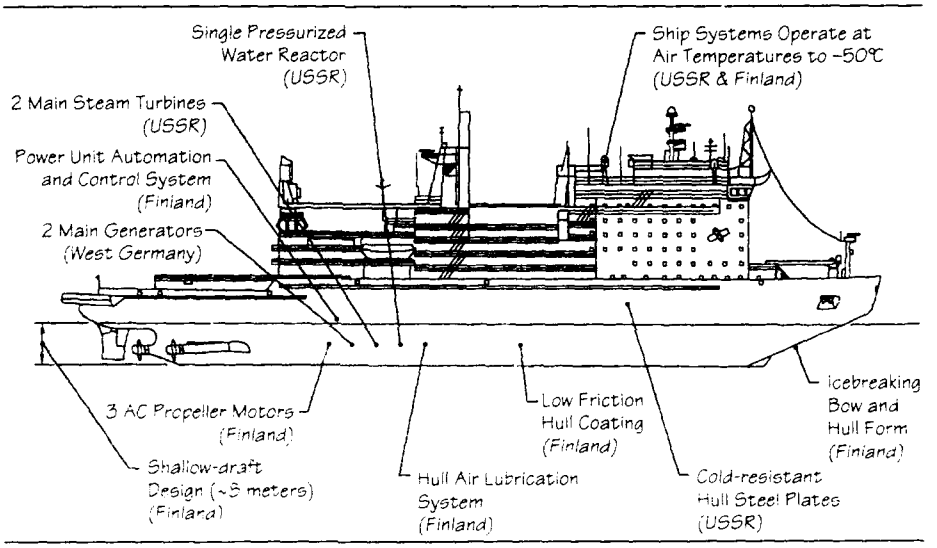


Figure 6. Taymyr-class shallow-draft nuclear icebreaker (from Brigham, 1991b).

systems installed in St. Petersburg. Figure 6 is a sketch of a *Taymyr*-class shallow-draft nuclear icebreaker, including relevant ship systems with their country of origin.

Similarly, developments in the U.S. and Canada have contributed to changes in key areas of icebreaking technology, such as hull and bow form, gas turbines, and the controllable-pitch propeller. In the early 1980s, modern hull and propulsion technologies were also applied to ant-arctic ships (for example, Japan's *Shirase* and Germany's *Polarstern*). In the late 1980s, the bow of the Finnish-built Soviet icebreaker *Mudyug* was converted to the newly developed Thyssen–Waas bow. The results of full-scale trials in open water and in ice indicate that this change to the *Mudyug* has resulted in overall increased icebreaking capability at reduced power requirements (Milano, 1987). Such an improvement in bow design may result in substantial savings in fuel costs. However, there were problems with wave slamming in open water operations during high seas. Recently, the bow of another Russian icebreaker, the *Kapitan Sorokin*, has been changed to the Thyssen–Waas bow. The performance of these ships is being evaluated both in ice and in open water. While there

is substantial improvement in the performance of polar ships with the Thyssen–Waas bow in level ice, their performance in rubble ice and ridges appears to be the same as that of ships with conventional bows.

Polar ships

Information on most of the icebreaking ships in the world is given in the appendix of the review paper by Dick and Laframboise (1989). For the sake of completeness, that list is included as Appendix A of this report. It contains data on icebreakers and icebreaking cargo ships from Argentina, Canada, Denmark, Finland, Japan, Sweden, United Kingdom, Russia (or the former U.S.S.R.), U.S.A., and Germany.

Trends in icebreaking technology

Dick and Laframboise (1989) have reviewed the development of icebreakers and icebreaking cargo ships. The following is a summary of the trends presented in their paper. For more detailed information, readers are referred to the papers and reports in the reference list and the bibliographies.

Sizes and dimensions

The main dimensions of a polar ship are its length, breadth, and depth. The depth of water in which a ship can operate without touching bottom depends on the draft. The dimensions of each icebreaker (cargo ships not included) listed in Appendix A are plotted in Figure 7. The length of polar ships ranges between 40 m and 140 m. This database includes river icebreaking vessels and ice management vessels in the Beaufort Sea.

Breadth

The mean length-to-breadth ratio varies from 3.6 to 4.6 for lengths from 40 m to 140 m, respectively. North American vessels are narrower than those from Finland, Sweden, and Russia. This may be explained by the practice of convoy escort that is used in the Baltic and the Russian Arctic.

Depth

The mean length-to-depth ratio varies from 8.9 to 8.2 for lengths from 40 m to 140 m, respectively. This ratio is high for supply vessels and low for conventional icebreakers.

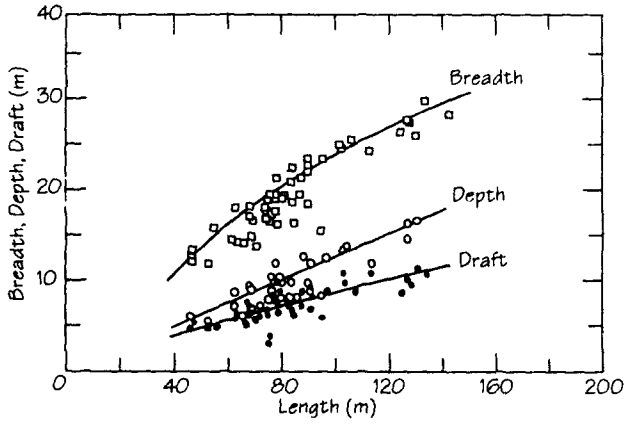


Figure 7. Dimensions of icebreakers (cargo ship not included) (from Dick and Laframboise, 1989).

Draft

The mean length-to-draft ratio varies from 11.4 to 12.2 for lengths from 40 m to 140 m, respectively. Draft, like other dimensions of a ship, is usually defined by the operating requirements of the ship.

Hull form

The primary consideration for the choice of hull form is the lowest power required to make progress in ice. Secondary considerations include power requirements in open water, maneuvering, and protection of propeller(s). The following considerations are taken into account when selecting a hull form:

- Performance in ice of all types,
- Performance in open calm water,
- Performance in heavy weather in open water,
- Maneuvering capability,
- Choice of overall dimensions,
- Ease and cost of construction,
- Ease of repair, and
- Type of ship (such as cargo or icebreaker).

Most icebreakers have a conventional bow, but recently a few ships have been constructed with nonconventional bows. These designs have been guided by one particular consideration, such as construction cost, icebreaking efficiency, or maneuvering.

Bow shape

The selection of bow shape is greatly influenced by the mission profile of a polar ship. The shape of an icebreaker's bow is characterized by five basic design features (Figure 8). Flare angles contribute to icebreaking and submergence efficiency, and waterline angles contribute to clearing efficiency. Buttock angle and stem angle are associated with the flare and waterline angles and contribute to breaking and submergence efficiencies.

The progression in the design of icebreaker bows over the last two decades has been to increase frame flare, reduce waterline angles, and reduce stem and buttock angles (Dick and Laframboise, 1989). These changes were developed by performing a systematic series of model tests to produce a more efficient icebreaking bow. When the values of stem angles of different icebreakers are compared, there is a general trend over the years of decreasing stem angle from 30° to 20°.

Different bow shapes are shown in Figure 9. The following is a brief discussion of each type.

(a) Straight stem with parallel buttocks. This shape was commonly used for Soviet and Finnish icebreakers since the 1950s, as demonstrated by the *Moskva*-class icebreakers in the '60s and the *Urho*-class Baltic icebreakers in the '70s.

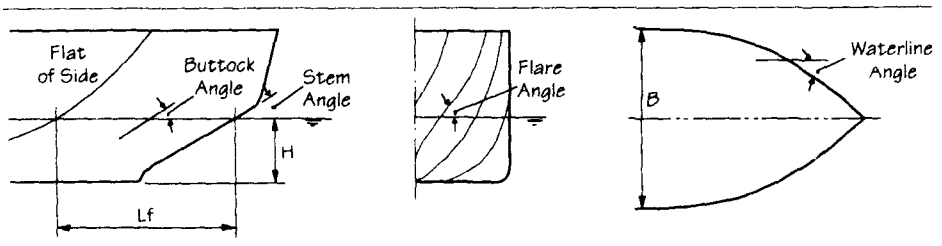


Figure 8. Main features of bow forms (from Dick and Laframboise, 1989).

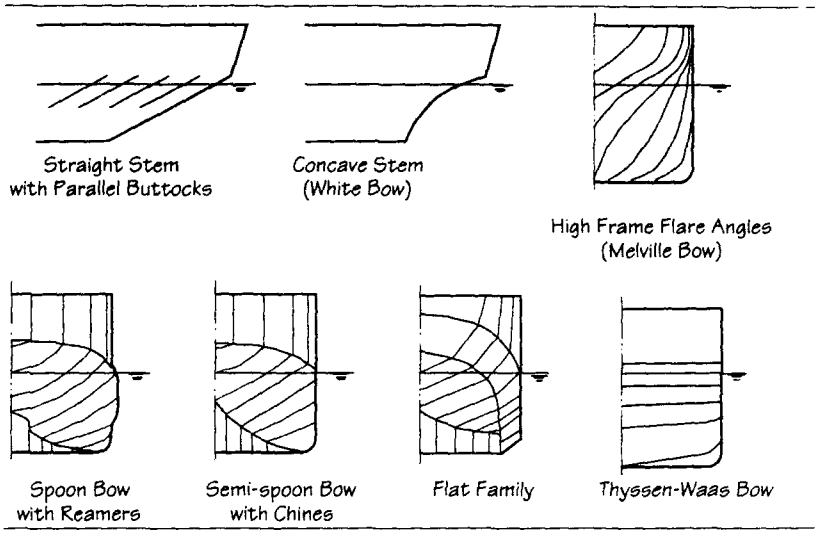


Figure 9. Different shapes of icebreaking bows (from Dick and Laframboise, 1989).

(b) Concave stem (White bow). The concave stem was developed for efficient icebreaking and ice clearing. This bow shape was used in the *Polar Star* and *Polar Sea*, built in the mid-70s; the *Arctic*, built in the late '70s; and the Canadian R-class icebreakers, built in 1978 and 1984.

(c) High flare angles (Melville bow). The high frame flare shape was developed to reduce the icebreaking component of ice resistance. Recently, *Arctic* was modified to this type of bow, and its performance increased from 2 to 8 knots in 1-m-thick ice.

(d) Spoon bow with reamers. The spoon-shaped bow is more efficient in icebreaking because the shape allows constant frame flare throughout the bow length. This shape was used in the past, but was discontinued due to high resistance in heavily snow-covered ice. With the introduction of bubbler systems or water-wash systems, snow resistance is of less concern. A modification of this shape was reintroduced on the *Canmar Kigoriak*, built in 1979, and the *Robert Lemeur*, built in 1981. The extended beam at the shoulder (reamers) with the abrupt change in shape causes extra resistance in open water.

(e) Semi-spoon bow with chines. This shape is similar to the spoon bow, except that the extended beams (reamers) are replaced by shoulder chines. This shape has been used on vessels for ice management operations in the Beaufort Sea and has demonstrated an improvement in icebreaking performance, with some detrimental effect on open-water resistance.

(f) Flat family. These shapes are similar to the spoon bow and semi-spoon bow shapes, except that flat plates have been used to reduce construction costs. This shape was developed as a compromise between icebreaking capabilities and construction costs. This type of bow has been used on the *Arctic Nanabush*, built in 1984, and the *Arctic Ivik*, built in 1985, both of which are used for ice management operations in the Beaufort Sea.

(g) Thyssen–Waas bow. Icebreaking with this type of bow shape is a significant departure from that with a conventional icebreaking

bow. The bow first breaks the ice by shearing at the maximum beam of the ship and then breaks the ice in bending it across the front of the bow. This shape is characterized by flat waterlines at the extreme forward end, extended beam, a low stem angle with an ice-clearing forefoot, and a high flare angle below the waterline. The ice clearing capability is so good that the channel behind the ship is about 85% free of ice. The vessels that have been fitted with this type of bow are the *Max Waldeck* (1980), the *Mudyug* (1986) and the *Kapitan Sorokin* (1991).

Of the seven bow shapes listed above, the first three can be referred to as "conventional" or "traditional" because they retain the smooth hull, which offers least resistance in open water. The other four shapes are "unconventional" or "nontraditional" in that they are a distinct departure from smooth hull shapes. Each shape has some benefits and some drawbacks, so the selection of a bow shape should be based on a full understanding of a ship's operational requirements.

Midbody shape

The midbody shape of a polar ship is characterized by three parameters: flare angle, parallel midbody, and longitudinal taper. The objective of midbody flare is to decrease the resistance caused by the midbody passing through the channel broken by the bow. Flare angles in various icebreakers range between 4° and 20°. Some of the icebreaking cargo ships have a long, parallel midbody. Some icebreakers have forward shoulders to break a wider channel to eliminate any ice resistance from a parallel midbody. Similarly, a midbody with longitudinal taper eliminates ice resistance aft of the forward shoulders. This shape has been used on barges that are pushed by small tugs that operate in sheltered water behind the barges. The drawbacks of longitudinal taper midbody are higher construction costs and an increased probability of getting stuck in pressured ice. No icebreakers or icebreaking cargo ships have used longitudinal taper midbody.

Stern shape

All icebreakers must move astern in ice. Some may move back only in a broken channel or in broken ice, but there are those providing a support role that must break ice while moving astern. Depending upon the mission profile, these ships may have an icebreaking/-deflecting stern shape. The main concern while moving astern is ingestion of ice blocks into the propellers. Despite many innovative stern designs and shrouded propellers, there is still substantial ice–propeller interaction.

Propulsion

The technology of icebreaking propulsion has changed over the years. The data from existing icebreakers and icebreaking cargo ships indicate that power per shaft has increased over time.

Developments in propulsion systems include diesel-electric power plants, propellers with fixed or controllable pitch, and the arrangement of propellers. For example, the propulsion system of the multipurpose icebreaker *Finnica* consists of diesel generators, a cycloconverter control system, and azimuth propulsion units. The *Finnica*'s requirements of extreme maneuverability are fulfilled by two azimuth thruster units, each consisting of fixed-pitch, 4.2-m-diameter propellers in a nozzle.

Propeller

Fixed-pitch (FPP) and controllable-pitch (CPP) propellers have been fitted to polar ships. FPPs continue to be used on most icebreaking ships,

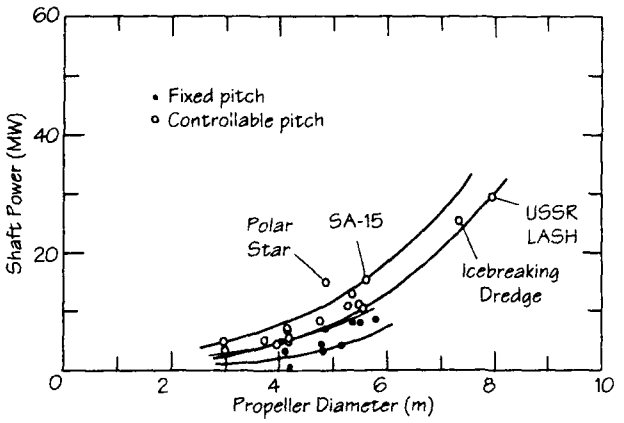


Figure 10. Shaft power vs. propeller diameter for icebreaking ships (after Dick and Laframboise, 1989).

but since 1966, CPPs are being used extensively. Using the data from existing icebreaking vessels, a plot of power vs. diameter for different types of propellers is shown in Figure 10.

Shafting

Large-diameter propeller shafts are needed in polar ships because of high power and high torque requirements. According to the data on existing polar ships, the range of power and diameter of propeller shaft are 5.5 to 15.4 MW and 380 to 775 mm, respectively.

Gear systems

The largest gearboxes fitted to an icebreaker are the single-input, double-reduction gears on the icebreakers *Polar Sea* and *Polar Star*. These ships are powered by a combined gas turbine and diesel electric system. The gas turbines, rated at 18.7 MW, are used only when high power is needed during heavy icebreaking. Most of the polar ships are fitted with gears of relatively low power. In some ships, fluid coupling and oversized flywheels have been used to limit overload torque.

Electrical systems

Four types of electrical propulsion systems have been used in polar ships. In chronological order of their development they are: dc–dc, ac–ac, ac–dc, and most recently ac–ffc–ac (ffc = full frequency control). The dc–dc system is the most commonly used in ships that have medium-speed diesel engines as prime movers. The ac–dc system was developed to take advantage of the lower weight, lower cost, and mechanical simplicity of ac generators. This system is being used in many icebreakers, including the Russian nuclear fleet and Canadian R-class vessels. The ac–ffc–ac system is now being installed on new icebreakers. This system can control the motor operation precisely and steplessly and is technically superior to ac–dc and dc–dc systems.

Prime movers

The prime mover of a ship propulsion system should have the characteristics of reliability, flexibility, maneuverability, robustness, and overtorque capability. None of the prime movers used in polar ships has all of these characteristics.

Experience with gas turbines as prime mover is limited to two vessels, *Polar Star* and *Polar Sea*. As mentioned earlier, these turbines are used

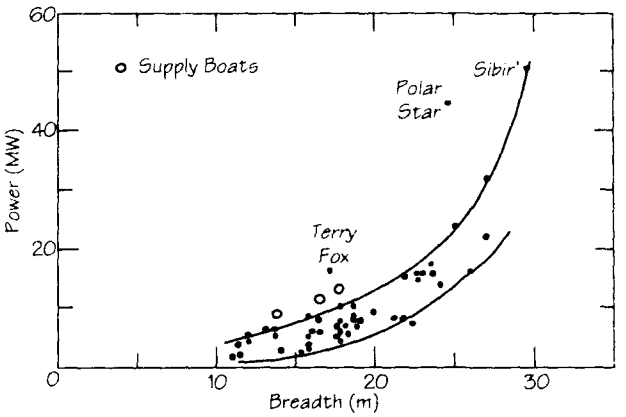


Figure 11. Power vs. breadth for icebreakers (from Dick and Laframboise, 1989).

for heavy icebreaking, and a medium-speed diesel–electric power system is used for cruising and light icebreaking. The Canadian icebreaker *Norman McLeod Roger* was initially fitted with two industrial turbines, but they have been replaced with conventional medium-speed diesel engines due to the high specific fuel consumption of the gas turbines. Steam turbines are used in a few icebreakers. These include the Canadian *Louis S. St. Laurent*, the Russian nuclear-fueled icebreakers, and the Russian LASH barge carriers. Recently, the *Louis S. St. Laurent* has undergone major reconstruction, which included changing the power plant from steam turbines to a diesel–electric system.

Medium-speed diesel engines are the most commonly used propulsion systems in icebreakers and icebreaking cargo ships. This popularity is due to their desirable characteristics, such as compactness, light weight, fuel efficiency, and reliability. Their disadvantage for use in polar ships is the lack of overtorque capacity. This shortcoming is overcome by using an electric transmission system, which damps out the high torque being transmitted to the engine. Some of the Russian icebreaking cargo ships are fitted with fluid coupling between the engine and the gearbox, allowing full-load torque to be developed at low propeller speeds.

Power and performance

The power-vs.-breadth plot of the data on existing polar ships (Figure 11) shows a trend of increasing power as a function of breadth. Except for a few data points, there appears to be a well-defined relationship between power and breadth.

Using the information on performance of existing polar ships in ice, the bollard pull/beam is plotted with respect to ice thickness in Figure 12. For comparison, the data on performance were normalized for a speed of 2 knots. There appears to be a well-defined relationship between bollard pull/beam and the ice thickness that may be broken at 2 knots. For a particular bollard pull/beam, the range of ice thickness above a minimum value represents an improvement in the icebreaking capability of the hull shape. It can be seen in Figure 12 that the most recent ships have more efficient hull forms.

Other developments to improve the performance of polar ships include the use of low-friction coatings on the hull, air bubbler systems to lubricate the ice/ship interface, air bubbler–water injection systems, and the water wash system to pump large volumes of water onto the ice. These improvements have resulted in better icebreaking capability.

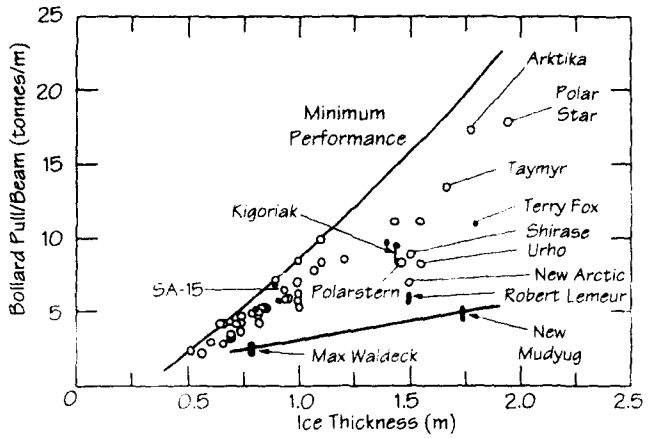


Figure 12. Icebreaking performance: bollard pull/beam vs. ice thickness (after Dick and Laframboise, 1989). Bollard pull is measured or calculated; data are adjusted for speed of 2 knots.

Structural design of polar ships

Structural design involves selection of material, size of plates, and frames for maintaining the structural integrity of polar ships under loads from waves and ice during their normal operation (Dick et al., 1987). As a result of research and from experience in operating ships in ice, much has been learned about the nature of ice loads and the mechanics of ice failure. Full-scale measurements of ice loads on many ships have yielded an empirical description of ice forces and pressures to be used in design. The magnitude of ice loads, the existence of significant damages, and the emergence of affordable nonlinear finite-element analysis packages has led to the wide use and acceptance of plastic design criteria.

Ice loads and pressures

Depending on the strain rate, compression of ice results in creep deformation with or without microcracking and brittle failure of the ice. The constitutive relations between stress and strain for creep deformation at low strain rate are well known. However, the brittle behavior of ice at high strain rate is quite complex because of instabilities caused by macrocracking of ice, and the failure mechanism for brittle failure is not yet fully understood. It is the brittle failure of ice that takes place during ship–ice interaction because of high rates of loading. The data on effective pressures obtained from full-scale measurement during ship–ice interactions are plotted with respect to contact area in Figure 13; these data provide empirical values for effective pressure to be used in design.

Materials

Classification societies and regulatory authorities have devoted considerable effort to the selection of steel grades suitable for use in the construction of ships that are exposed to very low temperatures. The toughness of steel depends on the operating temperature and the rate of loading. In Figure 14, the plane strain fracture toughness of two grades (A and EH) of steel are plotted with respect to temperature for three rates of loading. It can be seen that grade EH steel has better toughness values at low temperatures.

Steel fractures in a brittle manner without any warning of impending failure when the stresses are of sufficient magnitude to propagate a crack from a flaw or small crack in the material. The criterion for crack propa-

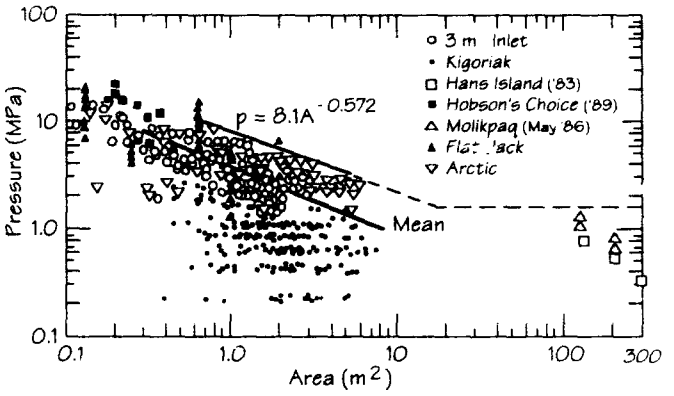


Figure 13. Measured effective pressure vs. contact area (after Masterson and Frederking, 1993).

gation in linear elastic fracture mechanics is that an existing crack will grow when the stress intensity factor at the crack tip is greater than the fracture toughness of the material. For nonlinear material behavior, the causes for brittle fracture have now been established, and the relationships between the cause of fracture, the toughness of the material, flaw size and shape, loading rate of the structure, and temperature are understood. From this understanding, material and welding techniques have been developed to increase the reliability of ship structures. It is the consensus of many operators that the steel used in the present generation of polar ships is mostly adequate. However, the experience of operating ships in the cold environment is much less than in warmer waters.

Welding

After selecting the steel, welding it is the next most important component in the reliability of a ship's structure. Welds in ships must withstand the corrosive effects of seawater and stresses caused by cargo, ice-breaking operations, and wave-induced motions. The biggest variable in welding technology is the skill of the welder, especially when working in confined spaces. The designer of a ship must take into consideration flaws in the material as well as in welds.

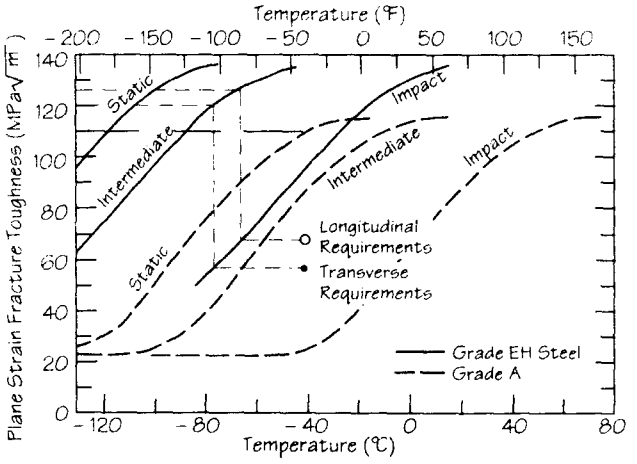


Figure 14. Plane strain fracture toughness vs. temperature for two grades of steel (from Dick et al., 1987).

Plating

The plating contributes the largest component to the structural weight of most ships, and together with the frames and the stringers forms the stiffened panels to resist the loads on a ship. The weight of a ship can be reduced by reducing the plate thickness and increasing the framing, but this increases the cost of fabrication.

For the design of plating, large-deflection plastic theory can be used to predict the ultimate load-carrying capacity of the plates. The large-deflection theory accounts for the membrane action during deformation of a plate.

Framing

The outer shell of a ship is supported by framing. Each frame acts like beams, resisting loads on the shell by bending and shear deformation. A failure of framing due to ice loads will constitute serious structural damage. Design of a frame usually takes into account plastic collapse mechanisms, torsional buckling, shear failure, and local web crippling.

Auxiliary systems

Technological advances in marine technology have brought considerable progress in the design and the operation of polar ships. Unique auxiliary systems have been developed to assist icebreaking operations.

The role of ice–ship friction has been understood through laboratory experiments and full-scale measurement of ice pressure on the hull of ships. A special coating called "Inerta 160," developed in Finland, appears to be good and cost effective, but a stainless steel belt on icebreakers has proven to be more resistant to extremely heavy ice, such as multiyear ridges. The application of the stainless steel belt is more expensive, but a cost-effective solution may be a combination of a stainless steel belt and Inerta 160 with cathodic protection to reduce corrosion. One Russian nuclear icebreaker has a heated ice belt near the waterline to reduce friction.

Heeling tanks are used to induce a rolling motion of the ship. This helps to reduce ship–ice friction and to free a ship stuck in rubble ice. Bubbler systems, also developed in Finland, pump large volumes of compressed air underwater to provide lubrication between the hull and the ice. Many icebreakers use water jet nozzles to throw water on top of an ice sheet. Use of these systems have been effective in reducing friction between a ship and a snow-covered ice sheet.

Future developments

It is anticipated that there will be more winter operations in the ice-covered waters of the Baltic, the St. Lawrence River, and the western part of the Northern Sea Route, and there will be a steady increase of polar research ships operating in the Arctic and the Antarctic. Currently, polar ships have operated successfully in the heavy ice that exists along the Northern Sea Route and the Northwest Passage. Future activities on these routes will depend on the following factors:

- Technology—Future polar ships will be larger and more powerful so they may proceed unimpeded through first-year, multiyear, and rubble ice. These ships will use the latest advances made in remote sensing technology to avoid obstacles in their path.
- Economy—Use of the northern routes will only be possible if there is an economical advantage in using them. Development of hydrocarbon and other resources in these regions may make

it worthwhile to transport those resources through the northern routes.

- Environment—Shipping through ice-covered waters must take place without any environmental damage to the fragile ecosystems in polar regions.
- Operations—Icebreaking technology can help to go from one point to another in ice-covered waters, but the skills of people operating the icebreakers are equally important. Well-trained crews will be essential for routine transport of cargo through these routes.
- Local people—Future development of trade routes should involve local people because their lives will be greatly affected by the development of the northern trade routes.
- Harmonization of regulations—As in open water transport, there is a need to harmonize regulations governing icebreaking operations in different parts of the world.

ADMINISTRATION AND REGULATIONS

From 1932 to 1953, the administration of the Russian marine Arctic rested with Glavsevmorput (CANSR), which was a direct arm of the Council of People's Commissars of the USSR. This special affiliation afforded it greater status and power for carrying out its mission to develop the Northern Sea Route. During this period large strides were made in organizing regular navigation and developing the fleet and port infrastructure. In 1953, CANSR became a department under the Ministry of Merchant Marine in Moscow, and for 17 years the infrastructure was improved to provide the capability for both summer and autumn shipping. Since 1970, when CANSR became the Administration of the Northern Sea Route (ANSR), the emphasis has been on achieving year-round trafficability. When it was established, the agency was staffed with 35 people. By 1981, that number had been reduced to 16 and, later still, had further dwindled to nine.

With the formation of the Commonwealth of Independent States in 1990, total jurisdiction over the route passed to the Russian Federation (Arikaynen, 1991). In 1991, the Ministry of Merchant Marine was downsized to a department and placed under the Russian Ministry of Transport. This consolidation was accompanied by reduced state subsidies, which then were followed by additional manpower cuts.

The director of the ANSR, since May of 1990, is Vladimir Mikhailichenko. He is the ex-captain of the ice-strengthened freighter *Pavel Ponomarev* and understands well the field operations end of the system. The ANSR is currently responsible for meeting the annual arctic freight transportation goals, while at the same time ensuring that personal and environmental safety is maintained (Mikhailichenko and Ushakov, 1993). These are very large tasks for such a small department to address adequately. One of Mikhailichenko's primary goals is to bring in more foreign revenue to reduce the arctic fleet's dependence on state subsidy.

After Gorbachev's 1987 speech, regulations for foreign usage of the NSR and a framework for administering them needed to be developed, protocol for escorting foreign ships had to be established, navigation guides and maps had to be declassified and made available, and so forth. The Russians officially opened the route to foreign use in July of 1991.

Actual operations, including scheduling, route assignment, navigational support, pilotage, and so forth, are controlled by the two marine operations headquarters (MOHQs). Their areas of authority are divided at longitude 125°E. Ships and shipments originating at the western end of

the route are directed by the MOHQ located at Dikson on the Kara Sea coast. The formerly state-owned Murmansk Shipping Company (MSC) runs the Dikson MOHQ. Contractual arrangements for plying the route in this direction must be made in advance with MSC's administrative offices in Murmansk. For traffic originating at the eastern end, the corresponding authority is the Far Eastern Shipping Company (FESCO). FESCO's administrative offices and MOHQ are located in Vladivostok and the East Siberian Sea port of Pevek, respectively.

The *Regulations for Navigation on the Seaways of the Northern Sea Route*, adopted in July 1991, were formulated by the Head Department of Navigation and Oceanography under the USSR Ministry of Defense. The regulations comprise a 21-page pamphlet in both Russian and English that is quite widely available (see Appendix B), as it has been reprinted in several conference proceedings and trade publications. In short, the regulations require:

- ANSR approval.
- Ship certification for ice worthiness and an experienced Master. If the MOHQ determines that the level of experience is inadequate, it may assign an ice pilot to the vessel for all or part of the voyage.
- Proof of indemnity for possible damage liability (mainly pollution).
- Vessels must abide by all decisions of the MOHQ or face removal from the route.

The regulations, in effect, grant full authority to the MOHQ to conduct all NSR shipping as field conditions warrant.

Three additional ANSR publications reportedly elaborate further on the rules and procedure. According to Mikhailichenko and Ushakov (1993), these are:

- *Requirements for the Design, Equipment, and Supply of Vessels Navigating the Northern Sea Route,*
- *Rates Charged for Escorting Foreign-Flag Vessels Through the NSR,* and
- *Guide to Navigation Through the Northern Sea Route.*

The first publication, in Russian (an unofficial CRREL translation is included as Appendix C), details such requirements as double hulls, steel plating thickness, powerplant size, and propeller design. Other requirements for foreign vessels include a 30-day supply of fuel, a 60-day supply of food, and a water distilling plant aboard for drinking water.

It is not absolutely clear what the other two documents will contain, since requests to the ANSR, MSC, and FESCO for copies were not answered. Mikhailichenko[5] stated that the second document (*Rates Charged* ...) has not yet been published, and another source[6] said that the Guide to Navigation is only a 607-page draft at this time and would not be available until the latter half of 1994 at the earliest. He listed its main sections as follows:

Section 1:	General overview
Section 2:	Hydrological/meteorological description

[5] Vladimir Mikhailichenko, 1993, Administration of the Northern Sea Route, personal communication.

[6] Mark G. Maliavko, 1993, HydroCon Ltd., personal communication.

Sections 3–6:	Navigation directions for the various seas
Section 7:	Navigational beacons and radio frequencies
Section 8:	General ice navigation techniques

PLANNING, LOGISTICS, AND OPERATIONS

A voyage along the Northern Sea Route consists of three phases: an analysis phase, a planning phase, and an operational phase.

The analysis phase involves the preliminary decision-making process that a ship owner would undergo to establish a need to use the NSR. This would include making initial contacts, doing preliminary cost estimates, and conducting a cost–benefit analysis to determine feasibility. The planning phase begins once the ship owner becomes convinced of the economic benefits and decides to use the route. It involves advance planning, negotiations, contracting arrangements, and shipboard preparations prior to setting sail. The operational phase begins once the ship is under way and involves the day-to-day operations necessary to physically transit the route.

The analysis phase

An analysis of the economic feasibility of arctic cargo transportation is highly individualized for each particular owner, cargo, ship type, destination, and so forth. Backlund et al. (1993) discuss a model used by Kvaerner Masa Yards, the Finnish shipbuilding firm, to help in this regard. Wergeland (1991) made a generalized attempt to compare the economic benefits of the NSR with the alternative canal routes using the limited available data. The reader is referred to the INSROP pilot studies report (Østreng and Jørgensen-Dahl, 1991), the collected works found in the special issue of *International Challenges* (vol. 12, no. 1, 1992), and those contained in Brigham (1991b) for excellent recent information that also might be helpful.

A cost–benefit analysis may well require information on the fees associated with the various route alternatives. The most recent and complete economic information available can be found in Wergeland (1991), which was relied on for the following. Prices are in U.S. dollars as of July 1991.

The guiding principles used by MSC and FESCO in determining the fees for their services are said to be:

- Rates should not be lower than the actual cost of services rendered; and
- Rates should be low enough that an economic advantage is maintained over the alternative canal routes.

That said, "Russian icebreaker fees," more specifically, depend on the vessel's displacement (size), its ice classification, the route chosen, and the level of escort or support required. In addition to icebreaking, this fee includes guiding by reconnaissance aircraft, hydrographic and meteorological services, and the use of communication systems. To arrive at a specific rate, a three-step process is used. First, the basis fee is determined for the size of the ship. This fee is derived from the relatively lowest cost of guiding a cargo ship having the highest ice classification (ULA) through the NSR. Table 9 shows the sliding scale that is used to determine the basis fee: the larger the ship, the lower the per-ton tariff.

Secondly, the NSR has been divided into three different tariff regions based on their historically known difficulty of transit.

Table 9. Icebreaker basis fees for leading vessels through the NSR.

Total displacement (tons)		Basis fee
From	To	(US$/ton)
100	1,000	15.20
1,001	2,000	9.16
2,001	5,000	5.51
5,001	8,000	4.73
8,001	11,000	4.21
11,001	14,000	3.98
14,001	17,000	3.82
17,001	20,000	3.72
20,001	23,000	3.64
23,001	27,000	3.56
27,001	30,000	3.26

From Wergeland (1991).

- Region A, from Novaya Zemlya to Severnaya Zemlya (60°E to 90°E);
- Region B, from Severnaya Zemlya to the Bering Strait (90°E to 169°W); and
- Region C, which includes all areas north of the 78°N parallel.

The tariff for Region A is set at 70% of Region C, and for B it is 80% of Region C. The tariff for Region C (Table 9) is assessed for any full-transit voyage or one that traverses two or more of these regions.

Thirdly, ships of lesser ice classification are required to pay the following relatively higher surcharges: UL = 20% more, L = 44%, B/kl = 73%. Wergeland calculated the icebreaker fee for an L-class vessel of 15,000 displacement tons sailing in Region B at $66,000 (that is, 15,000 tons × $3.82/ton × 0.8 × 1.44). The transit tariff for a foreign icebreaker, on the other hand, is 33% less than that for the ULA-class vessel.

Fees for compulsory piloting are assessed separately. The pilot fee is for having a Russian ice pilot on-board during operations in ice. It is $1.01 per nautical mile, based on the ship's "tariff distance" or shortest recommended route. The cost to transport the pilot out to the ship is also assessed. Wergeland lists the following additional cost elements that might be encountered during the voyage, citing a regulatory manual entitled "Port Dues and Charges for Commercial Soviet Seaports" (the prices are as of the manual's 1988 effective date):

- Route recommendation based on meteorological and ice forecasts where, for example, a one-day forecast is $90 and a three-day forecast is $231.
- Communication services billed at the rate of $2.20 per minute for telex and $4.50 per minute for telephone.
- Salary for a Russian helmsman at $33.33 per day if the vessel doesn't have one qualified for ice navigation.
- Maps, guidebooks, tide tables, signals book, and such can total $700 to $900 for the route.
- Special vessel steerage can be required by local authorities in various ports of call for safety considerations. Unstated local rates probably apply.
- Bunker-filling fee is $6.30 per ton, and the bunker itself is priced at "world market rates."
- Supply of fresh water en route ranges between $0.99 and $11.69 per ton, depending on location and its quality.

It should be emphasized that few foreign ships have undertaken the NSR, so there is little actual experience to draw upon. Further, the economic, social, and political instability in Russia makes the future uncertain: past experience does not necessarily reflect the future. There were reports that the fees are more subjective than those outlined above, depending more on the type of cargo than on actual cost of services (Armstrong, 1989).

Armstrong (1990) reported complaints of flat rate charges for icebreaking services without regard to the amount of work done, but it would appear that the rate schedule presented above will address those concerns. Armstrong has reported more recently on wage and labor disputes (1990, 1991, 1992a) and difficulties in arranging resupply voyages due to lack of operating funds and "enormous" insurance rates (1993).

There does not appear to be an established protocol at this time. Arrangements between foreign parties and the Russian shipping companies (MSC and FESCO) are negotiated on a case-by-case basis. Aleksandr Ushakov of the ANSR, when questioned at the 1992 Northern Sea

Route Expert Meeting, replied that the transit tariffs were open to negotiation depending on the specific shipping task and comparison with alternative transport by rail. While there are problems to be overcome and the costs appear to be in a state of flux, Ushakov was clearly open to and inviting of cooperative discussion. That being the case, it might be useful for potential NSR users to obtain information from other foreign parties that have already used the route (refer to Table 5). The annual summaries of NSR activities that are published in *Polar Record* by Terence Armstrong following each shipping season are another source of information. These usually include reports of foreign involvement.

The planning phase

The first step toward arranging passage through the NSR is to obtain official permission.[7] This involves contacting the ANSR in Moscow for the appropriate application documents and regulations. Our requests to the ANSR for copies of these documents went unanswered, but requests from potential clients may well be more fruitful. From various other sources, however, we were able to gain some understanding of what these documents are. An undated letter from Mikhailichenko addressed to the "Owner or Master of the Vessel" (Appendix D) states that the preliminary notification to ANSR must contain:

1. Name of ship, flag, port of registry, and owner;
2. Gross/net tonnage and displacement of the ship;
3. Ship dimensions, draft, age, speed, engine output, propeller material and design;
4. Ice class, classification society, and bow design;
5. Approximate date of voyage;
6. Certification of liability insurance; and
7. Purpose of the cruise (such as cargo transport, tourism, research).

Upon preliminary approval, the ship and its equipment are to be inspected for ice worthiness by agents of MSC or FESCO. It is assumed that said owner will pay all costs associated with delivering his ship to a port where a FESCO or MSC agent resides. We have not found a reference that lists those particular ports. One of the main qualifications for passage approval (Mikhailichenko, 1992) is the ship's ice classification, which must be at least L1 by the Russian Register or IA by the Lloyd's, American Bureau of Shipping, and Finnish registers, although ships having lesser classifications may be approved by special exception (see sections 2.2 to 2.5 in Appendix C). In 1991, a small German yacht with no ice rating was accepted for escort from Nar'yan-Mar to Igarka on the condition that she would sail only in ice-free waters.

After passing inspection, a vessel is granted a "Permission for Leading Through the Seaway of the Northern Sea Route." Cruises for scientific research, tourism, and fishing are not permitted under these guidelines and need additional approval through diplomatic channels. Contractual arrangements are then to be worked out between the applicant and the appropriate shipping company by contacting its main offices in Murmansk or Vladivostok.

Depending on the capabilities of the foreign vessel and the icebreaking resources at hand, the MOHQ will then tentatively schedule the date and determine the route of the voyage. The MOHQs are supposedly "full-service" providers for any authorized usage of the NSR. More to the

[7] Vladimir Mikhailichenko, 1993, ANSR, personal communication.

point, foreign ship masters must follow the directives of the MOHQ representatives at all times while on the route. All operational decisions, such as route selection, times of departure and travel, and mode of pilotage are decreed by the MOHQ representative. Additional planning information is apparently unnecessary since the foreign ship master is allowed no navigational decision-making autonomy.

MOHQ long-range forecasts originate with ice and meteorological forecasting models derived by experts at the Arctic and Antarctic Research Institute (AARI) in St. Petersburg. The long-range forecasts are based on the mean multiyear statistical data of ice conditions (Arikaynen, 1991). The Russian understanding of sea ice, meteorological processes, and other conditions for ice navigation is, in the opinion of U.S. experts, unparalleled. However, with the limited time frame for this study, we were not able to obtain enough information to enable us to evaluate these forecasting products in any way.

Although complete control of all shipping is assumed by FESCO and MSC during in-ice operations, a general awareness of climatic and oceanographic conditions of the Arctic Basin is a necessity for planning

Table 10. Atlases of the Arctic Basin

Author	Title	Date	Publisher
The Russian Arctic			
Gloersen et al.	Arctic and Antarctic Sea Ice, 1978–1987; SatellitePassive-Microwave Observations and Analysis	1992	NOAA, Washington, D.C.
S.G. Goreshkov	World Ocean Atlas—Volume 3: Arctic Ocean (in Russian with English introduction and keys to all maps)	1983	Pergamon Press, N.Y.
A.D. Hastings	Surface Climate of theArctic Basin; Selected climatic elements related to the performance of surface-effect vehicles, Report ETL-TR-71-5	1971	Ft. Belvoir, Va.
Jones & Bartlett Publishing, Inc.	Atlas of the Polar Regions	1981	J&B Publishing, Boston, Mass.
S. Orvig (Ed.)	Climates of the Polar Regions, Vol. 14 of the World Survey of Climatology:	1970	Elsevier Publishing Co., Amsterdam
I.P. Romanov	Atlas—Morphometric Characteristics of Ice and Snow in the Arctic Basin (in Russian and English)	1993	Arctic and Antarctic Research Institute, St. Petersburg
I.P. Romanov	Ice Cover of the Arctic Basin (in Russian and English)	1993	AARI, St. Petersburg
A.F. Treshnikov (Ed.)	The Atlas of the Arctic (in Russian)	1985	AARI, St. Petersburg
The Alaskan Arctic			
W.A. Brower,Jr. et al.	Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska; Vol. I—The Gulf of Alaska, Vol. II—The Bering Sea; Vol. III,The Chukchi-Beaufort Seas	1988	Natl. Climate Data Ctr.; Natl. Environmental Satellite, Data & Info Svc.; NOAA; & Arctic Environmental Info & Data Ctr
Dickins et al.	Environmental Atlas for Beaufort Sea Oil Spill Response	1987	Environmental Protection Service, Environment Canada
LaBelle et al.	Alaska Marine Ice Atlas	1983	Arctic Environmental Info & Data Ctr., Univ. of Alaska, Anchorage
U.S. Naval Oceanography Command Detachment	Sea Ice Climatic Atlas; Vol. II—Arctic East; NAVAIR 50-1C-541; and Vol. III—Arctic West; NAVAIR 50-1C-542	1986	USN OCD, Ashville, N.C.

purposes. For this, the single-source atlases listed in Table 10 were recommended by more than a half dozen experts from various U.S. agencies. The list is by no means intended to be all-inclusive.

The operational phase

Operations while en route are monitored and strictly controlled by the representative MOHQ. The regulations issued by the ANSR describe the various modes of assistance that the MOHQ can require, depending on the severity of ice conditions. These are:

- Shore-based pilotage, recommending routes up to specific geographic locations,
- Aircraft-assisted pilotage (fixed-wing and/or helicopter),
- Conventional pilotage with only a Russian ice pilot on board,
- Icebreaker-leading escort, and
- Icebreaker escort with ice pilot on board.

Shore-based guidance is likely to be rendered at the beginning and end of a transit voyage, that is, in ice-free areas of the Barents and Chukchi Seas. The level of control and guidance increases with the severity of ice conditions, both existing and expected. "Icebreaker escort with ice pilot on board" is mandatory for the perennially difficult straits of Vil'kitskogo, Shokal'skogo, Dmitriya Lapteva, and Sannikova.

The shore route has been sectioned into six zones of varying environmental severity (Batskikh and Mikhailichenko, 1993). Russian experience has shown that these areas typically require different navigational tactics:

1. From Murmansk to Kolguyev Island (33° to 50°E longitude)—Generally ice-free or has only primary ice present. Ice-class vessels can ply on their own without icebreaker assistance.
2. From Kolguyev Island to the port of Makarova (50° to 85°E)—Navigation requires assistance by *Arktika*-class (75,000 shp) icebreaker through drifting first-year ice.
3. From Makarova to the northernmost mainland peninsula of Chelyuskin (85° to 105°E)—Navigation through fast ice under convoy of *Arktika*- or *Vaygach*-class (50,000 shp) icebreaker.
4. From Chelyuskin Peninsula to the Novosibirskiy Islands (10° to 140°E)—Ice conditions and tactics are similar to those for section 2.
5. From the Novosibirskiy Islands to Wrangel Island (140° to 17°E)—Navigation is through drifting first- and multiyear sea ice with *Arktika*-class icebreaker assistance. It is currently preferred to convoy a single cargo vessel using two icebreakers.
6. From Wrangel Island to the Bering Strait (178°E to 170°W)—Navigation is in drifting first- and multiyear sea ice under *Arktika*-class icebreaker convoy.

The above prescription shows that the critical section is from the Novosibirskiy Islands to Wrangel Island and the Longa Strait. Successful NSR transit depends most critically on the ice conditions through this section; i.e., less consolidation and ice pressure, and the existence of leads, fractures, and polynyas. A paper by Buzuev and Likhomanov (1993) discusses current work at AARI to produce an atlas that sections the Northern Sea Route into zones of difficulty and provides important navigation-related guidelines for each. Table 11 is an example of the general information that this atlas will contain.

Table 11. Range of safe speeds (kn) for new ships operating in drifting, 1-m-thick ice with no compaction (ice pressure).

	Ice concentration (%)*			
Ice class	10–30	40–60	70–80	90–100
ULA	15–16	12–15	10–11	8–9
UL 1	10–14.5	7–12.5	7–7.5	5–8

* A ratio expressed in tenths or octas describing amount of sea surface covered by ice as a fraction of the whole area being considered.

Source: Buzuev & Likhomanov (1993).

Even though Igarka is the only port officially open to foreigners, Mikhailichenko and Ushakov (1993) state that, on a limited basis, all the arctic ports can supply food, tug service, fresh water, or repairs. Under extreme circumstances, repairs, water, or bunker fuel can be provided by the escorting icebreakers.

Information on weather, ice, and sea conditions along the Northern Sea Route is obtained using satellite, shipboard helicopter, fixed-wing aircraft, shore-based and drifting ice stations, drifting buoys, and shipboard observations. The information is summarily used in AARI models to produce both short- and long-range forecasts and ship routing aids such as the ice map shown in Figure 15. Ice maps and routing recommendations from the Dikson and Pevek MOHQs are sent twice a week to the icebreakers and then relayed to the ships under their escort. Radio communications along the route are handled from seven communications centers, which are located at Anderma, Dikson, Cape Chelyuskin, Tiksi, Pevek, Cape Shmidta, and Provideniya. Provideniya is operated by the Ministry of Merchant Marine, and the others are maintained by the State Committee for Hydrometeorology (Ushakov et al., 1991).

Ice mapping has been improved with the availability of high-resolution imagery from the European Space Agency's Earth Resources Satellite (ERS-1) platform. The Synthetic Aperture Radar (SAR) provides coverage that is independent of darkness and cloud cover with a resolution of 30 m. Nearly round-the-clock ice concentration mapping with a resolution of 30 km is possible using data from the U.S. Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/ Imager (SSM/I). Although these technologies are not yet in use by the Russians, who rely primarily on data in the visual and infrared spectrum, SAR and SSM/I services are commercially available. Russian ice pilots can make expert use of the information if it is available aboard a foreign ship under their escort. In 1991, routing for *L'Astrolabe*'s transit voyage was the joint work of the Nansen Environmental and Remote Sensing Center (NERSC), the European Space Agency, Mers Magnetique, the Norwe-

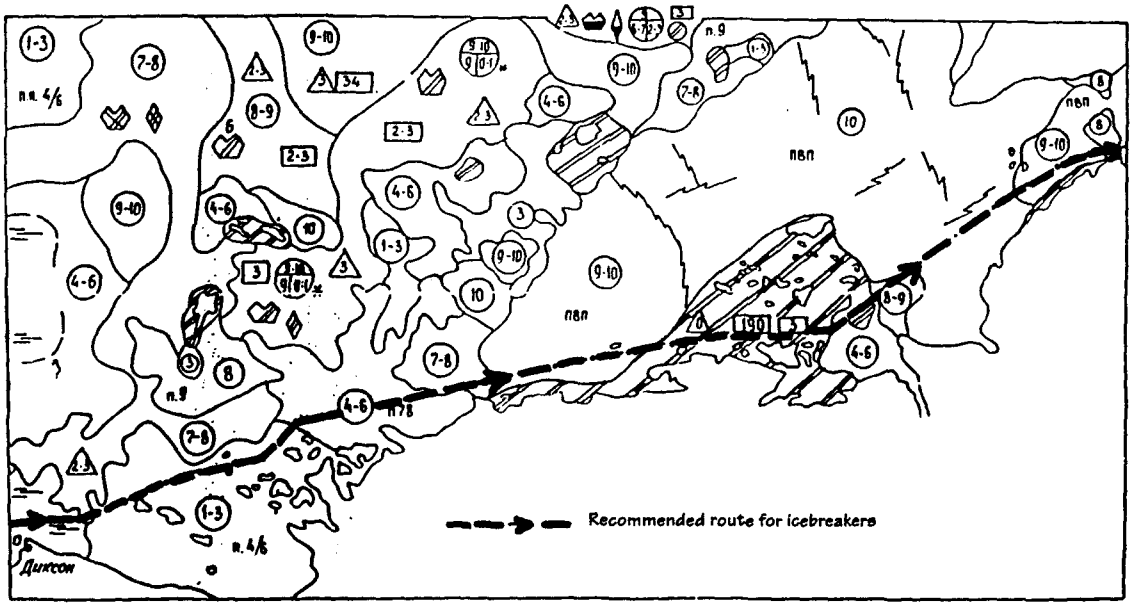


Figure 15. Sample ice forecast and ship routing analysis from the Arctic and Antarctic Research Institute, for the coastal area between Dikson (lower left) and Cape Chelyuskin (upper right). It represents the ice conditions on the 1st and 2nd of August, 1990, and was integrated from satellite, aircraft, and icebreaker observations (from Buzuev, 1991).

gian Space Center, and the Alaska SAR Facility. Ice maps made from the satellite products were telefaxed to the ship using the INMARSAT satellite telecommunications system. The time delay from satellite observation to shipboard reception of the maps ranged from 6 hours to 2 days. The quality and utility of the information was judged by the Russian ice pilots to be extremely good relative to their own products. A description of the routing work that was done for *L'Astrolabe* is contained in a report by Johannessen et al. (1992).

The U.S. agency in charge of sea ice analyses and forecasting is the Navy/NOAA Joint Ice Center (JIC), which is soon to be renamed the National Ice Center. It is the world's only organization that provides global coverage, and its routine ice guidance products are available to the general public. The data are derived from a variety of satellite-borne sensors. These products (see Appendix E) include:

- A weekly, global-scale (1:10,000,000) analysis showing sea-ice extent, concentration, stage of development, and the location of leads and polynyas for the entire Arctic basin;
- A biweekly, regional-scale (1:7,500,000) 30-day forecast of the above parameters; and
- A long-range seasonal outlook for the west Arctic, issued each year on May 15.

The agency maintains a convenient 24-hour, auto-polling system that subscribers can use to obtain analyses and forecasts in telefaxed

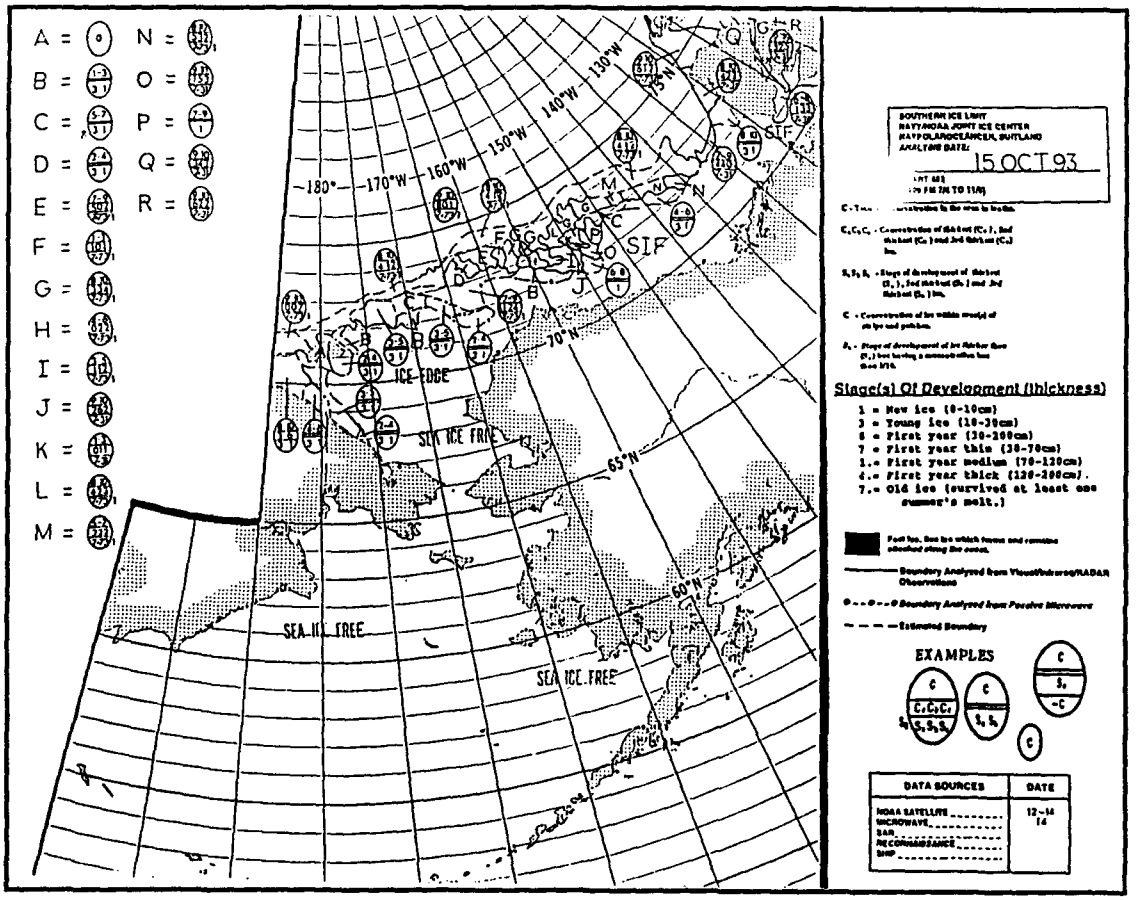


Figure 16. A portion of an Alaskan Regional Ice Analysis from the Joint Ice Center.

form. Figure 16 shows a portion of their Alaskan Regional Ice Analysis that was produced for 15 October 1993. The JIC can also provide to any U.S. government agency more specialized guidance products, including ship routing recommendations, operational briefings, and aerial reconnaissance support. For example, Figure 17 shows a ship routing recommendation that was transmitted via satellite to the USCGC *Polar Star*, en route from the Canadian archipelago to Point Barrow, Alaska, in September 1992. JIC provided latitude and longitude for each waypoint along the track and the distance and heading between each point. The figure shows several large ice floes that were avoided along the coastal route, resulting in a significant savings in time and fuel.

Image ID:	**32445Q0101**	**Sensor:**	**ERS-1**
Center Time:	**1992:270:22:07:56.285**	**Image size:**	**102 4 km (azimuth)**
Center Location:	**lat 71.69 lon -156.89**		**99.1 km (range)**

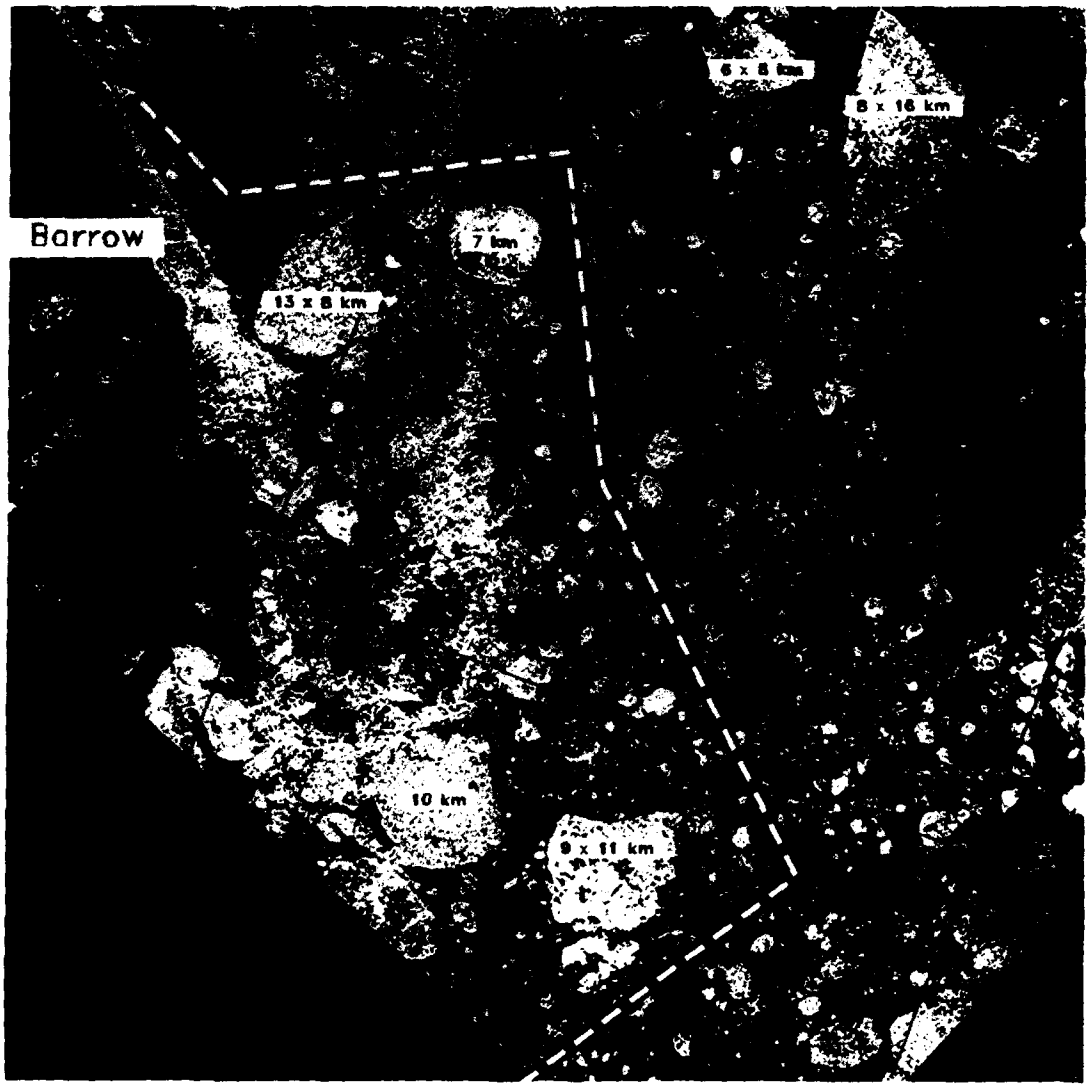


Figure 17. A specialized ship routing analysis from the Joint Ice Center. The image was produced in September 1992 using ERS-1 SAR imagery for the USCGC Polar Star, *which was en route from the Canadian archipelago to Pt. Barrow, Alaska. It was sent directly to the ship via satellite and digital video processing hardware and recommends a route to avoid several large floes and ice consolidation areas. (Photo courtesy of the Joint Ice Center.)*

A complete description of JIC products and support activities can be found in USN/NOAA JIC (1993). This publication is currently undergoing revision to reflect recent transfer of weather forecasting responsibilities to other Navy centers. Weather forecasts and ship routing support to government agencies for the east and west Arctic regions have been transferred to the Naval Atlantic Meteorology and Oceanography Command Center (NAVLANTMETOCCEN) and the Naval Pacific METOC Center (NAVPACMETOCCEN), respectively (refer to the *Points of Contact* section for addresses). The JIC products from previous years are archived on 9-track tape and are available upon request from either the National Climate Data Center (NOAA) in Asheville, N.C., or the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado. These and other archived products, which are available from the NSIDC and could prove useful for operations planning, are listed in Appendix F.

Rosenberg (1993) reports that satellites make voice and fax communications available to ships in all areas of the Arctic below 80°N latitude. The INMARSAT system, for example, can be used to send and receive a variety of communications, including positioning and navigational information, ice and weather forecasts, and emergency and distress transmissions. This system enables, for example, the JIC's auto-polled products to be transmitted directly to the ship. Various commercial firms also offer routing products that can be telefaxed regularly to client ships. For example, weather forecasts and route recommendations provided by OceanRoutes, Inc., were transmitted to the Finnish tanker for its three voyages from Arkhangel'sk to the Yana River in 1993. Laapio[8] of Neste Shipping reports that OceanRoutes products were used and well regarded by the Russian pilot on board.

Information about radio navigation and positioning systems in use on the Northern Sea Route is very sketchy. The best information we found totalled only one paragraph in Ushakov et al. (1991) and two in Kjerstad (1992). They state that, in the last 50 years, the Russians have installed more than 2,500 navigation markers, light buoys, light beacons, radio beacons, radar reflectors, and radar beacon responders throughout the Arctic. Radio navigation is by way of their hyperbolic MARS-75 system, which is similar in operation to the U.S. Loran-C system, though the two are not compatible. It has an operating range exceeding 1000 km from each of its three coastal links and provides essentially complete coverage of the route. The Chaika radio navigation system, which is compatible with Loran-S, operates for the Barents and Kara Seas. Satellite navigation systems, such as the Navigator (U.S.) and the Glonass (Russian), which will provide continuous and global coverage, are currently in development. Their deployment is expected in 1995. Reporting on his experiments using a GPS (Global Positioning System) satellite receiver aboard the SA-15 *Kapitan Danilkin*, Kjerstad concluded that coverage en route from Murmansk to the Bering Strait was continuous. He also stated that the ship had both Russian and western navigation equipment installed.

For this study, we investigated only U.S. and Russian sources for maps of the Northern Sea Route and, more specifically, hydrographic maps. Some maps of the Russian arctic and Alaskan coastlines were produced by the Defense Mapping Agency (DMA) and are available from the National Ocean Service (refer to *Points of Contact* section). The Alaskan coastline is fully covered, and there is fairly good coverage of the Russian coastlines in the Chukchi, East Siberian, and western portion of

[8] Juhani Laapio, 1993, Neste Shipping, personal communication.

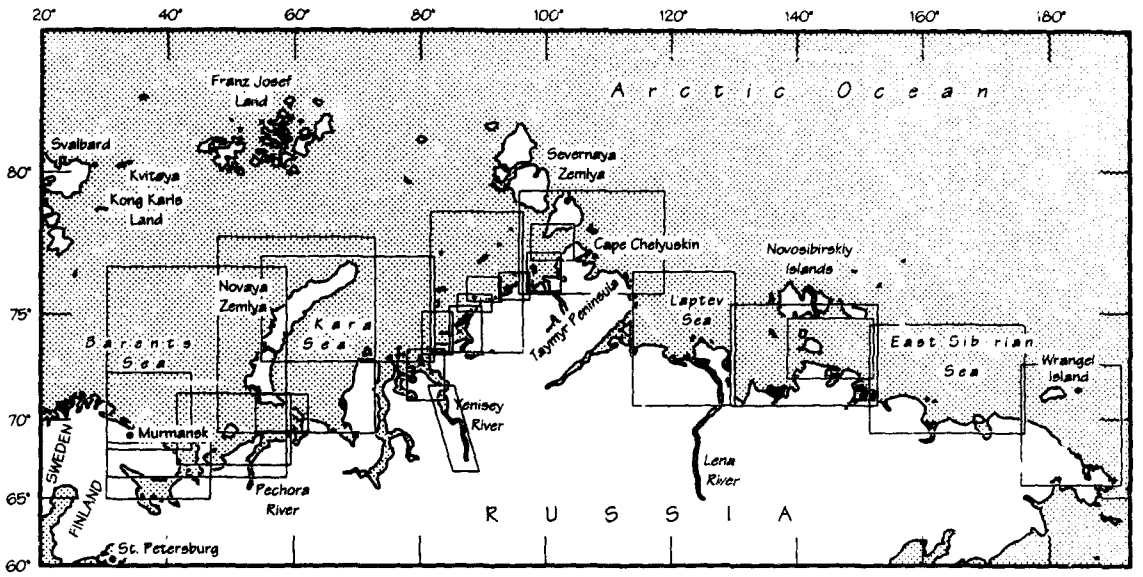


Figure 18. Navigation charts available from the Russian State Hydrographic Department, Ministry of Transport, as of September 1992. (Adapted from Mikhailichenko, unpublished.)

the Barents Sea. Appendix G provides the DMA diagrams showing the maps that can be ordered for Region 1 (Alaska), Region 4 (Northern Europe and Russia), and Region 9 (the Far East). Except for three large-scale maps, one each for the Kara Gates and the mouths of the Ob' and Yenisey Rivers, there is no coverage between 45° and 135°E (the White Sea to the Novosibirskiy Islands). We are not aware of any other publicly available maps for this area from U.S. sources.

According to Mikhailichenko,[9] Russian hydrographic charts covering the entire route are being declassified and made available for purchase from the Russian State Hydrographic Department under the Ministry of Transport. We experienced extreme difficulty in getting them (see Appendix H). At the October 1992 Northern Sea Route Expert Meeting, held in Tromsø, Norway, Mikhailichenko provided a diagram showing 23 charts that were available at that time; these are shown in Figure 18. In December 1993, we obtained a set of 37 charts (at a substantial mark-up in price) from HydroCon, Ltd., a private distributor of geographic products based in St. Petersburg. This source informed us that the nautical charts (in Russian) are actually issued by the Russian State Navigation and Oceanography Department under the Ministry of Defense, which has no policy for responding to one-time, small orders for their products. HydroCon acted as a facilitator in working through the official and unofficial bureaucracy to obtain the charts and arrange for their delivery. This exercise revealed the value of having an individual on-site in Russia to facilitate requests and negotiations. Face-to-face contact by one who speaks the language and knows the social system seems to be much more effective for producing the desired result than long-distance inquiries. The map scales range between 1:10,000 and 1:500,000, with the majority of them scaled between 1:100,000 and 1:200,000. They are considered by Kjerstad (1992) to have very good detail for their stated purpose.

[9] Vladimir Mikhailichenko, 1993, ANSR, personal communication.

OBSTACLES AND NEEDS

Social, economic, and political

Social, economic, and political instability are the fundamental obstacles standing in the way of developing the NSR (Franzen, 1993; Granberg, 1993a,b). When Boris Yeltsin assumed the Russian presidency in 1991, he inherited an economy on the verge of widespread collapse. The shortage of basic goods led to social and political unrest that in turn produced further chaos in the supply system. Drastic emergency reforms were instituted in 1992 to stem the tide, but during the three previous years, virtually every economic indicator was showing the strain. In 1991 alone, the Russian GNP dropped 17% while retail prices increased by 189%. Although salaries increased by 80% in response to inflation, purchasing power fell an estimated 2 1/2-fold (Franzen, 1993). The government's response to the crisis has been to print more rubles, which fuels inflation. Franzen projected that inflation for 1992 could run as high as 2000%. Granberg cites many examples of economic distress that may adversely affect NSR operations.

"Any optimistic discussion of the international prospects of the Northern Sea Route cannot afford to disregard today's economic situation in Russia. The crisis in Russia's economy has surpassed in severity the world's Great Depression of the late 1920's and early 1930's. The slump in production, now in its third year, affects all sectors of the economy. The Gross National Product for 1992 is projected to fall by 20–25%, the volume of investments by half, and foreign trade turnover by a third. For the first time in decades, Russia is confronted with unemployment..."
—Alexander Granberg, State Advisor for the Office of President of the Russian Federation (1993b)

The Russians declare that the Northern Sea Route is now open and the obstacles of the past are disappearing. Actual experience appears to indicate otherwise. Total cargo figures, which showed a steady annual increase to about 6,600,000 tons in 1987 dropped back to 4,900,000 tons in 1991 (Granberg, 1992). The fact that both traffic and tonnage along the route have dramatically decreased since 1990 in the face of shortages testifies to the current problems with moving freight in that area of the world. Reports of protests and labor strikes, stemming from poor wages and living conditions, are common. With producer privatization measures, the government is attempting to introduce profit incentives for its citizens. However, eliminating the old way of doing business has severely disrupted the producers' industry-to-industry connections and their ability to bring goods to market. It will take time to re-establish these networks (Arikaynen, 1991).

In addition to the overall national problems, Arikaynen discusses numerous problems between the administrative and operations entities in carrying out the arctic maritime transportation plan. While MSC and FESCO perform all icebreaking tasks and move most of the cargo, they do not appear to be working together to achieve an overall cargo transport plan. Together, they effectively make up the complete operations arm for the plan, and yet they have been forced to pursue their own respective economic interests due to reduced subsidies from Moscow.

The most pressing and difficult problem to address may be the lack of incentive to deliver freight in the most efficient and economical manner. Inefficiencies plague virtually all aspects of the system. Labor discontent is reported aboard icebreakers and cargo ships (Armstrong, 1990, 1991, 1992b). Several experts contacted for this study speculated that the shipping companies have an endemic preference for dealing with large bureaucratic entities, giving low priority to small business transactions where the profit potential for each is less. This may be a cultural artifact stemming from decades of state-mandated controls over the distribution of goods and services.

The emphasis on science and research in Russia has diminished with expanding social needs. As state funding for research decreased, it appears that AARI has entered the business of selling data, analysis, and forecasting services. An undated publication by Proshutinskii, describing the research and expertise residing at AARI, is in fact an advertisement of technical services. The INTAARI Joint Enterprise, a collaboration of

AARI, the Norwegian Polar Research Institute (NPRI), and Intera Information Technologies of Canada and Great Britain, was set up to market services such as sea ice reconnaissance, manufacture of marine and meteorological instrumentation, expedition support, ecological services, lease and sale of submersible vehicles, and lease of research vessels. A representative of AES and Intera Canada,[10] however, stated that their only involvement is to provide manpower and equipment for gathering ice reconnaissance data for AARI on a contractual basis. NPRI discontinued their involvement with INTAARI in 1993[11] following the appointment of Ivan Frolov as the new director of AARI. Frolov was reportedly dissatisfied with the INTAARI arrangements for undisclosed reasons, and NPRI withdrew so that the longstanding relationship between the two institutes would not be compromised. We were unsuccessful in contacting anyone from INTAARI who could supply the above-mentioned services. Our requests to AARI for information and samples of technical products were relayed to a private enterprise in St. Petersburg called EcoShelf. We received a few examples of ice and weather forecasts and a description of various AARI products for sale by EcoShelf (Appendix I). In light of the previous discussion, it is not clear whether these kind of entrepreneurial arrangements are officially sanctioned by AARI. As we received no direct response from AARI, we do not know whether their products are officially available. A foreign ship owner may be more successful in getting this type of information directly from MSC or FESCO during negotiations.

Negative social and ecological effects from uncontrolled arctic development have been identified as a potential risk. The arctic regions are a delicate ecosystem that recovers very slowly after change is introduced. Young and Osherenko (1991), Osherenko (1993), Hansson (1992, 1993), Roginko (1991, 1993), Arikaynen (1991), and Stokke (1992), for example, advocate international vigilance and strong cooperative agreement for environmental protection. Indeed, one of the four main focuses of INSROP is to inventory the indigenous human, animal, and plant populations of the arctic to create a baseline for assessing the impacts of development (Brekke and Fjeld, 1991). Though several authors point out that environmental protection has not been emphasized in the Soviet past (for example, Hansson, 1993; Osherenko, 1993; Hume, 1984), there appears today to be a shared international awareness and concern, which these authors and others hope will translate into adequate safeguards.

The fees for Russian services are not established, and it is difficult to obtain quotes for fees. (These and related problems were mentioned in the *Analysis Phase* section under *Planning, Logistics, and Operations*. Foreign shippers and ship owners view this as a drawback when considering use of the NSR. It is imperative that the Russians make available their rates and commit to estimates based on hard currency so that cost–benefit analyses can be relied on.

Another related problem is the difficulty in finding return cargo, which can lead to slow turn-around for ships or costly return voyages without cargo (Wergeland, 1992; Armstrong, 1993). This problem should diminish with increased import–export activity along the route. Greater international effort to promote awareness of the route, more demonstration voyages, and gradual elimination of the unknowns will help to expand the NSR cargo base.

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[10] Terry Mullane, 1993, Atmospheric Environment Service, personal communication.

[11] Torgny Vinje, 1993, Norwegian Polar Research Institute, personal communication.

Infrastructural

The language barrier may be of some concern to potential users of the NSR, but our experience in contacting various Russian agencies and businesses for this project did not reveal any serious communication problems, once we were able to establish contact. The ANSR, the shipping companies, and almost all other agencies we contacted had a staff member who understood and spoke English.

"At the end of 1991 the Russian Federation had only 750 'outside' lines (to make international calls), and trying to reach a colleague even inside the country can result in hours spent dialing and re-dialing to get a free line.... You can phone overseas destinations from any ordinary phone, i.e. from an apartment, hotel, etc. between 12:00 midnight to 6:00 a.m. Moscow time. However, you should be prepared to dial 25 to 50 times before getting a clear line. Should you wish to call during the daytime, you have to order the call with an operator. Depending on the destination a wait of several hours to a day can be expected. Because of the poor quality of the telephone lines, faxing can be even more frustrating than phoning. Aside from having to dial a number of times to get a clear line, often it takes three or four attempts to get a fax through."
—Franzen (1993)

On the other hand, Russia's telecommunications equipment is outdated and often unreliable (Franzen, 1993). Telephone lines into Russia are overloaded and very often busy. The quality of the connection is sometimes poor, which can be detrimental for facsimile transmission. There were no apparent difficulties in our receiving telefaxes, but we experienced much difficulty in trying to send fax messages to Russia. Franzen (1993) presents a recent evaluation of the communications systems servicing Russia and several alternatives to avoid the unreliable telephone and telefax systems. Our own experience in making contacts for this study confirmed Franzen's appraisal (see Appendix H). Due to these problems, many Russian businesses are setting up subsidiaries in neighboring European and Scandinavian countries to take advantage of modern and/or more reliable communications technology to the outside world. We learned from more than one knowledgeable U.S. source that fax machines in Russia are often shut off after business hours, which is a problem (though easily remedied) for potential clients half a world away. Many Russian businesses limit incoming faxes to a single page to conserve paper. The unwary sender, in the habit of preceding his message with a cover page, would thus not be in communication. The ANSR, in fact, does not have a fax machine. Like many government agencies in Russia, they rely primarily on a telex system for international communications.

Electronic mail is in the early stages of development in Russia. Though AARI is connected to Internet, no other agencies or companies we contacted were. Franzen (1993) reports that although E-mail allows electronic communication via modem from a desktop computer to any telex terminal worldwide, error correction software is required to help ensure clear messages. An alternative communication link that we explored briefly is a system that the San Francisco-based Institute for Global Communications has installed in Moscow called GlasNet. It is a nonprofit, nongovernment, computer network to locations in the former USSR with electronic media, typically a personal computer and modem. Message formats include electronic mail, conferencing, and fax service. Fees are based on monthly connection charges and actual message units used. Messages are sent to major cities in Russia as electronic mail and then relayed to their final destination using fax, telegram, telex, or even personal phone call or letter. The system is intended to facilitate rapid information exchange reliably and inexpensively. More information about this service can be obtained through GlasNet USA. (See *Points of Contact.*)

Although the infrastructure is already in place to fully support NSR traffic during the summer season, it has been suggested (Wergeland, 1991; Østreng, 1991) that it will be difficult to attract greater foreign interest unless the navigation season can be extended. The additional investment for building ice-class ships is considerable (15–20% more, according to Wergeland, 1993). These ships are not ideal for use in other parts of the world when the arctic passage is closed for the winter. They are less efficient and more costly to run in open water than conventional vessels. To offset their greater construction, operating, and maintenance costs, ship owners rely on them providing year-round service. Since depth limitations in some straits prevent passage of ships greater than 20,000 dwt

(Granberg, 1992), the shallow-draft fleet of the Northern Sea Route may not be desirable for use where larger ships can move cargo more efficiently. More northerly route options would enable larger and perhaps more efficient ship passage but would also require greater icebreaking capabilities than are currently available. As recently as 1988, there was discussion that the Soviets were considering the construction of a new 150,000-shp icebreaker, which was seen as a necessary step for expanding NSR shipping through the winter (Østreng, 1992). Although those plans have been deemed premature in light of current cargo volume, costs, and revenue possibilities, we are left wondering which has to occur first—improvements in icebreaking capacity that will allow more economical cargo transportation, or the development of markets for trade goods that will spur technological advance.

It is most likely that advances on both fronts must occur simultaneously to effect real progress. Import and export industries depend heavily on reliable, year-round transportation of goods. Few businesses can afford the limitation of a seasonal supply of raw materials or seasonal distribution of their finished products. Attracting year-round trade will encourage the establishment of alternative transportation modes for the off-season, such as overland rail or air freight service. This will introduce another source of competitive pressure on marine shipping that is perceived to be negative.

According to Makinen (1993), average ship speeds along the Northern Sea Route need to be increased from 6–13 to 10–15 knots to make the route more competitive with the alternative canal routes. Wergeland's economic analysis presents data that show the NSR advantage in transit time diminishes to only two days by assuming an average transit speed of 12 knots vs. the 21-knot speed possible on the canal routes. When other costs associated with the NSR are then considered (greater insurance risk, higher maintenance and operating costs, smaller ship capacity), the NSR advantage disappears. If ship speeds during the winter period on the NSR can be increased substantially, then the NSR's economic advantage can be maintained.

Use of the Northern Sea Route will also depend on wider availability of emergency services. Personal safety demands greater access to rescue and medical services, whereas equipment emergencies might include ship repairs, refueling sites, and pollution abatement response. At the present time, the MOHQs and icebreaker escorts must be relied upon for these emergency services. Only the port of Igarka is open as a stop-over for foreign ships. Others slated to be opened are Dudinka, Dikson, Tiksi, and Pevek (Mikhailichenko, 1992). Another advantage to opening more ports would be to stimulate spinoff support services that could bring additional foreign revenue into the northern economy, from tourism and lodging facilities, for example (Brigham, 1993a).

The ability to respond to an environmental disaster at sea in this harsh and remote region is of concern to the northern populations of Russia as well as to the international community. The need for a coordination center and establishment of standard emergency procedures is widely acknowledged (for example, Sandkvist, 1993; Roginko, 1993). A funding source to achieve these goals is needed but is not immediately apparent. Until more experience is gained and more facilities become established, transit shipping will continue to be perceived as riskier than the traditional canal routes.

Other improvements to navigation that have been mentioned for incorporation into the Russian infrastructure are

- Better communication between ships and the MOHQs (Mikhailichenko and Usyakov, 1993),

- Better ice imaging tools (Østreng, 1991),
- Modern hardware for positioning and communication, and
- Dredging of ports (Brigham, 1993a).

The hardware that allows for global communications from virtually any arctic location is already in place, although better coordination in the use of that hardware may be needed. The Russians do admit to knowledge gaps in the movement of sea ice. Arikaynen (1991) claims an 80% accuracy rate for AARI ice forecasts. The technology to receive ice data from satellite-based sensors that do not require clear sky or daylight would enable the Russian experts to substantially improve their forecasting and ship routing capabilities.

CONCLUSIONS

Our study of the current conditions surrounding international use of the Northern Sea Route leads to the following conclusions.

The Northern Sea Route is a substantially shorter passage for shipping between northern European ports and those of the Far East and Alaska than routes through the Suez and Panama canals. Comparisons show a 35% to 60% savings in distance.

The Russians have a highly developed maritime infrastructure along the Northern Sea Route and specialized ice navigation experience that spans many decades. Their arctic marine system has been used primarily to develop Russia's northern regions, extract raw materials, and resupply their coastal settlements. They have a fleet of the world's most powerful icebreaking ships and specialized, ice-strengthened ships for moving most types of cargo.

Overall responsibility for shipping activities on the route currently resides with the Administration of the Northern Sea Route (ANSR) in Moscow. Actual sea operations are directly controlled by two marine operations headquarters: the Murmansk Shipping Company (MSC) operates the icebreakers and controls shipping through the western half of the route, while the Far Eastern Shipping Company (FESCO) controls the eastern half of the NSR.

The western portion of the route, from Murmansk to Dudinka, has been open year-round since 1980. The remainder is normally kept open for both transit and local freighting from the beginning of July through October. For the Northern Sea Route to be more attractive as an international trade route, the length of the shipping season will have to be extended, if it is not actually kept open year-round. Average transit speeds need to be increased as well. While the former requirement can be immediately addressed, at least partially, by enlisting the underutilized icebreaking and transport capacity of the Russian fleet, the latter will likely require better ice forecasting tools and advances in ship technology.

Since 1987, when the Soviet Union's new spirit of openness and international cooperation was announced, much has been made of the possible use of the Northern Sea Route as a major marine trade corridor. Several international organizations and regional government bodies have endorsed the idea, formulated agenda, and begun promotional activities. There is currently much international interest and momentum toward expanded development.

The USSR's dissolution into the Commonwealth of Independent States has been accompanied by social and economic hardship. Shortages, inflation, and unemployment have extended even to the arctic fleet. The Russians have proposed the following ways of using their fleet to raise much-needed foreign capital:

- Escort foreign ships along the route by Russian icebreakers,
- Transport foreign goods aboard Russian ice-strengthened cargo ships,
- Employ of idle Russian icebreakers and cargo vessels in the U.S. and Canadian Arctic, and
- Promote arctic tourism.

Social instability may be the greatest impediment to the development of the Northern Sea Route. Labor discontent, currency devaluation, cutbacks in personnel and services, and the inability to maintain the fleet and navigation equipment are all problems that directly affect future development. They result in a climate of uncertainty for potential users of the route, which, accordingly, diminishes foreign interest. The Murmansk Shipping Company and the Far Eastern Shipping Company must be willing to offer some degree of rate guarantee so that the Northern Sea Route maintains an economic advantage over other route options. Communication between foreign parties, the NSR Administration, and the shipping companies is made difficult by outdated equipment. Finally, the NSR Administration and the shipping companies need to be more reliable and responsive to inquiries from potential foreign clients.

The technological advances required to enable year-round traffic along the Northern Sea Route will occur more rapidly if the international community recognizes a demand for them. This would help to promote the growth of the Russian economy and encourage a cooperative and constructive posture for that nation, both domestically and internationally.

Privately, there is measured skepticism as to whether the Russians can sufficiently reorganize their operations and develop enough continuity that foreign shippers will have faith in the system. There is hope, however, that increased foreign use of the Northern Sea Route will bring about greater stability, which will, in turn, encourage even greater international usage.

In spite of the challenges, or perhaps because of them, the Northern Sea Route, which has been a magnet for explorers and adventurers in centuries past, may be a passage to economic enhancement and closer political unity for all the world's northern nations.

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REFERENCES

Anon. (1980) The Northern Sea Route, 1979. *Polar Record*, 20(125): 170–174.

Anon. (1981) The Northern Sea Route, 1980. *Polar Record*, 20(126): 448–453.

ANSR (1991) *Regulations for Navigation on the Seaways of the Northern Sea Route* (A.P. Suchorukov, Ed.). Moscow: Administration for the Northern Sea Route.

Arikaynen, A.I. (1991) Management of the Northern Sea Route: Stages and problems of development. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 140–149. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Armstrong, T. (1958) *The Russians in the Arctic. Aspects of Soviet Exploration and Exploitation of the Far North, 1937–1957*. Fair Lawn, New Jersey: Essential Books.

Armstrong, T. (1972) The Northern Sea Route in 1968–70. *Inter-Nord*, 118, p. 118–120.

Armstrong, T. (1984) The Northern Sea Route, 1983. *Polar Record*, 22(137): 173–182.

Armstrong, T. (1988a) From the Barents to the Bering: Coming to grips with a circumpolar giant. *Northern Perspectives*, July–August, 16(4): 4–5.

Armstrong, T. (1988b) Soviet proposals for the Arctic: A policy declaration by Mr. Gorbachev. *Polar Record*, 24(144): 68–69.

Armstrong, T. (1989) The Northern Sea Route, 1988. *Polar Record*, 25(154): 247–249.

Armstrong, T. (1990) The Northern Sea Route. *Polar Record*, 26(157): 127–129.

Armstrong, T. (1991) The Northern Sea Route, 1990. *Polar Record*, 27(161): 136–138.

Armstrong, T. (1992a) The Northern Sea Route, 1991. *Polar Record*, 28(166): 239–240.

Armstrong, T. (1992b) A history of the Northern Sea Route. *International Challenges*, 12(1): 34–42.

Armstrong, T. (1993) The Northern Sea Route, 1992. *Polar Record*, 29(1): 245.

Backlund, A., K. Juurmaa and T. Mattsson (1993). Arctic cargo transportation economic evaluation. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany*, vol. 1, p. 159–168. Hamburg: Hamburg Ship Model Basin.

Barnett, D. (1991) Sea ice distribution in the Soviet arctic. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 47–62. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Barr, W. (1991) The Arctic Ocean in Russian history to 1945. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 11–32. Woods Hole Oceanographic Institution. Annapolis, Maryland: U.S. Naval Institute Press.

Barr, W. and E.A. Wilson (1985) The shipping crisis in the Soviet eastern arctic and the close of the 1983 navigation season. *Arctic*, 38(1): 1–17.

Batskikh, Yu.M. and V.V. Mikhailichenko (1993) The development of navigation along the Northern Sea Route. Presented at the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany.

Brekke, B. and P.E. Fjeld (Eds.) (1991) Pilot Project 1B: Environmental factors. In *The Northern Sea Route Project; Pilot Studies Report*, by W. Østreng and A. Jørgensen-Dahl, p. 126–179. Lysaker, Norway: Fridtjof Nansen Institute.

Brigham, L.W. (1985) New developmnents in Soviet nuclear Arctic ships. *U.S. Naval Proceedings*, 111(12): 131–133.

Brigham, L.W. (1987) Emerging polar ship technology—An introduction. *Marine Technology Society Journal*, 21(3): 3-5.

Brigham, L.W. (1991a) Soviet arctic marine transportation 1990. *U.S. Naval Proceedings*, October, 117(10): 109-110.

Brigham, L.W. (1991b) Technical developments and the future of Soviet Arctic marine transportation. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.). Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Brigham, L.W. (1992) Modern icebreaking ships. In *The Shipping Revolution: The Modern Merchant Ship* (R. Gardiner, Ed.), p. 154–158. London: Conway Maritime Press.

Brigham, L.W. (1993a) The Russians open the Arctic for business. *U.S. Naval Proceedings*, January, 119(1): 92–93.

Brigham, L.W. (1993b) Views on the opening of the Northern Sea Route and the Russian maritime arctic. In *Proceedings from the Northern Sea*

Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway (H. Simonsen, Ed.), p. 167–173. Lysaker, Norway: Fridtjof Nansen Institute.

Brigham, L.W. and R.P. Voelker (1985) Ice navigation studies in the Alaskan Arctic using *Polar*-class icebreakers. In *Proceedings of the Ocean Engineering and the Environment—OCEANS '85 Conference, 11–14 November, San Diego, California,* vol. 1, p. 441–447.

Brower, W.A. Jr., R.G. Baldwin, C.N. Williams, Jr., J.L. Wise, and L.D. Leslie (1988) *Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska;* vol. I, Gulf of Alaska, vol. II, Bering Sea, vol. III, Chukchi–Beaufort Sea. National Climate Data Center; National Environmental Satellite, Data, and Information Service; National Oceanic Atmospheric Administration; and Arctic Environmental Information and Data Center. Anchorage: University of Alaska.

Butler, W. (1991) The legal regime of the Soviet Arctic marine areas. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 215–234. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Buzuev, A.Ia. (1991) Appendix D to Pilot project A: Range and scope of physical attributes, by S. Vefsnmo, M. Mathiesen, S. Løset and A.Ya. Buzuev. In *The Northern Sea Route Project: Pilot Studies Report* (W. Østreng & A. Jørgensen-Dahl, Eds.), p. 90–125. Lysaker, Norway: Fridtjof Nansen Institute.

Buzuev, A.Ia. (1992) Natural factors and their influence on sailing on the Northern Sea Route. *International Challenges,* 12(1): 83–89.

Buzuev, A.Ia. and V.A. Likhomanov (1993) Division into zones of the Northern Sea Route by difficulty and safety of navigation. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany,* vol. 1, p. 393–402. Hamburg: Hamburg Ship Model Basin.

Cahill, T. (1993) You, too, can be a polar hero. *Outside,* December, p. 44–51, 119–125.

Davies, J. (1993) Arctic trade route a no-go; officials hoping to get cargo moving north by next year. *Anchorage Daily News,* September 15, p. D1.

Dick, R. A. and J.E. Laframboise (1989) An empirical review of the design and performance of icebreakers. *Marine Technology,* 26(2): 145–159.

Dick, R. A., D.N. Baker, E.W. Thompson and H.C. Cheung (1987) *Arctic Ship Technology.* Transport Canada Report TP 8094E 2 volumes. Ottawa, Ontario: Melville Shipping, Ltd.

Dickins, D., L. Martin, I. Bjerkelund, S. Potter, D. Erickson, J. Harper, P. Norton, S. Johnson and P. Vonk (1987) *Environmental Atlas for Beaufort Sea Oil Spill Response.* Yellowknife, N.W.T.: Environment Canada, Environmental Protection Service.

DMA (1993) *Catalog of Maps, Charts, and Related Products; Part 2, Vol. 1: Hydrographic Products.* Nautical Charts and Publications, Defense Mapping Agency, No. CATP2V01U, 4th edition, April. Washington, D.C.: Department of Defense.

Franckx, E. (1988) Non-Soviet shipping in the Northeast Passage, and the legal status of Proliv Vil'kitskogo. *Polar Record,* 24(151): 269-276.

Franzen, j. (Ed.) (1993) Russia 1993: Political and economic analysis and business directory. New York: Chamber World Network.

Frolov, I. (1991) The 1987 expedition of the icebreaker *Sibir'* to the North Pole. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 33–44. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Gloersen, P., W.J. Campbell, D.J. Cavalieri, J.C. Comiso, C.L. Parkinson and H.J. Zwally (1992) *Arctic and Antarctic Sea Ice, 1978–1987: Satellite Passive-Microwave Observations and Analysis.* Washington, D.C.: National Oceanic and Atmospheric Administration.

Gorshkov, S.G. (Ed.) (1983) *Atlas of the Oceans. Vol. 3, Arctic Ocean* (in Russian with English introduction and keys to all maps). USSR Ministry of Defense, Navy, Department of Navigation and Oceanography. New York: Pergamon Press.

Granberg, A. (1992) The Northern Sea Route and the policy of new Russia. *International Challenges*, 12(1): 5–14.

Granberg, A. (1993a) International economic cooperation along the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 153-166. Lysaker, Norway: Fridtjof Nansen Institute.

Granberg, A. (1993b) Importance of marine transportation for the Russian Arctic. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany*, vol. 1, p. 978–987, Hamburg: Hamburg Ship Model Basin.

Gudkovich, Z.M. et al. (1972) Foundations for a method of long-term ice prognosis for Arctic waters. Leningrad: Gidrometeoizdat.

Hansson, R. (1992) An environmental challenge to half the Arctic. *International Challenges*, 12(1): 90–97.

Hansson, R. (1993) The NSR—A route to destruction or protection. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 133–139. Lysaker, Norway: Fridtjof Nansen Institute.

Hastings, A.D. (1971) Surface climate of the Arctic Basin; selected climatic elements related to the performance of surface-effect vehicles. Report ETL-TR-71-5, Fort Belvoir, Virginia.

Hume, H. (1984) A comparative study of the Northern Sea Route and the Northwest Passage: With special reference to the future development of marine transportation along the latter route. Unpublished Masters thesis. Cambridge, England: Scott Polar Research Institute.

Ivanin, Y. (1978) Soviet A-power conquers the North Pole. *Canadian Shipping and Marine Engineering*, 49(6): 26–29.

Ivanov, Y. and A. Ushakov (1992) The Northern Sea Route—Now open. *International Challenges*, 12(1): 15–20.

Johannessen, O.M., S. Sandven, O. Skagseth, K. Kloster, Z. Kovacs, P. Sauvedet, L. Geli, W.F. Weeks, and J. Louet (1992) ERS-1 SAR ice routing of *L'Astrolabe* through the Northeast Passage. Nansen Environmental and Remote Sensing Center, Technical Report no. 56. Bergen, Norway: University of Bergen.

Jones & Bartlett Publishing, Inc. (1981) *Atlas of the Polar Regions.* (Originally published by the U.S. National Foreign Assessment Center.) 20 Park Plaza, Boston, Massachusetts.

Kjerstad, N. (1992) Navigation conditions along the NSR—Experiences from a transit voyage, September 1991. *International Challenges*, 12(1): 116–120.

Kolodkin, A.L. and M.E. Volosov (1990) The legal regime of the Soviet Arctic: Major issues. *Marine Policy*, 14(2): 158–169.

LaBelle, J.C., J.L. Wise, R.P. Voelker, R.H. Schulze and M. Wohl (1983) *Alaska Marine Ice Atlas.* Arctic Environmental Information and Data Center. Anchorage: University of Alaska.

Makinen, E. (1993) The fundamental assumptions and future uses of the Northern Sea Route traffic. In *Proceedings from the Northern Sea Route*

Expert Meeting, 13–14 October, 1992, Tromsø, Norway (H Simonsen, Ed.). Lysaker, Norway: Fridtjof Nansen Institute.

Masterson, D.M. and R.M.W. Frederking (1993) Local contact pressures in ship/ice and structure/ice interactions. *Cold Regions Science and Technology*, 21: 169–185.

Matyushenko, N. (1992) The Northern Sea Route: Challenge and reality. *International Challenges*, 12(1): 116–120.

Mikhailichenko, V. (1986) Operations with icebreaking cargo vessels on the Northern Sea Route. In *Proceedings of the International Polar Transporation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 2, p. 792–804. Vancouver, B.C.: D.F. Dickens Associates.

Mikhailichenko, V. (1992) The Northern Sea Route and the applicable regulations for navigation along its course. Presented at the Conference on Opening the Northern Sea Route, Trondheim, Norway, 2–4 September.

Mikhailichenko, V. and A. Ushakov (1993) The Northern Sea Route and the applicable regulations for navigation along its course. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 11–29. Lysaker, Norway: Fridtjof Nansen Institute.

Milano, V. R. (1987) The Thyssen/Waas icebreaking hull form. *Marine Technology Society Journal*, 21(3): 75–87.

Orvig, S. (Ed.) (1970) *World Survey of Climatology. Volume 14, Climates of the Polar Regions*. New York: Elsevier Publishing Co.

Osherenko, G. (1993) Using peripheral vision in the Northern Sea route: Assessing impacts on indigenous peoples. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 287–289, Lysaker, Norway: Fridtjof Nansen Institute.

Østreng, W. (1991) The Northern Sea Route: A new era in Soviet policy? *Ocean Development and International Law*, 22(3): 259–287.

Østreng, W. (1992) The geopolitics of the Northern Sea Route. *International Challenges*, 12(1): 21–25.

Østreng, W. and A. Jørgensen-Dahl (1991) The Northern Sea Route project; Pilot studies report. Lysaker, Norway: Fridtjof Nansen Institute.

Roginko, A.Y. (1991) Environmental protection in the Soviet arctic seas. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 63–82. London: Belhaven Press.

Roginko, A.Y. (1993) The Northern Sea Route: Protection of marine environment in the context of circumpolar cooperation. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 249–263. Lysaker, Norway: Fridtjof Nansen Institute.

Romanov, I.P. (1993a) *Atlas: Morphometric Characteristics of Ice and Snow in the Arctic Basin* (in Russian and English). St. Petersburg: Arctic and Antarctic Research Institute.

Romanov, I.P. (1993b) *Ice Cover of the Arctic Basin* (in Russian and English). St. Petersburg: Arctic and Antarctic Research Institute.

Rosenberg, G. (1993) Satellite-based services for arctic activities. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway (H. Simonsen, Ed.)*, p. 51–53. Lysaker, Norway: Fridtjof Nansen Institute.

Sandkvist, J. (1993) Impact assessment and contingency planning for remote operations, including a Swedish case. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 93–107. Lysaker, Norway: Fridtjof Nansen Institute.

Stokke, O.S. (1992) Arctic environmental cooperation after Rovaniemi: What now? In *Nordic Arctic Research on Contemporary Arctic Problems. Proceedings from the Nordic Arctic Research Forum Symposium* (L. Lyck, Ed.), p. 221–234. Ålborg, Denmark: Ålborg University Press.

Treshnikov, A.F. (Ed.) (1985) *Atlas of the Arctic* (in Russian). St. Petersburg: Arctic and Antarctic Research Institute

Ushakov, A.P., Yu.M. Ivanov, N.A. Isakov, Yu.M. Batskikh, and T. Armstrong (1991) A historical introduction. In *The Northern Sea Route Project: Pilot Studies Report* (W. Østreng & A. Jørgensen-Dahl, Eds.), p. 5–15. Lysaker, Norway: Fridtjof Nansen Institute.

USDC/NOAA (1981) *United States Coast Pilot, Pacific and Arctic coasts, Alaska: Cape Spencer to Beaufort Sea.* 10th edition, January. Washington D.C.: U.S. Department of Commerce.

USNOCD (1986a) *Sea Ice Climatic Atlas: Vol. 2, Arctic East.* U.S. Naval Oceanography Command Detachment. Asheville, N.C. NAVAIR 50-1C-541.

USNOCD (1986b) *Sea Ice Climatic Atlas, Vol. 3, Arctic West.* U.S. Naval Oceanography Command Detachment. Asheville, N.C., NAVAIR 50-1C-542.

USN/NOAA JIC (1993) *Environmental Services for Polar Operations.* Joint Ice Center. Washington, D.C.: U.S. Navy.

USSR Ministry of Defense, Department of Navigation and Oceanography (1991) Regulations for navigation on the seaways of the Northern Sea Route. Also appeared in *Notices to Navigators*, no. 29, 13 June 1991, and in *International Challenges*, 12(1): 121–126, 1992.

Vefsnmo, S., M. Mathiesen, S. Løset and A.Ya. Buzuev (1991) Pilot project A: Range and scope of physical attributes. In *The Northern Sea Route Project: Pilot Studies Report* (W. Østreng & A. Jørgensen-Dahl, Eds.), p. 27–125. Lysaker, Norway: Fridtjof Nansen Institute.

Voelker, R.P. (1990) Arctic Marine Transportation Program, 1979 to 1986, Executive Summary. Prepared for Maritime Administration, Office of Technology Assessment, Department of Transportation, Report No. MA-RD-840-90004. Columbia, Maryland: NKF Engineering, Inc., Arctic Technology Group.

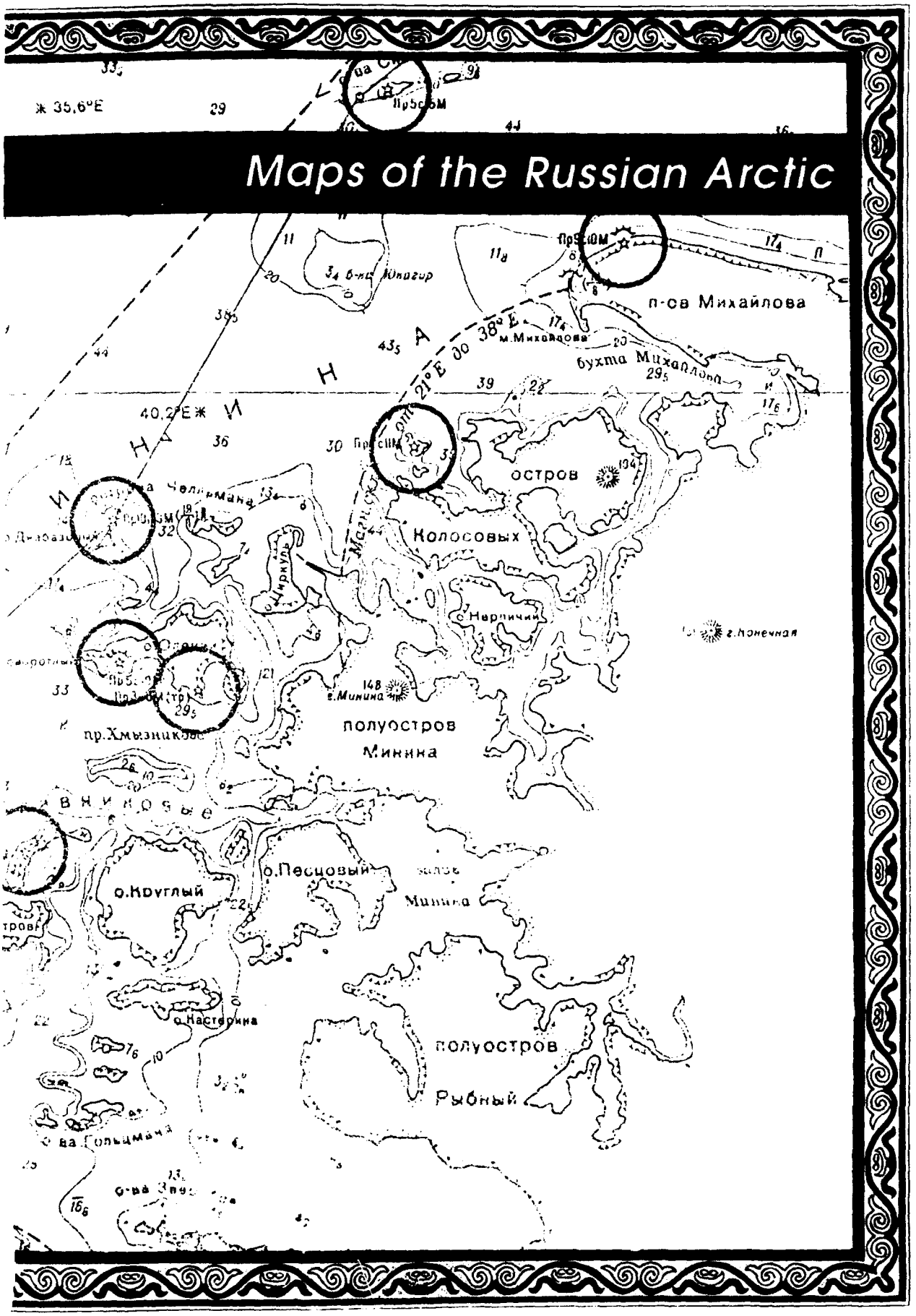
Weathersby, J. (1990) Inside Track: Breaking the trade ice; port would profit if Soviets open northern ship lanes. *The (Tacoma, Wash.) News Tribune*, 26 March, p. C9.

Wergeland, T. (Ed.) (1991) Pilot project report: Commercial shipping and the NSR. In *The Northern Sea Route Project: Pilot Studies Report* (W. Østreng & A. Jørgensen-Dahl, Eds.), p. 180–232. Lysaker, Norway: Fridtjof Nansen Institute.

Wergeland, T. (1992) The Northern Sea Route—Rosy prospects for commercial shipping. *International Challenges*, 12(1): 43–57.

Wergeland, T. (1993) Commercial shipping perspectives. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 63–72. Lysaker, Norway: Fridtjof Nansen Institute.

Young, O.R. and A. Osherenko (1991) International cooperation in the Arctic: Soviet attitudes and actions. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 258–283. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.


Maps of the Russian Arctic
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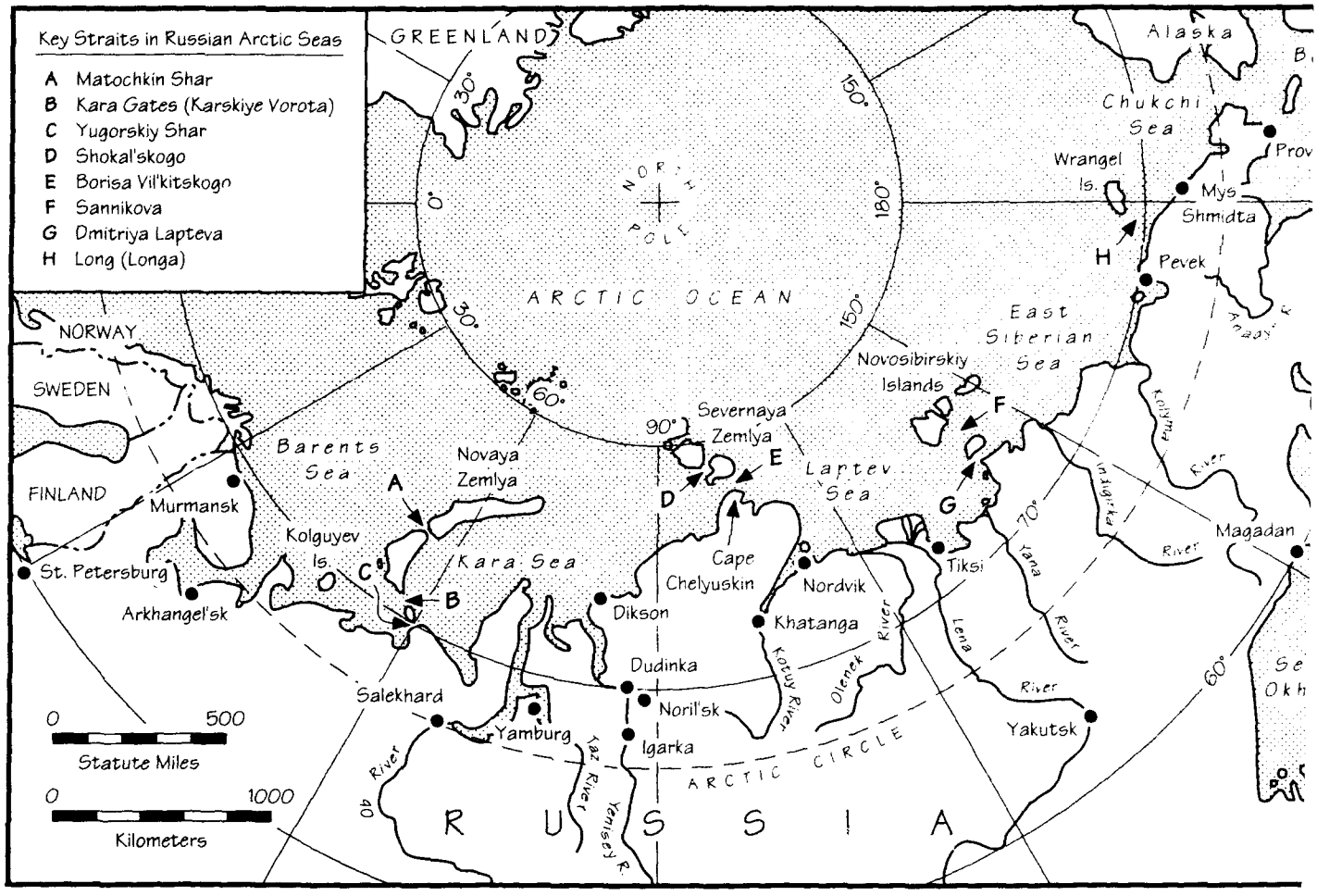
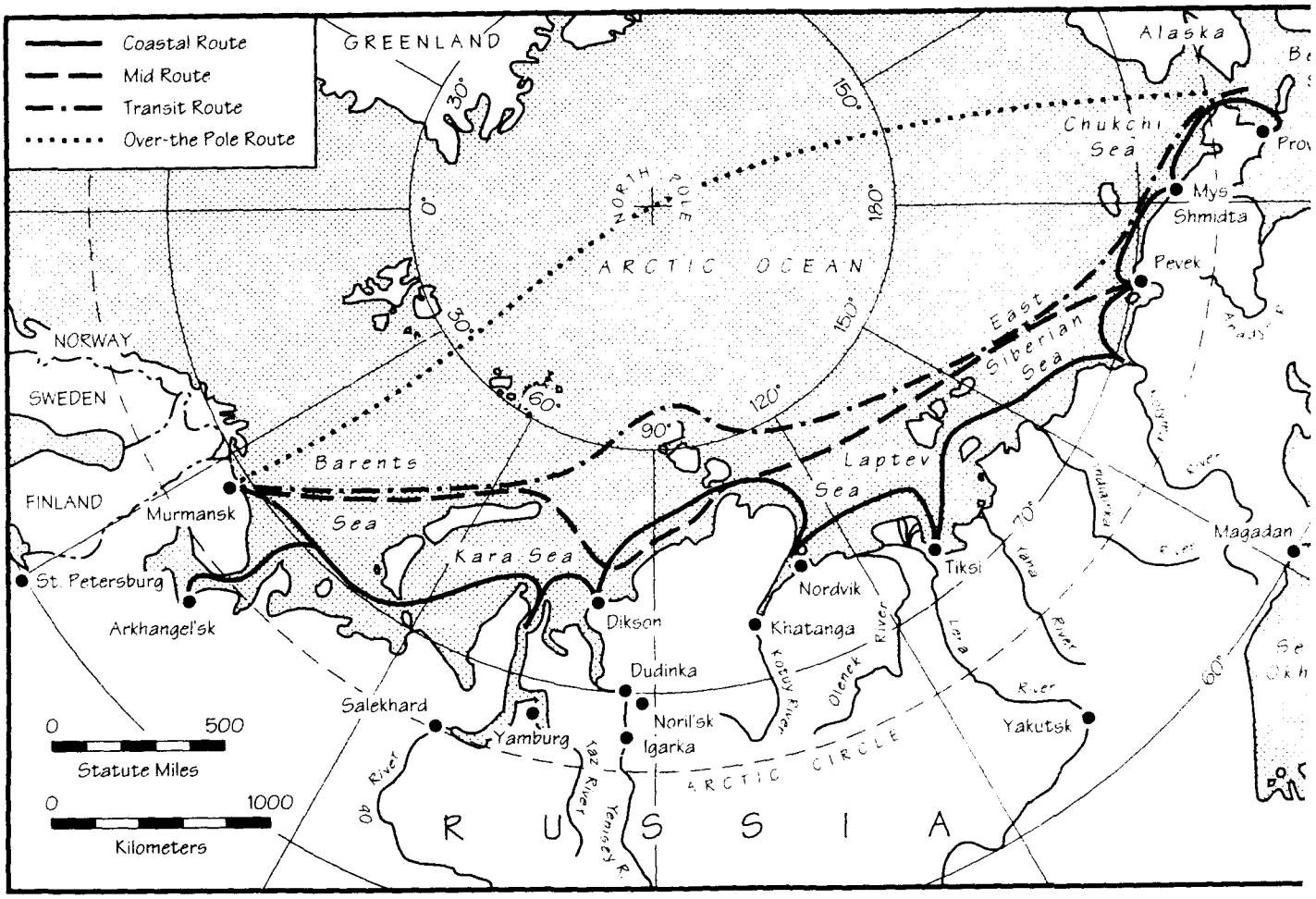
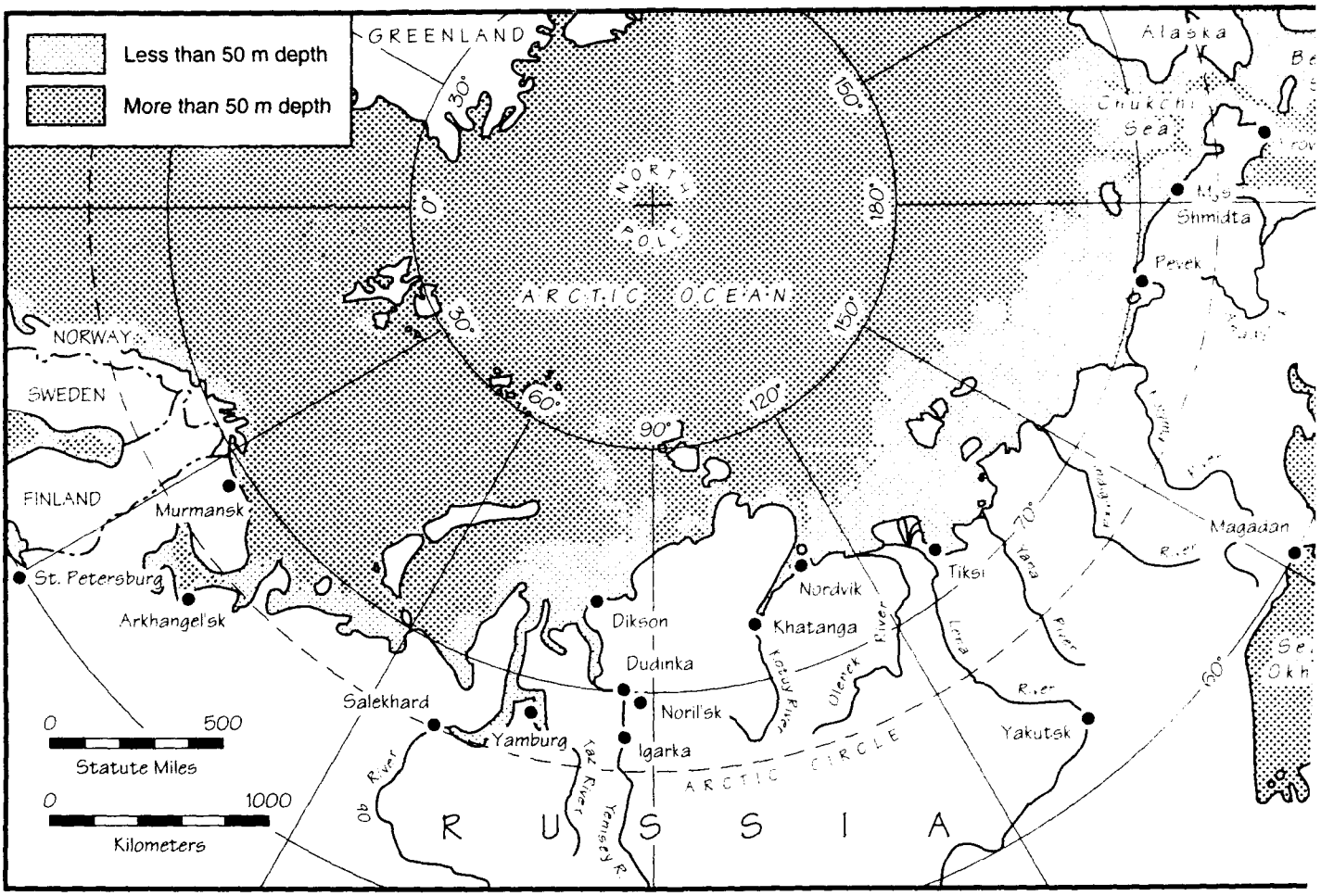


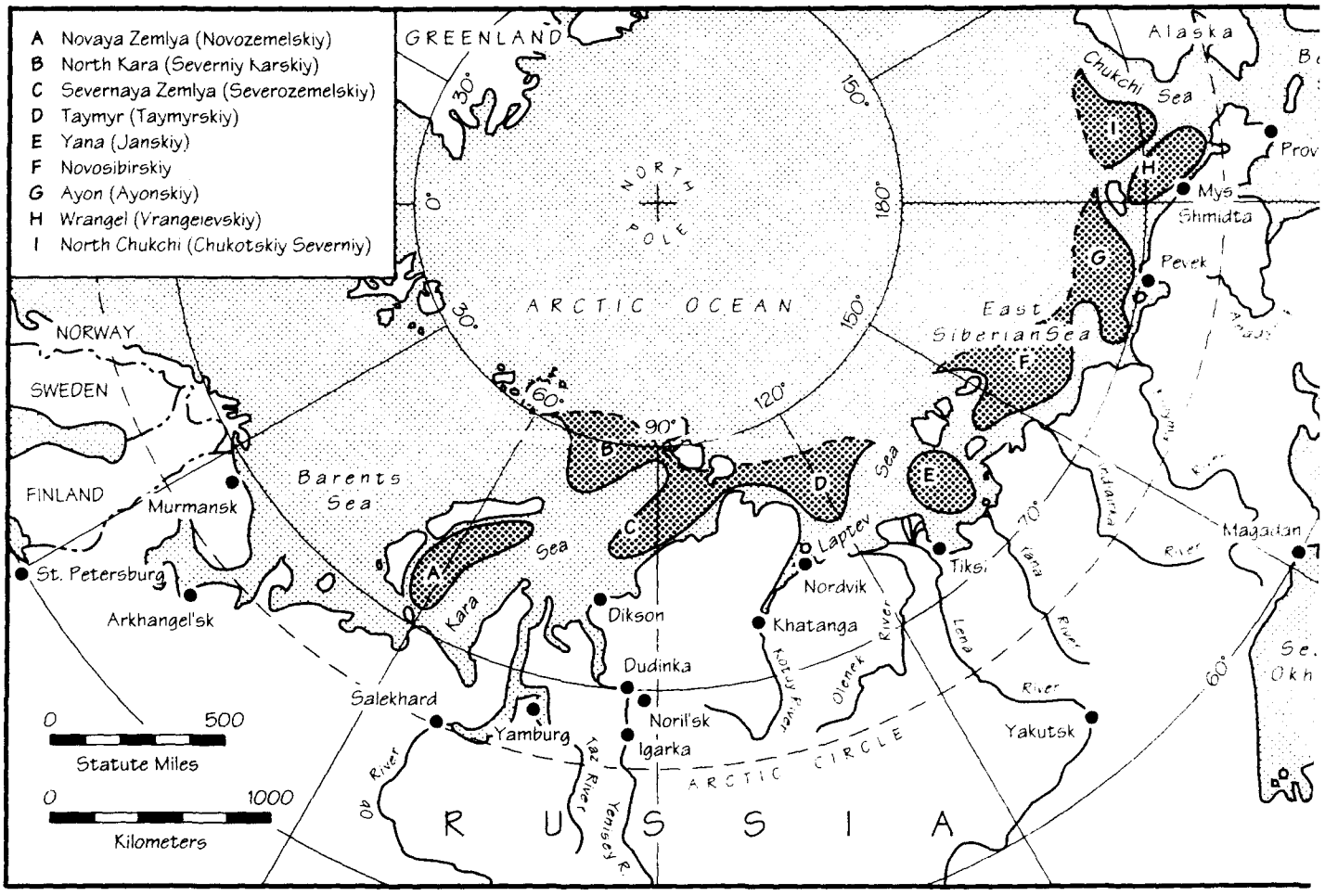
Map 1. The Russian Arctic.



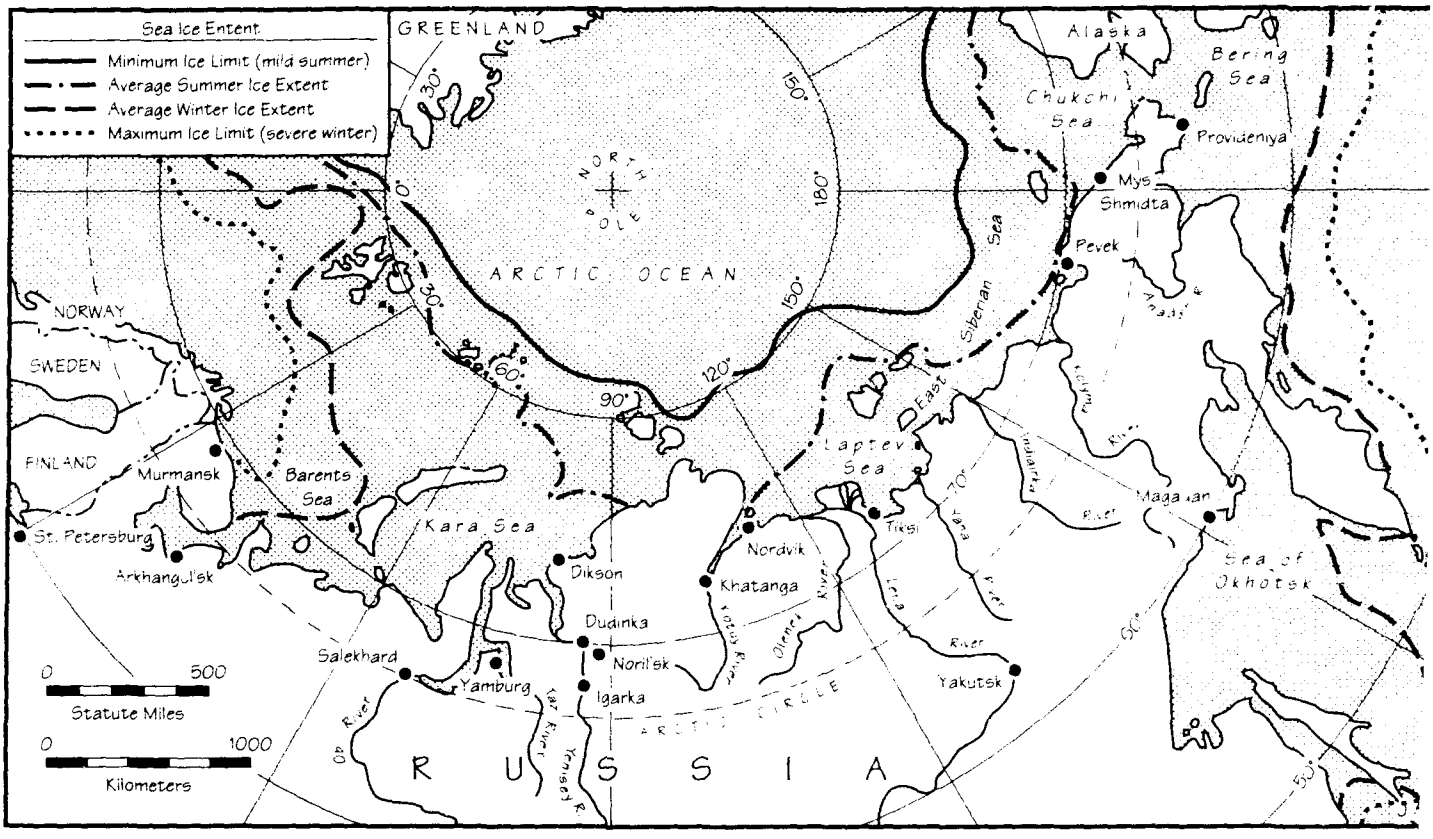
Map 2. The various Northern Sea Route options.



Map 3. The shallow continental shelf of the Russian Arctic.



Map 4. Main ice massifs of the Russian Arctic (adapted from Gudkovich et al., 1972).



Map 5. Seasonal extent of the sea-ice edge (from Barnett, 1991; USNOCD, 1986a,b).

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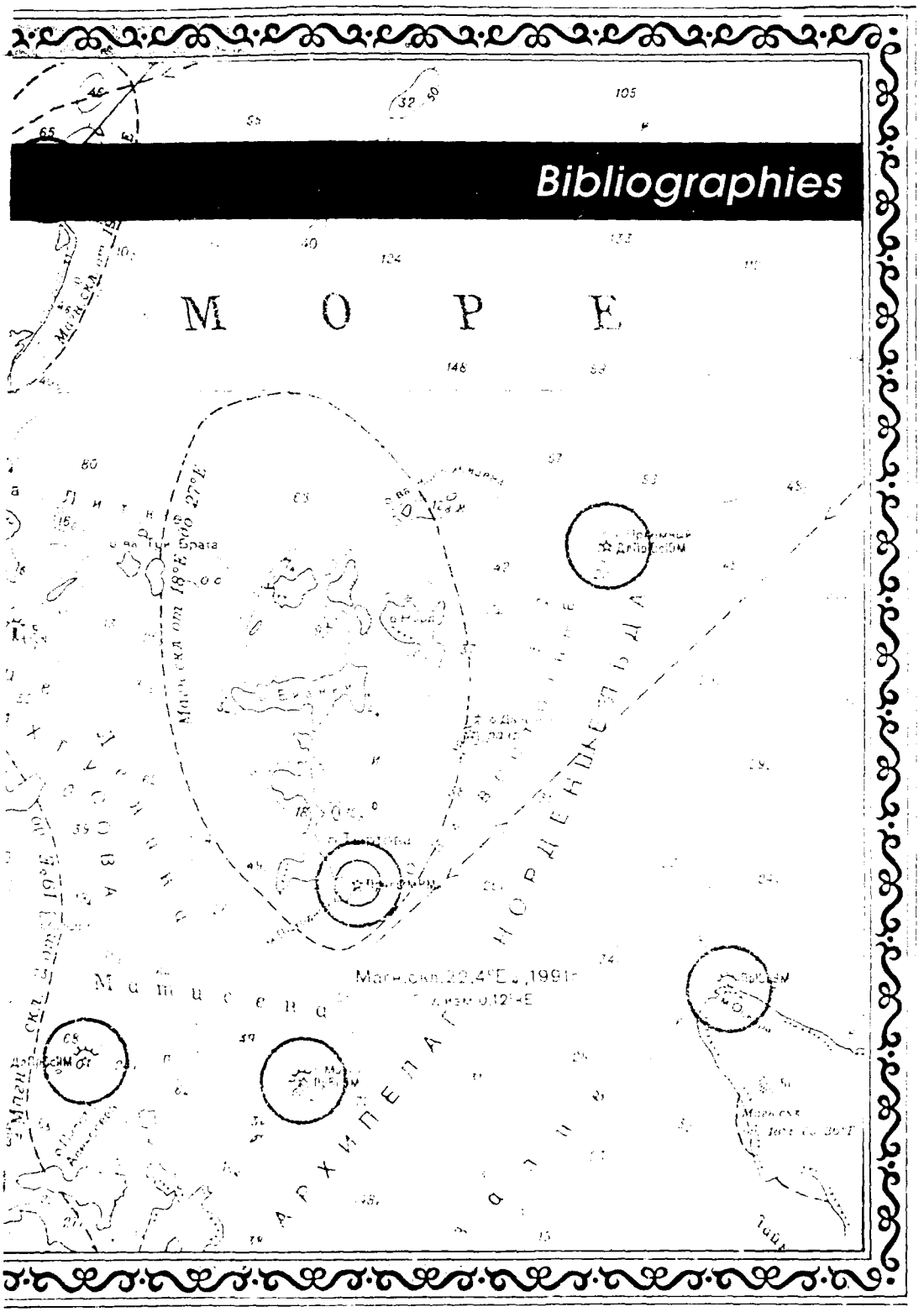

BIBLIOGRAPHIES

INTRODUCTION

The following nonannotated, selective bibliographies were compiled using commercially available databases and individual contacts with Northern Sea Route and icebreaker technology experts. We searched several multidisciplinary on-line databases, including newspapers, foreign collections, and scientific and economic files, and primary citations were retrieved from the Bibliography of Cold Regions Science and Technology, the Scott Polar Research Institute Bibliography, *Oceanic Abstracts*, and the *Anchorage Daily News*. Additional citations from the relevant literature were selected by Nathan Mulherin, Dr. Devinder Sodhi, and Elisabeth Smallidge, who compiled the bibliographies.

The Northern Sea Route bibliographies are divided into categories that reflect the informational areas identified by the scope of the Cold Regions Technical Information Analysis Center (CRSTIAC) Northern Sea Route study. The Alaskan Waters bibliography contains citations related to ice conditions, meteorology, hydrography, and ice climatology on the Bering, Chukchi, and Beaufort seas. The Russian/Arctic Waters bibliography comprises citations on sea ice climatology, sea ice observations, ice conditions, and meteorological, hydrographic, and oceanographic conditions on the East Siberian, Laptev, Kara, Barents, and White seas. These bibliographies bring to the reader's attention the most recent knowledge available on the Northern Sea Route and icebreaking technology. They are also intended to facilitate technology transfer and help prevent duplication in research and development work.

Of the more than 3500 citations that were reviewed for this study, 1098 were selected for these bibliographies. Citations that were not of direct interest to the CRSTIAC study of the Northern Sea Route were eliminated. The citations selected cover a 70-year span, from 1923 to 1993; citations prior to 1923 can be located in the Scott Polar Bibliography. More than 80% of those selected were published since 1981. This reflects not only an increase in citations relevant to the study, but the authors' selection of recent citations due to their greater relevance.

DATABASES SEARCHED

The Bibliography of Cold Regions Science and Technology (COLD) is produced annually by the Library of Congress for the U.S. Army Cold Regions Research and Engineering Laboratory. Vital to the CRSTIAC mission, the COLD database provides comprehensive coverage of literature relating to geographical areas that are temporarily or permanently affected by freezing temperatures, including the Arctic and the Antarctic. It covers publications in the fields of civil, mechanical, and environmental engineering and most of the earth, ocean, and atmospheric sciences, and includes the major subject areas of snow, ice, frozen ground, navigation in ice, civil engineering in cold regions, behavior and operation of materials and equipment in cold temperatures. Source materials include monographs, journal articles, conference papers, theses, patents, maps, and technical reports derived from private, academic, and government sources dating from 1951 to the present. This bibliography is international in scope—more than half of the 150,000 citations are of foreign ori-

and Exploitation of the Far North, 1937–1957. Fair Lawn, New Jersey: Essential Books.

Armstrong, T. (1972) The Northern Sea Route in 1968–70. *Inter-Nord*, 118, p. 118–120.

gin—and covers the world's literature on these subjects. It is available as the Arctic & Antarctic Regions CD-ROM from National Information Services Corporation, Suite 6, Wyman Tower, 3100 St. Paul Street, Baltimore, Maryland 21218, (410) 243-0797, and on-line from Orbit Online Products, Inc., 8000 Westpark Drive, McLean, Virginia 22102, (800) 456-7248. More than half of the citations in the following bibliographies are from the COLD database.

SPRI is an international multidisciplinary subject bibliography compiled by the Scott Polar Research Institute, University of Cambridge, in Cambridge, England. The SPRI database reflects current international polar and glaciological research, with specific strengths in anthropology, atmospheric chemistry and physics, climate change, cold regions engineering, exploration, geology, natural resources, oceanography, snow and ice issues, and zoology. Source materials include over 900 serials, monographs, and theses from 1750 to the present. SPRI is included on the Arctic & Antarctic Regions CD-ROM.

Oceanic Abstracts is produced by Cambridge Scientific Abstracts (CSA) in Cambridge. It organizes and indexes worldwide technical literature on all aspects of the oceans and offers researchers access to thousands of marine-related articles, books, reports, and papers published each year. In printed form it is issued as the bimonthly *Oceanic Abstracts*, available from CSA. The database, copyrighted by CSA, dates from 1964 and is available on-line as File 28 from Dialog Information Services, Inc., 3460 Hillview Avenue, Palo Alto, California 94304, (800) 334-2564.

The *Anchorage Daily News* is Alaska's largest daily newspaper; it provides local, national, and international news coverage. In addition to coverage of politics, government, business, economics, arts, and sports in Alaska and the lower 48, the *Daily News* reports on issues unique to Alaska. Special areas of interest include Pacific-rim trade, oil and gas, natural resources, northern defense, native sovereignty, frontier lifestyle, tourism, arctic and polar region studies, and the environment. It is available on-line as File 737 from Dialog Information Services, Inc.

PRIMARY SOURCES

The number of relevant Northern Sea Route and icebreaker technology citations selected for these bibliographies has steadily increased in the past decade: 22 citations were selected from 1980, 67 from 1990, and 89 from 1993. This increase is tied to an increase in conferences that relate to the Northern Sea Route and icebreaking technology as well as the increased accessibility of international electronic information. Even a casual review of the bibliographies reveals that some of these primary sources have provided a large proportion of the citations.

Many of the citations in the bibliographies are from conference proceedings. Some of the most notable of these are described below:

- The International Association of Hydraulic Research, Washington, D.C. sponsors an International Symposium on Ice every other year. These conferences provide a forum for international scientists and engineers to discuss ice problems in general and ice problems with hydraulic structures in particular. The bibliographies contain citations from the 7th (1984), 8th (1986), 9th (1988), and 10th (1990) conferences.
- The International Conferences on Port and Ocean Engineering under Arctic Conditions (POAC) are dedicated to various practical aspects of coastal engineering under polar and subpo-

lar conditions. Each conference is sponsored by the host country's various scientific and technical organizations and universities. The bibliographies contain citations from the 3rd (1976), 5th (1979), 6th (1981), 7th (1983), 8th (1985), 9th (1988), 11th (1991), and 12th (1993) conferences.

- The Northern Sea Route Expert Meeting was held in October of 1992 in Tromsø, Norway, and the proceedings were published jointly by the Finnish and Norwegian Foreign Ministries in collaboration with the Fridtjof Nansen Institute in Norway. The citations cover a range of topics, including economics, the environment, and international cooperation on the Northern Sea Route.

Two long-term studies provided a rich source of relevant information about arctic ice and waters:

- MIZEX was an international program for mesoscale air–ice–ocean interaction experiments in arctic marginal ice zones. In this connection, a series of reports were published by the U.S. Army Cold Regions Research and Engineering Laboratory. They were unrefereed and provided a permanent medium for the interchange of initial results, data summaries, and theoretical ideas relevant to experiments in the arctic marginal ice zones.
- The *AIDJEX Bulletin* (Arctic Ice Dynamics Joint Experiment) was contracted by the National Science Foundation and published by the Division of Marine Resources at the University of Washington in Seattle. This now-ceased publication included ice motion data collected from 1970 to 1978 by automatic data acquisition and transmission systems and accurate positioning systems.

A special 1992 issue of the serial *International Challenges* was devoted to the Northern Sea Route. It is published quarterly by the Fridtjof Nansen Institute, Lysaker, Norway. Issues cover ocean management, the law of the sea, deep seabed mining, polar regions, international oil and gas policy, and international environmental matters.

Polar Record is the journal of the Scott Polar Research Institute and is published by Cambridge University Press. It is a quarterly journal that contains articles, notes, and reviews on the polar and subpolar regions in archaeology, biogeography, glaciology, international law, and oceanography.

Several Russian-language journals are included in the NSR and Russian/Arctic Waters bibliographies. Among the most important of these periodicals are:

- *Morskoi Flot* (Journal of the USSR Merchant Marine) and its English translation, *Soviet Shipping Journal*, are published in Moscow by the Ministry of the Merchant Marine. *Morskoi Flot* was founded by the Association of Ship Owners and the Association of Merchant Marine Ports. Published since 1986, *Morskoi Flot* contains articles on naval art and science, the merchant marine, marine engineering, and naval history.

- *Problemy Arktiki i Antarktiki* (Problems in the Arctic and Antarctic) is published by the Arctic and Antarctic Scientific Research Institute (AARI) in Leningrad, now St. Petersburg, Russia. The institute, founded in 1921, concentrates on hydrological

studies with emphasis on ice conditions in the arctic and northern rivers of the former Soviet Union, long-range weather forecasting, and the study of the interaction of ice and ships. It receives information from the Institute's various stations, two research vessels, manned and automatic drift stations, and artificial satellites.

- *Letopis' Severa* (Annals of the North) is published in Moscow by the Commission on Problems of the North, Russian Academy of Sciences. It is a yearbook of arctic region studies, first published in 1949.

- *Sudostroenie* (Shipbuilding) is a monthly publication that was first published in 1898. It is produced by the Main Office of Shipbuilding of the Russian Federation Committee of Defense Industries and the Union of Scientific and Technical Societies of Shipbuilders. This publication deals with shipbuilding, naval architecture, marine engineering, and the history of shipbuilding. The English translation, *Soviet Shipbuilding*, is published in Suitland, Maryland, by the Naval Intelligence Support Center, Translation Division.

The book *The Soviet Maritime Arctic*, edited by Lawson W. Brigham, Capt., USCG, was of primary interest to the authors of this TIAC report. Published by the Naval Institute Press in Annapolis, Maryland, in 1991, it is the first book in a new Polar Research Series published in association with the Scott Polar Research Institute at the University of Cambridge. The chapters were written by a unique group of experts, historians, geographers, polar scientists, legal specialists, and environmentalists from North America, Europe, and the former Soviet Union. Capt. Brigham edited *The Soviet Maritime Arctic* while he was a Research Fellow at the Marine Policy Center of the Woods Hole Oceanographic Institution in 1989–1990. He graduated from the U.S. Coast Guard Academy in 1970, and assumed command of the USCGC *Polar Sea*, one of the nation's two polar icebreakers, in July 1993. Since that time *Polar Sea* has deployed to the Arctic, for the Northeast Water Polynya Project, and the Antarctic, for Deep Freeze 1994. Capt. Brigham has published widely on Russia's Northern Sea Route, polar ship technology, polar navigation, and polar oceanography, and through personal contact, the authors of this report have obtained additional relevant literature.

Terence Armstrong has been a major contributor to Northern Sea Route literature. Beginning in 1952, he wrote annual reports on the development of sea transport along the Siberian coast; most were published as notes in *Polar Record*. He has traveled widely in the Soviet Arctic, northern Scandinavia, Greenland, and North America for comparative studies of economic, educational, and social developments, and he was responsible for building the Scott Polar Research Institute's library collection on the Soviet Arctic. Mr. Armstrong is now retired after 36 years as Research Fellow, Assistant Director of Research, Reader in Arctic Studies, and Acting Director of the Scott Polar Research Institute.

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THE NORTHERN SEA ROUTE

Afanas'yev, A.A. (1985) The operations of the Head Office of the Northern Sea Route in the post-war period (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 23–33.

Agapkin, V.M. (1981) Economic effectiveness of pipe transportation by the Northern Sea Route (in Russian). *Stroitel'stvo Truboprovodov* (Pipeline Construction), no. 4, p. 16–17.

Anon. (1982) Cargo ships for Russia's Northern Sea Route. *Shipbuilding and Marine Engineering International*, 105(1264): 531, 533–534, 536–540.

Anon. (1993) Five years of ice data rounded off. *Arctic News-Record*, 9.1(5).

Anon. (1935) Freight voyages along whole length of Northern Sea Route during navigation season of 1935 (in Russian). *Bulletin of the Arctic Institute*, no. 10, p. 341.

Anon. (1957) The Northern Sea Route in 1956. *Polar Record*, 8(56): 453–455.

Anon. (1959) The Northern Sea Route in 1958. *Polar Record*, 9(62): 461.

Anon. (1961) The Northern Sea Route, 1960. *Polar Record*, 10(68): 515–516.

Anon. (1962) The Northern Sea Route, 1961. *Polar Record*, 11(71): 194–195.

Anon. (1963) The Northern Sea Route, 1962. *Polar Record*, 11(75): 719–720.

Anon. (1965) The Northern Sea Route, 1964. *Polar Record*, 12(81): 742–743.

Anon. (1968) Northern Sea Route, 1967. *Polar Record*, 14(90): 332–333.

Anon. (1970) Northern Sea Route, 1968. *Polar Record*, 15(94): 51–52.

Anon. (1970) Northern Sea Route, 1969. *Polar Record*, 15(95): 195–196.

Anon. (1972) The Northern Sea Route, 1971. *Polar Record*, 16(102): 421–422.

Anon. (1973) The Northern Sea Route, 1972. *Polar Record*, 16(104): 742–744.

Anon. (1974) Northern Sea Route, 1974. *Polar Record*, 17(110): 550–551.

Anon. (1976) Northern Sea Route, 1975. *Polar Record*, 18(114): 300–301.

Anon. (1977) Northern sea route, 1976. *Polar Record*, 18(116): 506–507.

Anon. (1978) The Northern Sea Route, 1977. *Polar Record*, 19(119): 182–186.

Anon. (1978) The Northern Sea Route, 1978. *Polar Record*, 19(122): 496–501.

Anon. (1979) Soviet merchant ships cleared for sailing on the Northern Sea Route, 1977. *Polar Record*, 19(122): 495–496.

Anon. (1980) The Northern Sea Route, 1979. *Polar Record*, 20(125): 170–174.

Anon. (1981) The Northern Sea Route, 1980. *Polar Record*, 20(128): 448–453.

Anon. (1982) The Northern Sea Route, 1981. *Polar Record*, 21(131): 175–179.

Anon. (1983) The Northern Sea Route, 1982. *Polar Record*, 21(134): 496–500.

Anon. (1983) Soviet Union—New class of Arctic ships. *Canadian Defence Quarterly*, 13(2): 64.

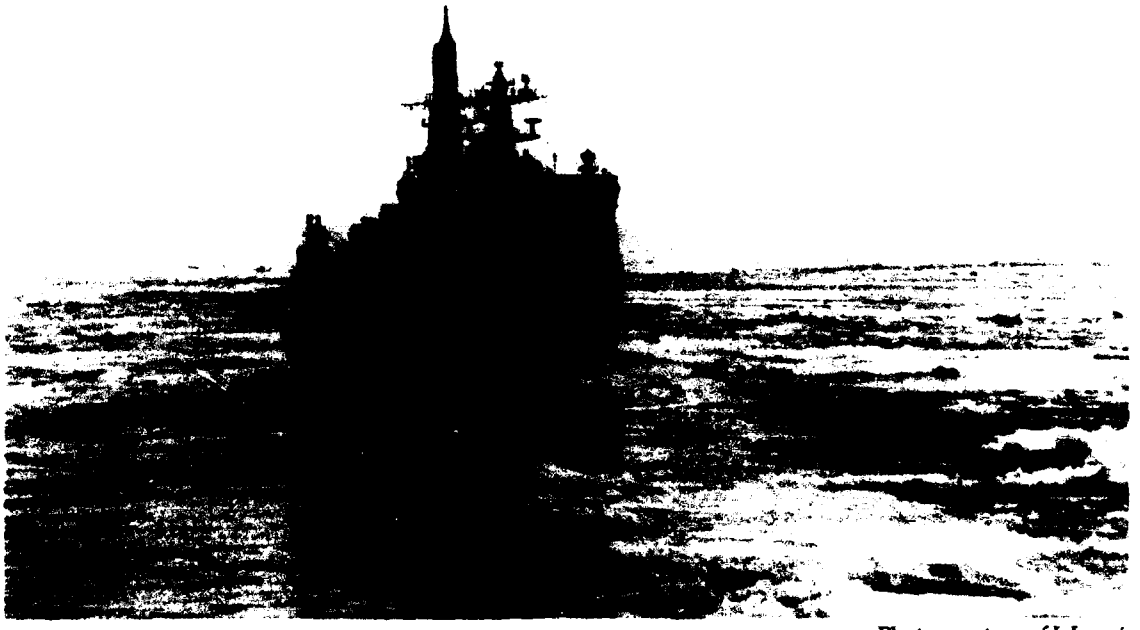

Photo courtesy of J. Laapio

Anon. (1984) Soviet Northern Sea Route today. *Arctic News-Record*, 3(1): 30–32.

Anon. (1985) Russia ready for Northern Sea Route. *Arctic News-Record*, 4(3–4): 62.

Anon. (1986) Two-way traffic on Northern Sea Route. *Arctic News-Record*, 5(3): 20, 29.

Anon. (1991) Northern news political warming opens Northern Sea Route. *Anchorage Daily News*, November 12, p. B3.

Anon. (1992) Hickel, in Moscow, lobbies Russia on Northern Sea Route. *Anchorage Daily News*, October 9, p. B1.

Anon. (1992) Hickel, Russia advance Northern Sea Route plan. *Anchorage Daily News*, October 13, p. F2.

Anon. (1992) Northern Sea route test run set. *Anchorage Daily News*, October 23, p. C2.

Anon. (1992) Radar satellites' imagery suits icy northern route. *Space News*, 3(4): 15.

Anon. (1992) Report: Assessment of Northern Sea Route potential. *Arctic News-Record*, 8(4): 2–6.

Anon. (1992) Revival of the sea transport of Russia under government's control. *Shipping Survey*, 1/2: 2–6.

Anon. (1992) Shortcut between oceans through Arctic studied. *Seattle Times*, January 26, p. A11.

Anon. (1993) Northern Sea Route move. *Arctic News-Record*, 9.3(7).

Anon. (1993) The Russians open the Arctic for business. *U.S. Naval Institute Proceedings*, 119(1079): 92–92.

ANSR (1991). *Regulations for Navigation on the Seaways of the Northern Sea Route* (A.P. Suchorukov, Ed.). Moscow: Administration for the Northern Sea Route.

Antonov, V.S. (1963) Power potential of the Siberian rivers and the Northern Sea Route (in Russian). *Priroda*, no. 6, p. 25–33.

Antonov, V.S. (1966) Energy of the Siberian rivers and the Northern Sea Route. Translation no. 979, of 1963 *Priroda* article. U.S. Department of the Navy.

Antonov, V.S. (1970) Navigable rivers of Siberia and the Northern Sea Route (in Russian). Leningrad: Gidrometeoizdat.

Antonov, V.S. and M.K. Fedorov (1965) Use of Ob' waters for electric power, and the Northern Sea Route (in Russian), p. 82–91. Novosibirsk.

Arikainen, A. (1985) Northern sea route: Its past, present and future. In *Proceedings of the 8th International Conference on Port and Ocean Engineering under Arctic Conditions, 7–14 September, Narssarssuaq, Greenland*, vol. 3, p. 1133–1148. Hørsholm: Danish Hydraulic Institute.

Arikainen, A. (1987) Arctic shipping: strategy of development. *Soviet Shipping*, 7(4): 20–23.

Arikainen, A. (1987) Arctic: The Canadian approach (in Russian). *Morskoi Flot* (Maritime Journal), no. 6, p. 34–36.

Arikainen, A. and G. Burkov (1985) Are Arctic ice conditions getting worse (in Russian). *Morskoi Flot* (Maritime Journal), no. 6, p. 36–37

Arikainen, A.I. (1984) Main transportation route in the Soviet Arctic (in Russian with English table of contents enclosed). Moscow: Nauka.

Arikainen, A.I. (1984) Year-to-year variability of the glacial extent of the Gulf of Anadyr in spring. In *Problems in the Arctic and the Antarctic, Collected Papers*, vol. 51, p. 57–67.

Arikainen, A.I. (1986) The Northern Sea Route. In *Proceedings of the 8th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC 85, 7–14 September, Narssarssuaq, Greenland. Additional POAC 85 papers ... Post Conference Seminar, Ilulissat/Jakobshavn, 14–18 September, 1985*, p. 1133–1148. Hørsholm: Danish Hydraulic Institute.

Arikainen, A.I. (1988) Center of attraction—The North Pole (in Russian). Moscow: Nauka.

Arikainen, A.I. (1988) Ice conditions in the Soviet Arctic: trends of multi-year variations. In *Proceedings of the 9th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–21 August, 1987, Fairbanks, Alaska* (W.M. Sackinger and M.O. Jeffries, Eds.), vol. 3, p. 215–220. Fairbanks: University of Alaska.

Arikainen, A.I. (1989) In North American arctic ice. Stages in development of the northwestern sea route (in Russian). Leningrad: Gidrometeoizdat.

Arikainen, A.I. (1990) Can the Northern Sea Route have international significance. In *Proceedings of the 10th IAHR Symposium on Ice, 20–23 August, Espoo, Finland*, vol. 3, p. 187–199. Finland: Helsinki University of Technology.

Arikainen, A.I. (1990) Comparative economic efficiency of icebreakers of different models and capacities: Methodology of evaluation. In *Proceedings of the 10th IAHR Symposium on Ice, 20–23 August, Espoo, Finland*, vol. 1, p. 542–553. Finland: Helsinki University of Technology.

Arikainen, A.I. (1991) Sustainable development of the Soviet Arctic: Some possibilities and constraints. *Polar Record*, 27(160): 17–22.

Arikainen, A.I. and K.N. Chubakov (1987) Primer of ice navigation (in Russian with abridged English table of contents enclosed). Moscow: Transport.

Arikainen, A.I. and O.A. Kossov (1989) Toward peace and security in the Arctic: Cooperation between the Soviet Union and the United States. *Arctic Notes*, no. 1, p. 58–70. Dartmouth College, Hanover, N.H.

Arikainen, A.I. and O.A. Kossov (1990) Technological possibility of safe convoy of non-ice class

ships along the Northern Sea Route. In *Proceedings of the 2nd International Conference on Ice Technology, 18–20 September, Cambridge, England* (T. K.S. Murthy, J.G. Paren, W.M. Sackinger and P. Wadhams, Eds.), p. 259–267. Southampton: Computational Mechanics Publications.

Arikainen, A.I. and B.Iu. Levit (1987) Basic characteristics and the elements of adaptive simulation of transportation processes on the Northern Sea Route (in Russian). In *Operation and Development of Economic Infrastructure, Collected Papers* (V.N. Livshits, Ed.), vol. 4, p. 20–33. Moscow: All-Union Scientific Research Institute for Systems Research.

Arikainen, A.I. and B. Levit (1988) Adaptive simulation of transportation marine system along the Northern Sea Route. In *Proceedings of the 9th IAHR Symposium on Ice, 23–27 August, Sapporo, Japan*, vol. 1, p. 706–718. Delft: International Association for Hydraulic Research, Committee on Ice Problems.

Arikainen, A.I. and B. Levit (1990) Northern Sea Route: International use? (in Russian). *Morskoi Flot* (Maritime Journal), no. 11, p. 4–5.

Arikainen, A.I., B.Iu. Levit and V.N. Livshits (1989) Methodological approach in evaluating the national economic effectiveness of extending navigation in the Arctic (in Russian). Moscow: All-Union Scientific Research Institute for Systems Research.

Arikainen, A.I., H. Saeki and H. Hiroshi (Eds.) (1988) The problem of year-round navigation along the Northern Sea Route. In *Proceedings of the 9th IAHR Symposium on Ice, 23–27 August, Sapporo, Japan*, vol. 1, p. 18–42. Delft: International Association for Hydraulic Research, Committee on Ice Problems.

Arikaynen, A.I. (1991) Management of the Northern Sea Route: Stages and problems of development. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 140–149. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Armstrong, T. (1940) The voyage of the *Komet* along the Northern Sea Route, 1940. *Polar Record*, no. 5, p. 291–295.

Armstrong, T. (1951) Observations on the Northern Sea Route (Beobachtungen auf dem nordsibirischen Schiffahrtsweg) (in German). *Polarforschung*, 21/3(2): 127–129.

Armstrong, T. (1952) The Northern Sea Route: Soviet exploitation of the North East Passage. Scott Polar Research Institute Special Publication 1. Cambridge, U.K.: Cambridge University Press.

Armstrong, T. (1964) The Northern Sea Route, 1963. *Polar Record*, 12(77): 179.

Armstrong, T. (1964) The Northern Sea Route in 1964 (La route maritime du nord en 1964) (in French). *Inter-Nord*, 8: 215–218.

Armstrong, T. (1966) Northern Sea Route. *Geographical Magazine*, 39(1): 23–25.

Armstrong, T. (1967) The Northern Sea Route in 1965 (La route maritime du nord en 1965) (in French). *Inter-Nord*, 9: 203–206.

Armstrong, T. (1968) The Northern Sea Route, 1968–70. *Inter-Nord*, 12: 118–120.

Armstrong, T. (1968) The Northern Sea Route in 1966. *Inter-Nord*, 10: 200–203.

Armstrong, T. (1970) The Northern Sea Route in 1967. *Inter-Nord*, 11: 123–124.

Armstrong, T. (1972) The Northern Sea Route in 1968–70. *Inter-Nord*, 112(118): 119.

Armstrong, T. (1974) The Northern Sea Route in 1971 and 1972. *Inter-Nord*, 13–14: 351–355.

Armstrong, T. (1974) Soviet merchant ships cleared for sailing on the Northern Sea Route, 1970. *Polar Record*, 17(106): 62–63.

Armstrong, T. (1977) The Northern Sea Route, 1976. *Polar Record*, 18(116): 506–507.

Armstrong, T. (1979) Soviet capabilities in arctic marine transport. In *Proceedings of the Symposium on Marine Transportation and High Arctic Development: Policy Framework and Priorities, 21–23 March, Montebello, Quebec*, p. 210–222. Ottawa: Canadian Arctic Resources Committee.

Armstrong, T. (1980) The Northeast Passage as commercial waterway, 1879–1979. *Ymer*, p. 86–130.

Armstrong, T. (1983) The Northern Sea Route today. *Cold Regions Science and Technology*, 7: 251–257.

Armstrong, T. (1984) The Northern Sea Route, 1983. *Polar Record*, 22(137): 173–182.

Armstrong, T. (1985) The Northern Sea Route, 1984. *Polar Record*, 22(140): 523–528.

Armstrong, T. (1986) The Northern Sea Route, 1985. *Polar Record*, 23(143): 183–187.

Armstrong, T. (1986) Soviet government policy towards northern peoples of the USSR. In *Arctic Policy* (M.S. Stenbaek, Ed.), p. 141–154. Montreal: McGill Centre for Northern Studies and Research.

Armstrong, T. (1987) Soviet voyage to the north pole, 1987. *Polar Record*, 23(147): 736.

Armstrong, T. (1987) The Northern Sea Route, 1986. *Polar Record*, 23(146): 585–590.

Armstrong, T. (1988) From the Barents to the Bering coming to grips with a circumpolar giant. *Northern Perspectives*, 16(4): 4–5.

Armstrong, T. (1988) Soviet proposals for the Arctic: A policy declaration by Mr. Gorbachev. *Polar Record*, 24(148): 68–69.

Armstrong, T. (1988) The Northern Sea Route, 1987. *Polar Record*, 24(149): 129–131.

Armstrong, T. (1989) The Northern Sea Route, 1988. *Polar Record*, 25(154): 247–249.

Armstrong, T. (1990) The Northern Sea Route. *Polar Record*, 26(157): 127–129.

Armstrong, T. (1991) Northern Sea Route operations in the 1986–7 season. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 150–157. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Armstrong, T. (1991) The Northern Sea Route, 1990. *Polar Record*, 27(161): 136–138.

Armstrong, T. (1991) The Northern Sea Route project. *Polar Record*, 27(160): 57.

Armstrong, T. (1992) A history of the Northern Sea Route. *International Challenges*, 12(1): 34–42.

Armstrong, T. (1992) The Northern Sea Route, 1991. *Polar Record*, 28(166): 239–240.

Armstrong, T. (1993) Opening the Northern Sea Route. *Polar Record*, 29(168): 60–61.

Armstrong, T. (1993) The Northern Sea Route, 1992. *Polar Record*, 29(170): 245.

Armstrong, T. (n.d.) The Soviet Northern Sea Route. *Geographical Journal*, 121(2): 136–148.

Armstrong, T. and L.W. Brigham (1991) Northern Sea Route operations in the 1966–7 season. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 150–157. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Armstrong, T., L.W. Lawson and E.M. Gately (Eds.) (1988) Northern sea route operations in the 1986–87 season. In *The Soviet Maritime Arctic, Proceedings of a Workshop, 10–13 May, 1987*, p. 24. Woods Hole, Massachusetts: Marine Policy Center, Woods Hole Oceanographic Institution.

Armstrong, T.E. (1950) Development of the Northern Sea Route. Cambridge, U.K.: University of Cambridge.

Armstrong, T.E. (1952) Soviet Russia's Northern Sea Route. *Listener*, 48(1218): 5–6.

Arshenevskiy, Yu. (1967) The Northern Sea Route during the years of Soviet power (in Russian). *Morskoi Flot* (Maritime Journal), no. 9, p. 9–11.

Backlund, A., K. Juurmaa and T. Mattsson (1993). Arctic cargo transportation economic evaluation. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany*, vol. 1, p. 159–168. Hamburg: Hamburg Ship Model Basin.

Barnett, D. (1991) Sea ice distribution in the Soviet arctic. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 47–62. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Barr, W. (1975) Tsarist attempt at opening the Northern Sea Route: The Arctic Ocean Hydrographic Expedition, 1910–1915. *Polarforschung*, 45(1): 51–64.

Barr, W. (1976) Role of Canadian ships in the Soviet Northern Sea Route. *Musk-ox*, 18 :112–115.

Barr, W. (1991). The Arctic Ocean in Russian history to 1945. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 11–32. Woods Hole Oceanographic Institution. Annapolis, Maryland: U.S. Naval Institute Press.

Barr, W. and E.A. Wilson (1985) The shipping crisis in the Soviet eastern arctic and the close of the 1983 navigation season. *Arctic*, 38(1): 1–17.

Batskikh, Yu. M. and V.V. Mikhailichenko (1993) The development of navigation along the Northern Sea Route. Presented at the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany.

Bauman, M. (1994) Corps studies sea route. *The Alaska Journal of Commerce*, Week of February 28, vol. 18, no. 1, p. 1, 3.

Belkin, S. (1990) Pioneers of the Northern Sea Route (in Russian). *Rybnoye Khozyaystvo* (Fishing Industry), no. 9, p. 77–81.

Belov, M.I. (1956) *History of the Discovery and Mastery of the Northern Sea Route*, Vol. 1, Arctic seafaring from ancient times to the middle of the 19th century (in Russian). Moscow: Maritime Transport Publishers.

Belov, M.I. (1957) Northern Sea Route (on the 40th anniversary of the conquest of the Soviet Arctic) (in Russian). Leningrad: Maritime Transport Publishers.

Belov, M.I. (1959) History of the discovery and utilization of the Northern Sea Route, vol. 3, Soviet Arctic navigation, 1917–32 (in Russian). Leningrad: Maritime Transport Publishers.

Belov, M.I. (1969) History of the discovery and utilization of the Northern Sea Route; vol. 4, Scientific and economic utilization of the Soviet North, 1933–45 (in Russian). Leningrad: Gidrometeoizdat.

Belov, M.I. (1975) On the work of organization of the Northern Sea Route (in Russian). *Letopis' Severa* (Annals of the North), no. 7 p. 4–14.

Berezkin, V.A. (1939) Actinometric observations of the polar stations by the board of the Northern Sea Route 1935/1936 (in Russian). Leningrad: Arkticheskogo Instituta, *Trudy*, 117(2): 1–134.

Berezovikov, L. (1986) Soviet Arctic navigation in 1986–1990. *Arctic New Record*, no. 5.1, p. 17.

Berg, S. and S. Devers (Eds.) (1990) The "Northern Sea Route," umbilical cord of the Soviet Arctic (La "Voie maritime du Nord," cordon ombilical de l'Arctique soviétique) (in French). In *102 Témoignages en Hommage à Quarante Ans d'Études Arctiques*, p. 596–609. Paris: CNRS.

Bergesen, H.O., A. Moe and W. Østreng (1987) *Soviet Oil and Security Interests in the Barents Sea*. London: Francis Pinter.

Boyd, S. (1984) The legal status of Arctic sea ice: A comparative study and proposal. *Canadian Year Book of International Law*, no. 22, p. 98, 103–111 (Canada) and p. 111–115 (Soviet Union).

Brown-Humes, C. (1989) Soviet shipping. Special Report. *Lloyd's List*, 13 September, p. 16–17.

Brekke, B. and P.E. Fjeld (1991) The Northern Sea Route Programme environmental factors: Introductory notes on available literature. Norsk Polarinstitutt rapportserie 70, p. 1–67. Oslo: Norwegian Polar Institute.

Brekke, B. and P.E. Fjeld (Eds.) (1991) Pilot Project 1B: Environmental factors. In *The Northern Sea Route Project; Pilot Studies Report*, by W. Østreng and A. Jørgensen-Dahl, p. 126–179. Lysaker, Norway: Fridtjof Nansen Institute.

Brigham, L.W. (1985) Arctic work systems. In *Proceedings of the 1st Spilhaus Symposium on Arctic Ocean Engineering for the 21st Century, 14–17 October 1984, Williamsburg, Virginia* (B.C. Gerwick, Ed.), p. 67–71. Washington, D.C.: Marine Technology Society.

Brigham, L.W. (1985) Future developments in the Soviet Arctic marine transportation system. In *Proceedings of the 1st Spilhaus Symposium on Arctic Ocean Engineering for the 21st Century, 14–17 October 1984, Williamsburg, Virginia* (B.C. Gerwick, Ed.), p. 207–213. Washington, D.C.: Marine Technology Society.

Brigham, L.W. (1985) New developments in Soviet nuclear Arctic ships. *U.S. Naval Institute Proceedings*, 111(12): 131–133.

Brigham, L.W. (1986) Arctic icebreakers: U.S., Canadian, and Soviet. *Oceanus*, 29(1): 47–58.

Brigham, L.W. (1986) Design evolution and performance of the Soviet Union's large polar icebreakers. In *Proceedings of the Ocean '86 Conference, 23–25 September, Washington, D.C.*, vol. 5, p. 1462–1467. New York: Institute of Electrical and Electronics Engineers.

Brigham, L.W. (1986) Development of an ice piloting handbook. In *Proceedings of the 1st International Conference on Ice Technology, Cambridge, Massachusetts*, p. 447–456. Berlin: Springer.

Brigham, L.W. (1986) Winter marine transportation off Alaska. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 2, p. 805–819. Vancouver, B.C.: D.F. Dickins Associates.

Brigham, L.W. (1988) Soviet Arctic marine transportation. *Northern Perspectives*, 16(4): 20–23.

Brigham, L.W. (1991) Plying the Northern Sea Route. *Arctic Circle*, 1(4): 10–11.

Brigham, L.W. (1991) Soviet arctic marine transportation 1990. *U.S. Naval Institute Proceedings*, 117(10): 109–110.

Brigham, L.W. (Ed.) (1991) *The Soviet Maritime Arctic*. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Brigham, L.W. (1993). The Russians open the Arctic for business. *U.S. Naval Proceedings*, January, 119(1): 92–93.

Brigham, L.W. (1993) Views on the opening of the Northern Sea Route and the Russian maritime arctic. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 167–173. Lysaker, Norway: Fridtjof Nansen Institute.

Brigham, L.W. and E.M. Gately (Eds.) (1988) Soviet maritime Arctic. In *Proceedings of a Workshop, 10–13 May, Woods Hole, Massachusetts*, Technical report WHOI-88-5. Woods Hole: Woods Hole Oceanographic Institution.

Brigham, L.W. and R.P. Voelker (1985) Ice navigation studies in the Alaskan Arctic using POLAR class icebreakers. In *Proceedings of the Ocean Engineering and the Environment—OCEANS '85 Conference, 12–14 November, San Diego, Calif.*, vol. 1, p. 441–447.

Brubaker, D. (1992) International law and Russian arctic waters. *International Challenges*, 12(1): 97–108.

Bryant, L. (1985) The Northwest Passage and Canadian Arctic claims. *The Journal of Polar Studies*, no. 2, p. 455–462.

Bulatov, V.N. (1982) The role of the Komsomol in the opening-up of the Northern Sea Route in the '30s (in Russian). *Letopis' Severa* (Annals of the North), no. 10, p. 64–71.

Bulatov, V.N. and V.N. Grekhov (1985) The activities of the political departments of the Head Office of the Northern Sea Route (Glavsevmorput') 1934–1954 (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 40–51.

Burkhanov, V.F. (1959) The Northern Sea Route and scientific investigation of the Arctic (in Russian). *Problemy Severa* (Problems of the North), no. 3, p. 115–127.

Burkhanov, V.F. (1985) The high-latitude expeditions of the Head Office of the Northern Sea Route (Glavsevmorput') 1954–1956 (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 34–40.

Burkov, G.D. (1986) Along the Northern Sea Route—All year round (in Russian). *Chelovek i Stikhiya* (Man and Nature), p. 148–150.

Burkov, G.D. and A. Arikainen (1985) Arctic routes of the USSR (in Russian). *Tekhnika i vooruzhenie* (Technology and Weaponry), no. 7, p. 3–4.

Burkov, G. and A. Arikainen (1986) *Tiksi* moves through ice (in Russian). *Morskoi Flot* (Maritime Journal), no. 6, p. 42–45.

Butler, W. (1965) Soviet concepts of innocent passage. *Harvard International Law Journal*, no. 7, p. 113–130.

Butler, W. (1969) The Soviet Union and the continental shelf. *American Journal of International Law*, no. 66, p. 103–107.

Butler, W. (1971) Soviet Arctic and the Northeast Passage. *The Nautilus Papers*, no. 2, p. 1–8.

Butler, W. (1971) *The Soviet Union and the Law of the Sea.* Baltimore: Johns Hopkins University Press.

Butler, W. (1972) Soviet maritime jurisdiction in the Arctic. *Polar Record*, no. 16, p. 418–421.

Butler, W. (1978) Northeast Arctic Passage. In *Alphen aan den Rijn*, p. 71–77. The Netherlands: Sijthoff & Noordhoff.

Butler, W. (1989) Innocent passage and the 1982 UNCLOS: The influence of Soviet law and policy. *Soviet Yearbook of Maritime Law*, p. 19–31.

Butler, W. (1990) Joint ventures and the Soviet Arctic. *Marine Policy*, vol. 14, no. 2.

Butler, W. (1991) The legal regime of the Soviet Arctic marine areas. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 215–234. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Buzuev, A. Ia. (1991) Appendix D to Pilot project A: Range and scope of physical attributes, by S. Vefsnmo, M. Mathiesen, S. Løset and A.Ya. Buzuev. In *The Northern Sea Route Project: Pilot Studies Report* (W. Østreng and A. Jørgensen-Dahl, Eds.), p. 90

Buzuev, A.Ia (1992) Natural factors and their influence on sailing on the Northern Sea Route. *International Challenges*, 12(1): 83–89.

Buzuev, A.Ia. (1993) Perfection and practical use of information about the environment. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 189–197. Lysaker, Norway: Fridtjof Nansen Institute.

Buzuev, A.Ia. and Iu.V. Nikolaev (1967) Choice of navigation routes in Arctic regions (in Russian). *Trudy*, vol. 281, p. 164–169. Leningrad: Arctic and Antarctic Research Institute.

Buzuev, A.Ia. and V.E. Fediakov (1981) Variability of ice conditions on ship navigation routes (in Russian with English summary). *Meteorologiia i Gidrologiia* (Meteorology and Hydrology), no. 2, p. 69–76.

Buzuev, A.Ia. and P.A. Gordienko (1976) Quantitative evaluation of ice navigation difficulties (in Russian). *Meteorologiia i Gidrologiia* (Meteorology and Hydrology), no. 9, p. 60–66.

Buzuev, A.Ia. and V.A. Likhomanov (1993) Division into zones of the Northern Sea Route by difficulty and safety of navigation. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany*, vol. 1, p. 393–402. Hamburg: Hamburg Ship Model Basin.

Buzuev, A.Ia. and A.A. Romanov (1990) General principles of accounting for ice conditions and estimating ice navigation difficulties (Russian). *Soviet Antarctic Expedition, Informatu.. Bulletin*, no. 114, p. 20–25.

Buzuev, A.Ia. and A.Ia. Ryvlin (1976) Non-uniformity of ice cover characteristics as a factor in determining navigability through ice (in Russian). *Meteorologiia i Gidrologiia* (Meteorology and Hydrology), no. 4, p. 68–73.

Buzuev, A.Ia., A.I. Brovin and V.E. Fediakov (1991) Natural conditions and arctic navigation. In *Proceedings of the 11th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 24–28 September, St. John's, Newfoundland* (D.B. Muggeridge, D.B. Colbourne, and H.M. Muggeridge, Eds.), vol. 2, p. 760–772. St. John's: Memorial University of Newfoundland.

Buzuev, A.Ia., V.Ye. Fedyakov, Ye.I. Tolstikov and N.A. Kornilov (Eds.) (1982) Studies of Arctic, Antarctic and world oceans; The study of natural conditions on the Northern Sea Route for the provision of transit sailing (in Russian). Studies of the Arctic, Antarctic and the Oceans. Leningrad: Gidrometeoizdat, p. 48–55.

Cahill, T. (1993). You, too, can be a polar hero. *Outside*, December, p. 44–51, 119–125.

Cherkasov, A. (1988) Prospects for Soviet–Canadian cooperation in the development of northern regions. *Northern Perspectives*, 16(4): 6–8.

Chilingarov, A.N. (1989) Hydrometeorological logistics of navigation in the Northern Sea Route (1) (Logistique hydrométéorologique de la navigation sur la Route Maritime du Nord (1)) (in French) In *Colloque internationale: Ingenierie et economie arctiques: Réalités, problémes posés, avenir* (International Colloquium: Arctic Technology and Economy: Present Situation, Problems, and Future Issues), *Paris, 15–17 February.* Paris: Banque Nationale de Paris.

Christofferson, I. (1989) Northern news: Norway, USSR study navigation project. *Anchorage Daily News*, May 23, p. B4.

Chubakov, K.N. (1979) The Northern Sea Route (in Russian). *News in Life, Science, and Technology*, Transport series, no. 3. Moscow: Knowledge.

Chubakov, K.N. (1982) The development of a main line of the Northern Sea Route in high latitudes (in Russian). *Letopis' Severa* (Annals of the North), no. 10, p. 91–102.

Chubakov, K.N. (1982) The Northern Sea Route: Past and present. *Soviet Shipping*, no. 4, p. 26–29.

Chubakov, K.N. (1985) The new stage in the development of the Northern Sea Route (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 51–59.

Conference on the Opening of the Northern Sea Route (1992) Invitation and Programme, 2–4 September, Trondheim, Norway. Trondheim: Nordic Institute of Navigation.

Crypton, C. (1956) Northern Sea Route. New York: Frederick A. Praeger.

Davies, J. (1993) Arctic trade route a no-go; officials hoping to get cargo moving north by next year. *Anchorage Daily News*, September 15, p. D1.

Dement'ev, A.A. (1989) Some meteorological service problems in the exploitation of the northern seas. In *Problems in the Arctic and the Antarctic, Collection of Articles* (B.A. Krutskikh, Ed.), vol. 61, p. 80–87. New Delhi: Amerind Publishing.

Department of the Navy, Intelligence Division (1943) Navigation along the Northern Sea Route. Intelligence Report 30-43.

Derbyshev, A.S., V.F. Puzanova, and V.F. Burkhanov (Eds.) (1978) Significance of the Northern Sea Route for the transport and economic links of Yakutskaya ASSR (in Russian). In *Geography of the Riverways of the Arctic (Collected Papers)*, p. 10–15. Leningrad: Vsesoyuznoye Geografischeskoye Obshchestvo.

Dubravin, A.I. (1973) D.I. Mendeleev and the high-latitude variant of the northern sea route. In *Problems in the Arctic and the Antarctic* (A.F. Treshnikov, Ed.), issues 33–35, p. 104–111.

Egan, D.M. and D.W. Orr (1987) *Sea Control in the Arctic; A Soviet Perspective* (final report). Available from NTIS AD-A184 793/8/XAB. Newport, Rhode Island: Naval War College.

Egan, R.S. (1968) Strategic significance of the Northern Sea Route. *U.S. Naval Institute Proceedings*, 94(4): 98–100.

Evgenov, N.I. (1932) Northern Sea Route (in Russian). *Morskoy Sbornik* (Collection of Maritime Articles) 15, 85(3): 142–151.

Falk-Petersen, S. (1993) Environmental monitoring and R & D activities in the Arctic. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 207–211. Lysaker, Norway: Fridtjof Nansen Institute.

Fossli, K. (1990) Charging an icy route to the east. *Financial Times*, Monday, July 23.

Franckx, E. (1987) The USSR position on the innocent passage of warships through foreign territorial waters. *Journal of Maritime Law and Commerce*, no. 18, p. 33–65.

Franckx, E. (1988) Non-Soviet shipping in the Northeast Passage, and the legal status of Proliv Vil'kitskogo. *Polar Record*, 24(151): 269–76.

Franckx, E. (1991) New developments in the North-East Passage. *International Journal of Estuary and Coastal Law*, 6(1): 33–40.

Franzen, J. (Ed.) (1993). Russia 1993: Political and economic analysis and business directory. New York: Chamber World Network.

Frolov, I. (1991). The 1987 expedition of the icebreaker *Sibir* to the North Pole. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 33

Fuhs, P. (1993) Marco Polo in the 21st century. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 71–81. Lysaker, Norway: Fridtjof Nansen Institute.

Gakkel', Ya.Ya. (1937) Experiment in assessing whether or not the ice was passable on Northern Sea Route for navigation seasons of 1933 and 1935 (in Russian). *Problemy Arktiki* (Arctic Problems), no. 1, p. 81–101.

Gakkel', Ya.Ya. (1957) Leningrad and the conquest of the Northern Sea Route (in Russian). All-Union Geographical Society. *Izvestiya* (News), 89(3): 181–192.

George, P. (1951) The Northern Sea Route (La voie maritime du Nord) (in French). *Larousse Mensuel*, 12(438): 607–608.

Gerasimov, B. (1988) Develop technical resources on the small rivers of Siberia. *Rechnoy Transport* (River Transportation), no. 8, p. 22–23.

Gordeichik, V. (1988) Across the Arctic in high latitudes. *Soviet Shipping*, 8(2): 28–30.

Gordienko, P.A., A.Ia. Buzuev and G.N. Sergeev (1967) Sea ice as a navigational environment (in Russian). *Problemy Arktiki i Antarktiki, Sbornik Statei* (Problems in the Arctic and the Antarctic, Collected Papers), vol. 27, p. 93–104.

Gorshkov, S.G. (Ed.) (1983) *Atlas of the Oceans. Vol. 3, Arctic Ocean* (in Russian with English introduction and keys to all maps). USSR Ministry of Defense, Navy, Department of Navigation and Oceanography. New York: Pergamon Press.

Granberg, A. (1992) The Northern Sea Route and the policy of new Russia. *International Challenges*, 12(1): 5–14.

Granberg, A. (1993) Importance of marine transportation for the Russian Arctic. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany*, vol. 1, p. 978–987, Hamburg: Hamburg Ship Model Basin.

Granberg, A. (1993) International economic cooperation along the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 153-166. Lysaker, Norway: Fridtjof Nansen Institute.

Grose, P. (1967) U.S. halts Arctic expedition as Soviet bars ships. *Polar Times*, December, p. 14.

Gudkovich, Z.M. et al. (1972) Foundations for a method of long-term ice prognosis for Arctic waters. Leningrad: Gidrometeoizdat.

Gusev, A.M. (1940) On temperature forecasts along the Northern Sea Route and their link with ice forecasts (in Russian). *News of the USSR Academy of Sciences*, Geographical and Geophysical Series, no. 2, p. 239–252.

Guzhenko, T. (1983) The great Northern Sea Route. *Soviet Union*, 4: 5–11.

Hannigan, J. (1988) Oil and gas activity in the Soviet north. *Northern Perspectives*, 16(4): 14–16.

Hansson, R. (1992) An environmental challenge to half the Arctic. *International Challenges*, 12(1): 90–97.

Hansson, R. (1993) The NSR—A route to destruction or protection. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 133–139. Lysaker, Norway: Fridtjof Nansen Institute.

Haugslett, A. (1993) Major aspects of the Northern Sea Route according to Tromsø Maritime College (TMC). In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 213–214. Lysaker, Norway: Fridtjof Nansen Institute.

Hayward, D. (1988) Gorbachev's Murmansk initiative: New prospects for arms control in the Arctic. *Northern Perspectives*, 16(4): 9–11.

Hoifodt, S. and F. Nilssen (1993) Trade and commercial shipping aspects. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 217–219. Lysaker, Norway: Fridtjof Nansen Institute.

Hume, H. (1984) A comparative study of the Northern Sea Route and the Northwest Passage: With special reference to the future development of marine transportation along the latter route. Unpublished Masters thesis. Cambridge, England: Scott Polar Research Institute.

Huuska, O. (1993) Finnyards and the Northern Sea Route Expert Meeting. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 215–216. Lysaker, Norway: Fridtjof Nansen Institute.

Il'nitskii, K. (1985) Large-capacity ships in the Arctic (in Russian). *Morskoi Flot* (Maritime journal), no. 1, p. 27–32.

Imbert, B. (1991) The Northern Sea Route (La Route maritime du Nord) (in French). *Navigation*, 153: 125–144.

International Challenges (1992) Journal of the Fridtjof Nansen Institute, 12(1): 1–151. Issue devoted to the Northern Sea Route.

Ioffe, O. (1985) *Soviet Law and Soviet Reality*. Dordrecht: Martinus Nijhoff Publishers.

Ivanin, Y. (1978) Soviet A-power conquers the North Pole. *Canadian Shipping and Marine Engineering*, 49(6): 26–29.

Ivanov, V. (1986) On the Leningrad–Dudinka run (in Russian). *Rechnoy Transport* (River Transportation), no. 10, p. 7.

Ivanov, Y. (1993) Present state and future prospects of research efforts on the arctic marine transport system. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 221–223. Lysaker, Norway: Fridtjof Nansen Institute.

Ivanov, Y. and A. Ushakov (1992) The Northern Sea Route—Now open. *International Challenges*, 12(1): 15–20.

Ivanov, Y., N.A. Isakov, Yu.M. Batskikh (1991) The Northern Sea Route—Pilot project report. Central Marine Research and Design Institute, Leningrad.

Joffe, S. (1936) The Northern Sea Route as a transport problem. USSR Council Papers no. 5. Moscow: USSR Council, Institute of Pacific Relations.

Jorgensen, T.S. (1992) Synoptic ice characteristics of the Northern Sea Route. *International Challenges*, 12(1): 68–74.

Jørgensen-Dahl, A. and W. Østreng (1992) Military/strategic aspects of the Northern Sea Route. *International Challenges*, 12(1): 108–115.

Juurmaa, K. (1993) Some aspects of the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 225. Lysaker, Norway: Fridtjof Nansen Institute.

Khvoscinski, N. (1993) Existing possibilities with the NSR. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 83–84. Lysaker, Norway: Fridtjof Nansen Institute.

Kitagawa, H. (1992) The Northern Sea Route: dream and reality in Japan. *International Challenges*, 12(1): 64–67.

Kitagawa, H. (1993) Some topical technical issues concerning the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 41–50. Lysaker, Norway: Fridtjof Nansen Institute.

Kjerstad, N. (1990) Atomic versus diesel-energy in polar icebreaking. In *Open Ship Symposium—Environment and safety aspects in maritime operations in the Arctic*. Tromsø, Norway.

Kjerstad, N. (1990) (in Norwegian) Ship operations in the Arctic, with special attention to the Northern Sea Route. Tromsø Marine College Report.

Kjerstad, N. (1992) Navigation and operation, experiencies from the Northern Sea Route. In *Proceedings of the Conference on the Opening of the Northern Sea Route, Trondheim, Norway.*

Kjerstad, N. (1992). Navigation conditions along the NSR—Experiences from a transit voyage,

September 1991. *International Challenges*, 12(1): 115–120.

Kjerstad, N. (1993) Important objectives related to navigation on the NSR—seen from a nautical point of view. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 227–230. Lysaker, Norway: Fridtjof Nansen Institute.

Kochetkov, K. (1992) Freezing of ships—Phenomenon of winter navigation. *Shipping Survey*, 1/2: 32–33.

Kolesov, L.I. (1982) Interbranch problems of the development of the transport system of Siberia and the Far East (in Russian). Novosibirsk: Nauka.

Kolodkin, A., N. Mirovitskaia and A.Y Roginko (1993) Arctic: Arena for international environmental security? In *Ocean Yearbook 10* (E.M. Borgese, Ed), p. 277–289. Chicago, Illinois: University of Chicago Press.

Kolodkin, A.L. and M.E. Volosov (1990) The legal regime of the Soviet Arctic: Major issues. *Marine Policy*, 14(2): 158–169.

Komolov, I. (1986) Rationalizing freight shipments (in Russian). *Rechnoy Transport* (River Transportation), no. 10, p. 10.

Kondakov, K. (1940) Light coastal freighting along the Northern Sea Route. (in Russian). *Sovetskaya Arktika* (The Soviet Arctic), no. 8, p. 17–25.

Kopylkov, B.N. (1960) Questions of present economics of the Northern Sea Route and tasks for study by economic geographers (in Russian). *Problemy Arktiki i Antarktiki* (Problems in the Arctic and Antarctic), no. 6, p. 5–10.

Kopylkov, B.N. and V.G. Sukhova (1962) Complex use and conservation of water resources of western Siberia and the Northern Sea Route (in Russian) *Problemy Arktiki i Antarktiki* (Problems in the Arctic and Antarctic), 10: 81–86.

Korshunov, S., A. Kazakova and Ye. Gagarine (1987) To develop arctic shipments (in Russian). *Rechnoy Transport* (River Transportation), no. 3, p. 33.

Kosovskii, S.B. and A.A. Karmanov (1988) Arctic supply vessel *Vitus Bering*, with supplement The multipurpose Arctic supply vessel *Alexei Chirikov* (in Russian). *Sudostroenie* (Shipbuilding), no. 5, p. 3–6.

Kozlov, M.P. (1937) Fogs along the Northern Sea Route (in Russian). Arctic Institute. *Trudy*, 109: 5–85.

Kristensen, M. (1993) Climate characteristics of the Norwegian arctic. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 231–235. Lysaker, Norway: Fridtjof Nansen Institute.

Krypton, C. (1953) The Northern Sea Route; its place in Russian economic history before 1917. New York: Research Program on the U.S.S.R.

Krypton, C. (1956) The Northern Sea Route and the economy of the Soviet north. Research Program on the USSR, Praeger publications in Russian history and world communism, no. 42. New York: Frederick A. Praeger.

Kurki, R. (1993) Maritime cooperation between Russia and Finland. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 237. Lysaker, Norway: Fridtjof Nansen Institute.

Kurnosov, M. (1987) Will we ever have scheduled sailings to Dudinka? (in Russian). *Morskoi Flot* (Maritime Journal), no. 12, p. 18–22.

Laforest, T.J. (1967) Strategic significance of the Northern Sea Route. *U.S. Naval Institute Proceedings*, 93(12): 56–65.

Laktionov, A.F. and Z. Romanovich (1961) The Northern Sea Route (survey of the literature) (in Russian). *Morskoi Flot* (Maritime Journal), no. 11, p. 45–56.

Lamson, C. (1987) Arctic shipping, marine safety and environmental protection. *Marine Policy*, no. 11, p. 3–15.

Lange, M.A. (1993) The Northern Sea Route: A splendid opportunity or a threat to the arctic environment. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 239–242. Lysaker, Norway: Fridtjof Nansen Institute.

Lavrov, A. (1931) Northern Sea Route (in Russian). *Morskoy Sbornik* (Collection of Maritime Articles) 14, 84(8): 80–93.

Lavrov, B.V. (1936) The economics of freight turnover on the Northern Sea Route (in Russian). *Sovetskaya Arktika* (The Soviet Arctic), no. 4, p. 11–24.

Leskov, M. (1987) Change the tactics of ice convoying (in Russian). *Morskoi Flot* (Maritime Journal), no. 2, p. 30–31.

Lloyd, T. (1950) The Northern Sea Route. *Russian Review*, 9(2): 98–111.

Lozhinikova, L. (1987) Unity of fleet and riverbank (in Russian). *Rechnoy Transport* (River Transportation), no. 1, p. 14–16.

Lyon, W. (1984) The navigation of Arctic polar submarines. *Journal of Navigation*, no. 37, p. 155–179.

Makinen, E. (1993) The fundamental assumptions and future uses of the Northern Sea Route traffic In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.). Lysaker, Norway: Fridtjof Nansen Institute.

Makinen, E. (1993) The future of Northern Sea Route traffic. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø,*

Norway (H. Simonsen, Ed.), p. 31–42. Lysaker, Norway: Fridtjof Nansen Institute.

Maksimov, I.V. (1945) Data on tides as characteristic of average ice conditions along the Northern Sea Route (in Russian). *Problemy Arktiki* (Problems in the Arctic), no. 1, p. 56–63.

Maksytov, D.D. and Yu.N. Popov (1981) Experience with the development and introduction of ice passports (in Russian). *Transactions of the Arctic and Antarctic Scientific Research Institute*, no. 376, p. 26–33.

Margolin, A.B. (1949) International intervention of 1918–20 and the Northern Sea Route (in Russian). *Letopis' Severa* (Annals of the North), no. 1, p. 154–174.

Masharova, L.A. (Ed.) (1985) In commemoration of the fiftieth anniversary of the Head Office of the Northern Sea Route (Glavsevmorput') (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 3–6.

Matiyasevich, A. (1988) The ice epic of the *Mossovet* (in commemoration of the 50th anniversary of its navigation of the Northern Sea Route from west to east and back) (in Russian). *Morskoi Flot* (Maritime Journal), no. 8, p. 42–46.

Matyushenko, N. (1992) The Northern Sea Route: Challenge and reality. *International Challenges*, 12(1): 116–120.

McMillan, C.H. (1988) Joint ventures in arctic resource development. *Northern Perspectives*, 16(4): 17–19.

Mikhailichenko, V. (1986) Operations with icebreaking cargo vessels on the Northern Sea Route. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 2, p. 792–804. Vancouver, B.C.: D.F. Dickins Associates.

Mikhailichenko, V. (1988) Not by power alone (in Russian). *Morskoi Flot* (Maritime Journal), no. 1, p. 23–27.

Mikhailichenko, V. (1992) Foreign ships on the Northern Sea Route (in Russian). *Morskoi Flot* (Maritime Journal), no. 1, p. 27.

Mikhailichenko, V. (1992). The Northern Sea Route and the applicable regulations for navigation along its course. Presented at the Conference on Opening the Northern Sea Route, Trondheim, Norway, 2–4 September.

Mikhailichenko, V. and A. Ushakov (1993) The Northern Sea Route and the applicable regulations for navigation along its course. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 11–29. Lysaker, Norway: Fridtjof Nansen Institute.

Mikhaylov, V. (1987) A complex and important task. How to improve the delivery of goods to the Far North (in Russian). *Rechnoy Transport* (River Transportation), no. 1, p. 4–5.

Nazarov, V. (1938) Northern Sea Route (in Russian). *Sovetskaia Arktika* (The Soviet Arctic), no. 6, p. 33–40.

Nichol, S. (1968) Russia's merchant shipping: Challenge of the Northern Sea Route. *Ship's Monthly* (London), 3(1): 10–18.

Nikol'skiy, I.V., V.I. Tonyayev and V.G. Krasheninnikov (1975) *Geography of Water Transport of the USSR* (in Russian). Moscow: Transport.

Novikov, V.D. (1949) On the history of the Northern Sea Route in the first years of Soviet power (in Russian). *Letopis' Severa* (Annals of the North), no. 1, p. 3–41.

North, R.N. (1987) Annotated bibliography on Soviet northern transport 1975–1986. University of British Columbia, Department of Geography paper no. 38.

Olenev, P. (1986) Delivering freight to the Far North (in Russian). *Rechnoy Transport* (River Transportation), no. 4, p. 28–29.

Olenev, P. (1988) Problems of delivering freight to the Far North. *Rechnoy Transport* (River Transportation), no. 4, p. 27–28.

Oritsland, N.A. (1993) Reflections on the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 287–289. Lysaker, Norway: Fridtjof Nansen Institute.

Osherenko, G. (1993) Using peripheral vision in the Northern Sea Route: Assessing impacts on indigenous peoples In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 115–132. Lysaker, Norway: Fridtjof Nansen Institute.

Osherenko, G. and O.R. Young (1989) *The Age of the Arctic: Hot Conflicts and Cold Realities*. Cambridge: Cambridge University Press.

Østreng, W. (1978) *The Arctic Ocean in International Politics*. FNI Publication Series, p. 139–141. Lysaker: Fridtjof Nansen Institute.

Østreng, W. (1987) Security implications for the northern flank of NATO, Chapter 4, in *The Soviet Union in Arctic Waters*, Occasional Paper no. 36, The Law of the Sea Institute. Honolulu: University of Hawaii.

Østreng, W. (1991) The Northern Sea Route: A new era in Soviet policy? Economic, legal and security–political aspects. Lysaker, Norway: Fridtjof Nansen Institute. Also in *Ocean Development and International Law*, 22(3): 259–287.

Østreng, W. (1992) The geopolitics of the Northern Sea Route. *International Challenges*, 12(1): 21–25.

Østreng, W. and A. Jørgensen-Dahl (1991) The Northern Sea Route project; Pilot studies report. Lysaker, Norway: Fridtjof Nansen Institute.

Orr, D. (1992) Northern sea route. *Alaska Economic Development News*, Winter, p. 2.

Papanin, I.D. (1985) The head office of the Northern Sea Route (Glavsevmorput') before and during the Great Patriotic War (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 15–23.

Petrow, R. (1968) *Across the Top of Russia*. London: Hodder and Stoughton.

Pinkhensen, D.M. (1962) History of the discovery and utilization of the Northern Sea Route, vol. 2, The problem of the Northern Sea Route in the epoch of capitalism (in Russian). Leningrad: Sea Transport Publishing.

Pinkhenson, D.I. and M. Ivanovich (Eds.) (1964) Russian Arctic expeditions of the 17th to 20th centuries. Questions of the history of the study and utilization of the Arctic; History of the Northern Sea Route (capitalist period) (in Russian), p. 37–43. Leningrad: Gidrometeoizdat.

Pharand, D. (1968) Innocent passage in the Arctic. *Canadian Year Book of International Law*, no. 6, p. 3–60.

Pharand, D. (1968) Soviet Union warns United States against use of Northeast Passage. *American Journal of International Law*, no. 62, p. 927–935.

Pharand, D. (1973) *The Law of the Sea of the Arctic, with Special Reference to Canada*. Ottawa: University of Ottawa Press.

Pharand, D. (1983) Canada's Arctic jurisdiction in international law. Dalhousie Law Journal, no. 7, p. 742–799.

Pharand, D. (1984) The legal regime of the Arctic: Some outstanding issues. *International Journal*, no. 39, p. 315–342.

Plotnikov, K. (1986) For a minimal risk, an obvious advantage (in Russian). *Morskoi Flot* (Maritime Journal), no. 12, p. 37–38.

Polmar, N. (1984) Sailing under the ice. *U.S. Naval Institute Proceedings*, 110(6): 121–123.

Popov, S. (1982) The legendary "A. Sibiryakov" (on the 50th anniversary of the through trip on the Northern Sea Route) (in Russian). *Morskoi Flot* (Maritime Journal), no. 10, p. 22–23.

Pullen, T.C. (1983) The Northwest Passage—prospects for year round navigation. In *Proceedings of the International Conference on Offshore and Marine Technology, Offshore Goteborg 83, Technology for the Arctic, 1–4 March, Goteborg, Sweden*. Goteborg, Sweden: Swedish Trade Fair Foundation, Session A3.

Prescott, J. (1985) *The Maritime Boundaries of the World*. London: Methuen.

Raptchinsky, B. (1953) The Northern Sea Route (De noordelijke zeeweg) (in Dutch). *Tijdschrift voor Economische en Sociale Geografie*, 44(4/5): 111–116.

Riska, K. (1993) The economic use of the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 243–248. Lysaker, Norway: Fridtjof Nansen Institute.

Roginko, A.Y. (1990) Arctic environmental cooperation: prospects and possibilities. Tampere Peace Research Institute, Occasional paper no. 41, p. 85–113.

Roginko, A.Y. (1991) Environmental protection in the Soviet arctic seas. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 63–82. London: Belhaven Press.

Roginko, A.Y. (1993) The Northern Sea Route: Protection of marine environment in the context of circumpolar cooperation. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 249–263. Lysaker, Norway: Fridtjof Nansen Institute.

Roginko, A.Y. and M.J. LaMourie (1992) Emerging marine environmental protection strategies for the Arctic. *Marine Policy*, 16(4): 259–276.

Romanov, I.P. (1993) *Atlas: Morphometric Characteristics of Ice and Snow in the Arctic Basin* (in Russian and English). St. Petersburg: Arctic and Antarctic Research Institute.

Romanov, I.P. (1993) *Ice Cover of the Arctic Basin* (in Russian and English). St. Petersburg: Arctic and Antarctic Research Institute.

Rosenberg, G. (1993) Satellite-based services for arctic activities. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 51–53. Lysaker, Norway: Fridtjof Nansen Institute.

Sackinger, W.M. (1992) The ice conditions in the eastern part of the Northern Sea Route. *International Challenges*, 12(1): 75–82.

Sackinger, W.M. (1993) Economics, safety and environmental sensitivities on the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 265–268. Lysaker, Norway: Fridtjof Nansen Institute.

Sammallahti, P. (1993) The Northern Sea Route and the utilization of the resources of the Russian North: Impact on the indigenous peoples. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 269–274. Lysaker, Norway: Fridtjof Nansen Institute.

Sandkvist, J. (1993) Impact assessment and contingency planning for remote operations, including a Swedish case. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 93–107. Lysaker, Norway: Fridtjof Nansen Institute.

Sandven, S., O.M. Johannessen and K. Kloster (1993) Real-time use of satellite data in ice monitoring of the Northern Sea Route. In *Proceedings*

of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 17–20 August, Hamburg, Germany, vol. 1, p. 969–972. Hamburg: Hamburg Ship Model Basin.

Sapaev, V.M. (1969) The Northern Sea Route: From the Barents Sea to the Bering Sea. *Marine Observer* (London), 39(226): 183–190.

Schytt, V. (1982) Ymer–80: A Swedish expedition to the Arctic Ocean. *Geographical Journal*, no. 149, p. 22.

Seleznev, S.A. (1985) Ice captains of Arkhangel'sk and the Northern Sea Route (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 77–89.

Shabad, T. (1983) Winter demonstration voyage in Soviet Far East. *Polar Geography and Geology*, 7(1): 73–74.

Shabad, T. (1984) Soviet arctic shipping activity in 1984. *Polar Geography and Geology*, 8(2): 166–170.

Shabad, T. (1986) Arctic shipping operations. *Polar Geography and Geology*, no. 10, p. 166–167.

Shapalin, B.F. (1965) Economic, scientific and technical problems of the Northern Sea Route (in Russian). *Problemy Severa* (Problems of the North), no. 9, p. 277–286.

Shatalin, N. (1984) From the experience of the Arctic, 1983 (in Russian). *Morskoi Flot* (Maritime Journal), no. 10, p. 24–25.

Shevelev, M.I. (1985) On the first period of operations of the Head Office of the Northern Sea Route (Glavsevmorput') (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 6–15.

Shirshov, P.P. (1940) New phase in the work of the Northern Sea Route (in Russian). *Sovetskaya Arktika* (The Soviet Arctic), no. 12, p. 3–7.

Shmidt, O.Yu and S.A. Bergavinov (1935) Northern Sea Route is turning into a normally working route (in Russian). *Bulletin of the Arctic Institute*, no. 11, p. 371–372.

Simard, C. (1988) Soviet sovereignty in the Arctic Seas. *Northern Perspectives*, 16(4): 24–28.

Simonsen, H. (1992) A chronology of the International Northern Sea Route Project. *International Challenges*, 12(1): 26–33.

Simonsen, H. (Ed.) (1993) *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway.* Lysaker, Norway: Fridtjof Nansen Institute.

Sinyajev, A. (1990) Safety aspects of operating along the Northern Sea Route. In *Open Ship Symposium—Environment and safety aspects in maritime operations in the Arctic.* Tromsø, Norway.

Sisula, H. (1993) Arctic monitoring and assessment programme. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 109–113. Lysaker, Norway: Fridtjof Nansen Institute.

Slavin, S.V. (1972) *The Soviet North: Present Development and Prospects.* Moscow: Progress Publishers.

Slavin, S.V. (1975) Planning the activities of the Chief Administration of the Northern Sea Route and the first researches on the economic development of the Northern Sea Route (in Russian). *Letopis' Severa* (Annals of the North), no. 7, p. 15–22.

Slavin, S.V. (1982) *The Northern Development of the Soviet Union* (in Russian). 2nd edition. Moscow: Nauka.

Slavin, S.V. (Ed) (1985) Study and economic development of the North during the Soviet period (in Russian with English table of contents). *Letopis' Severa* (Annals of the North), vol. 11.

Slavin, S.V. and I.A. Stoyanov (1985) The Northern Sea Route in the national economy of the USSR (in Russian). *Letopis' Severa* (Annals of the North), no. 11, p. 68–76.

Sledziuk, A.K. and Iu.S. Kuchiev (1976) New stage in the development of the Northern Sea Route. *Soviet Shipbuilding*, no. 2, p. 1–5.

Smele, J.D. (1988) An attempt to utilize the Northern Sea route to Siberia in 1919. *Sibirica*, 4: 28–39.

Soininen, H. (1993) Various aspects of the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 275–277. Lysaker, Norway: Fridtjof Nansen Institute.

Sokolov, A. (1959) Atomic icebreaker Lenin and prospects for further utilization of the Northern Sea Route (in Russian). *Morskoi Flot* (Maritime Journal), no. 12, p. 4–5.

Sokolov, A.L. (1966) Drift of ice in the Arctic Basin and changes in ice conditions over the Northern Sea Route. In *Problems in the Arctic and Antarctic, Collected Papers*, no. 11, p. j1–j20.

Sokolov, V.V., E.I. Gerasimova, A.V. Sokolov and A.M. Braginskii (1987) Far North. Peculiarities of mooring construction (in Russian). *Transportnoe Stroitel'stvo* (Transportation Construction), no. 7, p. 22–23.

Starokadomskii, L.M. (1976) Charting the Russian Northern Sea Route: The Arctic Hydrographic Expedition, 1910–1915. (W. Barr, Ed. and Trans.) Montreal: Arctic Institute of North America and McGill-Queen's University Press.

Steensen, R.S. (1957) The Northern Sea Route (Den nordlige søvej) (in Danish) Copenhagen: Lundsgaard.

Stepanov, N.P. (1936) Freightage on the Northern Sea Route (in Russian). *Sovetskaya Arktika* (The Soviet Arctic), no, 12, p. 79–83.

Stokke, O.S. (1992) Arctic environmental cooperation after Rovaniemi: What now? In *Nordic Arctic Research on Contemporary Arctic Problems. Proceedings from the Nordic Arctic Research Forum Sympo-*

sium (L. Lyck, Ed.), p. 221–234. Ålborg, Denmark: Ålborg Universi[illegible].

Synhorst, E. (1973) Sovi[illegible]ic interests in the maritime Arctic. *U.S. [illegible]nstitute Proceedings*, 99(843): 88–111.

Telle, N. (1993) Shipping aspects of the Northern Sea Route. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 279–280. Lysaker, Norway: Fridtjof Nansen Institute.

Tolstikov, E.I. (1982) Science and the Northern Sea Route. *Soviet Meteorology and Hydrology*, no. 12, p. 67–70.

Tolstikov, E., A. Arikainen and B. Khimich (1983) Development of the Arctic: Science and practice (in Russian). *Morskoi Flot* (Maritime Journal), no. 9, p. 32–35.

Tolstikov, Ye.I. (1961) The Northern Sea Route will become a large-scale freight route (in Russian). *Morskoi Flot* (Maritime Journal), no. 10, p. 13–15.

Tonyayev, V.I. (1977) *Geography of Inland Waterways of the USSR* (in Russian). Moscow: Transport.

Treshnikov, A.F. (1982) Mikhail Lomonosov and the Northern Sea Route. Royal Society of Canada, *Transactions*, 4th series, 20: 399–407.

Treshnikov, A.F. (Ed.) (1985) *Atlas of the Arctic* (in Russian). Leningrad: Arctic and Antarctic Research Institute.

Treshnikov, A.F. (1985) The role of science in the development of the Northern Sea Route (in Russian) *Letopis' Severa* (Annals of the North), no, 11, p. 59–68.

Tsenin, S.S. (1959) Questions of the development of economic and transport links in the north-east of the USSR (Yakutskaya ASSR and Magadanskaya Oblast) and the role of the Northern Sea Route (in Russian). *Problemy Severa* (Problems of the North), no. 3, p. 137–159.

Tsybin, E. and A. Kozhin (1975) Military transportation by sea in the Far North (in Russian). *Supplying the Soviet Army*, no. 7, p. 83–85.

United Nations (1982) The Law of the Sea: United Nations Convention on the Law of the Sea. United Nations Sales Publication E.83.V.5.

United Nations (1986) United Nations, Law of the Sea: Report of the Secretary-General, United Nations Document 1941/742 (28 October).

Ushakov, A.P., Yu.M. Ivanov, N.A. Isakov, Yu.M. Batskikh, and T. Armstrong (1991) A historical introduction. In *The Northern Sea Route Project: Pilot Studies Report* (W. Østreng and A. Jørgensen-Dahl, Eds.), p. 5–15. Lysaker, Norway: Fridtjof Nansen Institute.

USSR Ministry of Defense, Head Department of Navigation and Oceanography (1991). Regulations for navigation on the seaways of the Northern Sea Route. Also appeared in *Notices to Navigators*, no. 29, 13 June 1991, and in *International Challenges*, 12(1): 121–126, 1992.

Vanderzwaag, D. and C. Lamson (1986) Ocean development and management in the Arctic: Issues in American and Canadian relations. *Arctic*, 39(3): 327–337.

Varis, E. (1993) Cooperational aspects. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 281–283. Lysaker, Norway: Fridtjof Nansen Institute.

Vefsnmo, S., M. Mathiesen, S. Loset and A.Ya. Buzuev (1991). Pilot project A: Range and scope of physical attributes. In *The Northern Sea Route Project: Pilot Studies Report* (W. Østreng and A. Jørgensen-Dahl, Eds.), p. 27–125. Lysaker, Norway: Fridtjof Nansen Institute.

Vil'kitskiy, B.A. (1992) Northern Sea Route operations in 1920. *Polar Geography and Geology*, 16(1): 6–17.

Vil'kitskiy, B.A. (1992) Northern Sea Route operations in 1921. *Polar Geography and Geology*, 16(1): 18–33.

Vinogradov, A.A. and N.N. Rodionov (1985) Nuclear-powered icebreaking cargo ships mark a new stage in the exploitation of the Northern Sea Route (in Russian). *Sudostroyenie* (Shipbuilding), no. 9, p. 5–6.

Vinogradov, S., T. Onkina and T. Somonova (1986) The seaman in the Arctic (in Russian). *Vodnyy Transport* (Water Transportation), 26 and 28 August.

Vinogradova, N. (1986) A port beyond the Arctic Circle (in Russian). *Rechnoy Transport* (River Transportation), no. 4, p. 39–41.

Volkov, N.A. (1986) A Russian Columbus amidst the ice. *Priroda*, no. 9, p. 63.

Volkov, V. (1987) Line to Yakutia (in Russian). *Zheleznodorozhnyy Transport* (Railway Transportation), no. 2, p. 46–52.

Vorob'yev, Yu. (1986) For navigation on the Aldan (in Russian). *Rechnoy Transport* (River Transportation), no. 8, p. 42.

Weathersby, J. (1990) Inside track: Breaking the trade ice; port would profit if Soviets open northern ship lanes. *(Tacoma, Washington) News Tribune*, 26 March, p. c9.

Weinberg, B.P. (1936) Ice properties in relation to the Northern Sea Route (in Russian). *Bulletin of the Arctic Institute*, 6(8–9): 369–375.

Wells, R. (1966) Surveying the Eurasian Arctic. *U.S. Naval Institute Proceedings*, 92(764): 79–85.

Wells, R. (1968) The icy *niet*. *U.S. Naval Institute Proceedings*, 94(278): 73–79.

Wergeland, T. (Ed.) (1991) Pilot project report Commercial shipping and the NSR. In *The Northern Sea Route Project: Pilot Studies Report*

(W. Østreng and A. Jørgensen-Dahl, Eds.), p. 180–232. Lysaker, Norway: Fridtjof Nansen Institute.

Wergeland, T. (1992) The Northern Sea Route—Rosy prospects for commercial shipping. *International Challenges*, 12(1): 43–57.

Wergeland, T. (1993) Commercial shipping perspectives. In *Proceedings from the Northern Sea Route Expert Meeting, 13–14 October, 1992, Tromsø, Norway* (H. Simonsen, Ed.), p. 63–72. Lysaker, Norway: Fridtjof Nansen Institute.

Westermeyer, W.E. and V. Goyal (1986) Jurisdiction and management of Arctic marine transportation. *Arctic*, 39(4): 338–349.

Yunitsyn, B. (1983) Advanced equipment and technologies in Soviet shipping. *Soviet Shipping*, no. 4, p. 25–28.

Zachesov, B. (1986) Tasks in the development of traffic in the Far North. *Rechnoy Transport* (River Transportation), 3: 13–14.

Zaika, B. and Yu. Batskikh (1987) Problems of bulk carriers in the Arctic (in Russian). *Morskoi Flot* (Maritime Journal), no. 5, p. 14.

Zaika, B. and Yu. Batzkikh (1987) Problems of cargo transportation in the arctic. Translated from *Morskoi Flot* (Maritime Journal), 1987, Translation No. MF-8705–13, no. 5. Jackson Heights, New York: Engineering Consulting & Translation Center.

Zhitkov, B.M. (1933) Problem of navigation along the Northern Sea Route (in Russian). *Sovetskii Sever* (The Soviet North), 4(3): 27–34.

Young, O.R. and A. Osherenko (1991) International cooperation in the Arctic: Soviet attitudes and actions. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 258–283. Woods Hole, Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

RUSSIAN/ARCTIC WATERS

Adrov, N.M. and I.V. Smoliar (1987) Computerized simulation of ice conditions in the Barents Sea (in Russian). In *2nd All-Union Conference on Problems of Quaternary Paleoecology and Paleogeography of Northern Seas, Apatity. Summaries* (G.G. Matishov, Ed.), p. 5.

Ahlnas, K. and G. Wendler (1976) Sea ice conditions in the Chukchi, Beaufort, East Siberian and northern Bering Seas during March 1973, 1974 and 1975 as seen from the NOAA 2, 3, and 4 satellites. In *Proceedings of the 3rd International Conference on Port and Ocean Engineering Under Arctic Conditions, 11–15 August, Fairbanks*, vol. 1, p. 83–104. Fairbanks: University of Alaska.

Anon. (1984) The Arctic, autumn '83. *Soviet Shipping*. p. 32–35.

Appel, I., S. Nikolaev, S. Pozdnishev and D. Speransky (1991) Use of mathematical modelling for short-term forecasting of ice cover distribution in the southern Okhotsk Sea. In *Proceedings of the 6th International Symposium on Okhotsk Sea and Sea Ice, 3–7 February, Hokkaido*, p. 305–308. Mombetsu, Japan: Okhotsk Sea and Cold Ocean Research Association.

Arikainen, A.I. (1981) Method of calculating the state of the Chukchi flaw lead in June. In *Problems in the Arctic and Antarctic (Collected Articles)*, vol. 49, p. 44–51. New Delhi: Amerind Publishing.

Arikainen, A.I. (1981) Salinity and thermal state of Bering Sea waters as indices of development of the Chukchi flaw lead in June. In *Problems in the Arctic and Antarctic (Collected Articles)*, vol. 48, p. 75–82. New Delhi: Amerind Publishing.

Arikainen, A.I. (1984) Possibilities of long-range forecast of the state of the Chukchi flaw polynya in spring. In *Problems in the Arctic and Antarctic (Collected Articles)*, vol. 51, p. 51–56.

Arikainen, A.I. and K.N. Chubakov (1980) The ABCs of ice navigation. NISC Translation no. 8609 (for government use ony). Available from Foreign Languages Services Division, Naval Intelligence Support Center, Washington, D.C. Originally published in Russian by Transport, Moscow, 1987.

Armstrong, T. (1984) Russia's battle with the northern ice. *Jane's Merchant Shipping Review*. (Based on paper first published in *Polar Record*, vol. 22, no. 137.)

Arnol'd-Aliab'ev, V.I. (1938) Thickness, structure, and striation of Kara Sea ice according to the data obtained by the Malygin Expedition of 1934 (in Russian). *Trudy Arkticheskogo Instituta* (Transactions of the Arctic Institute), no. 110, p. 57–81.

Arsen'eva, N.IA. (1960) Calculation of ice distribution at sea (based on data from the White Sea) (in Russian). *Trudy Gos. Okeanograf. Instituta* (Transactions of the State Oceanographic Institute), vol. 55, p. 64–76.

Barnett, D. (1991) Sea ice distribution in the Soviet Arctic. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 47–62. Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Barr, W. (1982) First Soviet convoy to the mouth of the Lena. *Arctic*, 35(2): 317–325.

Barr, W. and E.A. Wilson (1985) The shipping crisis in the Soviet eastern Arctic and the close of the 1983 navigation season. *Arctic*, 38(1): 1–17.

Batten, E.S. (1976) Sea ice conditions in the Norwe-

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gian, Barents, and White Seas. Interim report, R-1921-ARPA. Rand Corporation.

Benedict, C. and J. Hall (1979) A study of iceberg detection for marine navigation. Transport Canada.

Bercha, F.G., J.A. Dechka and W. Spring (1990) Barents Sea ice SAR survey. In *Proceedings of the 9th International Conference on Offshore Mechanics and Arctic Engineering, 18–23 February, Houston, Texas*, (O.A. Ayorinde, N.K. Sinha and D.S. Sodhi, Eds.), vol. 4, p. 301–307. New York: American Society of Mechanical Engineers.

Berezkin, V.A. (1923) Winter navigation in the neck of the White Sea (in Russian). *Zapiski po Gidrografii* (Notes on Hydrography), no. 47, p. 29–36.

Biriulin, G.M. and M.M. Somov (1940) Effect of drift factors on ice conditions in the Laptev Sea (in Russian). *Problemy Arktiki* (Arctic Problems), no. 7–8, p. 5–12.

Borovaia, L.I. (1970) Hydrologic and ice conditions in the Barents Sea in 1968 (in Russian). *Fishery Studies of the Northern Basin*, 16(1): 53–61.

Bourke, R.H. and R.P. Garrett (1987) Sea ice thickness distribution in the Arctic region. *Cold Regions Science and Technology*, 13(3): 259–280.

Buzuev, A.Ia., E.I. Makarov and E.N. Skripnik (1990) Calculating ice navigation difficulties of ships in the White Sea in the compilation of navigation recommendations (in Russian). *Trudy*, vol. 418, p. 163–170. Leningrad: Arctic and Antarctic Research Institute.

Central Intelligence Agency (1978) *Polar Regions Atlas*. Washington, D.C.

Chirikhin, Iu.D. (1932) Hydrology of the southeastern Laptev Sea (in Russian). *Issledovaniia Morei SSSR* (Research of the Seas of the USSR), no. 15, p. 13–31.

Collins, M.J., R.O. Ramseier and S.P. Gogineni (1990) Active/passive microwave signatures of springtime Barents Sea ice. In *International Geoscience and Remote Sensing Symposium (IGARSS '90), 20–24 May, College Park, Maryland*. IEEE Digest, vol. 2, Remote sensing science for the nineties. New York: Institute of Electrical and Electronics Engineers, p. 1517–1520.

Colony, R. and A.S. Thorndike (1984) Estimate of the mean field of Arctic sea ice motion. *Journal of Geophysical Research*, 89(C6): 10623–10629.

Comiso, J.C. (1986) Characteristics of Arctic winter sea ice from satellite multispectral microwave observations. *Journal of Geophysical Research*, 91(C1): 975–994.

Dement'ev, A.A. (1985) Meteorological reports for economic development of Arctic regions (in Russian) In *Problems in the Arctic and the Antarctic*, vol. 61, p. 59–64.

Dement'ev, A.A., N.F. Orlov and T.N. Skvortsova (1985) Meteorological and aerological conditions for the Novaya Zemlya bora winds (in Russian). In *Problems in the Arctic and the Antarctic*, vol. 61, p. 64–70.

Dmitriev, N.E. and A.Iu. Proshutinskii (1991) Calculating tidal movements in the Kara Sea (in Russian). *Trudy*, vol. 424, p. 14–21. Leningrad: Arctic and Antarctic Research Institute.

Dorofeyev, A. (1992) Hydrometeorological service at the Northern Sea Route. In *Proceedings of the Conference on the Opening of the Northern Sea Route, Trondheim, Norway.*

Doronin, N.Iu. and A.Iu. Proshutinskii (1991) Mathematical modeling in studies of Arctic Ocean circulation. In *Proceedings of the International Conference on the Role of the Polar Regions in Global Change, 11–15 June, 1990, Fairbanks*, vol. 1, p. 310–316. Fairbanks: University of Alaska.

Doronin, N.Iu. and A.Iu. Proshutinskii (1990) Numerical modelling of Arctic Ocean water dynamics. In *Proceedings of the Conference of Arctic and Nordic Countries on Coordination of Research in the Arctic, 1988, Leningrad, U.S.S.R.* (V.M. Kotliakov and V.E. Sokolov, Eds.), pt. 1, p. 76–85, Arctic Research: Advances and Prospects. Moscow: Nauka.

Doronin, N.Iu., V.L. Kuznetsov and A.Iu. Proshutinskii (1991) Problem of water circulation in the Kara Sea (in Russian). *Trudy*, vol. 424, p. 34–41. Leningrad: Arctic and Antarctic Research Institute.

Drogaitsev, A.A. (1958) Winter cooling of arctic fields. Translated from *Problemy Severa* (Problems of the North), USSR Academy of Sciences, p. 42–51. U.S. Navy Hydrographic Office translation 72. Translation available from National Technical Information Service, Springfield, Virginia. AD 720148.

Eckardt, M., J. Gallas and W. Tonn (1993) Sea ice distribution in the Greenland and Barents Seas based on satellite information for the period 1966–89. *International Journal of Remote Sensing*, 13(1): 23–35.

Efremova, N.D. (1988) Methods of long-range forecasting of dates of ice breakup on rivers in the northern European USSR (in Russian). *Trudy*, vol. 295, p. 122–129. Leningrad: Hydrometeorological Research Center USSR.

Egan, D.M. and D.W. Orr (1987) Sea control in the Arctic: A Soviet perspective. Soviet strategy presented as conversation between two fictitious Soviet military planners but data on capabilities are factual. Newport, Rhode Island: U.S. Naval War College.

Egorov, A.G. (1990) Hydrometeorological conditions characteristic of separated and connected Severnaya Zemlya and Kara Sea ice massifs during the summer (in Russian). *Trudy*, vol. 423, p. 35–41. Leningrad: Arctic and Antarctic Research Institute.

Elferink, A.O. (1992) Environment protection in the Arctic—The Rovaniemi process. *Marine Pollution Bulletin*, 24(3): 128–130.

Elliott, F.E. (1956) Some factors affecting the extent of ice in the Barents Sea area. *Arctic Journal of the Arctic Institute of North America*, 9: 249–257.

Elverhoi, A. and A. Solheim (1983) The physical environment western Barents Sea. Sheet A: Surface sediment distribution. *Skrifter*, no. 179 A. Oslo: Norwegian Polar Institute.

Elverhoi, A. and A. Solheim (1983) Barents Sea ice sheet—A sedimentological discussion. *Polar Research*, 1(1): 23–42.

Fedorova, Z.P. (1963) Turbulent heat exchange and evaporation in the Laptev Sea (in Russian). *Trudy*, p. 185–196. Leningrad: Arctic and Antarctic Research Institute.

Franckx, E. (1992) Nature protection in the Arctic: Recent Soviet legislation. *International and Comparative Law Quarterly*, no. 41, p. 366–386.

Futsæter, G., G. Eidnes, G. Halmo, S. Johnsen, H.P. Mannvik, L.K. Sydnes and U. Witte (1991) Report on oil pollution. In *State of the Arctic Environment: Reports*, no. 2, p. 270–334. Rovaniemi: Arctic Centre Publications.

Gjevik, B., E. Nost and T. Straume (1990) Atlas of the tides on the shelves of the Norwegian and Barents Seas. Oslo: University of Oslo, Department of Mathematics.

Gloersen, P. and D.J. Cavalieri (1986) Reduction of weather effects in the calculation of sea ice concentration from microwave radiances. *Journal of Geophysical Research*, 91(C3): 3913–3919.

Gloersen, P., W.J. Campbell, D.J. Cavalieri, J.C. Comiso, C.L. Parkinson and H.J. Zwally (1992) Arctic and Antarctic Sea Ice, 1978–1987: Satellite Passive-Microwave Observations and Analysis. Washington, D.C.: National Oceanic and Atmospheric Administration.

Gomoiunov, K.A. (1939) East Siberian Sea (in Russian). *Sovetskaia Arktika* (The Soviet Arctic), no. 10, p. 46–55.

Gordienko, P.A. (1960) Ice drift in the central part of the Arctic Ocean. Translated from *Problemy Severa* (Problems of the North), no. 1, p. 5–29. U.S. Navy Hydrographic Office translation 71, available from National Technical Information Service, Springfield, Virginia. AD 720147.

Gorshkov, S.G. (Ed.) (1980) *World Ocean Atlas, Vol. 3, Arctic Ocean* (in Russian). (Distributed by Pergamon Press, New York.) USSR: USSR Ministry of Defense, Navy, Department of Navigation and Oceanography.

Gow, A.J. and W.B. Tucker (1991) Physical and dynamic properties of sea ice in the polar oceans. USA Cold Regions Research and Engineering Laboratory, CRREL Monograph 91–1.

Gudkovich, Z.M., V.P. Karklin, I.F. Romantsova and K.A. Teitel'baum (1981) Using statistical analyses for evaluating the dependence of ice conditions in the Kara Sea on river drainage (in Russian). *Trudy*, vol. 384, p. 53–60. Leningrad: Arctic and Antarctic Research Institute.

Gudmestad, O.T. and P. Strass (1993) Technological challenges for hydrocarbon production in the Barents Sea. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 403–412. Hamburg: Hamburg Ship Model Basin.

Harders, J.E. (1987) In quest of an Arctic regime: Marine regionalism—Concept of international law evaluated. *Marine Policy*, 11(4): 285–298.

Haugan, P.M., O.M. Johannessen, S. Sandven and R. Preller (1990) Sea ice modeling in the Barents Sea during SIZEX 89. In *International Geoscience and Remote Sensing Symposium (IGARSS '90), 20–24 May, College Park, Maryland*. IEEE Digest, vol. 2, Remote Sensing Science for the Nineties, p. 1509–1512. New York: Institute of Electrical and Electronics Engineers.

Johannessen, O.M., S. Sandven, O. Skagseth, K. Kloster, Z. Kovacs, P. Sauvadet, L. Geli, W.F. Weeks and J. Louet (1992) ERS-1 SAR ice routing of *L'Astrolabe* through the Northeast Passage. Bergen, Norway: Nansen Environmental and Remote Sensing Center.

Jørgensen-Dahl, A. (1990) The Northeast Passage; Northern Sea Route feasibility study planned. *Far Eastern Economic Review*, August 9, 149(32): 48.

Kalinin, E.N. (1993) Estimation of wind drift parameters of sea ice in Okhotsk coastal zone. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 913–920. Hamburg: Hamburg Ship Model Basin.

Kaminski, H. (1976) Remote sensing of variations of sea–ice surfaces in the Barents Sea from 1966–1975 by means of satellite data, among others NOAA-VHRR (in German). Presented at the 10th International Polar Meeting, Zurich, April. Zurich, Switzerland.

Karelin, D.B. (1946) Laptev Sea. Moscow: Izdatel'stvo Glavsevmorputi.

Kelly, P.M., P.D. Jones, C.B. Sear, B.S.G. Cherry and R.K. Tavakol (1982) Variations in surface air temperatures: Part 2, Arctic regions, 1881–1980. *Monthly Weather Review*, no. 110, p. 71–83.

Khmyznikov, P.K. (1937) Navigation in the Laptev Sea and in the western part of the East Siberian Sea during 1878–1935 (in Russian). Leningrad: Izdatel'stvo Glavsevmorputi.

Khromtsova, M.S. (1960) Forecasting the position of the ice edge in the Barents Sea (in Russian).

Problemy Arktiki i Antarktiki (Problems in the Arctic and Antarctic), no. 2, p. 23–33.

Kloster, K. (1993) Iceberg and glacier mapping using satellite optical imagery during the Barents Sea ice data acquisition program (IDAP). In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 413–424. Hamburg: Hamburg Ship Model Basin.

Koerner, R.M. (1973) The mass balance of the sea ice of the Arctic Ocean. *Journal of Glaciology*, 12(65): 173–185.

Korotkevich, E.S. and V.P. Rusanov (1985) Geographical aspects of ecological monitoring of the natural environment of arctic seas (in Russian). In *Geographic Problems of the Study and Development of Arctic Seas, Abstracts of Papers of the 2nd All-Union Conference on Geography and Ocean Mapping, Leningrad*, p. 22–27.

Korotkevich, E.S., E.S. Slevich and A.A. Panchenko (1985) Some geographic problems in the study and development of Arctic seas. In *Geographic Problems of the Study and Development of Arctic Seas, Abstracts of Papers of the 2nd All-Union Conference on Geography and Ocean Mapping., Leningrad*, p. 3–9.

Kristensen, M., C. Ulstad, E. Martinsen and H. Engedahl (199??) An operational model for ice border positions. Oslo: The Norwegian Meteorological Institute.

Kupetskii, V.N. (1961) Permanent polynyas in the White Sea (in Russian). *Trudy Gos. Okeanograf. Instituta* (Transactions of the State Oceanographic Institute), vol. 64, p. 78–92. Moscow.

Kurskaia, A.A. (1977) Airborne laboratory for studying White Sea ice (in Russian). *Trudy*, vol. 343, p. 122–126. Leningrad: Arctic and Antarctic Research Institute.

Kutsuruba, A.I. (1984) Statistical characteristics of dates of ice melting and the rate of ice disappearance in the Azov Sea (in Russian). *Trudy*, vol. 263, p. 101–105. Leningrad: Hydrometeorological Research Center USSR.

Lamson, C. (1987) Arctic shipping, marine safety and environmental protection. *Marine Policy*, 11(1): 3–15.

Lappo, S.D. (1939) Laptev Sea (in Russian). *Sovetskaia Arktika* (The Soviet Arctic), no.11, p. 71–82.

Lavrov, A. (1931) Northern Sea Route (in Russian). *Morskoy Sbornik* (Collected Maritime Articles) 14, 84(7): 79–95.

Lepparanta, M. (1981) On the structure and mechanics of pack ice in the Bothnian Bay. Finnish Marine Research Report no. 248. Helsinki: Institute of Marine Research.

Loeng, H. and T.E. Vinje (1979) On the sea ice conditions in the Greenland and Barents Seas. In *Proceedings of the 5th International Conference on Port and Ocean Engineering under Arctic Conditions, 13–18 August, Trondheim, Norway*, vol. 1, p 163–176. Norway: Trondheim University.

Loset, S. and T. Carstens (1993) Production of icebergs and observed extreme drift speeds in the Barents Sea. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 425–438. Hamburg: Hamburg Ship Model Basin.

Lovas, S.M., S. Vefsnmo, and R. Ramseier (1991) Barents Sea ice conditions as observed by passive microwave and other techniques. In *Proceedings of the 2nd WMO Operational Ice Remote Sensing Workshop, 10–13 September, Ottawa*, vol. 1, Abstracts and papers, p. 101–115. Ottawa: Environment Canada.

Lovas, S.M., W. Spring, and A. Holm (1993) Stereo photogrammetric analysis of icebergs and sea ice from the Barents Sea ice data aquisition program (IDAP). In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 439–449. Hamburg: Hamburg Ship Model Basin.

Markham, W.E. (1984) Supplement to ice atlas, Canadian Arctic waterways. Canada: Minister of Supply and Services.

McLaren, A.S. (1988) Analysis of the under-ice topography in the Arctic Basin as recorded by the USS *Nautilus* during August 1958. *Arctic*, 41(2): 117–126.

McLaren, A.S. (1989) The under-ice thickness distribution of the Arctic Basin as recorded in 1958 and 1970. *Journal of Geophysical Research*, 94(C4): 4971–4983.

Mileiko, G.N. (1957) Calculation of heat losses from the surface of the Barents Sea for determining the water temperature and boundary of ice cover (in Russian). *Trudy Tsentral'nogo Instituta Prognozov* (Transactions of the Central Forecasting Institute), no. 57, p. 60–82.

Mofjeld, H.O. (1984) Recent observations of tides and tidal currents from the Northeastern Bering Sea. Shelf NOAA Technical Memorandum, ERL PMEL-57.

Morozova, T.P. (1963) Fluctuation of the southern boundary of polar ice in the Laptev Sea. Translated from *Problemy Arktiki i Antarktiki*, no. 1, 1959, p. 5–10. U.S. Naval Oceanographic Office translation 126, Available from National Technical Information Service, Springfield, Virginia. AD 693579.

Moskal' T.N. (1977) Results of applying a numerical method of calculating ice conditions in the Barents Sea during the fall–winter period (in Russian). *Trudy*, vol. 346, p. 45–54. Leningrad: Arctic and Antarctic Research Institute.

Nalimov, Iu.V. and G.E. Usankina (1984) Estimating the freezeup and breakup dates for the parts

of beaches, which interfere with navigation, on rivers of the Kara Sea basin (in Russian). *Trudy*, vol. 394, p. 97–110. Leningrad: Arctic and Antarctic Research Institute.

National Snow and Ice Data Center (1992) DMSP SSM/I brightness temperature and sea ice concentration grids for the polar regions. User's guide. National Snow and Ice Data Center Special Publication NSIDC SP-1.

Nazintsev, Iu.L. (1972) Snow accumulation on Kara Sea ice. Arctic Ice Dynamics Joint Experiment. *AIDJEX Bulletin*, no. 17, p. 77–83.

Nikolaeva, A.Ia. and N.P. Shesterikov (1976) Method of calculation of ice conditions (on the examples of the Laptev Sea). In *Ice Forecasting Techniques for the Arctic Seas* (B.A. Krutskikh, Z.M. Gudkovich and A.L. Sokolov, Eds.), p. 150–230. New Delhi: Amerind Publishing Co.

Olaussen, T., O.M. Johannessen, P.M. Haugan and R. Preller (1988) Integrated remote sensing for Barents Sea ice. In *Proceedings of the International Conference on Technology for Polar Areas, 15–17 June, Trondheim, Norway* (A. Hansen and J.F. Storm, Eds.), vol. 2, p. 495–506. Trondheim: Tapir Publishers.

Panov, V.V. (1961) Role of Atlantic waters in hydrological and ice conditions of Arctic Seas (Kara Sea taken as an example) (in Russian). *Problemy Arktiki i Antarktiki Sbornik Statei* (Problems in the Arctic and Antarctic, Collected Papers), vol. 8, p. 75–77.

Podsechina, T.V. (1988) Ice accretion on the Volga water reservoirs and its dependence on atmospheric processes (in Russian). *Trudy*, vol. 295, p. 130–137. Leningrad: Hydrometeorological Research Center USSR.

Poliakov, I.V. and A.Iu. Proshutinskii (1988) Periods of eigen oscillations in the sea level of the Arctic Ocean (in Russian). *Meteorologiia i Gidrologiia* (Meteorology and Hydrology), no. 11, p. 91–100.

Ponomarev, M.B. (1988) Calculating the freezing of channels cut in ice cover of water reservoirs (in Russian). *Trudy*, vol. 395, p. 138–148. Leningrad: Hydrometeorological Research Center USSR.

Potanin, V.A. and V.Sh. Sagdeev (1983) Interrelations between ice conditions of the Barents Sea and the dynamic processes in its water masses (in Russian). In *Studying Ice Covers of Northwestern Seas* (V.L. Tsurikov, G.K. Zubakin and O.I. Sheremetevskaia, Eds.), p. 44–48. Moscow: Nauka.

Potanin, V.A. (1987) Possibility of long range forecasting of ice conditions in the Barents Sea (in Russian). *Trudy*, vol. 410, p. 117–124. Leningrad: Arctic and Antarctic Research Institute.

Preller, R. and P. Posey (1990) Design and development of an operational sea ice forecasting system for the Barents Sea. In *Proceedings of the 2nd International Conference on Ice Technology, 18–20 September, Cambridge, England* (T.K.S. Murthy, J.G. Paren, W.M. Sackinger and P. Wadhams, Eds.), p. 379–393. Southampton: Computational Mechanics Publications.

Presidium of the USSR Supreme Soviet (1984) Improving the protection of nature in the regions of the far north and in the sea areas. In *Record of the USSR Supreme Soviet*, no. 48, p. 863.

Proshutinskii, A.Iu. (1978) Calculation of surge level oscillations in the shelf zone of Arctic seas (in Russian with English summary). *Meteorologiia i Gidrologiia* (Meteorology and Hydrology), no. 8, p. 72–79.

Proshutinskii, A.Iu. (1988) Modeling seasonal variations of sea level in the Arctic Ocean (in Russian). *Meteorologiia i Gidrologiia* (Meteorology and Hydrology), no. 2, p. 57–65.

Proshutinskii, A.Iu. (1990) Ice cover effects in models of sea level fluctuations and water circulation (in Russian). *Trudy*, vol. 420, p. 90–104. Leningrad: Arctic and Antarctic Research Institute.

Proshutinskii, A.Iu. (1991) Tidal water and ice dynamics in the Arctic Ocean. In *Proceedings of the International Conference on the Role of the Polar Regions in Global Change, 11–15 June, 1990, Fairbanks*, vol. 1, p. 296–303. Fairbanks: University of Alaska.

Proshutinskii, A.Iu. and I.V. Poliakov (1991) Arctic Ocean eigen oscillations. In *Proceedings of the International Conference on the Role of the Polar Regions in Global Change, 11–15 June, 1990, Fairbanks*, vol. 1, p. 347–354. Fairbanks: University of Alaska.

Ratmanov, G.E. (1931) Hydrology of the East Siberian Sea (in Russian). *Issledovaniia Morei SSSR* (Ocean Research USSR), no. 13, p. 5–104.

Richter, J. (1934) Ice conditions in the White Sea (in German). *Ann. Hydrographie und Maritim. Meteorologie*, no, 62, p. 89–95.

Romanov, I.P. (1993) *Atlas: Morphometric Characteristics of Ice and Snow in the Arctic Basin*. St. Petersburg: Arctic and Antarctic Research Institute.

Romanov, I.P. (1993) *Ice Cover of the Arctic Basin*. St. Petersburg: Arctic and Antarctic Research Institute.

Sandven, S. and O.M. Johannessen (1990) Ice conditions in the Barents Sea during SIZEX 89. In *Proceedings of the 2nd International Conference on Ice Technology, 18–20 September, Cambridge, England* (T. K. S. Murthy, J. G. Paren, W. M. Sackinger and P. Wadhams, Eds.), p. 309–320. Southampton: Computational Mechanics Publications.

Savchenkova, E.I. (1988) Methods of long-range forecasting ice breakup dates for the Dnepr and Don Rivers (in Russian). *Trudy*, vol. 295, p. 113–121. Leningrad: Hydrometeorological Research Center USSR.

Sheremetevskaia, O.I. (1984) Predicting the spatial distribution of dates of ice disappearence from northwestern seas of the USSR (in Russian). *Trudy*, vol. 263, p. 91–100. Leningrad: Hydrometeorological Research Center USSR.

Sheremetevskaia, O.I. (1986) Space–time variations in ice conditions of the Barents, White and Baltic seas (in Russian). *Problemy Arktiki i Antarktiki, Sb. nauk. Statei* (Problems in the Arctic and Antarctic, Collected Papers), vol. 62, p. 88–93.

Shishkov, Iu.A. (1961) Ice concentration of the southwestern part of the Kara Sea and the meridional transport of heat in the atmosphere (in Russian). *Problemy Severa* (Problems of the North), vol. 4, p. 131–137.

Slagstad, D. (1985) Model of phytoplankton in the marginal sea-ice zone of the Barents Sea. In M. E. *Biology of Polar Regions and Effects of Stress on Marine Organisms* (J.S. Gray and M.E. Christiansen, Eds.), p. 35–48. Chichester, U.K.: John Wiley & Sons.

Snydes, L.K. (1991) Oil, water, ice and light. *Polar Research*, 10(2): 609–618.

Sobchenko, E.A. (1973) Long range forecasting of ice conditions in the southern Barents Sea (in Russian). *Trudy*, vol. 34, p. 135–138. Murmansk: Polar Research Institute of Salt-Water Fisheries and Oceanography.

Sokolov, A. (1929) Sailing directions for the Siberian Sea (in Russian). *Zapiski po Gidrografii* (Notes on Hydrography), 55, Suppl., p. 1–58.

Spring, W. and A. Sangolt (1993) Results of the ice data acquisition program (IDAP) in the Barents Sea 1988–1992. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 450–461. Hamburg: Hamburg Ship Model Basin.

Spring, W., T. Vinje and H. Jensen (1993) Iceberg and sea ice data obtained in the annual expeditions of the Barents Sea ice data acquisition program (IDAP). In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 462–474. Hamburg: Hamburg Ship Model Basin.

Swift, C.T. and D.J. Cavalieri (1985) Passive microwave remote sensing for sea ice research. *EOS*, 66(4): 1210–1212.

Tarbeev, D. (1940) *Laptev Sea and Its Shores*. Leningrad: Izdatel'stvo Glavsevmorputi.

Teitel'baum, K.A. (1977) Dependence of air temperature above the Kara Sea on ice conditions and atmospheric circulation during the spring–summer seasons (in Russian). *Trudy*, vol. 346, p. 109–117. Leningrad: Arctic and Antarctic Research Institute.

Teitel'baum, K.A. (1979) Dependence of summer air temperature above the Laptev, East Siberian and Chukchi seas on ice conditions and atmospheric circulation (in Russian). *Trudy*, vol. 365, p. 81–90. Leningrad: Arctic and Antarctic Research Institute.

Timofeev, V.T. (1962) Influence of deep Atlantic water on the formation and melting of ice in the Kara and Laptev Seas (in Russian). *Trudy*, vol. 242, p. 218–227.

Tiuriakov, A.B. (1984) Studying the possibility of long-range forecast of summer ice conditions in the southwestern Kara Sea (in Russian). *Trudy*, vol. 423, p. 105–111. Leningrad: Arctic and Antarctic Research Institute.

Treshnikov, A.F. (Ed.) (1985) [illegible] (in Russian). Leningrad: Arctic and Antarctic Research Institute.

Tsurikov, V.L. and G.K. Zubakin (1983) Evaluation of possible changes in ice conditions of the White Sea due to partial diversion of river runoff (in Russian). In *Studying Ice Covers of Northwestern Seas*, V.L. Tsurikov, G.K. Zubakin and O.I. Sheremetevskaia, Eds.), p. 36–43. Moscow: Nauka.

Ulmisek, G. (1984) Geology and petroleum resources of the Barents–Northern Kara Shelf in light of new geological data. Argonne National Laboratory, Report AN:/EES-tm-XXX. Available from National Technical Information Service, Springfield, Virginia 22161.

Uralov, N.S. (1961) Some features of seasonal and long-range changes in position of the outer ice edge of the Barents Sea (in Russian). *Trudy Gos. Okeanograf. Instituta* (Transactions of the State Oceanographic Institute), vol. 64, p. 39–77. Moscow.

U.S. Naval Oceanography Command Detachment (1986) *Sea Ice Climatic Atlas: Volume 2, Arctic East*. Asheville, N.C., NAVAIR 50-1C-541.

U.S. Naval Oceanography Command Detachment (1986) *Sea Ice Climatic Atlas: Volume 3, Arctic West*. Asheville, N.C., NAVAIR 50-1C-542.

Vangengeim, G.Ia. (1946) Ice conditions of the Barents Sea in relation to various types of atmospheric circulation (in Russian). *Trudy Nauchno-Issledovatel'skikh Uchrezhdenii* (Transactions of the Scientific Research Institutions), ser. 5, no. 12, p. 76–99.

Vefsnmo, S., S.M. Lovas and A.G. Kjelaas (1991) Statistical analysis of sea ice for the eastern Barents Sea. In *Proceedings of the 2nd WMO Operational Ice Remote Sensing Workshop, 10–13 September, Ottawa*, vol. 2, Abstracts and Papers, p. 61–80. Ottawa: Environment Canada.

Vefsnmo, S., S.M. Lovas, M. Mathiesen and A. Kjelaas (1992) Trend analysis of the Barents Sea ice cover. In *Proceedings of the 3rd International Conference on Ice Technology, 11–13 August, Cambridge, Massachusetts*. (T.K.S. Murthy, W.M. Sack-

inger and P. Wadhams, Eds.), p. 325–335. Southampton: Computational Mechanics Publications.

Vinje, T.E. (1980) On the extreme sea ice conditions observed in the Greenland and Barents Seas in 1979. *Årbok* (Annual), p. 59–65. Oslo: Norwegian Polar Institute.

Vinje, T.E. (1982) Frequency distribution of sea ice in the Greenland and Barents Seas, 1971–1980. *Årbok* (Annual), p. 57–61. Oslo: Norwegian Polar Institute.

Vinje, T.E. (1985) Drift, composition, morphology and distribution of the sea ice fields in the Barents Sea. *Skrifter*, no. 179 C. Oslo: Norwegian Polar Institute.

Vinje, T. (1988) Dynamics and morphology of the Barents Sea ice fields. In *Proceedings of the 9th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–22 August, Fairbanks* (W. M. Sackinger and M.O. Jeffries, Eds.), vol. 1, p. 263–268. Fairbanks: University of Alaska, Geophysical Institute.

Vinogradov, N.D. and V.V. Ivanov (1977) Transformation of circulation periods and background variations in ice conditions of the Barents and Kara Seas (in Russian). *Trudy*, vol. 339, p. 156–159. Leningrad: Arctic and Antarctic Research Institute.

Vize, V.Iu. (1930) Ice conditions of the Kara Sea (in Russian). *Izvestiia Tsentral'nogo Gidrometeorologicheskogo Biuro* (News of the Central Hydrometeorological Bureau), no. 9, p. 235–242. Leningrad: Central Hydrometeorological Bureau.

Vize, V.Iu. (1933) Ice conditions in the Barents and Northern Kara Seas in the summer of 1930 observed from the icebreaker *Sedov* (in Russian). *Trudy Arkticheskogo Instituta* (Transactions of the Arctic Institute), vol. 1, p. 109–123. Leningrad: Arctic Institute.

Weaver, R., C. Morris and R.G. Barry (1987) Passive microwave data for snow and ice research: Planned products from the DMSP SSM/I system. *EOS*, 68(39): 769, 776–777.

Weissenberger, J. (1992) Sea ice: A cast techniques to examine and analyze brine pockets and channel structure. *Limnology and Oceanography*, 37(1). 179–183.

Zakharov, V.F. (1967) Variations of ice conditions in the Laptev Sea in relation to pressure field fluctuations (in Russian). *Trudy*, vol. 257, p. 57–72. Leningrad: Arctic and Antarctic Research Institute.

Zubakin, G.K., A.N. Zuev, O.N. Maiorov and L.F. Iakovlev (1983) Application of a numerical ice drift model in winter navigation of transport ships in the Barents Sea (in Russian). *Trudy*, vol. 385, p. 26–31. Leningrad: Arctic and Antarctic Research Institute.

Zubakin, G.K. and A.N. Zuev (1989) Results of investigation of the dynamics of the Barents sea ice cover. In *Problems in the Arctic and the Antarctic, Collection of Articles* (B.A. Krutskikh, Ed.), vol. 61, p. 26–38. New Delhi. Amerind Publishing.

Zverev, N.I. (1977) Relationship between ice conditions in the Barents and Baltic Seas and the deficit (excess) of precipitation in the southern part of the European USSR (in Russian). *Truay*, 172, p. 34–37. Leningrad: USSR Hydrometeorological Scientific Research Center.

ALASKAN WATERS, BERING, CHUKCHI AND BEAUFORT SEAS

Aagaard, K. (1981) Current measurements in possible dispersal regions of the Beaufort Sea. In *Environmental Assessment of the Alaskan Continental Shelf, vol. 3, Physical Science Studies.* Principal investigators' final reports, p. 1–74. Rockville, Maryland: U.S. National Oceanic and Atmospheric Administration.

Aagaard, K., C.H. Pease and S.A. Salo (1988) Beaufort Sea mesoscale circulation study: Preliminary results. NOAA technical memorandum, ERL PMEL-82. U.S. National Oceanic and Atmospheric Administration.

Aagaard, K., C.H. Pease, A.T. Roach and S.A. Salo (1989) Beaufort Sea mesoscale circulation study: Final report. NOAA technical memorandum, ERL PMEL-90. U.S. National Oceanic and Atmospheric Administration.

Aagaard, K., S. Salo and K. Krogslund (1987) Beaufort Sea mesoscale circulation study: Hydrography, USCGC *Polar Star* cruise, October 1986. NOAA data report, ERL PMEL-19. U.S. National Oceanic and Atmospheric Administration.

Aagaard, K., S. Salo and K. Krogslund (1988) Beaufort Sea mesoscale circulation study: Hydrography, helicopter operations, April, 1987. NOAA data report, ERL PMEL-22. U.S. National Oceanic and Atmospheric Administration.

Abramov, V.A. and N.P. Sen'ko (1990) Mesoscale characteristics of the distribution of water masses in the Chukchi Sea (in Russian). *Trudy*, vol. 423, p. 126–132. Leningrad: Arctic and Antarctic Research Institute.

Alexander, V. and H.J. Niebauer (1981) Oceanography of the eastern Bering Sea ice-edge zone in spring. *Limnology and Oceanography*, 26(6): 1111–1125.

Andersen, P.F. and N.F.B. Allyn (1984) Ice management for Beaufort Sea production harbours. In *Proceedings of the 7th IAHR International Symposium on Ice, 27–31 August, Hamburg, F.R.G.*, vol. 1, p. 303–314.

Anon. (1981) Systems created to combat icy obstacles. *Offshore*, 41(10): 109–115.

Arctic Petroleum Laboratory, Inc. (1981) Analysis of NavSat buoy position data from the southeastern Beaufort Sea, 1980, vol. 4, Program listings. Report APOA No. 154-1V4. Calgary, Alberta: Arctic Petroleum Operators Association.

Arctic Petroleum Operators Association (1984) Ice appendices, Tarsiut Gulf, 1982–83. Report, [1984]-APOA 198, vol. 5.

Arctic Petroleum Operators Association (1984) Oceanographic and meteorological appendices, Tarsiut Gulf 1982–83. Report, [1984]-APOA 198, vol. 7.

Arikainen, A.I. (1984) Possibilities of long-range forecast of the state of the Chukchi flaw polynya in spring. In *Problems in the Arctic and Antarctic, Collection of Articles*, vol. 51, p. 51–56.

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Armour, R., J. Wainwright and H. Hutton (1986) Design and operation of the *Arctic Ivik*, a new Arctic class II vessel for the Beaufort Sea. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 1, p. 244–256. Vancouver, B.C.: D.F. Dickins Associates.

Barnes, P.W., E. Reimnitz and D.M. Rearic (1985) Ice gouge characteristics related to sea-ice zonation, Beaufort Sea, Alaska. National Research Council, Canada, Associate Committee on Geotechnical Research, Technical memorandum, no. 136, p. 185–219.

Bauer, J. and S. Martin (1980) Field observations of the Bering Sea ice edge properties during March 1979. *Monthly Weather Review*, 108(12): 2045–2055.

Becker, P., G.R. Garrison and R.K. Perry (1987) Coastal oceanography in the Beaufort Sea, summer 1985. Report for period ending 1985. University of Washington, Applied Physics Laboratory, Report APL-UW-8705.

Borstad, G.A., M.R. MacNeill and L.L. Armstrong (1988) 1987 seasonal ice cycle in the Canadian Beaufort Sea. Sidney, B.C., Canada: G.A. Borstad Associates.

Bourke, R.H. and R.G. Paquette (1981) Winter conditions in the Bering Sea. U.S. Navy Interim report, NPS 68-81-004. Monterey, California: Naval Postgraduate School.

Bowley, C.J. and J.C. Barnes (1981) Comparison of sea ice features in the Beaufort and Bering Seas using Slar and Landsat data. In *Proceedings of the 6th International Conference on Port and Ocean Engineering under Arctic Conditions, 27–31 July, Quebec, Canada*, p. 166–177. Quebec: Université Laval.

Brigham, L. (1984) Winter ice features and ice edge variability in the Chukchi Sea. *Abstracts of the Annual Meeting of the American Society of Limnology and Oceanography, Vancouver, British Columbia, June 11–14.*

Brigham, L.W. and R.P. Voelker (1985) Ice navigation studies in the Alaskan Arctic using *Polar*-class icebreakers. In *Proceedings of the Ocean Engineering and the Environment—OCEANS '85 Conference, 11–14 November, San Diego, California*, vol. 1, p. 441–447.

Brower, W.A. Jr., R.G. Baldwin, and C.N. Williams, Jr. (1988) *Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska*; vol. I, Gulf of Alaska, vol. II, Bering Sea, vol. III, Chukchi–Beaufort Sea. National Climate Data Center; National Environmental Satellite, Data, and Information Service; National Oceanic Atmospheric Administration; and Arctic Environmental Information and Data Center. Anchorage: University of Alaska.

Browne, R. (1984) Design and operation of a class four icebreaker fleet for the Beaufort Sea. In *Proceedings of the Arctic Offshore Technology Conference and Exposition, 6–9 November, Calgary, Alberta.*

Businger, S. and J.J. Baik (1991) Arctic hurricane over the Bering Sea. *Monthly Weather Review*, 119(9): 2293–2322.

Campbell, W.J., P. Gloersen, H.J. Zwally, R.O. Ramseier and C. Elachi (1980) Simultaneous passive and active microwave observation of near-shore Beaufort Sea ice. *Journal of Petroleum Technology*, 32(6): 1105–1112.

Carsey, F.D. (1986) Weddell–Scotia sea marginal ice zone observations from space, Oct. 1984. *Journal of Geophysical Research*, 91(C3): 3920–3924.

Carsey, F.D. and G. Philos (1989) Beaufort–Chukchi seas summer and fall ice margin data from Seasat: conditions with similarities to the Labrador Sea. *IEEE Transactions on Geoscience and Remote Sensing*, 27(5): 541–551.

Cavalieri, D.J. (1991) Aircraft active and passive microwave validation of sea ice concentration from the Defense Meteorological Satellite Program special sensor microwave imager. *Journal of Geophysical Research*, 96(C12): 21,989–22,008.

Cavalieri, D.J. and C.L. Parkinson (1987) On the relationship between atmospheric circulation and the fluctuations in the sea ice extents of the Bering and Okhotsk seas. *Journal of Geophysical Research*, 92(C7): 7141–7162.

Cavalieri, D.J., P. Gloersen and T.T. Wilheit Jr. (1986) Aircraft and satellite passive microwave observations of the Bering Sea ice cover during MIZEX West. *IEEE Transactions on Geoscience and Remote Sensing*, GE-24(3): 368–377.

Cavalieri, D.J., P. Gloersen, T.T. Wilheit, and C. Calhoon (1984) Passive microwave characteristics of the Bering Sea ice cover during MIZEX-West. In *Remote Sensing—From Research Towards Operation Use. Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS '84), 27–30 August, Strasbourg*, p. 379–384. ESA SP-215. Paris: European Space Agency.

Cavalieri, D.J., S. Martin and P. Gloersen (1982) Nimbus 7 SMMR observations of the Bering Sea ice cover during March 1979. *Journal of Geophysical Research*, 88(C5): 2743–2754.

Cheney, R.E. (1984) Applications of satellite altimetry to oceanography and geophysics. *Marine Geophysical Researches*, 7(1/2): 17–32.

Churcher, A.C., B.M. Johansson and J. Duff (1984) Operation, testing and design of vessels in the Canadian Beaufort Sea. In *Proceedings of the Arctic Offshore Technology Conference and Exposition, 6–9 November, Calgary, Alberta.*

Coburn, J.L., T.V. Kotras, J.W. St. John and J.R. Meyer (1986) Navarin Basin and ice edge data

collection aboard USCGC *Polar Sea*, vol. 2, Ice milling data, March/April 1985. Report MA-RD-760-87058. Washington, D.C.: U.S. Maritime Administration.

Cornett, S. (1987) Beaufort Gyre ice trajectories. In *Proceedings of the Workshop on Extreme Ice Features, 3–5 November, 1986, Banff, Alberta.* (compiled by G.R. Pilkington and B.W. Danielewicz), Technical memorandum no. 141, p. 11–37. Canada: National Research Council.

Cornford, A.B., D.D. Lemon, D.B. Fissel, H. Melling, B.D. Smiley, R.H. Herlinveaux and R.W. Macdonald (1982) Arctic data compilation and appraisal, vol. 1, Beaufort Sea: Physical geography—Temperature, salinity, currents and water levels. Canadian data report of Hydrography and Ocean Sciences no. 5. Sidney, B.C.: Institute of Ocean Science, Department of Fisheries and Oceans.

Cox, J. and T. McNeilan (1986) A geotechnical and cone penetrometer investigation of Northwest Chukchi Sea. Report MA-RD-760-87063. Washington, D.C.: Maritime Administration. Available from National Technical Information Service, Springfield, Virginia 22161, PB 88-223532/AS.

Cox, G.F.N., J.A. Richter-Menge, W.F. Weeks, M. Mellor and H. Bosworth (1984) Mechanical properties of multi-year sea ice. Phase 1: Test results. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, CRREL Report 84-09.

Cox, G.F.N., J.A. Richter-Menge, W.F. Weeks, W.F., H. Bosworth, N. Perron, M. Mellor, and G. Durell (1985) Mechanical properties of multi-year sea ice. Phase 2: Test results. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, CRREL Report 85-16.

Crasey, F.D. (1986) Weddell–Scotia Sea marginal ice zone observations from space, October 1984. *Journal of Geophysical Research*, 91(C3), p. 3920–3924.

Dallimore, S.R., P.J. Kurfurst and J.A.M. Hunter (1988) Geotechnical and geothermal conditions of near-shore sediments, southern Beaufort Sea, Northwest Territories, Canada. In *Proceedings of the 5th International Conference on Permafrost, 2–5 August, Trondheim, Norway* (K. Senneset, Ed.), vol. 1, p. 127–131. Trondheim: Tapir Publishers.

Dean, K.G., C.P. McRoy, K. Ahlnas and T.H. George (1987) Satellite observations of the northern Bering Sea. In *Proceedings of the 9th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–22 August, Fairbanks* (W.M. Sackinger and M.O. Jeffries, Eds.), vol. 1, p. 149–157. Fairbanks: University of Alaska, Geophysical Institute.

Defense Mapping Agency (1993) *Catalog of Maps, Charts, and Related Products; Part 2, Vol. 1: Hydrographic products.* Nautical Charts and Publications, Defense Mapping Agency, No. CATP2V01U, 4th edition, April. Washington, D.C.: Department of Defense.

Dey, B. (1980) Variations of August ice cover in the Beaufort Sea and related weather conditions. *American Meteorological Society Bulletin*, 61(3): 213–217.

Dickins, D. (1987) Environmental atlas for Beaufort Sea oil spill response. Yellowknife, N.W.T.: Environment Canada, Environmental Protection Service.

Dickins, D., L. Martin, I. Bjerkelund, S. Potter, D. Erickson, J. Harper, P. Norton, S. Johnson and P. Vonk (1987) *Environmental Atlas for Beaufort Sea Oil Spill Response.* Sponsored by Environmental Protection Service, Environment Canada, Yellowknife, N.W.T. Vancouver, B.C.: D.F. Dickins Associates, Ltd.

Dunton, K.H., S.V. Schonberg and D.M. Schell (1983) Geophysical and biological reconnaissance of rock habitats in western Camden Bay, Beaufort Sea, Alaska. Institute of Water Resources, Report IWR-104. Fairbanks: University of Alaska.

Edworthy, J.T., J.F. Yau, J.D. Miller and M. Oka (1984) Numerical modelling of ice thickness in the Beaufort Sea. In *Proceedings of the 3rd International Offshore Mechanics and Arctic Engineering Symposium, 12–17 February, New Orleans, Louisiana*, vol. 3, p. 34–37. New York: American Society of Mechanical Engineers.

Eid, B.M. and V.J. Cardone (1992) Beaufort Sea extreme waves study (with French summary). Canada, Environmental Studies Research Funds. Report 114.

Eley, F.J. (1986) Ice monitoring and forecasting for the BeauDril *Kulluk*. In *Proceedings of the Canadian East Coast Workshop on Ice, 7–9 January, Bedford, Quebec* (compiled by G. Symonds and I.K. Peterson). Canadian Technical Report of Hydrography and Ocean Sciences no. 73, p. 598–614.

Ellington, M.D., J.C Cox and M.G. Harrington (1986) Side scan sonar and sub-bottom profiling survey of the Chukchi Shelf and Barrow Sea valley. Report MA-RD-760-87062. Washington, D.C.: Maritime Administration. Available from National Technical Information Service, Springfield, Virginia 22161, PB 88-225289/AS.

Emery, W.J. (1991) Comparison of sea ice parameters computed from advanced very high resolution radiometer and Landsat satellite imagery and from airborne passive microwave radiometry. *Journal of Geophysical Research*, 96(C12): 22,075–22,085.

Feldman, U. (1986) Estimating open pack ice pa-

rameters using wind field and remotely sensed data. *Journal of Geophysical Research*, 91(C2): 2503–2509.

Fenco Consultants, Ltd. (1981) Pack ice/rubble field interaction study, Issungnak 1980. Report APOA No. 171-1V2. Calgary, Alberta: Arctic Petroleum Operators Association.

Fissel, D.B., M.S.W. Bradstreet and J. Moen (1987) Water mass distributions in the Canadian Beaufort Sea. In *Proceedings of the Oceans '87 Conference, 28 September–1 October, Halifax, Nova Scotia, vol. 3, Ocean—An international workplace*, p. 910–916. New York: Institute of Electrical and Electronics Engineer.

Fletcher, C. (1982) Taming Arctic ice. *Sohio*, 54(2): 6–8.

Garrett, R., V. Rinehart and R. Voelker (1982) Conclusions from the first marine transit to Point Barrow in winter 1981 (by USCGC *Polar Sea*). In *Proceedings of the Offshore Technology Conference, 3–6 May, Houston, Texas*, , p. 49–60.

Garrison, G.R. (1987) Environmental measurements in the Beaufort Sea, spring 1986. Technical Report, 1987-APL-UW-4-86. Seattle: University of Washington, Applied Physics Laboratory.

Gatto, L.W. (1980) Coastal environment, bathymetry, and physical oceanography along the Beaufort, Chukchi and Bering Seas. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, Special Report 80-05.

Giovando, L.F. and R.H. Herlinveaux (1981) Discussion of factors influencing dispersion of pollutants in the Beaufort Sea. Pacific Marine Science Report, 1981-81-4.

Gloersen, P., W.J. Campbell, D.J. Cavalieri, J.C. Comiso, C.L. Parkinson and H.J. Zwally (1992) *Arctic and Antarctic Sea Ice, 1978–1987: Satellite Passive-Microwave Observations and Analysis*. Washington, D.C.: National Oceanic and Atmospheric Administration.

Goodwin, C.R. and L.M. Howard (Eds.) (1984) The Beaufort Sea, Mackenzie Delta, Mackenzie Valley, and northern Yukon: A bibliographical review. Arctic Science and Technology Information System, Office of the Northern Research and Science Advisor. Calgary: University of Alberta, Arctic Institute of North America.

Gower, J.F.R., J.Y. Cherniawsky and G.A. Borstad (1986) Motion of ice in the Beaufort Sea from satellite and aircraft images. In *Proceedings of the Canadian East Coast Workshop on Sea Ice, 7–9 January, Bedford, Quebec* (compiled by G. Symonds and I.K. Peterson). Canadian Technical Report of Hydrography and Ocean Sciences, no. 73, p. 509–522.

Grenfell, T.C. (1986) Surface-based passive microwave observations of sea ice in the Bering and Greenland Seas. *IEEE Transactions on Geoscience and Remote Sensing*, GE-24(3): 378–382.

Hachmeister, L.E. and J.B. Vinelli (1984) Current, CTD, and pressure measurements in possible dispersal regions of the Chukchi Sea. In *Outer Continental Shelf Environmental Assessment Program, Final Report of Principal Investigators*. Ocean Assessments Division, vol. 57, p. 255–333. Anchorage: Alaska Outer Continental Shelf Office,

Hameedi, M.J. and A.S. Naidu (Eds.) (1988) Environment and resources of the southeastern Chukchi Sea. A review of scientific literature. Anchorage, Alaska: U.S. National Oceanic and Atmospheric Administration.

Hanson, A.M. (1985) Observations of ice and snow in the eastern part of the Chukchi Sea: A serendipitous cruise on the *Polar Sea*. In *MIZEX—A Program for Mesoscale Air–Ice–Ocean Interaction Experiments in Arctic Marginal Ice Zones, 6: MIZEX-West*. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, Special Report 85-06, p. 1–10.

Harper, J.R., S. Swift and P. Simpkin (1985) Beaufort Sea geophysical survey: scoping study. Dartmouth, Nova Scotia: Atlantic Geoscience Centre.

Harrington, M.G. and J.W. St. John (1987) Environmental data collection aboard USCG *Polar Sea*, vol. 1, Environmental data, Final report June 85–Nov. 86, Report MA-RD-760-87060. Washington, D.C.: U.S. Maritime Administration.

Harrington, M.G. and J.W. St. John (1987) Environmental data collection aboard the USCGC *Polar Sea*, vol. 2, Maps and ice flow cross section, Final report June 85–Nov. 86, Report MA-RD-760-87061. Washington, D.C.: U.S. Maritime Administration.

Hastings, A.D. (1971) Surface climate of the Arctic Basin; selected climatic elements related to the performance of surface-effect vehicles. Report ETL-TR-71-5, Fort Belvoir, Virginia.

Herbert, G.A. (1989) Meteorology and haze structure during AGASP-II, Part 1: Alaskan Arctic flights, 2–10 April 1986. *Journal of Atmospheric Chemistry*, 9(1–3): 17–48.

Hill, P.R., S.M. Blasco, J.R. Harper and D.B. Fissel (1991) Sedimentation on the Canadian Beaufort Shelf. In *Continental Shelf Research, Proceedings of the Canadian Continental Shelf Seabed Symposium, 2–7 October, 1989, Dartmouth, Nova Scotia*, p. 821–842.

Hill, P.R., K. Moran, P.J. Kurfurst and S. Pullan (1986) Physical and sedimentological properties of nearshore sediments in the southern Beaufort Sea. In *Proceedings of the 3rd Canadian Conference on Marine Geotechnical Engineering, June, St. John's, Newfoundland*. St. John's: Memorial University of Newfoundland, p. 301–327.

Hnatiuk, J. and B.D. Wright (1983) Sea bottom scouring in the Canadian Beaufort Sea. In *Proceedings of the 15th Offshore Technology Conference, 2–5 May, Houston, Texas*, vol. 3, p. 35–40.

Hoch, D.M. and B.T. Drage (1983) Sea ice characteristics in the nearshore environment. In *Managing Water Resources for Alaska's Development Proceedings* (J.W. Aldrich, Ed.), p. 2(1)–2(15), Report IWR-105. Fairbanks: University of Alaska, Institute of Water Resources.

Honda, K., Y. Yamamoto and R. Tatsukawa (1987) Distribution of heavy metals in antarctic marine ecosystem. In *Proceedings of the NIPR Symposium on Polar Biology*, no.1, p. 184–197, Tokyo: National Institute of Polar Research.

Hood, D.W. and J.A. Calder (Eds.) (1980) Eastern Bering Sea shelf: Oceanography and resources. Washington, D.C.: U.S. Department of Commerce.

Hood, D.W. and J.A. Calder (Eds.) (1981) Eastern Bering Sea shelf: Oceanography and resources, vol. 2. Washington, D.C.: National Oceanic and Atmospheric Administration.

Iakunin, L.P. (1992) Changeability of ice cover and navigation conditions in the Bering Sea. In *Proceedings of the 2nd International Offshore and Polar Engineering Conference, 14–19 June, San Francisco*, vol. 2, p. 795–796. Golden, Colorado: International Society of Offshore and Polar Engineers (ISOPE).

Inkster, D.R., J. Crawford and D. Grant (1983) Real time surveillance of the Bering Sea ice edge using airborne radar. In *Proceedings of the 7th International Conference on Port and Ocean Engineering under Arctic Conditions, 5–9 April, Helsinki, Finland*, vol. 3, p. 163–172. Espoo: Technical Research Centre of Finland.

Izrael', Iu.A. (1983) Investigation of the Bering Sea ecosystem (in Russian with abridged English table of contents). Leningrad: Gidrometeoizdat.

Jarlan, G. (1987) Remarks on the Arctic Ocean and ice-drifting in Beaufort Sea (Remarques sur l'Océan Arctique et la dérive des glaces en Mer de Beaufort) (in French with English summary). *Inter-Nord*, no. 18, p. 25–35.

Johnson, W.R. and Z. Kowalik (1986) Modeling of storm surges in the Bering Sea and Norton Sound. *Journal of Geophysical Research*, 91(C4): 5119–5128.

Johnson, W.R. (1988) Physical oceanography. In *Environment and Resources of the Southeastern Chukchi Sea* (M.J. Hameedi and A.S. Naidu, Eds.), p. 29–38. Anchorage: U.S. National Oceanic and Atmospheric Administration.

Kantha, L.H. and G.L. Mellor (1989) Two-dimensional coupled ice–ocean model of the Bering Sea Marginal Ice Zone. *Journal of Geophysical Research*, 94(C8): 10,921–10,935

Keinonen, A.J., R.P. Browne, C.R. Revill and I.M. Bayly (1990) Summary of Beaufort Sea icebreaker performance. In *Proceedings of the 4th International Conference on Icebreaking and Related Technologies, Calgary, Canada*, p. I/1–I/10. Calgary: Society of Naval Architects and Marine Engineers.

Kovacs, A. (1981) Shore ice ride-up and pile-up features. Part 1: Alaska's Beaufort Sea coast. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, CRREL Report 83-09.

Kovacs, A. (1982) Bering Strait sea ice and the Fairway Rock icefoot. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, CRREL Report 82-31.

Kovacs, A. (1983) Characteristics of mu pressure ridges. In *Proceedings of the 7th tional Conference on Port and Ocean Engi under Arctic Conditions, 5–9 April, Helsinki, Fin-*

land, vol. 3, p. 173–182. Espoo: Technical Research Centre of Finland.

Kovacs, A. (1983) Sea ice on the Norton Sound and adjacent Bering Sea coast. In *Proceedings of the 7th International Conference on Port and Ocean Engineering under Arctic Conditions, 5–9 April, Helsinki*, vol. 4, p. 654–666. Espoo: Technical Research Centre of Finland.

Kovacs, A. (1984) Shore ice ride-up and pile-up features. Part 2: Alaska's Beaufort Sea coast—1983 and 1984. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, CRREL Report 84-26.

Kovacs, A. and W.F. Weeks (1981) Dynamics of near-shore ice. In *Environmental Assessment of the Alaskan Continental Shelf, Vol. 7, Hazards*. Principal investigators' annual reports for the year ending March 1981, p. 125–135. Boulder, Colorado: Outer Continental Shelf Environmental Assessment Program.

Kowalik, Z. (1984) Storm surges in the Beaufort and Chukchi Seas. *Journal of Geophysical Research*, 89(C6): 10570–10578.

LaBelle, J.C., J.L. Wise, R.P. Voelker, R.H. Schulze and G.M. Wohl (1983) *Alaska Marine Ice Atlas*. Arctic Environmental Information and Data Center. Anchorage: University of Alaska.

Leendertse, J.J. and S.K. Liu (1981) Modeling of tides and circulations of the Bering Sea. In *Environmental Assessment of the Alaskan Continental Shelf, Vol. 5, Transport*. Principal investigators' annual reports for the year ending March 1981, p. 87–108. Boulder, Colorado: Outer Continental Shelf Environmental Assessment Program.

Lewis, J.K. and W.W. Denner (1988) Arctic ambient noise in the Beaufort Sea: seasonal relationships to sea kinematics. *Acoustical Society of America Journal*, 83(2): 549–565.

Lewis, J.K., R.D. Crissman and W.W. Denner (1986) Estimating ice thickness and internal and stress forces in pack ice using Lagrangian data. *Journal of Geophysical Research*, 91(C7): 8537–8541.

Lewis, J.K., R.E. Englebretson and W.W. Denner (1989) Examples of ice pack rigidity and mobility characteristics determined from ice motion. *Geojournal*, 18(1): 69–77.

Lindsay, R.W. and A.L. Comiskey (1982) Surface and upper-air observations in the eastern Bering Sea, February and March 1981. Technical memorandum, ERL PMEL-35. U.S. National Oceanic and Atmospheric Administration.

Lissauer, I.M., L.E. Hachmeister and B.J. Morson (1984) *Atlas of the Beaufort Sea*. U.S. Coast Guard, Report CG-D-33-84.

Liu, S.K. and J.J. Leendertse (1987) Modeling the Alaskan continental shelf waters. R-3567-NOAA/RC. U.S. National Oceanic and Atmospheric Administration. Santa Monica, California: Rand Corporation.

Loire, R. and W.Y. Chow (1985) Single point mooring for the Bering Sea. In *Conference Arctic '85, Proceedings of the Civil Engineering in the Arctic Offshore Conference* (F.L. Bennett and J.L. Machemehl, Eds.), p. 998–1008. New York: American Society of Civil Engineers.

Lyden, J.D., B.A. Burns and A.L. Maffett (1984) Characterization of sea ice types using synthetic aperture radar. *IEEE Transactions on Geoscience and Remote Sensing*, GE-22(5): 431–439.

Macdonald, D.M., L.E. Cuypers, D. McCullough, E.C. Carmack and R.W. Macdonald (1988) Physical data collected in the Beaufort Sea, March–June 1987. NOGAP B.6, vol. 2. Canadian Data Report of Hydrography and Ocean Sciences, no. 60. Sidney, B.C.: Institute of Ocean Sciences, Department of Fisheries and Oceans.

MacNeill, M.R. and J.F. Garrett (1975) Open water surface currents in the southern Beaufort Sea. BSP technical report no. 17. Victoria, B.C.: Beaufort Sea Project, Environment Canada.

Madsen, J. and D.N. Bhula (1985) North Sea technology transfer to the Bering Sea. In *Conference Arctic '85, Proceedings of the Civil Engineering in the Arctic Offshore Conference* (F.L. Bennett and J.L. Machemehl, Eds.), p. 1009–1017. New York: American Society of Civil Engineers.

Martin, S. (1985) Introduction to MIZEX-West. In *MIZEX—A Program for Mesoscale Air–Ice–Ocean Interaction Experiments in Arctic Marginal Ice Zones. 6: MIZEX-West*, p. 11–12. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, Special Report 85-6.

Martin, S. and P. Kauffman (1982) Movement and decay of ice edge bands in the winter Bering Sea. *Journal of Geophysical Research*, 88(C5): 2803–2812.

Martin, S., D.J. Cavalieri, P. Gloersen and S.L. McNutt (1982) Bering Sea ice cover during March 1979: Comparison of surface and satellite data with the Nimbus-7 SMMR (annual report). Seattle: Washington University.

Matthews, J.B. (1981) Observations of surface and bottom currents in the Beaufort Sea near Prudhoe Bay, Alaska. *Journal of Geophysical Research*, 86(C7): 6653–6660.

Maynard, N.G. (1986) Coastal zone color scanner imagery in the marginal ice zone. *Marine Technology Society Journal*, 20(2): 14–27.

Maynard, N.G. and D.K. Clark (1987) Satellite color observations of spring blooming in Bering Sea shelf waters during the ice edge retreat in 1980. *Journal of Geophysical Research*, 92(C7), p. 7127–7139.

McCullough, D., R.W. Macdonald, K. Iseki and E.C. Carmack (1988) Beaufort Sea current

measurements, March–August 1987. NOGAP B.6; vol. 1. Canadian Data Report of Hydrography and Ocean Sciences, no. 60. Sidney, B.C.: Institute of Ocean Sciences, Department of Fisheries and Oceans.

McCullough, D., R.W. Macdonald, K. Iseki and E.C. Carmack (1988) Beaufort Sea current measurements, September 1987–March 1988. NOGAP B.6, vol. 3. Canadian Data Report of Hydrography and Ocean Sciences, no. 60. Sidney, B.C.: Institute of Ocean Sciences, Department of Fisheries and Oceans.

McGonigal, D. (1983) Rubble field study, Issungnak, 1979–80, vol. 1, Executive summary. Report APOA no. 171–1V1. Calgary, Alberta: Arctic Petroleum Operators Association.

McGonigal, D. and B.D. Wright (1982) First-year pressure ridges in the Beaufort Sea. In *Proceedings of the International Conference on Marine Research, Ship Technology and Ocean Engineering, 29–30 September, Hamburg*, p. 444–459. Hamburg: Intermaritec '82.

McConigal, D., A.F. Stirbys and J.L. Lussenberg (1986) Incursion of Alaskan multiyear ice features and their associated scours in the Canadian Beaufort Sea. In *Proceedings of the Workshop on Ice Scour Research, 5–6 February, Calgary, Alberta* (C.F.M. Lewis, Ed.). Environmental Studies Revolving Funds, report no. 49, p. 51–59.

McKenna, R.F., J.F. Sykes, S. Venkatesh and V.R. Neralla (1985) Choice of reference frame for modelling pack ice motion. In *Proceedings of the 8th International Conference on Port and Ocean Engineering under Arctic Conditions, 7–14 September, Narssarssuaq, Greenland*, vol. 1, p. 249–260. Hørsholm: Danish Hydraulic Institute.

McLaren, A.S., P. Wadhams and R. Weintraub (1984) Sea ice topography of M'Clure Strait in winter and summer of 1960 from submarine profiles. *Arctic*, 37(2): 110–120.

McNutt, L. (1980) Ice conditions in the eastern Bering Sea from NOAA and LANDSAT imagery: Winter conditions 1974, 1976, 1977, 1979. U.S. National Oceanic and Atmospheric Administration, NOAA technical memorandum, ERL PMEL-24.

McNutt, S.L. (1980) Remote sensing analysis of ice growth and distribution in the eastern Bering Sea. In *Eastern Bering Sea Shelf: Oceanography and Resources* (D.W. Hood and J.A. Calder, Eds.), p. 141–165. Washington, D.C.: U.S. Department of Commerce.

Meese, D.A. (1989) Chemical and structural properties of sea ice in the southern Beaufort Sea. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, CRREL Report 89-25.

Melling, H. (1983) Oceanographic features of the Beaufort Sea in early winter. Canadian Technical Report of Hydrography and Ocean Sciences, no. 20.

Mercer, J.B., G. McAvoy, E. Leavitt and R. Lowry (1986) Advanced radar systems for support of Arctic marine operations. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 2, p. 839–858. Vancouver, B.C.: D.F. Dickins Associates.

Meyer, J.R. and J.L. Coburn (1986) Bering Sea winter ice edge data collection aboard USCGC *Polar Sea*, vol. 3, Propeller-ice loads, Draft report April–August 86. Report MA-RD-760-87066. Washington, D.C.: U.S. Maritime Administration.

Mitton, F.E. (1985) Beaufort Sea—An operating challenge. In *Proceedings of the Arctic Offshore Technology Conference and Exposition, 3–5 September, Anchorage, Alaska.*

Muench, R.D. (1983) Mesoscale oceanographic features associated with the central Bering Sea ice edge: February–March 1981. *Journal of Geophysical Research*, 88(C5): 2715–2722.

Muench, R.D., G.R. Stegen, L.E. Hachmeister and S. Martin (1983) Prediction of ice distribution and movement in the outer marginal ice zone. In *Proceedings of the 7th International Conference on Port and Ocean Engineering under Arctic Conditions, 5–9 April, Helsinki, Finland*, vol. 1, p. 190–199. Espoo: Tech ical Research Centre of Finland.

Muench, R.D., J.L. Newton and R.L. Rice (1985) Temperature and salinity observations in the Bering Sea winter. In *MIZEX—A Program for Mesoscale Air–Ice–Ocean Interaction Experiments in Arctic Marginal Ice Zones. 6: MIZEX-West.* Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, Special Report 85-06, p. 13–30.

Muench, R.D. J.D. Schumacher and S.A. Salo (1988) Winter currents and hydrographic conditions on the northern central Bering Sea shelf. *Journal of Geophysical Research*, 93(C1), p. 516–526.

Mungall, C. (1986) Beaufort Sea atlas. *Geos*, 15(2): 10–11.

Murphy, D.L., I.M. Lissauer, J.C. Myers, and J.W. Steen (1983) Satellite-tracked buoy trajectories in the Beaufort Sea. In *Proceedings of the 6th Arctic Marine Oilspill Program Technical Seminar, 14–16 June, Edmonton, Alberta*, p. 223–232. Edmonton.

National Ocean Survey (1983) United States Coast Pilot 9. Pacific and Arctic coasts Alaska: Cape Spencer to Beaufort Sea. Rockville, Maryland, 11th edition.

Neralla, V.R. and S. Venkatesh (1985) Winter ice experiment Beaufort Sea (WIEBS)—Collection and archival of data. In *Proceedings of the 8th International Conference on Port and Ocean Engi-*

neering under Arctic Conditions, 7–14 September, Narssarssuaq, Greenland, vol. 1, p. 283–292. Hørsholm: Danish Hydraulic Institute.

Niebauer, H.J. (1988) Effects of El Nino—Southern oscillation and North Pacific weather patterns on interannual variability in the subarctic Bering Sea. *Journal of Geophysical Research*, 93(C5): 5051–5068.

Niebauer, H.J. (1991) Bio-physical oceanographic interactions at the edge of the arctic ice pack. *Journal of Marine Systems*, 2(1–2): 209–232.

Niebauer, H.J. and R.H. Day (1989) Causes of interannual variability in the sea ice cover of the eastern Bering Sea. *Geojournal*, 18(1): 45–59.

Niebauer, H.J. and V. Alexander (1989) Current perspectives on the role of ice margins and polynyas in high latitude ecosystems. In *Proceedings of the 6th Conference of the Comité Arctique International, 13–15 May, Fairbanks, Alaska* (L. Rey and V. Alexander, Eds.), p. 121–144. Leiden, Netherlands: E.J. Brill.

Niebauer, H.J., V. Alexander and R.T. Cooney (1981) Primary production at the eastern Bering Sea ice edge: The physical and biological regimes. In *Eastern Bering Sea Shelf: Oceanography and Resources* (D.W. Hood and J.A. Calder, Eds.), vol. 2, p. 763–772. Washington, D.C.: National Oceanic and Atmospheric Administration.

NOAA (1986) Outer Continental Shelf Environmental Assessment Program; Final reports of principal investigators, vol. 40. National Oceanic and Atmospheric Administration, Ocean Assessment Division, Anchorage, Alaska.

NOAA (1986) Outer Continental Shelf Environmental Assessment Program; Final reports of principal investigators, vol. 41. National Oceanic and Atmospheric Administration, Ocean Assessment Division, Anchorage, Alaska.

NOAA (1988) Outer Continental Shelf Environmental Assessment Program; Comprehensive bibliography. National Oceanic and Atmospheric Administration, Ocean Assessment Division, Anchorage, Alaska.

Norton, D. and G. Weller (1984) Beaufort Sea: Background, history, and perspective. In *Alaskan Beaufort Sea: Ecosystems and Environments* (P.W. Barnes, D.M. Schell and E. Reimnitz, Eds.), p. 3–19. Orlando, Florida: Academic Press.

Overland, J.E. and C.H. Pease (1982) Cyclone climatology of the Bering Sea and its relation to sea ice extent. *Monthly Weather Review*, 110(1), 5–13.

Overland, J.E. and A.T. Roach (1987) Northward flow in the Bering and Chukchi Seas. *Journal of Geophysical Research*, 92(C7): 7097–7105.

Overland, J.E., B.A. Walter and K.L. Davidson (1992) Sea ice deformation in the Beaufort Sea. In *3rd Conference on Polar Meteorology and Oceanography, 29 September–2 October, Portland, Oregon*, p. 64–67. Boston: American Meteorological Society.

Padron, D.V., E.H.Y. Han and M.T. Faeth (1985) Bering Sea crude oil transportation systems. In *Conference Arctic '85, Proceedings of the Civil Engineering in the Arctic Offshore Conference* (F.L. Bennett and J.L. Machemehl, Eds.), p. 989–997. New York: American Society of Civil Engineers.

Parker, M.N. (1989) Polar lows in the Beaufort Sea. In *Polar and Arctic Lows* (P.F. Twitchell, E.A. Rasmussen, and K.L. Davidson, Eds.), p. 323–330. Hampton, Virginia: A. Deepak Publishing.

Pease, C.H. (1980) Eastern Bering Sea ice processes. *Monthly Weather Review*, 108(12): 2015–2023.

Pease, C.H. (1985) Sea ice dynamics and regional meteorology for the Arctic Polynya Experiment (APEX)—Bering Sea 1985. U.S. National Oceanic and Atmospheric Administration, NOAA technical memorandum, ERL PMEL-64.

Pease, C.H. and S.A. Salo (1981) Drift characteristics of northeastern Bering Sea ice during 1980. U.S. National Oceanic and Atmospheric Administration, NOAA technical memorandum, ERL PMEL-32.

Pease, C.H., S.A Schoenberg and J.E. Overland (1982) Climatology of the Bering Sea and its relation to sea ice extent. U.S. National Oceanic and Atmospheric Administration, NOAA technical report, ERL 419-PMEL 36.

Pilkington, G.R. and B.D. Wright (1991) Beaufort Sea ice thickness measurements from an acoustic, under ice, upward looking ice keel profiler. In *Proceedings of the 1st International Offshore and Polar Engineering Conference, 11–16 August, Edinburgh, U.K.*, vol. 2, p. 456–461. Golden, Colorado: International Society of Offshore and Polar Engineers.

Pilkington, R. (1983) Physical environment of the Beaufort Sea and its impact on operations and structures. In *Proceedings of the Conference on Canadian Offshore Drilling and Downhole Technology (CODD), 12–14 September, Edmonton, Alberta*. Calgary, Alberta.

Plotnikov, V.V. (1984) Statistical forecasting method for the ice edge in the Bering Sea. *Soviet Meteorology and Hydrology*, no. 2, p. 47–52.

Potter, R.E. (1985) Arctic transportation: an overview. In *Proceedings of the Arctic Offshore Technology Conference and Exposition, 3–5 September, Anchorage, Alaska.*

Pritchard, R.S. and M.D. Coon (1981) Canadian Beaufort Sea ice characterization. In *Proceedings of the 6th International Conference on Port and Ocean Engineering under Arctic Conditions, 27–31 July, Quebec*, p. 609–618. Quebec: Université Laval.

Pritchard, R.S., M.D. Coon and M.G. McPhee (1987) Forecasting summer ice conditions in the Beaufort Sea. In *Proceedings of the 6th International*

Offshore Mechanics and Arctic Engineering Symposium, 1–6 March, Houston, Texas, vol. 4, p. 371–377. New York: American Society of Mechanical Engineers.

Pritchard, R.S., A.C. Mueller, D.J. Hanzlick and Y.S. Yang (1990) Forecasting Bering Sea ice edge behavior. *Journal of Geophysical Research*, 95(C1): 775–788.

Ray, V.M. and W.R. Dupre (1980) Ice-dominated regimen of Norton Sound and adjacent areas of the Bering Sea. In *Eastern Bering Sea Shelf: Oceanography and Resources* (D.W. Hood and J.A. Calder, Eds.), p. 263–278. Washington, D.C.: U.S. Department of Commerce.

Reed, R.J. and S. Businger (1992) Comments on "An arctic hurricane over the Bering Sea." *Monthly Weather Review*, 120(11): 2713–2715.

Reimnitz, E., S.M. Graves and P.W. Barnes (1988) Map showing Beaufort Sea coastal erosion, sediment flux, shoreline evolution, and the erosional shelf profile. U.S. Geological Survey, Miscellaneous investigations series, MAP I-1182 G.

Reynolds, M. (1984) On the local meteorology of the marginal ice zone of the Bering Sea. *Journal of Geophysical Research*, 89(C4): 6515–6524.

Reynolds, M., C.H. Pease and J.E. Overland (1985) Ice drift and regional meteorology in the southern Bering Sea: Results from MIZEX West. *Journal of Geophysical Research*, 90(C6): 11,967–11,981.

S.L. Ross Environmental Research, Ltd. (1986) Testing of an oil recovery concept for use in brash and mulched ice. Environmental Studies Revolving Funds, Report no. 018.

Ryerson, C. and P.D. Longo (1992) Ship superstructure icing: Data collection and instrument performance on USCGC *Midgett* research cruise. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory, CRREL Report 92-23.

Ryzhov, V.M., V.P. Rusanov, and V.S. Latyshev (1984) Chemical–biological indication of water masses in the Chukchi Sea (in Russian). *Trudy*, vol. 368, p. 26–40. Leningrad: Arctic and Antarctic Research Institute.

Salo, S., R.D. Muench and J.D. Schumacher (1988) Oceanographic conditions on the northern Bering Sea shelf: 1984–1985. U.S. National Oceanic and Atmospheric Administration, NOAA technical memorandum, ERL PMEL-80.

Schulze, R., W. Thayer and P. Zahn (1983) Spill response system for breakup. In *Proceedings of the 6th Arctic Marine Oilspill Program Technical Seminar, 14–16 June, Edmonton, Alberta*, p. 154–160. Edmonton.

Schumacher, J.D., A.T. Roach and K. Aagaard (1985) Fluctuations of flow through Bering Strait. In *MIZEX—A Program for Mesoscale Air–Ice–Ocean Interaction Experiments in Arctic Marginal Ice Zones. 6: MIZEX-West.*, Special Report 85-06, p. 105–111. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory.

Seibold, F. and R. Voelker (1988) Mid-winter 1985 ship transit in the Alaskan arctic by the icebreaker *Polar Sea*. In *Proceedings of the 9th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–22 August, Fairbanks* (W.M. Sackinger and M.O. Jeffries, Eds.), vol. 1, p. 575–587. Fairbanks, University of Alaska, Geophysical Institute.

Semenov, S. (1988) Diesel-electric ship *Vitus Bering* (in Russian). *Morskoi Flot* (Maritime Journal), no. 2, p. 41–45.

Serreze, M.C., R.G. Barry and A.S. McLaren (1990) Reversals of the Beaufort Gyre sea ice circulation and effects on ice concentration in the Canada Basin. In *Sea Ice Properties and Processes, Proceedings of the W.F. Weeks Sea Ice Symposium, San Francisco, California. December 1988*, Monograph 90-01, p. 185–188. Hanover, N.H.: USA Cold Regions Research and Engineering Laboratory.

Shinde, S.B. (1981) Ice conditions around Issungnak, 1979–80. Data report. Report APOA no. 171-1V3. Calgary, Alberta: Arctic Petroleum Operators Association.

Sisodiya, R.G. and K.D. Vaudrey (1981) Beaufort Sea first year ice features survey—1979. In *Proceedings of the 6th International Conference on Port and Ocean Engineering under Arctic Conditions, 27–31 July, Quebec, Canada*, p. 755–764. Quebec: Université Laval.

Spedding, L.G., M.C. Hill and C. Hill (1987) Multi-year ice statistics. In *Proceedings of the Workshop on Extreme Ice Features, 3–5 November 1986, Banff, Alberta* (compiled by G.R. Pilkington and B.W. Danielewicz). National Research Council, Canada, Technical memorandum, no. 141, p. 81–120.

St. John, J.W. (1987) Bering Sea winter ice edge data collection aboard USCGC *Polar Sea*. vol. 2, Hull ice impact loads, Final report Apr.–Nov. 86. Report MA-RD-760-87065. Washington, D.C.: U.S. Maritime Administration.

St. John, J.W., G.M. Wohl, J.R. Meyer and J.L. Coburn (1986) Navarin Basin and ice edge data collection aboard USCGC *Polar Sea*, vol. 1, Environmental data, March/April 1985. Report MA-RD-760-87057. Washington, D.C.: U.S. Maritime Administration.

St. John, J.W., G.M. Wohl, J.R. Meyer and J.L. Coburn (1986) Navarin Basin and ice edge data collection aboard USCGC *Polar Sea*, vol. 3, Field study of personnel evacuation and survival from arctic class ships, March/April 1985. Report

MA-RD-760-87059. Washington, D.C.: U.S. Maritime Administration.

Steffen, K. and A.J. Schweiger (1989) Sensitivity of passive microwave sea ice concentration algorithms to the selection of locally and seasonally adjusted tie points. In *Proceedings of the International Geoscience and Remote Sensing Symposium, 10–14 July, Vancouver, Canada*, vol. 2, p. 773–776. IEEE Geoscience and Remote Sensing Society.

Steffen, K. and A. Schweiger (1991) NASA team algorithm for sea ice concentration retrieval from Defense Meteorological Satellite Program special sensor microwave imager: comparison with Landsat satellite imagery. *Journal of Geophysical Research*, 96(C12): 21,971–21,987.

Stringer, W.J. (1980) Nearshore ice characteristics in the eastern Bering Sea. In *Eastern Bering Sea Shelf: Oceanography and Resources* (D.W. Hood and J.A. Calder, Eds.), p. 167–187. Washington, D.C.: U.S. Department of Commerce.

Stringer, W.J. (1982) Characteristics of nearshore ice in southwestern Alaska. *Journal of Environmental Sciences*, 25(5): 23–29.

Stringer, W.J. and J.E. Groves (1985) Summertime sea ice intrusions in the Chukchi Sea. In *Proceedings of the Arctic Energy Technologies Workshop, 14–15 November, 1984, Morgantown, West Virginia.* U.S. Department of Energy, Morgantown Energy Technology Center, *DOE/METC-85/6014*, p. 91–101.

Stringer, W.J. and G.L. Hufford (1982) Interaction of Bering Sea and Norton Sound pack ice. *Arctic and Alpine Research*, 14(2): 149–156.

Stringer, W.J., S.A. Barrett and L.K. Schreurs (1980) Nearshore ice conditions and hazards in the Beaufort, Chukchi, and Bering Seas. Fairbanks: University of Alaska, Geophysical Institute.

Stringer, W.J., M.E. Bauman and L.J. Roberts (1981) Summertime ice concentration in the Harrison and Prudhoe Bay vicinities of the Beaufort Sea. Prepared for NOAA–OCSEAP by Research Unit 267. Contract no. 03-5-022-55, task 19.

Swift, C.T., L.S. Fedor and R.O. Ramseier (1985) Algorithm to measure sea ice concentration with microwave radiometers. *Journal of Geophysical Research*, 90(C1): 1087–1099.

Thomas, D.J., R.W. Macdonald and A.B. Cornford (1982) Arctic data compilation and appraisal, vol. 2, Beaufort Sea: Chemical oceanography. Canadian data report of hydrography and ocean sciences, no. 5. Sidney, B.C.: Institute of Ocean Sciences, Department of Fisheries and Oceans.

Torgerson, L.J. and Stringer, W.J. (1985) Observations of double arch formation in the Bering Strait. *Geophysical Research Letters*, 12(10): 677–680.

Tucker, W.B. and W.D. Hibler III (1987) Evaluation of an operational ice forecasting model during summer. In *Proceedings of the 9th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–22 August, Fairbanks* (W.M. Sackinger and M.O. Jeffries, Eds.), vol. 1, p. 159–174. Fairbanks: University of Alaska, Geophysical Institute.

Twitchell, P.F. and R.W. Fett (1988) Small high-latitude ocean storms. In *Proceedings of the 9th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–21 August, Fairbanks* (W.M. Sackinger and M.O. Jeffries, Eds.), vol. 3, p. 207–214. Fairbanks: University of Alaska.

U.S. Army Corps of Engineers (1993) Cook Inlet, Alaska, Deep Draft Navigation Reconnaissance Report. Alaska District, USA Corps of Engineers, Department of the Army. Anchorage: USA Engineer District, Alaska.

U.S. Ocean Assessments Division. Strategic Assessment Branch (1988) Bering, Chukchi, and Beaufort Seas coastal and ocean zones. Strategic assessment data atlas. Rockville, Maryland: National Oceanographic Atmospheric Administration.

Ulander, L.M.H. (1987) Interpretation of Seasat radar-altimeter data over sea ice using near-simultaneous SAR imagery. *International Journal of Remote Sensing*, 8(11): 1679–1686.

Vaudrey, K.D. (1980) Issungnak rubble pile—field installation of ice stress panels—Interim report. Report APOA no. 171-1V4. Calgary, Alberta: Arctic Petroleum Operators Association.

Veneziano, D. and L. Chouinard (1985) Spatial analysis of ice charts. In *Conference Arctic '85, Proceedings of the Civil Engineering in the Arctic Offshore Conference* (F.L. Bennett and J.L. Machemehl, Eds.), p. 386–394. New York: American Society of Civil Engineers.

Voelker, R.P. (1983) Trafficability program reports for April 1979, winter 1981, winter 1982 and winter 1983 to the U.S. Maritime Administration. Columbia, Maryland: ARCTEC, Inc.

Voelker, R.P., F.W. DeBord, F.A. Geisel, J.L. Coburn and K.E. Dane (1981) Winter 1981 trafficability tests of the USCGC *Polar Sea*. ARCTEC, Inc., Report, 1981-No. 583C-3, 12 volumes.

Voelker, R.P., F.A. Geisel and G.M. Wohl (1984) Bering Sea data collection aboard USCGC *Polar Star*, Feb.–Mar., 1984. vol. 1, Environmental data. Draft report Mar.–Nov. 1984. Report MA-RD-760-87042. Washington, D.C.: U.S. Maritime Administration.

Voelker, R.P., F.A. Geisel, A.P. Free and R.B. Strem (1985) Beaufort Sea data collection: Multiyear ice research aboard USCGC *Polar Sea*, November 11–December 4, 1984. Report 1985-MA-RD-760-

87056. Washington, D.C.: U.S. Maritime Administration.

Voelker, R.P., F.A. Geisel, L.W. Strayer and K.E. Dane (1982) Summer multiyear ice properties in the Beaufort Sea (October 1982). Report MA-RD-760-87054. Washington, D.C.: U.S. Maritime Administration.

Wainwright, J. and E. Makinen (1986) First winter's experience with the air cushion vehicle *Larus* in the Beaufort Sea. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 2, p. 693–709. Vancouver, B.C.: D.F. Dickins Associates.

Walter, B.A. (1980) Wintertime observations of roll clouds over the Bering Sea. *Monthly Weather Review,* 108(12): 2024–2031.

Walter, B.A. and J.E. Overland (1992) Aircraft measurements of regional air–ice drag coefficients during high wind conditions over the Beaufort Sea. In *3rd Conference on Polar Meteorology and Oceanography, 29 September–2 October, Portland, Oregon,* p. 48–49. Boston: American Meteorological Society.

Webster, B.D. (1981) Climatology of the ice extent in the Bering Sea. U.S. National Oceanic and Atmospheric Administration, NOAA technical memorandum, NWS AR-33.

Webster, B.D. (1982) Empirical probabilities of the ice limit and fifty percent ice concentration boundary in the Chukchi and Beaufort Seas. NOAA technical memorandum, NWS AR-34. U.S. National Oceanic and Atmospheric Administration.

Weeks, W.F. (1984) Variation of ice strength within and between multiyear pressure ridges in the Beaufort Sea. In *Proceedings of the 3rd International Offshore Mechanics and Arctic Engineering Symposium, 12–17 February, New Orleans, Louisiana,* p. 134–139. New York: American Society of Mechanical Engineers.

Wen, T. (1990) Environmental measurements in the Beaufort Sea, spring 1990. Technical report, 1990-APL-UW TR9105. Seattle: University of Washington, Applied Physics Laboratory.

Westermeyer, W.E. (1984) Transportation of Arctic energy resources. In *United States Arctic Interests: The 1980s and 1990s* (W.E. Westermeyer and K.M. Shusterich, Eds.), p. 105–133. New York: Springer-Verlag.

Williams, D.R.P. (1986) Determination of sea ice concentration and ice edge position in the Beaufort Sea using satellite passive microwave data. In *Proceedings of the Canadian East Coast Workshop on Sea Ice, 7–9 January, Bedford, Quebec,* (compiled by G. Symonds and I.K. Peterson) Canadian Technical Report of Hydrography and Ocean Sciences, no. 73, p. 526–536.

Wilson, J.G., A.L. Comiskey, R.W. Lindsay and V.L. Long (1984) Regional meteorology of the Bering Sea during MIZEX (Marginal Ice Zone Experiment) West, February and March, 1983. National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory, Contribution CONTRIB-729.

Wong, C.S., R.W. Macdonald, R.D Bellegay and P. Erickson (1980) Baseline data on chemical oceanography in the southern Beaufort Sea, 1974–5. Beaufort Sea Project, Canada, technical report no. 14.

Woods, S.M. and B.D. Smiley (1987) Arctic data compilation and appraisal, vol. 9, Beaufort Sea: Biological oceanography—Bacteria, plankton, epontic community 1914 to 1985. Canadian Report of Hydrography and Ocean Sciences, no. 5. Sidney, B.C.: Institute of Ocean Sciences, Department of Fisheries and Oceans.

Wright, B.D., D.L. Schwab and D. McGonigal (1982) Ice conditions affecting navigation in the Beaufort Sea. In *Proceedings of the 6th Ship Technology and Research (STAR) Symposium, 17–19 June 1981, Ottawa, Ontario.* Paper discussions, authors' closures, and panel transcript, Paper no. 9, p. 121–135. New York: Society of Naval Architects and Marine Engineers.

Zahn, P.B. and J.W. St. John (1987) Bering Sea winter ice edge data collection aboard USCGC *Polar Sea,* vol. 1, Environmental data. Final report Apr.–Nov. 86. Report MA-RD-760 87064. Washington, D.C.: U.S. Maritime Administration.

ICEBREAKING TECHNOLOGY

Aikashev, F.I. and B.S. Volenko (1987) Selecting methods of counteracting the icing of lighters (in Russian). In *New Types of Ships and Their Seagoing Qualities* (V.I. Peresypkin, Ed.), p. 64–68. Leningrad: Transport.

Albery, A.C.R., S.T. Mathews and B.D. Macissac (1984) M.V. *Arctic*, ice transiting performance in continuous mode. Report TP 5170E. Montreal: Transportation Development Centre.

Anon. (1981) Quadruple-screw river icebreakers for USSR. *Shipbuilding and Marine Engineering International*, 104(1248): 181.

Anon. (1982) Arctic tankers through the Northwest Passage. *Beaufort*, 2(2): 21–27.

Anon. (1982) Design for a nuclear-propelled icebreaking LASH and/or container ship (in German). *Schiff und Hafen* (Ships and Harbors), 34(2): 32–40.

Anon. (1982) Large icebreaking cargo ships are better than icebreakers for arctic operations (in Swedish). *Svensk Sjöfartstidning* (Swedish Shipping News), 78(47): 19–21.

Anon. (1982) Profile of an arctic tanker. *Beaufort*, 1(3): 15–18.

Anon. (1983) Diesel–mechanical transmission for Soviet sub-arctic icebreakers (*Mudyug, Magadan and Dikson*). *Shipbuilding and Marine Engineering International*, 106(1268): 153–155.

Anon. (1983) Shallower-draught Soviet icebreakers from Wartsila. *Shipbuilding and Marine Engineering International*, 106(1267): 155.

Anon. (1984) Finland—leader in icebreaking technology: Finns find market in special vessels. *Offshore*, 44(5): 167–172.

Anon. (1986) Arctic shipping. *Arctic News-Record*, 5(1): 17–29.

Anon. (1987) Ice navigation. *Arctic News-Record* and *Polar Bulletin*, 6.2(3–4): 22–25.

Anon. (1988) New class of arctic supply ship for the Soviet Union. *Maritime Defence*, 4: 141.

Anon. (1989) Atomic icebreaker *Taymyr*. *Soviet Shipping*, 9(2): 12–15.

Anon. (1989) Cathodic protection for ice-going ships. *Motor Ship*, 70(829): 17–18.

Anon. (1989) *Taymyr*: A new nuclear icebreaker for the Soviet Union. *Naval Architect*, E314–E315.

Anon. (1990) *Igor Ilinskiy*—multi-purpose arctic cargo ship. *Marine Log*, 95(11): p. 28.

Anon. (1991) Icebreaker systems show innovations in engineering. *HSB International*, 40(4): 34–35.

Anon. (1991) Masa-Yards to build icebreaker for USSR. *HSB International*, 39(11): 43.

Arikainen, A.I. (1973) Peculiarities of ice-condition variations in Arctic seas and their use in long-range forecasting (in Russian). *Trudy*, vol. 307, p. 97–102. Leningrad: Arctic and Antarctic Research Institute.

Arikainen, A.I. (198_) Icebreakers of Canada and the USA (in Russian). *Morskoi Flot* (Maritime Journal) , no. 6, p. 56–59.

Arikainen, A.I. (1982) Ships for the Arctic: Trends in design development (in Russian). *Morskoi Flot* (Maritime Journal), no. 9, p. 50–53.

Arikainen, A.I. (1984) National economic criteria of evaluating comparative economic efficiency of icebreakers of different models and capability—Moscow (in Russian). In *Collected Papers of the Institute for Systems Studies*, no. 9, p. 78–79.

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Arikainen, A.I. (1987) Systematic approach to the ice casualty rate (in Russian). *Morskoi Flot* (Maritime Journal), no. 8, p. 20–23.

Arikainen, A.I. (1988) Developing the structure of the ice-breaking fleet for objectives of the national economy (in Russian). *Objectives, Planning and Organization of Fleet Operations* (V.I. Peresypkin, Ed.), p. 99–103, Leningrad: Transport.

Arikainen, A.I. (1988) Economic calculations and icebreaker services (in Russian). *Morskoi Flot* (Maritime Journal), no. 6, p. 19–20.

Arikainen, A.I. (1988) What will be the icebreaker of the future (in Russian). *Morskoi Flot* (Maritime Journal), no. 4, p. 33–36.

Arikainen, A.I. (1989) Extending ice navigation (in Russian). Moscow: Znaniye.

Arikainen, A.I. (1989) National economic basis for developing ice navigating transport ships (in Russian). *Operation and Development of Economic Infrastructure (Collected Papers)* (V.N. Livshits and N.I. Belousova, Eds.) vol. 11, p. 9–19. Moscow: All Union Research Institute for Systems Research.

Arikainen, A.I. (1990) Navigation in the ice of the Arctic (in Russian). Moscow: Transport.

Arikainen, A.I. and B. Levit (1989) Estimation of ship and convoy speed in Arctic waters in evaluating fleet development effectiveness. In *Proceedings of the 10th International Conference on Port and Ocean Engineering under Arctic Conditions, 12–16 June, Luleå, Sweden* (K.B.E. Axelsson and L.A. Fransson, Eds.), p. 962–974. Luleå, Sweden: University of Technology.

Bagnekno, F.M. and V.A. Pankov (1981) Barge carrier *Aleksey Kosygin* (in Russian). *Sudostroyenie* (Shipbuilding), no. 12, p. 3–9.

Barabanov, N.V. (1982) Ice loads on the bottom plating of ships (in Russian). *Sudostroyenie* (Shipbuilding), no. 11, p. 9–11.

Barabanov, N.V. (1990) Ship performance in ice in shallow water (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 5–10. Gorky: Gorky Polytechnic Institute.

Basalygin, G.M. (1985) Modeling dynamics of the system turbines-hydraulic gear drive-shafting-propeller during its interaction with ice (in Russian). In *Ships' Power Plants and Electrical Equipment* (Iu.I. Panin, Ed.), p. 3–11. Leningrad: Transport.

Baudin, M. and M. Huther (1987) Design of an icebreaker hull (in French with English summary). *Inter-Nord*, 18: 103–106.

Beliakov, V.B. (1984) New modeling ice. Translated from *Problems of Theory, Strength and Design of Icebreaking Ships*, Gorky Polytechnic Institute. New York: Engineering Consulting and Translation Center.

Beliakov, V.B. (1990) Modeling the movement of icebreaking agents in a continuous ice field (in Russian) In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 26–37. Gorky: Gorky Polytechnic Institute.

Berezhnykh, O.A. (1991) Universal dry-cargo ships capable of ice navigating made in Spain (in Russian) *Sudostroyenie* (Shipbuilding), no. 4, p. 9.

Beyer, S. (1979) From "Yermak" to "Sibir." Washington, DC: U.S. Naval Intelligence Support Center. (Defense Technical Information Center AD B040668L.)

Bhat, S.U. (1988) Analysis for splitting of ice floes during summer impact. *Cold Regions Science and Technology*, 15(1): 53–63.

Blanchet, D., H.R. Kivisild and J. Grinstead (1990) Equations for local ice energy dissipations during ship ramming. *Cold Regions Science and Technology*, 18(2): 101–115.

Boriskin, V.S. and A.V. Savinov (1990) Turbo-supercharged unit of the pneumatic-wash system of an icebreaker hull (in Russian). *Sudostroyenie* (Shipbuilding), no. 11, p. 12–15.

Braginets, O.N. (1990) Forecasting and minimizing the time for mooring operations for transport ships in ice conditions (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 117–125. Gorky: Gorky Polytechnic Institute.

Brigham, L.W. (1987) Emerging polar ship technology—An introduction. *Marine Technology Society Journal*, 21(3): 3–5.

Brigham, L.W. (1991) Technical developments and the future of Soviet arctic marine transportation. In *The Soviet Maritime Arctic* (L.W. Brigham, Ed.), Woods Hole Oceanographic Institution. Annapolis, Maryland: Naval Institute Press.

Brigham, L.W. (1992) Modern icebreaking ships. In *The Shipping Revolution: The Modern Merchant Ship* (R. Gardiner, Ed.), p. 154–158. London: Conway Maritime Press.

Bugakov, V.N. (1981) Effectiveness of strengthening bottom structures in the ship's forebody (in Russian). *Sudostroyenie* (Shipbuilding), no. 5, p. 12–16.

Bugakov, V.N. (1990) Characteristics of an icebreaker design for shoal water (In Russian). *Sudostroyenie* (Shipbuilding), no. 10, p. 7–10.

Bulat, V. (1982) The effect of snow cover on ice resistance. *Naval Architect*, November, p. E253.

Bulat, V., I. Majid and L. Goossens (1985) Experimental determination of factors affecting loads imposed on propellers in ice. Transport Canada, Report TP 6812 E.

Bustard, E.E. (1975) Importance of size in an Arctic ship. In *Proceedings of the Ice Technology Sympo-*

sium, 9–11 April, Montreal, Canada. New York: Society of Naval Architects and Marine Engineers, p. F1–F7.

Buzuev, A.Ia., E.I. Makarov and E.N. Skripnik (1990) Calculating ice navigation difficulties of ships in the White Sea in the compilation of navigation recommendations (in Russian). *Trudy*, vol. 418: 163–170. Leningrad: Arctic and Antarctic Research Institute.

Canavan, M.S. and M.D. Noll (1988) U.S. Coast Guard's new polar icebreaker design. In *Proceedings of the Oceans '88 Conference, 31 October–2 November, Baltimore, Maryland*, vol. 4, p. 1087–1097. New York: Institute of Electrical and Electronics Engineers.

Carter, D. (1983) Ship resistance to continuous motion in level ice. Report TP 3679E. Montreal: Transportation Development Centre.

Chatterton, H.A. and W.M. Simpson (1982) U.S. Coast Guard wind-class replacement icebreaker. *Marine Technology*, 19(4).

Churcher, A., A. Kolomojcev and G. Hubbard (1984) Design of the icebreaking supply ship *Robert LeMeur*. *Marine Technology*, 21(2): 134–146.

Colburn, J.L., F.W. DeBord, J.B. Montgomery, A.M. Nawwar and K.E. Dane (1981) Rational basis for the selection of ice strengthening criteria for ships. U.S. Coast Guard, Ship Structure Committee, Project SR-1267.

Comfort, G. (1988) Ridge modeling: Model scale simulation of ramming tests conducted with the USCGC *Polar Star*. Transport Canada, Report TP 9496E.

Cowper, B. and M. Edgecombe (1987) 1985 global impact tests on the USCGC *Polar Sea*. Transport Canada, Report TP 8496E.

Daley, C. and R. Brown (1985) Review of proposed revision of the hull structural requirements of the ASPP (Arctic Shipping Pollution Prevention Regulations). Canadian Coast Guard, Report TP 6671E.

Daley, C., J.W. St. John, R. Brown, J. Meyer and I. Glen (1986) Consolidation of local ice impact pressures aboard the USCGC *Polar Sea*. Ship Structure Committee, Report SSC 339, 2 volumes. Washington, D.C.: National Academy of Sciences/National Research Council.

Daley, C.G (1984) Analysis of extreme ice loads measured on USCGC *Polar Sea*. *Society of Naval Architects and Marine Engineers Transactions*, 92: 241–252.

Daley, C.G. and S. Kivimaa (1991) Parametric model study of ships ramming multi-year ice floes. Research Report no. 744. Espoo: Technical Research Centre of Finland.

Daley, C.G., C. Ferregut and R. Brown (1991) Structural risk model of arctic shipping. In *IUTAM/IAHR Symposium, St. John's, Newfoundland, 1989* (S.J. Jones, R.F. McKenna, J. Tillotson and I.J. Jordaan, Eds.), p. 507–540. Berlin: Springer-Verlag.

Danilov, L. (1981) Safe operations of nuclear ships. *Marine Engineering Review*, 82(1): 16–17.

De Heering, P. and P. Sutcliffe (1987) Close range ice hazard detection: Phase 2. Transport Canada, Report TP-8186-E.

Demianchenko, V. (1984) Nuclear-powered icebreaker *Rossiia* (in Russian). *Sudostroyenie* (Shipbuilding), no. 8, p. 3–6.

Demianchenko, V. (1985) Soviet nuclear-powered icebreakers (in Russian). *Sudostroyenie* (Shipbuilding), no. 5, p. 27–29.

Demianchenko, V. (1986) Atomic icebreaker *Rossiya* (in Russian). *Morskoi Flot* (Maritime Journal), no. 4, p. 46–52.

Demianochenko, V., V. Kovalenko and V. Shershnev (1991) Nuclear-powered icebreakers of Murmansk Shipping Company. *Soviet Shipping*, 2: 22–23.

Dey, B.B. (1981) Shipping routes, ice cover and year-round navigation in the Canadian Arctic. *Polar Record*, 20(129): 549–559.

Dick, R.A. (1986) Development of arctic marine technology over the last ten years. In *Proceedings of the 1st International Conference on Ice Technology, June, Cambridge, Massachusetts*. Berlin: Springer, p. 519–536.

Dick, R.A. and J.E. Laframboise (1989) An empirical review of the design and performance of icebreakers. *Marine Technology*, 26(2): 145–159.

Dick, R.A., D.N. Baker, E.W. Thompson and H.C Cheung (1987) Arctic ship technology (state of the art). Transport Canada Report TP 8094E, two volumes. Ottawa, Ontario: Melville Shipping Ltd.

Dubiel, J. and L. Phillips (1987) Influence of bow shape on ice transiting vessel performance parameters. Transport Canada, Report FR 1728D, TP 8667E. Sable Maritime Ltd.

Elsner, R. and D. Kristensen (1993) Arctic research vessel design would expand science prospects. *EOS, Transactions, American Geophysical Union*, 74(45): 523, 525.

Ermakov, N. (1989) Arctic navigation through the eyes of "Thyssen Nordseewerke" (in Russian). *Morskoi Flot* (Maritime Journal), no. 9, p. 38–40.

Ettema, R., M. Matsuishi and T. Kitazawa (1985) Model tests on ice-rubble size and ship resistance in ice rubble. Iowa: Iowa Institute of Hydraulic Research, Report no. 293.

Filimonov, G.N., B.A. Osminin, L.V. Rebrov and V.I. Ermakov (1986) Propeller shafts for the icebreaker *Rossiia* (in Russian). *Sudostroyenie* (Shipbuilding), no. 4, p. 38–42.

Frederking, R.M.W. and G.W. Timco (1984) Compressive behavior of Beaufort Sea ice under vertical and horizontal loading. In *Proceedings of the 3rd International Offshore Mechanics and Arctic Engineering Symposium, 12–17 February, New Orleans, Louisiana* (V.J. Lunardini, Ed.),vol. 3, p. 145–149. New York: American Society of Mechanical Engineers.

Freitas, A. (1983) A new development in icebreaker technology. *Meerestechnik*, 14(4): 123–129.

Freitas, A. (1983) Marine operations in the Arctic based on the Thyssen-Waas concept. In *Proceedings 7th International Conference on Port and Ocean Engineering under Arctic Conditions, 5–9 April, Helsinki, Finland*, p. 505–515. Espoo: Technical Research Centre of Finland.

Freitas, A. (1983) Marine operations in the Arctic—a new development. In *Proceedings of the 15th Offshore Technology Conference, 2-5 May, Houston, Texas*, vol. 3, p. 350–368.

Freitas, A. and R.S. Nishizaki (1986) Model test of an ice class bulk carrier with the Thyssen/Waas bow form. *Journal of Energy Resources Technology*, 108(2): 168–172.

Frolov, I. (1991) 1987 expedition of the icebreaker *Sibir'* to the North Pole. In *Soviet Maritime Arctic* (L.W. Brigham, Ed.), p. 33–44. London: Belhaven Press.

Gavrilo, V.P., V.A. Nikitin and V.N. Smirnov (1989) Deformation and breakup of ice by the water stream from an icebreaker propeller (in Russian). In *Electro-physical and Physical-mechanical Properties of Ice* (V.V. Bogorodskii and V.P. Gavrilo, Eds.), p. 206–213. Leningrad: Gidrometeoizdat.

German, J.G. (1984) Arctic vessel design. *Marine Engineering/Log*, 89(11): 25–36.

Gershunov, E.M. (1985) Calculating the ice-clearing load on offshore structure imposed by a rubble field. *Oil and Gas Journal*, 83(50): 120–121.

Ghoneim, G.A. (1983) *Kigoriak* and *Robert LeMeur* full scale ice impact tests for 1983. Completion of experiment, design, testing and preliminary data analysis, final report. Ottawa: Transport Canada (performed by Canadian Marine Drilling, Ltd.), Coast Guard Northern, Report TP 5399.

Ghoneim, G.A. (1984) Global ship impact forces determined from full-scale tests and analytical modeling of the icebreakers *Canmar Kigoriak* and *Robert LeMeur*. *Society of Naval Architects and Marine Engineers Transactions*, 92: 253–282.

Ghoneim, G.A. (1987) Instrumentation for measuring forces on icebreakers. *Marine Technology Society Journal*, 21(3): 64–74.

Ghoneim, G.A., M.H. Edgecombe and J. Grinstead (1984) System development for measurement of full scale ship ice impact forces. In *Proceedings of the 3rd International Conference on Icebreaking and Related Technologies, May, Calgary*. New York: Society of Naval Architects and Marine Engineers.

Ginzburg, B.M. (1988) Calculating the dates of river freezeup and breakup in northern Siberia (in Russian). *Trudy*, vol. 295, p. 149–173. Leningrad: Hydrometeorological Research Center USSR.

Glebko, Iu.V., Iu.I. Fomenko and V.S. Cherkashin (1989) Ice tests on an "Enthusiast" class harbor tug with anti-ice protection of the rudder-propeller system (in Russian). In *Architectural and Structural Design, Seagoing and Ice Navigating Qualities of Ships (Collected Scientific Papers)* (V.I. Peresypkin, Ed.), p. 26–28. Leningrad: Transport.

Glen, I. (1985) MV *Arctic* structural performance, final report. Transport Canada report TP5680E.

Glen, I. and H. Blount (1984) Measurement of ice impact pressures and loads onboard CCGS *Louis S. St. Laurent*. In *Proceedings of the 3rd International Offshore Mechanics and Arctic Engineering, 12–17 New Orleans, Louisiana* (V.J. Lunardini, Ed.), vol. 3, p. 246–252. New York: American Society of Mechanical Engineers.

Glen, I., A.M. Nawwar and R. Brown (1985) *Arctic* Ship hull resistance to ice loads (in French with English summary). Transport Canada, Report TP 5681F.

Godon, A.M., A.M. Nawwar and I.M. Bayly (1988) Segmented model technology for ice resistance determination. In *Proceedings of the International Conference on Technology for Polar Areas, 15–17 June, Trondheim, Norway* (A. Hansen and J.F. Strom, Eds.), vol. 1, p. 113–124. Trondheim, Norway: Tapir Publishers.

Gor'kov, N. (1988) This year's navigation. *Vodnyy Transport* (Water Transportation), 28 April, p. 1.

Gowda, S.S. (1988) Behaviour of steel at low temperatures: State of the art. In *Proceedings of the International Conference on Technology for Polar Areas, 15–17 June, Trondheim, Norway* (A. Hansen and J.F. Strom, Eds.), vol. 2, p. 733–748. Trondheim, Norway: Tapir Publishers.

Gray, W.O. and R. Maybourn (1981) Manhattan's arctic venture—A semitechnical history. In *Proceedings of the 6th Ship Technology and Research (STAR) Symposium, 17–19 June, Ottawa, Ontario*, p. 1–20. New York: Society of Naval Architects and Marine Engineers.

Greisman, P. (1981) Brash ice behavior. U.S. Coast Guard, Research and Development Centre, Report USCG-D-81.

Hagiwara, Y., H. Takashima and T. Inoue (1988) Fracture mechanics approach to various Arctic steel structures and their reliability analysis. In *Proceedings International Conference on Technology*

for Polar Areas, 15–17 June, Trondheim, Norway (A. Hansen and J.F. Strom, Eds.), vol. 2, p. 757–768. Trondheim, Norway: Tapir Publishers.

Hellmann, J.H. (1982) Model and full scale tests in ice with the icebreaker Max Waldeck (in German with English summary). In *Proceedings of the International Conference on Marine Research, Ship Technology and Ocean Engineering, Intermaritec '82, 29–30 September, Hamburg*, p. 373–384

Hellmann, J.H. and J. Schwarz (1983) Performance tests of icebreaker *Max Waldeck* in model and full scale. In *Proceedings of the 7th International Conference on Port and Ocean Engineering Under Arctic Conditions, 5–9 April, Helsinki, Finland*, p. 534–549. Espoo: Technical Research Centre of Finland.

Hoogen, N. and K. Delius (1987) Report on sea trials with Soviet icebreaker *Mudyug*. *Marine Technology*, 18(4): 125–129.

Hunt, E.C. and J.L. Mathieson (1986) Arctic operational requirements for marine engineering systems. Report MA-RD-760-86018. Washington, D.C.: U.S. Maritime Administration.

Il'nitskii, K. (1985) Large-capacity ships in the Arctic (in Russian). *Morskoi Flot* (Maritime Journal), no. 1, p. 27–32.

Inoue, T., T. Koseki, Y. Yukihiko and T. Tsuzuki (1990) Local corrosion of high-strength steel weldments of icebreakers. In *Proceedings 1st Pacific/Asia Offshore Mechanics Symposium, 24–28 June, Seoul, Korea* (J.S. Chung, Ed.), vol. 3, p. 179–183. Golden, Colorado: International Society of Offshore and Polar Engineers.

Ionov, B.P. (1984) Theoretical studies of the redistribution of ice resistance components depending on the icebreaker hull shape and main dimensions. In *Proceedings of the 7th IAHR International Symposium on Ice, 27–31 August, Hamburg, F.R.G.*, vol. 3, p. 315–323.

Ionov, B.P. (1988) Evaluation of the effect of an icebreaker's hull shape and principal dimensions on the redistribution of values to the components of the sum total resistance due to the ice. Translation no. 391022 AA. Montreal, Quebec: East–West Technical Services.

Ionov, B.P. and V.B. Beliakov (1991) Energetic approach to the modeling of resistance of icebreaking craft motion in level ice. In *Proceedings of the 11th International Conference on Port and Ocean Engineering Under Arctic Conditions, 24–28 September, St. John's, Newfoundland* (D.B. Muggeridge, D.B. Colbourne, and H.M. Muggeridge, Eds.), vol. 2, p. 666–684. St. John's: Memorial University of Newfoundland.

Ionov, B.P., Iu.D. Utusikov and F.I. Golovchanskii (1990) Experimental studies on the maneuverability of icebreakers and ships in ice (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 55–65. Gorky: Gorky Polytechnic Institute.

Ionov, B.P., P.V. Kolbatov and Iu.D. Utusikov (1990) Method of calculating the speed of the automatic movement of a transport ship in pack ice (in the example of the SA-15 type ship) (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 44–54. Gorky: Gorky Polytechnic Institute.

Itoch, K. (1986) Local corrosion resistance steels with high strength, better low-temperature notch toughness and weldability. In *Proceedings of the International Offshore and Navigation Conference and Exhibition, POLARTECH '86, 27–30 October, Helsinki*, p. 869–896. Espoo: Technical Research Centre of Finland.

Javanainen, M. (1989) On a frequency analysis of ice impacts. Translated from *Proceedings of the Soviet-Finnish Seminar on the Ice Strength of Ships, Leningrad, 1988*. New York: Engineering Consulting and Translation Center (ECTC).

Jebaraj, C., A.S.J. Swamidas and S.D. Jones (1988) Dynamics of ship/ice interaction. In *Proceedings of the International Conference on Technology for Polar Areas, 15–17 June, Trondheim, Norway* (A. Hansen and J.F. Strom, Eds.), vol. 1, p. 89–100. Trondheim, Norway: Tapir Publishers.

Jebaraj, C., A.S.J. Swamidas, S.J. Jones and K. Munaswamy (1987) Finite-element analysis of the elasto-plastic modeling of the indentation problem in ship–ice interaction. In *Proceedings of the 9th International Conference on Port and Ocean Engineering Under Arctic Conditions, 17–22 August, Fairbanks, Alaska* (W.M. Sackinger and M.O. Jeffries, Eds.), vol. 1, p. 531–542. Fairbanks: University of Alaska, Geophysical Institute.

Joba, J.C. (1985) Ships navigating in ice—A selected bibliography, vol. 2, 1980–1984. Canada: Department of Transport, Technical Paper TP 3855E.

Johansson, B.M. and G.C. Liljestrom (1990) Oden: Icebreaker technology for the year 2000. *Society of Naval Architects and Marine Engineers, Transactions*, 97: 53–83.

Johansson, B.M., A.J. Keinonen and B. Mercer (1981) Technical development of an environmentally safe arctic tanker. In *Proceedings of the 6th Ship Technology and Research (STAR) Symposium, 17–19 June, Ottawa, Ontario*, p. 1055–120. New York: Society of Naval Architects and Marine Engineers.

Jones, N. (1986) Note on ice scaling. *Journal of Ship Research*, 30(2): 134–135.

Jones, S.J. (1989) Review of ship performance in level ice. In *Proceedings of the 8th International Conference on Offshore Mechanics and Arctic Engineer-*

ing, 19–23 March, The Hague (N.K. Sinha, D.S. Sodhi and J.S. Chung, Eds.), vol. 4, p. 340–342. New York: American Society of Mechanical Engineers.

Jordaan, I.J., M.A. Maes, P.W. Brown and I.P. Hermans (1993) Probabilistic analysis of local ice pressures. *Journal of Offshore Mechanics and Arctic Engineering*, 115(1): 83–89.

Jordaan, I.J., M.A. Nessim, G.A. Ghoneim and M.A. Murray (1987) Rational approach to the development of probabilistic design criteria for Arctic shipping. In *Proceedings of the 6th International Offshore Mechanics and Arctic Engineering Symposium, 1–6 March, Houston, Texas*, vol. 4, p. 401–406. New York: American Society of Mechanical Engineers.

Kanerva, M. and B. Lonnberg (1985) Icebreaking cargo ships. *Royal Institute of Naval Architects, Transactions*, vol. 127, p. 309–327.

Karavanov, S.B. (1987) Ice loads on the outer hull-plating of ice navigation ships (in Russian). In *New Types of Ships and Their Seagoing Qualities* (V.I. Peresypkin, Ed.) p. 81–86. Leningrad: Transport.

Karavanov, S.B. (1987) Possibility of increasing the arctic draught of *Noril'sk*-type ships according to ice-strake strength (in Russian). In *New Types of Ships and Their Seagoing Qualities* (V.I. Peresypkin, Ed.), p. 54–63. Leningrad: Transport.

Karavanov, S.B. and L.G. Tsoi (1989) Merit of incorporating an additional call of hull reinforcements for transport ships used in eastern regions of the Arctic (in Russian). In *Architectural and Structural Design, Seagoing and Ice Navigating Qualities of Ships (Collected Scientific Papers)* (V.I. Peresypkin, Ed.), p. 100–106. Leningrad: Transport.

Kashtelian, V.I. (1990) Problem of modeling ship movement in pack ice (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 22–26. Gorky: Gorky Polytechnic Institute.

Kavanagh, J. and A. Kendrick (1991) Systematic investigation of factors affecting astern performance of icebreakers (Phase I). Transport Canada Publication TP-10866E.

Kazakov, A.T. (1990) Effect of bow propellers on propulsion performance and handling of icebreakers in ice (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 65–67. Gorky: Gorky Polytechnic Institute.

Kendrick, A. and J. Carter (1988) CCGS *Louis S. St. Laurent* mid-life modernization design studies. *Marine Technology*, 25(2): 129–135.

Kitazawa, T. and R. Ettema (1985) Resistance to ship-hull motion through brash ice. *Cold Regions Science and Technology*, 10(3): 219–234.

Klinge, F. and J.H. Hellmann (1991) Conversion and icebreaking performance of the Soviet icebreaker *Kapitan Sorokin*. In *Proceedings of the 11th International Conference on Port and Ocean Engineering Under Arctic Conditions, 24–28 September, St. John's Newfoundland* (D.B. Muggeridge, D.B. Colbourne, and H.M. Muggeridge, Eds.). St. John's: Memorial Univeristy of Newfoundland.

Koehler, P.E. and L. Jorgensen (1985) Ship ice impact analysis. In *Proceedings of the 4th International Offshore Mechanics and Arctic Engineering Symposium, 17–21 February, Dallas, Texas*, vol. 2, p. 344–350. New York: American Society of Mechanical Engineers.

Kogan, B.A. and N.F. Orlov (1985) Studying sea-ice regime in the northwestern North Atlantic Ocean to develop ice for separate areas. In *Problems in the Arctic and the Antarctic*, vol. 61, p. 16–22.

Kohler, P.E., P.O. Brett and S. Ekholm (1986) Operation of ships in the Arctic. In *Proceedings of the 1st International Conference on Ice Technology, June, Cambridge, Massachusetts*, p. 553–562. Berlin: Springer.

Komarova, E.V. (Ed.) (1990) Design, theory and strength of ships navigating in ice (in Russian). Gorky: Gorky Polytechnic Institute.

Koshkin, S.V. (1984) Initial deforming and cracking of solid ice cover due to motion of an icebreaker. Unpublished Russian manuscript translated from Gorky Polytechnic Institute. New York: ECTC.

Kotras, T. (1985) Determination of propeller-ice milling loads. In *Proceedings of the 4th International Offshore Mechanics and Arctic Engineering Symposium, 17–21 February, Dallas, Texas*, vol. 2, p. 336–343. New York: American Society of Mechanical Engineers.

Kotras, T. (1987) Use of marine simulators to simulate ice conditions and ship transits through ice. Report MA-RD-760-87051. Washington, D.C.: U.S. Maritime Administration.

Kotras, T.V., A.V. Baird and J.N. Naegle (1983) Predicting ship performance in level ice. Transactions no. 11. New York: Society of Naval Architects and Marine Engineers.

Kozin, V. and I. Novolodskyi (1990) Experimental investigations of ice breaking by a moving load. In *Proceedings of the 1st Pacific/Asia Offshore Mechanics Symposium, 24–28 June, Seoul, Korea* (J.S. Chung, Ed.), vol. 2, p. 353–357. Golden, Colorado: International Society of Offshore and Polar Engineers.

Kozin, V.M. (1988) Estimate of ice breaking capacity by a moving load. In *Proceedings of the 7th International Conference on Offshore Mechanics and Arctic Engineering, 7–12 February, Houston, Texas* (D.S. Sodhi, C.H. Luk and N.K. Sinha, Eds.), vol.

4, p. 263–266. New York: American Society of Mechanical Engineering.

Kujala, P., R.V. Gol'dshtein, N.M. Osipenko and V.I. Danilenko (1993) Analysis of the ice failure process. Ship Laboratory Report M-165. Finland: Helsinki University of Technology.

Kurnosov, M. (1987) To the North Pole. On the 10th anniversary of the a/s *Arktika* voyage to the Pole. *Soviet Shipping*, 7(3): 20–21.

Kuz'menko, A.V. (1990) First powerful sea-going Gamburg type icebreaker (in Russian). *Sudostroyenie* (Shipbuilding), no. 10, p. 10–11.

Lewis, J., V. Bulat, I. Glen and T. Kotras (1983) A semi-empirical ice resistance model. Transportation Development Centre, Transport Canada, Report 4376E.

Likhomanov, V.A. (1987) Tensometric testing of transport ships (in Russian). In *New Types of Ships and Their Seagoing Qualities* (V.I. Peresypkin, Ed.), p. 46–54. Leningrad: Transport.

Likhomanov, V.A., M.V. Kuznetsov and O.V. Faddeev (1991) Improving the methods for strain measurement tests of ice navigating ships (in Russian with English summary). In *Problems in the Arctic and the Antarctic*, 66: 196–204.

Lindroos, H. and H. Rjorkestam (1986) Hydrodynamic loads developed during ice-clogging of a propeller nozzle and means to prevent the clogging. In *Proceedings of the International Offshore and Navigation Conference and Exhibition, POLARTECH '86, 27–30 October, Helsinki*, p. 1061–1092. Espoo: Technical Research Centre of Finland.

Lowry, R.T., J.G. McAvoy and A.R. Sneyd (1985) Shipboard ice navigation system. In *Proceedings of the 8th International Conference on Port and Ocean Engineering under Arctic Conditions, 7–14 September, Narssarssuaq, Greenland*, vol. 2, p. 838–847. Horsholm, Denmark: Danish Hydraulic Institute.

Lozgachev, B.N. (1985) Hull gear of a nuclear-powered Arctic barge-container-carrier (in Russian). *Sudostroyenie* (Shipbuilding), no. 9, p. 21–24.

Lozowski, E.P. and E.M. Gates (1985) Overview of marine icing modeling. In *Proceedings of the International Workshop on Offshore Winds and Icing, 7–11 October, Halifax, Nova Scotia* (T.A. Agnew and V.R. Swail, Eds.), p. 102–122. Downsview, Ontario: Atmospheric Environment Service.

Luce, M. (1987) Arctic shipping ice research. *Arctic News-Record and Polar Bulletin*, 6(1): 17–21.

Luce, M. (1987) M.V. *Arctic*: Arctic vessel design and operations. *Marine Technology Soviet Journal*, 21(3): 6–11.

Luk, C.H. (1986) Two-dimensional plasticity and momentum model for ship resistance in level ice. In *Proceedings of the 8th IAHR Symposium on Ice, 18–22 August, Iowa City*, vol. 2, p. 101–112.

Luk, C.H. (1988) Three-dimensional plasticity and momentum model for ship resistance in level ice. In *Proceedings of the 7th International Conference on Offshore Mechanics and Arctic Engineering, 7–12 February, Houston, Texas* (D.S. Sodhi, C.H. Luk and N.K. Sinha, Eds.), vol. 4, p. 307–315. New York: American Society of Mechanical Engineering.

Machemehl, J.L. (1987) Physical model study of an icebreaking tanker moored to an offshore SPM terminal in moving ice. In *Proceedings of the 6th International Offshore Mechanics and Arctic Engineering Symposium, 1–6 March, Houston, Texas*, vol. 4, p. 329–339. New York: American Society of Mechanical Engineers.

Maclennan, G. (1988) New Finnish-built icebreaker for the Soviet Union. *Maritime Defence*, 5: 182–183.

Maksutov, D.D. (1981) Soviet icebreaker construction. Its present position and future prospects (in Russian). *The Transactions of the Arctic and Antarctic Scientific Research Institute*, vol. 376.

Markovich, R.A. (1989) Corrosion of the underwater portion of hulls of icebreakers and ice navigating ships (in Russian). In *Hull Durability and the Protection of Ships Against Corrosion (Collected Scientific Papers)* (V.I. Peresypkin, Ed.), p. 113–126. Leningrad: Transport.

Maslovskii, M.I. (1984) Methods of calculating the rearrangement of drift ice. In *Problems in the Arctic and the Antarctic*, 51: 18–24.

Masterson, D.M. and R.M.W. Frederking (1993) Local contact pressures in ship/ice and structure/ice interactions. *Cold Regions Science and Technology*, 21(2): 169–185.

Matsuichi, M., J.I.Ikeda, H. Kawakami and M. Hirago (1984) Ship–ice floe collision analysis considering the elastic deflection of hull girder. In *Proceedings of the 3rd International Conference on Icebreaking and Related Technologies, May, Calgary, Canada*, p. E/1–E/13. Calgary: Society of Naval Architects and Marine Engineers.

Matusiak, J.F. (1986) Dynamic loads and response of a ship during continuous ice breaking. In *Proceedings of the 5th International Offshore Mechanics and Arctic Engineering Symposium, 13–18 April, Tokyo*, vol. 4, p. 607–613. New York: American Society of Mechanical Engineers.

McAvoy, G. (1987) Design, development, upgrading and testing of the existing marine radar image display system for an ice navigation workstation. Transport Canada, Report TP85495.

McKenna, R.F., J. Meyssonnier and I.J. Jordaan (1989) Peak pressures from a damage model for ice in compression. In *Proceedings of the 8th International Conference on Offshore Mechanics and Arctic Engineering, 19–23 March, The Hague* (N.K. Sinha, D.S. Sodhi and J.S. Chung, Eds.), vol. 4, p.

67–73. New York: American Society of Mechanical Engineers.

Mellor, M. (1980) Ship resistance in thick brash ice. *Cold Regions Science and Technology*, 3(4): 305–321.

Mercer, J.B., G. McAvoy, E. Leavitt and R. Lowry (1986) Advanced radar systems for support of Arctic marine operations. Vancouver, B.C.: Intera Technologies Ltd., Polar Technical.

Milano, V.R. (1987) The Thyssen/Waas icebreaking hull form. *Marine Technology Society Journal*, 21(3): 75–87.

Milkhailichenko, V. (1987) Ice experiment of *Mudyug* icebreaker is over. *Soviet Shipping*, 7(3): 36–37.

Minnick, P. and J. St. John (1986) The 1986 global ice impact tests on the USCGC *Polar Star*. Ship Structure Committee, Report SSC-341. Washington, D.C.: National Academy of Sciences/National Research Council.

Minnick, P. and J. St. John (1990) Global ice forces and ship response to ice: A second season. Ship Structure Committee, Report SSC-343. Washington, D.C.: National Academy of Sciences/National Research Council.

Minnick, P., J. St. John, B. Cowper and M. Edgecombe (1990) Global ice forces and ship response to ice. Columbia, Maryland: ARCTEC Engineering, Inc. for Maritime Administration, Ship Structure Committee Report SSC-341.

Minnick, P., J. St. John, B. Cowper, and M. Edgecombe (1986) The 1985 global ice impact tests on the USCGC *Polar Sea*. Ship Structure Committee, Report SSC 340. Washington, D.C.: National Academy of Sciences/National Research Council.

Munaswamy, K., C. Jebaraj and A.S.J. Swamidas (1986) Indentation problem in ship-ice interaction. Institute for Marine Dynamics, Laboratory memorandum, LM-AVR-09 National Research Council, Canada.

Narita, S. and S. Kishi (1988) Model tests of an icebreaker in snow-covered ice. In *Proceedings of the 9th IAHR Symposium on Ice, 23–27 August, Sapporo, Japan*, vol. 1, p. 216–226.

Nawwar, A., L. Goossens and M. Steele (1984) M.V. *Arctic* ice transiting performance in the ramming mode. Transport Canada Report TP 5320E.

Nikitin, M.N., I.I. Pozniak and S.V. Iakonovskii (1987) Theoretical and experimental study of propeller/ice interaction. ECTC Translation no. T-856-05.

Nikitin, P.A. (1989) Experience in using satellite radar images for ice navigation (in Russian). *Trudy*, vol. 33, p. 135–141. Leningrad: State Research Center for Natural Resources.

Nissen, P.C. (1989) Retrofitting of CCG icebreaker *Louis S. St. Laurent* (in German with English summary). *Hansa*, 126(9–10): 666–671.

Noble, P.G. and C.G. Daley (1980) Safe shipping in the Arctic. Society of Naval Architects and Marine Engineers, Pacific North–West Section, Fall Meeting.

Norrby, R. (1984) Propellers for Soviet Arctic ships: Lessons from initial experience. *Marine Engineering/Log*, 89(2): 31–39.

Nyman, T. and S. Kivimaa (1991) Ramming model tests of the MV *Canmar Kigoriak*. Research Notes no. 1251. Espoo: Technical Research Centre of Finland.

Okol'nichnikov, A. and V. Khudin (1987) Atomic icebreaker *Taymyr* (in Russian). *Morskoi Flot* (Maritime Journal), no. 8, p. 42–49.

Olano-Eren'ya, A. and N. Strel'nikov (1983) The geared diesel icebreaker (in Russian). *Sudostroyenie* (Shipbuilding), no. 7.

Omar, A.F. and A.S.J. Swamidas (1988) Ice force estimation during local impact of a ship's plate. In *Proceedings of the International Conference on Technology for Polar Areas, 15–17 June, Trondheim, Norway* (A. Hansen and J.F. Strom, Eds.), vol. 1, p. 101–112. Trondheim, Norway: Tapir Publishers.

Oshima, M. (1986) Ice engineering research activities on the Japanese coast of Okhotsk Sea. In *Proceedings of the International Offshore and Navigation Conference and Exhibition, POLARTECH '86, 27–30 October, Helsinki*, p. 15–29. Espoo: Technical Research Centre of Finland.

Panin, Iu.I., Ed. (1985) *Ships' Power Plants and Electrical Equipment* (in Russian). Leningrad: Transport.

Parker, N. and J. Alexander (1983) Weather, ice and sea conditions relative to Arctic marine transportation. Department of Fisheries and Oceans, Canadian Technical Report of Hydrography and Ocean Sciences no. 26.

Perchanok, M.S., G.D. Wells and M.G. Lowings (1986) Merchant ship ice navigation studies in the Canadian Arctic. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 2, p. 859–877. Vancouver, B.C.: D.F. Dickins Associates.

Peresypkin, V.I. (Ed.) (1987) *New Types of Ships and Their Seagoing Qualities* (in Russian). Leningrad: Transport.

Permanent International Association of Navigation Congresses (1984) Ice navigation report. Brussels, Supplement to Bulletin 46.

Petrakov, E.V. (1990) Modernization of the *Kapitan Sorokin* type of icebreakers (in Russian). *Sudostroyenie* (Shipbuilding), no. 10, p. 3–5.

Popov, Iu.N. (1988) Features of the determination of the basic characteristics of ice category cargo vessels in the initial design stage. Montreal, Quebec: East–West Technical Services, Translation no. 391005 AA.

Potter, R.E. (1985) Arctic transportation: An overview. In *Proceedings of the Arctic Offshore Technology Conference and Exposition, 3–5 September, Anchorage, Alaska.*

Richardson, C. (1989) Proposed tactical investigation of a model arctic submarine. In *Proceedings of the Arctic Technology Workshop, 20–23 June, Hanover, New Hampshire* (J. Richter-Menge, W.B. Tucker, III and M.M. Kleinerman, Eds.), p. 249–259. USA Cold Regions Research and Engineering Laboratory, CRREL Special Report 89-39

Rinehart, V., F. Seibold and R. Voelker (1986) Review of research on polar class icebreakers to develop arctic ship design guidelines. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 1, p. 19–40. Vancouver, B.C.: D.F. Dickins Associates.

Riska, K. (1991) Theoretical modeling of ice–structure interaction. In *Proceedings of the IUTAM/IAHR Symposium, St. John's, Newfoundland, 1989* (S.J. Jones, R.F. McKenna, J. Tillotson, and I.J. Jordaan, Eds.), p. 595–618. Berlin: Springer-Verlag.

Riska, K., P. Kujala and J. Vuorio (1983) Ice load and pressure measurements on board *I.B. Sisu.* In *Proceedings of the 7th International Conference on Port and Ocean Engineering Under Arctic Conditions, 5–9 April, Helsinki, Finland,* p. 1055–1069. Espoo: Technical Research Centre of Finland.

Rottier, P. (1989) Observations of wave/ice interactions and ambient noise generation in the Marginal Ice Zone. Scott Polar Research Institute Sea Ice Group, Technical report 89-5.

Rubanov, A.N. (1990) Effect of small-scale variations in the ice cover of the Yenisey River on the operation of an icebreaker with an ice-removing attachment (in Russian). *Trudy,* vol. 418, p. 171–173. Leningrad: Arctic and Antarctic Research Institute.

Sanderson, D. and G. Smith (1982) Ships navigating in ice: A selective bibliography. Transport Canada, Report TP 3855E.

Savateev, A.V. (1990) Estimating the ice breaking capability of icebreaker platforms on air cushions (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 80–86. Gorky Polytechnic Institute.

Schwarz, J. (1985) Icebreaking trials with the polar research vessel *Polarstern. Marine Technology,* 16(4): 131–133.

Schwarz, J. (1986) Some latest developments in icebreaker technology. *Journal of Energy Resources Technology,* 108(2): 161–167.

Segal, Z. (1982) Determination of the icebreaking capability of river icebreakers and cargo vessels (in Russian). *Sudostroyenie* (Shipbuilding), no. 7, p. 8–10.

Segal, Z. (1987) Ice loads and the requirements for hulls of icebreakers (in Russian). *Rechnoy Transport* (River Transportation), 5: 31–32.

Seibold, F. and R. Voelker (1987) Mid-winter 1983 ship transit in Alaskan arctic by the icebreaker *Polar Sea.* In *Proceedings of the 9th International Conference on Port and Ocean Engineering Under Arctic Conditions, 17–22 August, Fairbanks, Alaska* (W.M. Sackinger and M.O. Jeffries, Eds.), vol. 1, p. 575–587. Fairbanks: University of Alaska, Geophysical Institute.

Shemendiuk, G.P., V.A. Babtsev and O.I. Bratukhin (1988) Design of hull structures for ice-navigating ships. In *Proceedings of the 7th International Conference on Offshore Mechanics and Arctic Engineering, 7–12 February, Houston, Texas* (D.S. Sodhi, C.H. Luk and N.K. Sinha, Eds.), vol. 4, p. 337–341. New York: American Society of Mechanical Engineering.

Shepherd, J. (1980) Saint John Shipbuilding and Dry Dock Co. Ltd. hull 1132. The *Canmar Kigoriak.* Society of Naval Architects and Marine Engineers, Eastern Canadian Section, February 19.

Shih, L.Y. (1991) Modesto of ship penetration into a mush ice field. *International Journal of Non-Linear Mechanics,* 26(3–4): 293–300.

Ship Technology and Research (STAR) Symposium (1981). In *Proceedings of the 6th Ship Technology and Research (STAR) Symposium, 17–19 June, Ottawa, Ontario.* New York: Society of Naval Architects and Marine Engineers.

Shutov, V.L. (1990) Basis for the requirements of the Ministry of the River Fleet for future additional icebreakers to the year 2000 (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 10–12. Gorky: Gorky Polytechnic Institute.

Smirnov, A. (1987) To tow or to push? (in Russian). *Morskoi Flot* (Maritime Journal), no. 12, p. 42–43.

Sodhi, D.S. (1991) Ice-structure interaction during indentation tests. In *Proceedings of the IUTAM/IAHR Symposium, St. John's, Newfoundland, 1989* (S.J. Jones, R.F. McKenna, J. Tillotson and I.J. Jordaan, Eds.), p. 619–640. Berlin: Springer-Verlag.

Soldatkin, O.B. (199) Effect of a bulb in the bow tip on resistance to movement in ice debris (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 42–44. Gorky: Gorky Polytechnic Institute.

St. John, J.W. (1987) MV *Icebird* early season transit to Prudhoe Bay, July 1986. Report MA-RD-760-87050. Washington, D.C.: U.S. Maritime Administration.

St. John, J.W. and C. Daley (1985) Shipboard measurement of ice pressures in the Bering, Chukchi,

and Beaufort Seas. In *Proceedings of the 3rd International Offshore Mechanics and Arctic Engineering Symposium, 12–17 February, New Orleans, Louisiana* (V.J. Lunardini, Ed.), vol. 3, p. 260–266. New York: American Society of Mechanical Engineers.

St. John, J.W., C. Daley and H. Blount (1984) Ice loads and ship response to ice. Ship Structure Committee, Report SSC-329. Washington, D.C.: National Academy of Sciences/National Research Council.

St. John, J.W., C. Daley, H. Blount and I. Glen (1984) Ice loads and ship response to ice USCG *Polar Class* 1982/83 deployment. Transport Canada, Report TP 6039E.

St. John, J.W., P.V. Minnick and E. Devine (1989) Ship–ice impact load model correlated with full-scale impact data. In *Proceedings of the U.S. Navy Symposium on Arctic/Cold Weather Operations of Surface Ships, 29 November–1 December*, vol. 1, p. 123–138. Washington, D.C.: Department of the Navy.

Starshinov, V.A. and A.M. Kuperman (1985) A towing connection for arctic icebreakers (in Russian). *Sudostroyenie* (Shipbuilding), no. 1, p. 14–16.

Starshinov, V.A., B.P. Ionov and A.N. Makeev (1990) Experimental studies of stresses during the towing of transport ships through ice (in Russian). *Sudostroyenie* (Shipbuilding), no. 3, p. 17–19.

Story, J.F. (1989) Decline of the icebreaker fleet. *U.S. Naval Institute, Proceedings*, 115(10): 84–88.

Story, J.F. (1989) Only two polar icebreaker left. *U.S. Naval Institute, Proceedings*, 115(1): 84–88.

Stubbs, J.T. and E. Makinen (1986) Arctic marine technology: state of the art and prospects for the 1990's. In *Proceedings of the International Polar Transportation Conference (IPTC 86), 4–8 May, Vancouver, Canada* (A. Cassidy, Ed.), vol. 1, p. 220–243. Vancouver, B.C.: D.F. Dickins Associates.

Suvorov, A.S. and V.G. Kharchenko (1983) New requirements of the USSR Register for propulsion plants of icebreakers and ice-strengthened vessels (in Russian). *Sudostroyenie* (Shipbuilding), no. 1, p. 9–11.

Technical Research Centre of Finland (1984) Ship strength and winter navigation. In *Proceedings of the VTT (Valtion Teknillinen Tutkimuskeskus) Symposium 52: Ship Strength and Winter Navigation, 10–11 January, Espoo, Finland.*

Titov, I.A. and S.N. Klimashevskii (1990) Some problems in improving the ice-navigability of icebreakers and ice navigating ships (in Russian). *Sudostroyenie* (Shipbuilding), no. 10, p. 5–7.

Tomin, M.J. (1990) Materials aspects for arctic vessels. In *Proceedings of the 4th International Conference on Icebreaking and Related Technologies, March, Calgary, Canada*, p. Y/1–Y/10. Calgary: Society of Naval Architects and Marine Engineers.

Toyosada, M. (1986) Development of new steel and welding procedure for hull structure of ice breaking vessels. *Naval Architecture and Ocean Engineering*, 24: 199–210.

Tronin, V.A. and A.S. Poliakov (1988) Research of ice-going qualities of river icebreakers. In *Proceedings of the 9th IAHR Symposium on Ice, 23–27 August, Sapporo, Japan*, vol. 1, p. 686–696.

Tronin, V., V. Malinovsky and Yu. Sandakov (1984) Problems of river shipping in ice-bound conditions. In *Proceedings of the 7th IAHR International Symposium on Ice, 27–31 August, Hamburg, F.R.G.*, vol. 3.

Tronin, V.A., A.S. Poliakov and V.A. Malinovskii (1986) Investigation of ice navigation properties of icebreakers and organization of icebreaking operations in river basins. In *Proceedings of the 8th IAHR Symposium on Ice, 18–22 August, Iowa City*, vol. 2, p. 87–99.

Tronin, V.A., S.V. Zheleznov and V.A. Malinovskii (1988) Scientific and operational support of river navigation in ice conditions. In *Proceedings of the 9th IAHR Symposium on Ice, 23–27 August, Sapporo, Japan*, vol. 1, p. 697–705.

Tsoi, L.G. and V.I. Kashtelian (1989) Serial testing of the propulsive performance of models of ice navigating ships with different hull forms (in Russian). In *Architectural and Structural Design, Seagoing and Ice Navigating Qualities of Ships (Collected Scientific Papers)* (V.I. Peresypkin, Ed.), p. 14–19. Leningrad: Transport.

Tsoi, L.G., A.A. Bogdanov and A.A. Petrov (1987) Influence of ship hull forms on propulsion performance in calm and agitated seas (in Russian). In *New Types of Ships and Their Seagoing Qualities* (V.I. Peresypkin, Ed.), p. 14–19. Leningrad: Transport.

Tue-Fee, K.K. and A.J. Keinonen (1986) Full-scale maneuvering tests in level ice of *Canmar Kigoriak* and *Robert LeMeur. Marine Technology*, 23(2): 131–138.

Tunik, A.L. (1986) Safe speeds for navigation in ice. In *Proceedings of the International Offshore and Navigation Conference and Exhibition, POLARTECH '86, 27–30 October, Helsinki*, p. 1106–1124. Espoo: Technical Research Centre of Finland.

Tunik, A.L. (1988) Ramming forces on the USCGC *Polar Sea*. In *Proceedings of the 9th IAHR Symposium on Ice, 23–27 August, Sapporo, Japan*, vol. 1, p. 746–761.

Tunik, A.L. (1991) Impact ice pressure: More questions than answers. In *Proceedings of the IUTAM/IAHR Symposium, St. John's, Newfoundland, 1989* (S.J. Jones, R.F. McKenna, J. Tillotson

and I.J. Jordaan, Eds.), p. 693–714. Berlin: Springer-Verlag.

U.S. Coast Guard (1984) United States polar icebreaker requirements study. Washington, D.C.

Vance, G.P. (1984) *Review of Icebreaking Technology. Arctic Technology and Policy* (I. Dyer and C. Chryssostomidis, Eds.), p. 125–130. Washington, D.C.: Hemisphere Publishing.

Varges, G. (1987) Advances in icebreaker design: the conversion of the Soviet polar icebreaker *Mudyug* into a Thyssen/WAAS ship. Paper presented at the *6th West European Conference on Marine Technology Symposium, 2–5 June, Travemunde, Germany.* Emden, FRG: Thyssen Nordseewerke GmbH.

Varges, G. (1988) Revolution in polar shipping—Thyssen/Waas in the Arctic. In *Proceedings of the 9th IAHR Symposium on Ice, 23–27 August, Sapporo, Japan*, vol. 1, p. 719–734.

Varges, G.R. (1990) Full-scale experiences with Thyssen/Waas icebreakers. In *Proceedings of the 4th International Conference on Icebreaking and Related Technologies, March, Calgary, Canada*, p. H/1–H/14. Calgary: Society of Naval Architects and Marine Engineers.

Voelker, R., I.F. Glen, F. Seibold and I. Bayly (1984) Arctic trafficability program—A review. *Naval Engineers Journal*, 96(3): 169–175.

Voelker, R.P. (1982) Arctic deployment of USCGC *Polar Star*—Winter 1982. Six volumes. Washington, D.C.: U.S. Maritime Administration.

Voelker, R.P. (1983) Arctic deployment of USCGC *Polar Sea*—Winter 1983. Four volumes. Washington, D.C.: U.S. Maritime Administration.

Voelker, R.P., F.W. DeBord and K.E. Dane (1979) Operational assessment of commercial icebreaking ships in western Alaskan waters based on USCG Polar-class trafficability test data. Washington, D.C.: U.S. Maritime Administration, 2 volumes: MA-RD-940-79071 and MA-RD-940-79072. Available from National Technical Information Service, Springfield, Virginia 22161, PB 80-145097 and PB 80-145105.

Voelker, R.P., F.W. DeBord, J.J. Nelka, J.W. Jacobi and J.L. Coburn (1981) Assessment of ice conditions in the South Bering Sea based on April 1980 USCG Polar class trafficabilty test data. Four volumes. Washington, D.C.: U.S. Maritime Administration.

Voelker, R.P., F.W. DeBord, T. Brennan and C.W. Parker (1981) Evaluating commercial Arctic marine transportation with *Polar* class icebreakers. In *Proceedings of the 6th Ship Technology and Research (STAR) Symposium, 17–19 June, Ottawa, Ontario*, p. 145–157. New York: Society of Naval Architects and Marine Engineers.

Voevodin, V. (1989) Arctic groans from ice adhesion. *Sovbloc Naval News*, 9(5): 86–90.

Voevodin, V.A., A.I. Migulin and V.V. Panov (1987) Icing and ice sticking to ships during autumnal–winter navigation. Jackson Heights,

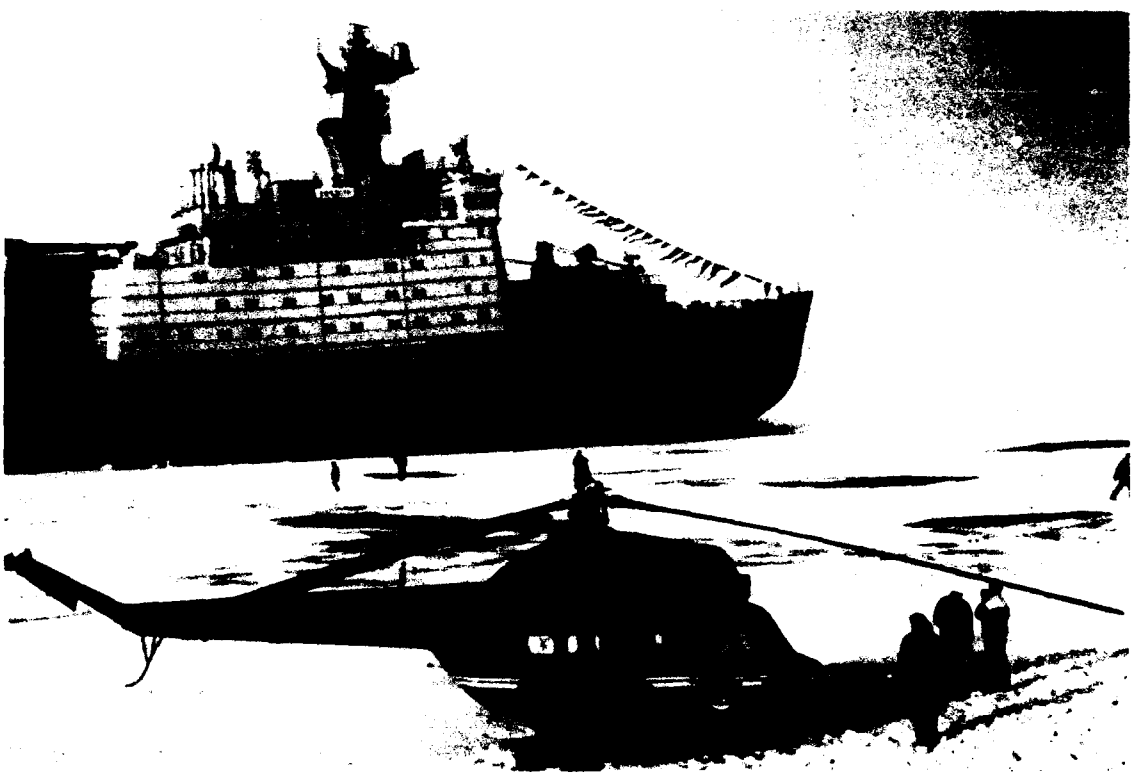

Photo courtesy of Murmansk Shipping Co.

New York: Engineering and Consulting and Translation Center, Translation T-815–18.

Voinov, E. (1985) Advanced technology for Arctic ships (in Russian). *Morskoi Flot* (Maritime Journal), no. 8, p. 29–30.

Volenko, B.S. and F.I. Aikashev (1990) Means of preventing the development of and the removal of an ice basin from floating objects (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)* (E.V. Komarova, Ed.), p. 125–131. Gorky: Gorky Polytechnic Institute.

Volosov, M.I. (1985) Operating conditions of main engines of *Mikhail Strekalovskii* type ships in ice (in Russian). *Ships' Power Plants and Electrical Equipment* (Iu.I. Panin, Ed.), p. 11–24. Leningrad: Transport.

Vorontsov, A.V. and G.I. Goleevskii (1991) Evaluating the possibility of improving the efficiency of an advanced nuclear powered icebreaker (in Russian). *Sudostroyenie* (Shipbuilding), no. 6, p. 18–19

Vuorio, J., K. Riska and P. Varsta (1979) Long term measurements of ice pressure and ice-induced stresses on the icebreaker *Sisu* in winter 1978. Styrelsen for Vintersjöfartsforskning (Agency for Winter Maritime Research), Research Report 28.

Wartsila Marine (1988) Nuclear-powered icebreaker *Taymyr*. Press Release 5, April 1988.

Wells, D.B. (1990) Trafficability study for the Soviet nuclear icebreaker *Rossia* voyage to the North Pole, July 31 to August 15, 1990. Report TP 10740E. Montreal: Transport Canada, Transportation Development Centre.

Wells, D.B., A. MacCharles and D. Lapp (1988) Seasonal and historical analysis of the M.V. *Arctic* vessel performance and trafficability data base, 1983–87. Transport Canada, Report TP 9063E.

Witthoeft, H.J. (1983) New developments for Soviet Arctic shipping. (Translated from *Marine Rundschau Transactions*, Germany, F.R.) Washington, D.C.: Naval Intelligence Support Center, Translation Division, NTIS no. AD A135 552/8.

Wright, B. and D. Berenger (1980) Ice conditions affecting navigation in the Beaufort Sea. In *Proceedings of the Ship Technology and Research (STAR) Symposium, 17–19 June, Ottawa, Ontario* (Paper discussions, authors' closures and panel transcript), paper no. 9, p. 121–135. New York: Society of Naval Architects and Marine Engineers.

Young, O.R. (1991) Arctic navigation: Problems of two seaways. *Soviet Shipping*, 3: 35–37.

Yuen, C. and N.P. Lasca (1989) Fracturing of an ice sheet by ship-induced, ice-coupled waves. *Cold Regions Science and Technology*, 16(1): 75–82.

Zahn, P.B. (1989) The estimation of icebreaker powering and propulsion. Report MA-RD-840-89006. Washington, D.C.: U.S. Maritime Administration.

Zahn, P.B., F.W. DeBord and P.V. Minnick (1988) Arctic marine transportation program, 1979 to 1986. Technical summary. U.S. Maritime Administration Report MA-RD-840-88021.

Zakharov, B.N. and E.V. Petrakov (1988) Increasing the ice propulsion capability of the icebreaker *Mudyug*. New York: Engineering Consulting and Translating Center, CY-8712-06.

Zuev, V.A. and M.B. Dekhtiar (1990) Principles for the prioritized design of icebreaker platforms on air cushions (in Russian). In *Design, Theory, and Strength of Ships Navigating in Ice (Interuniversity Collected Scientific Papers)*, p. 12–22 (E.V. Komarova, Ed.). Gorky: Gorky Polytechnic Institute.

MISCELLANEOUS AND NONPRINTED SOURCES

Anon. (1983) Russ fight to save 26 ice-bound ships. *Milwaukee Journal*, Sunday, October 16.

Anon. (1993) Russia 1993: Political and economic analysis and business directory. Taipei, Taiwan: Chamber World Network.

Anon. (1993) Transportation development crucial to expanding trade. *Journal of Commerce and Commercial*, March 29, 395(27944): 5B.

Arctic and Antarctic Research Institute (n.d.) Medium-range and daily long-range weather forecasts for high latitudes. St. Petersburg: Arctic and Antarctic Research Institute.

Atmospheric Environment Service (1974–1986) Canadian ice charts. Ottawa: Ice Forecasting Centre, Environment Canada.

Backlund, A., K. Juurmaa and T. Mattsson (1993) Arctic cargo transportation economic evaluation. In *Proceedings of the 12th International Conference on Port and Ocean Engineering under Arctic Conditions, 17–20 August, Hamburg*, p. 158–168. Hamburg: Hamburg Ship Model Basin.

Bernton, H. (1991) Norwegians finding problems in Arctic shipping route. *Anchorage Daily News*, November 6, p. E3.

Bernton, H. (1992) Cargo ships to test route in North Sea. *Anchorage Daily News*, October 24, p. C2.

Black, J.L. (1988) The Soviet perspective on Canada's north: An overview of the literature, 1947–1988. *Northern Perspectives*, 16(4): 29–32.

Bowditch, N. (1977) *American Practical Navigator, vol. 1.* Washington, D.C.: Defense Mapping Agency.

Canadian Hydrographic Service (1986) Nautical charts 7661, 7662, 7663, 7664, 7608, 7685, 6433, 6434, 6436, 6441. Sidney, B.C.: Department of Fisheries and Oceans.

Canadian Hydrographic Service (1986) Sailing directions—Arctic Canada, vol. III, 4th edition. Ottawa: Department of Fisheries and Oceans.

Davies, J. (1993) Trial run of polar sea route may go on without Alaska. *Anchorage Daily News*, August 26, p. C2.

Dobrovol'skiy, A.D. and B.S. Zalogin (1981) Seas of the USSR. Moscow. (Translated from Russian by the Foreign Broadcast Information Service, Washington, D.C., 1982.)

Fomin, V. (1992) Methods of remote sensing of sea ice cover in the Northern Sea Route and Arctic Basin. In *Proceedings of the Conference on the Opening of the Northern Sea Route, Trondheim, Norway.*

Holburn, J.G. (1984) Lifesaving equipment for Arctic ships. Ottawa: Transport Canada, CMTA, Coast Guard Northern, Report TP 5361.

Johannessen, O.M. (1993) Seasonal ice zone application of satellite data in science-monitoring and forecasting. In *Proceedings of the 8th International Symposium on Okhotsk Sea and Sea Ice and ISY/Polar Ice Extent Workshop, 1–5 February, Hokkaido, Japan*, p. 212. Mombetsu, Japan: Okhotsk Sea and Cold Ocean Research Association.

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Joint Ice Center (n.d.) *Environmental Services for Polar Operations*. Washington, D.C.: U.S. Navy/NOAA Joint Ice Center.

Joint Ice Center (n.d.) Optimum ship tack route from ERS-1 SAR (Synthetic aperture radar). Washington, D.C.: U.S. Navy/NOAA Joint Ice Center.

Joint Ice Center (n.d.) Routine ice guidance products: Alaskan regional ice analysis. Biweekly charts, regional scale 1:7,500,000. Washington, D.C.: U.S. Navy/NOAA Joint Ice Center.

Joint Ice Center (n.d.) Routine ice guidance products: East and West Arctic 30-day forecast. Bimonthly charts. Washington, D.C.: U.S. Navy/NOAA Joint Ice Center.

Joint Ice Center (n.d.) Routine ice guidance products: East and West Arctic ice analyses. Weekly charts, global scale 1:10,000,000. Washington, D.C.: U.S. Navy/NOAA Joint Ice Center.

Joint Ice Center (n.d.) Routine ice guidance products: West Arctic seasonal outlook. Long-range prediction. Washington, D.C.: U.S. Navy/NOAA Joint Ice Center.

Joint Ice Center (n.d.) Special support ice guidance products. Washington, D.C.: U.S. Navy/NOAA Joint Ice Center.

Jones & Bartlett Publishing, Inc. (1981) *Atlas of the Polar Regions*. (Originally published by the U.S. National Foreign Assessment Center.) 20 Park Plaza, Boston, Massachusetts.

Lindsay, D.G. (1977) *Sea Ice Atlas of Arctic Canada, 1969–1974*. Ottawa: Energy, Mines and Resources Canada.

Lindsay, D.G. (1981) *Sea Ice Atlas of Arctic Canada, 1975–1978*. Ottawa: Energy, Mines and Resources Canada.

Mellgren, D. (1990) Norwegian scientists study Arctic trade route. Associated Press, November 13, Oslo, Norway.

Mellgren, D. (1992) Arctic shortcut. Associated Press, January 14, Oslo, Norway.

Meserve, J.M. (1974) *U.S. Navy Marine Climatic Atlas of the World*, vol. I, North Atlantic Ocean. Asheville, North Carolina: U.S. Naval Weather Service Detachment.

Murmansk Shipping Company (1991) Notes on passage fees. Murmansk: Murmansk Shipping Company.

National Ocean Survey (U.S.) (1981) United States Coast Pilot 9; Pacific and Arctic Coasts Alaska: Cape Spencer to Beaufort Sea. Washington, D.C., 10th edition.

Orvig, S. (1970) *Climates of Polar Regions*. World Survey of Climatology, vol. 14. New York: Elsevier.

Parker, N., B. Thomson, J. Bullas and W. Hume (1983) Weather, ice and sea conditions relative to Arctic marine transportation. Canadian Technical Report of Hydrographic and Ocean Sciences, no. 26. Sidney, B.C.: Institute of Ocean Sciences, Department of Fisheries and Oceans.

Proshutinskii, A.Iu. (n.d.) Arctic technology at the Arctic and Antarctic Research Institute. St. Petersburg: Arctic and Antarctic Research Institute.

Splettstoesser, J. and B.D. Splettstoesser (1993) First transit of the Northwest Passage by Russian icebreaker. *Polar Record*, 29(169): 148.

Stokke, O.S. (1992) Arctic environmental cooperation after Rovaniemi. In *Proceedings of the Nordic Arctic Research Forum Symposium* (L. Lyck, Ed.), p. 221–234. Ålborg, Denmark: Ålborg University Press.

Sukhovey, V.F. (1986) *Seas of the World Oceans*. Leningrad. (Translated from Russian by the Foreign Broadcast Information Service, Washington, D.C., 1987.)

Tunik, A.L. (in press) Route-specific ice thickness distribution in the Arctic Ocean during a North Pole crossing in August 1990. New York: American Bureau of Shipping. To be published in *Cold Regions Science and Technology*.

U.S. Arctic Research Commission (1988) Entering the age of the Arctic. Opportunities and obligations of an Arctic nation. Report of the U.S. Arctic Research Commission to the President and the Congress of the United States of America for the period 1 October 1986–30 September 1987. Los Angeles, California.

Voelker, R.P. (1990) Arctic Marine Transportation Program, 1979 to 1986, Executive Summary. Prepared for Maritime Administration, Office of Technology Assessment, Department of Transportation, Report No. MA-RD-840-90004. Columbia, Maryland: NKF Engineering, Inc., Arctic Technology Group.

World Data Center/National Snow and Ice Data Center (1992) DMSP F8 Special Sensor Microwave/Imager (SSM/I) sea ice concentration grids. Two CD-ROMs, contain all F8 SSM/I ice concentrations, 9 July 1987–31 December 1991. Boulder, Colorado: National Oceanographic and Atmospheric Administration.

World Data Center/National Snow and Ice Data Center (1992) Nimbus-7 SMMR polar radiances. One CD-ROM, contains sea ice concentrations for October 1978–August 1987. Boulder, Colorado: National Oceanographic and Atmospheric Administration.

World Data Center/National Snow and Ice Data Center (1993) Digital sea ice extent and concentration data for Arctic and Antarctic regions. January 1972–December 1990 for Arctic. Data digitized and gridded from weekly sea ice charts

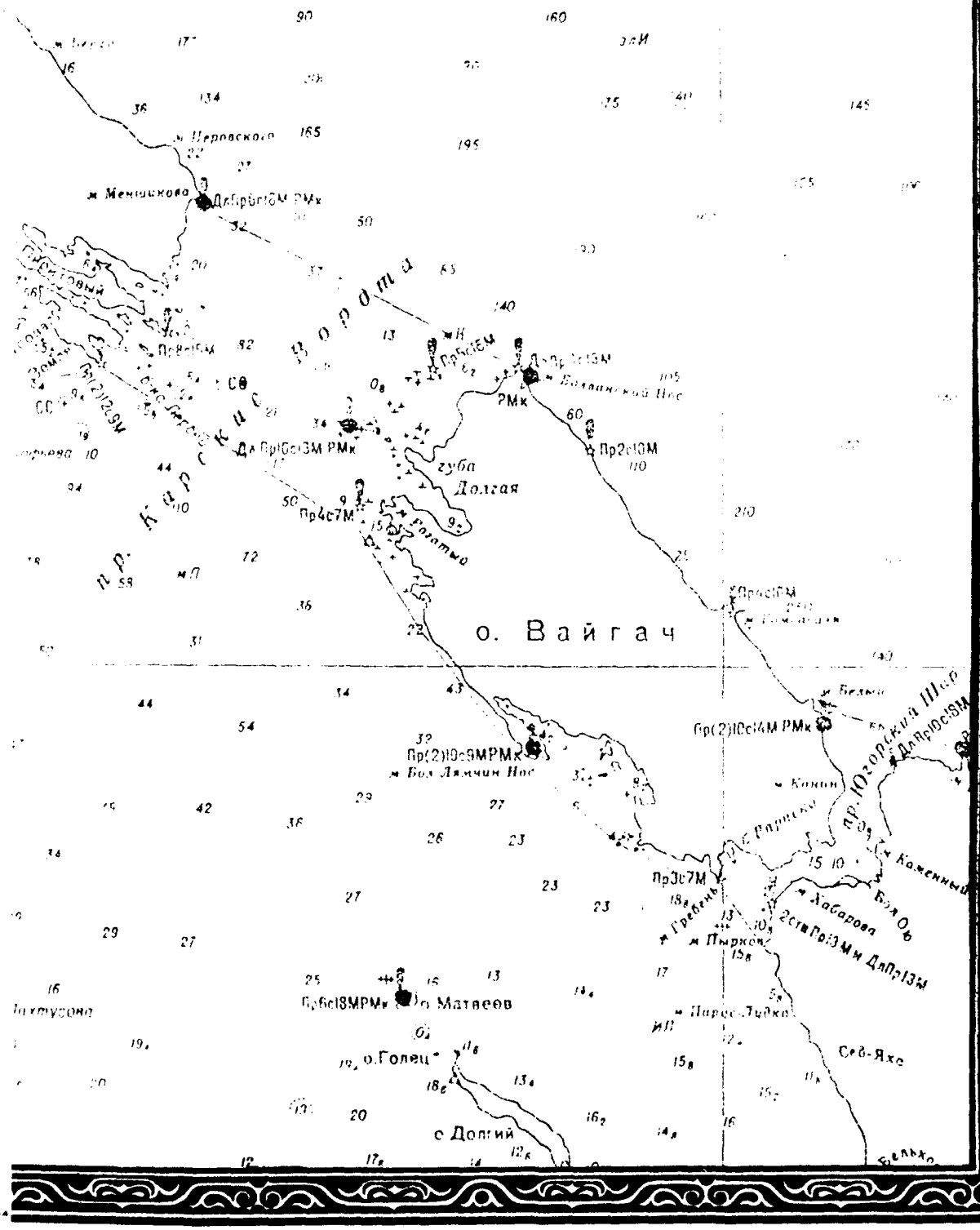
produced by the U.S. Navy/NOAA Joint Ice Center. Boulder, Colorado: National Oceanographic and Atmospheric Administration.

World Data Center/National Snow and Ice Data Center (1993) DMSP SSM/I brightness, temperature, and sea ice concentration grids for the polar regions. 14 CD-ROMs. Boulder, Colorado: National Oceanographic and Atmospheric Administration.

World Data Center/National Snow and Ice Data Center (1993) Navy–NOAA Joint Ice Center weekly sea ice concentration and extent, Arctic and Antarctic. Three reels of 6250 bpi tape. Boulder, Colorado: National Oceanographic and Atmospheric Administration.

World Meteorological Organization (1970) WMO sea–ice nomenclature. Terminology, codes and illustrated glossary. Geneva: WMO.

Appendixes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APPENDIX A
ICEBREAKING SHIPS OF THE WORLD (after Dick and Laframboise, 1989)

Icebreaking Ships: Argentina, Australia, and Canada

Ship & country	Almirante Irazar Argentina	Aurora Australis Australia	S.R. Humphrey Gilbert Canada	John Cabot Canada	Norman McLeod Rogers Canada
Vessel type	Icebreaker	Icebreaker supply ship	Icebreaker	Icebreaking cable layer	Icebreaker
Year construction completed	1978	1989	1980	1985	1969
Dimensions					
LBP (m)	ND	88.4	68.9	84.1	81.2
B (m)	25.0	20.3	14.7	18.3	19.1
D (m)	ND	ND	6.4	10.4	7.9
H (m)	9.5	7.85	5.0	9.7	6.3
Displacement (tonnes)	14,900	3,500	3,048	5,318	6,569
Form variables					
Stem angle (deg)	22	ND	25	ND	62-28
Bow type	Straight	ND	ND	ND	ND
Propulsion					
Total power (MW)	11.9	10.0	3.2	6.7	9.7
Bollard pull (tonnes)	138	ND	40	81	112
No. shafts	2	ND	3		2
Power/shaft (MW)	6.0	ND	1.8	3.4	4.9
Machinery	Diesel ac-dc	ND	Diesel Direct drive	Diesel dc-dc	Diesel dc-dc
Propeller(s)	2 x FP	ND	2 x FP	2 x FP	2 x FP
Diameter (m)	ND	ND	3.51	3.98	3.66
No. blades	ND	ND	4		4
Nozzle(s)	No	ND	No	No	No
Performance					
Open water (kn)	18.5	13	13.0	15.0	15.0
In ice	ND	ND	2 kn in 0.87 m	2 kn in 0.75 m	2 kn in 0.91 m
BP/B (tonnes/m)	ND	ND	2.7	4.4	5.9

Icebreaking Ships: Canada

Ship & country	Louis S. St.-Laurent (1969–88) Canada	Louis S. St.-Laurent (1993–) Canada	Arctic (1978–86) Canada	Arctic (1986–) Canada	Sir John Franklin Pierre Radisson Des Groseiller Canada	Canmar Kigoriak Canada
Vessel type	Icebreaker	Icebreaker	Cargo	Cargo	Icebreakers	Ice mgmt supply vessel
Year(s) construction completed	1969	1969	1978	1978	1978–84	1978
Dimensions						
LBP (m)	101.8	101.8	196.6	206.0	87.9	79.3
B (m)	24.4	24.4	22.9	22.9	19.4	17.3/19.3
D (m)	13.1	13.1	15.2	15.2	ND	10.0
H (m)	9.4	9.4	10.9	10.9	6.9	8.5
Displacement (tonnes)	13,513	13,300	38,104	38,466	7,825	8,549
Form variables						
Stem angle (deg)	32	ND	30	20	18	24
Bow type	ND	ND	White	Melville	White	Spoon/reamers
Propulsion						
Total power (MW)	17.7	17.9	10.9	10.9	10.0	12.2
Bollard pull (tonnes)	202	ND	155*	155	115	162
No. shafts	3	3	1	2	1	
Power/shaft (MW)	5.9	5.9	10.9	11.08	5.0	12.2
Machinery	Steam turbine dc–dc	Diesel ac–dc	Diesel Direct drive	Diesel Direct drive	Diesel ac–dc	Diesel Direct drive
Propeller(s)	3 x FP	3 x FP	1 x CP	1 x CP	2 x FP	1 x CP
Diameter (m)	4.57		5.23	5.23	4.12	5.3
No. blades	4		4	4	4	4
Nozzle(s)	No		Yes	Yes	No	Yes
Performance						
Open water (kn)	17.8	17.75	16.5	17.3	13.5	18.8
In ice	1.0		2 kn in 1.0 m	2 kn in 1.5 m	2 kn in 1.15m	2 kn in 1.45 m
BP/B (tonnes/m)	8.3		6.8	6.8	5.9	9.4/8.4

* Calculated or measured value.

Icebreaking Ships: Canada

Ship & country	Robert LeMeur Canada	Arctic Nanook Arctic Nutsukpok Canada	Terry Fox Kalvik Canada	Ikaluk Miscardo Canada	Arctic Shiko Seaforth Atlantic Canada
Vessel type	Ice mgmt supply vessel	Ice mgmt supply vessels	Ice mgmt supply vessels	Ice mgmt supply vessels	Ice mgmt supply vessels
Year construction completed	1982	1982	1983	1983	1984
Dimensions					
LBP (m)	73.0	44.2	75.0	75.5	60.9
B (m)	18/19	12.2	17.5	17.2	14.5
D (m)	7.5	5.3	10.0	9.7	6.9
H (m)	5.7	4.1	8.0	7.5	5.9
Displacement (tonnes)	5,853	ND	6,910	ND	ND
Form variables					
Stem angle (deg)	20	22	23	23	32
Bow type	Spoon/reamers	Flat family	ND	ND	White
Propulsion					
Total power (MW)	7.1	4.8	17.7	11.2	9.01
Bollard pull (tonnes)	107	72*	190	165	129*
No. shafts	2	2	2	2	2
Power/shaft (MW)	3.6	2.4	8.9	5.6	4.5
Machinery	Diesel Direct drive	Diesel Direct drive	Diesel Direct drive	Diesel Direct drive	Diesel Direct drive
Propeller(s)	2 x CP	2 x CP	2 x CP	2 x CP	2 x CP
Diameter (m)	3.0	ND	4.8	3.75	3.0
No. blades	4	4	4	4	4
Nozzle(s)	Yes	Yes	No	Yes	Yes
Performance					
Open water (kn)	13.5	15.0	14.0	ND	16.0
In ice	2 kn in 1.5 m	ND	7 kn in 1.22 m(82%)	3–4 kn in 1.2 m	2 kn in 1.05 m
BP/B (tonnes/m)	5.9/5.6	5.9	10.8	9.6	8.9

* Calculated or measured values.

Icebreaking Ships: Canada

Ship & country	Arctic Nanabush Canada	Arctic Ivik Canada	1100s Geo. R. Pearkes Martha L. Black Canada	Edward Cornwallis Sir Wilfred Laurier Canada	Earl Grey Samual Risley Canada
Vessel type	Ice mgmt supply vessel	Ice mgmt supply vessel	Light icebreakers	Light icebreakers	Light icebreakers
Year(s) construction completed	1984	1985	1986	1986	1985–86
Dimensions					
LBP (m)	44.2	64.7	83.0	78.4	69.7
B (m)	12.2	14.0	16.2	16.2	13.7
D (m)	5.3	5.8	7.9	7.8	6.7
H (m)	4.6	4.9	5.8	6.0	5.2
Displacement (tonnes)	ND	ND	5,031	4,966	2,930
Form variables					
Stem angle (deg)	22	22	25	25	25
Bow type	Flat family	Flat family	ND	ND	ND
Propulsion					
Total power (MW)	5.3	5.3	5.3	5.3	6.5
Bollard pull (tonnes)	80*	81*	65	65	78
No. shafts	2	2	2	2	2
Power/shaft (MW)	2.7	2.7	2.6	2.6	3.3
Machinery	Diesel Direct drive	Diesel Direct drive	Diesel ac-fcc-ac	Diesel ac-fcc-ac	Diesel Direct drive
Propeller(s)	2 x CP	2 x CP	2 x FP	2 x FP	2 x FP
Diameter (m)	ND	ND	3.6	3.6	4.0
No. blades	4	4	4	4	3
Nozzle(s)	Yes	Yes	No	No	No
Performance					
Open water (kn)	15.0	14.1	15.5	15.5	14.3
In ice	2 kn in 0.9 m	2 kn in 0.9 m	ND	ND	ND
BP/B (tonnes/m)	6.6	5.8	4.0	4.0	5.7

* Calculated or measured values.

Icebreaking Ships: Denmark and Japan

Ship & *country*	Danbjørn Isbjørn *Denmark*	Damsa Dan *Denmark*	Fuji *Japan*	Soya *Japan*	Shirase *Japan*
Vessel type	Icebreakers	Cargo	Icebreaker	Icebreaking patrol vessel	Icebreaker
Year construction completed	1965	1973	1965	1978	1982
Dimensions					
LBP (m)	68	125	90	94	127
B (m)	17.0	18.1	22.0	15.6	28.0
D (m)	9.0	11.3	11.8	8.0	14.5
H (m)	6.0	7.4	9.0	5.5	9.8
Displacement (tonnes)	3,744	12,091	9,120	4,000	18,600
Form variables					
Stem angle (deg)	ND	ND	30	ND	21
Bow type	ND	ND	ND	ND	ND
Propulsion					
Total power (MW)	7.7	6.8	8.8	11.5	22.1
Bollard pull (tonnes)	96	78.1	103	132	243
No. shafts	2A + 2F	1	2	ND	3
Power/shaft (MW)	1.9	6.8	4.4	ND	7.3
Machinery	Diesel dc-dc	Diesel Direct drive	Diesel dc-dc	ND —	Diesel ac-dc
Propeller(s)	4 x FP	1 x CP	2 x FP	ND	3 x FP
Diameter (m)	ND	ND	4.9	ND	4.9
No. blades	ND	ND	4	ND	4
Nozzle(s)	No	No	No	ND	No
Performance					
Open water (kn)	14.0	17.5	17.0	ND	19.0
In ice	2 kn in 1.0 m	2 kn in 0.67 m	2 kn in 0.8 m	2 kn in 1.2 m	3 kn in 1.5 m
BP/B (tonnes/m)	5.7	4.2	4.7	8.5	8.7

Icebreaking Ships: Finland

Ship & country	Voima Finland	Karhu Murtaja Sampo Finland	Tarmo Varmo Apu Finland	Hanse Finland	Finlandia Finland	Finn Carrier Finland
Vessel type	Icebreaker	Icebreakers	Icebreakers	Icebreaker	Passenger Ro-Ro	Cargo
Year(s) construction	1953 (1978)	1957/58/60	1963/68/76	1966	1967	ND
mpleted						
sions						
BP (m)	80.8	68.3	82.0	74.0	134.0	129.9
B (m)	18.7	16.7	21.2	17.4	20	24.6
D (m)	9.6	8.8	9.6	ND	ND	17.3
H (m)	6.7	5.8	6.2	6.1	5.6	5.7
Displacement (tonnes)	4,488	3,424	5,944	3,759	6,706	10,567
Form variables						
Stem angle (deg)	27	25	24	25	ND	ND
Bow type	ND	ND	ND	ND	ND	ND
Propulsion						
Total power (MW)	7.7	5.5	8.8	5.8	12.1	8.2
Bollard pull (tonnes)	96	70	108	71	137	97
No. shafts	2A + 2F	2A + 2F	2A + 2F	2A + 2F	2	2
Power/shaft (MW)	1.9	1.4	2.2	1.4	6.1	4.1
Machinery	Diesel dc–dc	Diesel dc–dc	Diesel dc–dc	Diesel dc–dc	Diesel Direct drive	Diesel Direct drive
Propeller(s)	4 x FP	4 x FP	4 x FP	4 x FP	2 x CP	2 x FP
Diameter (m)	ND	ND	ND	ND	ND	ND
No. blades	4	4	4	4	4	4
Nozzle(s)	No	No	No	No	No	No
Performance						
Open water (kn)	16.5	16.0	17.0	16.0	23.0	17.0
In ice	2 kn in 0.82 m	2 kn in 0.7 m	2 kn in 0.85 m	2 kn in 0.72 m	2 kn in 1.0 m	ND
BP/B (tonnes/m)	5.1	4.2	5.1	4.1	6.9	3.9

* Calculated or measured values.

Icebreaking Ships: Finland and Sweden

Ship & country	Urho Sisu *Finland*	Lunni Sotka Tiira Uikku *Finland*	*Otso* *(class of 2)* *Finland*	Finnica Nordica *Finland*	Tor Njord *Sweden*	Ale *Sweden*
Vessel type	Icebreakers	Oil tankers	Icebreakers	Multipurpose icebreakers	Icebreakers	Icebreaker
Year(s) construction completed	1974–197?	1976/77	1986	1993/94	1964/69	1973
Dimensions						
LBP (m)	96	150	90	116	ND	47
B (m)	23.5	21.5	23.5	26	21.2	13
D (m)	ND	12.0	ND	12.5	9.5	ND
H (m)	8.3	9.5	8.0	7.0/8.4	6.5	5.2
Displacement (tonnes)	7,925	ND	ND	4,800	5,357	1,500
Form variables						
Stem angle (deg)	20	ND	ND		ND	ND
Bow type	Straight	ND	Straight	Spoon/reamers	ND	ND
Propulsion						
Total power (MW)	16.2	11.5	15.0	15.0	8.8	ND
Bollard pull (tonnes)	190	116	165	234	108	ND
No. shafts	2A + 2F	1	2	2	2A + 2F	ND
Power/shaft (MW)	4.1	11.5	7.5		2.2	ND
Machinery	Diesel dc–dc	Diesel Direct drive	Diesel ac-ffc-ac	Diesel ac-ffc-ac	Diesel dc–dc	ND ND
Propeller(s)	4 x FP	1 x CP	2 x FP	2*	4 x FP	2 x CP
Diameter (m)	ND	5.45	—	—	ND	ND
No. blades	4	4	—	—	4	ND
Nozzle(s)	No	No	No	Yes	Yes	ND
Performance						
Open water (kn)	17.0	14.5	18.5	16.0	18.0	ND
In ice	2 kn in 1.56 m	2 kn in 1.0 m	ND	8 kn in 0.8 m	2 kn in 0.85 m	ND
BP/B (tonnes/m)	8.1	5.4	7.0	ND	5.1	ND

*Azimuth-mounted propellers

Icebreaking Ships: Sweden, U.K., and U.S.A.

Ship & country	Ymer Atle Frej Sweden	Oden Sweden	Bransfield U.K.	Polar Shore U.K.	Endurance U.K.	Mackinaw U.S.A.
Vessel type	Icebreakers	Icebreaker	Icebreaker	Icebreaking supply vessel	Icebreaker	Icebreaker
Year(s) construction completed	1974–77	1988	1971	1973	1974	1945
Dimensions						
LBP (m)	96	108	90	51	82.5	85.4
B (m)	23.8	31.5	18.3	11.8	17.9	22.6
D (m)	12.1	ND	9.5	5.1	ND	ND
H (m)	7.3	7.0/8.5	6.2	4.3	6.5	5.8
Displacement (tonnes)	8,000	13,000	7,011	ND	2,500	5,252
Form variables						
Stem angle (deg)	20	ND	ND	ND	ND	29
Bow type	Straight stem	ND	ND	ND	ND	ND
Propulsion						
Total power (MW)	16.2	18	3.7	3.9	6.0	7.5
Bollard pull (tonnes)	191	240	44	48	ND	94
No. shafts	2A + 2F	2	1	2	ND	2A + 1F
Power/shaft (MW)	4.1	9	3.7	2.0	ND	1.9
Machinery	Diesel dc–dc	Diesel Direct drive flywheel	Diesel dc–dc	Diesel Direct drive	Diesel electric	Diesel dc–dc
Propeller(s)	4 x FP	2 x CP	1 x CP	2 x CP	ND	3 x FP
Diameter (m)	ND	ND	ND	ND	ND	ND
No. blades	4	ND	ND	ND	ND	ND
Nozzle(s)	No	ND	No	Yes	ND	No
Performance						
Open water (kn)	17.0	17.0	13.5	13.8	15	18.7
In ice	2 kn in 1.1 m	3 kn in 1.8 m	2 kn in 0.52 m	2 kn in 0.76 m	ND	2 kn in 0.82m
BP/B (tonnes/m)	8.1	ND	2.4	4.1	ND	4.2

Icebreaking Ships: U.S.A. and U.S.S.R.

Ship & country	Polar Star Polar Sea U.S.A.	Katmai Bay U.S.A.	Akademik Fedorov U.S.S.R.	Kapitan Belousov Kap. Veronin Kap. Melekhov U.S.S.R.	Lenin U.S.S.R.
Vessel type	Icebreakers	Icebreaker	Research & supply vessel	Icebreakers	Icebreaker
Year(s) construction completed	1973/76	1978	1987	1954/55/55	1957
Dimensions					
LBP (m)	107.3	ND	13.9	80.8	128.0
B (m)	25.5	11.4	23.5	19.4	27.6
D (m)	15.0	ND	ND	9.5	16.1
H (m)	8.5	3.7	8.5	7.0	10.5
Displacement (tonnes)	13,190	660	10,000	5,350	19,240
Form variables					
Stem angle (deg)	15/28	28	ND	21	ND
Bow type	White	White	ND	ND	ND
Propulsion					
Total power (MW)	44.8	1.9	13.9	7.7	32.4
Bollard pull (tonnes)	454*	24	ND	96	303*
No. shafts	3	1	1	2A + 2F	3
Power/shaft (MW)	14.9	1.9	13.9	1.9	10.8
Machinery	GT direct drive or Diesel ac-dc	Diesel dc-dc	Diesel electric	Diesel dc-dc	3 x nuclear reactors 3 x steam turbines dc-dc
Propeller(s)	3 x CP	1 x FP	1	4 x FP	3 x FP
Diameter (m)	4.88	ND	ND	3.5	5.64
No. blades	4	ND	ND	4	ND
Nozzle(s)	No	No	ND	No	No
Performance					
Open water (kn)	17.0	14.7	16	16.5	18.0
In ice	3 kn in 1.83 m	5.5 kn in 0.41 m	ND	2 kn in 0.82 m	2 kn in 1.43 m
BP/B (tonnes/m)	17.8	2.1	ND	5.0	11.0

* Calculated or measured values.

Icebreaking Ships: U.S.S.R.

Ship & country	Lena-class (6) U.S.S.R.	Moskva Leningrad Kiev Murmansk Vladivostok U.S.S.R.	Drobrynya Nikitich-class (22) U.S.S.R.	Amguema-class (13) U.S.S.R.	Semyon Deshnov Ivan Moskvitin U.S.S.R.
Vessel type	Cargo	Icebreakers	Icebreakers	Cargo	Icebreakers
Year(s) construction completed	1950	1961–69	1st in 1961	1962–72	1971
Dimensions					
LBP (m)	ND	112.4	62	123	ND
B (m)	18.9	24.5	18.0	18.9	ND
D (m)	11.2	11.5	9.3	11.6	ND
H (m)	8.3	10.5	5.5	9.1	ND
Displacement (tonnes)	ND	15,360	2,718	13,540	15,000
Form variables					
Stem angle (deg)	ND	26.5	26	29	ND
Bow type	ND	ND	ND	ND	ND
Propulsion					
Total power (MW)	6.2	16.2	4.1	5.4	22.5
Bollard pull (tonnes)	70	186	53	62	ND
No. shafts	1	3	2A + 1F	1	ND
Power/shaft (MW)	6.2	5.4	1.0	5.4	ND
Machinery	Diesel dc-dc	Diesel dc-dc	Diesel dc-dc	Diesel ac-dc	ND
Propeller(s)	1 x FP	3 x FP	3 x FP	1 x FP	ND
Diameter (m)	ND	5.8/4.82	ND	ND	ND
No. blades	ND	ND	ND	ND	ND
Nozzle(s)	No	No	No	No	ND
Performance					
Open water (kn)	15.4	18.0	14.5	15.0	ND
In ice	2 kn in 0.73 m	2 kn in 1.07 m	2 kn in 0.61 m	2 kn in 0.7 m	ND
BP/B (tonnes/m)	3.7	7.6	2.9	3.3	ND

Icebreaking Ships: U.S.S.R.

Ship & country	Ermak Admiral Makarov Krasin U.S.S.R.	Leonid Brezhnev Sibir' Rossiya U.S.S.R.	Kap. M. Izmaylor Kap. Kasolapov Kap. A. Radzhbov U.S.S.R.	Kap. Sorokin Kap. Nikolaev Kap. Dranitsyn Kap. Khlebnikov U.S.S.R.	Kapitan Chechkin Kap. Plahin Kap. Chadayev Kap. Krutov Kap. Bukaev Kap. Zarubin U.S.S.R.
Vessel type	Icebreakers	Icebreakers	Icebreakers	Icebreakers	Icebreakers
Year(s) construction completed	1974	1975/77/85	1976	1977–78	1977–78
Dimensions					
LBP (m)	13.0	133	54	125	74
B (m)	26.0	30	15.7	26.5	16.3
D (m)	16.7	ND	ND	ND	ND
H (m)	11.0	10.4	4.2	8.5	3.3
Displacement (tonnes)	20,214	23,460	2,045	14,900	2,240
Form variables					
Stem angle (deg)	26	24	ND	23	ND
Bow type	ND	Straight	ND	Straight	ND
Propulsion					
Total power (MW)	26.5	56	2.6	16.2	4.7
Bollard pull (tonnes)	285	515	33	186	59
No. shafts	3	3	2	3	3
Power/shaft (MW)	8.8	19	1.3	5.4	1.6
Machinery	Diesel dc-dc	Nuclear reactors Steam turbines ac-dc	Diesel ac-dc	Diesel ac-dc	Diesel ac-dc
Propeller(s)	3 x FP	3 x FP	2 x FP	3 x FP	3
Diameter (m)	5.4	ND	ND	ND	ND
No. blades	ND	ND	ND	ND	ND
Nozzle(s)	No	No	No	No	No
Performance					
Open water (kn)	20	21	13	19	14
In ice	2 kn in 1.53 m	2 kn in 1.77 m	ND	ND	ND
BP/B (tonnes/m)	11.0	17.2	2.1	7.0	3.6

Icebreaking Ships: U.S.S.R.

Ship & country	Stroptivy Spraved Livy Stakhanovets Suvorovets Sibirskiy U.S.S.R.	Mudyug Magadan Dickson U.S.S.R.	SA-15-class (19) U.S.S.R.	Kapitan-Yevdokimov-class (8) U.S.S.R.	Alekseï-Kosygin-class (3) U.S.S.R.	Sevmorput U.S.S.R.
Vessel type	Icebreakers	Icebreakers	Cargo	Icebreakers	LASH cargo	LASH cargo
Year(s) construction completed	1979–80	1982–83	1982–86	1983–84	1984	1986
Dimensions						
LBP (m)	69	78.5	164	73	232	228.8
B (m)	18.0	21.2	24.5	16.6	32.2	32.2
D (m)	ND	10.5	15.2	ND	18.3	18.3
H (m)	6.5	6.0	9.0	2.5	11.7	10.7
Displacement (tonnes)	4,200	7,250	24,255	2,150	61,950	61,000
Form variables						
Stem angle (deg)	ND	26	30	25	ND	30
Bow type	ND	Straight	Straight	Spoon	ND	Straight stem
Propulsion						
Total power (MW)	5.6	9.1	15.4	3.8	24.7	29.4
Bollard pull (tonnes)	68	106	146	49	245	353
No. shafts	2	2	1	4	2	1
Power/shaft (MW)	2.8	4.6	15.4	1.0	12.4	29.4
Machinery	Diesel Direct drive	Diesel	Diesel Direct drive	Diesel Direct drive	2 x slow speed ac–dc Direct drive	Nuclear reactor diesel Direct drive
Propeller(s)	2 x CP	2 x CP	1 x CP	4 x FP	2 x FP	1 x CP
Diameter (m)	ND	4	5.6	ND	5.6	8
No. blades	ND	4	4	ND	ND	ND
Nozzle(s)	No	No	No	ND	No	Yes
Performance						
Open water (kn)	15	16.5	17.0	13.5	18.4	20
In ice	ND	ND	2 kn in 1 m	ND	ND	ND
BP/B (tonnes/m)	3.8	5.0	6.0	3.0	ND	11.0

Icebreaking Ships: U.S.S.R. and West Germany

Ship & country	Taymyr-class (2) U.S.S.R.	Vitus Bering U.S.S.R.	Werdertor F.R.G.	Max Waldeck (modified) F.R.G.	Polarstern F.R.G.
Vessel type	Icebreakers	Supply vessel	Icebreaking supply vessel	Icebreaker	Icebreaker
Year construction completed	1988	ND	ND	ND	1982
Dimension					
LBP (m)	142.5	142.4	ND	46.6	102.2
B (m)	28.6	22.4	14	11.9/13.1	25
D (m)	ND	12.0	ND	ND	13.6
H (m)	8.0	8.5	ND	5.0	10.5
Displacement (tonnes)	23,500	10,800	ND	1,295	15,000
Form variables					
Stem angle (deg)	ND	ND	ND	16	24
Bow type	ND	ND	ND	Thyssen-Waas	ND
Propulsion					
Total power (MW)	38.3	11.5	7.0	2.4	14.7
Bollard pull (tonnes)	379	ND	ND	30	209
No. shafts	3	2	ND	1	2
Power/shaft (MW)	12.8	4.6	ND	2.4	7.4
Machinery	Nuclear reactor Steam turbine ac-ffc-ac	Diesel ac-dc	ND	ND Direct drive	Diesel
Propeller(s)	3 x FP	ND	ND	1 x FP	2 x CP
Diameter (m)	ND	ND	ND	3.25	4.2
No. blades	ND	ND	ND	ND	4
Nozzle(s)	No	ND	ND	No	Yes
Performance					
Open water (kn)	ND	15.9	ND	ND	15.5
In ice	1 kn in 1.7/1.8 m	ND	2 kn in 0.85 m 6.5 in 0.6 m	2 kn in 0.8 m (at 1.6 MW)	2 kn in 1.45 m
BP/B (tonnes/m)	13.3	ND	ND	2.5/2.3	8.4

APPENDIX B
REGULATIONS FOR NAVIGATION ON THE SEAWAYS OF THE NORTHERN SEA ROUTE (1991)

CONTENTS

1. Definitions 137
2. Principles, object, and goals of regulating 137
3. Request for leading through the Route 137
4. Requirements for vessels and command personnel .. 138
5. Due security of liability 138
6. Check 138
7. Order of navigation 138
8. Control of navigation 139
9. Suspension of navigation 139
10. Removal of vessels off the Route 139
11. Liability 139
12. Notification 139

Regulations for Navigation on the Seaways of the Northern Sea Route

Approved by USSR Minister of Merchant Marine
14 September 1990

These regulations were worked out in accordance with the USSR Council of Ministers Decision No. 565 of 1 June 1990, taking into account the relevant provisions of the Soviet legislation and rules of international law.

1. Definitions

The terms and phrases listed below shall have the following meaning when cited in the text:

1.1. *The Regulations*—these Regulations for Navigation on the Seaways of the Northern Sea Route the official text of which is published in the Notices to Mariners;

1.2. *The Northern Sea Route*—the essential national transportational line of the USSR that is situated within its Inland seas, territorial sea (territorial waters), or exclusive economic zone adjacent to the USSR Northern Coast and includes seaways suitable for leading ships in ice, the extreme points of which are limited in the west by the WESTERN entrances to the Novaya Semlya Straits and the meridian running north through Mys Zhelaniya, and in the east (in the Bering Strait) by the parallel 66° N and the meridian 168°58'37" W;

1.3. *The Administration*—the Administration of the Northern Sea Route, USSR Ministry of Merchant Marine, established by the USSR Council of Ministers Decision No. 683 of 16 September 1971 and having its domicile at 1/4 Rozhdestvenka, Moscow, 103759, USSR;

1.4. *Vessel*—any ship or other craft regardless of her nationality;

1.5. *Special requirements*—technical and operational rates and standards as set forth in publications issued by the Administration in addition to the Regulations, including the Guide to Navigation through the Northern Sea Route and the Requirements for the Design, Equipment and Supply of Vessels Navigating the Northern Sea Route;

1.6. *Administration Representative(s)*—the Head, Deputy Head, Chief State inspectors, or State Inspectors of the Administration as well as officials of Marine Operations Headquarters and other persons authorized by the Administration to exercise specific functions within its competence; and

1.7. *Marine Operations Headquarters*—special navigational services of the Murmansk and Far East Shipping Companies, directly performing ice operations as sea on the Northern Sea Route, the work of which is generally coordinated by the Administration. The requisite postal data of the Marine Operations headquarters are given in the Guide to Navigation through the Northern Sea Route.

2. Principles, object, and goals of regulating

The Regulations shall, on the basis of non-discrimination for vessels of all States, regulate navigation through the Northern Sea Route for the purposes of ensuring safe navigation and preventing, reducing, and keeping under control marine environment pollution from vessels since the specifically severe climatic conditions that exist in the Arctic Regions and the presence of ice during the most part of the year bring about obstacles, or increased danger, to navigation while pollution of the Northern Coast of the USSR might cause great harm to the ecological balance or upset it irreparably, as well as inflict damage on the interests and well-being of the North peoples.

3. Request for leading through the Route

3.1. The Owner or Master of a vessel intending to navigate through the Northern Sea Route shall submit to the Administration (Marine Operations Headquarters) a notification and request for leading through the Northern Sea Route in

compliance with the form and time stated in the Guide to Navigation through the Northern Sea Route.

3.2. The Administration (Marine Operations Headquarters) shall consider the submitted request and inform the submitter of the possibility of leading through the Route and other circumstances to be taken into consideration by the Owner or Master.

4. Requirements for vessels and command personnel

To navigate the Northern Sea Route, a vessel shall satisfy special requirements while the Master, or the person that performs his duties, shall be experienced in operating the vessel in ice.

In case where those persons have no such experience, or when the Master requests so, the Administration (Marine Operation Headquarters) may assign a State Pilot to the vessel to assist in leading it through the Northern Sea Route.

5. Due security of liability

It should not be permitted to navigate the Northern Sea Route to vessels that have not aboard a certificate of due financial security with respect to the civil liability of the Owner for damage inflicted by polluting marine environment and the Northern Coast of the USSR.

6. Check

6.1. In cases where unfavourable ice, navigational, hydrographic, weather, and other conditions occur that might endanger a vessel, or where there is a threat of polluting marine environment or the USSR Northern Coast, an Administration Representative may carry out in inspection of the vessel while it navigates the Northern Sea Route.

6.2. In case where there is a threat of polluting marine environment or the USSR Northern Coast, inspections of vessels may be also carried out by representatives of other Soviet State Bodies authorized to do so.

6.3. At the discretion of the Administration Representative, inspections may include examination of documents certifying that the vessel complies with special requirements and cargo documents and, depending upon the particular circumstances, direct examination of the vessel's condition, her equipment, facilities, technical navigational instruments, and readiness and ability to fulfill requirements concerning prevention of marine pollution.

6.4. The Master of the vessel shall be obliged to render necessary assistance to the Administration Representative in order that examinations should be completed in the most comprehensive and prompt way.

7. Order of navigation

7.1. The leading of vessels through the seaways of the Northern Sea Route shall be performed during the navigational period the beginning and end of which shall be determined by the Administration and Marine Operations Headquarters taking into account predictions and the actual state of ice, navigational, hydrographic, weather, and other conditions.

7.2. A vessel that has been admitted for leading through the Northern Sea Route shall navigate it following the sea way that has been assigned her and keeping the routes recommended by the Marine Operations Headquarters.

7.3. The Master of a vessel navigating the Northern Sea Route shall be obliged to carry out orders from the Marine Operations Headquarters concerning correction of the route due to changes in ice conditions and occurrence of other circumstances capable of affecting safety of navigation or bringing about a threat to the ecological situation.

7.4. Compulsory icebreaker-assisted pilotage* is established in the Proliv Vil'kitskogo, Proliv Shokal'skogo, Proliv Dmitriya Lapteva, and Proliv Sannikova due to adverse navigational situation and ice conditions and for the purpose of ensuring safe navigation.

In other regions the Marine Operations Headquarters shall, in consideration of ensur-

* "Icebreaker-assisted pilotage" implies an icebreaker leading a vessel, a pilot being on board the latter (Note by the Administration).

ing safe navigation and for the purpose of providing the most favourable navigation conditions, prescribe one of the following types of leading as determined by the circumstances:

(1) Leading along recommended routes up to a certain geographical point**;

(2) Aircraft-assisted leading***;

(3) Conventional pilotage;

(4) Icebreaker leading; and

(5) Icebreaker-assisted pilotage.

The Marine Operations Headquarters shall be entitled to substitute one type of leading for another.

7.5. The Master of the vessel navigating the Northern Sea Route shall be obliged to maintain contact with the Radio Centre of the appropriate Marine Operations Headquarters, depending upon the geographical position of the vessel.

8. Control of navigation

8.1. Navigation of vessels admitted to be lead through the Northern Sea Route shall be organized and controlled by the Administration through the Marine Operations Headquarters.

8.2. Navigation of vessels through the seaways of the Northern Sea Route shall be organized and controlled by the following authorities:

(1) In the western part, up to the meridian 125° E—by the West Marine Operations Headquarters at the port of Dikson; and

(2) In the eastern part, E of the meridian 125° E—by the East Marine Operations Headquarters at the port of Pevek.

8.3. Marine Operations Headquarters (or the Administration) shall provide that vessels should be supplied with navigational information and rendered leading and rescuing services.

8.4. When navigating the Northern Sea Route, payments for the services rendered to vessels by the Marine Operations Headquarters and the Administration shall be collected in accordance with the rates duly adopted.

9. Suspension of navigation

In cases where an obvious necessity of environment protection or safe navigation dictates so, the Administration or Marine Operations Headquarters may suspend navigation of vessels on specific parts of the Northern Sea Route for the period that the circumstances exist that have caused such a measure.

10. Removal of vessels off the route

If a vessel navigating the Northern Sea Route violates the provisions of these Regulations, in particular Regulations 3 and 4, it may be ordered to leave the Route.

The direction of the vessel's leaving the Route shall be determined by Marine Operations Headquarters taking into account the safety of the vessel, its crew, and cargo and necessary measures to protect nature.

11. Liability

The Administration and the Marine Operations Headquarters shall not be liable for damage inflicted on a vessel or property located aboard her by leading in ice conditions unless it is proved that they bear guilt for damages inflicted.

12. Notification

In addition to the existing requirements concerning reports on marine environment pollution, the Master of a vessel navigating the Northern Sea Route shall be obliged to promptly inform an Administration Representative of any fact of pollutant discharge, as effected by that vessel or detected thereby.

** Shore-based pilotage.
*** May be conducted by planes or helicopters (Note by the Administration).

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APPENDIX C
REQUIREMENTS FOR THE DESIGN, EQUIPMENT AND SUPPLY OF VESSELS NAVIGATING THE NORTHERN SEA ROUTE*

ADMINISTRATION OF THE NORTHERN SEA ROUTE

The present set of requirements takes into account the especially complex and dangerous navigation conditions along the Northern Sea Route and is intended to ensure navigation safety and to prevent pollution of the marine environment and northern coast of the USSR, a region that is especially vulnerable and where it is forbidden to dispose of petroleum products and other harmful substances in any amount, or of mixtures of such substances that contain such substances at percentages that exceed established standards, in accordance with the applicable legislation.

The requirements have been developed in accordance with the Administrative Legislation of the Northern Sea Route, approved by resolution of the Council of Ministers of the USSR (No. 683), September 16, 1971 (Legislation of the USSR, 1971, Part 07, page 124) and the Rules for Navigation on Sections of the Northern Sea Route (Rule 1, Part 1.5, and Rule 4) approved by the Ministry of the Sea-going Fleet September 14, 1990.

CONTENTS

1 Definitions 141
2 General Regulations 141
3 Hull of Ship 144
4 Mechanical Devices 145
5 Systems and Equipment 145
6 Stability and Unsinkability 146
7 Navigation and Communications Equipment 147
8 Provisions and Emergency Facilities 148
9 Crew of Vessel 148
Appendix 149

*USACRREL translation of the original Russian text.

1. DEFINITIONS

1.1. ***Administration:*** Administration of the Northern Sea-going Fleet of the Ministry of the Sea-going Fleet of the USSR.

1.2. ***Headquarters:*** Headquarters of sea operations: special navigation services of the Murmansk and Far East sea-going steamship associations directly responsible for commercial sea operations along the Northern Sea Route. Overall coordination of the operations is the responsibility of the Administration.

1.3. ***Requirements***: Requirements on the design, equipment, and provisions of ships plying the Northern Sea Route.

1.4. ***NSR***: Northern Sea Route.

1.5. ***Inspector***: Chief state inspector or state inspector the Administration, or the latter's authorized agent.

1.6. ***Petroleum products:*** Any type of petroleum product, including crude oil, refined petroleum products, liquid fuel, oil, waste products, and residue of the latter, as well as mixtures of any of the latter with other substances.

1.7. ***Harmful substance***: Any substance that, if disposed of in the sea, may present a danger to living resources, marine fauna and flora, or the health of human beings, interfere with activities in the sea, such as fishing, or worsen the quality of sea water with respect to the different ways it is utilized.

1.8. ***Rules of USSR Registry***: Rules of classification and construction of sea-going vessels of the USSR Registry.

1.9. ***Rules of Navigation***: Rules of Navigation Along Sections of the Northern Sea Route.

1.10. ***Handbook of Navigation***: Handbook of navigation for vessels along the Northern Sea Route.

1.11. ***Ship owner***: Person or organization holding ownership of a vessel.

1.12. ***Self-propelled ship***: Ship with a mechanical engine intended to propel the ship.

1.13. ***Non-self-propelled ship***: Ship lacking a mechanical engine for propulsion.

1.14. ***Icebreaker:*** Special ship intended for guiding, icebreaking, and towing vessels and carrying out rescue and other operations on ice floes.

1.15. ***Ice conditions:*** Distribution of ice of different characteristics in a navigation area.

1.16. ***Favorable ice conditions***: Presence of ice of compaction up to level 3.

1.17. ***Unfavorable ice conditions***: Present of ice of compaction level 7 or higher, and of icebergs.

2. GENERAL REGULATIONS

2.1. Unless otherwise stated, the present requirements cover all vessels with gross tonnage of 300 t (registered) or greater that travel along the Northern Sea Route.

2.2. Besides the present Regulations, vessels that travel along the NSR must also satisfy the applicable Rules of the USSR Registry for vessels containing the following literal designations of ice resistance categories as part of the symbol of their class: L1, UL, or ULA, or the literal designations of the equivalent ice categories used by other classifying orga-

nizations,[1] and must also satisfy the Regulations of applicable international conventions and the Code of the International Maritime Organization.

If the Administration (headquarters) so decrees, a ship belonging to ice resistance category L1 of the USSR Registry, or to equivalent ice resistance categories used by other classifying organizations, may be permitted to travel, while under the control of icebreakers, along sections of the Western (up to 125°E) district of the Northern Sea Route and along individual sections of the Eastern district of the Northern Sea Route during the summer navigation period if the navigation conditions are favorable.

2.3. Icebreakers are permitted to navigate along the Northern Sea Route under ice conditions that correspond to the designation of their respective ice resistance category. Operation of an icebreaker under more severe ice conditions than that envisaged by its ice resistance category is permitted in each individual case upon decision of the Administration (headquarters) following a review of the appropriate documentation provided by the owner of the vessel confirming that the state of the hull, machinery, and systems of the particular icebreaker is such as to ensure the necessary navigation safety when the vessel is in the particular district as well as to preclude any possibility of pollution of the sea.

2.4. Operation of ships of ice resistance category L2 may be permitted as an exception, upon special resolution of the Administration (headquarters), in the summer navigation period along sections of the Western district of the Northern Sea Route under favorable navigation conditions and favorable forecasts of navigation conditions. Operation of ships belonging to ice resistance category L2 in the Eastern district of the northern navigation route is not permitted in ice floes.

2.5. As an exception, transport ships that are currently in service and assigned to Arctic ports at the time of publication of the present set of Requirements and, moreover, have been assigned ice resistance category L2 or ice resistance category L3 may be permitted to travel along the Northern Sea Route exclusively during the period of summer navigation under favorable ice conditions within coastal pools of ice-free water in Arctic seas.

Such vessels may travel in this region only during the summer period upon a special decision of the Administration (headquarters) subject to the technical state of the vessel and the particular ice conditions.

2.6. Inland navigation vessels that have put out to sea (Marine Registry classes M-SP, M-pr, and O-pr), may be permitted to travel along the Northern Sea Route in regions and during periods prescribed for them by Internal Navigation Legislation,[2] though the ice conditions in these regions must not be more severe than the conditions prescribed in the Regulations of the Marine Registry for ships of the corresponding classes.

2.7. On ferry operations during the summer navigation period, inland and mixed-use navigation vessels may be permitted to travel along sections of the Northern Sea Route only on one-time excursions. The possibility, conditions, and provisions that are provided to inland and mixed-use navigation vessels on ferrying operations completed along sections of the Northern Sea Route are determined in each individual

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[1] A rough comparison of the literal designations of ice resistance categories between those employed by the USSR Registry and other classifying organizations is presented in the Appendix.

[2] Protocol on prescribed conditions which much be satisfied by inland navigation vessels that put out to sea.

case by the Administration (headquarters) subject to the actual ice situation along the particular section, the ice class of the vessel (ice resistance category), the technical state of its hull, machinery, and systems under the applicable conditions to ensure safe passage and to prevent pollution of the marine environment.

2.8. One-time excursions of ships and vessels belonging to the navy along sections of the Northern Sea Route are performed upon special authorization of the Administration (headquarters) following review and consultation regarding plans for additional equipment required to ensure safe passage and to prevent pollution of the marine environment.

2.9. Non-self-propelled vessels may be permitted to navigate along the Northern Sea Route under the condition that they fulfill the present set of Requirements (Parts 3 and 6) and that the towing method has been approved by the Administration (headquarters). Whether other Parts of the present set of Requirements have to be fulfilled is something that has to be determined in each individual case by the Administration (headquarters).

2.10. The captain (owner) of a ship that is to travel along the Northern Sea Route must transmit to the Administration (headquarters) an application for a commercial run or excursion along the Northern Sea Route that confirms the degree to which the vessel fulfills the present set of Requirements. The content of the application is [illeg] in the Navigation Manual.

2.11. Inspection of the ship to verify its compliance with the present set of Requirements is performed at the expense of the owner of the vessel and may be carried out from the harbors of Murmansk, Nakhodka, Vladivostok, or Provideniya, as well as from any other harbor convenient to the owner of the vessel.

2.12. Ships engaged in excursions along the Northern Sea Route may be freed (by the Administration (headquarters)) from the responsibility of having to fulfill certain Parts of the present set of Requirements if, following an inspection, it is found that the ship is in sufficient compliance with the navigation safety regulations and regulations for prevention of pollution of the environment for completing the particular excursion under the given ice conditions.

2.13. Reviews are carried out by the Inspector in accordance with the Supervisory Manual to ensure that the ship is in compliance with the present set of Requirements. The Administration may assign the task of carrying out the inspection to agents of the Inspector or to organizations recognized by the Inspector.

2.14. Places for carrying out a reinspection (harbors, harbor stations, harbor anchorage, etc.), which is done in accordance with Part 6 of the Navigation Rules, is established by the Administration (headquarters) in light of the particular route which the ship is to follow.

2.15. In the course of a ship inspection, the captain (owner of the ship) is required to provide the Inspector with all necessary information, indicating which Parts of the Regulations the ship is in violation of, together with all ships documents, including the Certificate of Seaworthiness of the ship, if it is provided for by the Regulations of the particular country, a Certificate of Classification, and an International Certification that confirms that all requirements that are part of the following International Conventions have been satisfied:

- Convention on the Protection of Human Life at Sea (SOLAL-74/78)
- Convention on the Prevention of Pollution from Ships (MARPOL-73/78)
- International Loadline Convention (1966), as well as the

- Code of the IMO on Safety, Construction, and Equipment for Special Types of Ships (nuclear-powered vessels, chemical carriers, gas carriers, etc.).

2.16. From the results of the inspection, the Inspector completes a Ship Inspection Report and determines whether the particular ship may travel along the Northern Sea Route and under what conditions and issues the corresponding decision.

3. HULL OF SHIP

3.1. All ships must be provided with a double-bottom floor throughout the entire width of the ship and over the entire breadth between the forepeak and afterpeak bulkheads. The height of the double-bottom floor corresponds to the applicable rules of the classifying organizations.

On ships with an icebreaker stem and short forepeak the double-bottom floor need not extend to the forepeak bulkhead in the area of the raked stem under the condition that the watertight compartments situated between the forepeak bulkhead and the bulkhead in the area of the joint between the stem and the keel line are used exclusively for storage of nonpolluting substances.

Double-bottom and double-side tanks may not be used for storage of petroleum products or other harmful substances. The use of double-bottom and double-side tanks on ships in service at the time of publication of the present set of Requirements is permitted for storage of fuel and lubricants.

3.2. The cargo tanks of tankers with deadweight greater than 5000 t used to transport petroleum products, as well as the cargo tanks of chemical carriers and gas carriers, must be situated at a distance of not less than 0.76 m from the outer sheathing of the ship hull. Space in the double-bottom floor and the double sides of tankers may be used as tanks for isolated ballast or must be kept empty.

3.3. The shape of the hull of ships intended for use on the Northern Sea Route must be adapted for navigation under the ice conditions of the Arctic basin. If bow line shapes different from that recommended by the Rules of the USSR Registry are used, operation of the particular vessels on sections of the Northern Sea Route must be approved by the Administration (headquarters). Navigation of ships with bulb-like bow lines is not permitted.

3.4. The ice toughness and construction of the hull of ships intended for navigation along sections of the Northern Sea Route must satisfy the requirements set forth in the applicable Rules of the USSR Registry for ships subsumed under ice resistance categories ULA, UL, and L1, or the equivalent regulations of other classifying organizations.

3.5. To ensure safe navigation along sections of the Northern Sea Route, from the standpoint of the toughness of the ship hull, it is recommended that ships plying these routes carry onboard the ship's Ice Log or, if the latter is lacking, Temporary Recommendations on Safe Speeds When Traveling through Ice Floes. This will allow the ship's navigator to determine a safe speed for the ship when traveling through ice floes as a function of the region and season of operation, the ice conditions along the section of the route, as well as the technical state of the hull.

3.6. In deciding whether domestically produced ships constructed in accordance with the Rules of the USSR Registry effective prior to 1981 should be permitted to navigate along sections of the Northern Sea Route, the technical state, construction, and strength of the hull of the

ship must be subjected to a special examination by the Administration (headquarters).

3.7. Additional supports of the sheathing and equipment must be provided in the bow part of the ship hull in order to ensure that the towed vessel is right next to the icebreaker. It must also be possible to fasten a tow line to the tip of the bow. If necessary, devices should be provided for removal and packing of the milled anchors onboard the ship.

4. MECHANICAL DEVICES

4.1. Mechanical devices must satisfy the requirements set forth in the Rules of the USSR Registry or those of equivalent rules of foreign classifying organizations for ships of the corresponding categories.

4.2. The time it takes to reverse one of the main propulsion engines (in maneuver mode) or to switch the blades of the controllable-pitch propeller from "full speed ahead" to "full speed backward" must not exceed 45 seconds.

4.3. When operating in reverse, the main propulsion engines must develop at least 70% of the rate of revolution of the forward running mode.

4.4. The propellers must have at least four blades and must be produced from stainless steel or high-strength bronze. It is recommended that propellers with detachable blades be used.

4.5. The propeller shaft tunnels must have local and remote controlled waterproof closings. On ships that entered into service prior to publication of the present set of Requirements, the presence of only a local drive is permitted.

4.6. On all ships one of the Kingston boxes must be an ice box with devices for heating and blast cleaning.

5. SYSTEMS AND EQUIPMENT

5.1. All ships must be equipped with a closed-dec[illegible]rain system that includes a device for biological cleaning or physicochemical treatment and sterilization of drainage water. The efficiency of the device must be sufficient to ensure simultaneous treatment of both drainage and domestic water. A collecting tank with capacity sufficient for independent navigation of the ship must be provided in order to collect wastes (slurry) from the device. If no device is provided for treatment of the drainage water, a system with a collecting tank of capacity sufficient for storage of the drainage water onboard the ship is required whenever the ship is in regions where it is forbidden to discharge drainage water.

5.2. An ice water separator intended for maintaining the content of petroleum in the effluent below 15 ml/l[3] must be installed on every ship, and storage tanks must be provided for storage of ice, washing, and ballast water that has become contaminated with petroleum products, including that from the bilgeway when transporting toxic loads, all of which it is forbidden to discharge along any section of the Northern Sea Route. The volume of the storage tanks must be sufficient for self-contained navigation of the ship for a period of 30 days.

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[3] [This number is not clear in the original Russian. Translator.]

5.3. Each ship must be provided with a device for collection and destruction (incineration) of refuse and the ship's production wastes that have become contaminated with petroleum products (wastes from separation and filtration of fuel, oil, rinse water, etc.) or a tank for storage of these wastes that is of sufficient volume for independent navigation of the ship for a period of 30 days.

5.4. The tanks specified in Parts 5.1 and 5.2 must be supplied with a pipeline laid out on the deck and leading to both sides of the ship, together with suitable pumping equipment for pumping out polluted water to a floating collector or a mooring rope.

5.5. The ballast tanks, which are adjacent to the outer side above the load waterline, including the double side tanks, must be supplied with a heating system.

6. STABILITY AND UNSINKABILITY

6.1. The stability of ships in the undamaged state must satisfy the requirements set forth in the USSR Registry or applicable international requirements provided for in international Conventions, Codes, and other documents of the IMO [International Maritime Organization].

6.2. The stability of the ship must be verified with respect to the potential ice accretion on the ship. In this verification, the quantity of ice per square meter of area of the total horizontal projection of the open decks must be taken to be at least 30 kg; similarly, the quantity of ice per square meter of area of the lateral surface exposed to the wind must be at least 15 kg.

6.3. The division into compartments and the stability of the ship in the damaged state must correspond to the requirements set forth in the Rules of the USSR Registry or in international regulations set forth in the SOLAS-74/78 and MARPOL-73/78 Conventions and other documents developed by the IMO for different types of vessels.

6.4. Regardless of the requirements set forth in Part 6.3., all ships must meet the requirements set forth in Part 6.5 in the case of the different forms of ice-induced damage described in Part 6.6. The forms of ice-induced damage for oil-carrying ships, chemical carriers, gas carriers, category ULA of dry-cargo ships, and drilling and passenger ships may occur at any point within the zone of ice-induced damage; for category UL and category L1 of dry-cargo ships, including ro-ro-type ships, these may occur between the watertight bulkheads, platforms, and decks. The requirements in Part 6.5 do not extend to the case when the engine compartment is flooded if the latter is situation in the afterbody on ships belong to category UL measuring less than 90 m in length or on ships belonging to category L1 measuring less than 125 m in length.

6.5. The requirements stipulated for emergency embarkation and the stability of a damaged ship are considered to have been fulfilled if the following conditions are satisfied:

6.5.1. Following righting of the ship and, in cases in which no attempt is made to right the ship, after flooding, the emergency waterline passes below the bulkhead deck.

6.5.2. The initial metacentric height of the ship in the final stage of flooding, assuming the ship is not in a tilted position, determined by the constant displacement method, prior to taking measures to increase this height, must not be less than 0.05 m.

6.5.3. The bank angle in the case of nonsymmetric flooding must not exceed 20° (for passenger vessels, 15°), and after measures have been taken to right the ship, 12°.

6.5.4. The statistical stability diagram of a damaged ship in the final stage of flooding must have an area of at least 0.0175 m-rad, the span of the section from the positive arms must be at least 20°, and the maximal arm at least 0.1 m within this span.

6.6. Calculations of the emergency stability must assume the following dimensions of the ice-induced damage in the zone where the damage occurs extending from the main line to the level 1.2 d_i within the length L_i:

- lengthwise space, 0.045 L_i if the middle of the puncture is at a distance of 0.4 L_i from the fore perpendicular and a distance of 0.015 L_i from any other part of the ship;
- depth of damage, measured along the normal to the outer sheathing at any point of the area of the calculated damage, 0.75 m;
- vertical dimension, 0.2 d_i.

Here L_i is the length of the ship measured along the waterline corresponding to a draft of d_i to the upper boundary of the ice belt.

7. NAVIGATION AND COMMUNICATIONS EQUIPMENT

7.1. All the electrical, radio, and navigation equipment and communications instruments installed onboard the ship must correspond, in terms of characteristics, to the requirements set forth in international conventions, regulations of the Registry, or the IKO [expansion unknown] and navigation conditions in the Arctic Ocean. The equipment must be provided with all necessary spare parts as well as factory instructions on operation and repair of the equipment.

7.2. All ships traveling along the L_i must be equipped with standard means of navigation together with the following additional instruments:

7.2.1. Gyroscopic compass with repeaters at all control stations as well as a fathometer and a direction finder, are installed on all ships.

7.2.2. Ships with gross tonnage of more than 1600 t (registered) as well as all passenger ships, are provided with two radar sets that operate independently of each other, one of which should have a wavelength of 10 cm. Ships with lesser tonnage are provided with a single radar set with wavelength of 3 cm.

7.2.3. All ships must be equipped with a receiving display of a radio navigation or satellite navigation system that makes it possible to determine the position of the ship to within at least 100 m at a 95% probability.

7.2.4. All ships must be provided with a log for measurement of speed. It is recommended that a radio log or an acoustic log supplied with a system of transmitters and receivers protected from the possibility of collisions with ice be used.

7.3. In addition to ordinary means of radio communications, all ships must be provided with the following equipment:

7.3.1. Onboard ground station for satellite communications (or some other type of station that makes possible reliable communication in the zone defined by the sections of the Northern Sea Route).

7.3.2. Receiver of navigation warnings (NAVTEKS).

7.3.3. Trailing sea-marker radio buoy.

7.3.4. Instruments for sound recording and reception of facsimiles, including receipt of maps of hydrometeorological information.

7.3.5. Ultra-short-wave stations for communications with aircraft, helicopters, and ships traveling in a convoy and operating at a frequency of 122.5 MHz.

8. PROVISIONS AND EMERGENCY FACILITIES

8.1. Each ship must be provided with a double store of fuel and lubricants at the start of a voyage along the Northern Sea Route, determined on the basis of the planned voyage along the Northern Sea Route. On non-stop trips along the Northern Sea Route, the stores of fuel and lubricants must be sufficient for 30 days. In calculating the fuel stores, the full speed in open water must be used as the rated speed. Stores of provisions and fresh water (taking into account replenishment from a distilling plant) and all other types of ships provisions must be sufficient for at least 60 days.

8.2. Spare parts, instruments, and fire-fighting equipment must be available onboard the ship, the range and quantity of which is determined by the corresponding requirements set forth in the Rules of the USSR Registry or the rules of other classifying organizations for ships of the appropriate categories.

Moreover, the set of spare parts must include a screw propeller or two spare blades for each propeller in the case of propellers that are installed with detachable blades.

8.3. All ships must be provided with emergency supplies the volume of which is determined by the Rules of the USSR Registry or the rules of other classifying organizations for ships with unlimited cruising range, together with the additional equipment as specified in Table 1.[4]

Table 1.

No.	*Type of equipment onboard*	*Characteristic*	*Quantity*
1	Pulleys or notch blocks for raising a damaged detachable propeller or damaged blades to the deck	Full set	1
2	Portable gas-welding equipment for welding and cutting, including spare electrodes (not on tankers)	Full set, weight around 30 kg	1
3	Search light with set of spare bulbs for illuminating the channel	At least 2 kW	1
4	Portable electric submersible pump with delivery 100 t/hr, including a full set of hoses		2
5	Full sets of very warm clothing		Based on size of crew
6	Hydrothermal suits (recommended)		Based on number of people on ship

9. CREW OF VESSEL

9.1. The size of the crew for trips in ice floes must be large enough to guarantee a three-shift watch, where this duty is required, at the ship control and equipment stations.

[4] In case the set of additional equipment is not present onboard the ship, it may be obtained on lease at the ports of Murmansk or Provideniya.

9.2. The captain of the ship or person substituting for him on an operating watch must possess the minimal level of knowledge of navigation in ice floes in accordance with the supplements to Rule 11/2 of Convention on Training and Licensing of Seamen and Maintenance of Watches, 1978, have the experience of steering ships traveling under ice conditions along sections of the Northern Sea Route for not less than 15 days. In the absence of such experience, it is necessary to take onboard the ship a pilot with experience navigating in ice floes (Navigation Rules, Part 4).

9.3. The captain of the vessel or person substituting for him on an operating watch must know the signals that are employed by ice breakers on runs in ice floes and presented in the Navigation Manual.

9.4. Radio specialists must know the rules of practical radio communications presented in the Navigation Manual.

9.5. The crew of the ship must be forewarned concerning prohibitions against discharging polluting substances and rubbish along sections of the Northern Sea Route as well as their responsibility for any pollution of the sea and ice cover in accordance with the laws of the USSR.

APPENDIX

Rough Correspondence Between the Literal Designations of Ice Resistance in the Class Symbols of the USSR Registry and Other Classifying Organizations*

Classifying organization	*Types of ice classes*			
USSR Register	UL	L1	L2	L3
Lloyd's Register	Ice class I* or IL Super	Ice Class I or IA	Ice Class 2 or IB	Ice Class 3 or IC
German Lloyd's	E4	E3	E2	E1
Veritas Bureau	Ice I Super or IA Super	Ice I or IA	Ice II or IB	Ice III or IC
Norwegian Veritas	Ice IA*	Ice IA	Ice IB	Ice IC
American Bureau of Navigation	Ice AA	Ice A or IAA	Ice B or IA	Ice C or IB
or IC				
Italian Sea Registry	RGI* or IAS	RGI or IA	RG2 or IB	RG3 or IC
Japanese Registry	Class IA Super IS or AA IS	Class IA IS or A IS	Class IB IS or B IS	Class IC IS or C IS
Finnish–Swedish ice classes	Ice Class IA Super	Ice Class IA	Ice Class IB	Ice Class IC
Canadian Rules for Prevention of Pollution of the Arctic Ocean	A	B	C	D

* The ice resistance categories for transport vessels that are presented above correspond to the rules set forth by the classifying organizations in the period 1985–1990.

APPENDIX D
LETTER FROM THE HEAD OF THE ADMINISTRATION OF THE NORTHERN SEA ROUTE "TO THE OWNER OR MASTER OF THE VESSEL"

To the Owner or Master of the Vessel

Dear sir,

We would like to draw your attention to the fact that "Regulations for Navigation on the Seaways of the Northern Sea Route" (NSR) officially are published 13.07.91 in the Notices to Mariners N 29.

Due to this "Regulations" the vessel intending to navigate through the NSR shall satisfy special requirements.

For taking decision concerning the possibility of leading your ship through NSR you should submit to Northern Sea Route Administration (NSRA) a notification, where you must indicate the following:

1. Name of ship, flag, port of registry, shipowner (full name and full address)
2. Gross/net tonnage Reg. T
2.1. Full displacement of the ship
3. Main dimensions (length, breadth, draft), output of main engines, propeller (construction, material), speed, year of build
4. Ice class and classification society, date of last examination
4.1. Construction of bow (ice knife or bulb-bow)
5. Expected time of sailing through the NSR
6. Presence of certificate of insurance or other financial security in respect of civil liability for environmental pollution damage
7. Aim of sailing (commercial voyage, tourism, scientific research, etc.)

The permission to pass through NSR, dates, region of navigation and conditions of ice-pilotage you would be given by our experts after survey of your ship on her compliance to the Requirements for the Design, Equipment and Supply of Vessels Navigating the NSR.

Such survey could be done at any suitable for you port (all expenses on your account). After that all details of the leading of vessel via seaways of NSR must be clarified in your agreement with Murmansk Shipping Co. or Vladivostok Far-Eastern Shipping Co. which is responsible for arrangement of the above escort.

Please take notice that this permission for navigation on the seaways of the Northern Sea Route would not give you right to conduct any scientific research in Russian Arctic, and tourism or fishing as well. For these purposes you must send a special request to the Ministry for Foreign Affairs of Russian Federation.

Now only tranzit escort of the foreign vessels via NSR (or sailing to port of Igarka) is possible, becouse Russian Arctic ports (except Igarka) are not open for entering of foreign vessels.

On this subject you may contact to
Northern Sea Route Administration
Address: 1/4, Rozhdestvenka, Moscow
103759, Russian Federation
Telex: 411197 MMF SU
Tel: (095) 926 16 96

Best Regards
Capt. V. Mikhailichenko
Head of NSRA

APPENDIX E
OVERVIEW OF U.S. NAVY JOINT ICE CENTER PRODUCTS AND SERVICES FOR NSR OPERATIONS

by D. Pashkevich and D. Benner
USN/NOAA JIC, Washington, D.C.

At present, the Joint Ice Center (JIC) prepares three categories of products and/or services that would provide information on sea ice conditions along the Northern Sea Route. Routine Ice Guidance products are available to all JIC customers via an autopolling distribution system. Tailored Special Support and Sea Ice Services are only created for U.S. Government customers. Vessels can access all of the products hosted in the autopolling system via the global communication satellite (COMSAT) system operated by the INMARSAT organization. In addition, a West and East Arctic Ice Edge Analysis and Forecast is posted weekly (each Tuesday) on the SCIENCEnet electronic mail and bulletin board service operated by OMNET (617-244-4333). The JIC bulletin board is SEA.ICE within OMNET.

1. Routine Ice Guidance Products

a) East and West Arctic Ice Analyses

These weekly charts (updated each Wednesday) are "global-scale" (1: 10,000,000) analyses and are used for general guidance regarding total ice extent (location of the ice edge), ice concentration (coverage in tenths), and ice stage of development (thickness category). Areas covered in these products include (but are not limited to) the five Russian seas (Barents, Kara, Laptev, East Siberian, and Chukchi) of the NSR and the waters (Bering and Beaufort Seas) bordering Alaska. Data are derived from visual/infrared imagery from the Advanced Very High Resolution Radiometer (1.1-km resolution) on the NOAA TIROS satellites and the Operational Linescan System (0.6-km) on the Defense Meteorological Satellite Program (DMSP) satellites. In cloud-covered situations, the primary data source is passive microwave imagery (25-km) from the Special Sensor Microwave Imager aboard the DMSP satellite.

b) East and West Arctic 30-day Forecast

These bimonthly charts (issued on the 1st and 15th) show the predicted ice conditions valid in 30 days. These "global-scale" forecasts are used primarily for mission planning.

c) Alaskan Regional Ice Analysis

These biweekly charts (issued on Tuesday and Friday) detail the ice conditions on a "regional-scale" (1:7,500,000) in the Bering and Beaufort Seas. Ice parameters of interest include the location of the ice edge, concentration, stages of development, and smaller scale features like coastal leads/polynyas. Data are derived from NOAA TIROS AVHRR, DMSP OLS, and DMSP SSMI.

d) West Arctic Seasonal Outlook

This annual long-range (issued on 15 May) forecast product predicts the severity of ice conditions along the north slope of Alaska for the up-

coming summer shipping season (July–August). Of greatest interest are the opening and closing dates of the coastal shipping lanes (between Pt. Barrow and Prudhoe Bay) for unescorted vessels.

2. Special Support Ice Guidance Products

Tailored sea ice support products can be requested (via letter or facsimile) by any U.S. Government agency needing detailed ice information. Requests must specify the objective of the mission, start/end dates of the operation, and geographic area of interest. Most tailored support products are high-resolution "local-scale" sea ice analyses that are typically used for safety of navigation by vessels operating near or within the sea ice pack.

This highly detailed sea ice analysis is produced by "blending" together several high-resolution data sources, which include: 1) infrared/visual DMSP OLS imagery (0.6-km resolution), 2) Synthetic Aperture Radar (SAR) data (30–240-m resolution) from the European Space Agency's (ESA) European Remote Sensing (ERS-1) satellite, and 3) U.S. Navy aerial reconnaissance data derived from either visual observations or Side-Looking Airborne Radar (SLAR) imagery (5.5-m resolution).

For the purpose of ship routing along the NSR and Alaskan waters, the ideal data source is all-weather high-resolution SAR. Unfortunately, due to the absence of a data storage capability on the ERS-1 spacecraft, SAR imagery is available only in limited quantities in direct read-out mode in the mask of the receiving station. With respect to the NSR, the JIC receives limited quantities of imagery for the East Siberian, Chukchi, Bering, and Beaufort Seas from the Fairbanks, Alaska, station and can purchase imagery from the Tromsø, Norway, station as required for analysis in the Barents, Kara, and Laptev Seas. The limitation on SAR imagery availability from Alaska may change with the launch of the Canadian RADARSAT in the 1995–96 time frame. It is hoped that this satellite will provide a much greater volume of SAR data to the JIC for operational ice support.

3. Sea Ice Services

The following sea ice services can be provided or coordinated by the JIC upon request to any U.S. Government agency: a) Ship routing, b) Ship visits and operational briefings, and c) Aerial ice reconnaissance support. All three services are described in Chapter 2 of the Joint Ice Center Environmental Services Guide.

The Environmental Services Guide is in revision due to the recent transfer of weather forecasting responsibilities in Chapter 3 to other forecast centers. The Naval Pacific METOC Center, Pearl Harbor, Hawaii (formerly Naval Western Oceanography Center) and the Naval Atlantic METOC Center, Norfolk, Virginia (formerly Naval Eastern Oceanography Center) are tasked to provide weather support and ship routing for the Arctic region. Their addresses are as follows:

NAVPACMETOCCEN
Box 113
Pearl Harbor, HI 96860-5050
DSN: 471-0349
COMM: 808-471-0349

NAVLANTMETOCCEN
Mcadie Building U117
Norfolk, VA 23511-5399
DSN: 564-4967
COMM: 804-444-04967

APPENDIX F
WORLD DATA CENTER PRODUCTS FOR THE ARCTIC

Announcements of data sets and information on arctic sea ice available at the World Data Center-A for Glaciology, and National Snow and Ice Data Center.

General

_____ 90-GLA-01 General Description
_____ 90-GLA-05 Price List for Snow and Ice Data Sets
_____ 88-GLA-ARC WDS/NSIDC Arctic Data Sets

Bibliographic Collection and Publications

_____ 91-GLA-02 Information Center and Bibliographic Collection
_____ 90-GLA-03 Microfiche Index to Information Center Collection

Snow Cover Data Sets

_____ 83-GLA-11 Defense Meteorological Satellite Program (DMSP) Visible and Infrared Imagery Collection*
_____ 90-GLA-11B DMSP Arctic Mosaic

Glacial Geophyics

_____ 80-GLA-43 Airborne Polar Ice Sounding and Geomagnetic Data

Sea Ice Data Sets (see also Satellite Passive Microwave Data, below)

_____ 81-GLA-51 Arctic Ocean Buoy Data — 1979 to present
_____ 83-GLA-50 Sea Ice Charts
_____ 83-GLA-53 International Ice Patrol Iceberg Data — 1960 to present*
_____ 83-GLA-54 Joint Ice Center Digital Data — 1972 to present*
_____ 83-GLA-55 Digital Sea Ice Data (9 sets)
_____ 83-GLA-58 Arctic Ice Dynamics Joint Experiment (AIDJEX) Data

Satellite Passive Microwave Data

_____ 89-GLA-52 Antarctic Microwave (ESMR) Sea Ice Data*
_____ 89-GLA-80.1 Special Sensor Microwave Imager (SSM/I) Sea Ice Data Products
_____ 89-GLA-81.2 SMMR Brightness Temperatures, 1978–1987 (CD-ROM)

MIZEX and CEAREX Data

_____ 90-GLA-57 Marginal Ice Zone Experiment (MIZEX) Data*
_____ 91-GLA-59.1 Eastern Arctic Ice, Ocean and Atmosphere: CEAREX CD-ROM

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* National Snow and Ice Data Center Sets are included.

World Data Center/National Snow and Ice Data Center
National Geophysical Data Center, NOAA
Boulder, Colorado 80303

APPENDIX G
DEFENSE MAPPING AGENCY INDEX MAPS OF AVAILABLE CHARTS FOR THE NSR

The maps in this section were drawn from 1993 index maps provided by the U.S. government's Defense Mapping Agency, located in Bethesda, Maryland. Each rectangle shown on these maps corresponds to a navigation chart that is available from the DMA. Further information about these hydrographic products can be obtained by contacting the agency directly at:

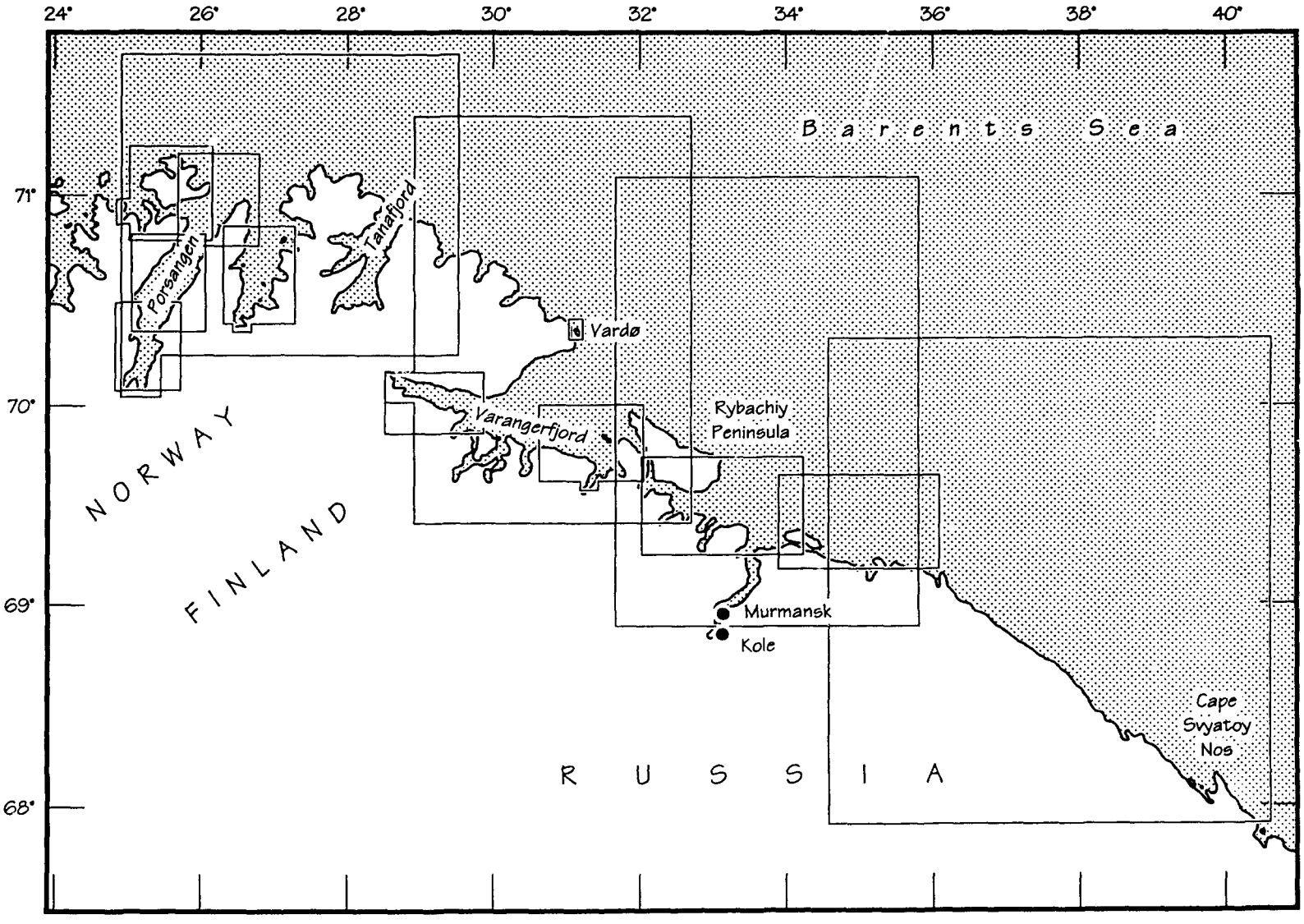
U.S. government inquiries:

DMA Hydrographic Center
ATTN: GAF1, Stop D-28
4600 Sangamore Road
Bethesda, MD 20816-5003
DSN: Fax: 287-2498
Tel: Fax: (301) 227-2498

All others:

National Ocean Service
Distribution Branch (N/CG33)
6501 Lafayette Avenue
Riverdale, MD 20737-1199
Tel: (301) 436-6990

National Ocean Service
Chart Sales & Control Data Office
701 C Street, P.O. Box 38
Anchorage, AK 99513
Tel: (907) 271-5040



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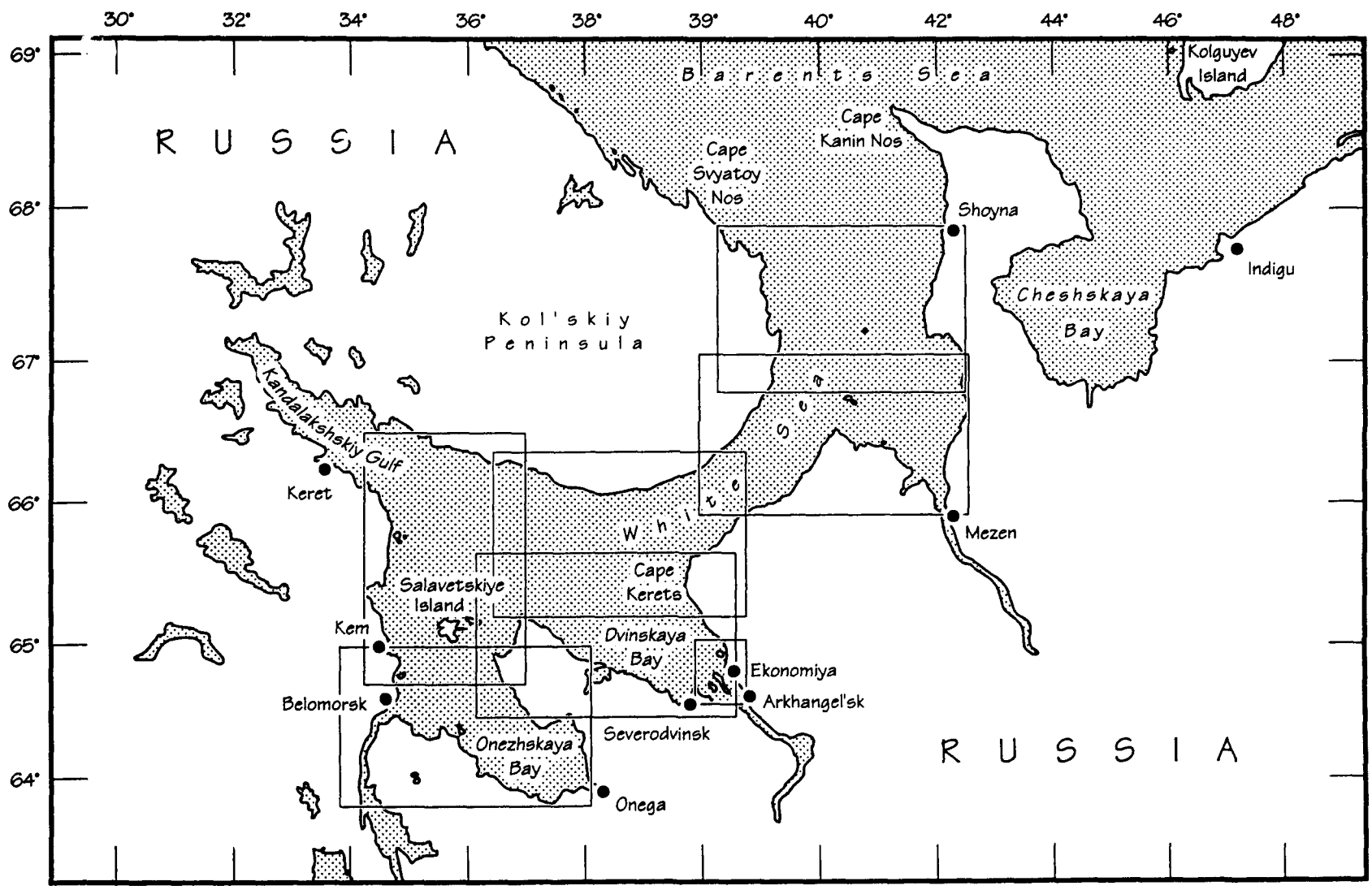

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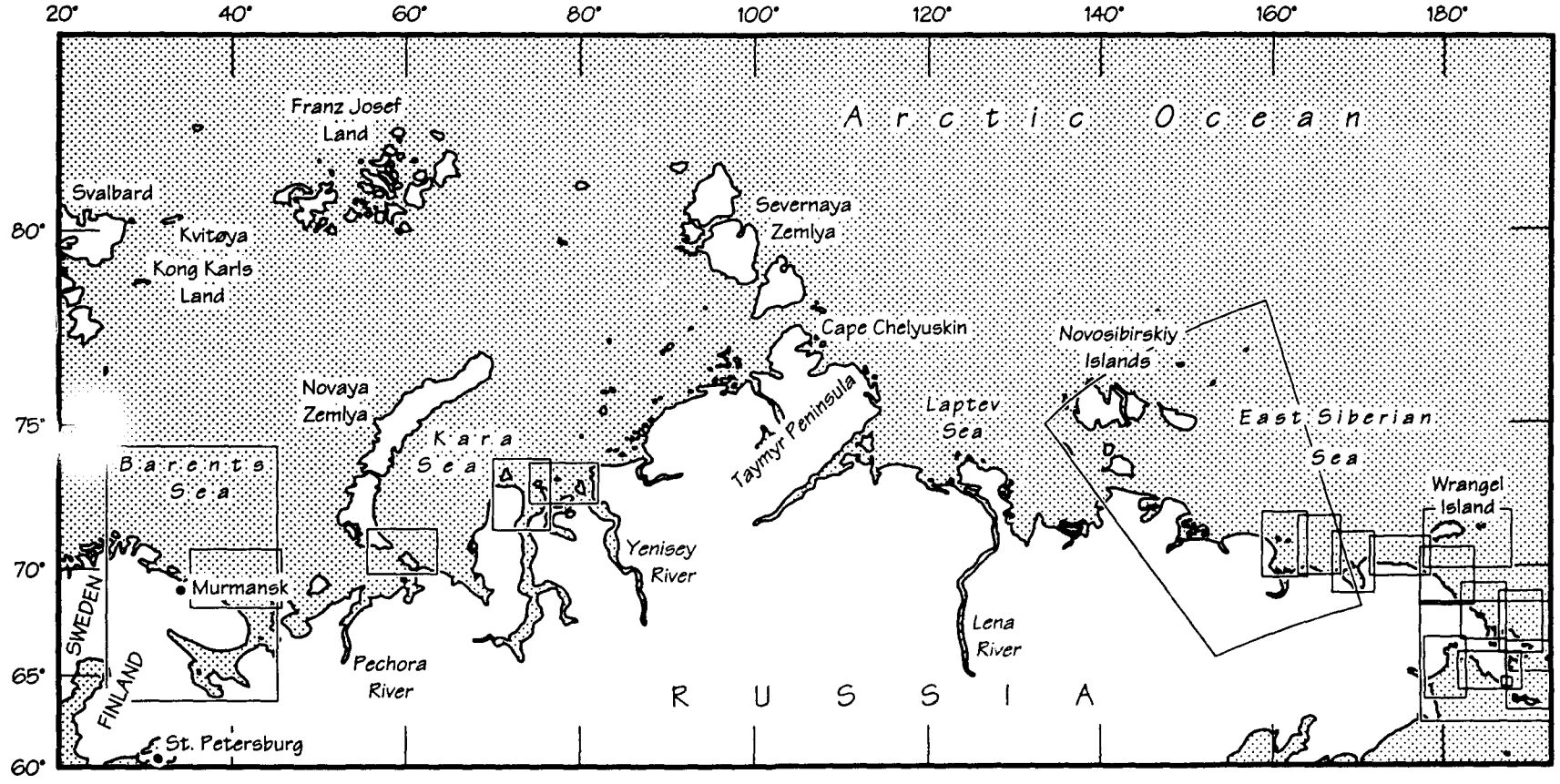

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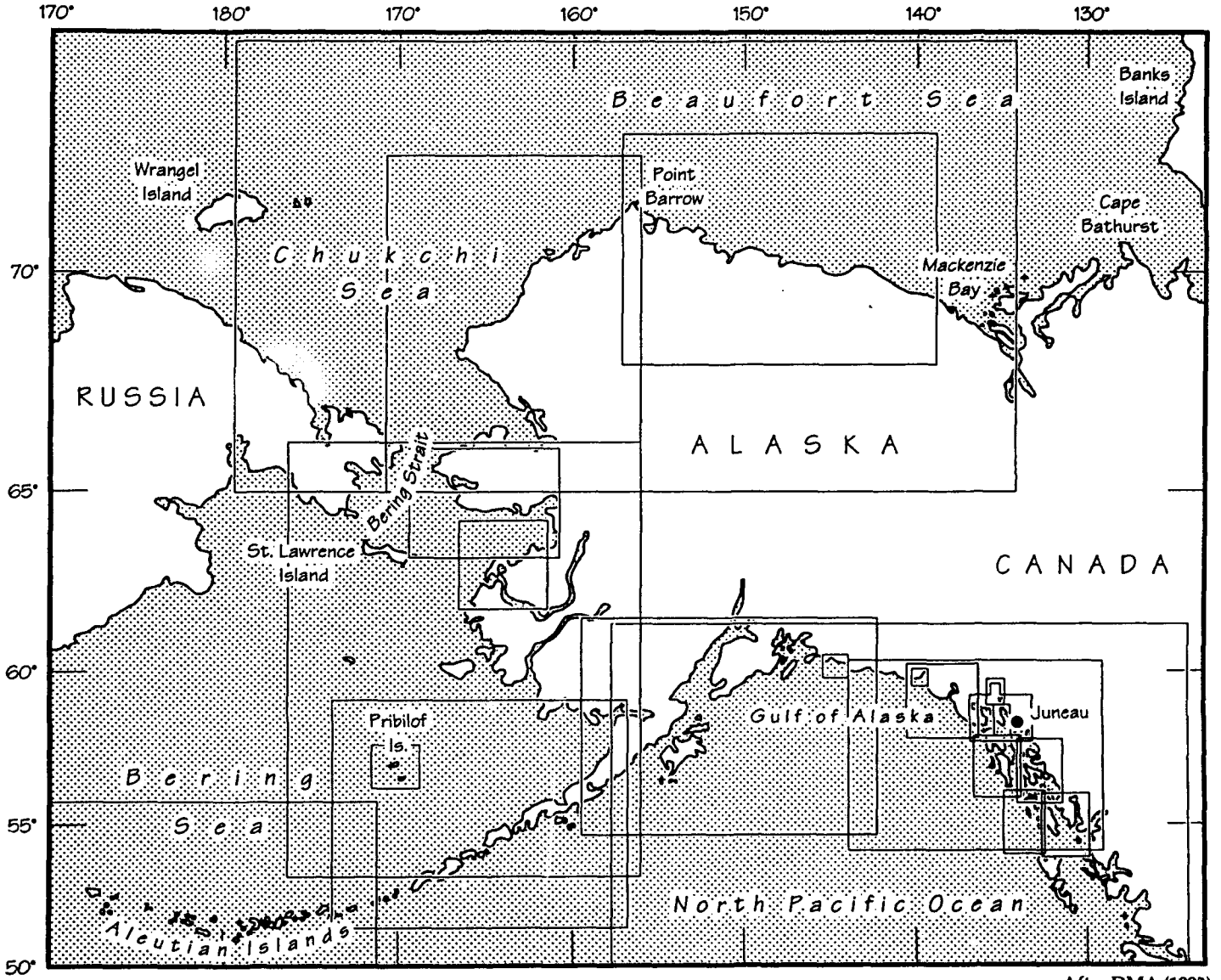

After DMA (1993)

APPENDIX H
AN ADVENTURE IN ORDERING RUSSIAN MAPS OF THE NSR

Abbreviations:

ANSR	Administration for the Northern Sea Route (Moscow, Russia)
FESCO	Far Eastern Shipping Company (Vladivostok, Russia)
FNI	Fridtjof Nansen Institute (Norway)
HYD	HydroCon, Ltd. (a private company with offices in Horten, Norway, and St. Petersburg, Russia)
INSROP	International Northern Sea Route Project at the Fridtjof Nansen Institute
JIC	US Navy/NOAA Joint Ice Center (Suitland, Md.)
MSC	Murmansk Shipping Company (Murmansk, Russia)
ONR	Office of Naval Research (Arlington, Va.)
RSHD	Russian State Hydrographic Department (St. Petersburg, Russia)

Date	Journal entry
8/26	Got phone number for ANSR from Moscow directory assistance.
8/30	Began attempts to call ANSR.
9/2	Began phone call attempts to contact MSC—no answer. Also mailed letter and began fax attempts of same letter to MSC—no answer.
9/14	Fax dated 9/2 finally went through.
9/20	Began attempts to send a 1-page fax to MSC; gave up after a week.
9/21	Tried calling MSC several times but lines were busy. Got through to ANSR with first attempt but was told to call back tomorrow, I think (language barrier).
9/27	Sent 1st telexes to ANSR, MSC, and FESCO.
9/28	Called and spoke with Head of ANSR who said there were approximately 15 maps of the route at about $12 each. Gave me contact for RSHD from where they are issued. Sent 1st telex to RSHD requesting maps.
9/29	Tried calling two different numbers for MSC but got only recording of "technical difficulties in Russia."
10/1	Received fax from RSHD confirming availability of maps but providing no ordering information.
10/5	Sent 2nd telex to RSHD requesting prices and ordering procedure.
10/14	Called JIC to request a contact in Russia for maps.

10/15 Received fax from JIC with contact at HYD Norway.

Re-sent 1st telex to MSC; re-sent 2nd telex to RSHD; tried to re-send 1st telex to FESCO, but it wouldn't go.

10/18 Received telex "hello" from MSC. Sent 3rd telex to MSC requesting information on maps.

Tried to re-send 1st telex to FESCO but their machine is out of order.

10/19 Received fax from RSHD saying 25 maps were unclassified but not yet priced. He hopes to get back with prices by end of December.

10/21 Mailroom calls directory assistance and gets two other telex numbers for FESCO; re-sent 1st telex to FESCO.

Received 1st reply from FESCO confirming receipt of both 9/27 and 10/21 telexes from me.

10/22 Sent 2nd telex to FESCO requesting information on maps.

Tried sending fax to HYD Norway requesting maps, but it wouldn't go.

10/26 Sent telex to HYD Norway.

Called INSROP at FNI and asked where to get maps. They suggested MSC and offered to forward my request along with their plea. Faxed MSC request for maps and ordering information through FNI.

10/27 Received fax (dated 10/25) from MSC saying they have maps, but did not provide ordering information.

10/29 Received urgent fax from HYD Russia offering to send atlas and 37 maps at $15–20 each. Tried to respond using my "best guess" of their illegible fax number before their deadline (they shut off their fax machine at 1200 EST), but couldn't get through. Sent telex to HYD Norway for forwarding.

11/1 Sent faxes to HYD Norway and Russia requesting maps.

11/3 Received call from a captain at ONR saying he had carried the maps and atlas home from HYD Russia and will send them out right away via priority mail.

11/8 Called ONR to ask about maps; he hadn't yet sent them.

11/15 Received letter and invoice for 37 maps at $17.50–18.50 each from HYD Russia through ONR. Called ONR to learn maps were sent out on 11/10.

11/17 Maps finally received from ONR but atlas did not arrive until 11/23. No further reply was ever received from MSC or FESCO regarding our map request.

APPENDIX I
AARI'S HYDROMETEOROLOGICAL AND ICE FORECASTING PRODUCTS

by N. Doronin
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1. ICE OBSERVATIONS

1.1. Aircraft observations

The major part of ice information was received with the help of aviation. First ice reconnaissance flights along the Northern Sea Route started in 1936. During decades they were carried out on a regular basis each ten days except for the dark periods of the year when there was no light for visual observations. The area of Russian Arctic was subdivided into three regions: the western sector over the Barents and Kara seas, the central one over the Laptev Sea, and the eastern one over the East Siberian and Chukchi seas. Each sector was covered by separate surveys. It is possible to estimate that during the period since 1936 there were about 1000 comprehensive coverages made by flight observations along the Northern Sea Route. The flights gave information to plot ice maps containing the following:

—ice border position,
—areas covered by ice of different age and concentration—leads. cracks, hummocks, pressure ridges,
—icebergs,
—snow coverage,
—polluted areas,
—degree of melting.

As an example of the detalisation of this information it is possible to mention that recent studies allowed to extract from the ice maps about 30 000 icebergs sightings in the area of the Barents Sea.

There were flights with airborne radar carried out over some parts of the NSR in particular years.

1.2. Field measurements

There were tens of expeditions organised by AARI during decades for in situ ice measurements. They brought information about ice thickness, snow cover thickness, ice deformations, mechanical properties, chemical composition, etc. Lately, some experience was obtained in field studies of ridges and stamukhas, including measurements of their underwater parts and coring to determine the degree of ice consolidation.

There was a method developed in AARI for instrumental field monitoring of ice pressure induced by convergence.

1.3. Ship operations in the ice

Historically AARI was involved in studies for designing of ice-going ships. It has an ice tank, one of the biggest in the world. AARI specialists have knowledge of simulating the sea ice with the given mechanical properties to test and calibrate ships' hulls. Hundreds of Russian ships navigate along the NSR each year. There is information about navigation conditions collected in the archives of AARI.

1.4. Ice forecasts

AARI was established as an institute responsible for the hydrometeorological services for navigation along the NSR, and forecasting activity was of primary importance. Now numerical and statistical ice forecasts are produced by AARI. They comprise short-term ice displacement predictions, calculations of freezing and melting, and general outlooks for month up to one year ahead.

Specialists of AARI take part in ship routing during navigation season in the relevant operational centres in the Arctic.

2. METEOROLOGICAL INFORMATION

2.1. Data collection

There are about 50 meteorological stations on the islands and along the coast of Russian Arctic. Some of them started recordings since the beginning of the century, and some of them at the end of forties. They register four or eight times a day standard meteorological parameters: air temperature, pressure, humidity, precipitation, wind speed and direction, visibility, cloudiness, sometimes solar radiation, icing and other elements. The data are displayed on meteorological maps that include also information coming from ships, operating in the area. All this information is partly stored in the archives of AARI and partly in the Arctic hydrometeorological centres.

2.2. Meteorological forecasts

AARI is able to provide numerical short-term weather forecasts for 3–10 days in advance for the area of the NSR. There are methods allowing to predict air pressure with daily detalisation for the periods of 10–35 days in advance with the skill score better than 20% over the pure chance estimation. It is also possible to get general 90 days' outlooks.

3. OCEANOGRAPHIC OBSERVATIONS

3.1. Ship expeditions

Since 1940 three oceanographic expeditions from AARI operated each summer in the corresponding sectors of the Russian Arctic. They covered open water areas with hydrographic cross-sections, providing data on temperature, salinity, oxygen, nutrients, etc. Hundreds of current measurements were fulfilled. This information is stored in AARI archives.

3.2. Coastal observation

There are several coastal stations that record sea level oscillations during last decades. In some research projects special wind wave registrations were carried out. This information is partly stored in AARI and partly in the Arctic hydrometeorological centres.

3.3. Oceanographic forecasts

AARI has several methods of sea level and wind wave predictions that are used in practical work.

The following forecast products are prepared by the Institute:

Weather Forecasts

1. 3- to 10-day short-term forecasts comprising air temperature, pressure, and wind.
2. 1-month to 1-year long-term forecasts comprising air temperature with respect to climatic mean, pressure, and air flow.

Hydrographic Forecasts

1. Sea level
2. Surface currents
3. Wind and waves

Ice Forecasts

1. Statistical 1- to 3-month long-term forecasts comprising ice coverage, areas of consolidation, ice edge location, maximum fast ice thickness, dates of destruction, dates of stable ice cover formation.
2. Model calculations for both 1- to 3-month long-term and 4- to 8-day short-term forecasts comprising ice distribution, thickness, drift and some other parameters
3. Specialized navigation recommendations.