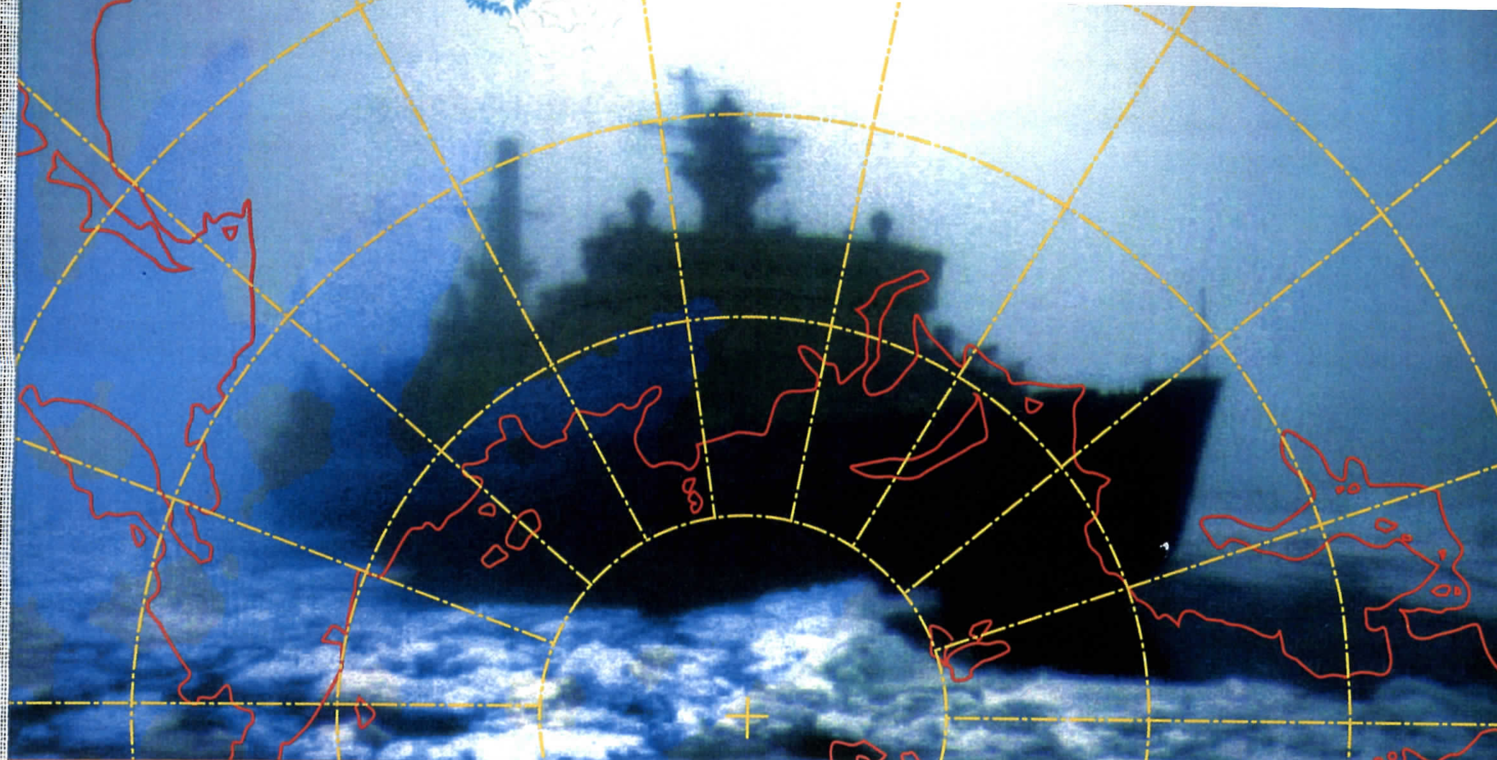

INSROP WORKING PAPER
NO. 45-1996, I.3.1

Variability Analysis of Natural Conditions and Influence on NSR Sailing.

Sylvi Vefsnmo and Stig Magnar Løvås

INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia | The Fridtjof Nansen Institute, Norway | Ship & Ocean Foundation, Japan

INSROP WORKING PAPER NO. 45-1996

Sub-programme I: Natural Conditions and Ice Navigation.

Project I.3.1. Design and Development of Information System.

Title: Variability Analysis of Natural Conditions and Influence on NSR Sailing.

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Date: 26 April 1996.

Reviewed by: Dr. Robert Frederking, National Research Council of Canada, Ottawa, CANADA.

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FOREWORD - INSROP WORKING PAPER

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

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

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

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

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TITLE

INSROP Natural Conditions and Ice Navigation

Project I.3.1: Variability analysis of natural conditions and influence on NSR sailing.

AUTHOR(S)

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CLIENT(S)

Fridjof Nansen Institute

REPORT NO.	CLASSIFICATION	CLIENT'S REF.	
STF22 F96206	Restricted	Henning Simonsen	
CLASS. FRONT PAGE	ISBN	PROJECT NO.	NO. OF PAGES/APPENDICES
Open		605675	79/2
ELECTRONIC FILE CODE		DISCIPLINARY RESPONSIBILITY	
F:\HOME\VEFSNMO\INSROP\I31-FORS.W61		Stig Magnar Løvås	
FILE CODE	DATE	RESPONSIBLE SIGNATURE	
	1996-04-22	Torbjørn Sotberg	

ABSTRACT

The purpose of the 1995 activity has been to perform analysis of physical environment parameters affecting transit sailing. Regional analysis as well as analysis along given sailing routes have been performed by use of INSROP GIS. Furthermore the project includes a risk analysis related to ship-in-ice operation.

The AARI Sea Ice Charts covering the period 1967-90 have been analyzed statistically and the results are implemented into INSROP GIS. Variability analyses are carried out for parameters such as total ice concentration, ice thickness, fraction of old ice and presence of fast ice on a monthly basis.

In order to evaluate the ice conditions along a planned sailing route, a methodology to analyze the distribution of different ice conditions along a specified route has been developed and implemented into INSROP GIS. As a demonstration example two sailing routes have been chosen, one representing a coastal transit route and the other representing a northern transit route.

Ship accident data reported in different INSROP reports have been compiled and compared to the variability analysis of the AARI Sea Ice Charts Database. The data cover the period 1954-90 and 1991-94. The comparison shows that the ship accidents are closely related to unfavourable ice conditions.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Environment	Miljø
GROUP 2	Arctic	Arktis
SELECTED BY AUTHOR(S)	Northern Sea Route	Nordøstpassasjen
	Ice conditions	Isforhold

PREFACE

Due to reduced funding in 1995 within Sub-programme I, the most vital data implementation and analysis tasks within the planned Project I.5.1 activities are included in Project I.3.1. This report presents the outcome of these tasks of the project. The purpose of the 1995 activity has been to perform analysis of physical environment parameters affecting transit sailing. Regional analysis as well as analysis along given sailing routes have been performed by use of INSROP GIS. Furthermore the project includes a risk analysis related to ship-in-ice operation.

The delivery of Russian physical data are delayed and recently a contract has been signed between FNI and AARI including delivery of ocean current data, pressure data and discontinuities. The Russian data are to be delivered by 30 April 1996. Within this project, two atlases have been ordered from Backbone Publishing Co.:

- Atlas of Ice and Snow of the Arctic Basin and Siberian Shelf Seas
- Atlas of Arctic Icebergs.

The atlases are digital, but the delivery is delayed and will not arrive before 15 March 1996. Consequently, the data can not be implemented into INSROP GIS and analyzed within Phase I, but will still be important data for a potential Phase II.

Dr. Robert Frederking at the National Research Council in Ottawa has reviewed the report and the project review is enclosed as Appendix B. The authors are grateful to the reviewer and all the comments have been taken into consideration when finalizing the report.

Trondheim, 22 April 1996

Sylvi Vefsnmo

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Research Scientist

SUMMARY

The AARI Sea Ice Charts covering the period 1967-90 have been derived from the World Data Center for Glaciology at the National Snow and Ice Data Center through World Wide Web and implemented into INSROP GIS and analyzed. Variability analyses are carried out for parameters such as total ice concentration, ice thickness, fraction of old ice and presence of fast ice on a monthly basis.

Seasonal freeze-up of the sea begins in September at the northern ice edge and along the rapidly cooling mainland coast and is complete by mid-October. On average the total ice concentration is high in October due to high fraction of new ice. During mild years no ice is observed in the southern part of the sea except for the Severnaya Zemlya massif. In the winter months November to April the whole region is covered by very dense drifting ice. The thinnest ice is mainly found in the southern Kara and Laptev Seas. The East-Siberian Sea has the highest fraction of old ice and the Ayon massif has more than 60 % of old ice on average. The average thickness may be 250 cm in the winter months. The coastal zone is occupied by fast ice in the winter period which is non-uniformly developed. The Laptev Sea has the largest expanse of fast ice from January to June and expands to cover most of the continental shelf up to 500 km from the mainland. The thickness of the fast ice commonly reaches 200 cm and may grow up to 250 cm in severe years.

Seasonal breakup throughout the entire sea begins in June and July. In June to September the ice concentration is low in the Kara Sea, especially in the western part where drifting thick ice may be present. In the eastern part, especially the Severnaya Zemlya massif, the ice concentration is high and the ice consists mainly of thick first-year ice. When the seasonal ice minimum is reached by mid September, the entire Kara Sea south of 75 °N is normally ice free. In extremely mild summers, the Kara Sea may become ice free as far north as 80 °N. The East-Siberian Sea experiences the least summer melt of any of the arctic seas. The Chukchi Sea experiences wide seasonal variations in total ice extent. The Severnaya Zemlya, Novosibirskiy and Ayon massifs carry large amounts of old ice which is very resistent to summer melt. In the summer months the fast ice is only present from Dikson to Severnaya Zemlya.

Ice concentration statistics from analysis of daily SSM/I data for the period July 1987 to December 1990 were implemented into INSROP GIS in 1994. In order to study the representativeness of short time series, the SSM/I analyses have been compared with the analyses of the AARI Sea Ice Chart Database. In the winter months November-April both the AARI and SSM/I analyses show very dense drifting ice both in the Laptev and East-Siberian Seas. In both the Kara Sea and the Chukchi Sea the SSM/I data show lower ice concentrations than the AARI data. The greatest seasonal fluctuations occur at the east and west ends of the route and a short time period will not be representative for regions with large fluctuations. 1990 was a year with especially light ice conditions and this will heavily influence the variability analysis for a short time period. In the Laptev and East-Siberian Seas where the fluctuations are small in winter, the variability analysis will not be very sensitive for the length of the time series.

Statistical data on air temperature, sea surface temperature, salinity and river flow rates have been implemented into INSROP GIS and analyzed. During the winter period October to May the lowest air temperatures are registered in the Boris Vil'kitsky and the Sannikov straits where minimum is about -40 °C in January/February. The temperature data show highest air

temperatures in the Kara Gates where the average temperature is ranging from -17 °C to -5 °C in winter and 1°C to 5 °C in summer. In summer the most saline waters are found in the north/ western region where the salinity ranges from 32-34 ppt. In winter the salinity increases due to freezing and the most saline waters are found in the western and eastern parts of the region where the the easiest ice conditions are found.

In order to evaluate the ice conditions along a planned sailing route, a methodology to analyze the distribution of different ice conditions along a specified route has been developed and implemented into INSROP GIS. As a demonstration example two sailing routes have been chosen, one representing the coastal transit route and the other representing a northern transit route. Most of the **northern** transit route passes through very dense drifting ice, only 10-40 % passes through open waters during the summer months June-November. About 30-50 % of the route experience old ice which is dominating in late summer. The most dominating ice conditions are very thick first-year ice. Only 20 % of the route are in thin ice (less than 70 cm). Very dense drifting ice is also dominating along the **coastal** transit route. The amount of open water increases from May to September where about 60 % of the route goes through open water. In the winter months 30 % of the route goes through fast ice. About 30 % of the route is in old ice during the whole year, except in late summer when the fraction is 50 %. In the summer months about 60-80 % of the route goes through thin ice. During the winter months there is multi-year ice present over 10-20 % of the route.

Ship accident data reported in different INSROP reports have been compiled and compared to the variability analysis of the AARI Sea Ice Charts Database. The data cover the period 1954-90 and 1991-94. When comparing average number of accidents with the total number of navigating ships the data from 1954-90 shows that the eastern part of the NSR has a greater accident risk than the western part. In the Arctic seas about 40 % of the damages occur in the Kara Sea where the intensity of sailing is highest. About 20 % of the accidents occur in the Laptev Sea and the East Siberian Sea while only about 14 % occur in the Chukchi Sea. The data also show that most of the accidents occur at the end of the navigation period (August-September). Based on the statistical analysis of the AARI Sea Ice Charts Database, this period shows a high fraction of open water simultaneously with the presence of old ice, which represents obstacles to the ship traffic. The ice accidents are closely related to the ice conditions and the analysis shows that more than 50 % of the accidents are connected to unfavourable ice conditions. When comparing the accident data for 1983, 1990 and 1993 with the ice conditions, the correlation is very high. Especially 1983 was a year with severe ice conditions and high accident rate.

TABLE OF CONTENTS

1 INTRODUCTION

When addressing the possibility of establishing an economically attractive maritime traffic in the NSR, the question of ice conditions and their influence on navigation arises immediately. Important elements such as sailing distances, average speed, icebreaker capacity and transport regularity depend on the ice conditions and will influence the attractiveness of commercial NSR shipping. Transit of the NSR is today limited to the period July-October mainly due to severe ice conditions. To make the NSR really an international sea route the length of the operational season must be substantially prolonged. New ice breaker and ship technology, together with improved navigational systems, will give possibilities for extending the navigation period. Regularity is another key factor to NSR profitability. Irregularity might occur due to rapid changes in the ice and weather conditions as well as to inefficient coordination of convoys and ice-breaker support.

The purpose of Project I.3.1 is to develop an information system to serve as a tool to store, analyze and integrate information on natural conditions of importance to ice navigation along the NSR. The 1995 work has focused on finalizing the first version of the system, user guidance and training. Due to reduced funding in 1995 within Sub-programme I, the most vital data implementation and analysis tasks within the planned Project I.5.1 activities are included in Project I.3.1. The purpose of the 1995 activity has been to perform analysis of physical environment parameters affecting transit sailing. Regional analysis as well as analysis along given sailing routes have been performed by use of INSROP GIS. Furthermore the project includes a risk analysis related to ship-in-ice operation. This report presents the work and findings from this part of the project.

Chapter 2 includes a decription of the data sources, both data acquisition, content of dataset and data processing. The variability analysis of sea ice conditions, air temperature, sea surface temperature, salinity and river discharge is presented in Chapter 3. An analysis method to analyze the distribution of different ice conditions along a specified route has been developed and implemented. Coastal and northern transit sailing routes have been selected for demonstration of the analysis method and the results are presented in Chapter 4. Chapter 5 includes a risk analysis related to ship-in-ice operation.

2 GLOBAL DIGITAL SEA ICE DATA BANK - AARI SEA ICE CHARTS

2.1 Data acquisition

The AARI sea ice charts are based on airborne visual and SLAR data, and satellite data. Except for in 1972, the charts were split into western and eastern charts. These 'twin' charts may be a few days apart. The charts should in principle be issued with a 10-day interval (3 per month), but in some 10-day periods only the western or the eastern chart exists, and there are also a number of 10-day periods where no charts are available. The sea ice charts cover the period 1967-90 and the total data coverage is shown in Appendix A.

The sea ice charts have been digitized into SIGRID format at the Arctic and Antarctic Research Institute (AARI) in St.Petersburg, Russia. The complete data set was acquired at SINTEF from the World Data Center-A (WDC-A) for Glaciology [Snow and Ice] maintained at the National Snow and Ice Data Center (NSIDC) through World Wide Web (http://nsidc.colorado.edu/NSIDC/wdc-a.html) as three compressed UNIX tar files (aari-72.tar.z, aari-east.tar.z, aari-west.tar.z).

2.2 Data processing and analysis

As this data set is the most comprehensive and detailed sea ice data set available for Project I.3.1 in 1995, it was necessary to use the data set to derive a number of sea ice parameters, such as total ice concentration, ice thickness, concentration of old ice (second-year and multi-year ice) and presence of fast ice. The purpose of the data processing and analysis was to establish a statistical sea ice data set for NSR-related evaluations. The statistical data should be provided as monthly statistics, based on all available ice charts within each month, for each single year and for all years (multi-year statistics). The resulting data sets should also be prepared for use in INSROP GIS.

At the data set location (NSIDC), also software utilities to extract sea ice information from a SIGRID-formatted data set were available. The C-program (strip_geog.c) was the basis for developing the data processing and analysis software at SINTEF. The first step was to modify this program to export data in a format suitable for import into ARC/INFO, as ArcView can use ARC/INFO-formatted data directly and also because the initial plan was to run the analysis in the ARC/INFO GRID module. The format chosen was the ARC/INFO ASCIIGRID format. To display selected ice chart in INSROP GIS (ArcView), software utilities to convert a SIGRID ice chart to an ARC/INFO point cover were developed. Hence, at this point there were two options for displaying the original sea ice charts in INSROP GIS.

The next step was to derive the ice parameters to be statistically analysed from the original attributes of the data points in each sea ice chart. The SIGRID data comprise unique codes for each attribute, but as some codes may represent ranges rather than discrete values, this calls for special treatment to derive discrete values for use in the statistical analyses (See Sections 2.4-2.7). The statistical parameters to be provided include minimum, mean, median and maximum values, and probability for a certain criteria (e.g. ice concentration > 70%) to be fulfilled.

The third step was to create single-year monthly statistics. This was originally planned to be handled by ARC/INFO (aml-code), but problems with handling NODATA values in the statistical analysis and experienced large requirements for processing time and temporary storage, forced a change in strategy. Therefore a FORTRAN (aaristats_sy.f) program was developed to prepare monthly statistical files for each parameter for each year and the strip-geog.c program was modified further to be a subroutine of the FORTRAN program. By specifying ice parameter to be derived, threshold value (for ice parameters where this is required) and input file name, the modified C-program returns the derived ice parameter in a fixed grid. For grid cells where the source ice chart has no data value, a NODATA value (101) is used. The FORTRAN program handles the statistical analysis and stores the results on files in the ARC/INFO ASCIIGRID format. In this process NODATA values are excluded and the mean monthly value is derived by taking the sum of the real data values and dividing by the number of real data values (excl. NODATA values).

The fourth step was to create the multi-year statistics. The aaristats_sy.f FORTRAN program was used as basis to develop the aari_sy2my.f FORTRAN program. This program reads the single-year monthly files, runs the statistical analyses, and stores the multi-year statistics on monthly files in the ARC/INFO ASCIIGRID format for each parameter. In this process NODATA values are excluded and each single-year monthly parameter grid is given equal weight, that is, the number of data sets within each month is not considered. This avoids getting biased results due to some years having far more original data sets than others, but it also means that if a month in a year had only one (or two) ice chart value(s) at a given location, this value will be used as representative for the entire month.

The last step is to prepare the statistical grid files for use by INSROP GIS. This was achieved by developing a FORTRAN program that, for each month, reads the parameter grids for each time period (single-year months and multi-year months), and stores the data in the INSROP GIS Point ASCII import format. To save storage space and increase performance, the data are split into several files for each time period (YY = year [67-90], MM = month [01-12]):

- File 1: Total ice concentration and ice thickness (myMMa00.pos, syYYMMa0.pos)
- File 2: Old ice concentration (myMMb00.pos, syYYMMb0.pos)
- File 3: Fast ice (myMMc00.pos, syYYMMc0.pos)
- File 4: Data coverage (myMMd00.pos, syYYMMd0.pos)

Files of Type 1 and 4 include all points with at least one real data value, while files of Type 2 and 3 comprise only points where presence of old ice (Type 2) or fast ice (Type 3) is observed.

2.3 Implementation in INSROP GIS

Due to the size of the statistical data set, only the multi-year data subset and selected single-year data subsets are implemented in INSROP GIS. The data were prepared in the INSROP GIS Point ASCII import file format and implemented using the *Theme - Create New Feature Theme menu* option in the View window. The data set is called *AARI Sea Ice Statistics.*

2.4 Deriving ice concentration values

Ice concentration codes are used for total ice concentration and partial ice concentrations. To solve the problems of some SIGRID ice codes representing ranges, each ice concentration code is assigned a minimum, mean and maximum ice concentration value. The mean value is the average of the minimum and maximum values, and the median value is the median of the same average values. For codes representing discrete ice concentrations, these values are all equal, but for codes representing ranges, the range limits are used as the minimum and maximum values. Table 2.1 shows how the SIGRID codes are recoded (incl. special codes).

Table 2.1 Conversion of SIGRID codes to ice concentration values.

Code	Explanation	Minimum	Mean	Maximum
00	Ice free	0	0	0
01	Open water (< 1/10)	1	5	9
02	Bergy water[1]	2	2	2
04	Fast ice	100	100	100
10	1/10	10	10	10
.	.			
13	1/10 - 3/10	10	20	30
.	.			
71	7/10 - 10/10	70	85	100
.	.			
90	9/10	90	90	90
91	more than 9/10, less than 10/10	91	95	99
92	10/10	100	100	100
99	Unknown[2]	101	101	101
102	Land[2]	102	102	102

1) Artificial low concentration value to indicate presence of ice
2) Values greater than 100 are ignored in the statistical analysis

When deriving the probability of ice concentration above a given threshold, the 'range codes' also require special treatment. If, for a given code, the minimum ice concentration value is above the threshold, the probability is 100 percent. Similarly, if the maximum ice concentration value is below the threshold, the probability is 0 percent. However, if the threshold concentration is within the ice concentration range of the given code, a uniform distribution of ice concentrations within the range is assumed, and the fraction of the ice concentration range above the threshold is taken as the probability; e.g. it is assumed that for areas where the ice concentration is coded as 4/10 - 6/10, there is a 50 per cent probability to encounter ice concentrations above 5/10.

2.5 Deriving ice thickness values

Ice thickness codes may represent ice thickness or stage of development. To solve the problem of some SIGRID ice codes representing ranges, each code value is assigned a minimum, mean and maximum ice thickness value. The average value is the average of the minimum and maximum values. For codes representing discrete ice thicknesses, these values are all equal, but for codes representing stage of development, associated ice thickness range limits are used as the minimum and maximum values. Table 2.2 shows how the SIGRID codes are recoded (incl. special codes).

Table 2.2 Conversion of SIGRID codes to ice thickness values

Code	Explanation	Minimum	Mean	Maximum
00	Ice free	103	103	103
01	Ice thickness in cm	1	1	1
50	Ice thickness in cm	50	50	50
51	Ice thickness in 5 cm intervals	55	55	55
.	.			
60	Ice thickness in 5 cm intervals	100	100	100
61	Ice thickness in 10 cm intervals	110	110	110
.	.			
70	Ice thickness in 10 cm intervals	200	200	200
71	Ice thickness in 50 cm intervals	250	250	250
.	.			
74	Ice thickness in 50 cm intervals	400	400	400
75	Ice thickness in 100 cm intervals	500	500	500
.	.			
79	Ice thickness in 100 cm intervals	900	900	900
80	No stage of development[1]	103	103	103
81	New ice	1	15	30
82	Nilas, ice rind less than 10 cm	1	5	9
83	Young ice	10	20	30
84	Gray ice	10	13	15
85	Gray-white ice	15	23	30
86	First year ice	30	115	200
87	Thin first year ice	30	50	70
88	Thin first year ice stage 1	30	40	50
89	Thin first year ice stage 2	50	60	70
91	Medium first year ice	70	95	120
93	Thick first year ice	120	160	200
95	Old ice	120	280	420
96	Second year ice[2]	120	185	250
97	Multi year ice[3]	240	330	420
98	Glacier ice[4]	104	104	104
99	Unknown[4]	101	101	101

1) Ice free (zero ice thickness) codes are ignored in the statistical analysis of ice thickness

2) Thicker than thick first year ice and less than 250 cm (Romanov, 1993)

3) According to Romanov (1993)
4) Values 101-104 are ignored in the statistical analysis of ice thickness

At any given ice chart location, there may be information on the thickest, second thickest and third thickest ice. The minimum ice thickness at a location is the minimum thickness registered, while the maximum ice thickness value is the maximum thickness of the thickest ice. When calculating the average ice thickness, the average thickness of all thickness registrations are weighted by the fraction of average associated partial ice concentration to the average total ice concentration. The mean and median ice thicknesses are derived from the average ice thicknesses.

When deriving the probability of ice thicknesses within a given ice thickness range, the same methodology as used to derive probability of ice concentrations above a given threshold is employed. However, as the probabilities are to be valid for a thickness range, not just above a thickness threshold, the fraction of the observed thickness range being within the specified analysis thickness range multiplied with the associated partial ice concentration, is used as the probability percentage.

2.6 Deriving old ice concentration values

Information on ice types is included in the Stage of development codes. As the term old ice includes both second year ice and Multi year ice, all partial ice concentrations associated with 'Stage of development' codes 95, 96 and 97, are counted as an 'old ice' concentration value (as specified in Table 2.1). In addition, the partial concentrations of ice with codes representing ice thickness above 200 cm (codes 71-79) are counted as old ice concentration values. All partial 'old ice' concentration values are summarized into one old ice concentration value for each point.

When deriving the probability of old ice above a given threshold, the same methodology as described in Section 2.4 for total ice concentration is employed, with the additional requirement that partial ice concentration ranges are involved rather than one total ice concentration range.

2.7 Deriving fast ice concentration values

Fast ice is shown as code value 08 in the Form of ice codes. For points with Form of ice code equal 08 (Fast ice), the ice concentration is set to 100 (ref. Table 2.1). For other code values (except the unknown code value: 99) the fast ice concentration is set to zero. For each location, the probability of fast ice within a time period is calculated as the percentage of fast ice data values out of the total number of data values with 'Form of ice' code different from unknown.

3 VARIABILITY ANALYSIS OF PHYSICAL ENVIRONMENT DATA

3.1 Sea ice conditions

The ice conditions along the NSR are extremely dynamic, leading to large annual, seasonal and regional variations. Large ice fields are observed in the same regions each summer (see Figure 3.1) and are obstacles to ship traffic along the NSR since the massifs contain significant concentrations of multi-year ice and frequently heavily hummocked ice is present.

The AARI Sea Ice Charts have statistically been analyzed on a monthly basis. The analysis comprises the following information:

- minimum total concentration of sea ice
- maximum total concentration of sea ice
- median total concentration of sea ice
- average total concentration of sea ice
- probability distribution of total ice concentration greater than 10 %
- probability distribution of total ice concentration greater than 40 %
- probability distribution of total ice concentration greater than 70 %
- minimum concentration of old ice
- maximum concentration of old ice
- median concentration of old ice
- average concentration of old ice
- probability distribution of old ice concentration greater than 10 %
- probability distribution of old ice concentration greater than 40 %
- probability distribution of old ice concentration greater than 70 %
- minimum ice thickness
- maximum ice thickness
- median ice thickness
- average ice thickness
- probability distribution of ice thickness less than 70 cm
- probability distribution of ice thickness less than 120 cm and greater than 70 cm
- probability distribution of ice thickness less than 200 cm and greater than 120 cm
- probability distribution of ice thickness greater than 200 cm
- probability distribution of fast ice

The analysis results provide statistical information about the ice conditions during the period 1967-90 and the information should be useful as reference information on the general ice conditions in the region. However, ridges, hummocked areas and leads are not included in these data. In order to describe the large annual, seasonal and regional variations, the analysis has been commented on a seasonal basis. The following division has been applied:

- Summer (July-August)
- Autumn (September-October)
- Winter (November-April)
- Spring (May-June)

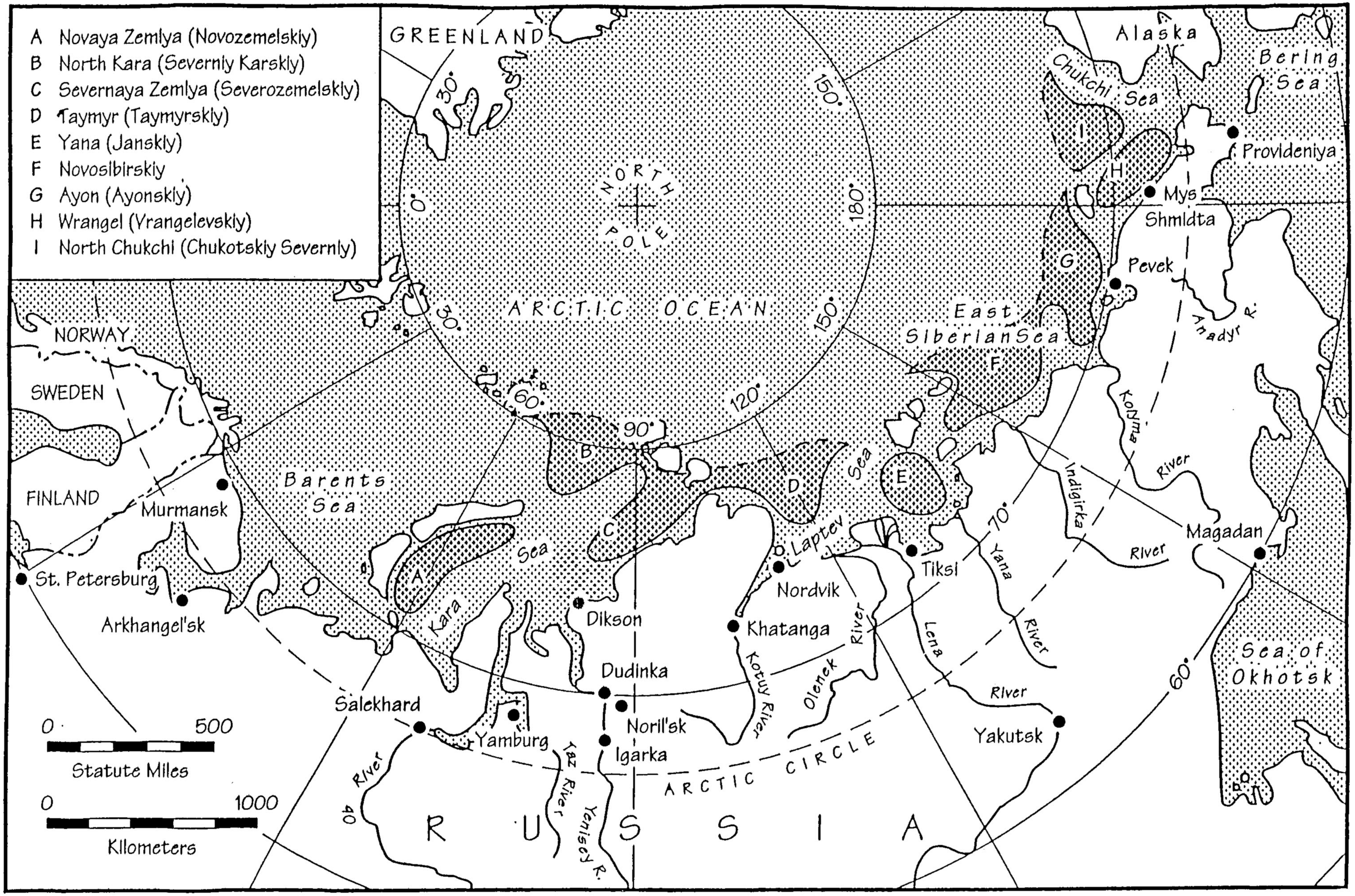


Figure 3.1 Main ice massifs of the Russian Arctic (Mulherin et al., 1994)

3.1.1 Autumn conditions

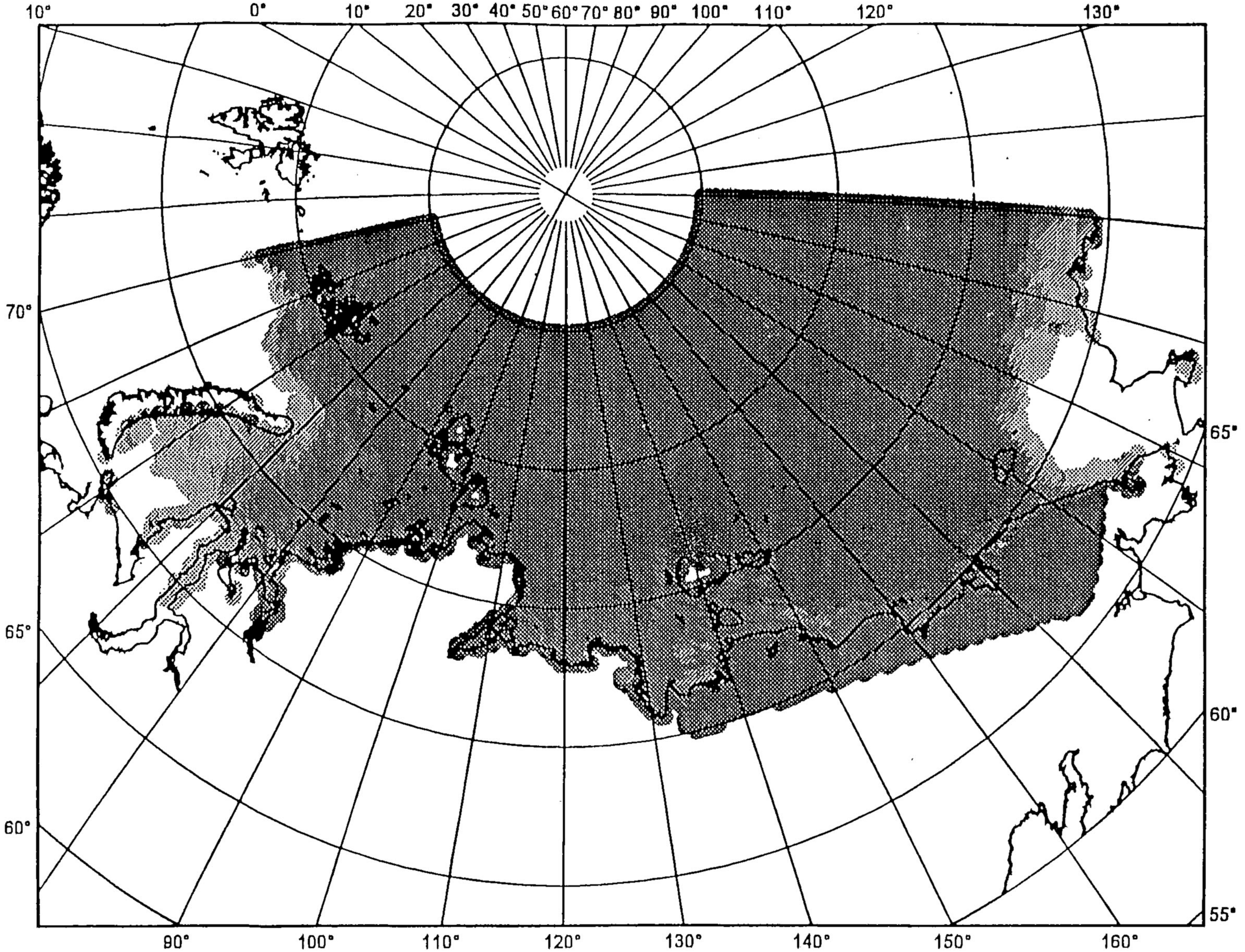
Figures 3.2-3.7 show the variability analysis of total ice concentration, ice thickness, old ice and fast ice for September (representing the autumn conditions).

Ice concentration
Seasonal freeze-up of the sea begins in September at the northern ice edge and along the rapidly cooling mainland coast. Freeze-up is complete by mid-October. On average the total ice concentration is high in October due to a high fraction of new ice. East of Dikson the concentration is about 90-100 % for the whole region. During mild years no ice is registered in the southern part of the sea except for the Severnaya Zemlya massif.

Old ice
In some years no old ice is observed in the region except in the Severnaya Zemlya massif. On average the main old ice is found in the ice massif, with Severnaya Zemlya and the Ayon massif showing the highest concentrations (up to 70 %). On average, no old ice is found in the western part of the Kara Sea and the southern part of the Laptev Sea. In extreme years the fraction of old ice is very high, up to 90-100 %, being observed both in the Kara Sea and the Laptev Sea.

Fast ice
Fast ice is very seldom observed at this time of the year and fast ice is only observed in 1-3 years during the analyzed period. When fast ice has been observed the extension has been very limited.

Total ice concentration - October - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_oct_a.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.2

500 0 500 1000 Kilometers

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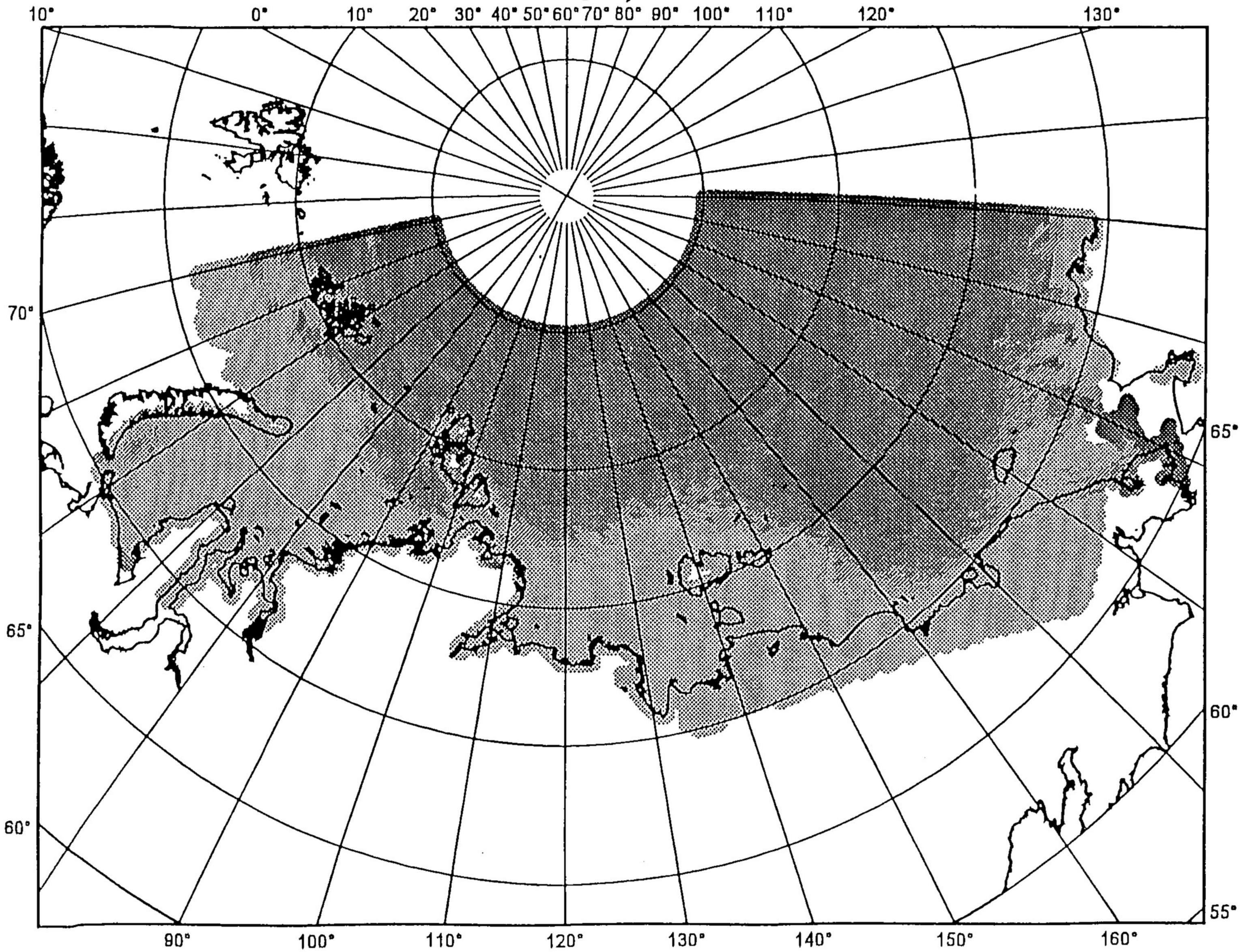
Ice thickness - October - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_oct_a.shp
Ice free
< 10cm
10 - 29cm
30 - 49cm
50 - 69cm
70 - 89cm
90 - 119cm
120 - 159cm
160 - 199cm
200 - 239cm
240 - 419cm
420cm <
No data

500 0 500 1000 Kilometers

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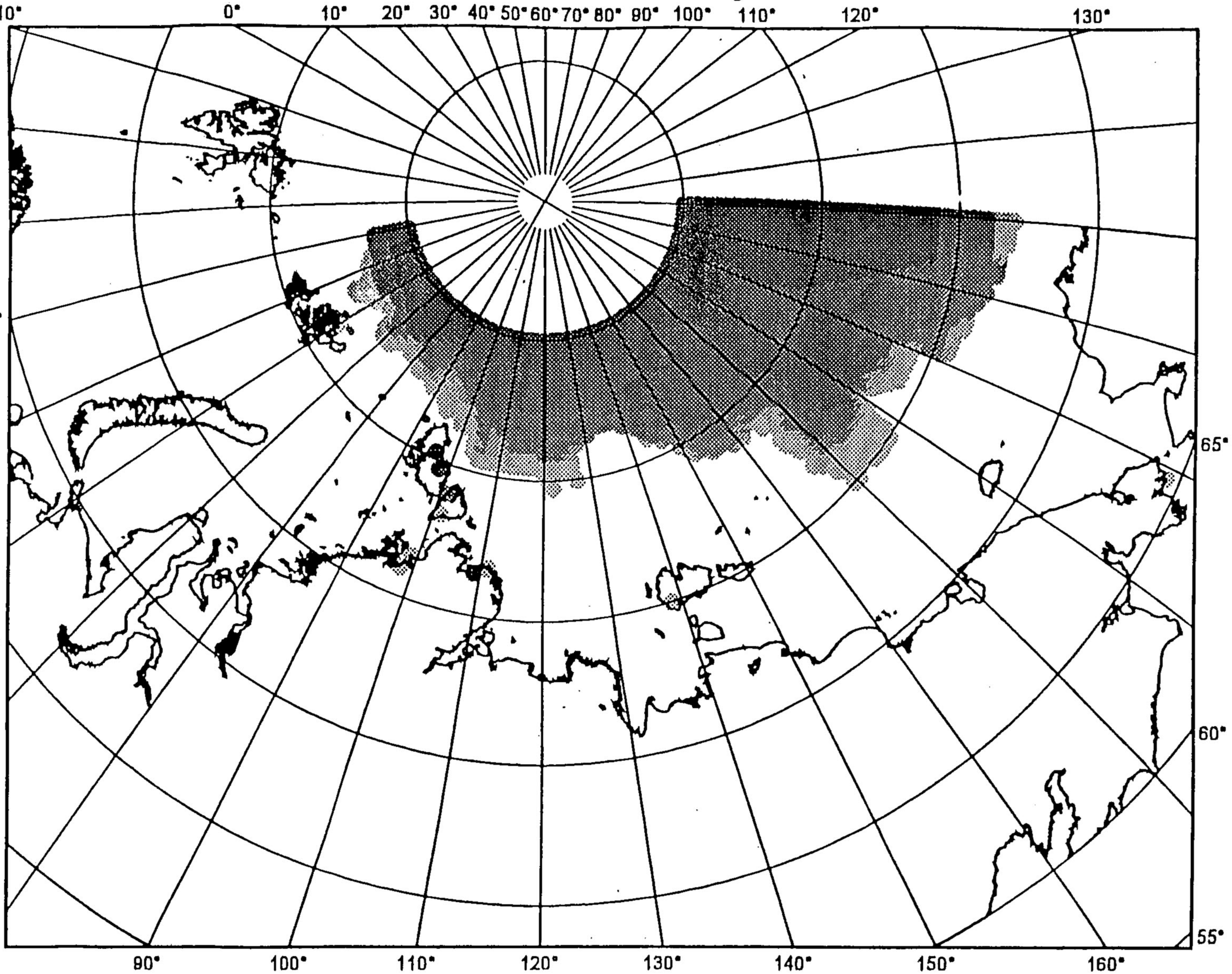
Figure 3.3

Old ice concentration - October - Multiyear minimum



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_oct_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

500 0 500 1000 Kilometers

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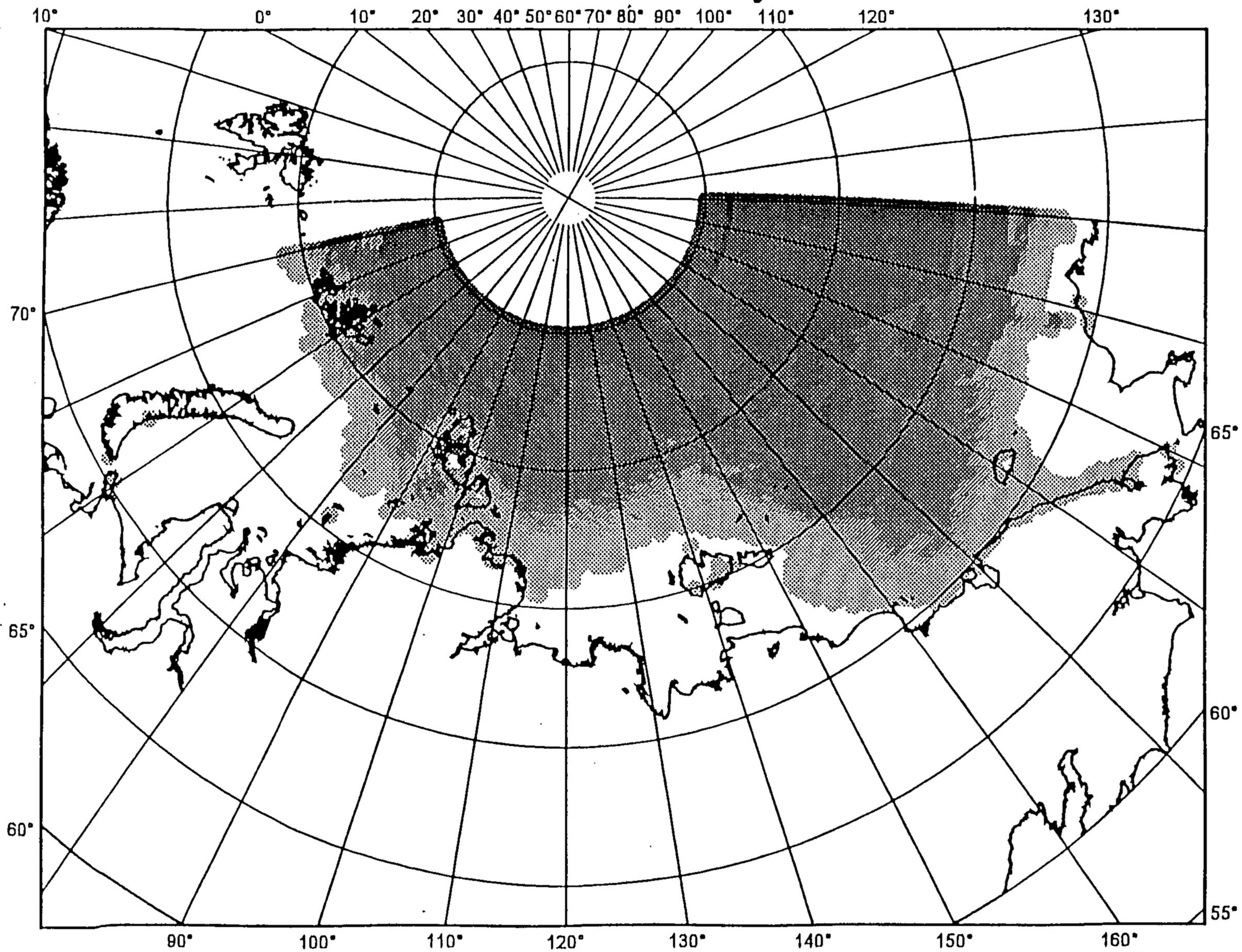
Figure 3.4

Old ice concentration - October - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_oct_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.5

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500 0 500 1000 Kilometers

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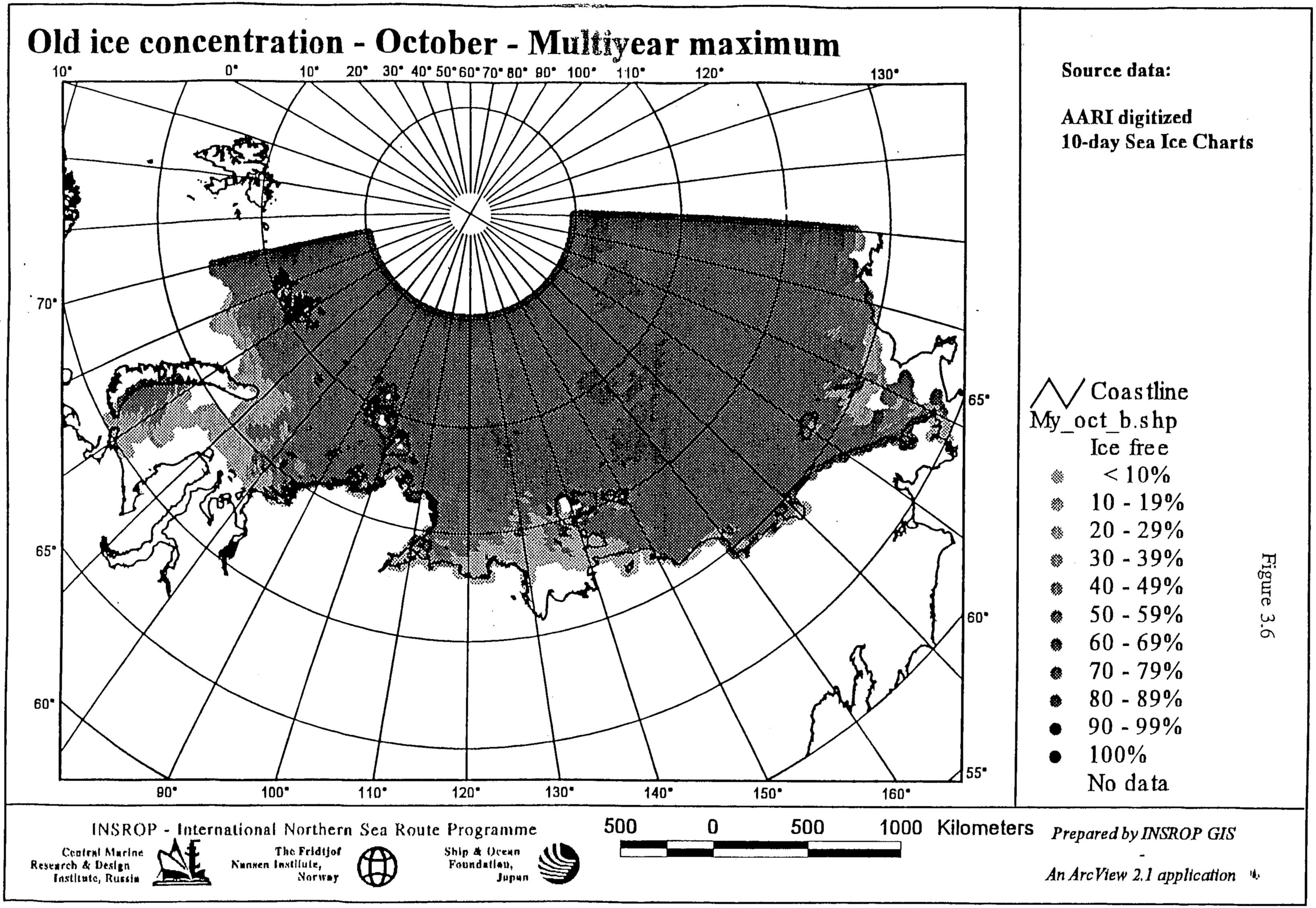
Old ice concentration - October - Multiyear maximum
10° 0° 10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130°
70°
65°
60°
65°
60°
55°
90° 100° 110° 120° 130° 140° 150° 160°
Source data:
AARI digitized
10-day Sea Ice Charts
Coastline
My_oct_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data
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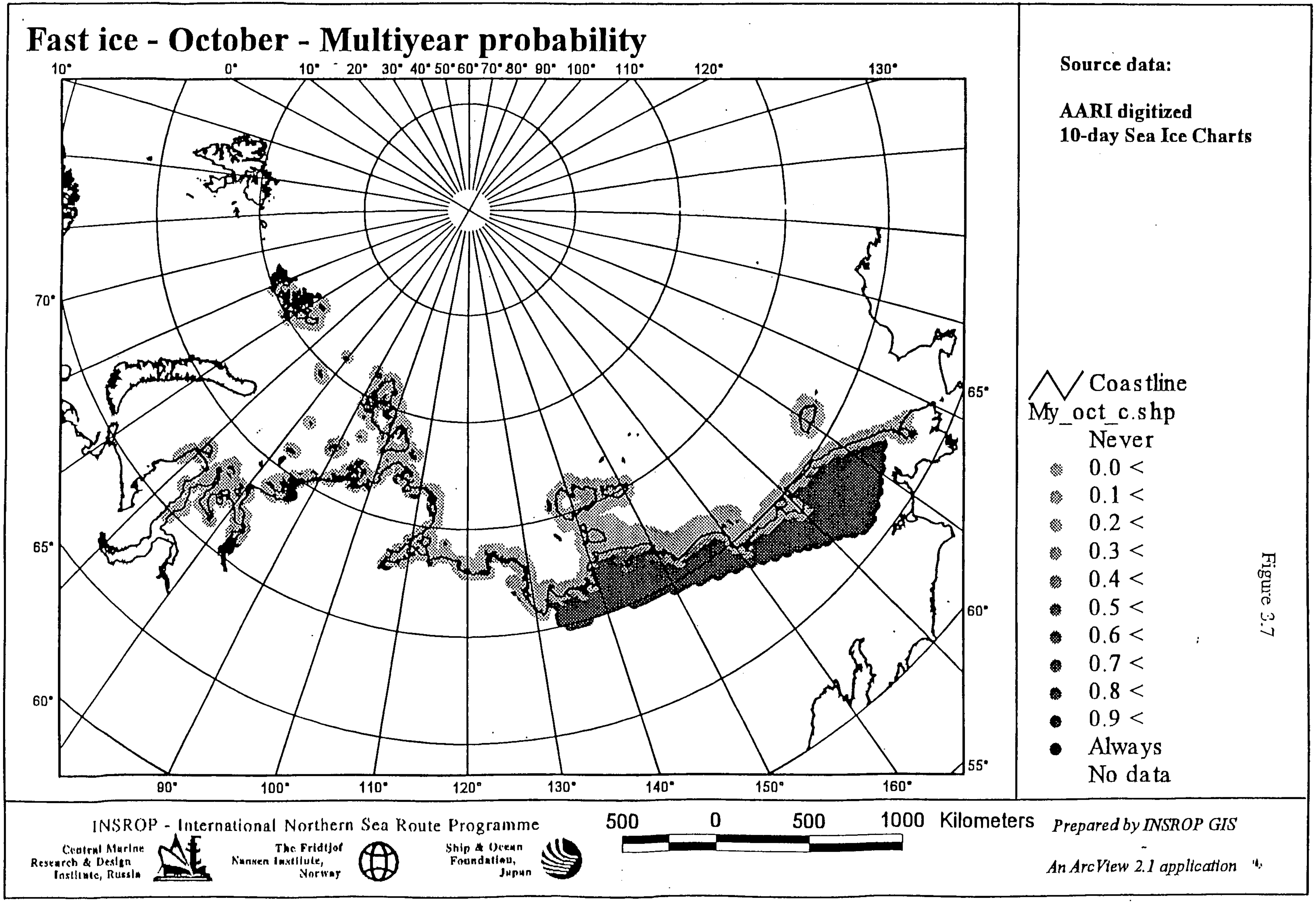
Ship & Ocean Foundation, Japan
500 0 500 1000 Kilometers
Prepared by INSROP GIS
-
An ArcView 2.1 application

Figure 3.6


Fast ice - October - Multiyear probability
10° 0° 10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130°
70°
65°
60°
90° 100° 110° 120° 130° 140° 150° 160°
65°
60°
55°
Source data:
AARI digitized
10-day Sea Ice Charts
Coastline
My_oct_c.shp
Never
0.0 <
0.1 <
0.2 <
0.3 <
0.4 <
0.5 <
0.6 <
0.7 <
0.8 <
0.9 <
Always
No data
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500 0 500 1000 Kilometers
Prepared by INSROP GIS
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Figure 3.7

3.1.2 Winter conditions

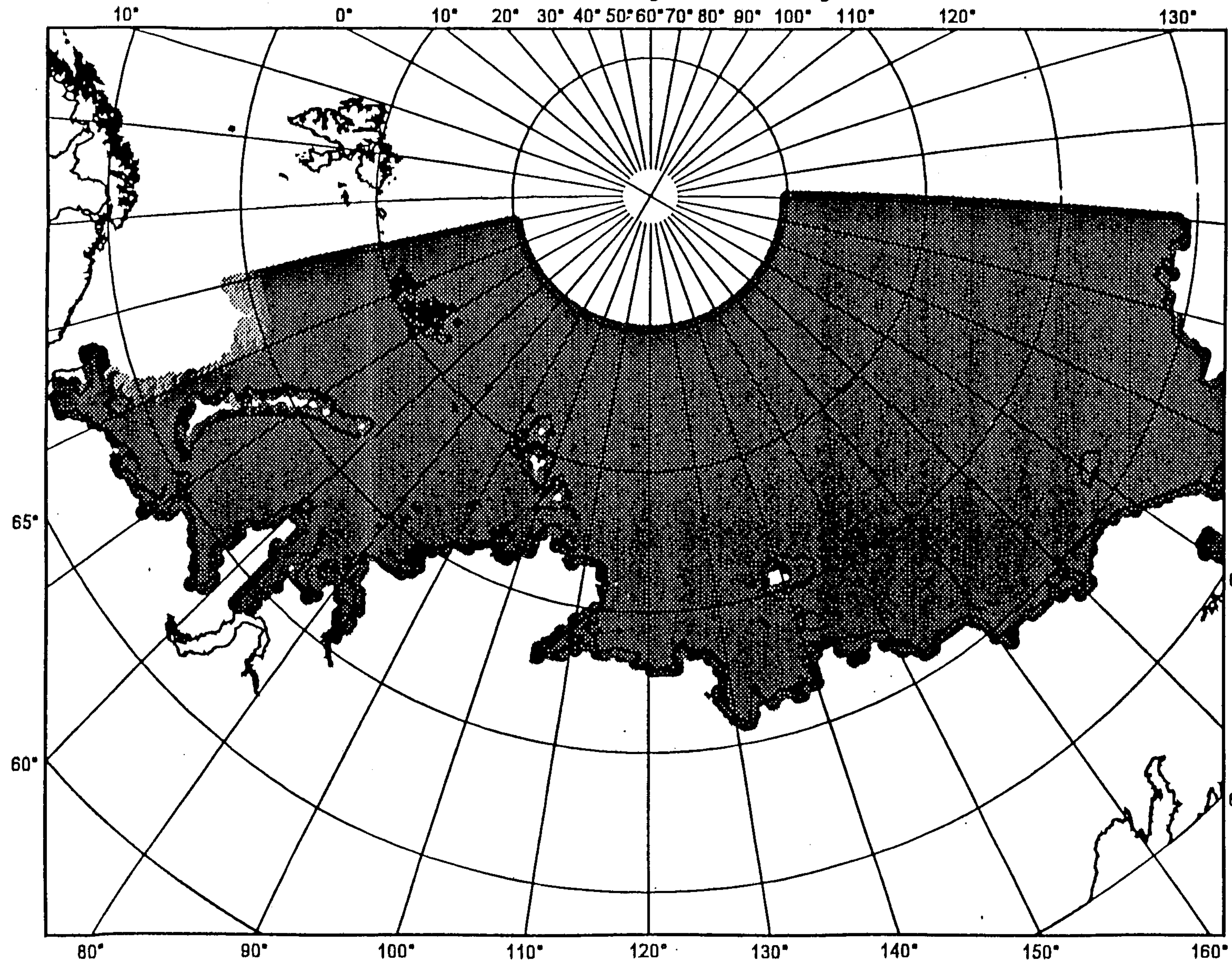
Figures 3.8-3.13 show the variability analysis of total ice concentration, ice thickness, old ice and fast ice for February (representing the winter conditions).

Total ice concentration
In the winter months November to April the whole region is covered by very dense drifting ice. The total ice concentration is between 90 and 100 %. The entire sea is covered with ice of different type and stage of development. The ice thickness distribution shows regions with thick ice in the ice massif and especially in the Ayon massif, where the average thickness may reach 250 cm. The thinnest ice is mainly found in the southern Kara and Laptev Seas.

Fraction of old ice
Minor fractions of old ice are found in the western part of the Kara Sea. West of Severnaya Zemlya the fraction of old ice varies between 20-40 % and the thickness may reach 160-180 cm in late winter. The amount of old ice in the Laptev Sea is limited due to wind directions and ocean currents. In the western part of the Laptev Sea the ice drift is southwards and large masses of ice are deposited along the coast of Severnaya Zemlya and the Taymyr Peninsula. The main old ice found in the southern Laptev Sea is in the Taymyr massif. The majority of this old ice persists through the summer and the mean ice thickness may reach 200 cm. The East-Siberian Sea has the highest fraction of old ice and the Ayon massif has more than 60 % of old ice on average, where the thickness may be up to 250 cm in the winter months. Ocean currents and wind tend to transport old ice from the Arctic to the Longa Strait under great pressure, which sometimes presents the greatest obstacle on the route. The Wrangel massif consists of low concentrations of old ice and the ice thickness may reach 200 cm in late winter. Some years almost no old ice has been observed in the southern part of the seas, which may be due to erroneous classification, e.g. overlooked due to snow cover.

Presence of fast ice
The coastal zone is occupied by fast ice in the winter period which is non-uniformly developed (Figure 3.13). The fast ice extent is generally narrow except in the eastern Kara Sea where it may extend up to 150-200 km seaward. The Laptev Sea has the largest expanse of fast ice from January to June. Fast ice begins to form in mid-October in the fresher water of the river estuaries and expands to cover most of the continental shelf up to 500 km from the mainland. The thickness of the fast ice commonly reaches 200 cm and may grow up to 250 cm in severe years. The fast ice in the East-Siberian Sea extends 250-500 km from the mainland and may reach a thickness of 150-170 cm in late winter. Only a narrow band of fast ice (about 10-15 km) forms along the mainland coast and around Wrangel Island.

Total ice concentration - February - Multiyear median



Source data:

AARI Digitized
10-day Sea Ice Charts

Coastline
My_feb_a.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

500 0 500 1000 Kilometers

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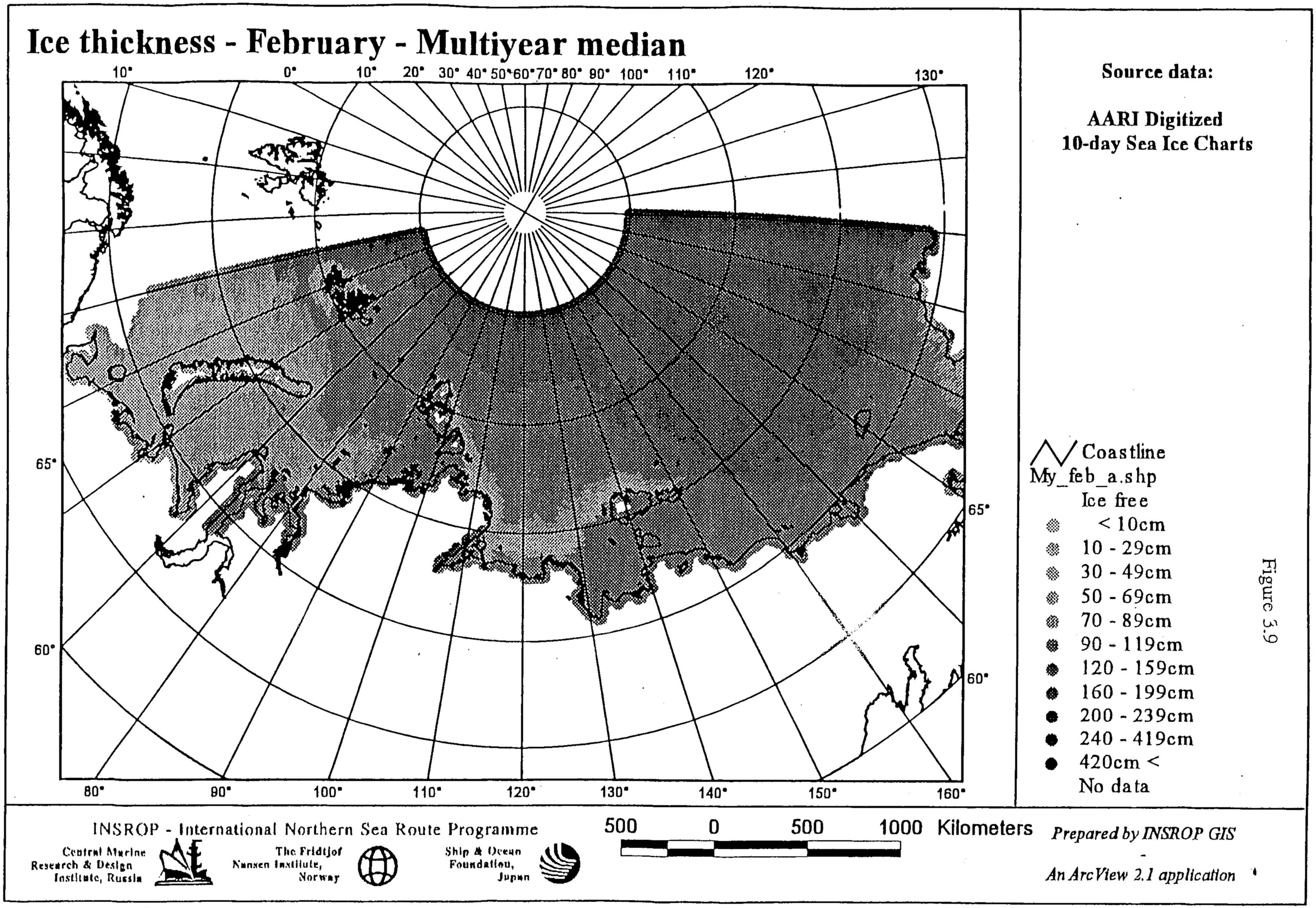
Figure 3.8


Ice thickness - February - Multiyear median
10°
0°
10°
20°
30°
40°
50°
60°
70°
80°
80°
100°
110°
120°
130°
65°
60°
65°
60°
80°
90°
100°
110°
120°
130°
140°
150°
160°
Source data:
AARI Digitized
10-day Sea Ice Charts
Coastline
My_feb_a.shp
Ice free
< 10cm
10 - 29cm
30 - 49cm
50 - 69cm
70 - 89cm
90 - 119cm
120 - 159cm
160 - 199cm
200 - 239cm
240 - 419cm
420cm <
No data
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500
0
500
1000
Kilometers
Prepared by INSROP GIS
-
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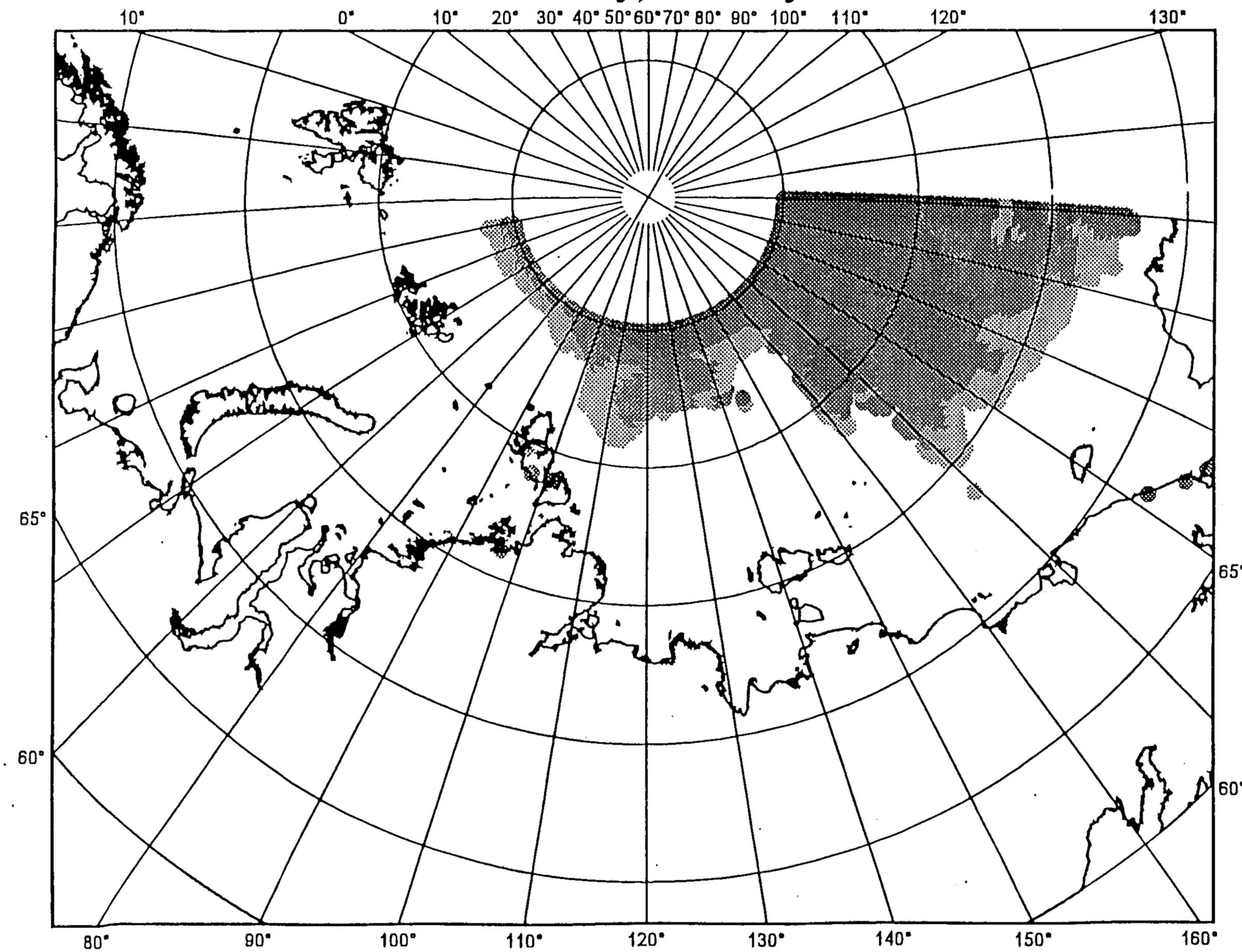
Figure 3.9

Old ice concentration - February - Multiyear minimum



Source data:

AARI Digitized
10-day Sea Ice Charts

Coastline
My_feb_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.10

500 0 500 1000 Kilometers

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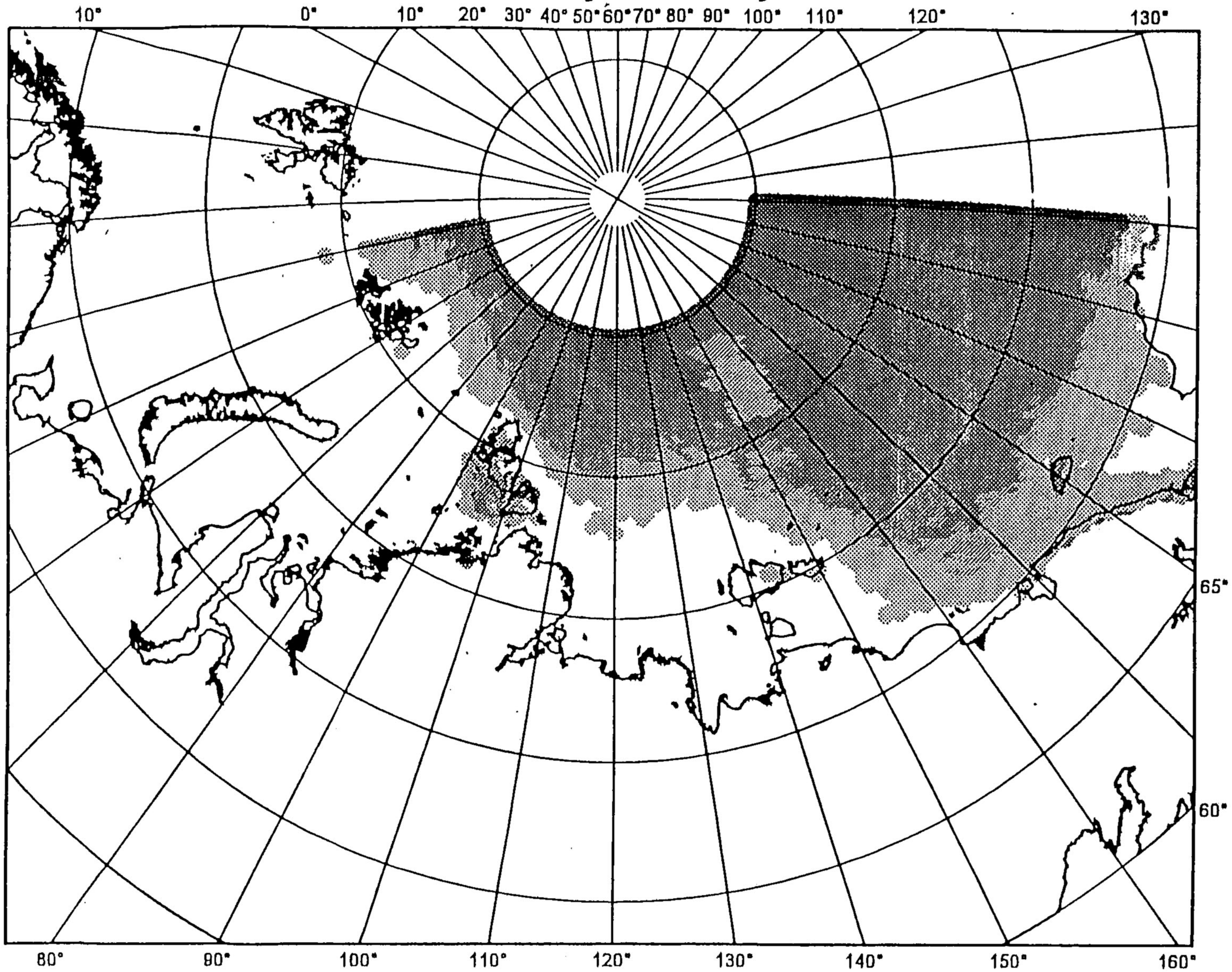
Old ice concentration - February - Multiyear median



Source data:

AARI Digitized
10-day Sea Ice Charts

Coastline
My_feb_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.11

500 0 500 1000 Kilometers

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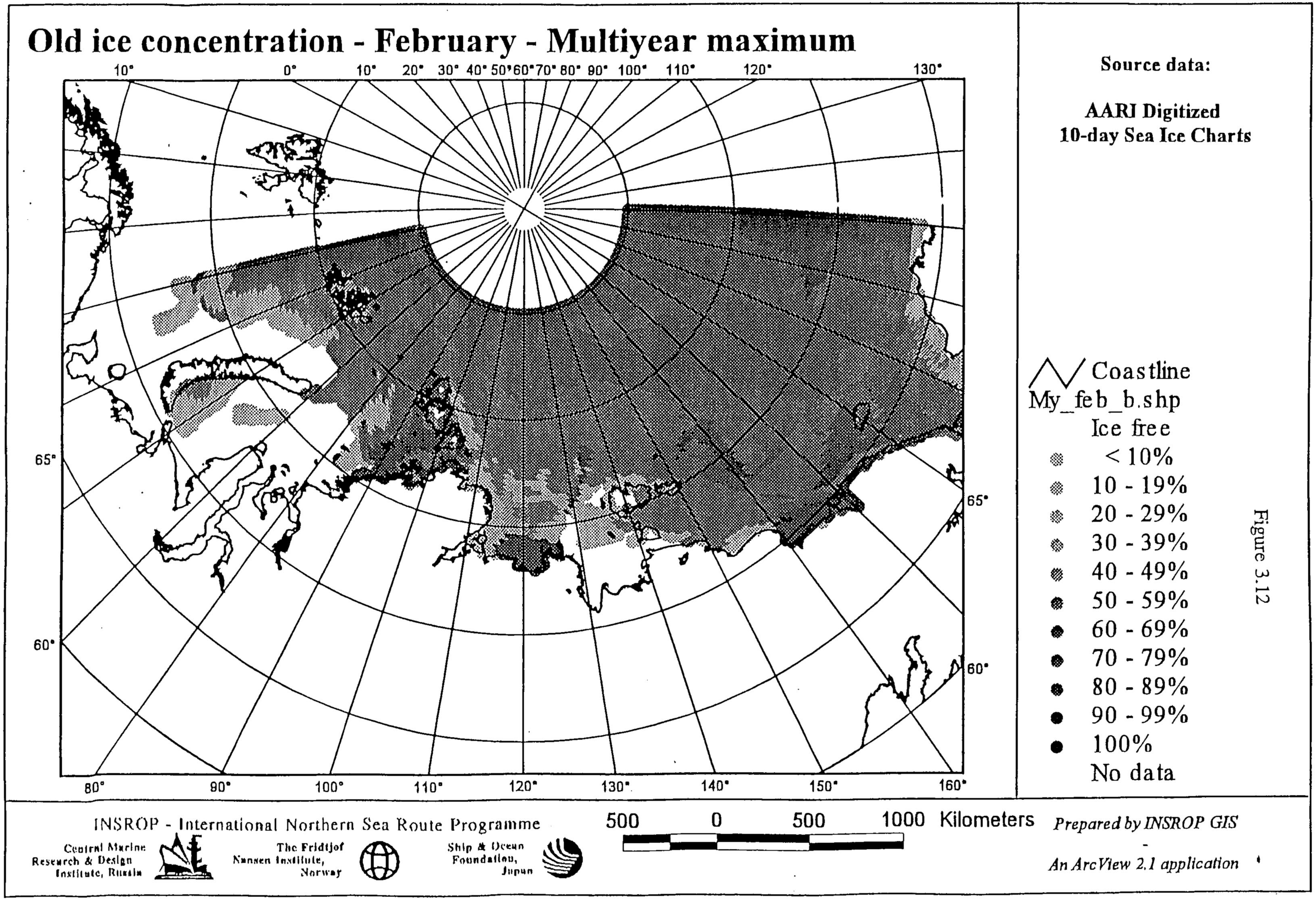
Old ice concentration - February - Multiyear maximum
10°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
65°
60°
80°
90°
100°
110°
120°
130°
140°
150°
160°
Source data:
AARI Digitized
10-day Sea Ice Charts
Coastline
My_feb_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data
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Ship & Ocean Foundation, Japan
500 0 500 1000 Kilometers
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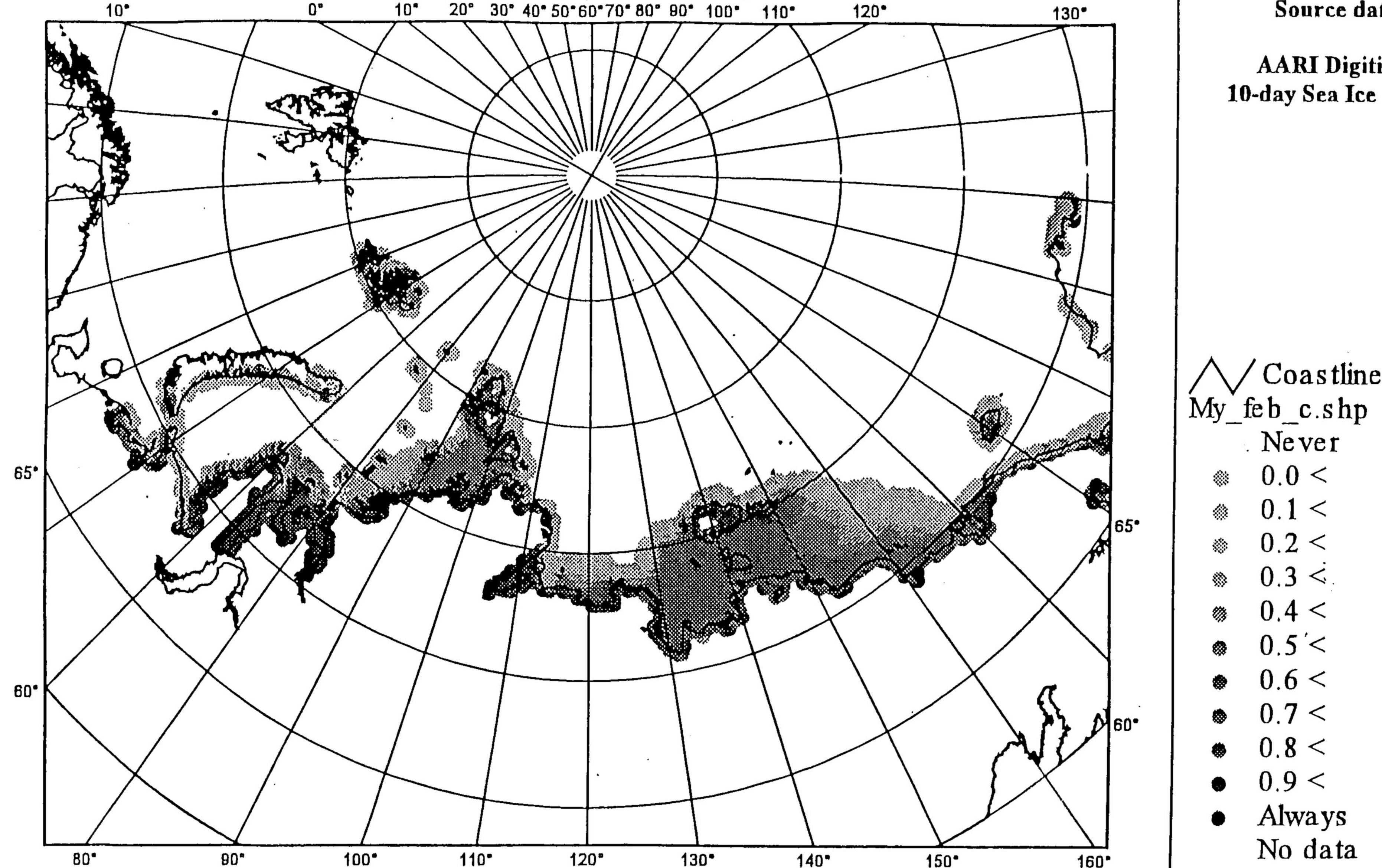
Figure 3.12

Fast ice - February - Multiyear probability



Source data:

AARI Digitized 10-day Sea Ice Charts

Figure 3.13

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3.1.3 Spring conditions

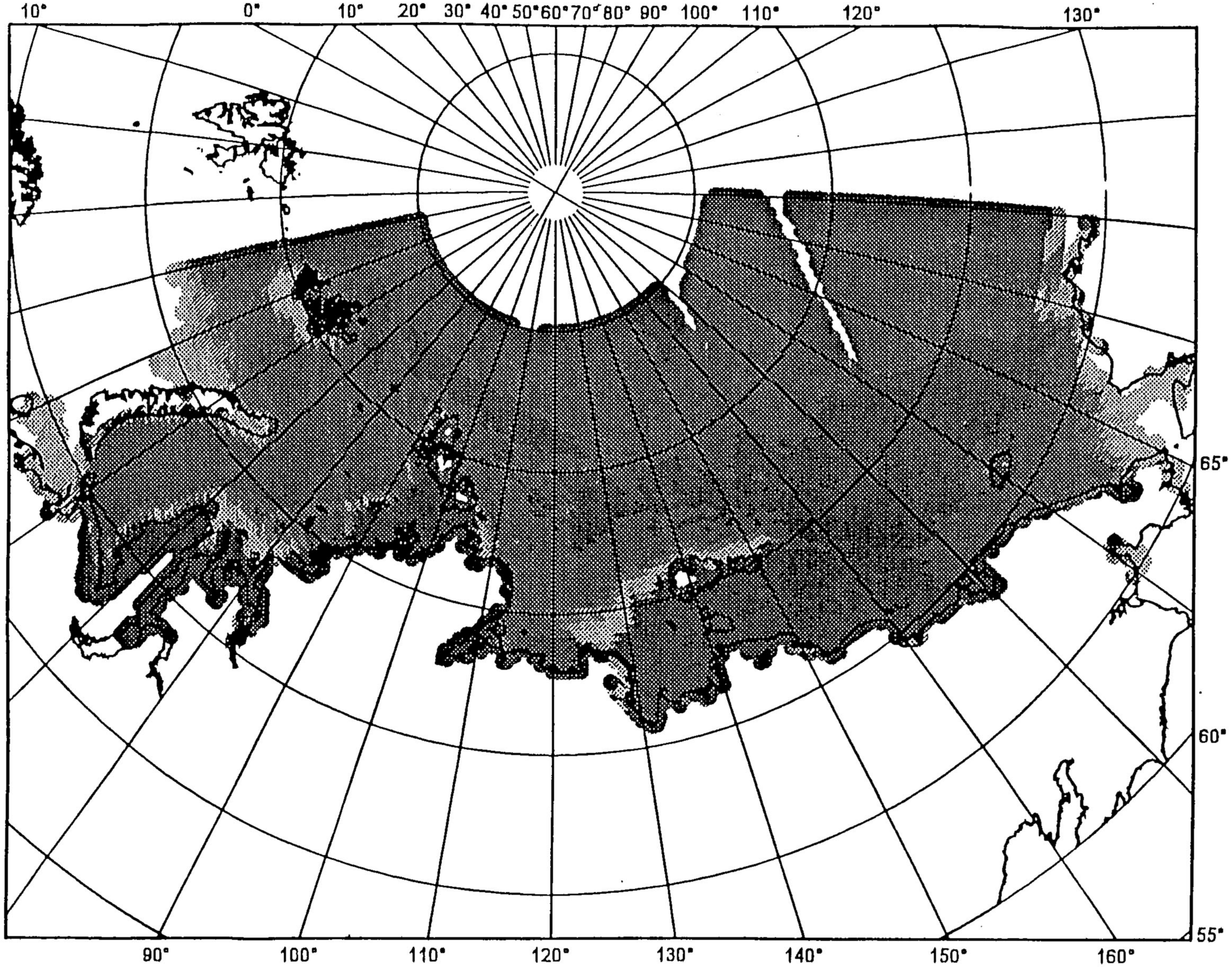
Figures 3.14-3.19 show the variability analysis of total ice concentration, ice thickness, old ice and fast ice for June (representing the spring conditions).

Total ice concentration
Seasonal breakup throughout the entire sea begins in June and July. During extreme years the whole region is covered by very dense drifting ice in June with concentration up to 100 %. In mild years large parts of the route will be ice free except for the regions of Severnaya Zemlya, Ayon and Wrangel. An ice free region north of the Novosibirskiy Island is also present. Despite mild winters the ice concentration in the western Kara Sea is high, about 40-90 %. Breakup of the Chukchi ice cover initiates in the eastern part and progresses westward due to influx of warm water from the Bering Sea.

Old ice fraction
The old ice is mainly present in the regions of Severnaya Zemlya, Ayon and Wrangel massifs where the median concentration is 20-40 %. During extreme years the fraction of old ice is 70-100 % east of the Severnaya Zemlya. In the western Kara Sea no old ice is present. In "mild" years no old ice is present along the traditional sailing routes. The old ice may either have melted or been erroneously classified.

Fast ice
On average, the fast ice is present along the whole coast (Figure 3.19). In mild winters the fast ice is only present east of the Novosibirskiy Island, mainly in the eastern Kara Sea and the East-Siberian Sea.

Total ice concentration- June - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_jun_a.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.14

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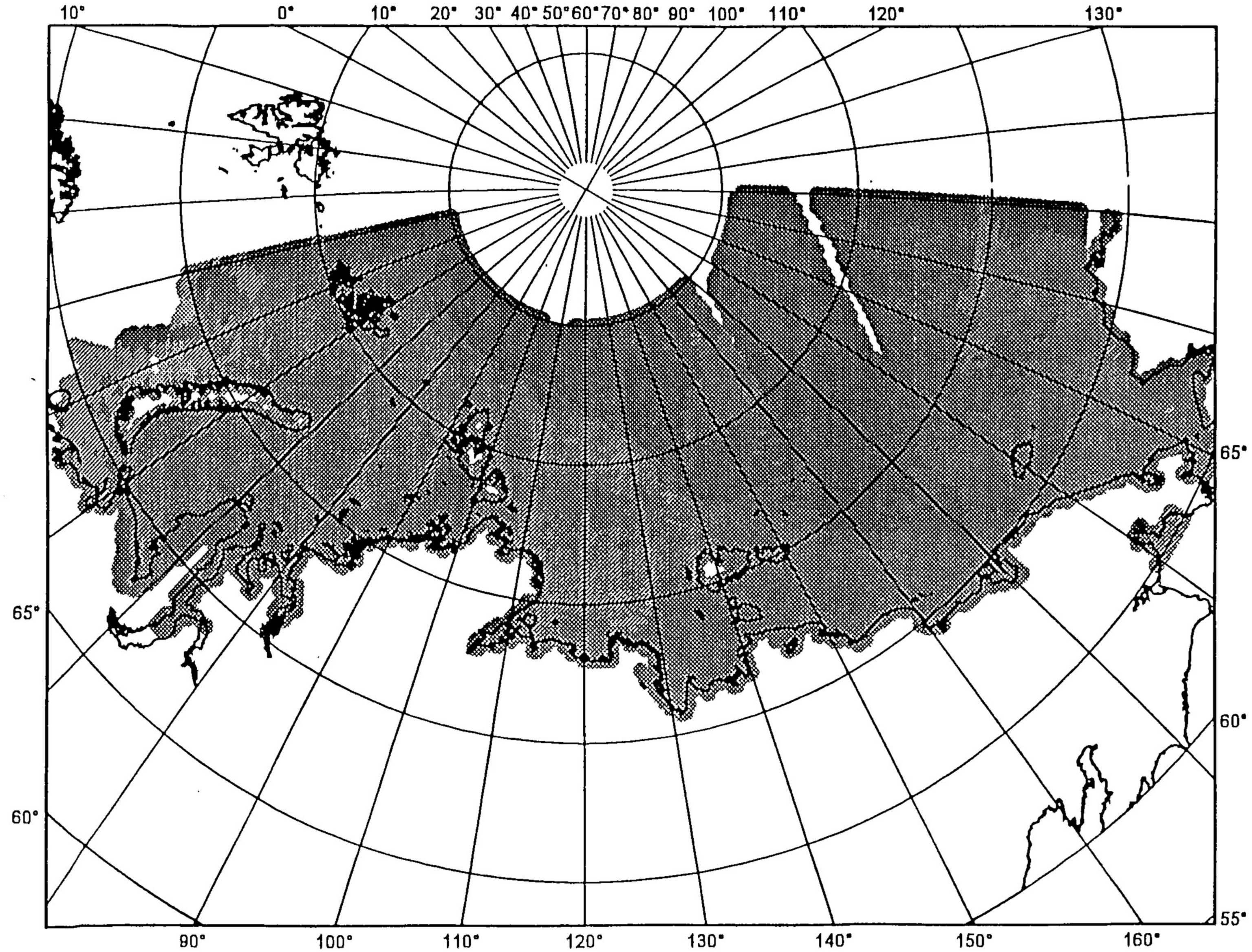
Ice thickness - June - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_jun_a.shp
Ice free
< 10cm
10 - 29cm
30 - 49cm
50 - 69cm
70 - 89cm
90 - 119cm
120 - 159cm
160 - 199cm
200 - 239cm
240 - 419cm
420cm <
No data

Figure 3.15

500 0 500 1000 Kilometers

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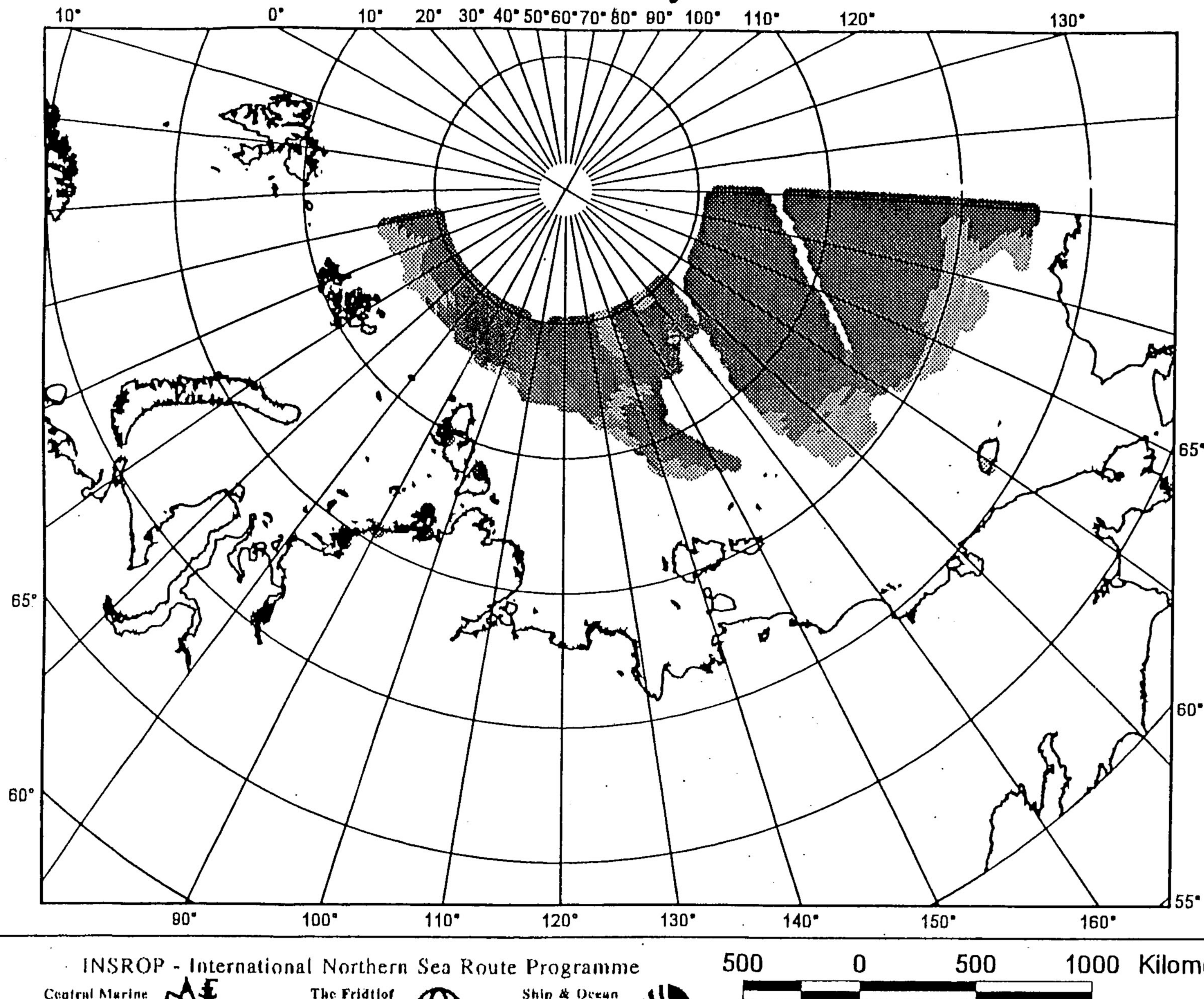
Old ice concentration - June - Multiyear minimum



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_jun_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.16

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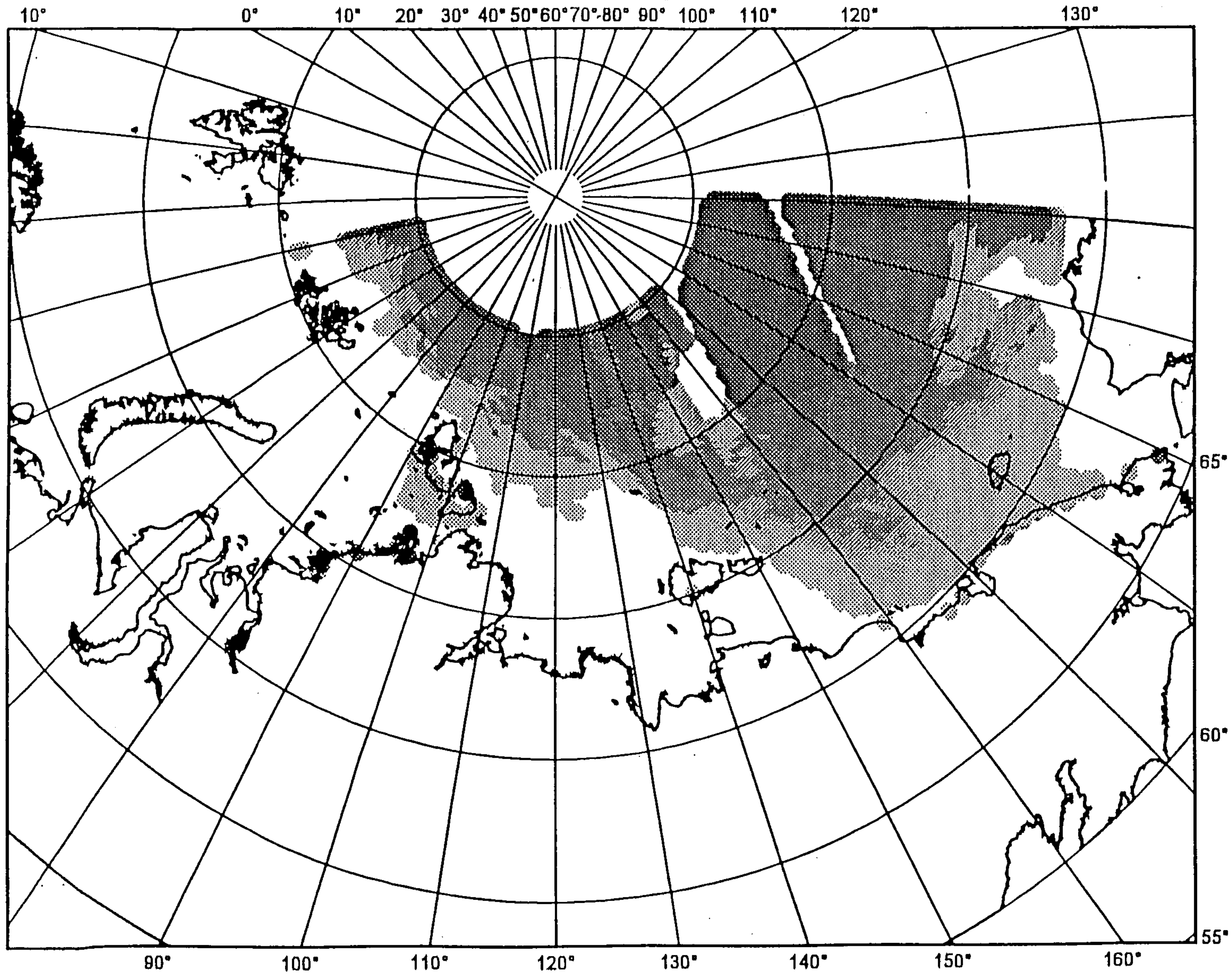
Old ice concentration - June - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_jun_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.17

500 0 500 1000 Kilometers

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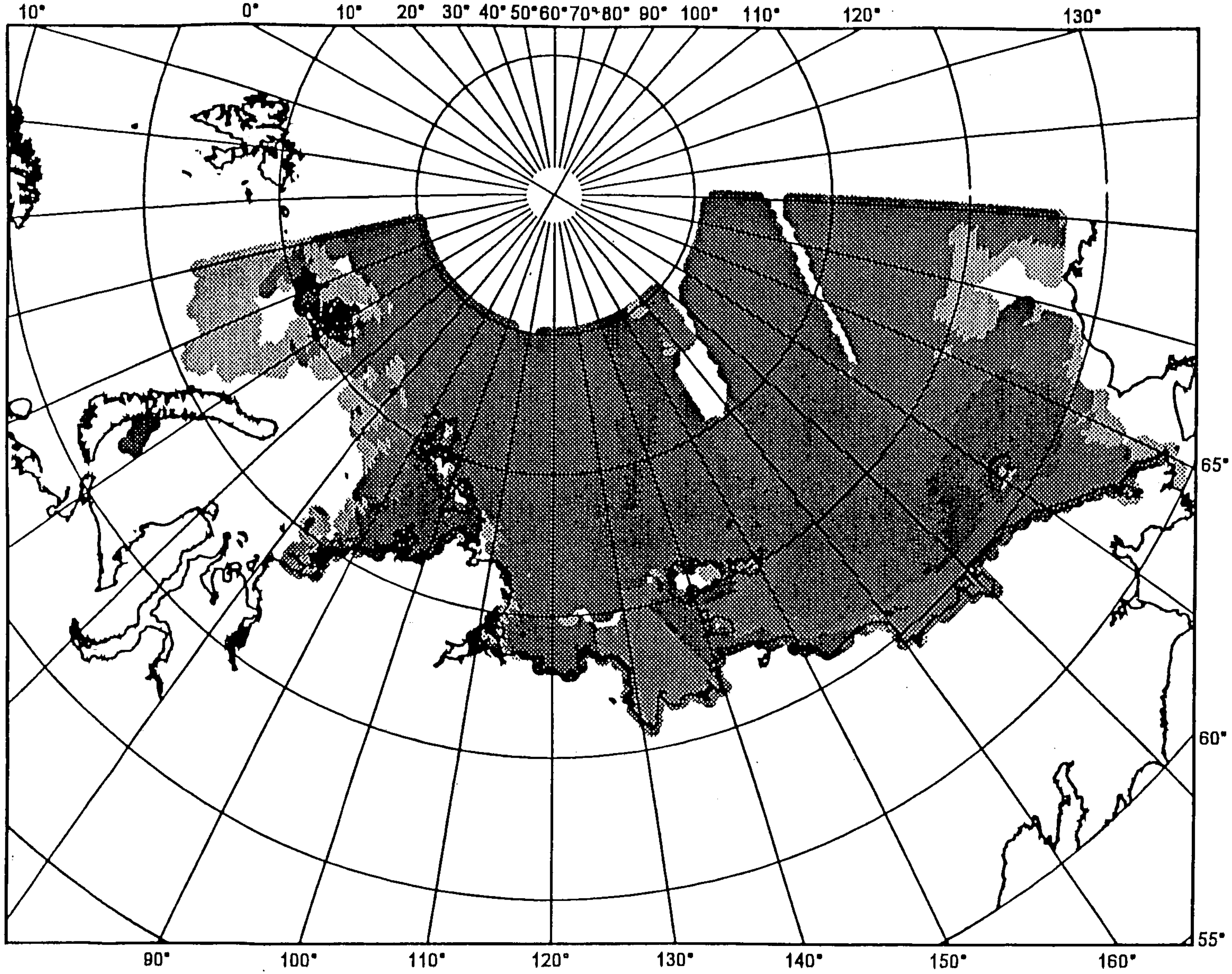
Old ice concentration - June - Multiyear maximum



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_jun_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.13

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500 0 500 1000 Kilometers

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Fast ice - June - Multiyear probability

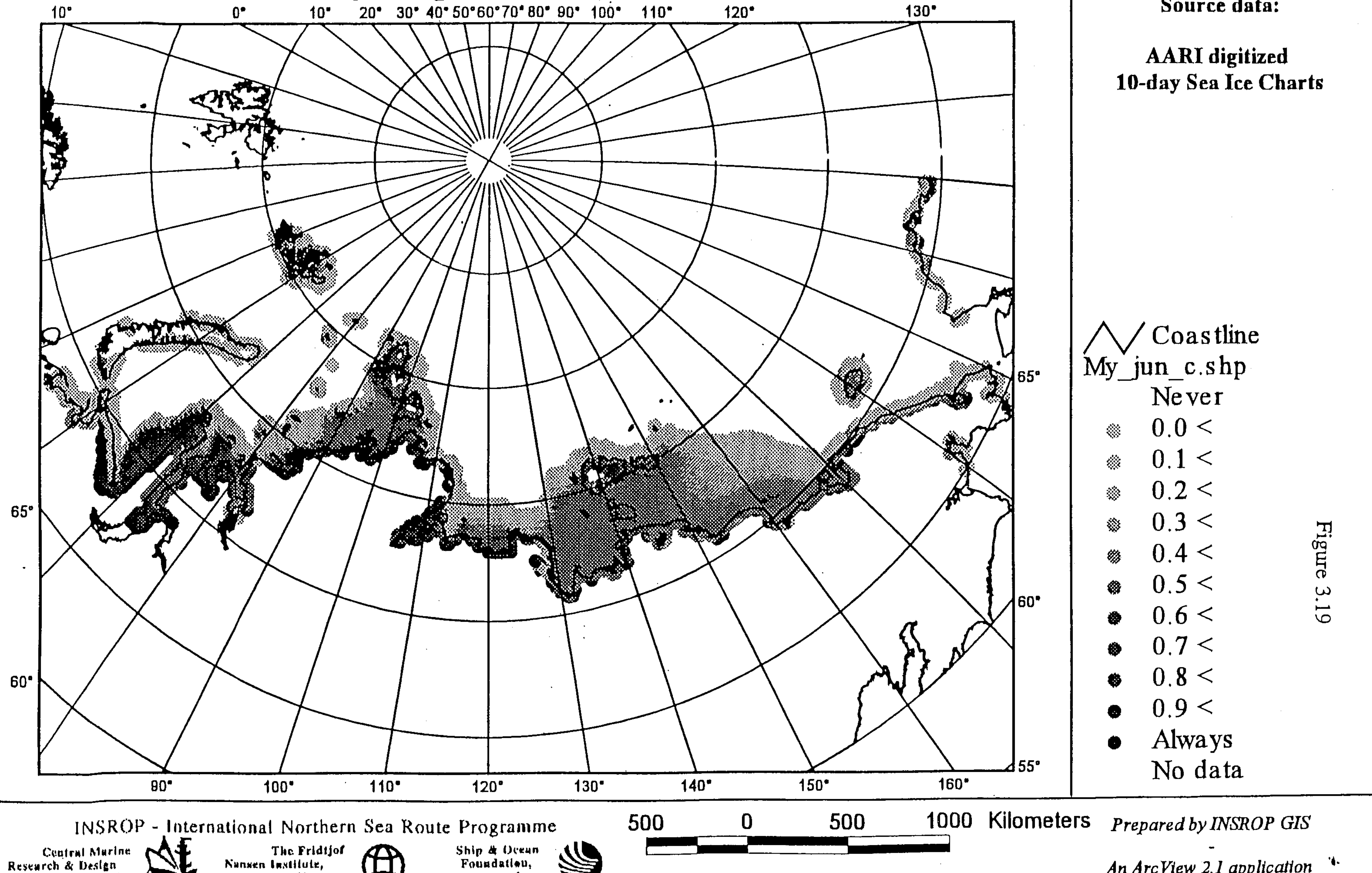

Figure 3.19

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3.1.4 Summer conditions

Figures 3.20-3.25 show the variability analysis of total ice concentration, ice thickness, old ice and fast ice for August (representing the summer conditions).

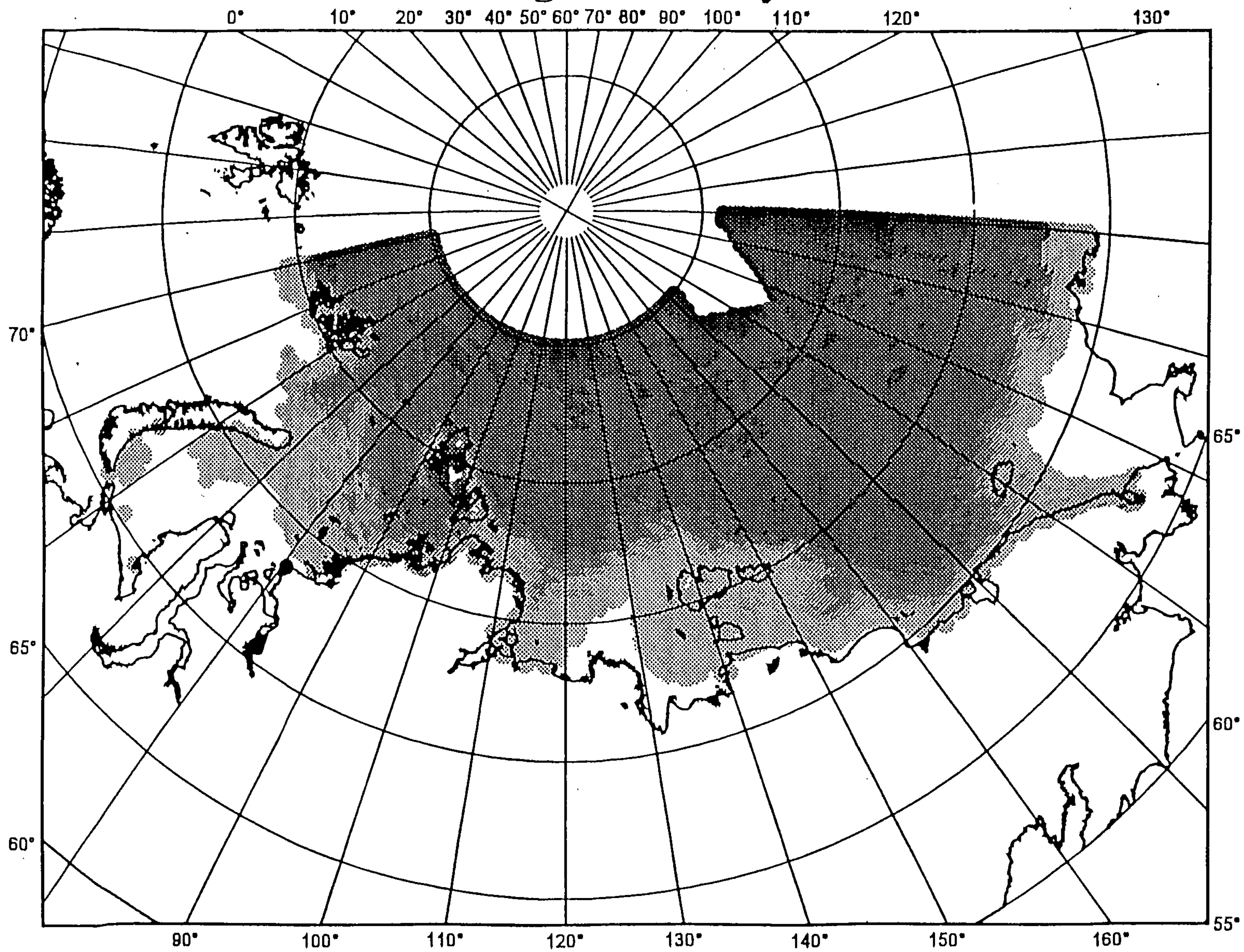
Ice concentration
In June to September the ice concentration is low in the Kara Sea (see Figure 3.20), especially in the western part where drifting thick-ice may be present. In the eastern part, especially the Severnaya Zemlya massif, the ice concentration is higher and the ice consists mainly of thick first-year ice. When the seasonal ice minimum is reached by mid September the entire Kara Sea south of 75°N is normally ice free. In extremely mild summers, the Kara Sea may become ice free as far north as 80°N. The East-Siberian Sea experiences the least summer melt of any of the arctic seas. The Chukchi Sea experiences wide seasonal variations in total ice extent. Summer ice melt is extensive. South of the Taymyr massif the ice conditions are relatively open in the summer period.

In normal years weakness in the Laptev Sea ice begins to appear offshore of the Lena river delta by mid-June. By July, a nearly ice-free area extends seaward of the delta to about 75°N. Expansion of this ice free area continues until mid-September. At this time most of the sea south of 77°N is ice-free except for the areas west of about 117°E where ice usually persists south to 74-75°N in the East Taymyr coastal flow.

Old ice
The Severnaya Zemlya, Novosibirskiy and Ayon massifs carry large amounts of old ice and are very resistant to summer melt. The concentrations show that during more than half of the year no ice has been present in the southern part of Kara Sea, Laptev Sea and Chukchi Sea. In the mildest years no old ice is observed along the traditional sailing regions (either due to melting or due to erroneous classification). In extreme years high concentrations of old ice are found in the Novaya Zemlya massif. Except for the ice massif, no old ice is present in the Kara Sea.

Fast ice
In the summer months fast ice is present only from Dikson to Severnaya Zemlya (see Figure 3.25), prevailing southerly winds constantly pushing drift ice northwards from the immobile fast ice. The drift ice is quickly replaced by polynyas of newly formed young and new ice.

Total ice concentration - August - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_aug_a.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.20

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500 0 500 1000 Kilometers

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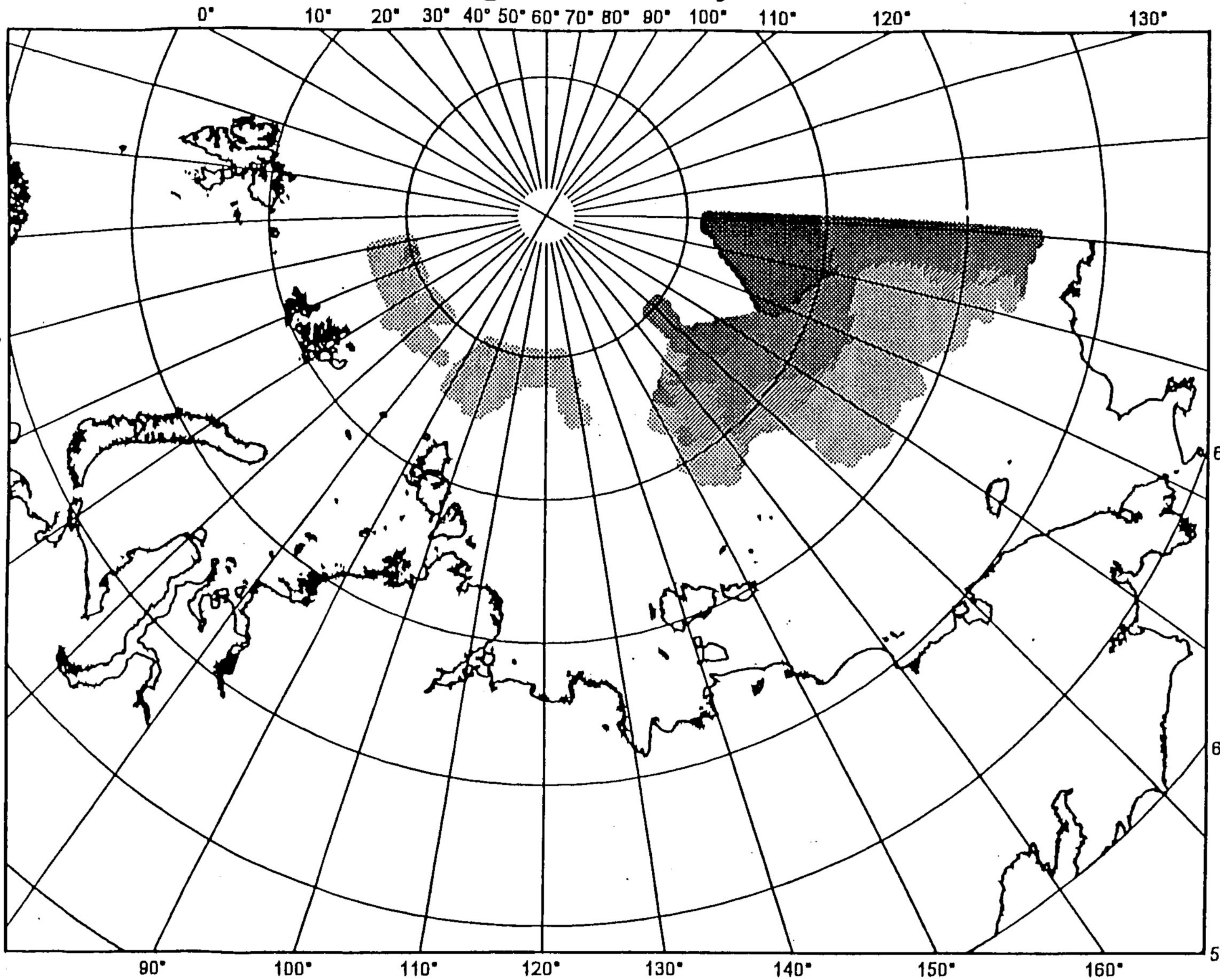
Old ice concentration - August - Multiyear minimum



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_aug_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.21

500 0 500 1000 Kilometers

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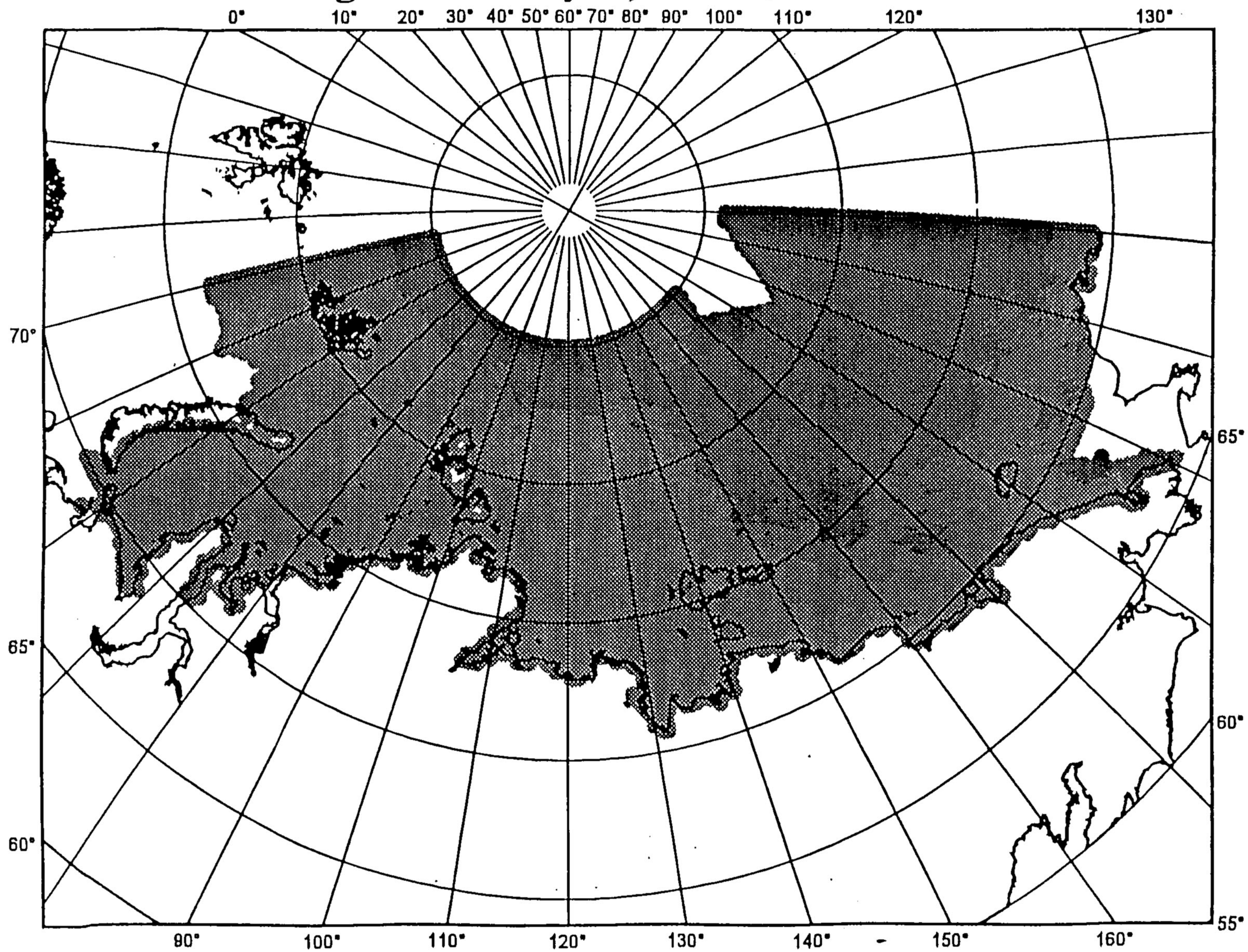
-
An ArcView 2.1 application

Ice thickness - August - Multiyear median



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_aug_a.shp
Ice free
< 10cm
10 - 29cm
30 - 49cm
50 - 69cm
70 - 89cm
90 - 119cm
120 - 159cm
160 - 199cm
200 - 239cm
240 - 419cm
420cm <
No data

Figure 3.22

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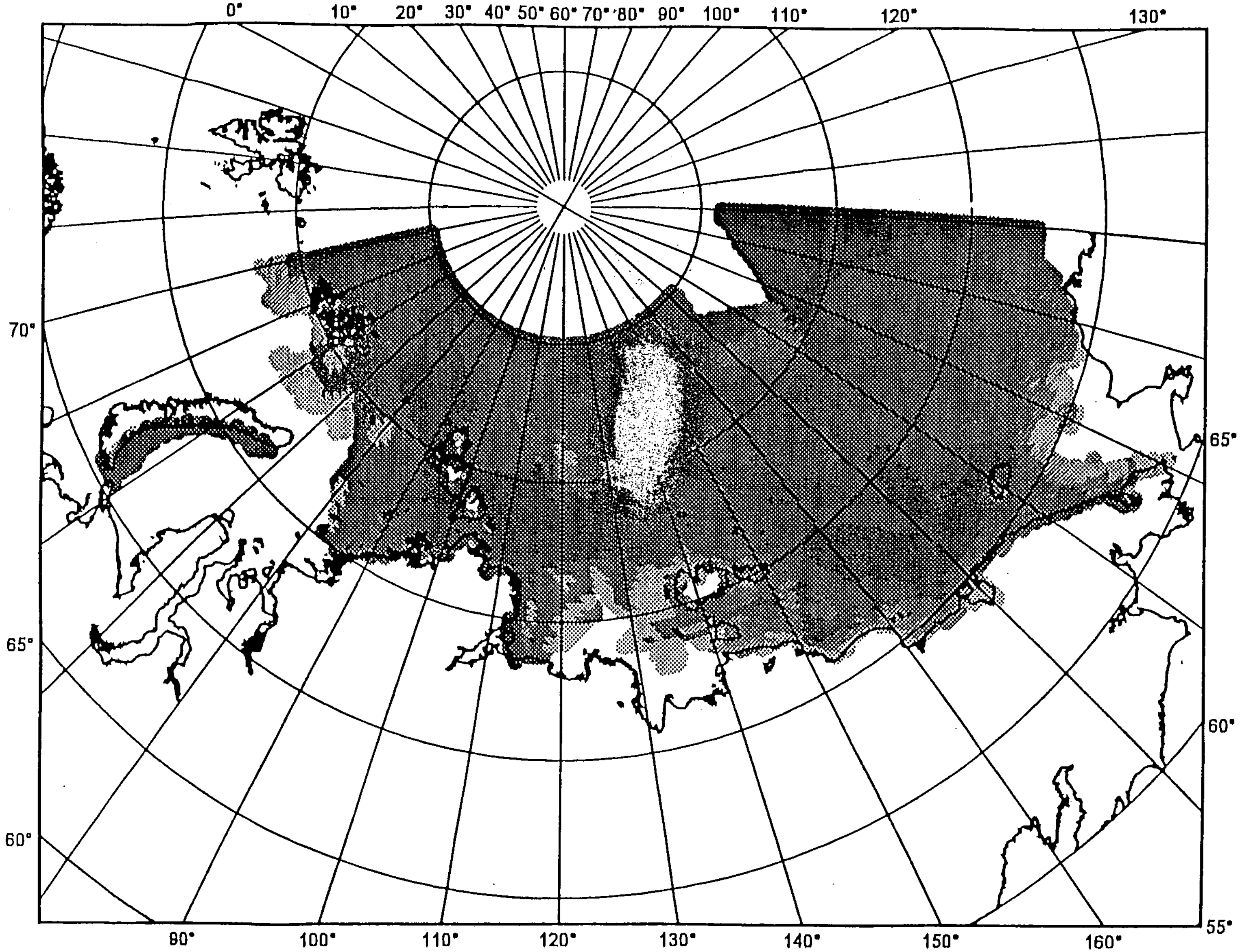
-

An ArcView 2.1 application

Old ice concentration - August - Multiyear maximum



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_aug_b.shp
Ice free
< 10%
10 - 19%
20 - 29%
30 - 39%
40 - 49%
50 - 59%
60 - 69%
70 - 79%
80 - 89%
90 - 99%
100%
No data

Figure 3.23

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Ship & Ocean Foundation, Japan

500 0 500 1000 Kilometers

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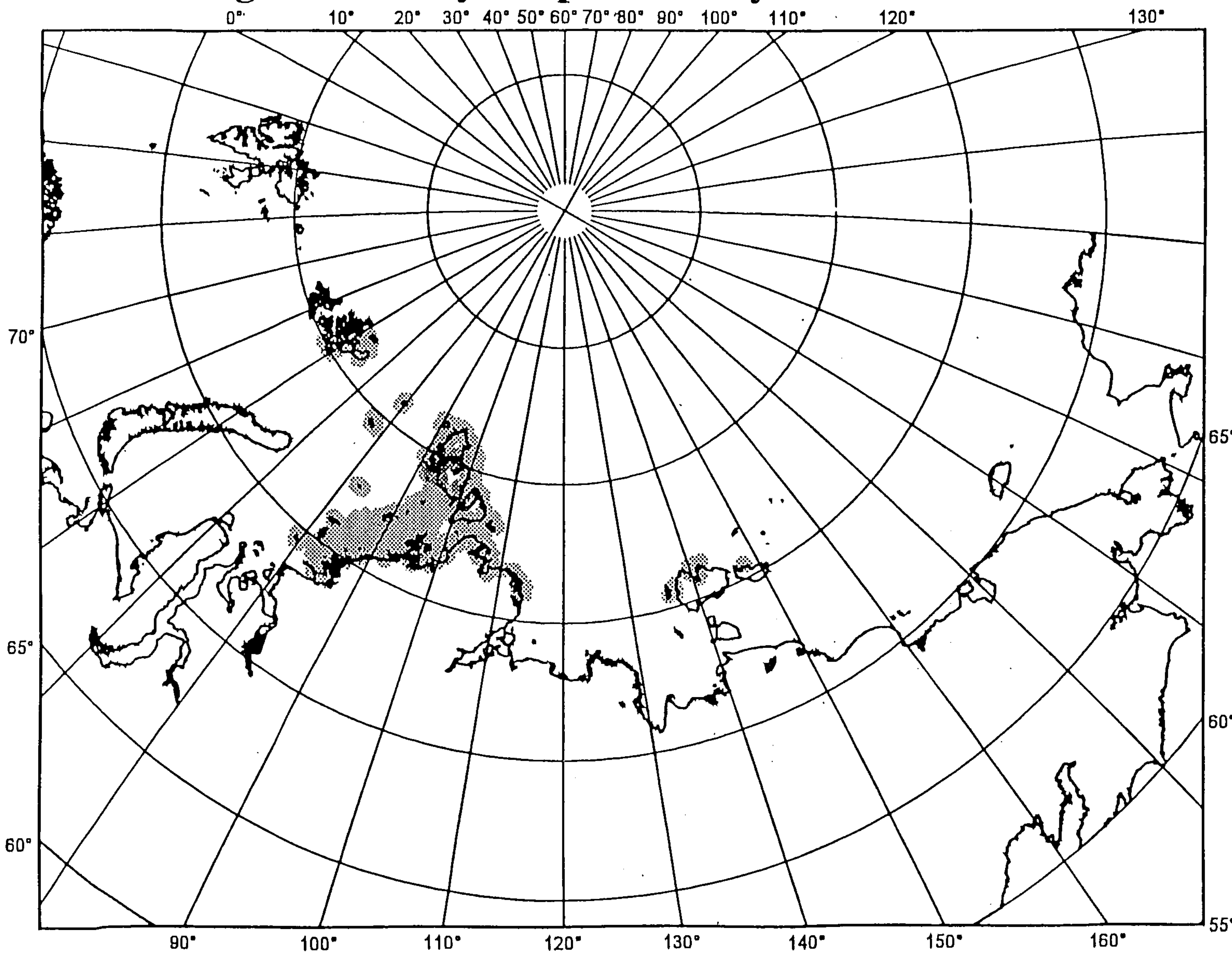
An ArcView 2.1 application

Fast ice - August - Multiyear probability



Source data:

AARI digitized
10-day Sea Ice Charts

Coastline
My_aug_c.shp
Never
0.0 <
0.1 <
0.2 <
0.3 <
0.4 <
0.5 <
0.6 <
0.7 <
0.8 <
0.9 <
Always
No data

Figure 3.24

500 0 500 1000 Kilometers

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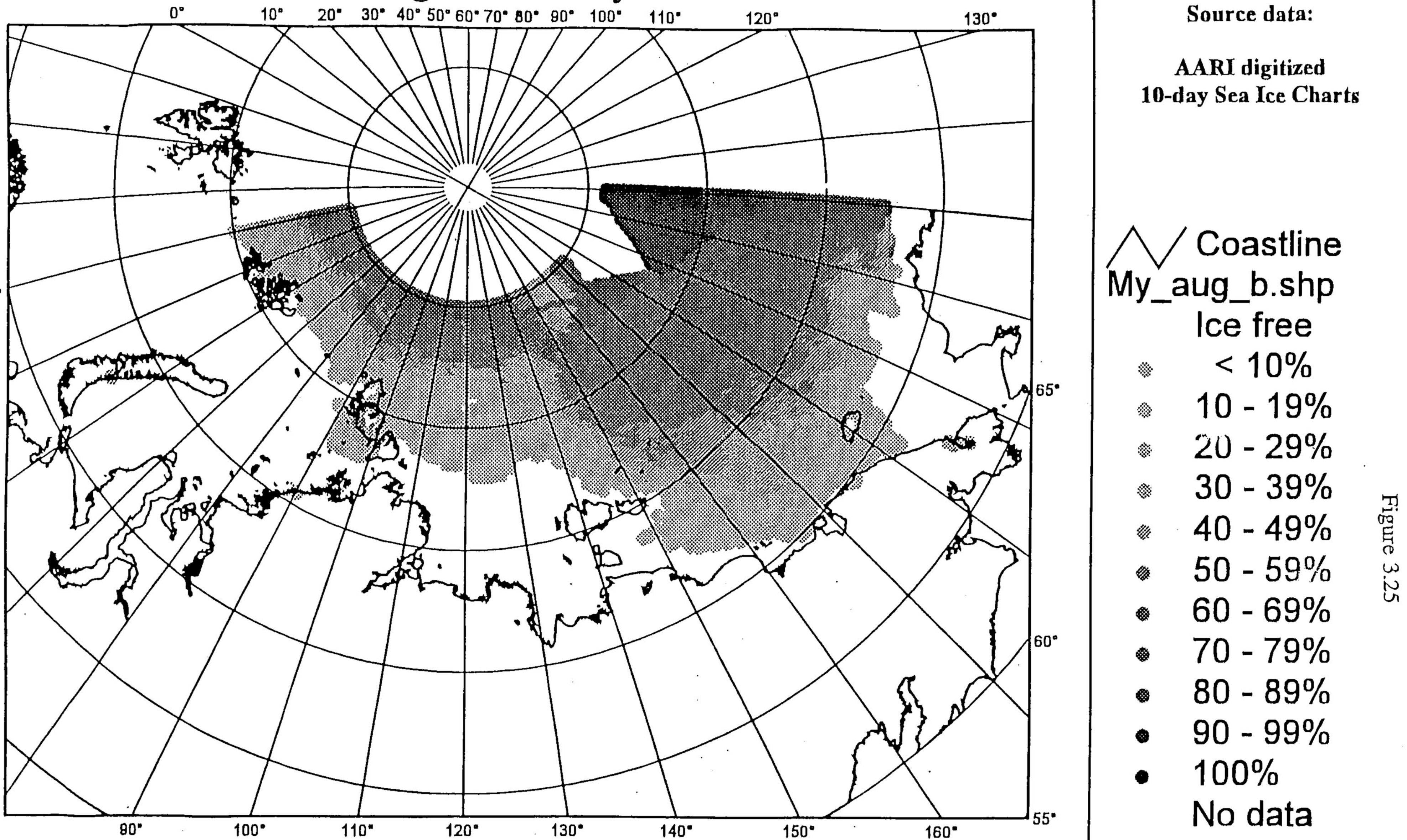
An ArcView 2.1 application

Old ice concentration - August - Multiyear median



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An ArcView 2.1 application

Figure 3.25

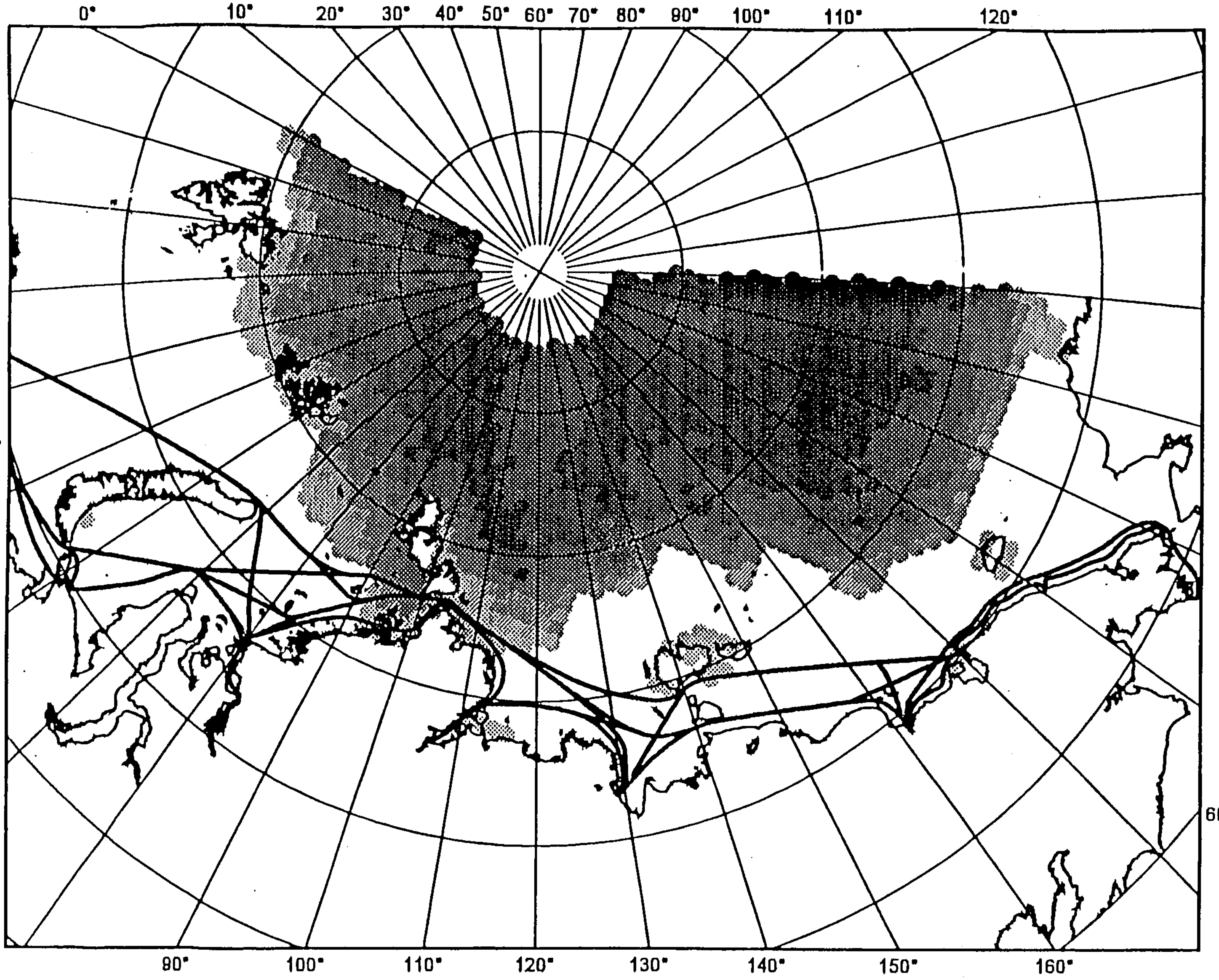
3.2 Comparison between AARI and SSM/I ice concentration data

Daily SSM/I data for the period July 1987 to December 1991 was implemented into INSROP GIS in 1994 and presented in Vefsnmo et al. (1996). The SSM/I sea ice concentrations for the polar regions are gridded in the polar stereographic projection at a resolution of 25 km x 25 km. The analyzed period of the SSM/I ice concentration data is relatively short. In order to study the representativeness for the NSR ice conditions variability, the SSM/I analyses have been compared with the analyses of the AARI Sea Ice Chart Database.

In the winter months November-April both the AARI and SSM/I analyses show very dense drifting ice both in the Laptev and East-Siberian Seas. In both the Kara Sea and the Chukchi Sea the SSM/I data show lower ice concentrations than the AARI data. The greatest seasonal fluctuation occurs at the east and west ends of the route and a short time period will not be representative for the great fluctuations. Especially, 1990 was a year with light ice conditions and will heavily influence on the variability analysis for a short time period. In the Laptev and East-Siberian Seas where the fluctuations are small in winter, the variability analysis is not as dependent on long time series. Influence of ocean currents moving northward from warmer Atlantic Ocean in the west and the Bering Sea in the east accelerates the ice decay in the spring and retards the freeze-up in the fall. Both datasets show the summer season for the region occuring roughly from June to September, when the ice cover melts significantly, diminishing in both extent and strength. However, the ice concentrations are lower in the SSM/I analysis than in the AARI analysis. Both datasets show minimum ice extent in August/September (see Figures 3.26 and 3.27). The ice massifs Taymyr, Severnaya Zemlya, Ayon and Wrangel are all visible both on the AARI and SSM/I ice maps with ice concentration greater than 70 %.

A trend analysis of the Barents Sea ice conditions showed a principal cycle of about 10-12 years. This Barents Sea analysis included weekly data from 1966-90 and pointed out the years 1968 and 1989 as the years with heaviest ice conditions (Vefsnmo et al., 1992).

Probability of total ice concentration > 70%



Source data:

Daily SSM/I data sets from the National Snow and Ice Data Center, Boulder, Colorado, USA

Atlas Arktiki Ship routes
Coastline
September 1987-91
Never
0.0 <
0.1 <
0.2 <
0.3 <
0.4 <
0.5 <
0.6 <
0.7 <
0.8 <
0.9 <
Always
No data

Figure 3.26

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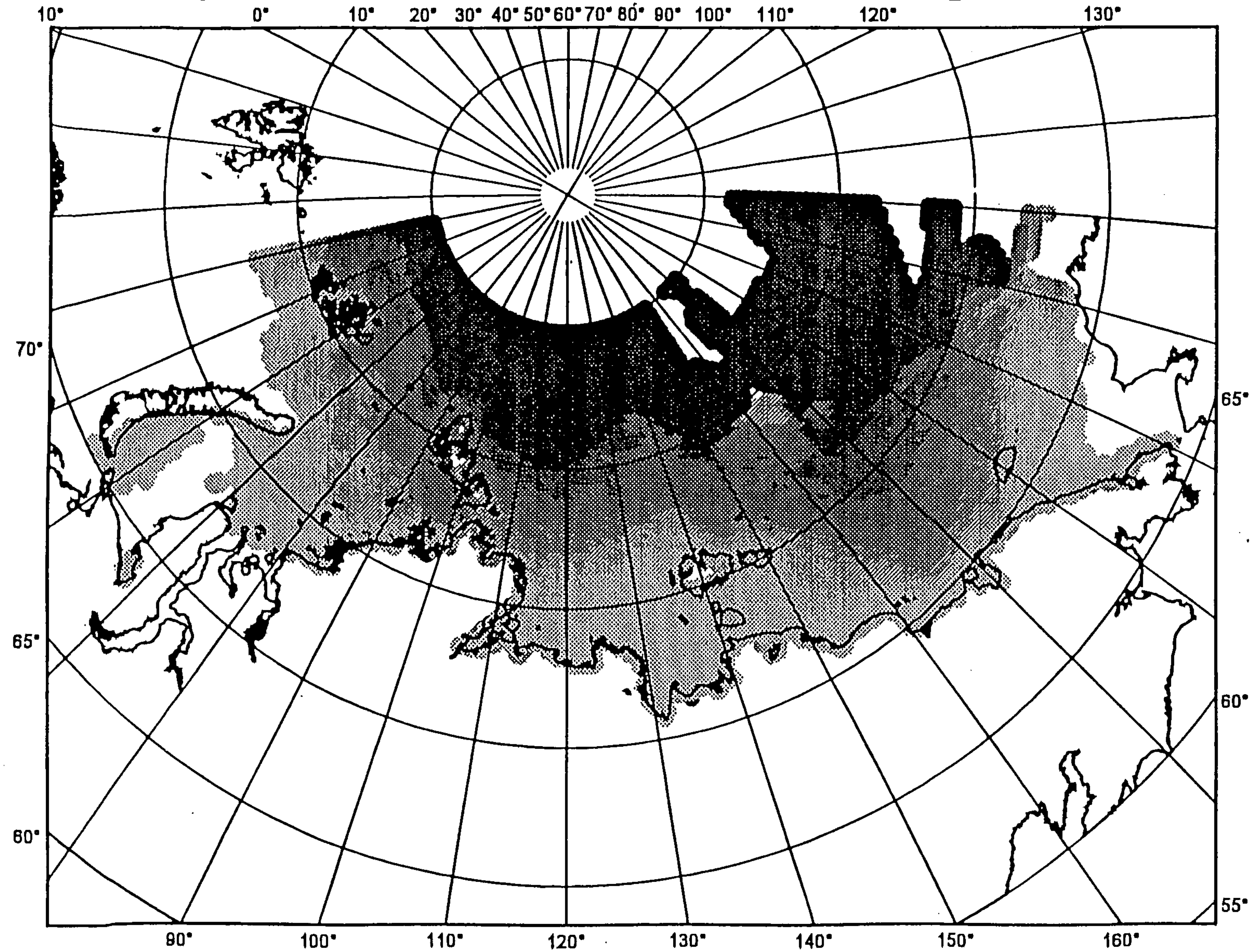
Probability of total ice concentration > 70 % - September



Source data:

AARI digital
10-day sea ice charts

Coastline
My_sep_a.shp
Never
0.0 <
0.1 <
0.2 <
0.3 <
0.4 <
0.5 <
0.6 <
0.7 <
0.8 <
0.9 <
Always
No data

Figure 3.27

500 0 500 1000 Kilometers

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An ArcView 2.1 application

3.3 Special conditions of importance to sailing

There are a number of ice condition parameters that affect sailing. Some are related to sailing speed, while others are more important to the safety of navigation. The safety of navigation due to ice conditions is primarily related to whether ice conditions exceeding the ship design criteria are encountered, either due to the ice conditions being too heavy, or the ship speed being too high when 'hitting' ice features (e.g. old ice 'pieces'). Sailing speed is primarily affected by the ice type/thickness, ice concentration, ridges, leads, ice compression, and in some conditions also by the snow cover. Within INSROP Phase I, Projects I.3.1/I.5.1 have not had access to digital data on ridging, leads or ice compression. However, the analysis of the AARI digital 10-day sea ice charts has revealed some interesting observations on ice concentration and ice type/thickness.

In the absence of information on ridging, leads and ice compression, areas with favourable ice conditons are areas with low ice concentration and/or thin ice. Section 3.1 presents some maps on total ice concentration, ice thickness, concentration of old ice and probability of fast ice. These maps show that the median ice thickness is at a maximum during summer, due to all thin ice being melted and only the thicker ice remaining. At the same time the ice concentration is at a minimum. In order to visualize 'favourable' ice conditions for navigation, rather than an isolated ice conditions parameter, we have calculated an 'averaged' ice thickness. This measure is calculated by multiplying the median total ice concentration by the median ice thickness and dividing by 100. The effect of this is that both areas with high thickness, but low concentration, and areas with high concentration, but low thickness, will be converted to a low 'averaged' ice thickness. For example both 100 % ice of 50 cm thickness and 25 % ice of 200 cm thickness will give an 'averaged' ice thickness of 50 cm.

Figures 3.28-3.32 show the distribution of 'averaged' ice thickness for December, March, May, June and July. In December (Figure 3.28) the 'averaged' ice thickness is less than 50 cm in the Kara Sea increasing to 75-100 cm towards the Boris Vil'kitsky Strait and in the Laptev Sea. There is however a zone of 25-75 cm thickness along the coast from Taymyr to the Lena Delta. In the eastern part of the East Siberian Sea towards Wrangel Island the thicknesses are above 125 cm. From Wrangel Island and east towards the Bering Strait the conditions are the same as from Boris Vil'kitsky Strait and west towards the Kara Strait.

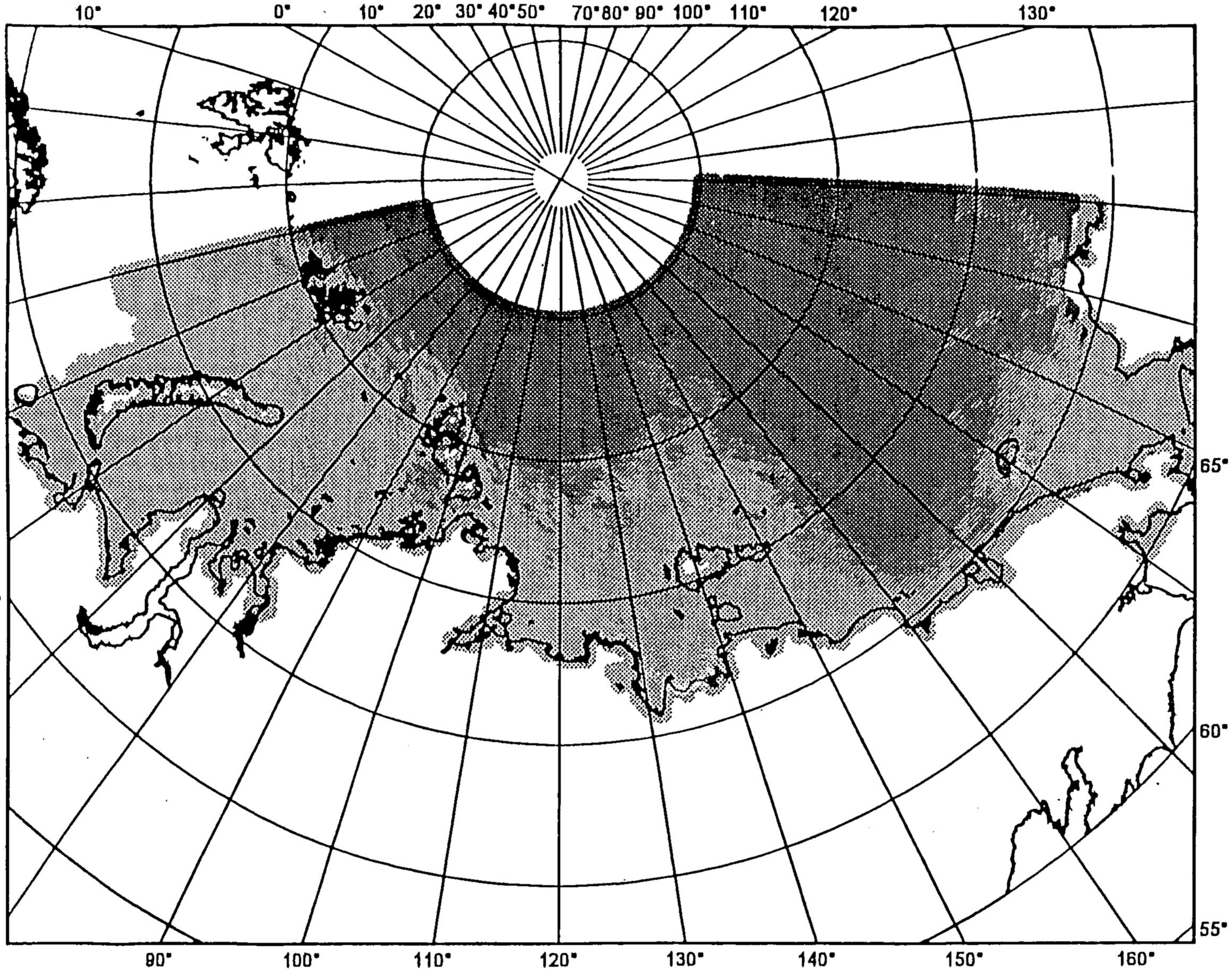
In March (Figure 3.29) the fast ice has developed from the coast and outwards, especially in the area between the coast and the New Siberian Islands. The ice in the northwestern part of the Kara Sea is also thicker. However, the 'averaged' ice thicknesses are below 100 cm along the fast ice in the southeastern part of the Kara Sea to Dikson and further towards the Boris Vil'kitsky Strait, and from the eastside of the strait along the fast ice in the Laptev Sea all the way to the northern side of the New Siberian Islands. This latter zone of low 'averaged' ice thickness is mainly caused by the wind conditions (AARI staff., pers. comm.). The area from the New Siberian Islands towards the Bering Strait shows 'averaged' ice thicknesses above 125 cm, with the 170°E meridian as an approximate centerline of the thickest ice.

In May (Figure 3.30) the conditions are fairly similar to the March conditions. However, the larger part of the Kara and the Laptev Seas, beyond the fast ice, shows an 'averaged' ice thickness of 125-150 cm. The zone of lower 'averaged' ice thicknesses along the fast ice in the eastern part of the Kara Sea and in the Laptev Sea is still visible, but is narrower and somewhat thicker. The centerline of the thickest ice in the East Sberian Sea is now slighly more to the west, approximately at 167°E.

In June (Figure 3.31) the zones of lower 'averaged' ice thicknesses are even smaller. In the Laptev Sea the zone of 'averaged' ice thickness below 100 cm now extends from north of the Lena river delta to the northern side of the New Siberian Islands. East of this area the conditions are fairly stable. There is a sharp gradient towards lower 'averaged' ice thicknesses in the Kara and Bering straits.

In July (Figure 3.32) the zones of lower 'averaged' ice thicknesses has increased again. In the southeastern part of the Kara Sea a zone of approximately 100 km follow the coast along Yamal and to the east of Dikson (Pyasina outlet). There is also a zone of lower 'averaged' ice thicknesses ouside the Taymyr coast on the eastern side of the Boris Vil'kitský Strait. In the eastern part of the NSR a gradient zone (120-140 km wide) where the 'averaged' ice thickness decreases from above 150 cm to below 25 cm is located about 150 km east of Wrangel Island. There is also a narrow zone of lower 'averaged' ice thicknesses along the coast from the Lena river delta and eastwards to this gradient zone. This is probably caused by the fast ice having broken up and drifted offshore.

'Averaged' ice thickness - December



'Averaged' ice thickness = Median total ice concentration divided by 100 and multiplied by Median ice thickness

Figure 3.28

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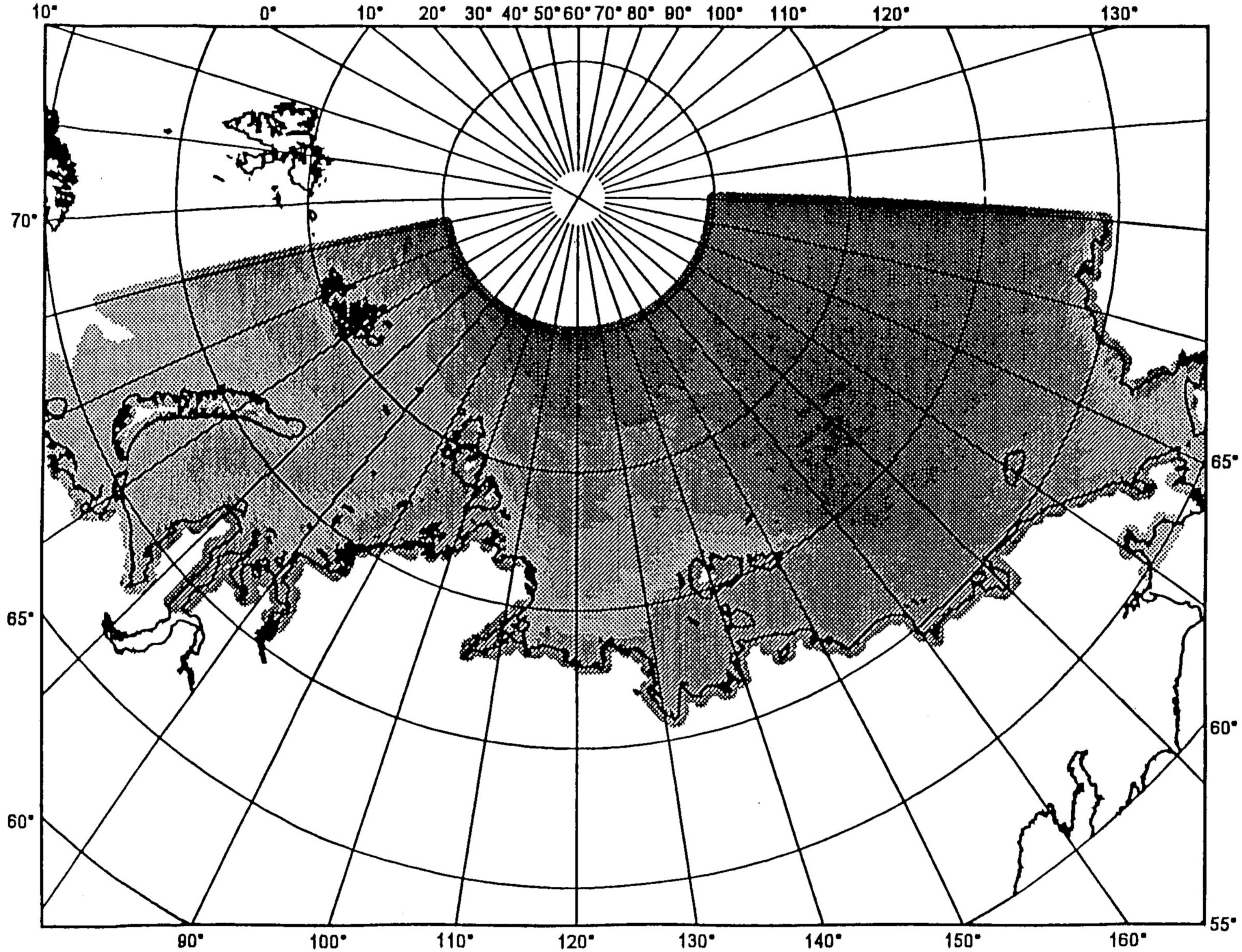
-

An ArcView 2.1 application

'Averaged' ice thickness - March



'Averaged' ice thickness = Median total ice concentration divided by 100 and multiplied by Median ice thickness

Figure 3.29

Coastline
My_mar_a.shp
< 25 cm
25 - 50 cm
50 - 75 cm
75 - 100 cm
100 - 125 cm
125 - 150 cm
150 - 175 cm
175 - 200 cm
200 - 225 cm
225 - 250 cm
250 - 275 cm
275 - 300 cm
300 cm <

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500 0 500 1000 Kilometers

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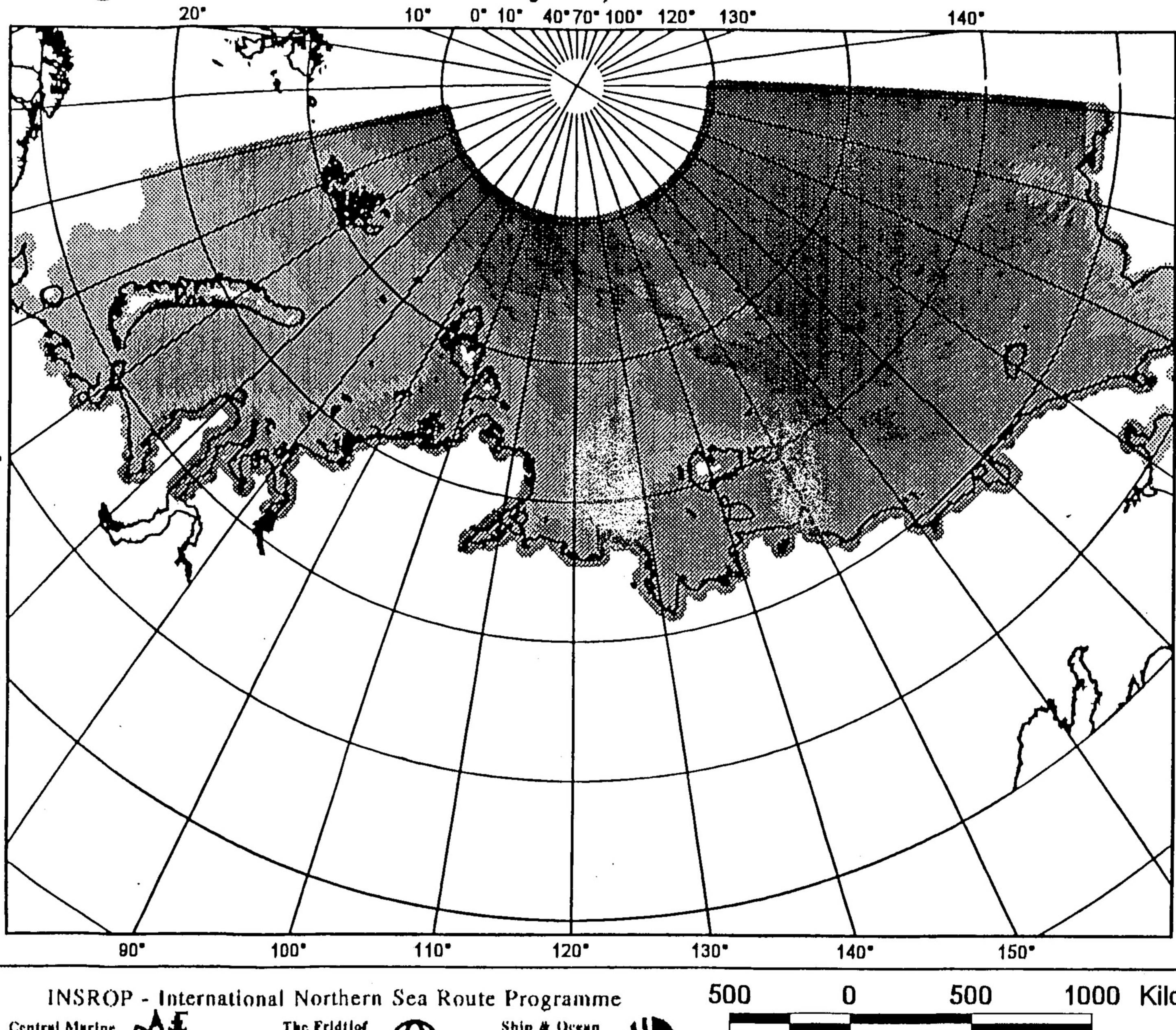
'Averaged' ice thickness - May



'Averaged' ice thickness = Median total ice concentration divided by 100 and multiplied by Median ice thickness

Figure 3.30

Coastline
My_may_a.shp
< 25 cm
25 - 50 cm
50 - 75 cm
75 - 100 cm
100 - 125 cm
125 - 150 cm
150 - 175 cm
175 - 200 cm
200 - 225 cm
225 - 250 cm
250 - 275 cm
275 - 300 cm
300 cm <

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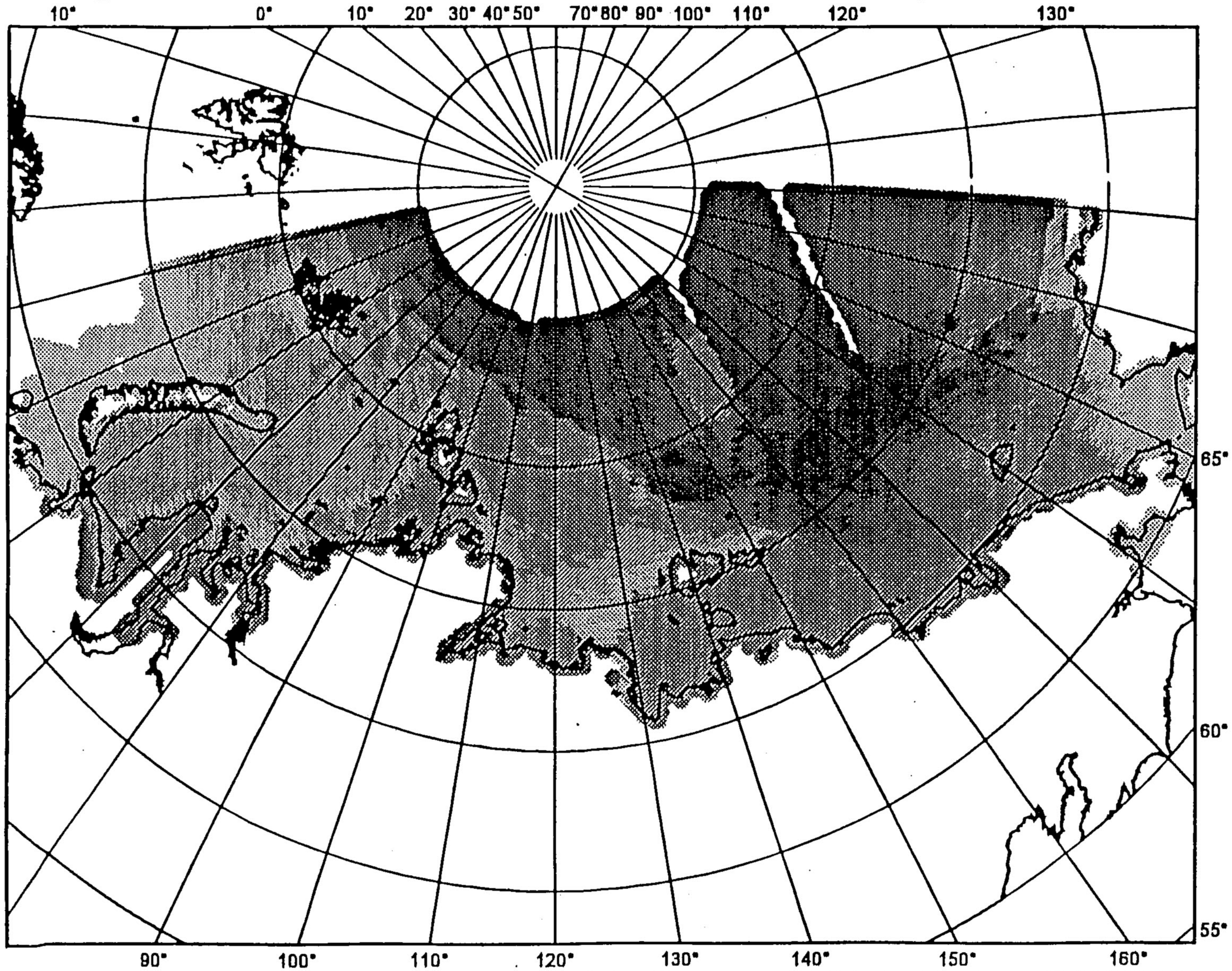
'Averaged' ice thickness - June



'Averaged' ice thickness = Median total ice concentration divided by 100 and multiplied by Median ice thickness

Figure 3.31

Coastline
My_jun_a.shp
- < 25 cm
- 25 - 50 cm
- 50 - 75 cm
- 75 - 100 cm
- 100 - 125 cm
- 125 - 150 cm
- 150 - 175 cm
- 175 - 200 cm
- 200 - 225 cm
- 225 - 250 cm
- 250 - 275 cm
- 275 - 300 cm
- 300 cm <

500 0 500 1000 Kilometers

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-

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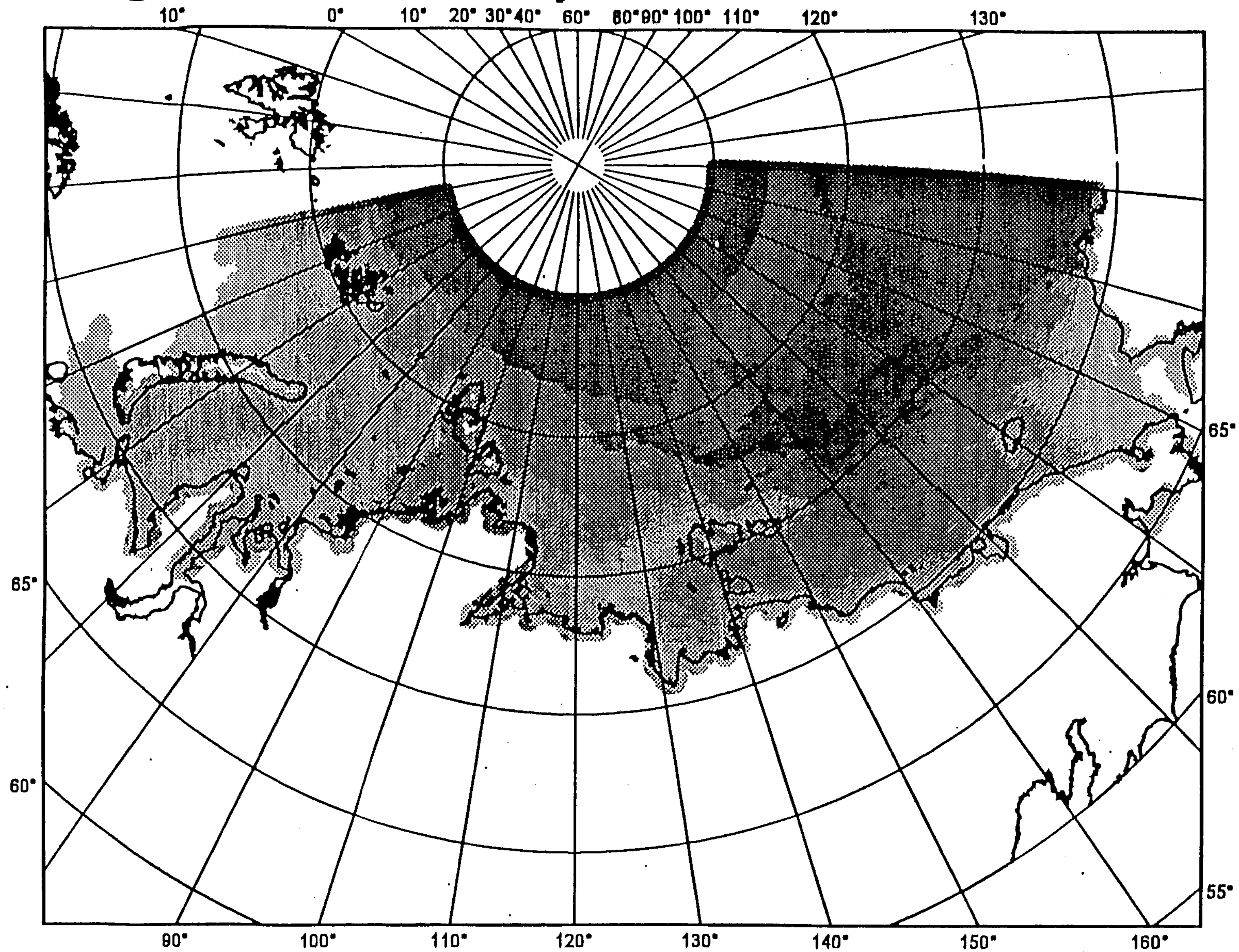
'Averaged' ice thickness - July



'Averaged' ice thickness = Median total ice concentration divided by 100 and multiplied by Median ice thickness

Figure 3.32

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-

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3.4 Air temperature

NOAA Baseline Climatologic DataSet has been derived from the Global Historical Climate Network and implemented into INSROP GIS. The data include minimum, maximum and average air temperature data for the WMO stations presented in Figure 3.33. Four stations along the NSR have been selected, representing respectively the Kara Gates, the Boris Vil'kitskogo, Sannikova and Longa Straits:

- Mys Menshikova
- GMO IM.E.K. Fedorova
- Mys Salaurova
- Ostrov Vrangelja

Figures 3.34-3.37 show the temperature distribution on a monthly basis for the four stations. During the winter period October to May the lowest air temperatures are registered in the Boris Vil'kitskogo and the Sannikova Straits where minimum is about -40°C in January/February. The minimum temperatures in the Kara Gate and the Longa Strait are -25°C and -30°C, respectively. The temperature data show highest air temperatures in the Kara Gates where the average tempe-rature is ranging from -17°C to -5°C during winter and 1°C to 5°C in summer. For the other stations the average temperature in the summer months is about 0-2°C. The lowest air temperatures are in December-March and the highest in June-September. Based on the temperature data the melting starts on average in June/July and the freezing process in September/October, which agrees well with the analysis of the AARI sea ice data. The minimum sea ice extent is on average in August/September.

3.5 Sea surface salinity

Mean seasonal (summer and winter) sea surface salinity data are presented in Brestkin et al. (1995). The data cover the region 65-82.5°N and 55-195°E with a resolution of 2.5°Nx5°E and have been implemented in INSROP GIS. The temporal resolution of the data is very sparse and gives only general seasonal trends. High salinities give low freezing temperatures. Due to river runoff brackish waters are found near the coast where fast ice is formed during relatively high temperatures in winter. In summer the most saline waters are found in the north/western region where the salinity ranges from 32-34 ppt (Figure 3.38). In winter the salinity increases due to freezing and the most saline waters are found in the western and eastern parts of the region where the easiest ice conditions are found (see Figure 3.39).

Location of WMO air temperature stations

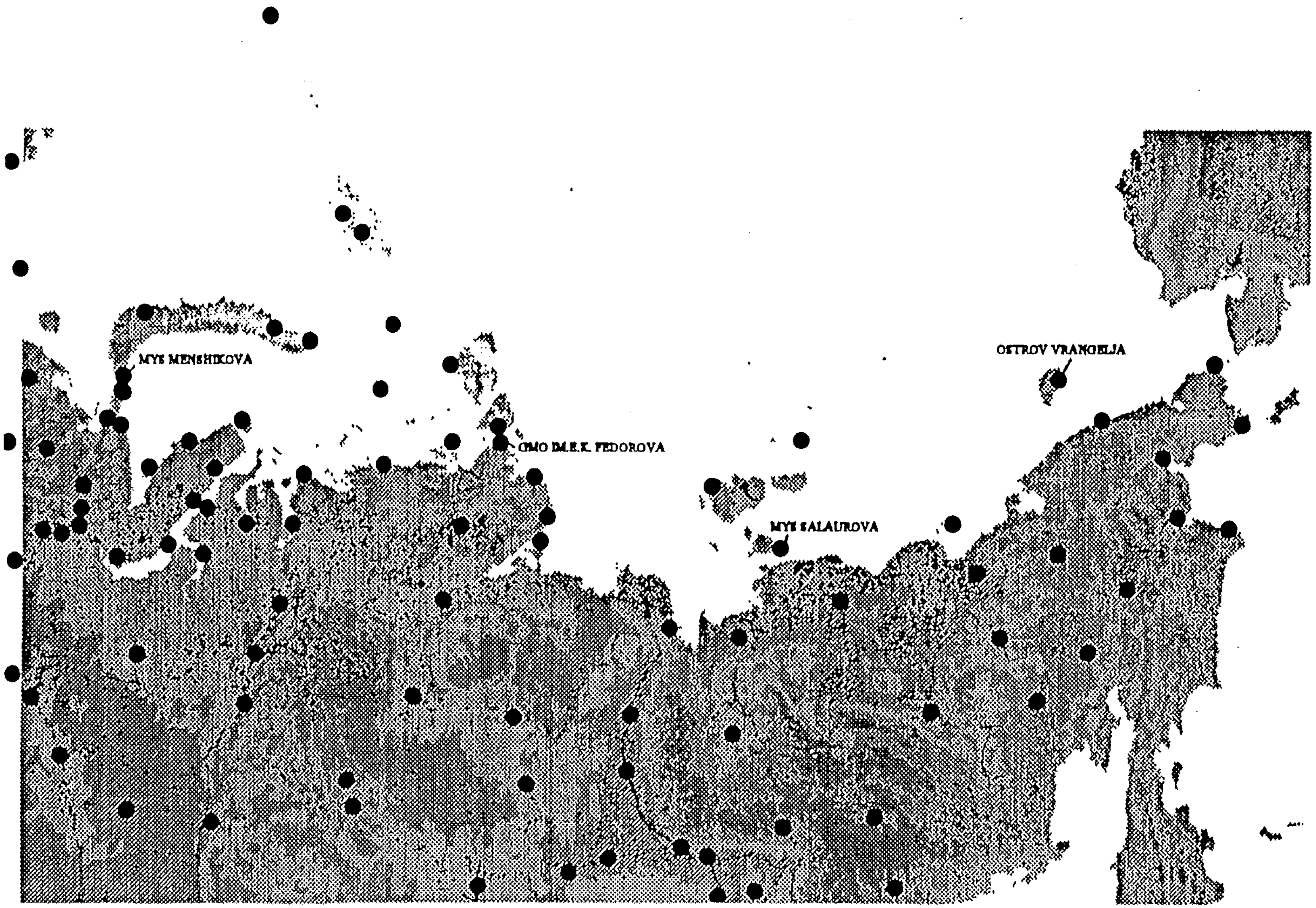

Figure 3.33 WMO air temperature stations.

● WMO stations

500 0 500 1000 Kilometers

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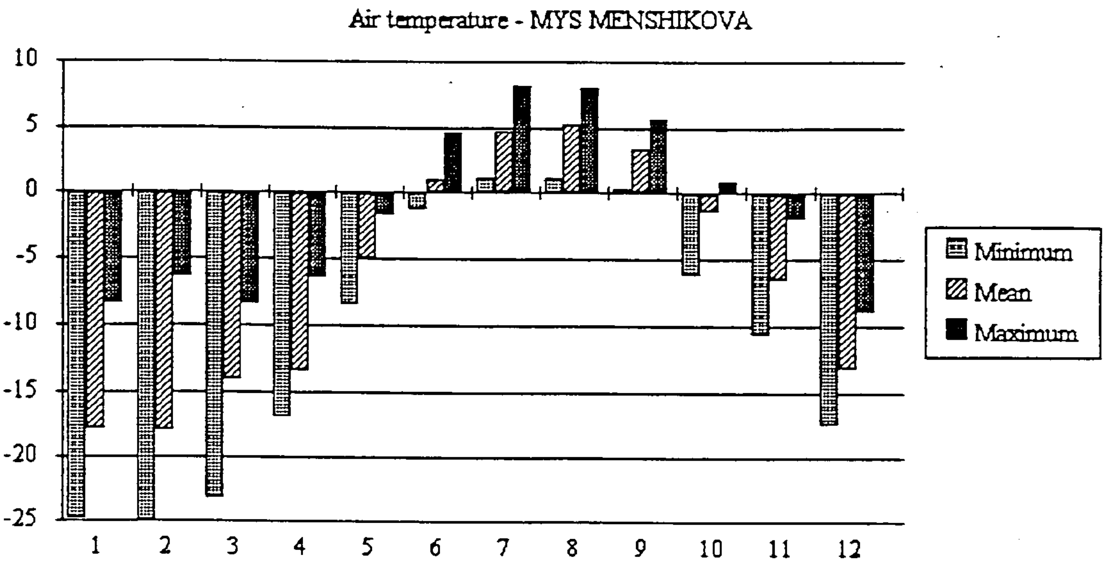


Figure 3.34 Minimum, maximum and average air temperature for Mys Menshikova.

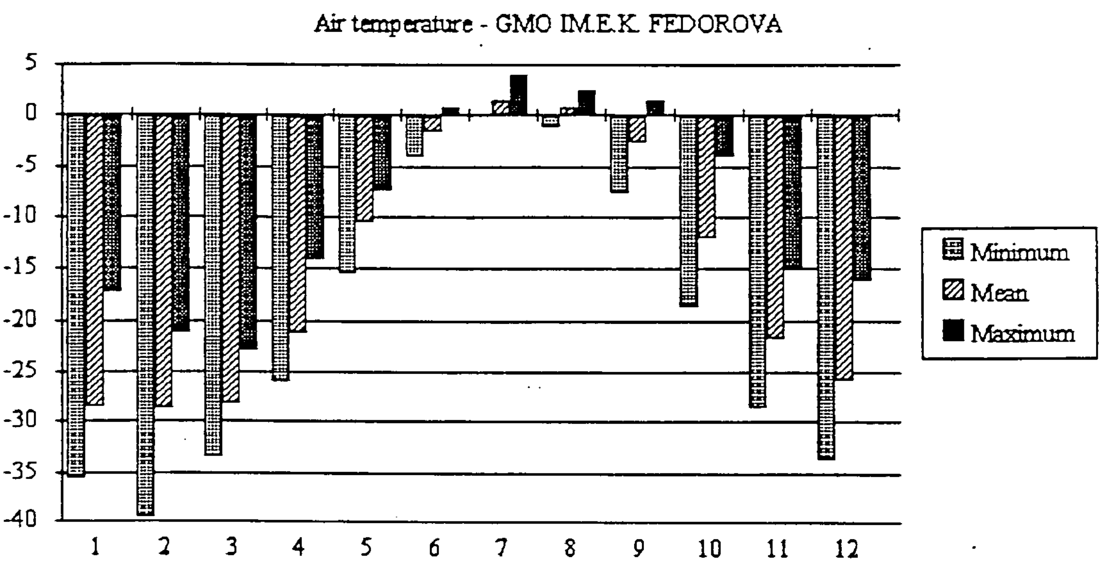


Figure 3.35 Minimum, maximum and average air temperature for GMO IM.E.K Fedorova.

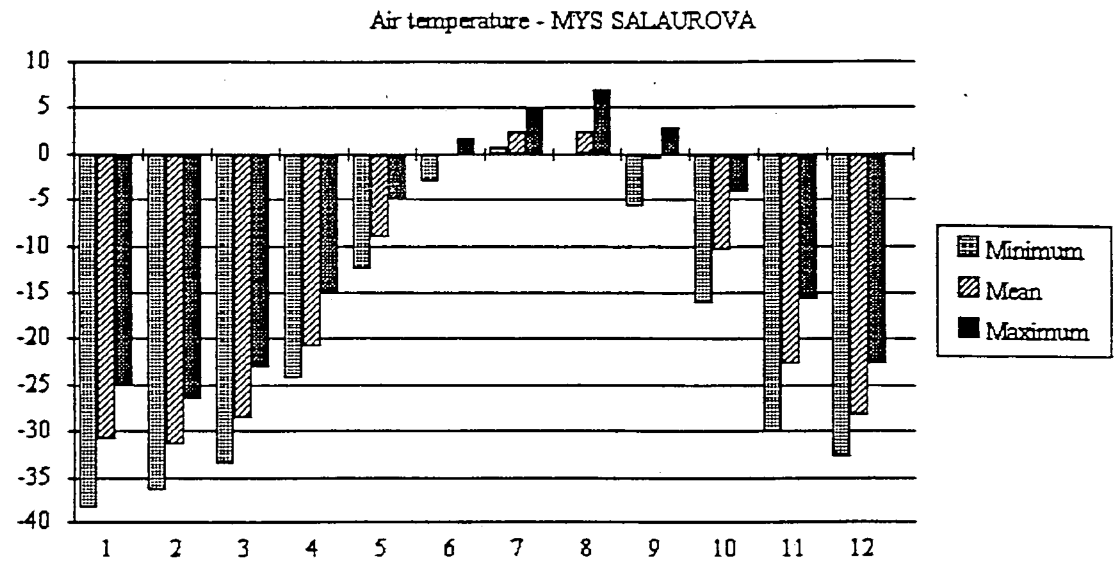


Figure 3.36 Minimum, maximum and average air temperature for Mys Salaurova.

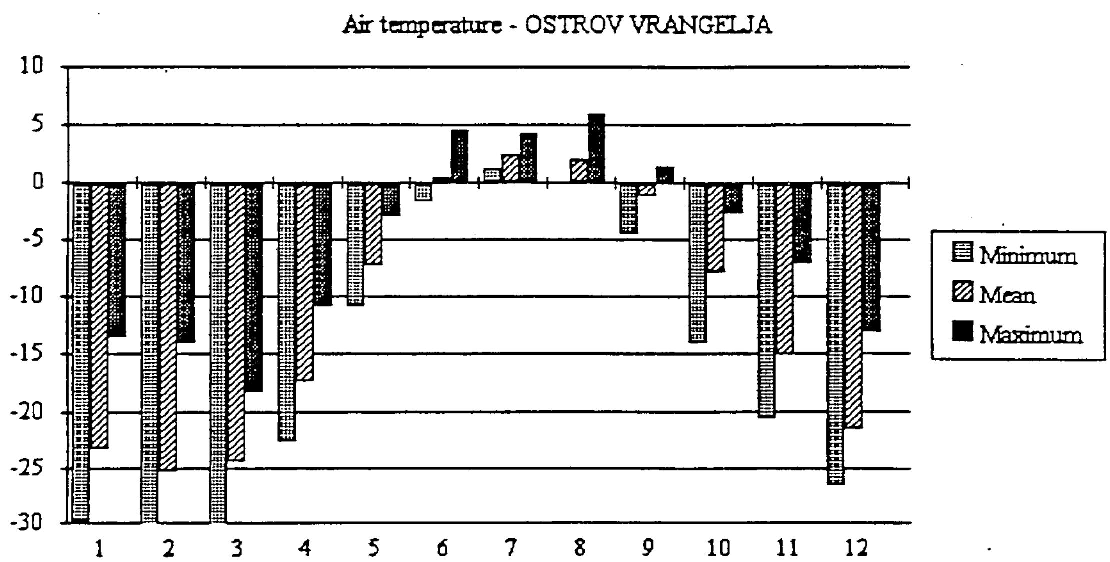
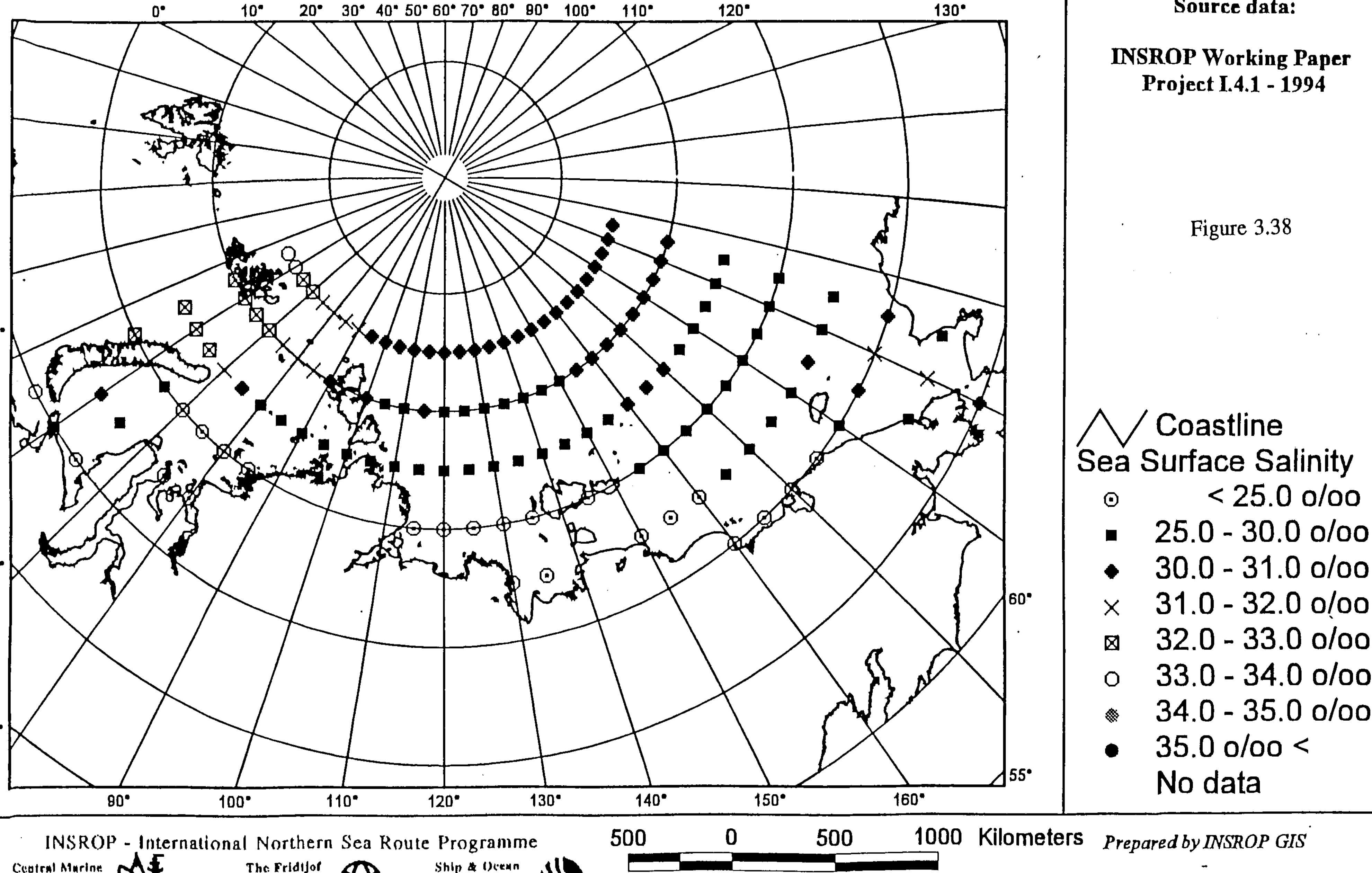


Figure 3.37 Minimum, maximum and average air temperature for Ostrov Vrangelja.

Sea Surface Salinity - Summer



Source data:

INSROP Working Paper
Project I.4.1 - 1994

Figure 3.38

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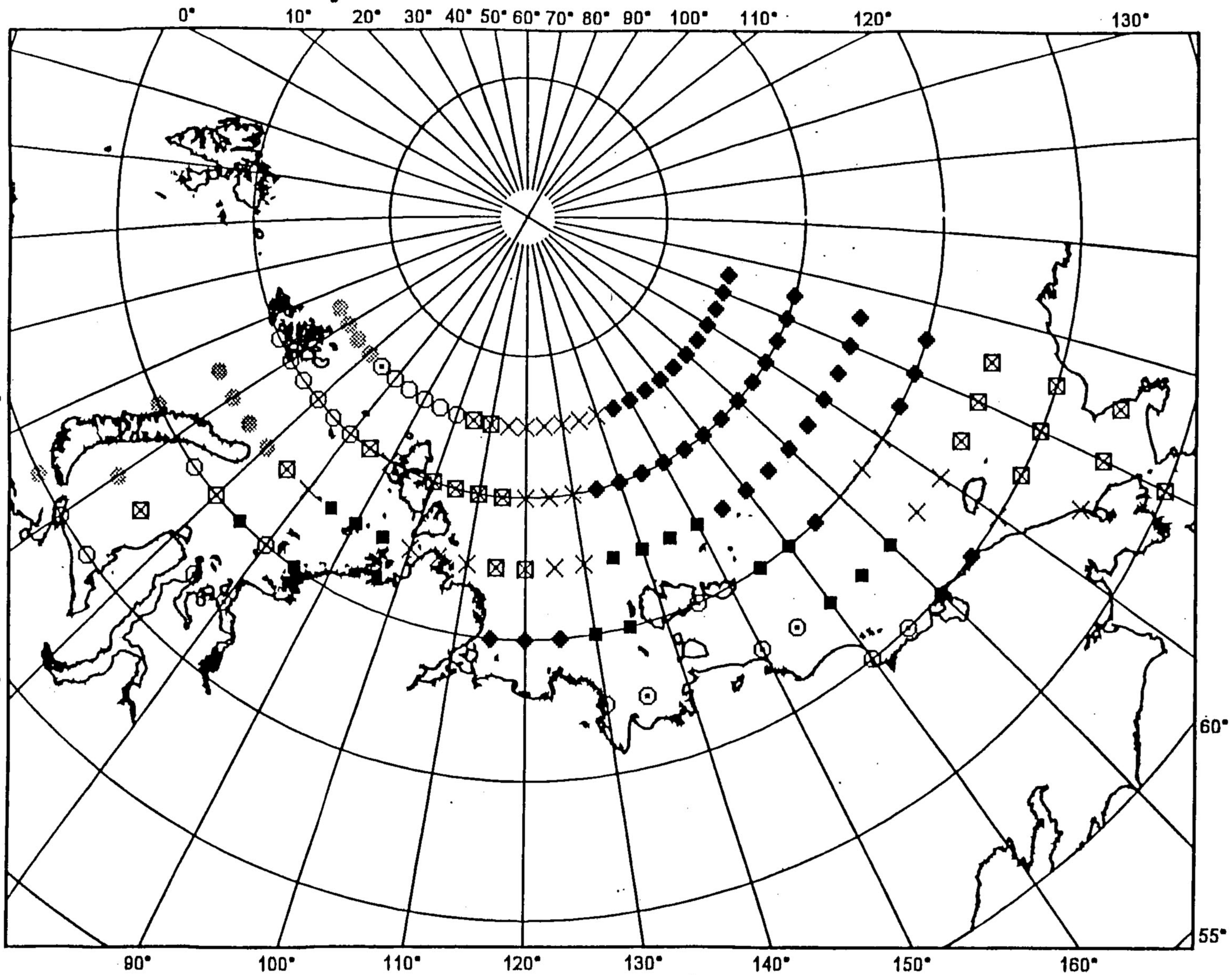
Sea Surface Salinity - Winter



Source data:

INSROP Working Paper Project I.4.1 - 1994

Figure 3.39

Coastline
Sea Surface Salinity
< 25.0 o/oo
25.0 - 30.0 o/oo
30.0 - 31.0 o/oo
31.0 - 32.0 o/oo
32.0 - 33.0 o/oo
33.0 - 34.0 o/oo
34.0 - 35.0 o/oo
35.0 o/oo <
No data

500 0 500 1000 Kilometers

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-
An ArcView 2.1 application

3.6 Flow rates of main Russian rivers

River flow rates have been derived from the Data Support Section, Scientific Computing Division, National Center for Atmospheric Research. The source data have been collected by UNESCO and include the following information:

- monthly flow rates
- annual average flow rates
- maximum daily flow rates
- date of maximum flow rate
- minimum flow rates

Flow rates for the main northern Russian rivers have been implemented into INSROP GIS and Figure 3.40 shows the location of the implemented stations. Figure 3.41 shows the monthly flow rates for the rivers:

- Ob at Salekhard
- Yenisei at Igarka
- Lena at Kusus

The Yenisei and Ob rivers are mainly lowland rivers. Spring run-off is fast and heavy, and it causes extreme fluctuations in the depth of the main river. Due to the ice conditions the flow rate is low in winter and increases rapidly in May/June. The Yenisei river may rise 15-20 m at Igarka in June and flow rate may be up to 75 000 m^3/s. The port of Dudinka is normally evacuated for two weeks or more to avoid ice and flood damage. Low water flowrate occurs in the summer after the spring run-off. The land is underlain by permafrost and melting snow cannot seep into the ground to even out stream flow. The precipitation is also low in summer. For the Ob river the spring flood starts in May and the maximum flow rate occurs in June and is about 43 500 m^3/s on average. The river alimentation is mainly due to snow. For the Lena river the spring flood occurs in June and is very heavy. The maximum flow rate may reach 90 000 m^3/s. The flow rate is also relatively high in the summer period, about 30-50 m^3/s. The spring outflow of river waters reduces the salinity at the river mouth and in the coastal regions. Seasonal breakup of the ice throughout the entire sea begins in June and July, about one month after the river flood.

Figure 3.42 shows the flow rate for the rivers:

- Yana at Dzanghky
- Indigirka at Vorontsovo
- Amguerma at the mouth of Shoumny Brook

The flow rates of these rivers are small compared to the rivers Ob, Yenisei and Lena. The spring flood is mainly in June which corresponds to the flood time for the Lena river. The maximum flow rate for Indigirka in June is about 10 000 m^3/s and decreases during the summer period due to permafrost and low precipitation. The rivers are very shallow and freeze to the bottom in the winter. Therefore, the flow rates are very low during October to May.

Location of UNESCO river flowrate stations

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Figure 3.40

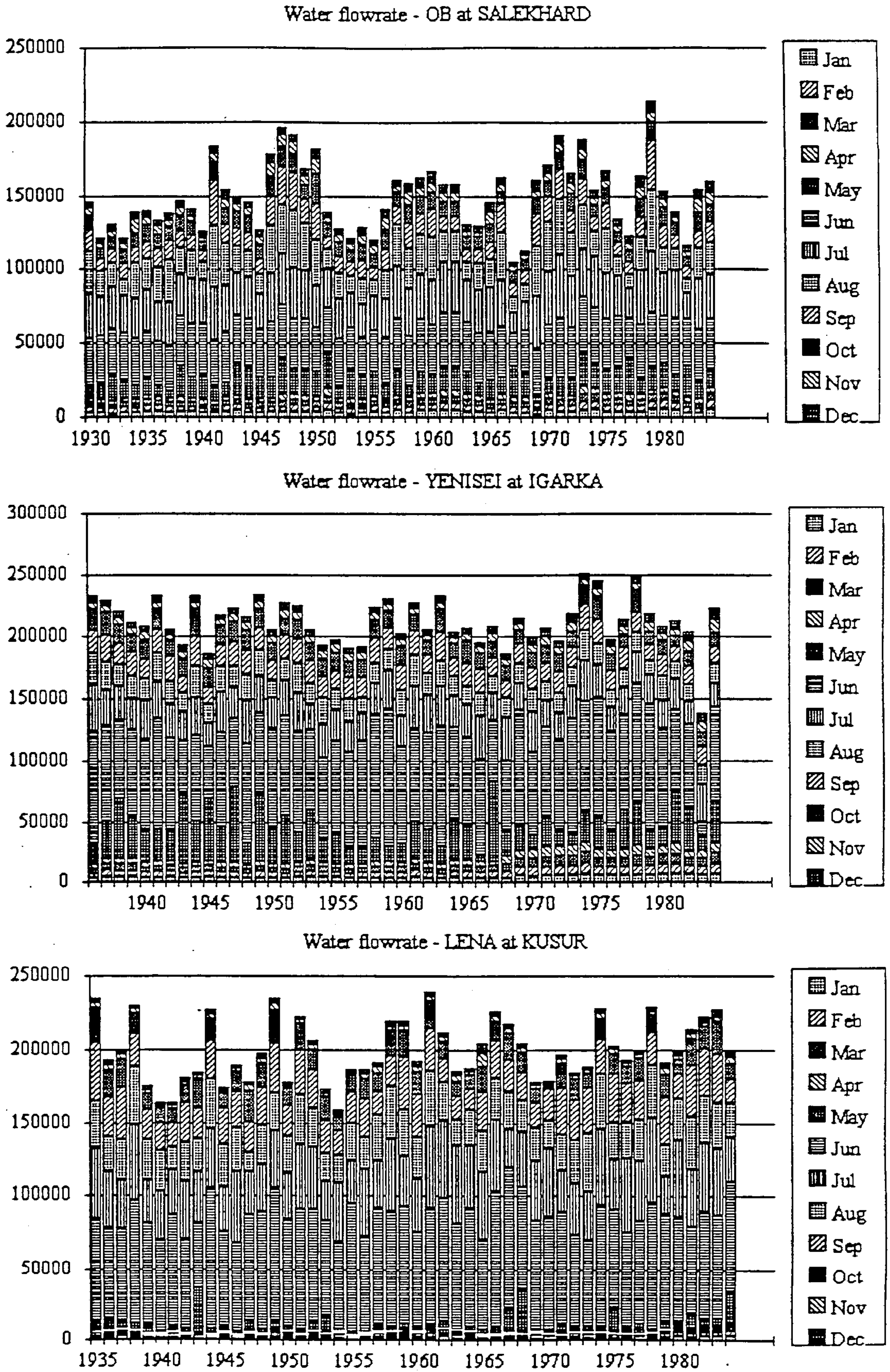


Figure 3.41 Averaged monthly flowrates of the rivers Ob, Yenisei and Lena.

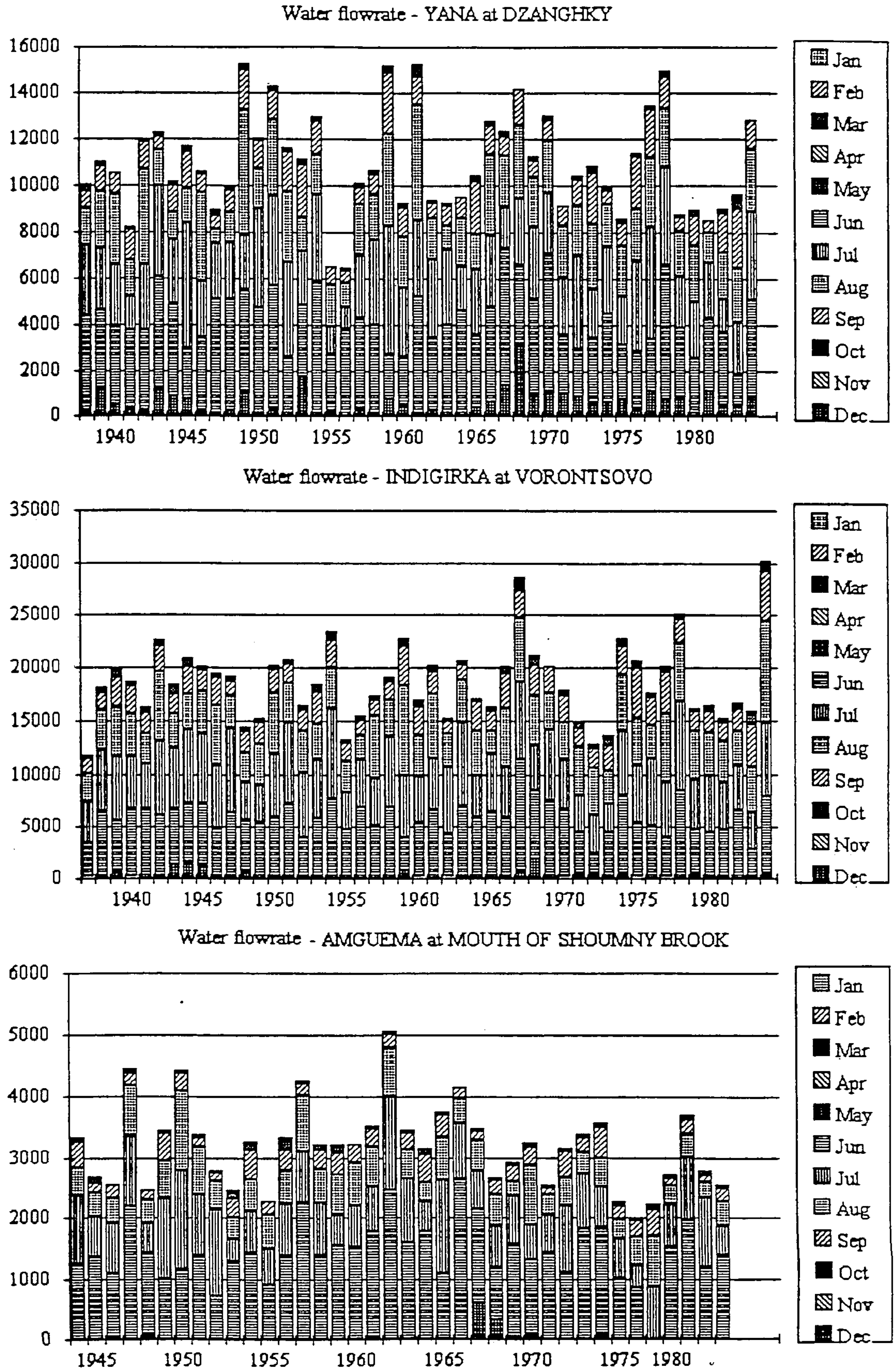


Figure 3.42 Averaged monthly flowrates of the rivers Yana, Indigirka and Amguema.

4 PROBABILITY DISTRIBUTION OF DIFFERENT ICE CONDITIONS ALONG THE SHIP ROUTE

The length of the season and the average speed through the NSR are key factors to the NSR profitability. Transit of the NSR is today limited to the period July-October mainly due to severe ice conditions. To make the NSR really an international sea route the length of the operational season must be substantially prolonged with sustained average speed times. New ice breaker and ship technology, together with improved navigational systems, will give possibilities for extending the navigational period. The main limiting factors for transit sailing are the ice conditions and the water depth. The sailing length in ice of 7-10/10 concentration serves as criterion of the complicated ice navigation conditions. In winter the success of the voyages will mainly depend on the polynyas and the discontinuities in the drifting ice.

4.1 Data sources

The AARI Sea Ice Charts for the Arctic Ocean have been applied for a preliminary analysis of sea ice conditions along a given ship route. The data include information on sea ice concentration and stages of development from integrated charts and cover the time period 1967-90 with a spatial resolution of 10 days. The Atlas of the Arctic has been applied for digitizing traditional sailing routes.

4.2 Analysis method

In order to evaluate the ice conditions along a planned sailing route, a methodology to analyze the distribution of different ice conditions along a specified route has been developed and implemented in INSROP GIS. A given ship route is digitized and a buffer zone of 15 km on each side is set up according to the resolution of the sea ice data applied. In order to give the percentage part of the route representing the given conditions within the obtained polygon, the number of points given the actual conditions is divided by the total number within the whole route. Open waters are defined as conditions with ice concentration lower than 10 %.

Based on a specified ship route the following information about the ice conditions is calculated:

- Total sea ice concentration
  - Open water (C < 10 %)
  - Very open drift ice (10% < C < 40%)
  - Open drift ice (40 % < C < 70 %)
  - Close and very close drift ice (C > 70 %)
  - Fast ice

- Old ice concentration
  - Open water (C < 10 %)
  - Very open drift ice (10% < C < 40%)
  - Open drift ice (40 % < C < 70 %)
  - Close and very close drift ice (C > 70 %)

- Ice thickness
  - Thin first year ice (T < 70 cm)
  - Medium first year ice (70 < T < 120 cm)
  - Thick first year ice (120 < T < 200 cm)
  - Old ice (T>200 cm)

4.3 Results

As an demonstration example two sailing routes have been chosen, one representing a coastal transit route and the other representing a northern transit route (see Figure 4.1). The transit routes have also been divided into two segments (Tiksi meridian), in order to analyze the western and eastern ice conditions separately. The length of the different segments is given in Table 4.1. The total length of the two routes is almost the same, 4654 and 4685 km.

Table 4.1 The length of the different route segments.

Region	Length (km)
Northern transit route (whole)	4654
Northern transit route- western part	2324
Northern transit route- eastern part	2330
Coastal transit route (whole)	4685
Coastal transit route- western part	2306
Coastal transit route- eastern part	2379

4.3.1 Northern transit route

Figure 4.2 shows the distribution of different ice conditions along the northern route. Most of the route goes through very dense drifting ice, only 10-40 % goes through open waters during the summer months June-November. About 30-50 % of the route experiences old ice which is most dominating in late summer. Therefore, about 15-20 % of the route is in ice with thickness more than 200 cm. The most dominating ice conditions are very thick first-year ice. Only 20 % of the route is in thin ice less than 70 cm thick.

Northern transit route - western and eastern segment
Figures 4.3 and 4.4 show the distribution for the different ice conditions both for the western and eastern parts of the northern transit route. Both the western and eastern segments contain mainly very dense drifting ice. In the summer period about 10-40 % of the route goes through open water, both the western and the eastern part. During the winter no open water is present in the eastern part, in the western part only 5-10 %. Thick first-year ice is dominating in both parts of the route. Old ice is more frequent in the eastern part where about 50 % of the route goes through old ice, while the corresponding figure for the western part is 10-30 %. About 20 % of the eastern route contains ice with thickness greater than 200 cm, while the corresponding figure for the western part is 5-10 %. The amount of thin ice is also greater in the western part compared to the eastern part.

4.3.2 Coastal transit route

Figure 4.5 shows the distribution of different ice conditions along the coastal route. Very dense drifting ice is dominating along the coastal route. The amount of open water increases from May to September when about 60 % of the route goes through open water. In the winter months 30 % of the route goes through fast ice. Most of the year about 30 % of the route goes through old ice, except in late summer where only half of the route goes through old ice. In the summer months about 60-80 % of the route are in thin ice. The most dominating ice thickness in winter is dense first-year ice and about 10 % of the route goes through ice thickness above 200 cm, also in the summer months. The Taymyr, Ayon and Wrangel massifs contain significant concentrations of multi-year ice and heavily hummocked ice is frequently present.

Coastal transit route - western and eastern segment
Figures 4.6 and 4.7 show the distribution of the different ice conditions along the western and eastern segments of the coastal route. Very dense drifting ice is dominant in both segments. During winter, 40 % of the eastern part goes through fast ice compared to only 10 % for the western part. In winter the fraction of old ice is highest in the eastern part (40 %) compared with the western part (10 %). The highest concentration of old ice is found in late summer where 70 % of the route for the eastern part goes through old ice. Thin ice (less than 70 cm) is dominating in the summer period in both segments. In the western part 50-90 % of the route can go through thin ice. In the winter months thick first-year ice and multi-year ice are dominatng in the eastern part, while thin ice and thick first-year ice are dominating in the western part.

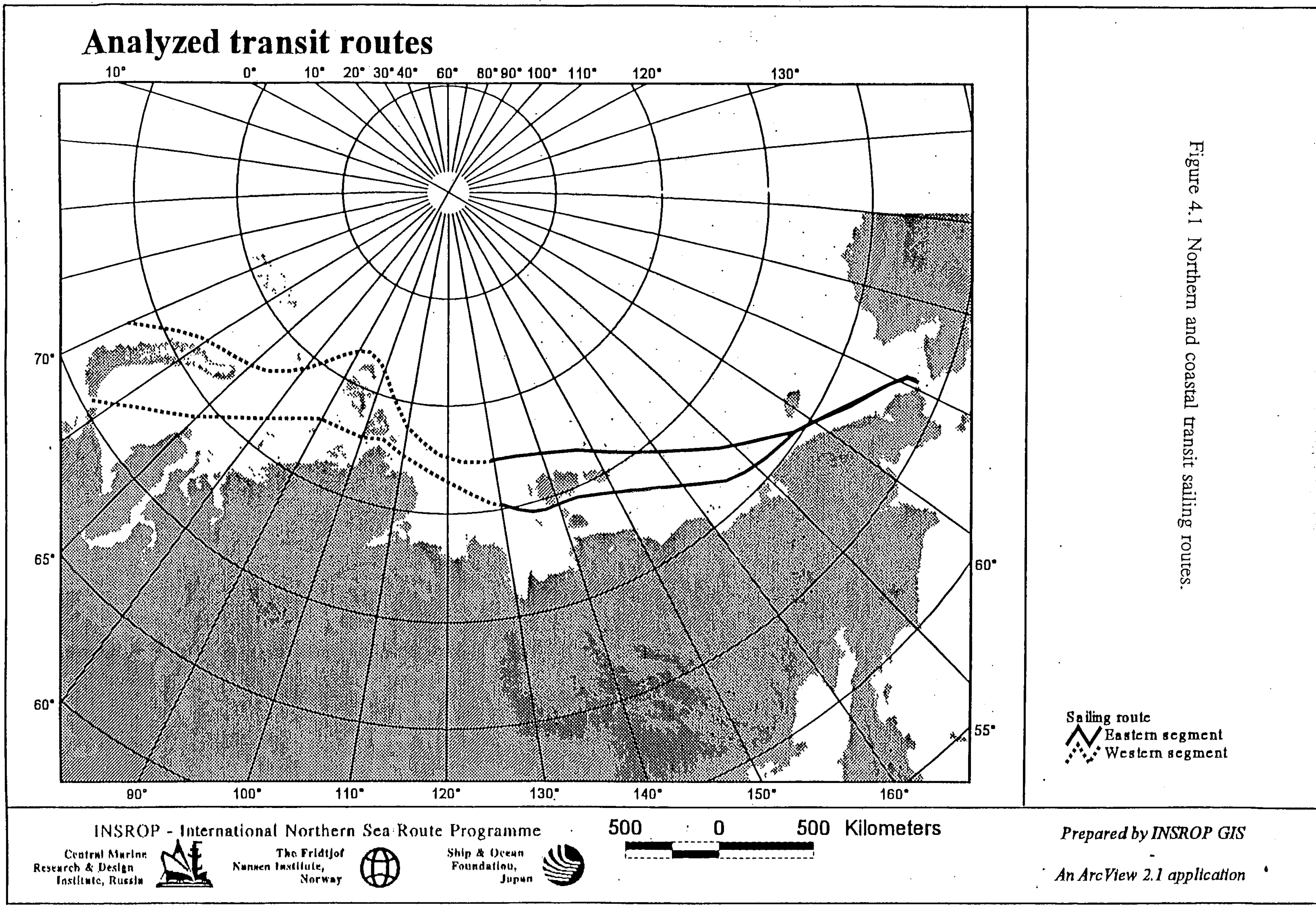


Figure 4.1 Northern and coastal transit sailing routes.

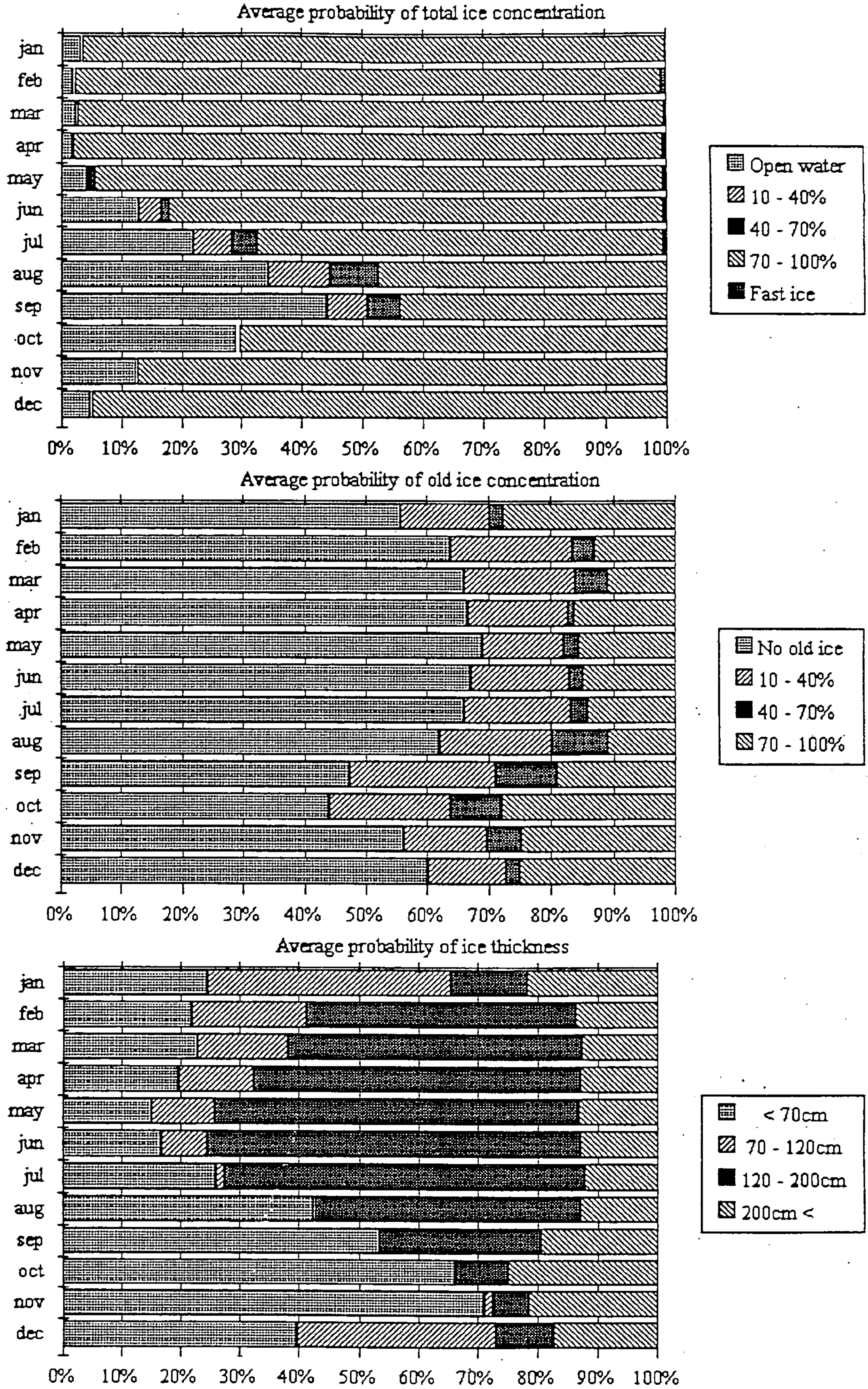


Figure 4.2 Distribution of different ice conditions along the northern transit sailing route.

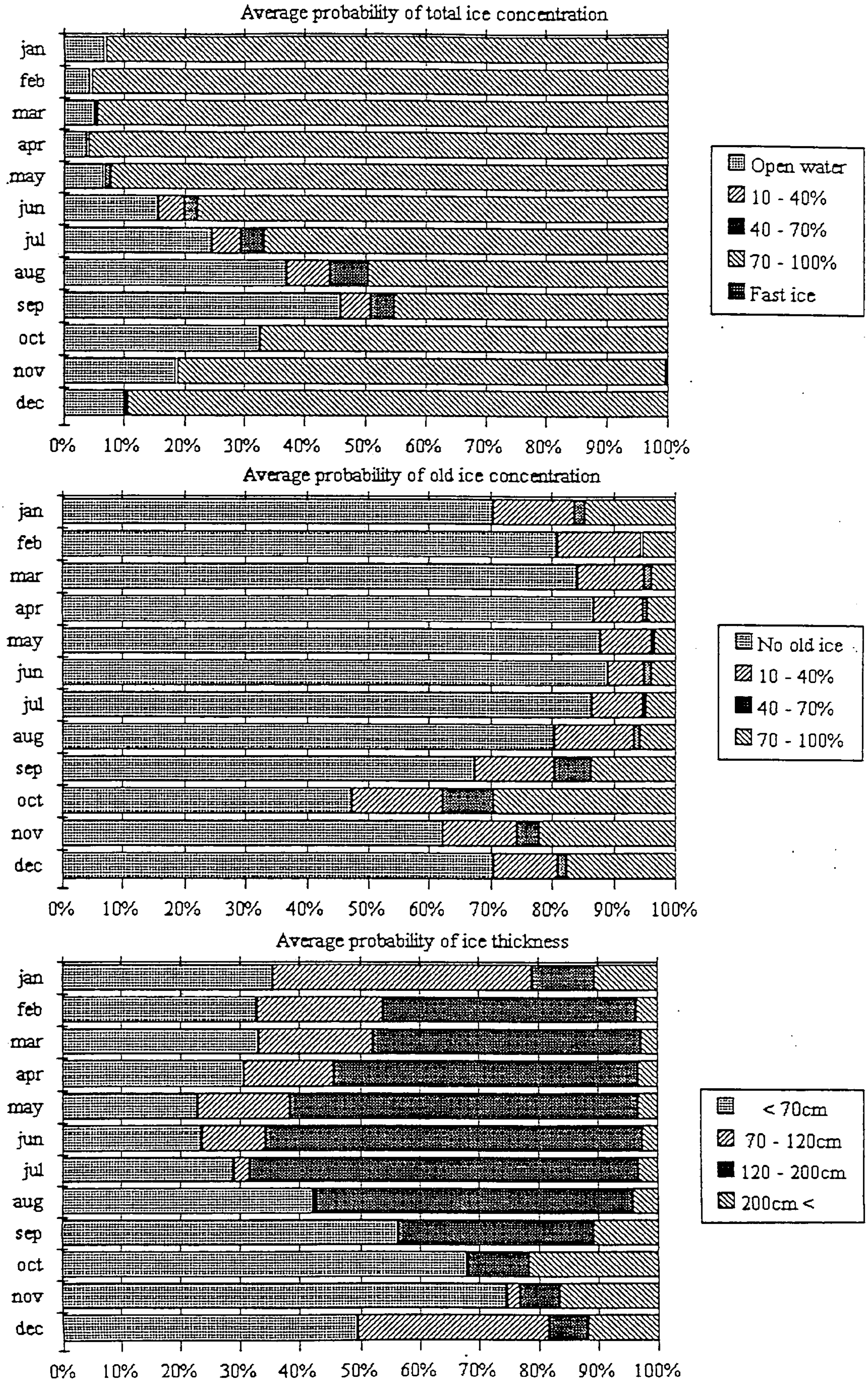


Figure 4.3 Distribution of different ice conditions along the western part of the northern transit route.

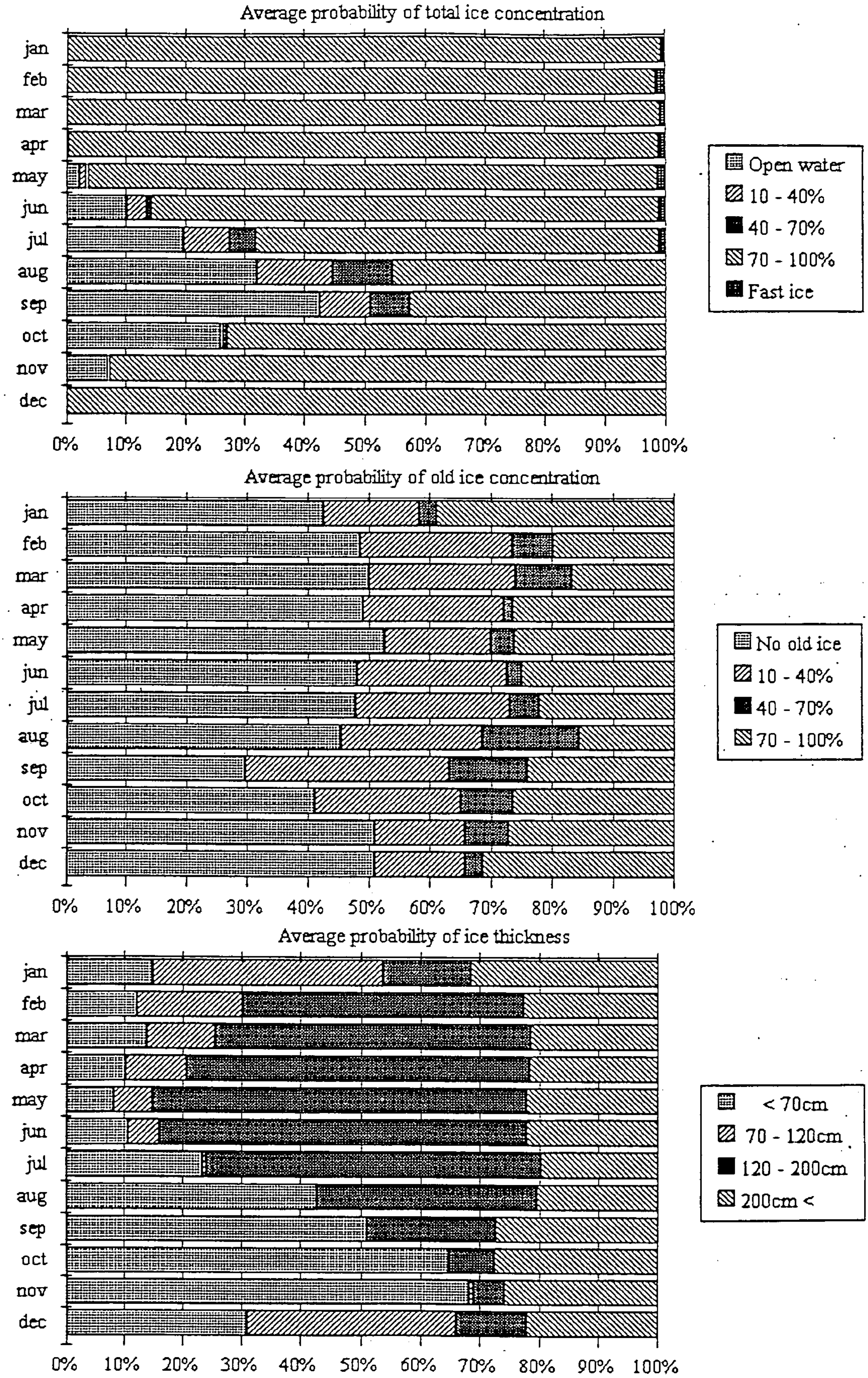


Figure 4.4 Distribution of different ice conditions along the eastern part of the northern transit route.

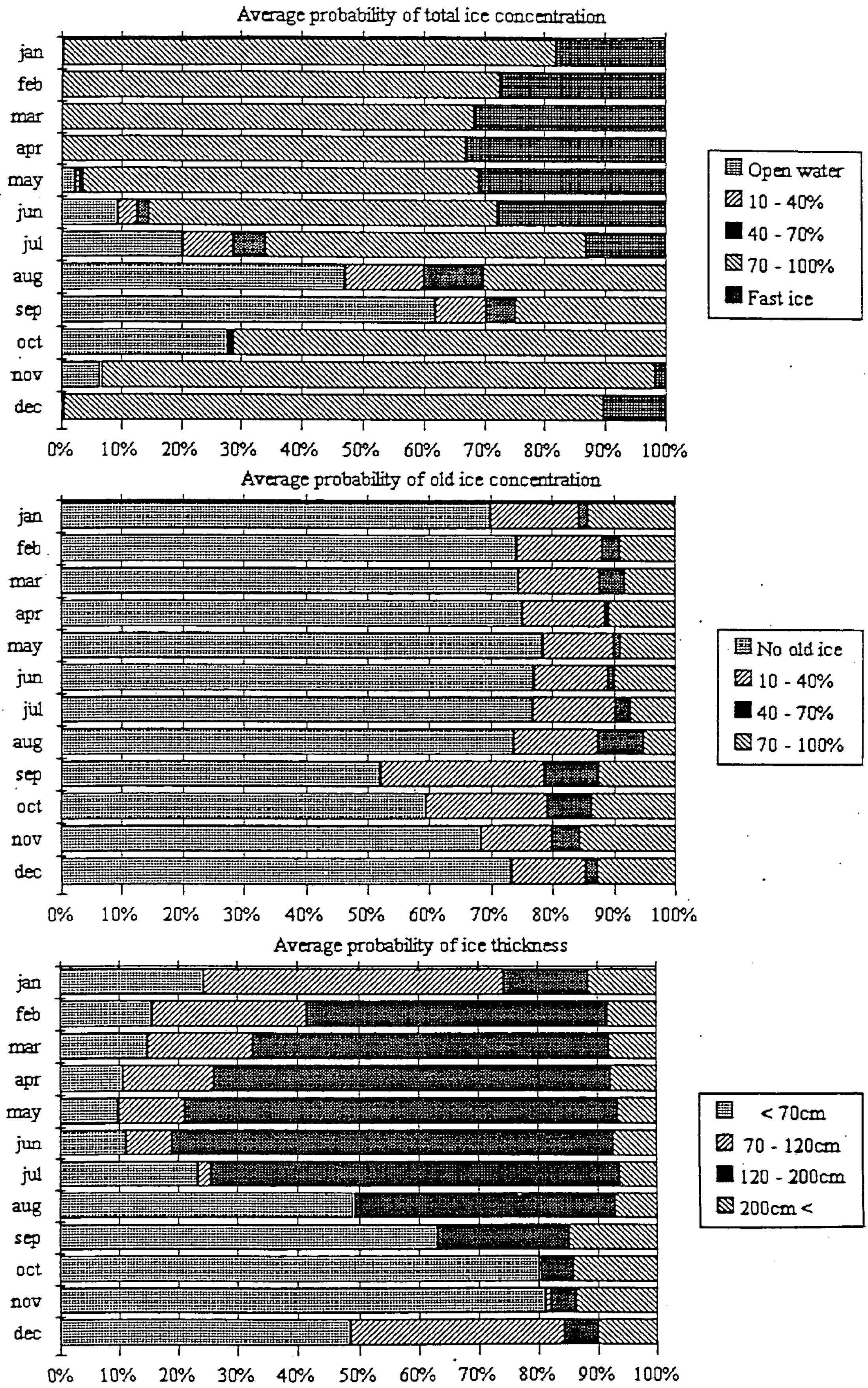


Figure 4.5 Distribution of different ice conditions along the coastal transit sailing route.

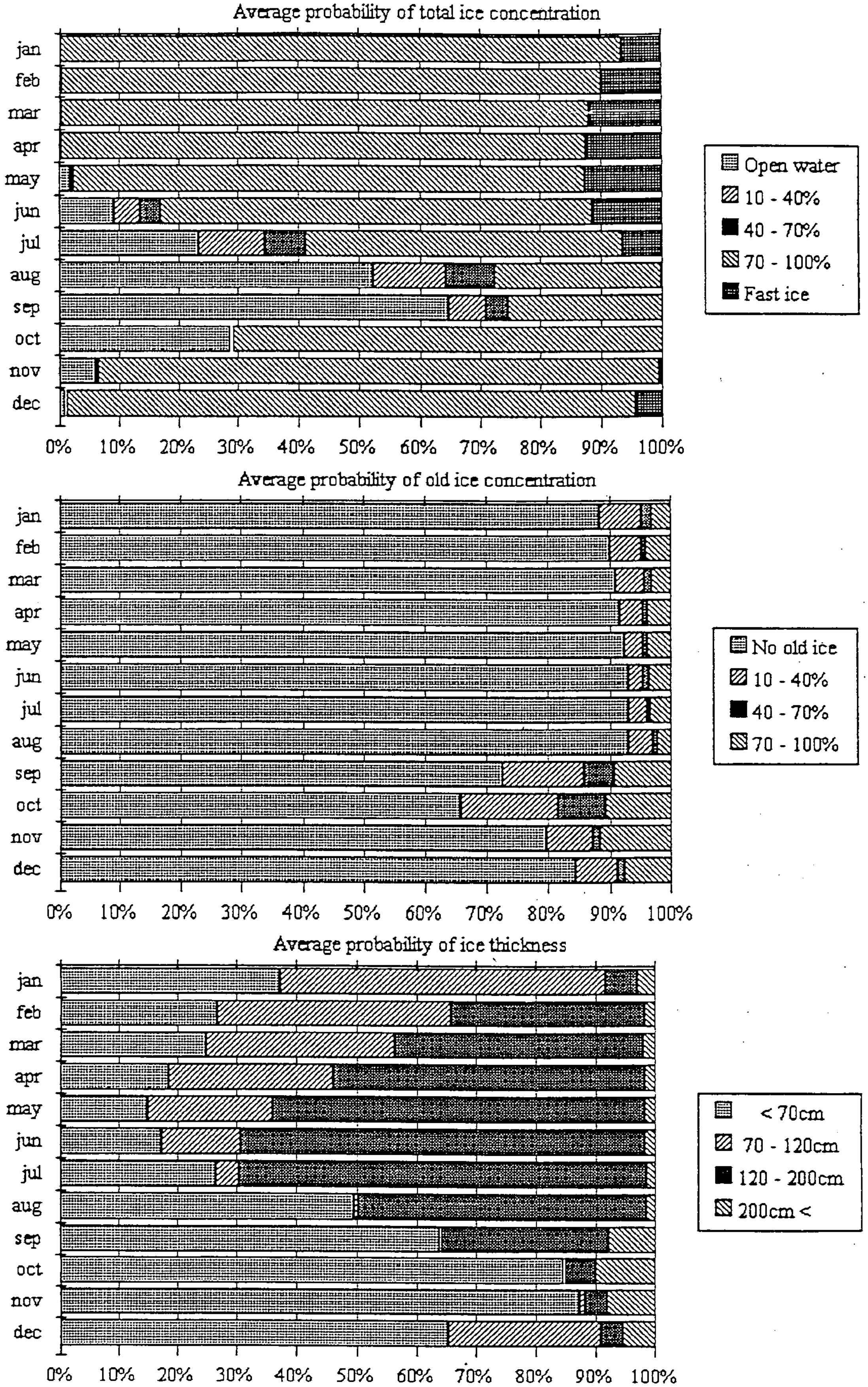


Figure 4.6 Distribution of different ice conditions along the western part of the coastal transit route.

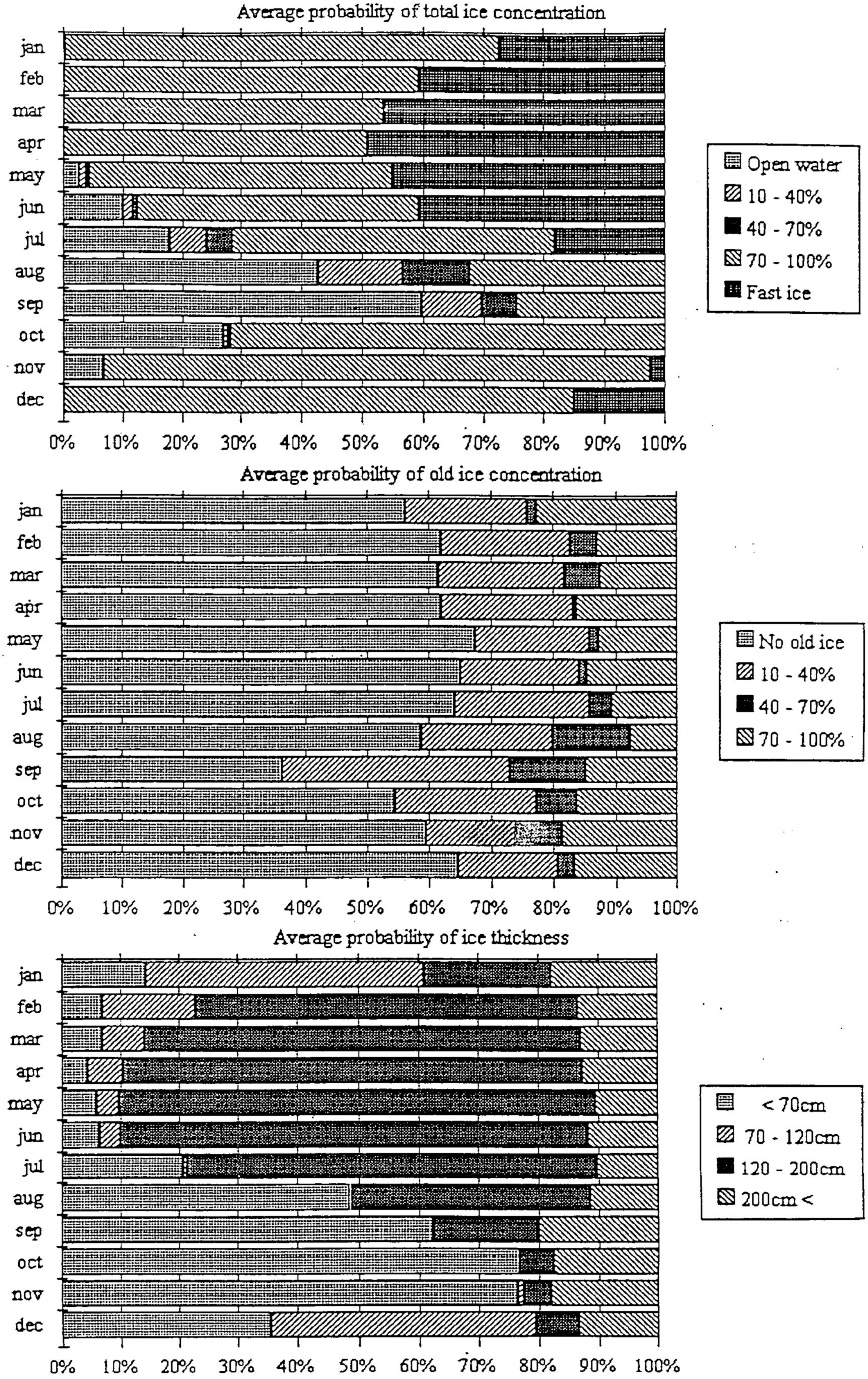


Figure 4.7 Distribution of different ice conditions along the eastern part of the coastal transit route.

5 RISK ASSESSMENT OF NSR SAILING

Sailing the NSR represents a potential hazard to the environment, personal safety and damage to vessels. A major concern is the possible impact on the environment from accidental oil spills either from cargo or bunker fuel. High spill risk zones are regions where large volumes of oil are transported and where transit lines are crossing each other in difficult navigational conditions. Large volumes of oil cargo are delivered to the port in Harasaway where the unloading operations are difficult to perform, usually as strong winds, currents, and waves. The ships often have to go out to the sea to wait for better weather conditions. The cargo traffic to Hatanga Bay is performed with large ships which reload their cargoes to smaller ships in heavy ice conditions. Shallow waters, narrow straits and areas with heavy ice conditions are potential navigation risk areas. Contact with the ice itself may cause damages to the ship hull, its propulsion equipment, steering devices etc., which are large enough to seriously limit the operational capability of the ship or even stop the operation totally.

The continental shelf waters along the route are very shallow, in some straits only a few metres deep. Most straits exceed 20 m, except the Sannikova and Dmitriya Lapteva straits which are only 13 m and 8 m deep. For instance, the 40 000 tonnes Ob-Max tanker (Niini, 1995) with a draught of 9 m will meet depth limitations in some straits. In the rivers and the estuaries the clearance will often be marginal when the ships are loading in river ports like Dudinka and Igarka. The draft limitations will seriously influence ice routing and transit time. The more northerly routes are deeper, but the ice conditions are more severe.

5.1 Statistical data of ship accidents

Murmansk Shipping Company has performed an analysis of ship accident data for the time period 1954-90. Information from the Western and Eastern Arctic Marine Operation staffs as well as investigations of accident events carried out by AARI and CNIIMF have been used in the analysis. More than 800 accident cases were considered and the analysis grouped them according to the ice class and ice-breaker assistance.

When comparing average number of accidents with the total number of navigating ships the data shows that the eastern part of the NSR has a greater accident risk than the western part. During the 1965 navigation season in the eastern Arctic about 72 ships suffered ice damages and accidents, which represent more than 40 % of the total number of navigating ships. Most ship damages occur during heavy ice conditions and with ships of ULA and L1 classes. The majority of ice damages on ships of L1 class occur during assistance from ice-breakers. The ships of ULA class are most frequently damaged when sailing alone. In the Arctic seas about 40 % of the damages occur in the Kara Sea where the intensity of sailing is highest. About 20 % of the accidents occur in the Laptev Sea and the East Siberian Sea while only about 14 % occur in the Chukchi Sea. The following sections are most frequently subjected to ice damages: Bely Island - Dikson Island, Boris Vilkitskiy Strait, Tiksi - Indigirka river and Billings cape - Schmidta cape. The data also show that most of the accidents occur at the end of the navigation period (August-September). Based on the statistical analysis of the AARI Sea Ice Charts data this period shows a high fraction of open water simultaneously with presence of old ice, which represents obstacles to the ship traffic.

Baskin et al. (1995) pointed out the Kara Gate strait, the segment from Bely Island to Yenisey Bay, Boris Vil'kitsky strait and the segment from East-Siberian Island to the Longa strait as regions with high occurrence of ice accidents. The accidents are located in regions of the ice massifs Novaya Zemlya, Severnaya Zemlya, Ayon and Wrangel with high concentrations of multi-year ice both in winter and summer seasons. The ice accidents are closely related to the ice conditions and the analysis shows that more than 50% of the accidents are connected to unfavourable ice conditions.

Statistical analysis of accident rate of marine fleet of Russia from 1991-94 has been presented in Baskin et al. (1995). The data has been collected by the Northern Sea Route Administration and controlled by Department of Marine Transport (DMT). During the last years Russia had more than 100 shipping companies which did not always inform about emergency cases to the DMT. For the period 1991-94 the following emergency cases were registered by the different companies (Baskin et al., 1995):

- Arctic Shipping Company 1
- Far Eastern Company 26
- Novorossiysk Shipping Company 19
- Murmansk Shipping Company 14

The statistical analysis presented below is based solely on data submitted from DMT (see Table 5.1). Most of the accident data were due to navigational problems (59 % on average). Most of the accidents happened in the western part and about 40 % of the accidents occurred with ships older than 20 years. On average 69 % of the emergency cases in the period were caused by "human factors" for the period. The analysis shows that most of the accidents happened in the western part of the NSR. This is in contrast with the period 1954-90 where the MSC analysis concluded that most of the accidents happened in the eastern part.

Table 5.1 Accident data for the period 1991-94.

Category	1991	1992	1993	1994	Average
Emergency cases	46	33	39	29	37
Human factors	26	20	27	19	23
Ice damages	15	24	7	26	18
Age of ship > 20 years 10-20 years <10 years unknown					 15 14 6 2

5.2 Monthly accident data for 1983, 1990 and 1993

The MSC analysis (see Section 5.1) of the 1954-1990 period identified the 1983 summer Arctic navigation as the heaviest and the 1990 summer Arctic navigation as the lightest. We have therefore used these years to illustrate the dependence of accident rate on ice conditions. During the summer period June-October 1983 a total of 104 ships were damaged in accidents and the majority of the incidents happened in the eastern part of the route. In 1990 and 1993 only 15 and 7 accidents were registered and the accidents happened mainly in the western part. The number of accidents should be evaluated together with the total number of sailings. The total number of ships sailings are not available and the accident data do not give any accident risk for sailings. Table 5.2 shows an increase in damages in 1983 during periods with favourable ice conditions. The main reasons may be the high number of ships with low ice class, high number of ships sailing alone, or reduced attention of the navigators. The statistical analysis of the AARI Sea Ice Charts data shows high fraction of open water simultaneously with presence of old ice in this period and may explain the high accident numbers.

Table 5.2 Ice damages and accidents on ships in 1983, 1990 and 1993.

Characteristics		Ice damages on ship					
		1983		1990		1993	
		No	%	No	%	No	%
Region of sailing	West	33	29	12	80	6	86
	East	80	71	9	20	1	14
Navigation period	Winter/ spring	5	4.5	5	33	-	-
	Summer	104	92	9	60	2	28
	Autumn/ winter	4	3.5	1	7	5	72

Table 5.3 Monthly numbers of reported ship damages for 1983, 1990 and 1993.

	1983		1990		1993	
	West	East	West	East	West	East
Jan	1		1			
Feb	1		1			
Mar	2		3			
Apr	1		1			
May	-				1	-
Jun	2		1			
Jul	1	11	1	2		
Aug	13	18	2		2	-
Sep	7	13	1			
Oct	5	34	2		2	-
Nov	-	4			1	-
Dec	-	-			-	1

5.3 Ice conditions in 1983, 1990 and 1993

The accident data for 1983 and 1990 have been compared with the distribution of ice conditions along a traditional coastal sailing route. Figures 5.1-5.3 show the distribution of total ice concentration, fraction of old ice and thickness along the route during the period 1967-90, and in 1983 and 1990.

In the winter months the most dominating ice condition is very dense drifting ice most of the years, except in the summer months where up to 80 % of the route is in open water (in 1990). The ice conditions in 1983 are heavier than the multi-year statistics show, while the ice conditions in 1990 are easier than the multi-year conditions. In 1990, about 20-80 % of the route will be in open water during the summer months May-October. In January-June 1990, about 20 % of the route is in fast ice which is less than the multi-year statistics show. The expansion of fast ice is large in February-June 1983 where about 30 % of the route is in fast ice. Thin ice with thickness less than 70 cm is dominating in summer/autumn, while thick first-year ice is dominating in winter/spring. In October 1983, about 50 % of the route will be in old ice, otherwise 30 %. In 1990, about 10 % of the route is in old ice. Based on the accident data for 1983 the highest number of accident cases were registered in October which also has the largest fraction of old ice.

In the winter 1992/93 the air temperatures in the Kara and Laptev Seas were lower than average. In early May the ice conditions are characterized as severe in the north-east of the Kara Sea and in the western part of the Laptev Sea and close to normal in the East-Siberian Sea, the Chukchi Sea and the eastern part of the Laptev Sea. During June the air temperature increased and in the southern part of all the seas the ice melted rapidly. In October and November the air temperature decreased and grey and grey-white ice was observed on all seas which in late November passed on to thin first-year ice. Totally, the navigation conditions in 1993 were easy on all seas except for the western part of the Laptev Sea.

A trend analysis of the Barents Sea ice conditions showed a principal cycle of about 10-12 years. This Barents Sea analysis included weekly data from 1966-89 and pointed out the years 1968 and 1989 as the years with heaviest ice conditions (Vefsnmo et al., 1992). As mentioned in the report by Murmansk Shipping Company (1992) the ice conditions in the eastern part was very severe in 1983, while the conditions in the western part were from light to medium. Based on the Barents Sea trend analysis the ice conditions were lightest in 1985 and consequently also in 1983. Murmansk Shipping Company (1992) pointed out 1990 as a year with light ice conditions. The Barents Sea analysis does not include 1990, but 1989 was pointed out as a year with heavy ice conditions. Most of the accidents in 1990 happened in the western part and this may indicate that the ice conditions in the western part were heavier than in the eastern part in that year, which agree more with the ice conditions in the Barents Sea.

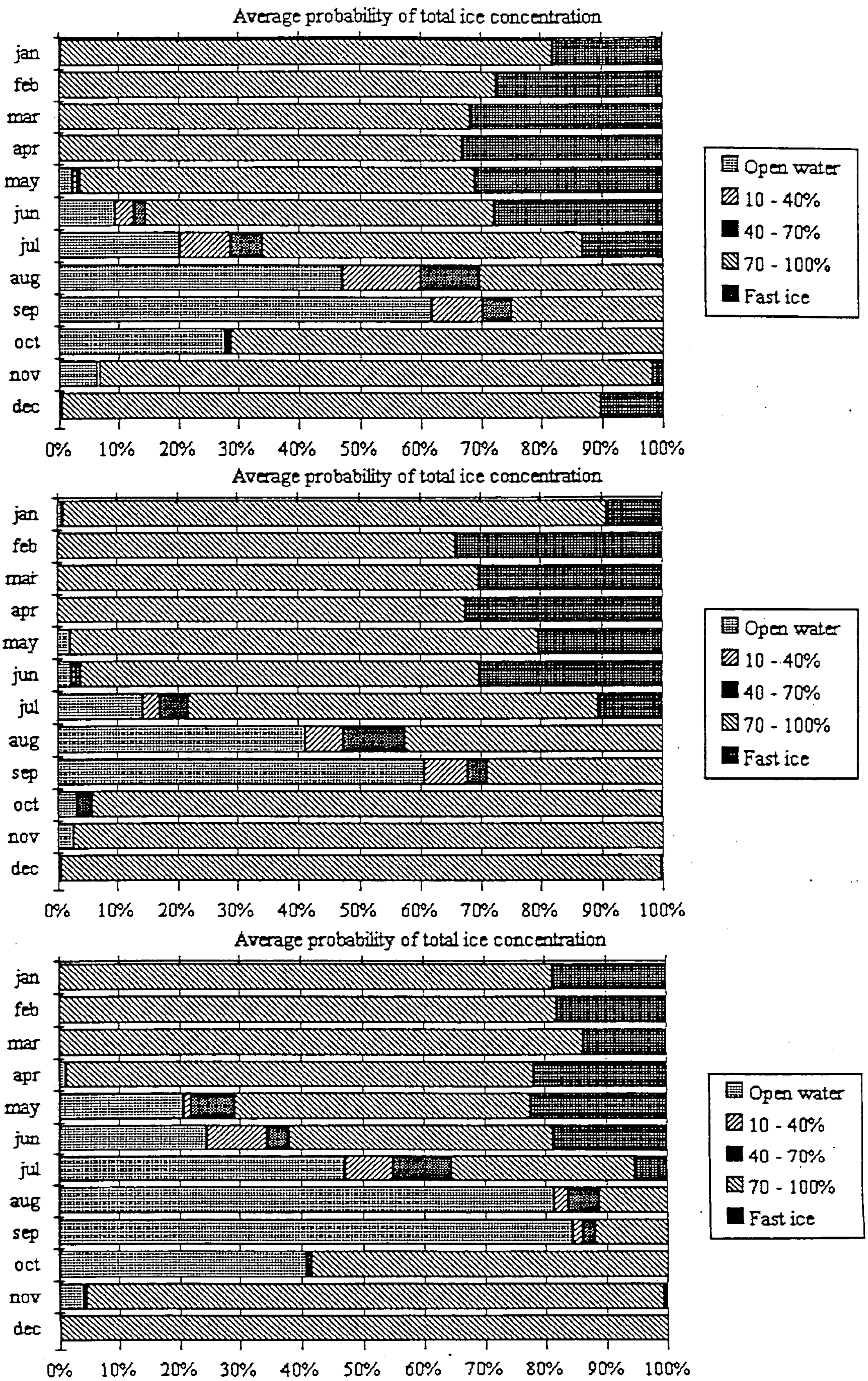
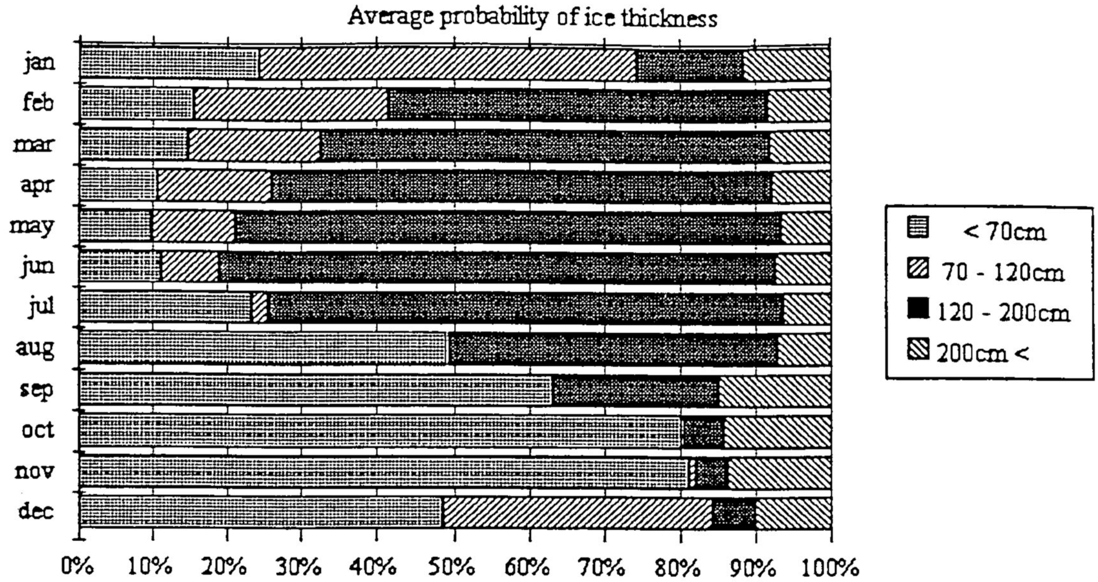
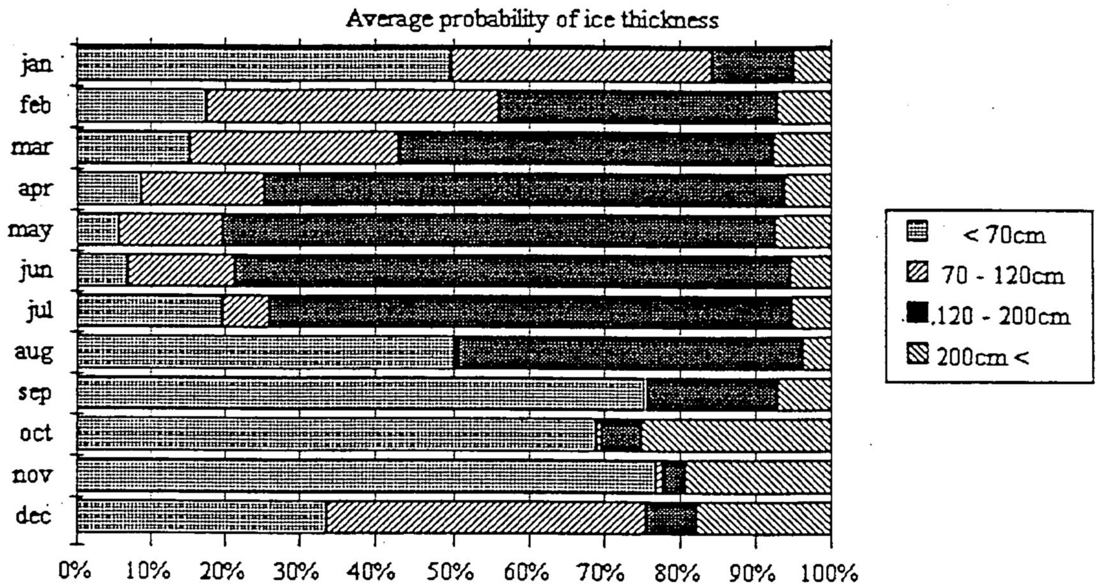


Figure 5.1 Distribution of total ice concentration along the coastal route during multi-year (top), in 1983 (middle) and in 1990 (bottom).





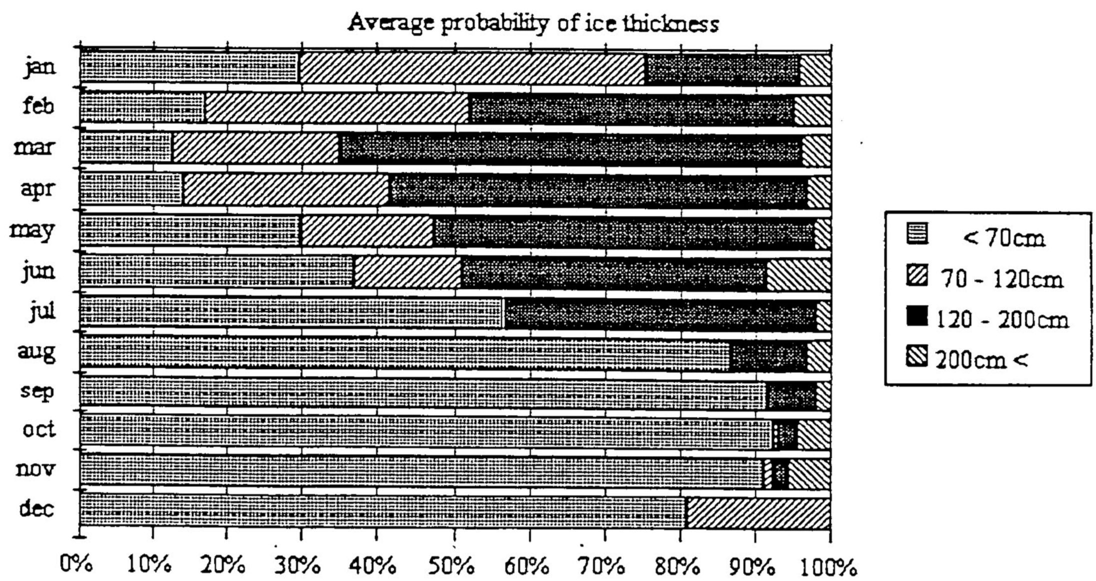


Figure 5.2 Distribution of ice thicknesses along the coastal route during multi-year (top), in 1983 (middle) and in 1990 (bottom).

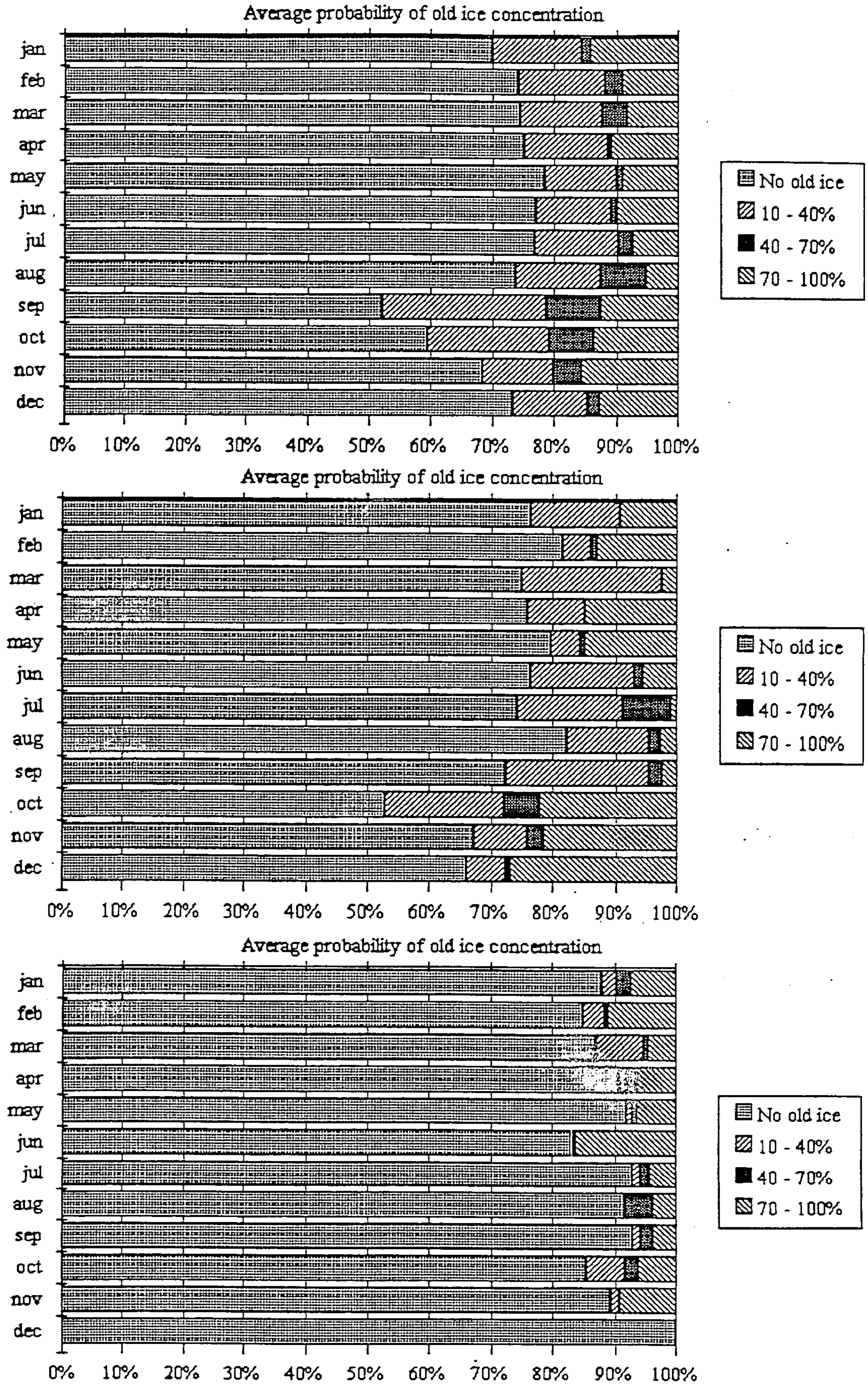


Figure 5.3 Distribution of old ice along the coastal route during multi-year (top), in 1983 (middle) and in 1990 (bottom).

6 CONCLUSIONS AND RECOMMENDATIONS

The delivery of Russian physical data is delayed and all data will not be delivered before 1 April 1996. The remaining data includes ocean current, air pressure and polynyas. Two digital atlases have also been ordered, but the delivery is delayed. Hence, these data cannot be implemented into INSROP GIS and analyzed within Phase I, but will be important data for a potential Phase II. Up to now the following physical environment data have been implemented and analyzed in INSROP GIS (Brude et al., 1995):

- AARI Sea Ice Chart Database Statistics
- SSM/I Total Ice Concentration Statistics
- AARI Sea Surface Temperature and Salinity
- NOAA Air temperature statistics for the WMO stations
- UNESCO River flow rates

The AARI Sea Ice Charts covering the period 1967-90 form a good basis for a variability analysis of parameters such as total ice concentration, ice thickness, fraction of old ice and presence of fast ice.

Seasonal freeze-up of the sea begins in September and is complete by mid-October. On average the total ice concentration is high in October due to high fraction of new ice. In the winter months November to April the whole region is covered by very dense drifting ice. The total ice concentration varies between 90 and 100 %. The thinnest ice is mainly found in the southern Kara and Laptev Sea. The East-Siberian Sea has the highest fraction of old ice and the Ayon massif has more than 60 % of old ice on average. The average thickness may be 250 cm in the winter months. The coastal zone is occupied by fast ice in the winter period which is non-uniformly developed. The Laptev Sea has the largest expanse of fast ice from January to June and expands to cover most of the continental shelf up to 500 km from the mainland. The thickness of the fast ice commonly reaches 200 cm and may grow up to 250 cm in severe years.

Seasonal breakup throughout the entire sea begins in June and July. In June to September the ice concentration is low in the Kara Sea, especially in the western part where drifting thick ice may be present. In the eastern part, especially the Severnaya Zemlya massif, the ice concentration is higher and the ice consists mainly of thick first-year ice. When the seasonal ice minimum is reached by mid September the entire Kara Sea south of 75°N is normally ice free. In extremely mild summers, the Kara Sea may become ice free as far north as 80°N. The East-Siberian Sea experiences the least summer melt of any of the arctic seas. The Chukchi Sea experiences a wide seasonal variation in total ice extent. Summer ice melt is extensive. The Severnaya Zemlya, Novosibirskiy and Ayon massifs carry large amounts of old ice very resistant to summer melt.

In order to study the representativeness for the variability of the NSR ice conditions, the daily SSM/I data for the period July 1987 to December 1990 have been compared with the analyses of the AARI Sea Ice Chart Database. In the winter months November-April both the AARI and SSM/I analysis show very dense drifting ice both in the Laptev and East-Siberian Seas. In areas with great seasonal fluctuation the SSM/I data show lower ice concentrations than the AARI data. Especially, 1990 was a year with light ice conditions and that year will heavily influence the variability analysis for a short time period. In the Laptev and East-Siberian Seas where the fluctuations are small in winter, the variability analysis is not dependent on long time series.

As a planning tool for transit sailing a methodology has been developed to analyze the distribution of different ice conditions along a specified route. As a demonstration example, two sailing routes have been chosen, one representing the coastal transit route and the other representing a northern transit route. For a given ship the ice conditions should be converted to velocity and hence the transit time for the whole route. The QAD model calculates velocity based on different information on ice conditions. All such information is not available (ridges, hummocked ice and snow on ice) and a modified version of the model should be implemented into INSROP GIS in order to execute such analysis.

Ship accident data contained in different INSROP reports have been collected and compared to the variability analysis of the AARI Sea Ice Charts Database. The data cover the period 1954-90 and 1991-94. When comparing average number of accidents with the total number of navigating ships the data from 1954-90 shows that the eastern part of the NSR has a greater accident risk than the western part. During the 1965 navigation season in the eastern Arctic about 72 ships were subjected to ice damages and accidents, which represents more than 40 % of the total number of navigating ships. Most ship damages occur during heavy ice conditions and with ships of ULA and L1 classes. The majority of ice damages on ships of L1 class occur during assistance from ice-breakers. The ships of ULA class most frequently suffered damage when sailing alone. In the Arctic seas about 40 % of the damages occur in the Kara Sea where the intensity of sailing is highest. About 20 % of the accidents occur in the Laptev Sea and the East Siberian Sea while only about 14 % occur in the Chukchi Sea. The data also show that most of the accidents occur at the end of the navigation period (August-September). Based on the statistical analysis of the AARI Sea Ice Charts data in this period shows a high fraction of open water simultaneously with presence of old ice, which represents obstacles to the ship traffic.

The ice accidents are closely related to the ice conditions and the analysis shows that more than 50 % of the accidents are connected to unfavourable ice conditions. When comparing the accident data for 1983, 1990 and 1993 with the ice conditions, the correlation is very high. Especially 1983 was a year with severe ice conditions and high accident rate. By pointing out areas with unfavourable ice conditions along the route, potential accident regions are known. When evaluating the accident rate the total number of navigating ships in the region has to be known in order to provide knowledge on high risk areas. The accidental data together with total number of ships should be systematized and analyzed in more detail.

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APPENDIX A

Temporal coverage of AARI Sea Ice Chart Dataset

Year	R	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1967	W	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
	E	- - -	- 19 -	- 17 -	- 14 -	- 16 29	- 15 24	03 12 24	02 11 22	02 13 24	04 12 21	- - -	- - -
1968	W	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
	E	- - -	- 15 -	- - 20	- 17 -	- 19 -	04 12 23	04 13 -	04 12 23	07 15 24	03 14 24	- - -	- - -
1969	W	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
	E	- - -	- 17 -	- - 20	- 17 -	- 16 -	09 15 26	04 15 24	07 12 22	06 16 25	07 1 22	- - -	- - -
1970	W	- - -	- - -	- - -	- : -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
	E	- - -	- 17 -	- 12 -	- 12 -	- - 22	05 12 24	05 16 24	03 15 20	02 15 26	05 14 22	- - -	- 18 -
1971	W	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
	A	- - -	- 13 -	- 13 -	- 13 -	- 11 -	05 13 24	05 14 25	04 16 23	05 16 24	05 13 25	- - -	10 - -
1972	A	- - -	- 17 -	- 17 -	- 11 -	06 - -	02 11 24	05 13 22	04 13 21	07 15 24	04 16 -	- - -	- - -
1973	W	- - -	- 14 -	- 15 -	- 13 -	- 15 -	01 12 24	06 12 22	04 14 20	04 14 22	05 16 25	07 13 23	02 12 -
	E	- - -	- 18 -	- 19 -	- 14 -	- - 21	01 13 25	06 13 22	04 12 20	05 15 24	05 16 28	- - -	04 15 20
1974	W	- - -	- - -	- 14 -	- 11 -	07 - -	01 14 21	01 11 22	03 16 22	02 12 22	03 13 28	02 15 25	03 15 20
	E	- - -	- - -	- 13 -	- 15 -	09 - -	04 15 23	03 11 23	06 16 25	06 14 24	03 14 23	- - -	- - -
1975	W	- - -	- 13 -	- 15 -	- 11 -	- 14 -	07 10 20	01 13 23	04 15 21	06 15 25	03 12 25	02 15 24	06 17 -
	E	- - -	- 17 -	- 18 -	- 11 -	- - 20	02 14 25	05 14 26	06 13 21	06 12 26	01 14 22	- -	- - -
1976	W	- - -	- 14 -	- 14 -	- 12 -	05 - -	05 12 22	04 15 24	05 16 25	01 16 21	02 11 22	05 11 27	08 18 -
	E	- - -	- 18 -	- 14 -	- 15 -	- 11 -	04 12 23	05 16 25	06 13 22	04 16 25	02 14 25	- - -	08 11 29
1977	W	- - -	- 14 -	- 13 -	09 -	10 - -	01 15 24	02 12 23	02 15 25	04 13 24	- 16 24	09 16 23	05 16 26
	E	- - -	- 17 -	- 16 -	- - 20	- 18 -	01 15 27	06 14 25	05 15 22	04 13 25	06 16 27	- - -	- - -
1978	W	- - -	- 14 -	- 16 -	09 - -	06 15 22	05 14 25	03 14 24	02 16 22	01 15 25	02 13 23	05 15 -	09 - -
	E	- - -	- 16 -	- 19 -	- 16 -	04 13 21	04 17 22	02 14 26	05 13 25	02 13 25	05 14 27	- - -	- - -
1979	W	08 - -	- 16 -	- 15 -	05 - -	- 17 -	03 16 23	03 14 25	03 17 24	04 10 24	05 12 22	05 12 26	05 10 20
	E	- 12 -	- 16 -	- 14 -	09 - -	- - 23	01 14 25	05 15 26	04 16 24	02 16 25	05 14 22	- - -	- - 21
1980	W	- 11 -	- 12 -	- 14 -	10 - -	- - -	03 14 23	04 13 25	03 14 22	06 14 25	06 13 21	01 13 24	02 - -
	E	- 14 -	- 15 -	- 13 -	- 13 -	- - -	01 12 23	02 16 22	02 15 24	06 15 25	04 15 21	05 - -	- 17 -

Year	R	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	W	04 17 25	06 10 23	03 08 27	05 12 21	02 13 21	01 14 24	01 13 22	04 13 22	04 11 24	05 15 23	05 14 22	03 09 13
	E	06 14 23	02 08 22	04 10 23	04 10 25	05 16 22	05 13 23	04 13 22	01 15 22	06 15 24	03 14 23	- - -	- 13 -
1982	W	04 14 24	03 14 18	04 12 22	03 09 23	05 15 21	04 14 22	06 15 23	04 14 25	04 12 27	03 14 23	04 15 21	05 14 24
	E	03 13 23	01 12 22	02 12 23	03 13 22	03 13 24	07 16 24	02 17 26	04 16 24	03 13 22	03 15 23	02 11 22	03 16 23
1983	W	06 12 25	03 17 23	01 12 20	03 14 22	05 13 23	03 11 26	05 16 23	04 14 24	02 12 23	05 15 23	05 16 28	03 13 22
	E	04 13 23	04 12 22	06 16 23	03 11 22	03 11 24	01 11 24	04 16 22	04 15 22	05 15 23	07 15 23	03 14 24	04 - -
1984	W	05 16 25	05 16 24	04 13 24	06 15 23	02 12 25	02 14 23	05 14 22	03 12 25	05 14 22	03 14 25	04 14 23	02 15 23
	E	05 14 23	05 13 23	05 13 23	03 14 24	05 14 26	04 14 21	03 16 22	04 13 26	04 13 23	04 12 23	06 14 23	04 18 23
1985	W	04 14 24	05 13 22	04 13 22	03 14 21	05 14 22	01 13 25	05 14 24	04 16 23	03 13 24	06 15 26	04 13 26	03 13 24
	E	02 14 22	04 14 23	04 13 22	04 13 23	02 13 25	04 14 22	04 15 23	03 15 22	03 12 22	03 09 22	09 14 23	03 13 22
1986	W	07 13 21	05 15 24	02 12 22	03 13 23	01 12 22	05 13 23	01 11 23	01 15 25	03 11 25	03 12 22	01 15 24	05 15 23
	E	03 12 23	03 13 23	03 11 25	03 11 22	02 13 21	01 12 22	03 12 23	02 13 27	03 13 26	02 13 23	02 12 22	02 14 26
1987	W	04 11 23	03 12 22	06 12 21	02 13 24	01 11 21	03 15 22	03 13 23	04 13 22	02 15 23	03 10 22	03 14 24	05 12 24
	E	05 13 25	02 10 20	02 12 24	03 11 23	04 12 22	01 13 23	02 12 24	04 12 20	04 16 21	02 11 22	- - -	- 13 -
1988	W	04 13 22	03 12 22	03 13 20	04 12 22	03 14 22	03 12 22	03 13 22	05 12 22	01 13 23	03 14 24	02 12 21	02 13 22
	E	07 14 19	03 11 27	02 12 21	04 12 22	03 13 22	01 14 27	03 14 29	04 15 24	02 15 22	04 13 21	08 12 -	02 13 23
1989	W	05 15 22	03 14 22	01 15 23	04 12 23	02 13 22	06 11 24	04 13 21	02 13 23	03 12 23	04 12 22	08 13 25	03 11 20
	E	- - 22	- 15 22	05 14 24	02 11 27	03 14 21	03 13 29	04 13 26	05 14 23	03 17 22	02 12 21	09 - 23	03 17 23
1990	W	06 13 22	06 12 23	02 13 -	06 13 24	04 10 22	02 12 22	04 12 24	02 13 23	04 13 25	04 15 28	03 13 22	06 14 25
	E	- 13 24	07 12 -	02 16 25	- 16 -	- 16 26	05 12 24	04 15 23	07 13 31	05 12 23	04 12 21	04 13 -	- - -

APPENDIX B

Project review

National Research Council Canada
Conseil national de recherches Canada

DOCUFAX

NRC·CNRC

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DATE: March 24, 1996

OF PAGES (INC. COVER): 4

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RE: INSROP Project I.3.1 Variability of natural conditions and influence on NSR sailings

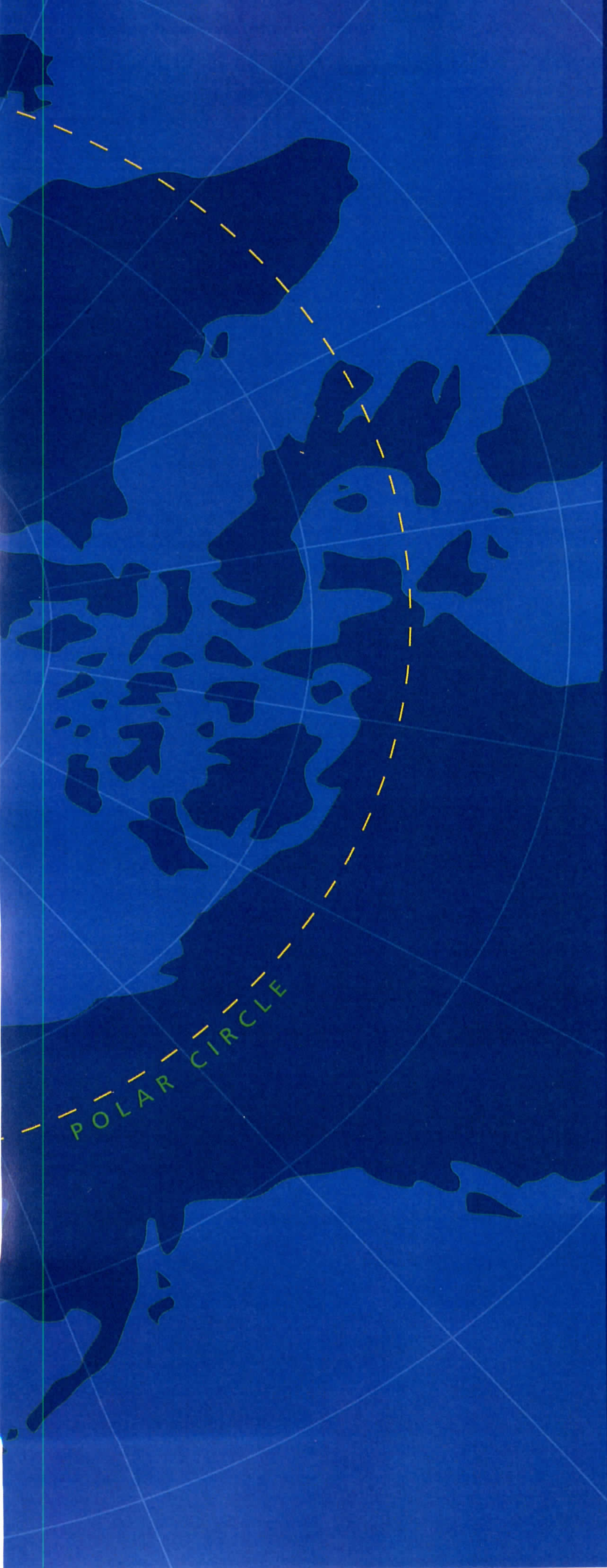
Dear Dr. Vefsnmo,

I have reviewed the report and find that it is well thought out, thorough and clearly written. It has analysed ice charts of the Northern Sea Route region for the period 1987 to 1990, extracted information on ice concentration, thickness, old ice concentration and fast ice concentration, and incorporated these data into the INSROP GIS. From this a variability analysis has been conducted. Probability distributions of ice conditions along two selected routes were determined. Ship accident data were obtained and evaluated in terms of location and time of year. Altogether this is a very pertinent and useful report.

Minor editorial corrections are noted on the following pages:
p. 49, correct figure numbers, should be Figure 3.33, not Figure 3.28
p. 53, correct figure numbers, should be Figure 3.38, not Figure 3.33
p. 54, correct figure numbers, should be Figure 3.39, not Figure 3.34
Plus a few other corrections on the following pages.

Regards,

[signature]



The three main cooperating institutions of INSROP

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

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

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