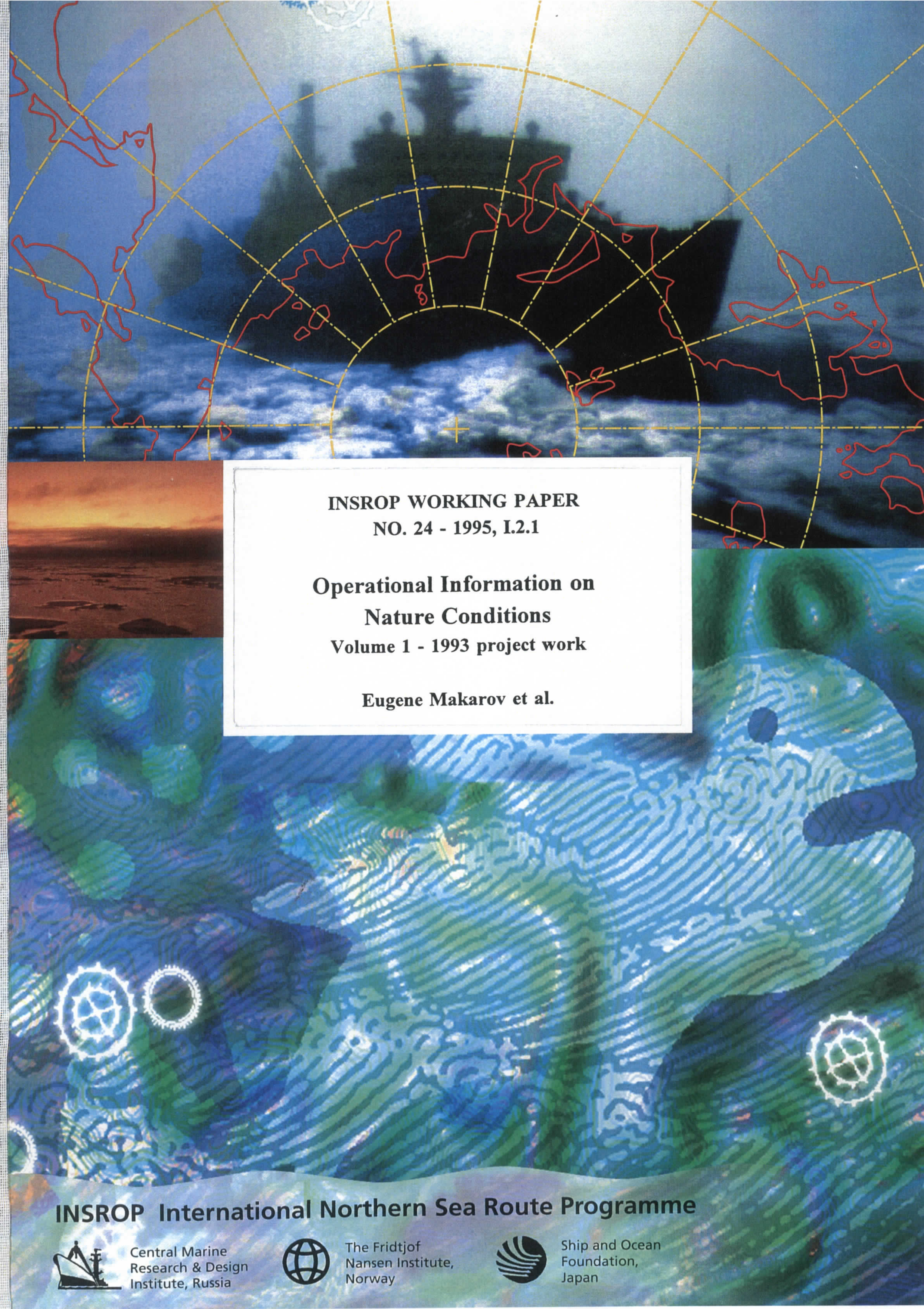


INSROP WORKING PAPER
NO. 24 - 1995, I.2.1

Operational Information on Nature Conditions

Volume 1 - 1993 project work

Eugene Makarov et al.

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. 24-1995

Sub-programme I: Natural Conditions and Ice Navigation

Project I.2.1: Operational Information on Nature Conditions
Volume 1 - 1993 project work.

By : E. Makarov (supervisor)*, N. Adamovich, A. Korzhikov, E. Fomina, Yu. Vanda, I. Karelin and V. Kuptevsky.

Address:

*Arctic and Antarctic Research Institute
38 Bering Street
199 397 St. Petersburg
The Russian Federation

Date: 6 December 1995.

Reviewed by: Prof. William M. Sackinger, University of Alaska, Geophysical Institute, Alaska, USA

What is an INSROP Working Paper and how to handle it:

This publication forms part of a Working Paper series from the **International Northern Sea Route Programme - INSROP**. This Working Paper has been evaluated by a reviewer and can be circulated for comments both within and outside the INSROP team, as well as be published in parallel by the researching institution. A Working Paper will in some cases be the final documentation of a technical part of a project, and it can also sometimes be published as part of a more comprehensive INSROP Report. For any comments, please contact the authors of this Working Paper.

FOREWORD - INSROP WORKING PAPER

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

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

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

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

SPONSORS FOR INSROP

- Nippon Foundation/Ship & Ocean Foundation, Japan
- The government of the Russian Federation
- The Norwegian Research Council
- The Norwegian Ministry of Foreign Affairs
- The Norwegian Ministry of Industry and Energy
- The Norwegian Ministry of the Environment
- State Industry and Regional Development Fund, Norway
- Norsk Hydro
- Norwegian Federation of Shipowners
- Fridtjof Nansen Institute
- Kværner a.s.

PROFESSIONAL ORGANISATIONS PERMANENTLY ATTACHED TO INSROP

- Ship & Ocean Foundation, Japan
- Central Marine Research & Design Institute, Russia
- Fridtjof Nansen Institute, Norway
- National Institute of Polar Research, Japan
- Ship Research Institute, Japan
- Murmansk Shipping Company, Russia
- Northern Sea Route Administration, Russia
- Arctic & Antarctic Research Institute, Russia
- ARTEC, Norway
- Norwegian Polar Research Institute
- Norwegian School of Economics and Business Administration
- SINTEF NHL (Foundation for Scientific and Industrial Research - Norwegian Hydrotechnical Laboratory), Norway.

PROGRAMME COORDINATORS

- **Yuri Ivanov, CNIIMF**
  Kavalergardskaya Str.6
  St. Petersburg 193015, Russia
  Tel: 7 812 271 5633
  Fax: 7 812 274 3864
  Telex: 12 14 58 CNIMF SU
- **Willy Østreng, FNI**
  P.O. Box 326
  N-1324 Lysaker, Norway
  Tel: 47 67 53 89 12
  Fax: 47 67 12 50 47
  Telex: 79 965 nanse n
  E-mail: Elin.Dragland @fni.
  wpoffice.telemax.no
- **Masaru Sakuma, SOF**
  Senpaku Shinko Building
  15-16 Toranomon 1-chome
  Minato-ku, Tokyo 105, Japan
  Tel: 81 3 3502 2371
  Fax: 81 3 3502 2033
  Telex: J 23704

SUMMARY

The work comprises an introduction and 6 chapters and presents a national approach to resolving the problem of issuing operational information on natural conditions affecting transit ice operations in the Arctic along the NSR. The problem is shown to suffer from poor framework structure both with regard to the technological part, as well as the meaningful (content) aspects of the hydrometeorological information category.

It is suggested that the problem be considered in terms of the analysis of composite systems. The examples given, characterise a given composite system.

The structuring of the system is fulfilled by splitting up the problem area arbitrarily into two independent parts, which use inadequate languages of the system description. The first part corresponds to the stage of the study and description of typical natural features. The second part corresponds to the stage of the application of known typical natural features of arranging and managing specific marine operations.

It is stressed that the solution to the problem is to develop a model for the application of natural information of an adequate existing model for the production of natural information.

The principal block diagrams of the model are proposed for the application of operational information on the natural shipping conditions.

It is emphasised that the proposed approach indicates the genetic relationship between the solution of the problem of an effective production of the operational hydrometeorological information and the problems of hydrometeorological regioning of the NSR, arising during the analysis of the operating aspects of the international transit shipping (Project I.1), and its management (Project I.5).

These relationships are also closely tied to the solution of the problem of creating the geoinformation system (GIS) for INSROP purposes (Project I.3).

A possible constructive use of the expected results of creating the model for the application of ice-hydrometeorological information during the study of the commercial aspects of transit shipping (Program III) is suggested.

KEY PERSONNEL:

Makarov E.	- Senior scientist, chapter 1, 2, 3, 4.1, 6.
Adamovich N.	- Head of SIIC, Dikson, chapter 1, 6.
Korzhikov A.	- Head of the division, chapter 3.
Fomina E.	- Senior scientist, chapter 3, 5.1.
Vanda Yu.	- Head of the Department, chapter 4, 5.
Karelin I.	- Head of the laboratory, chapter 5.5.
Kupetsky V.	- Chief engineer, Pevek, chapter 6.

TABLE OF CONTENTS

INTRODUCTION

Historically Russia has always been giving a lot of attention to the studies of the Arctic Ocean nature and the development of shipping in the Arctic.

The development of the Northern Sea Route (NSR) as a transportation seafare was rather uneasy, especially at the first stages. A detailed evidence on the history of the discovery and exploration of the NSR can be found in the monographs of M.I.Belov (1959; 1969) and other historians, specialists on the history of the North. On the basis of a rich documentary material these works disclose in the context of the economics, policy, science and culture the key aspects of the navigation development in the Russian Arctic.

The navigation along the NSR resulted from a long struggle between the supporters and opponents of the practical use of this route. The struggle of the ideas around the NSR has an objective nature. The supporters of the NSR exploration had some solid arguments. One of them is in the geographical advantage of this route. It goes along the shores of Russia, therefore being independent on the international situation formed in some or other time interval. This is the shortest route between the western and far eastern ports; also, the NSR going along the mouths of the largest rivers of the Asian North forms together with the rivers Ob', Taz, Yenisey, Pur, Pyasina, Khatanga, Anabar, Olenek, Lena, Indigirka and Kolyma a kind of a common water transport communication line of Russia. But the fact that the largest area of this Arctic route is covered in winter and summer by heavy Arctic ice, blocking a free navigation of the transport vessels has been restraining for a long time not only the exploration but also the study of this seafare.

The current NSR system as a marine transport communication line includes the following main subsystems: icebreaking and transport fleet, port facilities, communication means, navigation-hydrographic, airborne and ice-hydrometeorological support to navigation.

The management of the activities of the Arctic fleet and other blocks of the NSR system requires a special attention, which is governed by complex and specific natural conditions of the Arctic region. During the past years the organization forms of management in the Arctic, including the fleet activities varied with the change of the main goals and general objectives in this region, the logistics base of the NSR on the whole and each of its subsystems separately.

From experience the effectiveness of the fleet operation on the NSR is closely connected with the system of a scientific-operational hydrometeorological support to navigation, and in the Arctic this relation is more close than anywhere else in the world. The support aims at the collection, analysis and dissemination of the actual and prognostic information on the ice, hydrological and weather conditions, and on its basis at the preparation of short- and long-range specialized navigation recommendations for icebreakers, ships, Headquarters of marine operations and other management links of the fleet in the Arctic in order to achieve maximum cost-effectiveness of the work of the fleet and provide for its safety.

For the first time the idea to establish a national system of the hydrometeorological support (NSHS) to marine operations on the NSR was mentioned by Rusakov and Lesgaft (1910-1911) and its implementation began in the 20s during the Kara Sea expeditions. At that time it was suggested to set up along the Northern Sea Route a network of meteorological stations, as well as to organize ice reconnaissance by means of a ship, equipped either by hydroplane or an air balloon. Before the revolution only 6 polar stations were set up at the western margin of the NSR. In later years the network of hydrometeorological stations was expanded.

As a result while in 1931 there were 17 polar stations in the Russian Arctic Zone, by early 40s their number reached 75. Of them 13 were located in the Chuckchi Sea and the Bering strait, 14 - in the East-Siberian Sea, 16 - in the Laptev Sea, 32 - in the Kara and Barents Seas. By 1955 the total number of polar stations along the NSR was 98 thus, in the second half of the 50s the hydrometeorological network in the Russian Arctic zone was practically established and has since then remained unchanged with a small exception.

By the beginning of the WWII methods for hydrometeorological observations in the Arctic Ocean using coastal, shipborne, drifting stations, airborne expeditions "Sever" with the landing of scientists in different regions of the Arctic Ocean and the marginal seas had been defined. At the initiative of the Arctic Research Institute since 1936 the "Ice Patrol" expeditions to the

Arctic seas were organized, which at first faced the task of a systematic observation of the ice edge position and changes and comprehensive hydrological observations.

In 1937 the first polar station the "North Pole-1" (NP-1) was established on the drifting ice of the central Arctic Basin. Since 1954 such stations have been organized annually. In the block of the hydrometeorological data collection a special place is devoted to the "NP" drifting stations whose number varied since 1971 from 2 to 4, along with the airborne high latitudinal expeditions "Sever". They allow obtaining a wide set of data on the natural environment of difficult-to-access high latitudinal regions. In addition to these methods, since 1957 the drifting automated radiometeorological stations (DARMS) were used. They allow determining not only the ice drift, but also the main meteorological parameters (pressure, air temperature, wind speed and direction).

Airborne visual observations of the ice cover occupied an important place in hydrometeorological support to Arctic shipping. In 1924 a hydroplane was used for the first time for visual ice reconnaissance. And since that time different types of hydroplanes (Dornier-Valle, MP-7, etc, 1929-1942) and aircraft (C-47, Li-2, IL-12, Il-14, etc.) and helicopters (Mi-1, Mi-2, Mi-8 and K-32) were used for visual airborne ice reconnaissance.

Since the 1950s different instrumental observation methods are used for airborne ice reconnaissance: aerial photography surveys, and since 1968 - the SLAR equipment (Side-Looking Radar Stations of different modifications "Toros", "Nit"').

In the 1970-80s in addition to surface, marine, airborne methods for obtaining ice and hydrometeorological information, space methods began to be used from national or foreign Earth's satellites. Satellite data had one important advantage: a possibility for obtaining an instant picture of the distribution of the parameters of three media (atmosphere-ice-hydrosphere) over vast spaces of the Arctic Seas.

An important block of the general system of the hydrometeorological support in the Arctic appears to be the scientific-operational groups (SOGs), which collect, analyze the actual ice, meteorological and hydrological information and develop the forecasts, navigation recommendations of different specification and period in advance. The first such group began to work in 1924 aboard the icebreaking vessel of the Kara expedition (the icebreaker "Malygin"). This group investigated the currents and ice conditions of the Kara Sea. In the same year this group prepared the first forecast of the ice state in the Kara Sea. In 1926 the SOG began to include synopticians and meteorologists. Since 1927 the scientific weather and ice service offices for supporting the navigation in the Kara Sea started to be formed onboard the main icebreaking ship, and since 1929 - onboard the main icebreaker. In 1932 the experience gained in the western Arctic was used in the eastern Arctic. And since that time scientific-operational hydrometeorological support has been provided annually throughout the Arctic. Initially, the SOGs were based onboard icebreakers of the western and eastern regions of the NSR. Later on, the Arctic Research Institute organized the SOGs in the Headquarters of Marine Operations which were located at the main bases of the NSR - Dikson, Tiksi and Pevek.

With the appearance of the scientific-operational groups (SOGs) at the Headquarters of Marine Operations (HMO) the present management subsystem of the Arctic Marine Transport System (MS AMTS) was formed.

At the present stage the development of the MS AMTS is characterized by the local initiatives and the efforts of navigators, hydrometeorologists and airmen to establish a reliable information system, providing the necessary data about the state of the natural conditions, governing the shipping results along the NSR.

From this time the development of the branch of ice research - study of ice navigation conditions, using the scientific information methods - a systems approach began.

The basis of the approach is taking into account the available genetic information relationships between the management object - transportation vehicle, and also a set of the transportation means moving in specific hydrometeorological conditions, and the management subject - MS AMTS.

With the development of the volume of cargo transportation along the NSR, which peak was in the 80s, the AMTS was transformed into a large complex system. The MS AMTS has also undergone qualitative changes.

The emphasis in them is given to the management of a powerful icebreaking support (nuclear-powered icebreaking fleet). And mainly the technical management aspect develops - the concept of the reservation of the icebreaking fleet power appears. And the attitude to the consideration of the environmental state, formed in the previous years changes (Malarov, 1989).

Nevertheless, the results of summer navigations of 1981, 1983, 1989 when heavy ice conditions on the specific NSR segments governed significant difficulties for the entire transportation process, emphasised the importance of the information on the "natural" shipping medium, its place in the MS AMTS.

In other chapters of the Report an attempt is made to give a systems presentation of the problems of the hydrometeorological support to Arctic navigation and, primarily, to transit navigation along the NSR. The stress in the discussion is laid on ice-hydrometeorological information of an operational character.In the framework of the work process - the AMTS functioning - the operational information on natural conditions is considered as such, used at the stage of the operational (regulating) management of the work.

In accordance with the established notions (Adamovich and Makarov, 1991) the stage of the operational regulation begins 10 days prior to the beginning of a specific voyage and ends after its completion.

It should be noted that a regular through navigation upon the NSR has not yet been made. The experience of some transit cruises, particularly, in the most heavy conditions of the beginning or the end of navigation convincingly indicates the need for taking into consideration the differences between the coastwise and transit navigation both with regard to the organization and hydrometeorological support in these areas (Makarov, 1991).

It is clear that the hydrometeorological support of transit navigation, including vessels of other countries should be based on the operating system.

Thus, the Report aims to give the main aspects of the HMS to the AMTS at the present time and justify the proposals for its improvement taking into account the specific features of transit shipping.

1 MAIN NOTIONS AND DEFINITIONS OF THE OPERATIONAL INFORMATION SYSTEM (OIS) ON THE NATURAL CONDITIONS OF SHIPPING

It appears to be common to use the notion - the System of the Roshydrometservice which, in turn, is a subsystem of the System for the management of the Russian economy. The organization and functions fulfilled by the Roshydromet system correspond to the definition of the real systems (Skugarev, Dubravin, 1972). As a real system, one should define a set of interrelated real objects and processes, fulfilling the specific functions or leading to a definite result. This requires considering a problem of the information development for the practical needs in terms of the systems positions, which in our opinion greatly contributes to the understanding of the main aspects of the problem and finding the effective ways for its solution (Yakovlev, Smolyaninov, 1982). Let us explain the notion of the complexity of solving the problem - natural information and ice navigation in the Arctic using a set of the features, characterizing complex systems.

First: a large number of the divisions of the Russian Federal Hydrometeorological Service (Roshydromet) are concerned with the production of natural information about the Arctic region. Such divisions are located rather far from each other and exchange information by a complex system of communication channels.

Second: the Hydrometservice divisions are organized using the hierarchy system (subordination) of interaction through the central administration.

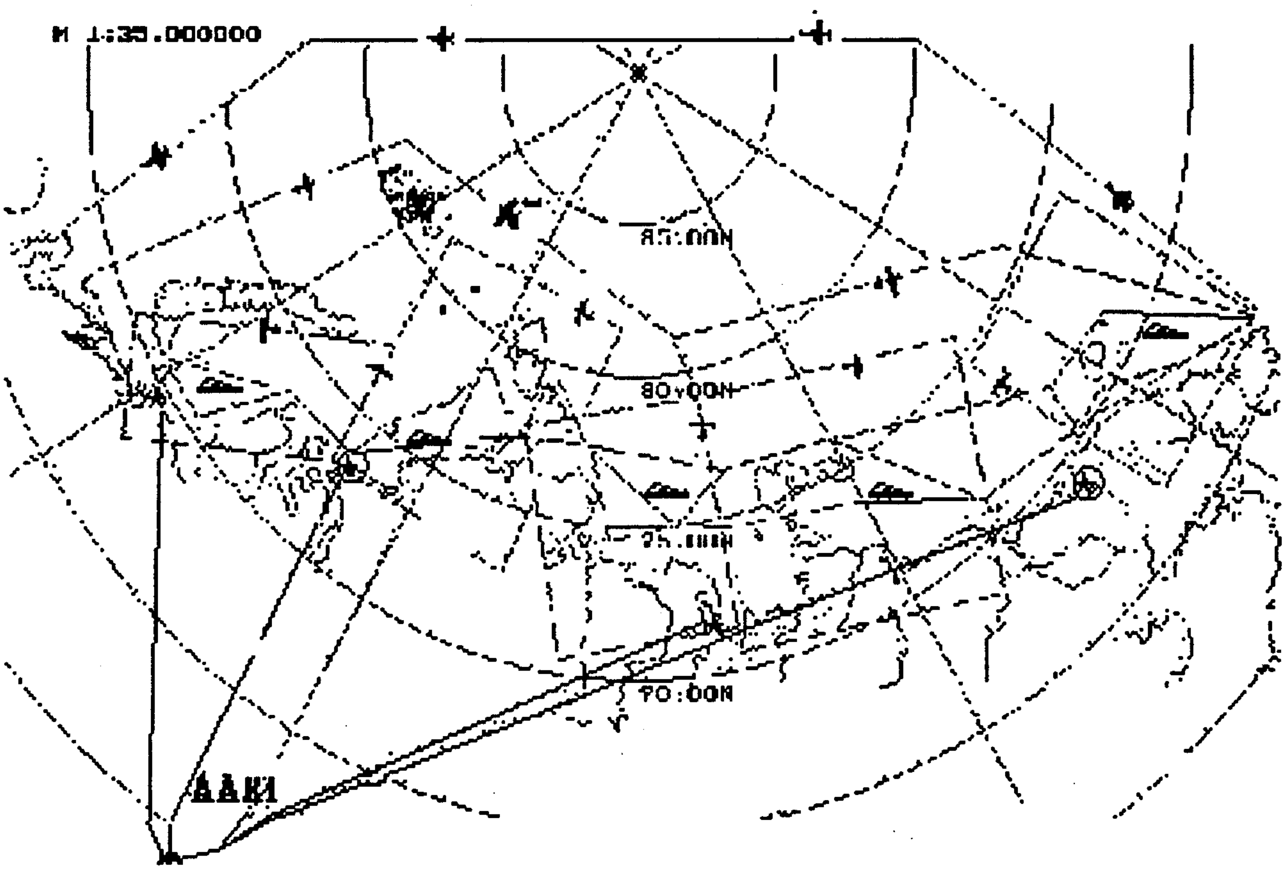
Third: the process of the development and the distribution of natural information during the provision of hydrometeorological services to the different users governs the interaction between the divisions, the appearance of non-centralized information relationships.

Fourth: in the general structure of the Roshydromet each division can fulfil independent functions to meet the demands of the outside "users", which can be considered as the existence of the subsystems.

Fifth: the organization and the functions fulfilled by the Roshydromet divisions, undergo considerable transformations during the changes in the requirements of the user to the content of the environmental information.

Also real appears to be a System for a Scientific - Operational Hydrometeorological Support (SO HMS) to shipping along the Northern Sea Route. Under this one understands a large number of the organization forms of the divisions of the Roshydromet Service fulfilling the functions of the development of hydrometeorological information in the interests of Arctic shipping (Fig.1).

However, we have not yet answered the question, why one should use the systems approach method when describing the operational information on natural ice navigation conditions. Bear in mind that each real system is reflected in our consciousness in the form of a definite knowledge or evidence about it which serves as initial data for abstract thinking. It is the abstract thinking which allows one to learn most deeply and correctly the real systems and hence, manage them. The aim of this Report is, first of all, to present in a clear way the main aspects of the problems of the operational hydrometeorological information, the degree of their present effective solution and the development prospects in the framework of international cooperation. On the basis of the purpose set we are interested in the set of data - the knowledge system on the category "operational information on natural conditions.." At the present time the "knowledge system" about the indicated category is represented by many volumes of annual reports about the SO HMS of the winter and summer navigation periods separately for the western and eastern Arctic regions, beginning from 1936, Provisions and Instructions on the SO HMS in the Arctic, Handbooks on the preparation of short-range ice forecasts for the Arctic seas, numerous publications in special issues, devoted to the problems of hydrometeorological support to Arctic shipping. The list of data on the problem indicated will be rather long, explaining why we ought to consider the notion of an abstract system (Berg, Chernyak, 1966). The abstract system appears to be a method of the arrangement of



Arbitrary designations:

- ● Ice-information center of the AARI
- ★ Scientific-operational Groups (SOGs) at the hydrometeorological (HM) territorial centers
- ⬤ SOGs at the Headquaters of Marine Operations (HMO) of the western (Dikson island) and the eastern (Pevek) regions of the Arctic
- —+— Boundaries of the operational management regions of HMO (OMR HMO), strategic by ice condition
- A diagram of the possible navigation variants for the strategic OMR HMO at different types of the ice navigation difficulty
- Boundaries of the strategic (seasonal) ice reconnaissance (IR)
- Boundaries of the tactical (10 day) IR
- ●—★ Organisational relationships of the Roshydromet divisions at HM scientific-operational support to ice navigation on the NSR

Fig. 1. A scheme of the hydrometeorological operational support to ice navigation along the Northern Sea Route (NSR)

knowledge on the investigated or managed process or the object from the point of view of a specific observer and within the strictly formulated problem. Under the arrangement method one should understand the sampling order of specific data on the given real system, its pattern and presentation form. It is known that a real object or process can be investigated or managed using its model, made in some form or other and reflecting one or several sides of its functioning. Sometimes for an adequate reflection of the aspects of the investigated or managed object (process) we are interested in,the use of two or more models is required. The models used can be constructed in quite different forms and each written in its own language, differing from that of the other model. A set of such models presents an abstract system. The more the number of some models of the given real object or the process we are able to combine into a separate model - an abstract system, the more this abstraction will resemble reality. In the human practical activities during the management of real systems the degree of knowledge and reflection of this reality in its abstraction is governed each time by the final management goals. In order to achieve the desirable management goals, each time one constructs an abstract system of a certain adequacy, not attempting to achieve an infinitely close consistency of the abstract and real systems. This is the primary difference between the process of the practical management and the process of research studies. A manager tries in practice to learn and reflect the process to an extent necessary and sufficient for its management. The excess of sufficient extent results in complication of its activity, not bringing anye gain in terms of management. The principle of necessary and sufficient knowledge about the investigated (managed) system is also quite valid in our case - the problem of presenting information (knowledge system) on operational data on natural conditions for ice navigation. The only possible way for achieving the acceptable results here will be the application of the systems approach contrary to the traditional one - reductional. The traditional methods, as already mentioned, resulted in an abundance of data on the SO HMS. However, this information volume does not allow for an unambiguous definition of the notion of the operational information as the object of the study and management. Such a situation is quite regular. The thing is that the object we are interested in - the operational information cannot be described by means of one model, using a single language reflecting all specific features. The operational information on natural conditions for ice navigation as an objective process is described by not less than two models - the model for information production and the model for its application. The language of the first model reflects the properties of the natural environment, the second - the production environment. At the existing level of knowledge the compatibility of such two models in one language is difficult. Hence, to investigate a real object one uses the existing known element-models, but the synthesis of the systems properties is made in the so-called creative way. In this case the abstract system is created to a full extent only in the human mind where the existing models are supplemented by intuition and imagination of the human being. Thus, studies of the object we are interested in with a prescribed purpose (management purpose) are complicated and in terms of management such system is also complicated.

First of all, the need for introducing the notion - the operational information system should be stressed. At the very beginning let us answer the question what should be considered as the operational information (OI) on natural conditions (title of the INSROP Project 1.2) used during "ice navigation" (name of the subprogram I.2 of the INSROP Project "Natural conditions and ice navigation").

A key aspect in the formulation of the question is in our opinion the definition of the purpose of information on natural conditions in the context of navigation. The question is not trivial. Its understanding should result in a clear formulation of the OI category.

Let us "reach the purpose" by considering the use of information on natural conditions when adressing the ice navigation objectives. For this we shall look for the features of such use for all cases, irrespective of the specific content of some problem or other. However, in the very general form most of the ice navigation objectives can be described as the choice of the navigation variant(s)in ice conditions; of the possible navigation variants the one is selected whose navigation conditions are the easiest.

Even from such a primitive description of the main aim of the ice navigation objectives the following conclusions can be made:

Firstly, the user of data on natural conditions makes investigations in all cases at the stage of planning the respective actions (the stage of decisionmaking). During the implementation of the plan (decision fulfilment) such information is not needed if the decision made cannot be reconsidered. If the change of the decision is permissible, then information on natural conditions is used to work out a new plan(decision), i.e. again at the planning stage.

As is known, the succession of stages (cycles) of planning and fulfilment of the plans is the main point in managing a specific process or object - in this case ice navigation or specific voyages in the framework of ice navigation. Hence, one can say that information on natural conditions is used in ice navigation for managing and by all means at the planning stage (decisionmaking).

In our example the navigation route in the ice is in fact chosen prior to navigating it.

Secondly, information on natural conditions is always used for management in the form of a forecast. It is explained by the fact that the planning stages in the implementation of the plan are always divided by the time interval different from zero. It is principally important that this interval always exists. On the other hand, it is obvious that during planning a person or institution making the decision (PMD or IMD) (managing body) should take into account the state of the environment at the time (at the instant, during the period) of implementing the plan, rather than at the time of planning. Hence, information on the state of the environment is a forecast whose advance period is equal to the advance time interval separating both managing stages.

Thus, for example, plotting of the easiest route by ice conditions at the map of "instant" ice distribution received from the Earth's satellite by high resolution instruments, should take into account possible changes in ice conditions not less than 6 hours in advance. If these changes fail to be taken into account, this can lead to serious difficulties (for example, the situation with the convoy of river ships on the route Dikson island - Cheluskin cape in summer navigation of 1989)(Makarov, 1989).

Thirdly, information on natural conditions used in ice navigation is inevitably inaccurate having always a degree of uncertainty (error). This is governed by its prognostic character: forecasting, in principle, cannot be absolutely accurate or reliable. One speaks here about multiple repeated statements whose accuracy (reliability) can be characterized statistically.

The error degree of the forecast depends:

- on the mobility of the forecasted element;
- on the advance period of the forecast;
- on the forecasting method.

To what extent these information features on natural conditions are taken into account largely governs the effectiveness of the decisions made on its basis.

Fourthly, the use of information on natural conditions during the ice navigation management is possible if one knows the relations between the indicators of ice navigation results and the values of the environmental elements or other values characterizing the state of natural conditions.

These relations can be expressed in analytical, tabular, graphical or other form, that is, presented in the form of functions. Such functions in the practice of HMS are called the relation functions (Belyaev, 1986; Gol'cman, 1982).

A specific character of the relation functions can be most different not only in the form of their presentation, but also in the character and complexity of the relations described by them.

Thus, in the known situations the relation functions between the ship navigation possibility and ice conditions are expressed by the system of formalized empirical-statistical dependencies between the values of motion velocity and the ice cover characteristics - thickness, concentration, pressures, amount of hummocking, snow, fracturing, degree of destruction, as well as extent of the ice zones identified by the system of numerical values of the indicated characteristics.

In other cases the relation functions have a character of dependencies of the type "yes" and "no". In this event the actions in ice navigation conditions are governed by a system of criteria. The actions are possible before or after the characteristics of natural conditions reach some limit (critical) values and impossible in the opposite case.

In the fifth place, the use of information on natural conditions in ice navigation should be based on the fulfilment of some certain rules prescribing an order of actions when receiving some information or other. In other words, there should exist an algorithm for making navigation management decisions on the basis of prognostic information or data on natural conditions or taking such into account.

In the most simple case such algorithm is reduced to the recommendation to rely fully upon the forecast. The choice of the route in heavy ice by the results of the operational ice reconnaissance or during the aircraft barraging along the course of an icebreaker or a ship can serve as an example. However, in this case too the algorithms for decisionmaking can be sufficiently complicated (Adamovich, 1985).

In a more general case the indicated algorithm should take into account the uncertainty inherent to the given forecast, which allows one to arrive at a decision which in a known sense apears to be optimal (Buzuyev, 1991).

Thus, let us summarize the above as a list of requirements which govern the need for the existence and use of information on natural conditions during ice navigation:

- availability of the forecast and knowledge of thevalues characterizing the uncertainty (error) degree of the forecast;
- knowledge of the relation function between the results of solving the specific tasks of ice navigation and hydrometeorological conditions;
- existence of an algorithm for decisionmaking on the basis of prognostic information on the environmental state or for taking this information into account. Let us stress that these necessary conditions are not sufficient for the corresponding ice hydrometeorological information to be actually useful and the efforts spent for its collection, processing, generalization and dissemination to be justified, i.e. reasonable.

In order to be useful and advisable (the existence goal) the forecast and the method of its use (algorithm of the decision making) should have specific properties. To achieve these properties is the goal of the scientific development of the methods and practical tests carried out at present in the framework of the national system of hydrometeorological services (NS HMS) to Arctic and Antarctic navigation. At the same time the very fact of the existence of the conditions mentioned above and the need for fulfilling such studies are of principal importance from the viewpoint of methods. The problems of methods for producing and using ice-hydrometeorological information in the interests of ice navigation are resolved only on the basis of complex relationships between the results of Arctic shipping and the environmental state taking into account the properties of the information itself.

On the basis of the above mentioned, one can finally give a definition of the category - operational information (OI) on natural conditions of ice navigation - as an object for studies and management. This is a complicated, organizationally determinate and dynamic material system with a reverse relationship consisting of the managing body, management object and direct and reverse relationships. The description of such a system should be made at present in the language of not less than two uncoupled models indicating the specific features of the properties of hydrometeorological information (HMI) on the one hand, and the specific features of the HMI application in the Arctic shipping management, on the other.

Most clear at present appears to be the model of the OI application at the stage of regulating (operational management) the marine operations from the Headquarters of Marine Operations (HMO) on the Northern Sea Route (NSR) (Adamovich, Makarov et al., 1991). One of the features of this stage is the need and sufficiency to use for the decisionmaking the environmental information 10 days in advance of the beginning of a specific ice routing (marine operation (MO)).

The management model (decisionmaking) at the stage of the MO operational regulating uses the following terms:

- plan of marine operation (PMO) - guiding instructions developed by the divisions of the Administration of the shipping companies (SC) for the HMO management regions which define the cargo transportation volume, its distribution by directions (destination-loading ports), number of ships in each direction of cargo transportation, number of icebreakers for the HMO management region (MR). The PMO is prepared for a period of not less than 2 months based on the organization features of the SC planning;

- the schedule of cargo transportation - indicates the time of ships arriving at ports for loading, the time of the planned repair of icebreakers covering the time interval corresponding to the PMO;
- stage of marine operations (SMO) - the time period, determined at the HMO, of random unidirectional changes in ice-hydrometeorological situations during which a specific management type is used - distribution of icebreaking support by the route segments, designation of the convoy composition, type of hydrometeorological support;
- standard marine operations - specific icebreaking escorting the implementation results of which are achieved by standard management means;
- non-standard marine operations - specific icebreaking escorting, the implementation results of which are achieved by additional (special) organizational and information measures;
- a through icebreaking routing - type of icebreaking support at which the escorting is made over the entire route of the management region by a convoy of not more than 2 ships per single icebreaker. Such type of escorting is usually used at the beginning of navigation and in heavy ice conditions;
- mass icebreaking routing - MO are supported by the icebreakers at some route segments with the convoys consisting of more than two ships per single icebreaker;
- occasional icebreaking routing - icebreakers escort ships through some close ice isthmus on the route segments providing ships with the recommendations for unaided motion on the given segment;
- unaided navigation - independent ship motion along the segments or along the entire management region. This navigation type is defined by the HMO separately for each category of ships of a specific ice class.

The enumerated management categories (types of decision-making) govern the respective type of the operational hydrometeorological information, necessary and sufficient to make such management decisions.

2 CONCEPT OF THE OPERATIONAL INFORMATION SYSTEM FOR THE HYDROMETEOROLOGICAL SUPPORT TO THE OPERATIONAL MANAGEMENT OF TRANSIT SHIPPING ALONG THE NORTHERN SEA ROUTE

This section considers the approach to the analysis of the current state of the applied hydrometeorological activities in the interests of the Arctic Marine Transportation System (AMTS) on the basis of the systems methods. A systems consideration of the activity of the Hydrometorological Service in these interests has the following definite goals.

In the first place - the statement of the fact about the available viable technological structure producing the required products. In our case this is the development of hydrometeorological information governing the effective solution of the practical tasks of the AMTS management, in particular, transit shipping in the Arctic along the NSR.

In the second place - determination of the viability of the considered structure as a complex system.

In the third place - search for a possibility to improve the system structure, that is, to improve the quality of the output information products.

The development of the complex systems aims to achieve the goals set. The term development arbitrarily combines a set of actions from the assessment of the hydrometeorological situation to the creation of the algorithm, necessary to make the management decisions.

The main objective at the stage of the decisionmaking is the development of the best plan of transit navigation along the NSR in the conditions of a significant effect of random factors (Makarov,1990). Here the environmental state is considered to be a random factor, that is: atmospheric processes, evolution of the ice cover and hydrological conditions, predicted at a definite (prescribed or possible) period in advance.

Let us note that historically hydrometeorological support of marine operations in the Arctic was formed outside the systems approach as a methodological direction, which has only recently come to be widely used. In accordance with this the available description of the considered support is rather indistinct. This affects the possibility to analyze its properties with regard to regulating them, although there are a number of the documents regulating the functional properties of the system under consideration (Table 1). In accordance with the objectives of the analysis proposed, let us formulate the task to investigate the properties of the system for hydrometeorological support of transit shipping in the Arctic as an information system of scientific-operational support (ISSOS). Then the concept for the indicated information system should be based on the principles of usefulness and advisability of applied hydrometeorological activities. The analysis and improvement of the ISSOS is directed to enhance the effectiveness of the supersystem for the management of practical activities, in particular, transit shipping along the NSR. The emphasis on the initiation of these actions (analysis and improvement of the ISSOS) provides at present the conditions for the usefulness of hydrometeorological information.

Making the conclusion on the usefulness of the ISSOS formed, it is necessary to conduct careful studies on the advisability for preserving or improving it.

It is obvious that the current stage of the development of the country's economy requires modern forms of economic management. And development of the management functions, improvement of its methods and techniques presupposes the need to create new data sets, including hydrometeorological data, further improvement of the analysis as a method for justification of the decisions. The objective is to find the optimal way of deducting this process. The decision, probably, can be the use of the methods formed for the design and analysis of the information systems (Druzhinin, Kontorov, 1976; Smol'yaninov, Yakovlev, 1982).

Accordingly, the formation of the management system support consists of two interrelated stages:

- justification of the data set required for the effective functioning of the management system, as well as for the content of the information system - nomenclatures of the parameters included into the information, their sources, measurement methods, periods of updating, etc.;

- determination of the order of receiving, storage, distribution and use, i.e. directions, intensity and forms of information distribution in the managed object and the managing system.

At the first stage the content of the information support is determined, at the second - its form. The first stage governs a statistical approach to the formation of information, the second - a dynamic transect of the information system, its change and procession.

The degree of improvement of the first stage of information support is governed by the level of knowledge on the environment. The prospects to fulfil this stage fully depend on the state of the research studies of the management object, being in this context natural shipping conditions in the Arctic.

One of the main criteria of the improvement degree of the ISSOS at the second stage is the analytical level of the information sets, i.e., their consistency with the decision types worked out in the management system. And the analysis is considered not as a description but as a study of the formed relationships and tendencies for the development of the information subsystem with a management supersystem. Let us show the significant possibilities for improving the ISSOS in the framework of the second stage of its formation by the example of the analysis of the support structure formed at present at a functional level. It is known that at this level standard information models are formed which correspond to the standard management decisions and types of activities in the Arctic shipping system (Fig.2, 3).

The presented schemes show the directions of the flows and transformation form of hydrometeorological information in the AMTS management system at different stages of making practical decisions. According to the balance condition of the management scheme, the direct managing flows should have reverse information relations.

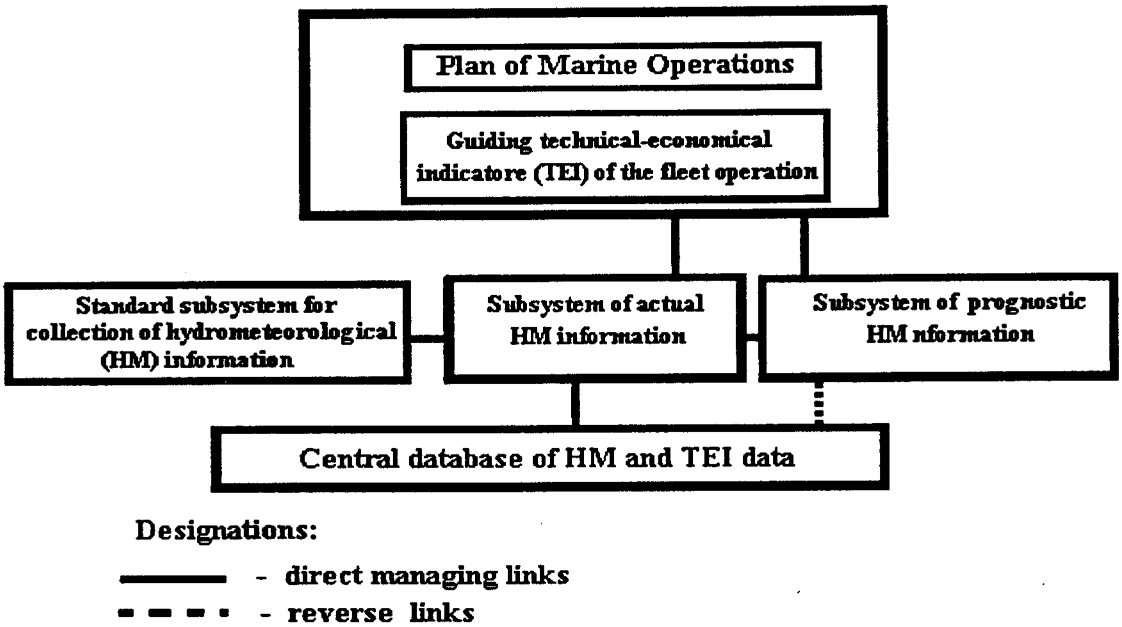


Fig. 2. A block-diagram of the information hydrometeorological support to the stage of the strategical planning of marine operations in the Arctic

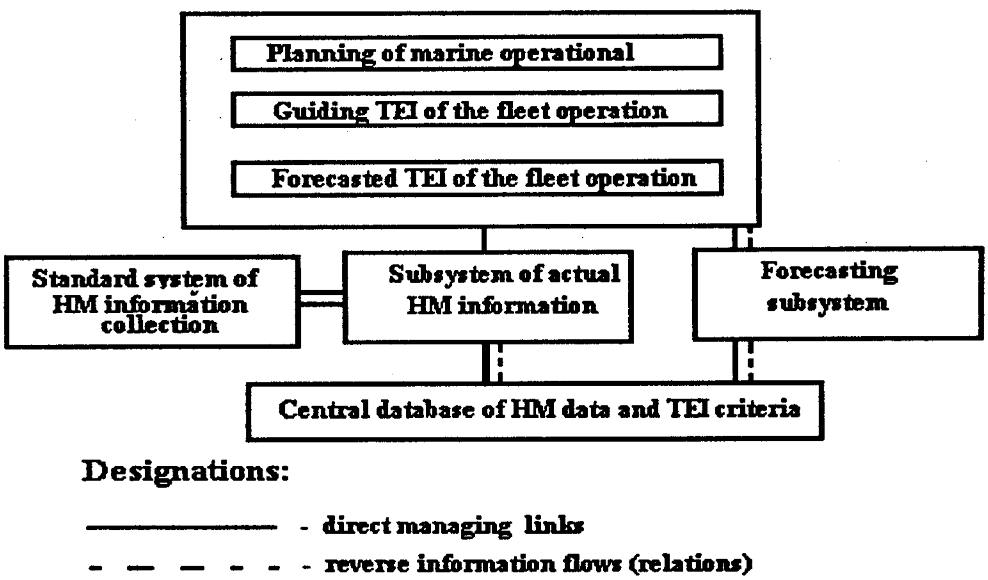


Fig. 3. A block diagram of the hydrometeorological support to the stage of current planning of the fleet operation in the Arctic

Table 1. Ice navigation conditions and content of ice forecasts at different navigation stages

Characteristics of ice conditions	Characteristics of ice navigation conditions	Ice cover data required by navigator	Ice cover data necessary to make ice forecasts	Content of short-range ice forecasts
Initial winter-spring navigation period				
Fast ice is preserved within the maximum development limits. Drifting ice is represented by ice breccia and big floes. Visible features of ice destruction are pronounced only in the areas of river deltas and a narrow coastal strip. Flaw polynyas and thaw holes are not covered by young ice, as water in open areas begins to accumulate heat.	Ship routing is planned and made by flaw polynyas and thaw holes with the passage of fast ice, which has a seaward extent limit - the 10 m isobath. When routing the convoys the icebreakers have to penetrate heavy isthmus of compact and unbroken ice. The number of ships in the convoy is limited (usually not more than two)	Position of fast ice boundaries, boundaries of flaw polynyas, ice distribution on the ship route, amount of ice fracturing in the isthmus, thickness of level ice segments in fast ice, amount of hummocking in fast ice on the passage segments, strength of fast ice. Data on ice pressure zones.	Ice state and distribution on the whole . over the region with identification of ice of different age categories. Some ice characteristics : amount of hummocking, snow, fracturing, degree of destruction. For the navigation region the ice cover characteristics in details, indicated in the preceding graph. Strength of fast ice, data on compacting and diverging. Ice drift direction	Forecasts: total direction of ice processes, position of ice edges, fast ice limits, polynya boundaries, changes of ice concentration on the convoy movement course, ice thickness in fast ice, formation of zones of ice compacting and diverging. Calculations of fast ice strength in the areas of breaking the channels

These conditions, as follows from the diagrams, are not always observed. Let us consider a possible reason of such inconsistency. It is known that information should be adapted for use at any stage of the management system functioning. Depending on the preparation degree, the information types at different stages of the management of marine operations (MO) can be identified:

- primary information, as a set of data, indicators, describing some aspects of the process components;
- secondary information which has to some extent been systematized, summarized and divided into classes;
- information models of some components and local processes describing the static state of the object;
- information models of dynamics characterizing changes in some components and processes;
- integrated information models describing specific situations (Fig. 4).

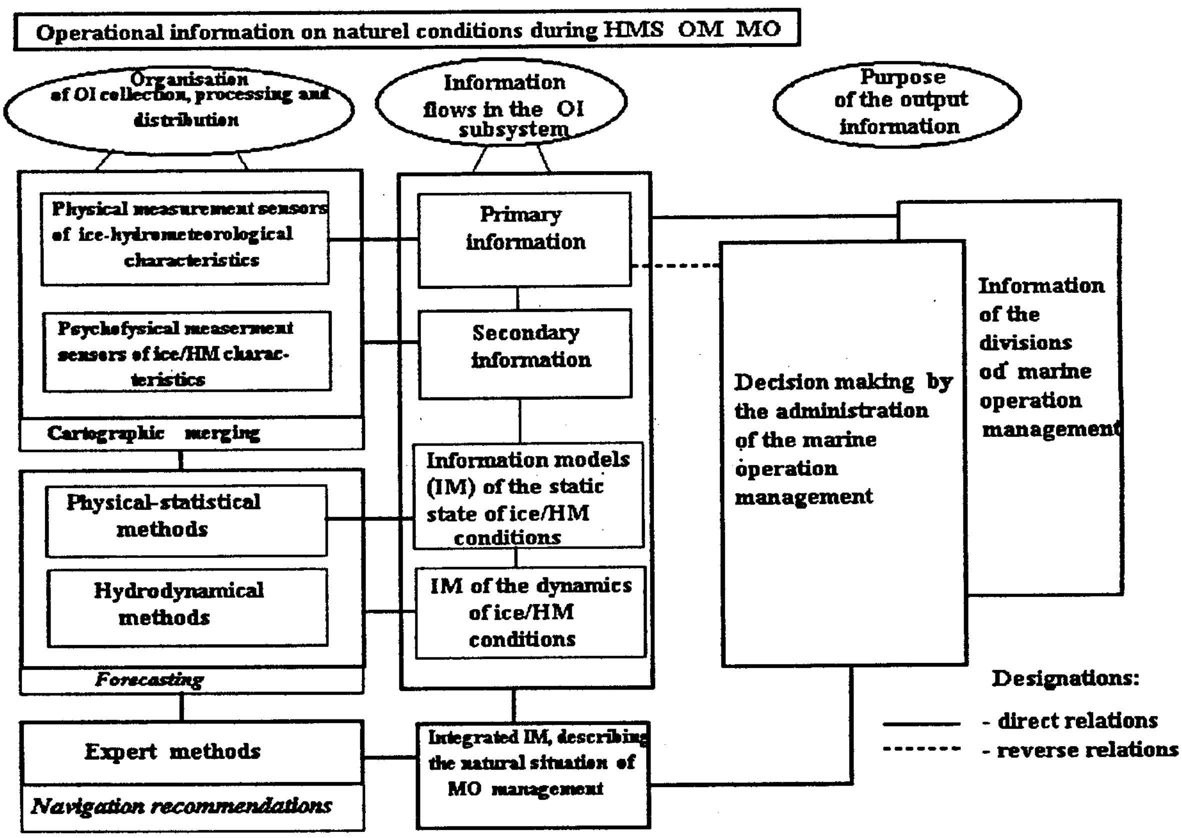


Fig. 4. Scheme for the organization of operational information on natural conditions of ice navigation

For the information systems of the production process the first two models appear to belong to the information system proper; the third and the fourth stages are related to activities of the specific operating divisions. The last group of the models is used by production administrators.

The ISSOS is a subsystem relative to the production information system, but it ultimately functions to improve production. The justification measure for the ISSOS functioning can be the extent of its consistency with the production information system which takes into account the effect of the environment. And this is the main feature and the contradiction of the ISSOS. The contradiction is that the adaptation of the ISSOS functioning under specific conditions of a separate body (shipping company, central management body, etc.) presupposes additional expenses from the side of the information user. However, only such approach allows one to resolve the management goal in an optimal way in the framework of the "senior" system, that is, the production information system used for the shipping management in the Arctic. And this also explains the differences in the functional ISSOS schemes presented in Fig. 2, 3.

The inconsistency in the extent of information preparation (specialization) governs the absence of reverse relations between the management system and the information subsystem. This, in fact, means from the very beginning a low effectiveness of the information use, and, hence, the problem of the advisability of its use in such a form. The most balanced appears to be the ISSOS of the stage of the operational regulating of marine operations (Fig. 5). The advisability to use the modern system of scientific-operational support of the stage of operational regulating of marine operations is evident for users of hydrometeorological information.

The obvious step in the direction governing the increase in the effectiveness, advisability and usefulness of the ISSOS functioning appears to be merging of the existing schemes of support to the shipping management stages into one technological cycle (Fig. 6). Let us note that there are sufficiently balanced direct and reverse relations between the ISSOS subsystem and the managing supersystem. In this structure there is an evident central role of the data bank which is to coordinate the functioning of all blocks of the information system for scientific-operational support.

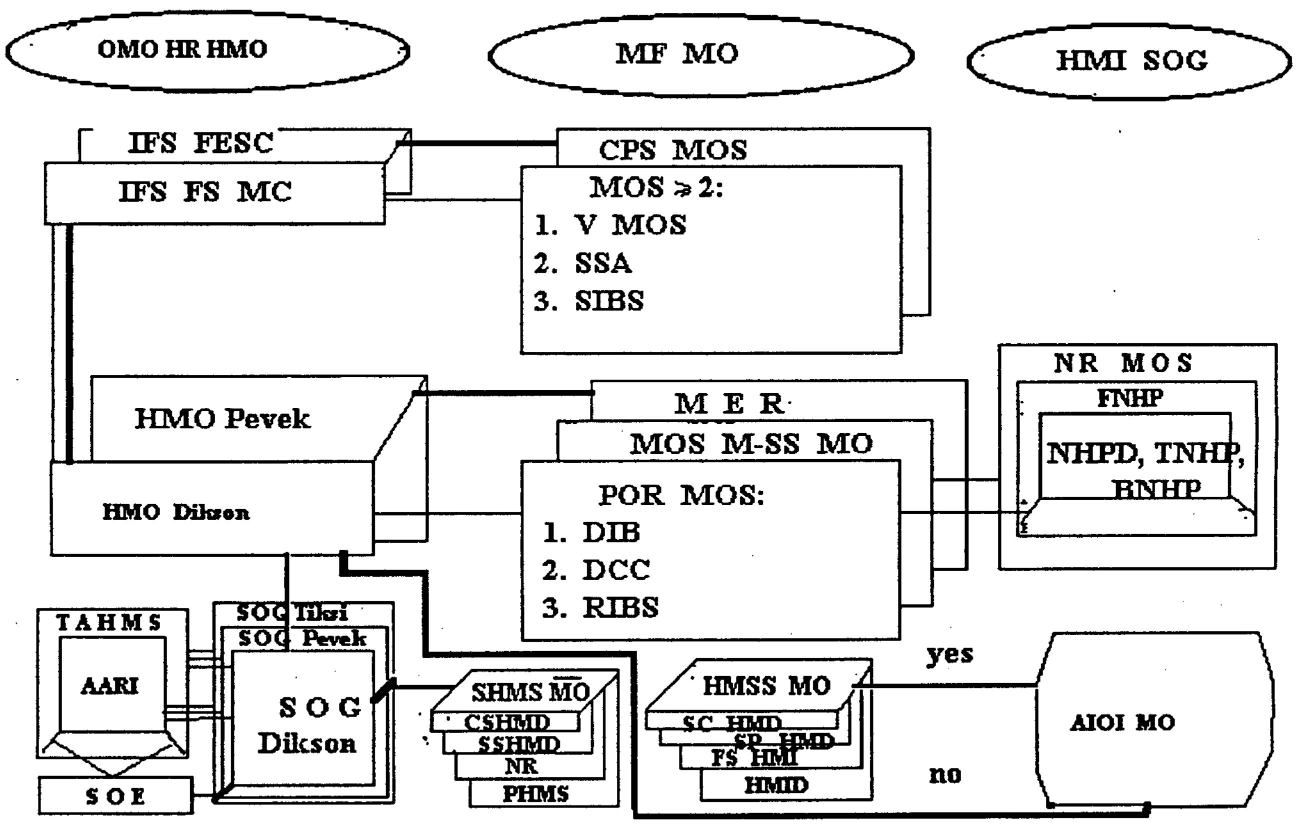


Fig. 5. Management structure of the AMTS and the subsystem of the scientific-operational hydrometeorological support to shipping along the NSR

DESIGNATONS FO FIG. 5:

OMO MR HMO	- Organization of marine operations (MO) by the management regions of the Headquarters (HMO);
IFS MS SC	- Icebreaking Fleet Service (IFS) of the Murmansk Shipping Company (SC);
IFS FE SC	- IFS of the Far Eastern SC;
HMO Dikson	- Headquarters of marine operations (HMO) of Dikson island;
HMO Pevek	- HMO of Pevec city;
TAHMS	- Territorial Administrations of the Hydrometeorological Service;
SOG Tiksi	- Scientific-operational group of Tiksi;
SOG Pevek	- Scientific-operational group of Pevek;
SOG Dikson	- Scientific-operational group of Dikson island;
AARI	- Arctic and Antarctic Research Institute;
SOE	- Scientific-operational expedition;
MF MO	- Management functions of marine operations;
MOS	- Marine operation stage;
CPS MOS	- Change of the plan of the subsequent MOS;
MOS $\geq$ 2	- Plan of the MOS for the period not less than 2 months:
1. V MOS	- Volume of MOS transportation,
2. SSA	- Schedule for ship arrival,
3. SIBS	- Schedule of icebreaking(IB) support;
MER	- Management of each routing;
MOS M-SS MO	- MOS management - by a sequence of specific MO;
POR MOS	- Plan for operational regulating of MOS:
1. DIB	- Distribution of icebreakers along the route segments,
2. DCC	- Designation of the convoy composition by segments,
3. RIBS	- Reservation of IB support;
SHMS $\overline{MO}$	- Specialized Hydrometeorological support (HMS) of non-standard MO;
CSHMD	- Collection of Specialized Hydrometeorological Data (SHMD);
SSHMD	- Systematization of SHMD;
NR	- Navigational recommendations;
PHMS	- Personal HMS;
HMSS MO	- HMS of standard MO;
SC HMD	- Standard collection of HM data;
SP HMD	- Standard procession of HMD;
FSHMI	- Formation of specialized hydrometeorological information (HMI);
HMID	- HMI distribution;
HMI SOG	- Hydrometeorological information (HMI) of scientific-operational groups (SOG);
NR MOS	- Navigation recommendations for MOS;
FNHP	- Forecast of the preservation time of the natural hydrological period (NHP) type;
NHPD	- NHP diagnostics;
TNHP	- Division of NHP into types;
BNHP	- Time of NHP beginning;

AIOI MO - Analysis of the consistency of ice-operating indicators (IOI) of the MO sequence to the planned IOI of MOS.

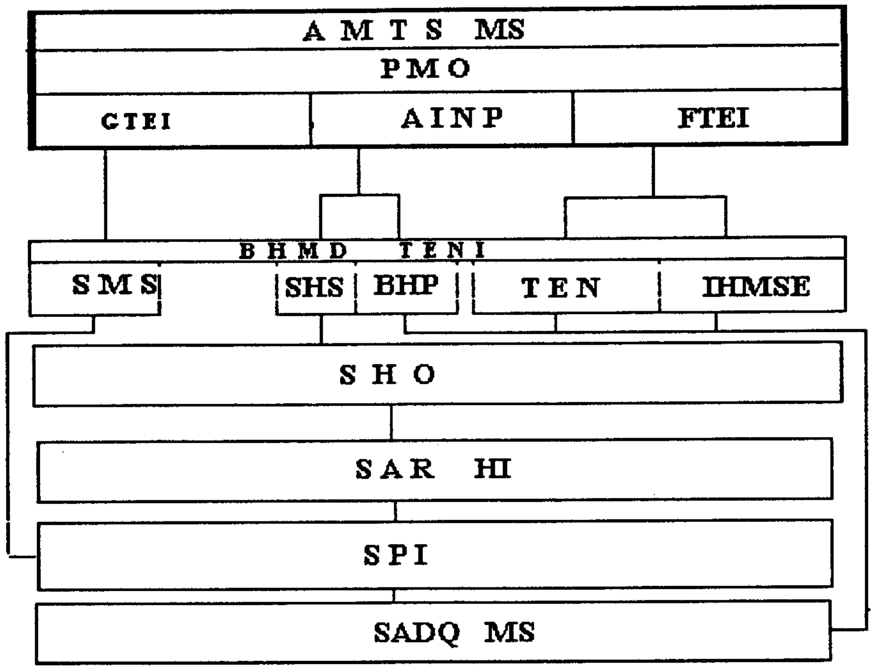


Fig. 6. A prospective structure for the organization of the scientific-operational support to transit shipping along the Northern Sea Route

DESIGNATIONS FOR FIG. 6:

AMTS MS	- AMTS Management System;
PMO	- Planning of marine operations ;
GTEI	- Guiding technical-economical indicators;
AINP	- Actual implementation of the ice navigation plan;
FTEI	- Forecasted technical-economical indicators;
BHMD TEI	- Bank of hydrometeorological data and technical-economical navigation indicators;
SMS	- Standard management situation;
SHS	- Standard hydrometeorological situations;
BHP	- Base of hydrometeorological parameters;
TEN	- Technical-economical norms (criteria);
IHSE	- Indicators of hydrometeorological support effectiveness;
SHO	- Subsystem of standard and specialized hydrometeorological observations;
SAR HI	- Subsystem of actual and review-analytical hydrometeorological information;
SPI	- Subsystem of standard and specialized prognostic information ;
SDQ MS	- Subsystem of the analysis of data quality and methodological studies.

3 STRUCTURE OF THE OPERATIONAL INFORMATION SYSTEM AND ITS EFFECTIVENESS FOR VARIOUS TYPES OF ARCTIC NAVIGATION, MODELS AND METHODS FOR THE TRANSFORMATION OF INFORMATION INTO A SPECIALIZED TYPE

The problem to develop the information description of the system for scientific-operational support arises from the need to estimate the effectiveness and prospects of the system as a final stage of the development or analysis. And it is assumed that the effectiveness criteria are determined and mutually agreed upon. From experience of using the system for scientific-operational support it is known that the efforts to develop the characteristics of the effectiveness of the system in the form of the functional economical effectiveness criterion, physically possible to measure, have failed.

It seems to be more promising to employ as a physical criterion the energy which the system directs and uses to achieve the purpose - to make minimum the uncertainty in the information on the state of shipping medium (experience of using such criteria is quite in the area of systems technology) (Druzhinin, Kontorov, 1976). This is useful energy and the larger it is (at permissible losses), the more effective the system under consideration.

Based on the fact that we resolve the task of the systems analysis, one envisages the presence of its systems description. It should reflect three main aspects of the system in their relationship and the relation with the environment. These are the functional properties (content of activity), morphology (components, their relationships), information properties (assessment of accuracy, organization, uncertainty, ability to be managed). A functional description of the system is presented by the guiding documents (in our study it is assumed to be constant) (Instruction, 1983). The morphology of the system is defined when developing its concept (Chapter 2). Thus, it is assumeded that the maximum possibilities to achieve the task function of the system (increase in the informatization quality of the AMTS management system) are hidden in the information properties of the system. Hence, the relationship between the development of the effectiveness criterion of the system and its information description is logically evident.

In accordance with the proposed definition of the effectiveness criterion in the form of energy E, let us present the ratio:

$$E = \varepsilon I \qquad (2)$$

where: ϵ - full energy resource of the system whose components are the means for data collection, processing, formation (forecasting) and distribution;

I - informativity of the energy unit.

Let us note that E is expressed in the power units and represents power used to obtain information.

The information description in the most general form can be presented by the energy enthropy of the system (H):

$$H = \sum_{i=1}^{n} p_i(X) lg_2 p_i(X)$$

where: $p_i(X)$ - a discrete probability distribution of some parameter X characterizing the system.

The connection of the information enthropy with energy is determined by the ratio:

$$\Delta H = K \Delta \varepsilon$$

Taking into account (1) we have:

$$\Delta H = K \Delta \frac{E}{I} \qquad (2)$$

where: K - a constant depending on the system of the units.

From the information enthropy one can proceed to errors in the assessment of the factor (parameter) x_i and δ_i by the ratio:

$$H(X) \cong -lg_2 \frac{\prod_{i=1}^{n} X_{oi}}{\prod_{i=1}^{n} \delta_{xi}} \tag{3}$$

where: X_{oi} - parameter change range:

δ_{xi} - assessment error;

n - number of the estimated parameters.

$$\Delta I = \frac{\Delta H}{K \Delta E} \tag{4}$$

Let us further use the formulas (3) and (4) to assess the informativity of the ISSOS for easy and heavy navigation types.

Let us note a fact following from (4), that the increase in enthropy of the system (increase in uncertainties of its state) should be accompanied by the losses of additional energy in order to preserve the informativity at a given level.

Let us determine in the most general form those environmental characteristics whose measurement corresponds during the ISSOS functioning to the procedure of the assessment of X factors with measurement errors (3). Let us compare the number of the estimated factors for the conditions of the ISSOS functioning in different seasons of the year, in the years differing in navigation difficulty.

The ice conditions of the "cold" and "warm" periods of the year differ significantly. The "cold" period of the year in the Arctic Seas differs by the drifting ice of 9-10/10 concentration prevailing everywhere. That is why, the success of shipping at this time is governed by the following ice cover characteristics:

- amount and location of ice zones of different age categories;
- thickness;
- presence, state and location of the break-up zones in solid ice cover;
- presence and location of the pressure zones;
- presence and state of the flaw zones of young ice, young ice zones in the systems of the break-ups in solid ice massifs. In the "warm" period the shipping effectivenes is governed, first of all;
- by the distribution of ice zones of various concentration;
- location of the ice massifs and, particularly, ice zones of the highest concentration (9-10/10).

In the zones of close ice the success of shipping is governed by the following main ice cover characteristics:

- amount and location of ice zones of different age categories;
- thickness;
- amount of hummocking;
- degree of destruction;
- presence and location of compacting zones;
- dimensions of ice formations;
- geometry and distribution of open water zones in the massifs.

Due to the circumstances most attention was given to the improvement of the form and the content of specialized ice forecasts 8-10 days in advance. During the HMS to shipping on the NSR the scheme for the information presentation on the actual and expected state of the environment has been developed at the indicated period in advance in a general and specialized form. On the basis of actual information on the meteorological and ice processes the assessment of their development over a 10 day period preceding the preparation of the specialized forecast is given. It includes the following characteristics:

- air temperature background (in anomalies);
- direction of air flows;

- ice cover extent and areas of ice massifs;
- type of location of ice massifs and ice distribution;
- background of sea level variations (non-periodical wind-induced sea level rise/drop - surges);
- type of natural hydrological process transformation.

The listed indicators characterize variations in atmospheric and ice-hydrological processes in the region of the location of the specific segments of the NSR.

In the "warm" period of the year on the NSR difficult ice conditions usually occur in the following regions:

- north-eastern Kara Sea (the Vil'kitsky strait, western and sometimes eastern approaches to it);
- western Laptev Sea (the Taimyr ice massif);
- the East-Siberian Sea and the Long strait (region of the Aion ice massif).

In years with heavy ice conditions the extent of the route in close ice increases not only in the key regions, indicated above, but also at the approaches to them forming a strategic region. In this connection to issue specialized forecasts (the choice of the optimal routes and calculation of the navigation difficulty coefficient) an increased ice information volume is required, in particular:

- ice distribution over large areas of the strategic navigation regions;
- an increased set of ice cover characteristics (concentration of ice of different age categories, thickness, amount of hummocking, degree of destruction, dimension of ice formations, presence and location of compacting zones, etc.);
- enhanced accuracy of the characteristics governing the ice cover state on the optimal shipping routes (can be obtained as a result of special observations from aboard an icebreaker using high resolution means of the instrumental diagnostics of the ice cover).

In years with easy ice conditions the boundaries of close ice shift everywhere northward and shipping becomes possible over the entire NSR in open water and open ice. That is why the information volume, necessary to prepare specialized ice forecasts significantly declines. There is no need for detailed characteristics of the close ice state on the route (due to its absence). The information volume necessary to calculate the navigation difficulty indicators is reduced and sometimes there is no need for such calculations. For easy ice conditions the information on the direction and the value of the shift of the close ice (ice massifs) limits becomes the main one, especially in cases of its close location to the shipping routes. Also important is information on the hydrological processes (heat content of the active sea layer, surges, etc.), necessary to estimate the type of natural hydrological processes and their transformations.

As can be seen, the number of factors estimated can be considered to be approximately equal (of one order of magnitude) for different seasons of the year and differs considerably for different navigation types.

The accuracy of the assessment of natural characteristics during the heavy types of years should be higher, that is, the errors should be smaller. However, the accuracy of the determination of the environmental characteristics in the modern ISSOS is not dependent on the type of navigation difficulty, but is governed by the capabilities of the means producing information in each ISSOS subsystem.

To determine the range of the change of X factors, according to (3), let us consider the study, made at the Department for Long-Range Weather Forecasts of the AARI (Korzhkov, Kuznetsov, 1993).

Fig. 7-10 presents the features of a spatial-temporal distribution of the variability of the prevailing directions of air flows (WD 120°) from August 15 to October 15 for two groups of years: 1968-1970 and 1986-1988.

In the first group of years heavy ice conditions in the north-east of the Kara Sea and easy ice conditions in the east of the Laptev Sea, west of the East-Siberian Sea prevailed, being close to a norm in the Chukchi Sea.

In the second group of years easy ice conditions were observed in the Kara sea and western East-Siberian Sea, close to a norm - in the west of the Laptev Sea, east of the East-Siberian and in the Chukchi Seas.

Fig. 7 presents the map of the occurrence frequency of the deviations of the directions (WD 120°) from one elementary synoptic process (ESP) to the other over the seas of the Russian Arctic in 1968-1970.

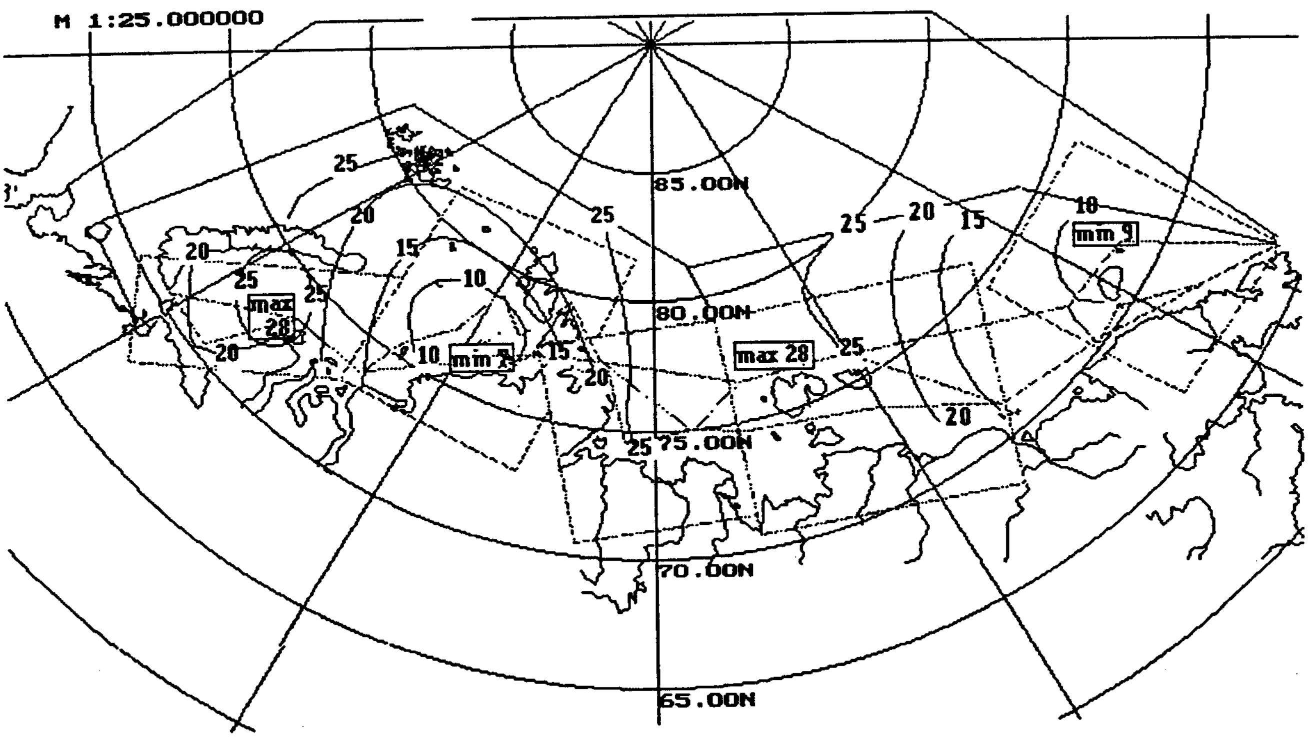


Fig. 7. Occurrence frequency (%) of the deviations of the directions of air flows by the value not less than 120 degrees (WD > 120) from one elementary synoptic process (ESP) to another from August 15 to October 15 for 1968-1970.

The occurrence frequency by the ESP of the deviations of the directions (WD 120°) from mean multiyear values over the Arctic seas for one and the same group of years is presented in Fig. 8.

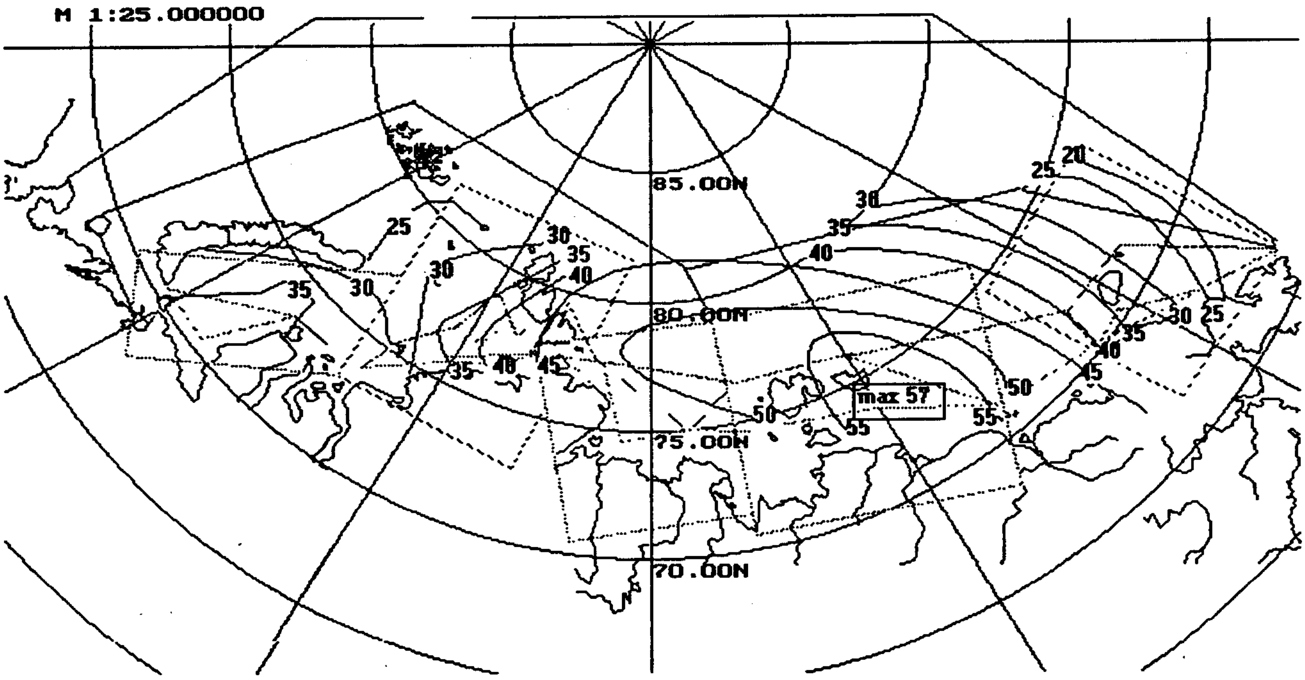


Fig. 8. Occurrence frequency (%) of the deviations of the directions of air flows WD>120° from mean multiyear during the period from August 15 to October 15 for 1968-1970

The maps for the groups of years of 1968-1988 are given in the same succession in Fig. 9, 10.

The analysis of the data presented in Fig. 7-10 indicates that the minimum variability of the directions (WD 120°) during the period from August 15 to October 15 was observed in the north-east of the Kara Sea where in 1968-1970 heavy ice conditions were formed. Near the western coast of Taimyr it was only 7%. In the east of the Laptev Sea and the west of the East-Siberian Sea where easy ice conditions were formed, the variability of the directions (WD 120°) increased up to 20-28%. Over the same regions in 50-70% of the cases of all ESP of the most favourable navigation period the directions of the flows WD deviate from mean multiyear ≥ 120° (Fig. 8, 10). At the same time over the largest part of the area of the north-eastern Kara Sea WD deviated from the directions of the climatic flows ≥ 120° in 25-30% of the ESP. It is also seen from Fig. 7 and 8 that over the extreme east of the Kara Sea and B.

Vil'kitsky strait the stability of the directions (WD) decreases by 1.5-2 times, as compared with the remaining area of the north-eastern sea region which, undoubtedly, affects the conditions of the ice hydrometeorological regime formation in this region.

In the second group of years when an easy ice situation was observed in the western Arctic, the variability of WD directions by the ESP over the largest part of the Kara Sea increased by 1.5-3 times as compared with the same period in the group of years 1968-1970 (Fig. 9, 10). In the Laptev Sea in the west of which heavy ice conditions formed, the stability of the directions (WD) increased by 4-7%. In the East-Siberian Sea where heavy ice conditions were observed in the east and also in the Chukchi Sea where they were heavier than those of 1968-1970, the WD variability by direction, vice versa, decreased by 1.5-3 times.

The analysis of deviations of the directions (WD 120°) from mean multiyear values indicates that under easy ice conditions in the Kara Sea they are more often (up to 50% of the ESP of the favourable period) observed in the north of the sea which is twice as high as their occurrence frequency under heavy ice conditions (Fig. 8 and 10).In the Laptev Sea the occurrence of deviations in the directions WD 120° decreased by 10-20% as compared with the same period of 1968-1970. In the east of the East-Siberian and the Chukchi Seas the occurrence frequency of deviations of WD 120 from mean multiyear flows increased by 10-35% as compared with 1968-1970 when easier ice conditions were observed in this region.

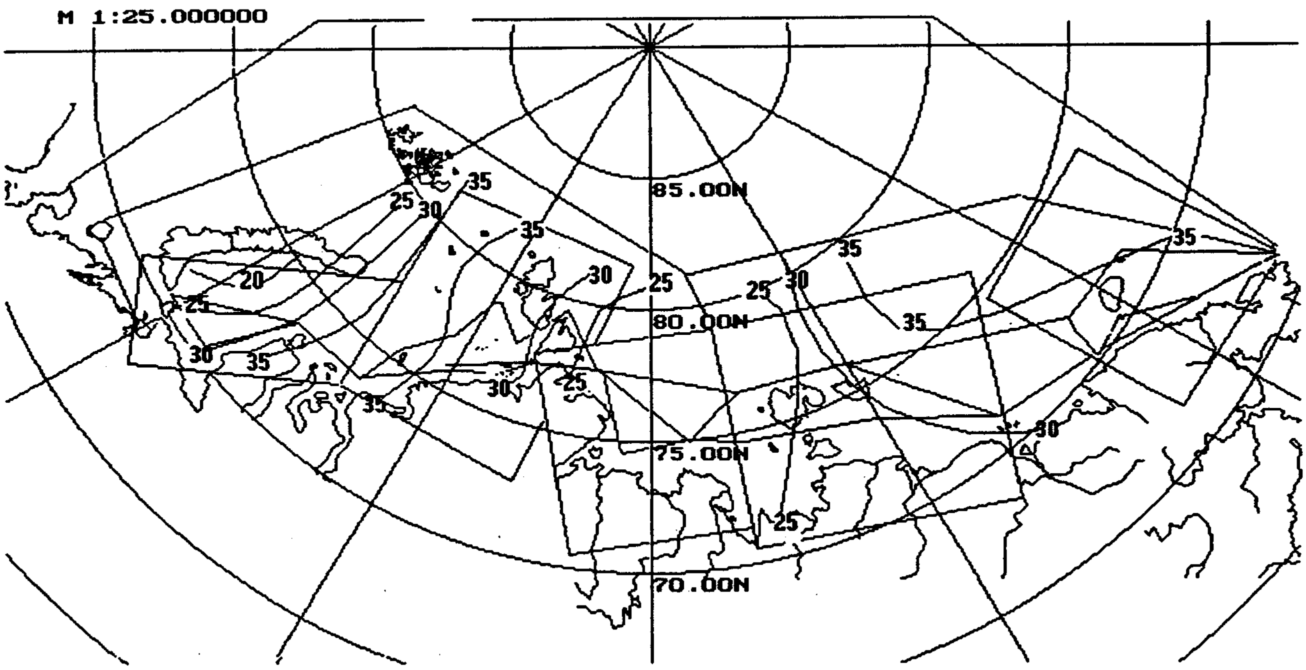


Fig. 9. Occurrence frequency (%) of the deviations of the directions WD > 120° of air flows from the ESP to ESP during the period from August 15 to October 15 for 1986-1988

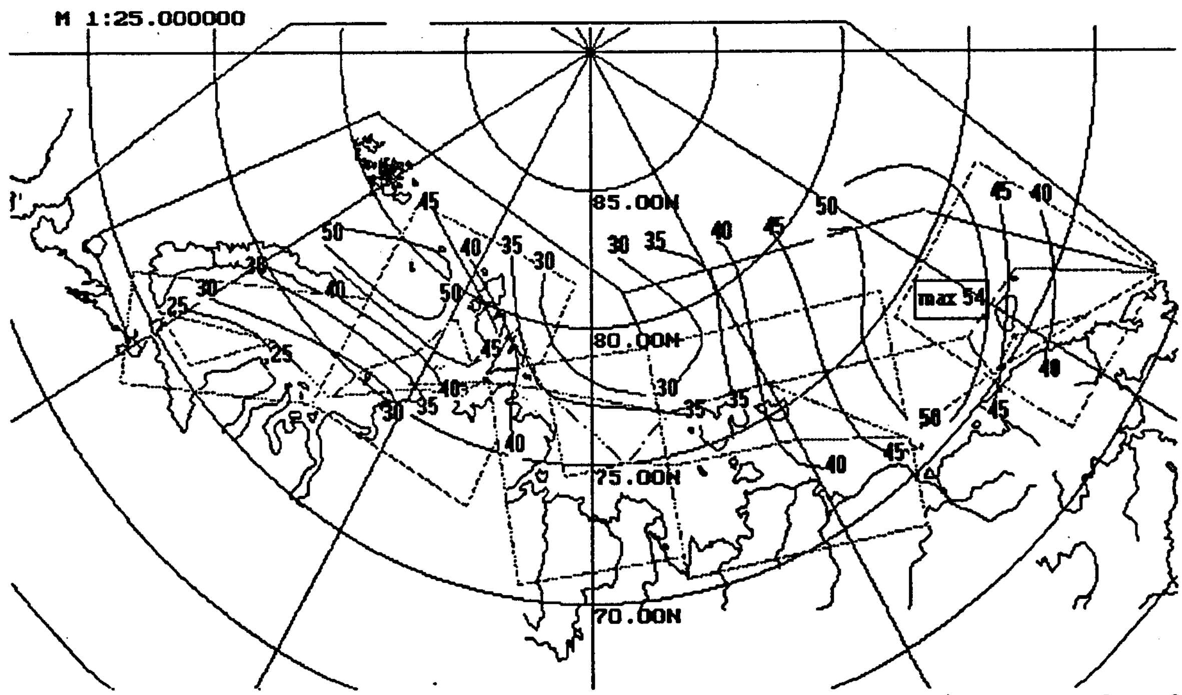


Fig. 10. Occurrence frequency (%) by the ESP of the deviations of the directions of air flows WD>120° from mean multiyear during the period from August 15 to October 15 for 1986-1988

As a result of the analysis, the following preliminary conclusions on the relationship of the variability of atmospheric processes with ice conditions in the Arctic Seas during the period most favourable for transit navigation along the NSR (from August 15 to October 15) can be made:

- in the Kara Sea the stability of atmospheric processes increases with the increase in difficulty of ice conditions. This is indicated by the decrease in the occurrence frequency by 1.5-3 times of changes in the directions of air flows from the ESP to ESP;
- under heavy ice conditions in the Kara Sea the stability of atmospheric processes over the B.Vil'kitsky strait is twice as low as near the western coast of the Taimyr peninsula;
- the tendency of an increase in the stability of atmospheric processes with an increase in the difficulty of ice conditions persists for the Laptev Sea and the west of the East-Siberian Sea;
- in the east of the East-Siberian and in the Chukchi Sea, vice versa, with an increase in the difficulty of ice conditions the instability of the atmospheric processes increases;
- a decrease in the instability of the atmospheric processes with the decrease of ice cover extent in the Kara Sea is also indicated by the occurrence of deviations in the direction of air flows from mean multiyear values.

While over the Kara Sea, especially its northern part in August-October one expects a synoptic process considerably differing from mean multiyear pressure (WD ≥ 120°), during the period from August 15 to October 15 the probability of the formation of easy ice conditions on the western NSR segment increases. A similar relation of synoptic processes, climate and ice cover extent, only weaker, is observed for the Laptev Sea and the west of the East-Siberian Sea. In the east of the East-Siberian and the Chukchi Seas the relationship changes the sign: the larger the difference of the synoptic processes from the mean multiyear pressure field (WD > 120°), the larger the probability for the formation of heavy ice conditions in the east of the Arctic.

The obtained conclusions indicate the existence of significant differences in the character of the synoptic processes at heavy and easy ice conditions in the Arctic seas. They can be used during the interpretation of long-range pressure fields with the aim of forecasting the ice conditions on the NSR.

To obtain more reliable conclusions on the relationship of the stability of the atmospheric processes with the ice cover extent in the Arctic Seas it is necessary to carry out studies based on a long observation series.

As follows from the study made, the range of change in the estimated natural factor, in this case of the deviation in the directions of air flows, in the regions with heavy type of ice conditions on an average exceeds two-fold such range for easy and medium types of ice conditions. Hence, we have a ratio:

$$X_{OT} \cong 2 X_{OC}$$

where X_{OT}, X_{OC} - the range of changes in the parameters for heavy and medium types of navigation, respectively.

Taking into account that $\delta_{XT} = \delta_{XC}$, substituting into (3) the values sought,

$$\Delta X_{C \to T} = H(X_T) - H(X_C) = -lg_2 \frac{\prod_{i=1}^{n} 2X_{OC}}{\prod_{i=1}^{n} \delta x_{oc}} + lg_2 \frac{\prod_{i=1}^{n} X_{OC}}{n\prod_{i=1}^{n} \delta x_{oc}}$$

hence, $\Delta H_{C \to T} > 0$.

Thus, the information enthropy (uncertainty) of the ISSOS at heavy navigation types is always higher than that for medium and moreover, easy types. Hence, the informativity of the ISSOS, functioning under the conditions of heavy navigation type, will be lower than at other types at the condition of constant energy resources of the system.

Such conclusion, made on the basis of the information description, is confirmed by experience of the ISSOS operation.

The need for preserving or increasing the informativity of the scientific-operational support system is evident. This, in fact, means an increase in the effectiveness of its operation by increasing its energy resources. An increase in the energy resources of the system is impossible without a comparison and interrelation of the morphological and the information description of the existing system. And such activities govern one of the directions of the ISSOS improvement.

4 ORGANIZATION OF HYDROMETEOROLOGICAL SUPPORT TO THE OPERATIONAL MANAGEMENT OF MARINE OPERATIONS DURING TRANSIT NAVIGATION ALONG THE NSR

There is still no regular through navigation along the NSR. The experience of some transit voyages, particularly in the most complicated conditions at the beginning or end of navigation provides convincing evidence of the need to take into account the differences between coastwise and transit navigation, both with regard to the organization and hydrometeorological services to these voyages (Makarov, 1991).

It is understandable that the hydrometeorological support to transit voyages, including foreign ships should be based on the operating system.

Thus, the present section briefly describes the main aspects of the hydrometeorological support (HMS) to the Arctic Marine Transportation System (AMTS) at the present time and the proposals for its improvement taking into account special features of transit shipping.

4.1 System for the acquisition, processing, analysis and presentation forms of the operational information on natural conditions

The organization of the operation of AMTS, including its HMS is regulated by the formal documents (Instructions, 1983; A Handbook, 1974). The management of ice navigation on the whole is carried out through the administration of the NSR (ANSR) under the Russian Department of Marine Transport(DMT). The general management of the hydrometeorological services for the fleet operations on the NSR is carried out by the Arctic and Antarctic Marine Administration (AAMA) of Rosgidromet.

For the operational management of marine operations directly on the NSR the Murmansk and Far Eastern Shipping Companies set up the Headquarters of Marine Operation (HMO).

The Headquarters of the western region of the Arctic are based on Dikson island in Pevek port. The boundary between the regions is along 125°E.

For the hydrometeorological support special divisions - scientific-operational groups (SOG) of the specialists of the Territorial Administrations of the Hydrometeorological Service (TAHMS) and the Arctic and Antarctic Research Institute (AARI) are formed at the HMO.

The Arctic Seas of the Siberian Shelf are divided into zones within which the entire complex of HMS is carried out by TAHS. The AARI is responsible for the specific HMS functions, first of all through the automated ice-information system (ALISA).

All hydrometeorological information (HMI) - actual, prognostic, review-analytical is reported to SOGs for the support of the effective and safe work of the fleet. The information content, the form of its presentation and the time interval are regulated by special documents, requirements of the user and agreements.

The SOG specialists conduct the analysis of the entire information along the whole management region and main attention is given to the parts of marine operations. SOGs inform the administration of marine operations and the navigators about the current natural conditions, expected changes in the characteristics of these conditions, governing the shipping (meteorological, ice, hydrological) with different periods in advance.

In recent years the specialized hydrometeorological information including specialized ice forecasts prepared for the planning and implementation of the specific sea operations (see section 3) becomes widely used.

Thus, the existing system for operational planning and management of marine operations and their hydrometeorological support through the HMO and SOGs is mainly oriented to supporting the effective operations of the fleet in the management zones. As a result, there is no priority in icebreaking-hydrometeorological support for transit ships, although in specific conditions it is due to priority that a through voyage can be a success.

It should be noted that the operating system of hydrometeorological services has some shortcomings and their elimination can contribute to an increase in the effectiveness of its operation in general and in particular with regard to transit shipping. The main shortcomings and the approach towards the improvement of the hydrometeorological services are considered below.

The difference between coastwise and transit navigation along the NSR, mentioned above is in our opinion as follows.

With coastwise navigation the progress of transportation means takes place along the routes more or less fixed geographically governed not only by the location of the destination places, but mainly by the features of natural conditions. The classification of such natural conditions is carried out on the basis of criteria of their being uniform in time and space. A set of such criteria indicates the ice-navigation regime of the given region: optimal navigation routes, the most informative characteristics of natural conditions, etc. They allow identifying the periods corresponding to arbitrary-monotonous "improvement" (in the "warm" period of the year) and "deterioration" (in the "colder" period), as well as to the division of these periods into subperiods on the basis of monotonous criteria of the latter. In such a way it is possibie to plan cargo transportation along each direction (route).

Transit navigation in the general form can be represented by a set of the routes mentioned. It is evident that when planning such operations one cannot use spatial-temporal homogeneity criteria similar to those used for coastwise navigation.

At present the system of management of marine operations and its hydrometeorological information subsystem are organized on the principles of mass coastwise cargo transportation and single transit voyages.

From this point of view the identification of the zones (regions) of responsibility both for the management system and zone of the hydrometeorological support system adequate to it appears to be optimal.

However, it is the organization of the management of transit navigation that creates certain difficulties which must be taken into account during the establishment of the system for regular transit shipping along the NSR.

First, let us define the purpose of establishing such a system. From general considerations its obvious purpose is to provide for a guaranteed by time and safe navigation of commercial vessels within the limits of the NSR (geographical and legal).

It is clear that like any other system this one should have a set of parametrs, the range of changes which according to the existing constraints for technical, organization and economic decisions, provides for the fulfilment of its main purpose.

Let us consider one of the parameters of the management subsystem (Druzhinin, Kontorov, 1976) assuming that the system of transit shipping consists of two subsystems. According to the allowances of the binary decompositions of the systems we have the management sybsystem (S_1), including the system of hydrometeorological services and the executive system (S_2), including the technical means of icebreaking support, as well as time resources.

One of the parameters of the management subsystem is the passage capacity of the routes - density of the flow of ships (number of units of a specific tonnage) on a specific direction of cargo transportation (measured in length units) for a definite time interval. Its value depends on the number of the "n" resolution of the management subsystem. Let us assume "n" to be a number of the management parameters of the time periods arbitrarily uniform by a constancy criterion in the western region of the management of sea operations.

$$n = \frac{\Omega_0 R_0 A_\varepsilon \Delta f}{\lambda^2 k_n}$$

where Ω_0 - responsibility zone of the management sybsystem;

R_0 - distance range of the information means of the management subsystem referred to the uniform management period;

A_ε - effective survey area allowing for a strict assessment of the situation to make a guaranteed decision in the given geographical region;

Δf - specific informativity of the management subsystem means;

λ^2 - value, reverse to the value of the uniform management period for the entire responsibility zone;

k_n - coefficient, normalizing the dimension of the formula.

Let us note that the specific values of the parameters in the formula given above govern the properties of the management subsystem within its responsibility zone. The moderm AMTS includes two management subsystems of marine operations. As already mentioned, the western and eastern responsibility zones correspond to them.

Let us define the restrictions for the values of the management parameters on the basis of data (Buzuyev, 1991). It is proved that the western NSR segment is characterized by "many variants" of the optimal navigation route, as compared with the eastern segment where changes in its position are insignificant. Hence, by designating the number of the navigation variants as m^w; m^0 for the western and eastern segments, respectively, one can assume:

$$m^w \cong 2m^0$$

Considering:

$$\Delta f \cong m$$

We obtain:

$$\Delta f^{w} \cong 2 \Delta f^{0}$$

The extent of the "heavy" navigation segments (at mean velocities $\vartheta_{ie} \geq 3$ knots) for the Western region is about 50-70% of such extent for the Eastern region of the Arctic both for the winter and summer periods (Table 2) (Buzuyev, 1991). On the basis of this we assume:

$$A_{\varepsilon}^{w} \cong 0{,}5 A_{\varepsilon}^{0}$$

Table 2. A relative extent of the way (%), on which $\vartheta_{ie} \leq$ 1.0-3.0 knot

Convoy composition	Calculated value (knots)	Western segment		Eastern segment	
		Summer	Winter	Summer	Winter
nuclear icebreaker of the "Arktika" type	2-3 knots	0.02	0.24	0.03	0.33
and one ship of the "Amguema" type	1.0-1.5 knots	0.01	0.16	0.02	0.23

The most probable (60-70%) appears to be the existence of the types of ice conditions opposite by difficulty on the routes of the Western and Eastern regions of the Arctic (Table 3) (Adamovich, 1985).

Table 3. Occurrence frequency of the navigation conditions of one type and different types ("cold" season) on the Western and Eastern segments simultaneously

Combination of types	Easy type on both segments	Heavy type on both segments	Medium type on both segments	Different types on both segments
Occurrence frequency (%)	0.04-0.07	0.08-0.17	0.09-0.23	0.80-0.76

Hence, the ratio:

$$\lambda^{w}=\frac{1}{\lambda^{0}}$$

is logic.

Let us use the obtained estimates for the following ratio:

$$n^{w}-n^{0}=\frac{\Omega_0 R_0 A_\varepsilon \Delta f}{\lambda^2 k_n}-\frac{\Omega_0 R_0 A_\varepsilon \Delta f \lambda^2}{k_n}=$$

$$=C\left(\frac{1}{\lambda^2}-\lambda^2\right)\Delta f=C\Delta f(\tau^2-\lambda^2)$$

Considering that:

$$\Omega_0^{w}\cong\Omega_0^{o}$$
$$R_0^{w}\cong R_0^{o}$$
$$C^{w}\cong C^{o}=const$$
$$\Delta f^{w}\cong\Delta f^{o}=const$$

Let us define the E energy as the effectiveness criteria of the considered AMTS system, directed to maintain the passage capacity of the routes, the collection and processing of information on the situation in the management routes, in other words, on the informativity of the I system at a given level.

Let us introduce an additional parameter:

$$\beta=\log\frac{E_1 I_1}{E_2 I_2}$$

where: E_1, I_1 - energy resource and informativity of the management subsystem;

E_2, I_2 - energy resource and informativity of the executive subsystem;

then:

$$\beta^{w} - \beta^{o} = \log\frac{E_2^{o} I_2^{o}}{E_2^{w} I_2^{w}}$$

at the condition:

$$E_1^{w} I_1^{w} = E_1^{o} I_1^{o}$$

on the basis, that

$$C = f(E);\ \Delta f = f(I)$$

we have:

$$n^{w} - n^{o} \cong \log\frac{E_2^{o} I_2^{o}}{E_2^{w} I_2^{w}} = f(E;I)f(\tau)$$

where: τ - values of the uniform management period for the entire NSR (UMP of the NSR).

It follows from this formula that in terms of the systems approach the difference in the passage capacity is proportional to the ratio of energy resources and the informativity of the operating susbsystems for each management zone and requires additional energy resources, informativity and time resources in the framework of the common AMTS system. The need for additional energy, information and time resources is removed only in the event of equal passage capacities of the routes for each responsibility zone.

These conclusions are drawn making allowance for the equality of the energetics and informativity of the management subsystem which envisages the equality of the plans for marine operations when the transportation means are shifted from one management zone to another. An assessment coordination of such plans on the basis of a long-range ice forecast of the AARI in March exists at the stage of a preliminary planning of marine operations with 3-5 months in advance before the implementation. However, the practice of implementation of transit voyages in the early periods of summer navigation (May-June) shows that such distribution of energy resources by the AMTS subsystems does not guarantee the stability of the transit voyage in the indicated period. Let us note that under the stability of a specific transit navigation we understand the allowance for non-productive lags of the transportation means not more than 20% from the total time for the implementation of the entire operation.

In 30% of the cases of implementation of early transit voyages the delays due to ice conditions, exceeding 20% from the the total passage time appear outside the responsibility zone of the management subsystem, planning such operation (Table 4). In other cases there were no non-productive delays. However, the information given enables consideration of the problem of guarantee (reliability) of transit voyages from the positions of increasing the informativity of the management subsystem. Such conclusion follows from the fact that in the considered cases of "ineffective" voyages the reserves of the energy resources were maximum. Thus, in 1986 the voyage was made by the most modern transport of ULA class vessel the "Monchegorsk" escorted by the nuclear icebreaker "Rossiya". In 1988 the transit voyage was made by the nuclear icebreaker "Arktika" during a self-contained voyage (Table 4). Thus, the navigation effectiveness could be achieved only due to the time reserves. Also, at all stages of the operation management in 1986 the maximum errors of the time assessments were made right on the segments of the difficulties encountered (Table 5).

The generalization of the limited experience of the ship navigation (mainly of the SA-15 class) in early and late periods allows for a preliminary understanding of the actual conditions and navigation difficulty from the Kara Sea to Pevek (and back). The analysis of the possibility to foresee ice conditions long in advance indicates that with regard to ice cover characteristics governing the conditions and navigation difficulties on the segment under consideration, the development and introduction of the forecasting methods still encounter insuperable problems. At the same time the results of the studies of the ice regime, features of ice cover formation and destruction, its effect on shipping in the Arctic seas allowed one to work out the technology of the use of the accessible HMI on the navigation conditions during planning and, mainly operational management of ice shipping. The foundation for the creation of such technology has been laid during the preparation and implementation of the experimental voyages of the nuclear icebreakers "Lenin" (1971), "Arktika" (1977), "Sibir'" (1978), organization of the winter headquarter rehearsal of marine operations on the eastern

NSR segment, as well as during spring routings of the SA-15 ships from west to east in 1948-1986 (Adamovoch, Makarov, 1991).

Table 4. Summarized data on ice conditions and navigation difficulty from the Kara Sea eastward in May-June (from special shipborne observation data of the scientific-operational expeditions of the AARI)

Convoy composition and year	Main operation stages	Segment with the most difficult natural conditions	Delays on the most difficult segment
nuclear icebreaker "Lenin" icebreaker "Vladivostok" 1971	5/VI - Arktichesky cape 18/VI - Zhokhov island VI - Pevek port	Arktichesky cape - M.Taimyr island	65 hours
nuclear icebreaker "Sibir'" diesel/electric ship "Myshevsky" 1978	1/VI - Arktichesky cape 7/VI - Anisiy cape 13/VI - Serdtse-Kamen'	Zhokhov island - Shelagsky cape	12 hours
nuclear icebreaker "Arktika" M/V "Monchegorsk" 1984	19/VI - Cheluskin cape 22/VI - Kamenny cape	Taimyr ice massif (80 miles)	4 hours of continuous breaking
nuclear icebreaker "Sibir'" M/V "Kola" 1985	19/VI - Cheluskin cape 21/VI - Zhokhov island 25/VI - Pevek port		
nuclear icebreaker "Rossiya" M/V "Monchegorsk" 1986	19/V - Cheluskin cape 25/V - Vil'kitsky island 4/VI -Pevek port	Vil'kitsky island - Shelagsky cape	130 hours
nuclear icebreaker "Arktika" self-contained 1988	18/V - ice edge in the Barents Sea 20/V - Dikson island 23/V - Vil'kitsky strait 6/VI - Shelagsky cape	Vil'kitsky island - Shelagsky cape	216 hours progress is ineffective, mainly by ramming

Table 5. Expected from the specialized forecast and actual navigation difficulties of SA-15 class of ships

Year	Advance period of specialized forecast (month)	Calculated times (hour)	Actual times (hour)	Forecast error %	the NSR segment
Spring period (May-June)					
1993	2.5	426	617	45	Dickson - Uellen
1993	2.5	78	63	19	Dickson - Faddeya isl.
1993	2.5	72	48	34	Faddeya isl. - Shalaurova cape
1993	2.5	180	392	118	Shalaurova cape - meridian 180°
1993	2.5	96	114	19	meridian 180° - Uellen
1993	1	504	617	22	Dickson - Uellen
1984	2	256	183	144	Murmansk-Pevek
1984	2	168	68	147	Anisiy-Shelagsky
1986	2	40	37	8	Zhelaniya-Vil'kitsky
1984	1	112	46	145	B.Vil'kitsky-Anisiy
1986	1	118	298	60	Anisiy-Shelagsky
1984	0.5	24	22	8	Zhelaniya-Vil'kitsky-Anisiy cape
1984	0.5	38	37	4	
1984	0.5	53	46	15	
1986	0.5	59	55	7	B.Vil'kitsky-Anisiy cape
		71	55	29	
1984	0.1	66	68	2	Anisiy-Shelagsky cape
1986	0.1	68	63	8	
1986	0.1	165	298	45	
Fall period (November)					
1985	0.1	82	75	9	Edge-Bear islands-125 meridian
1985	0.1	29	28	4	
1985	0.1	31	26	19	
1985	0.1	75	75	0	
1985	0.1	14	15	7	
1985	0.1	10	12	17	
1994	0.5	240	204	15	Dickson - Uellen
1994	0.3	42	34	20	Billings cape - Kolyuchin isl.
1994	0.3	48	34	30	Matissen strait - Petr islands

The technology in a relatively complete form is implemented relative to the objectives of the operational shipping planning and management in winter time on the western NSR segment (Makarov, 1990). It envisages (Fig. 11):

- presentation from the MMF of the initial information on the operations planned (time, ports of departure and destination, convoy composition and icebreaking support); depending on the advance period of the operation preparation such information is reported either to SOG (up to 30 days in advance) or to the AARI;
- presentation of data on natural navigation conditions (weather, ice data) on the basis of the data of forecasts, regime generalizations (mean multiyear data) and their interpretation in the form of the distribution of ice cover characteristics for the possible navigation variants, navigation recommendations on the most favourable route and expected navigation difficulties by separate segments; generalized characteristics of natural conditions and navigation recommendations are submitted to the DMT institutions effecting the planning and management of the operations (State Inspection of Marine Operations, shipping companies, ANSR), Glavflot);
- corrections with the approaching of the date of the operation and the income of additional information both with regard to the content of marine operations and the expected navigation conditions and difficulty;
- compilation of a composite ice chart and special ice observations (with the use of the "Akvamarin", "Nit' equipment, etc.) directly before operation beginning an during its implementation; the formulation of the operational navigation recommendations;
- analysis of the consistency between the expected and actual conditions and difficulties of navigation and the conclusions on the further improvement of the SCS and the technology on the whole.

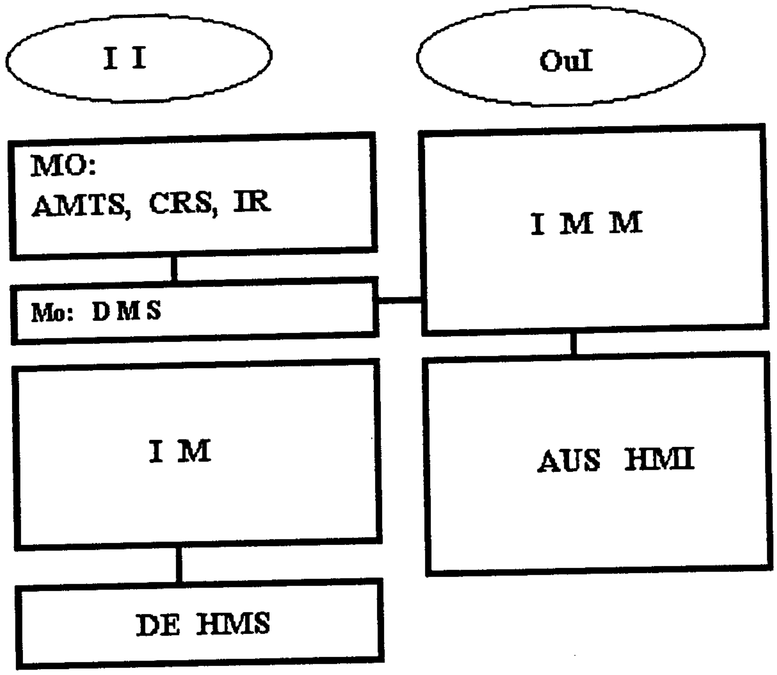


Fig. 11. The technological scheme of the specialized SOS in Westernarctic SOGs for NSR marine operation

ABBREVIATIONS:

II	- Input information,
MO	- Management objects:
AMTS	- Arctic marine transports system,
CRS	- Cargo flow by the route segments,
SIR	- Specific icebreaking routings,
Mo	- Management objectives,
DMS	- Definition of the management stage,
SII M	- Identification of the interaction model of the management object (relation functions), information accumulation and analysis in the implementation process of the management stages (reverse relations), analysis of model errors and sensitivity, model adjustment,
DE HMS	- Development of the HMS effectiveness criteria, assessment of the verification score of the forecasts, calculation of the economic effect,
OuI	- Output information,
IMM	- Interaction model of the management object with the external conditions, background of HM conditions in the specialized terms, background discretization, specialized forecast for 8-10 days by the route segments, specialized forecast for a specific operation
AUS HMI	- Algorithm for the use of specialized HMI, recommendations for the optimal dates of the beginning and end of the management stage, changes in the convoy composition, localization of the optimal routes, forecasting of the operation modes of transportation means.

The last item is quite principal, however, its implementation is often affected by the subjective factors, the absence of the objective approach to the estimates of the navigation difficulty conditions on various scales (background, on separate segments, on the whole on the route, etc.). The main reason is that the "actual" ice conditions, assessed by means of airborne ice reconnaissance, other remote sensing methods for ice cover (SLAR, satellites, etc.) can differ significantly from ice conditions on the direct route of the ship (convoy).

Summing it all up one can make the following conclusion. In order to achieve reliable and effective transit shipping along the NSR it is necessary:

- to establish a common system for planning and operational management of transit shipping, an important component of which appears to be the HMS subsystem;
- to prepare the database on the environmental elements which produce the most significant effect on shipping; one of the features of this base is taking into account the changes of the environmental elements in the process of the operation;
- to employ the systems approach to the organization of the HMS to the transit navigation of ships.

It is clear that fulfilment of these proposals requires time.

5 RELIABILITY OF THE HYDRO-METEOROLOGICAL SUPPORT TO THE OPERATIONAL MANAGEMENT OF TRANSIT NAVIGATION ALONG THE NSR TAKING INTO ACCOUNT THE LEVEL OF KNOWLEDGE OF THE ICE AND HYDROMETEOROLOGICAL REGIME OF THE ARCTIC SEAS

5.1 Concept of the reliable functioning of the operational information subsystem on natural conditions

At the present time the problem of the reliability of the systems, including the information ones, is considered to be problem No.1.

This problem of developing the estimates of the reliability of the information system of the scientific-operational support is formulated in this section for the first time. The obvious complexity of the problem allows one to consider the identification of the directions in this area and the choice of the most acceptable model for the ISSOS reliability calculation to be a solution at this stage.

The most rational way in our opinion can be the establishment of the relationship between the quality of the system functioning and reliability (Druzhinin, Sergeeva,1990).

For this one assumes the percentage loss of the functioning quality, found out earlier, to be the operating state of the system. And the output of random process realizations of the quality indicator change of the system functioning outside the allowance limits corresponds to the failure of the system, while the boundary crossing in the opposite direction - to the recovery of the operating ability. The common reliability indicators can be found by the values of the time of the appearance of failures and recoveries of the system. Under the quality of the ISSOS functioning we shall understand the result of its operation in the form of the data, corresponding to the existing quality standards for the information systems.

By data quality one understands a set of their properties, governing their suitability to satisfy definite requirements in accordance with their purpose (i.e. similar to the product quality according to GOST 15467-79). The quantitative characteristics of these properties appear to be the data quality indicators. For the data quality there exist the indicators of the purpose, characterizing the useful effect from the use of the data according to their purpose and governing the area of their use.

From the point of view of the user the data quality is governed by the fulfilment of the following conditions:

- data availability to the user at the necessary moment in time;
- coincidence (within the required degree of the details and accuracy) of the information model of the depicted phenomenon with reality.

The analysis of the reasons for the non-fulfilment of the conditions ennumerated above leads to the identification of some data properties, governing their quality and the quality of the functioning of the system.

Among these properties one can identify the internal properties which are preserved when the data are transferred to another medium (system), and the external properties, characteristic of the data which are in a specific medium (system) and which disappear when the data are transferred to another system.

The presence of the quantitative characteristics of the above data properties is considered to be a necessary condition for the assessment of the quality of the functioning and, hence, also the assessment of the system reliability. To obtain such characteristics is the goal for the near future.

Having determined the methods for the development of the estimates of the ISSOS reliability, let us choose the appropriate reliability model which enables the calculation of the estimates. For this the technology providing a relative reliability of the existing ISOSS should be clear. Such technology exists and is used in practice (Fig.12) (Gol'cman,1982). The structure of the presented technological block allows one to refer it to the class of the network models which have a successive-parallel structure. For such models there is an interval method for estimating the reliability of the operation system (Druzhinin, Sergeeva,1990). Its application is desirable for an approximate assessment of the reliability of the operation system in cases where the distribution laws of the operation duration are unknown. According to this method one determines the upper and lower limits of time consumption t_j^l and t_j^u at each line of the information link j, identified, for example, in Fig. 12.

Then the mode of the operation duration is estimated by the limits of the interval of its possible values. Then one calculates the operation duration at each line in the form of two limit functions of timeliness $q_l(t_j)$ and $q_u(t_j)$. To calculate $q_l(t_j)$ it is assumed that all the works included into the system under consideration have a minimum normalized mode $y_j^l = 0.25$; to calculate $q_u(t_j)$ it is assumed that for all the works the normalized mode has a maximum possible value $y_j^u = 0.5$. The calculations according to the network model are made for the conditions of the functioning of the ISSOS reliability block in different situations, for example, at heavy and medium ice conditions. And the reliability of the system is considered to be achieved if for a prescribed percentage of the total number of calculation realizations the conditions:

$$q_l(t_j) \leq q(t_j) \leq q_u(t_j)$$

are fulfilled.

Varying the quantitative characteristics of the data properties (quality indicators) the relationship between the estimates of the quality of the system operation and the reliability is established.

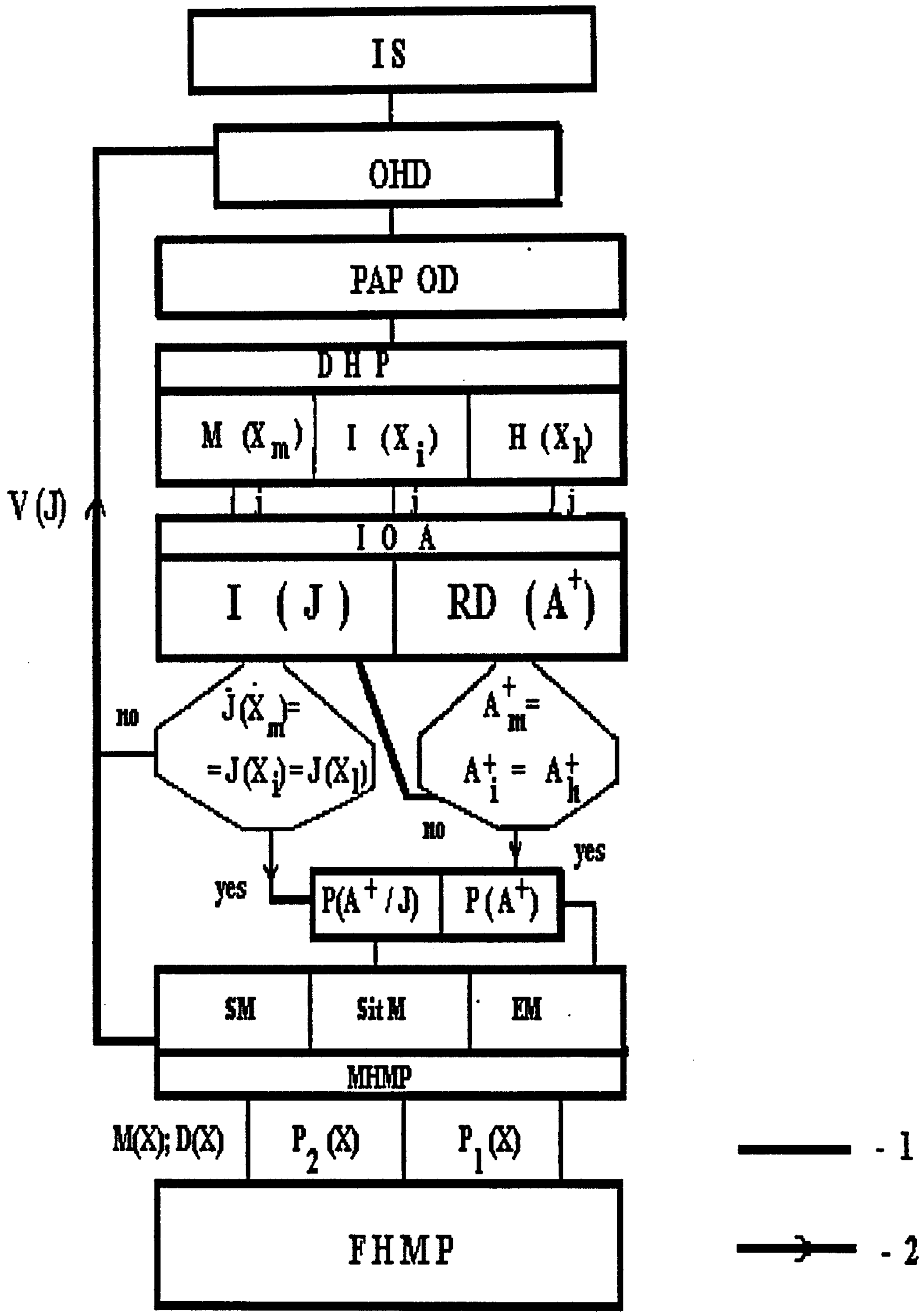


Fig. 12. A logical pert model of a single block for the provision of the reliability of the scientific-operational support

1 - information links, 2 - functional-management relations

ABBREVIATIONS:

IS	- Information source,
OHD	- Operational hydrometeorological data,
PAP OD	- Processing, analysis, presentation of operational data,
DHP	- Diagnostics of hydrometeorological processes,
M	- Meteorological,
I	- Ice,
H	- Hydrological
X	- Nature conditional parameters,
IQA	- Information Quality Analysis,
I	- Informativity,
RD	- Reliability of distinguishing,
SM	- Standard model,
SitM	- Situation model,
EM	- Evolution model,
MHMP	- Modelling of hydrometeorological processes,
FHMP	- Forecasting of hydrometeorological processes,

DESIGNATIONS:

V(J)	- plan of information collection,
M(X), D(X)	- statistical estimates of the information reliability (accuracy),
$P_1(X)$	- probability risk,
$P_2(X)$	- situation risk,
J(X)	- informativity of the realized V(J),
A^+	- mean probability by alternatives of the correct distinguishing of hydrometeorological process,
j	- index of the information links line.

5.2 Current state of the level of knowledge of the hydrometeorological and ice regimes taking into account varying spatial and temporal resolution

The ice navigation experience indicates the reliability of the operational support system to shipping in ice to depend to a great extent on the reliability of determining a set of necessary ice information for a specific moment in time and on the possibility of an assured forecasting of the changes of the characteristics of the set during the time necessary to fulfil the operation - as a rule, 3 -10 days.

Due to a large spatial-temporal variability of natural conditions in the Arctic seas the sets of ice parameters include those, on which mainly the navigation conditions depend. For all seasons this is, first of all, ice distribution in different regions by concentration and thickness (or age categories). These data are differentiated by types and serve as a basis for all further estimates and calculations. To take all other features of the ice cover structure and dynamics can be by indirect methods (Buzuyev, 1990).

In particular, at the beginning of the navigation period fast ice can be present on the ship's course, which leads to the necessity to calculate the time for breaking the channel in fast ice. Close ice navigation is often accompanied by compacting. The compacting is very closely connected with the wind direction and speed and is quite easily predicted by the data of weather forecasts. In the fall the pressures are accompanied by the adhesion of ice to the ship's hull ("ice cushion" phenomenon), and in some regions narrow zones with a very rapid drift appear ("ice river"). These dangerous ice phenomena are local and can be foreseen only on the basis of the ice regime of the specific sea regions and they are contained in special handbooks.

In winter the success of the voyages can to some degree depend on the presence of flaw polynyas and the systems of discontinuities in the drifting ice. But the winter voyages are made only in the south-western Kara Sea on the route Novozemel'skiye straits - Dudinka port.

Systematic data on winter navigation conditions are available only for this region and cannot be extended to the other seas. For this additional studies are required.

Thus, the main initial information for the transit navigation planning appears to be the maps of drifting ice distribution by concentration and thickness (or age category) in the specific regions. Multiyear regime studies, carried out at the AARI have allowed one to combine all diverse types of ice distribution for all the seas into several distribution types and develop the sets of meteorological and hydrological processes, forming some distribution type or other.

The development of the forecasts of the future type of ice distribution is presented in the section of the Report devoted to the short- and long-range ice forecasts. Here we shall dwell only on the justification of the presentation of initial ice data necessary for planning and management of marine operations in the form of ice distribution types.

The point of using the ice distribution types for the operational planning of marine operations is in the sufficiently confident expected development of the ice process on the basis of the actual ice cover and the suggested development of the atmospheric, hydrological and ice-dynamic processes.

The division of ice conditions into types, initiated in the 40s by Viese, Karelin, Gordienko, Treshnikov, Somov, Ivanov, Kirillov, etc., was further developed at the AARI in the 50s and 60s (Gudkovich, Kirillov et. al., 1972).

During the last decade studies on the search of the objective methods for dividing ice conditions into types in the uniform hydrological sea regions were carried out (Krutskikh, 1979).

The identification of the uniform hydrological regions (UHR) by the objective features, characterizing a definite stratification of the water masses, identical conditions of insolation and heat exchange with the atmosphere, uniaxial changes of the hydrological and ice characteristics have considerably strengthened the base for the division of ice conditions into types in the seas with a sufficient space interval.

A synoptic variability of the water and ice dynamics in the uniform hydrological regions is 80% governed by the change of the pressure and wind fields. It became possible to combine all of them into 6 groups of the development of the synoptic processes (Krutskikh 1963; 1970; 1971; 1972; 1973) and the diagrams of the dynamic processes corresponding to them (Fig. 13).

The period of the unaxial dynamic process can be called a natural hydrological period (NHP), the duration of which in the Arctic Seas in 87% of all cases is 2-10 days at mean duration of 7 days.

The synoptic processes in the Arctic are forecasted from 3 to 8-10 days with the confidence of about 85%. This is a good basis to forecast the dynamic hydrological and ice processes in the uniform hydrological regions.

The six groups of the dynamic processes in the seas differ by a large scale of level variations, water and ice circulation at the background of which local smaller-by-scale water and ice gyres are formed.

The analysis made of different systems of dividing ice conditions into types in local sea regions has shown all areas with uniaxial changes of ice conditions to be in good agreement with the uniform hydrological regions in most cases.

One - three ice regions with the ice characteristics not much changing in space and differing by a uniaxial change in ice conditions during the natural hydrological period (Fig. 14) can be situated within one hydrological region. Such sea regions are called natural ice regions (Yegorov, Spichkin, 1990). In natural ice regions (NIR) the temporal variability of ice conditions is closely related to the dynamic processes during the NHP. The objective of assessing and forecasting changes in ice conditions within the NIR refers to the division of ice distribution into types and to possible changes in the initial distribution under the effect of the forecasted dynamic processes during the NHP.

The natural ice regions were identified by the data of ice observations from 1940 to 1991, presented as the regular grid squares with a 50 km spacing. Most indicative for the regions appears to be the occurrence of the ice presence in three main concentration gradations: 7-10/10, 1-6/10, open water. To delineate the boundaries the difference of the occurrence frequency of the ice of different concentration in adjacent squares was determined. The thus obtained NIR are quite justified statistically and, as mentioned above, they are in agreement with the UHR.

The assessment of ice conditions within the NIR to meet the demands of shipping is made, as a rule, within the three main gradations - easy, heavy and medium ice conditions. Their examples for the strategic regions are given in Fig. 15 where ice concentration distribution is shown. In addition to concentration at the charts of standard ice distribution, and they can be up to three for each gradation, one also plots other ice characteristics - ice age category, snow amount, degree of destruction, compacting, important for the given time.

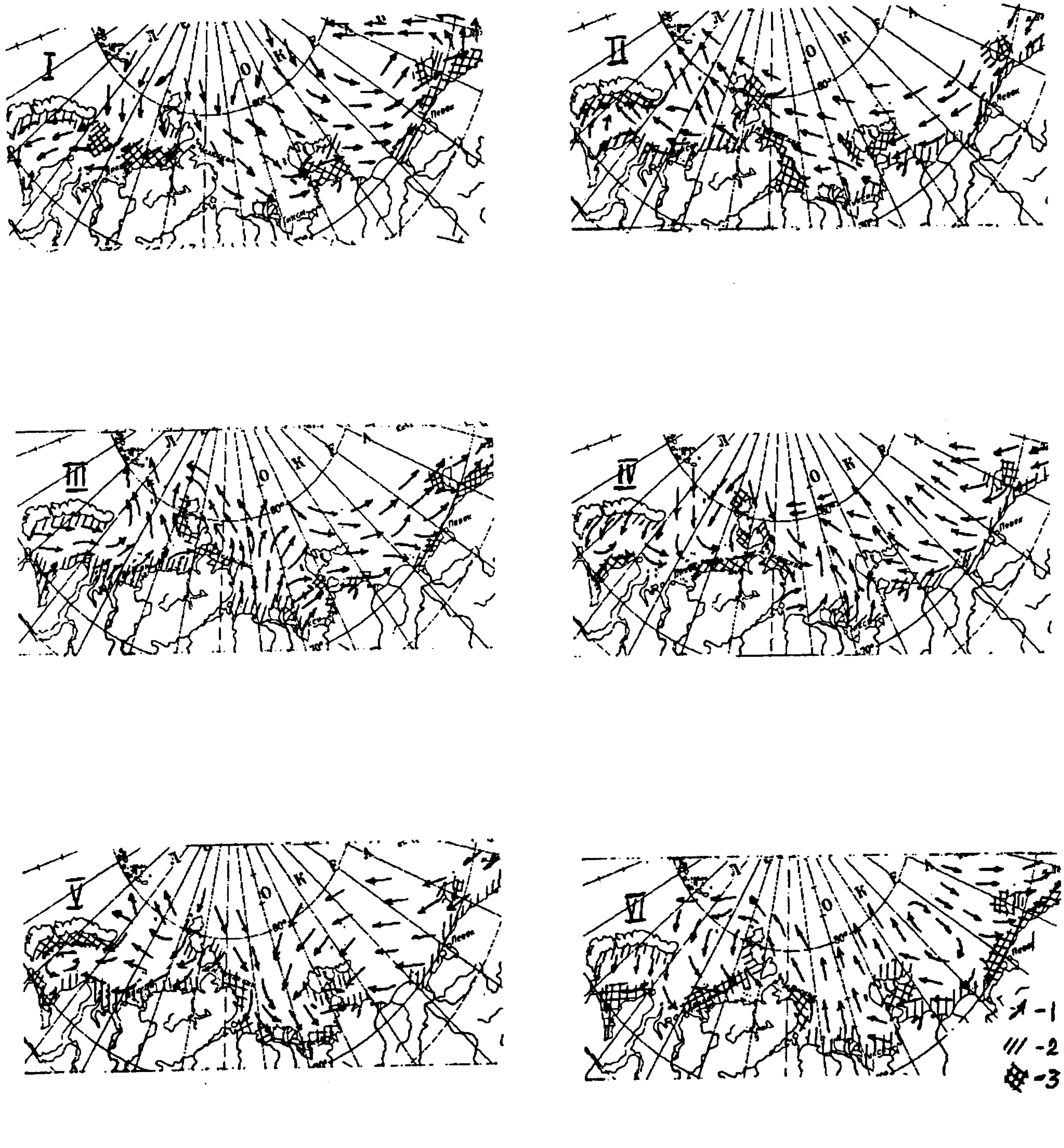


Fig. 13. Ice drift at different types (I-IV) of dynamic processes:

1 - drift direction, 2 - open ice, 3 - close ice

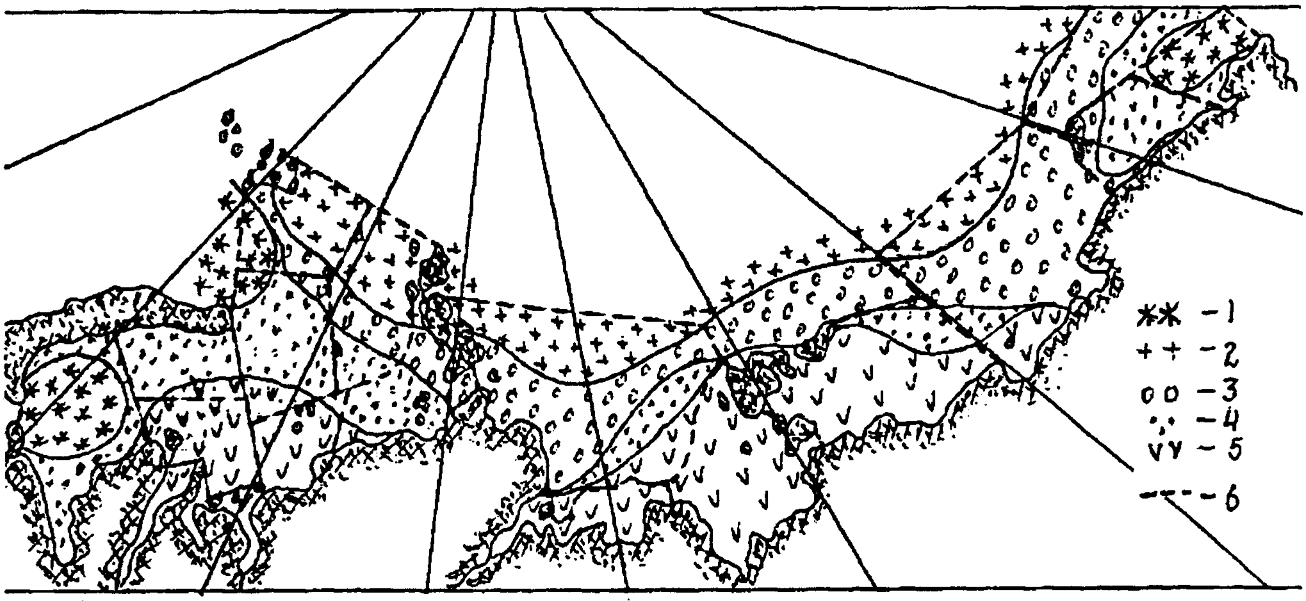


Fig.14. Scheme of uniform hydrological and natural ice regions:

1 - Barents sea and Pacific Ocean waters, 2 - surface waters of the Arctic basin, 3 - surface waters of the Arctic seas with ice presence, 4 - surface waters of the Arctic seas in the absence of ice, 5 - brackish sea waters, 6 - boundaries of natural ice regions

Thus, the division of ice distribution into types made for easy, medium and heavy ice conditions in the NIR comprehensively taking into account the role of the dynamics of the meteorological and hydrological processes in the UHR allows for a quite complete characterization of the actual ice conditions in any region of the Arctic Seas and forecasting of their changes on a synoptical spatial-temporal scale on a common physical-statistical basis.

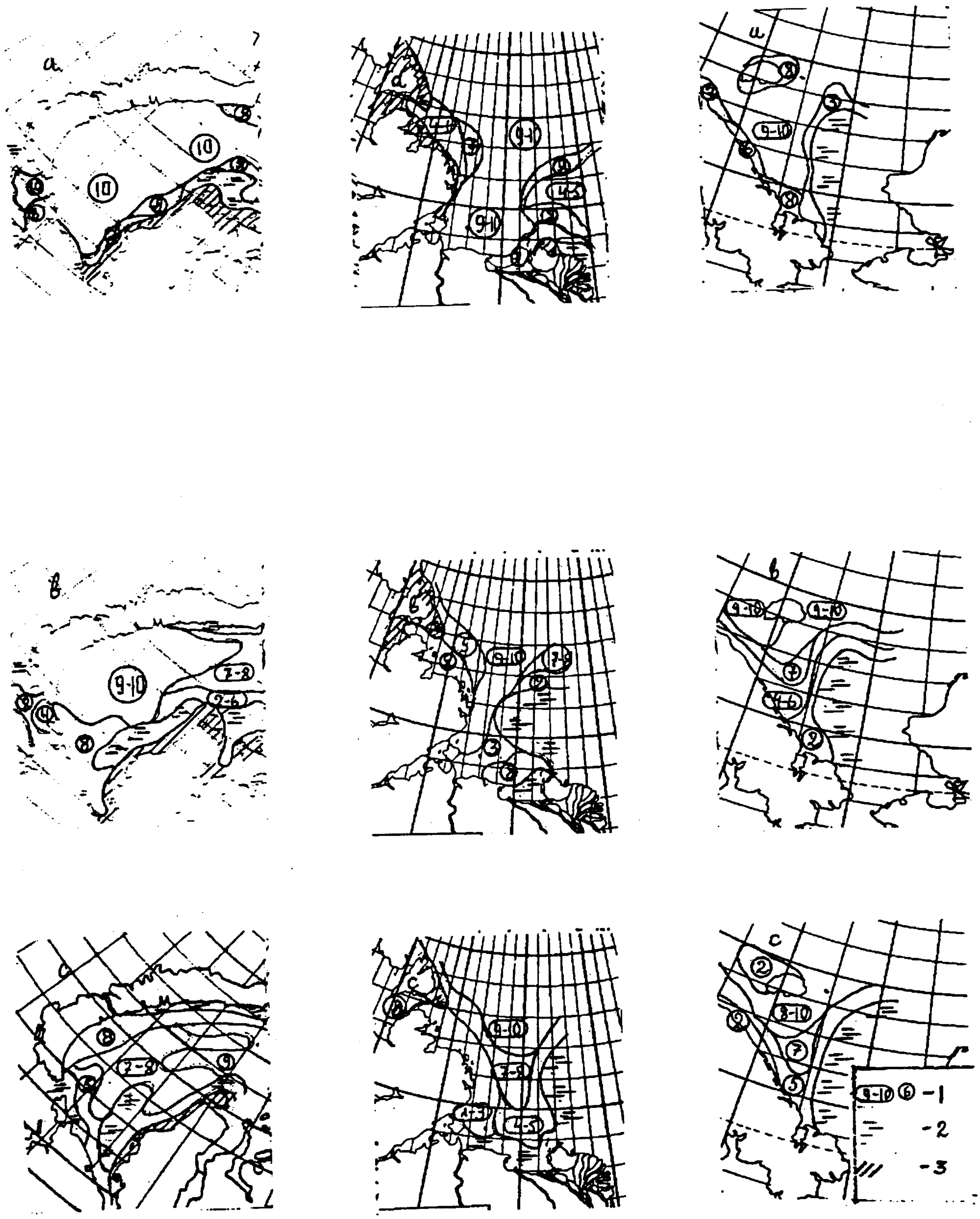


Fig. 15. Distribution of ice concentration at heavy (a), medium (b) and easy (c) conditions in some sea regions: the Kara Sea -late June, the Laptev Sea-late July, the Chukchi Sea-mid July (1 - ice concentration, 2 - open water, 3 - fast ice)

6 PROSPECTS TO IMPROVE THE SYSTEM FOR THE OPERATIONAL INFORMATION ON NATURAL SHIPPING CONDITIONS

Considering the AMTS to be a complex production system with inherent development dialectics, further studies of the system for the scientific-operational hydrometeorological support, which experiences the transformation effect of the "senior" fleet management system, and directly of its technical base - the AMTS icebreakers and ships, are required.

Thus, the specialized HMI, used in the practical and management purposes is an objective process. This process shows the application properties of the hydrometeorological products on the one hand, the stimuli, indicating a possible economic effect in the management, production and scientific-operational HMS on the other hand (Makarov, 1989).

It is this formulation which indicates the logics of the transition to the standardization of the AMTS production process, that is, marine opertions in the Arctic (Fig. 16).

The standardization and classification of marine operations in the Arctic indicate one simple and apparent approach during the scientific-operational HMS to marine transportation in the Arctic. That is,to develop HMI necessary to address the specific goals, either the management of marine operations or direct implementation of the latter. And the application properties of the information itself significantly change when proceeding from one class of economic goals to another.

During the management of large production structures the most effective appears to be the systems approach which requires consideration of the management object as a system of interrelated characteristics of the object and the prognostic background - environment - from the point of view of the goals and aims to achieve a maximum effect of its functioning.

One speaks here about the development of a class of objectives of the management object whose effect of HMS can be expressed in the units of the profit by the user of such information.

The direction of such approach is shown by studies for developing the algorithms for the existing types of the actual and prognostic HMI on the coastwise routes and the algorithms designed for entire transit navigation along the NSR.Such studies have been made by the AARI and the Dikson TAHMS (Fedyakov, 1988, Adamovich, Buzuyev, 1990). These studies aim to reveal the functions of the link of the necessary and sufficient HMI on the route segments of the western and eastern management regions in the Arctic with the parameters of the functioning of the transportation means on these segments. Here, experience in developing a model for quantitative assessment of difficulty of navigation (QAD) is used (Buzuyev, Fedyakov, 1985).

So, practical operation of the system for marine cargo transportation should be designated by standard marine operations in the Arctic. The decisionmaking for the management of this system has a given level of guaranteed economic results at varying technical support depending on the purpose when the reliability of taking into account the environmental effects is prescribed by a limited set of the known parameters of the latter and the information amount about it is prescribed by the model of the functioning of the management object and can always be obtained with an accuracy satisfactory for practice.

Thus, standard marine operations are characterized by a number of the identifying features:

- reliability of the management impacts provided by a given level of technical resources;
- effectiveness of the information structure providing a guaranteed level of taking into account the environmental effects by a limited number of the known parameters of its state (Makarov, 1989).

All operations which do not have such features, should be referred to the category of non-standard ones. As follows from the definition, the main difference between standard and non-standard marine operations is in a much greater uncertainty of the results of the management effects on the system of functioning of technical means taking into account the environmental effect. In accordance with this, the effectiveness of the functioning of the management system when implementing non-standard marine operations is governed to the largest extent by the reliability of its information HMS. The reliability of the latter is governed by the availability and improvement of the systematic knowledge on shipping medium. The development of the system of such knowledge at present can only be in the conditions of field experiments.

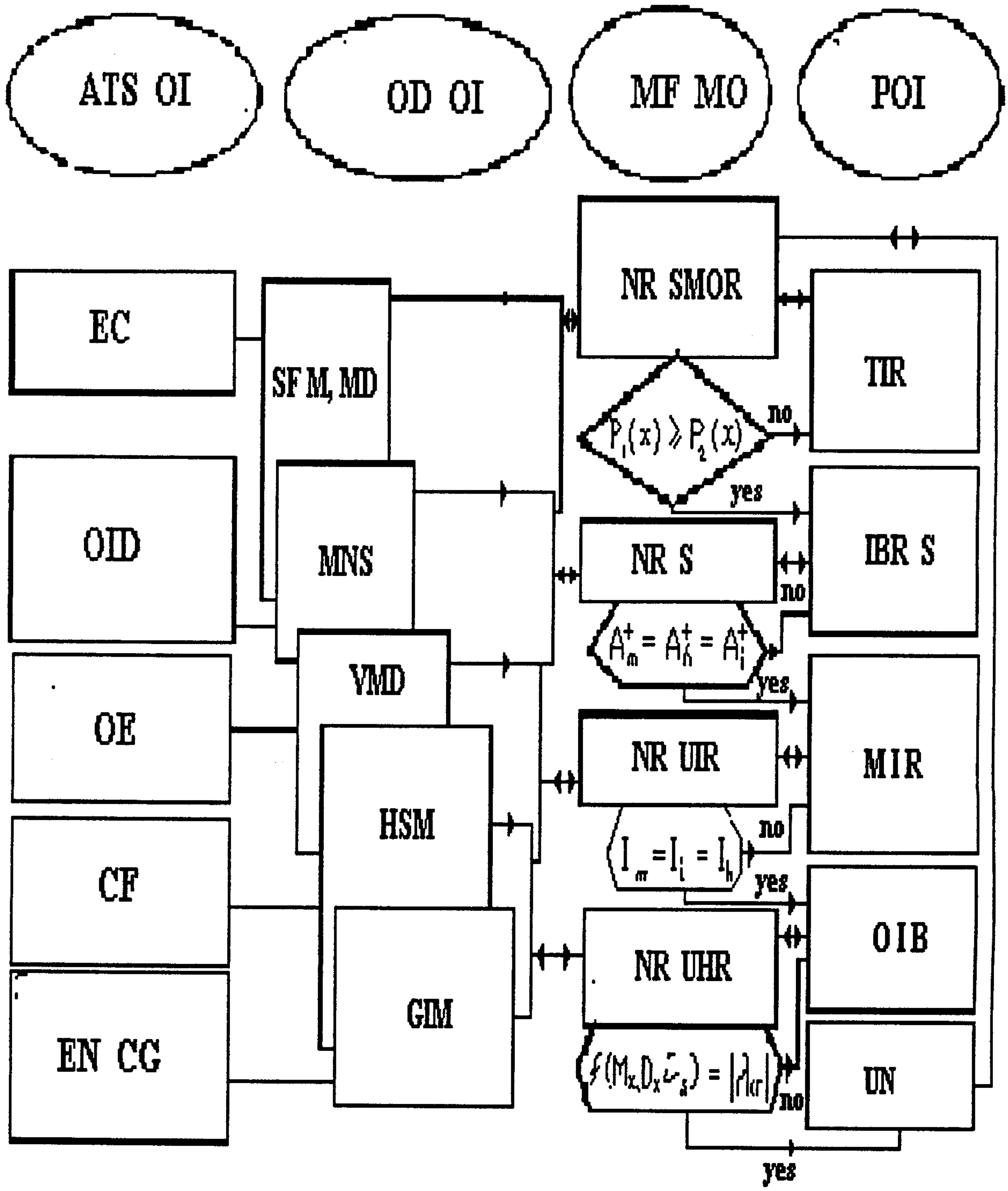


Fig. 16. A block-diagram for the document turnover in the OIS and the algorithms for the transformation of operational hydrometeorological information into a specialized type (for designations see fig.12)

ABBREVIATIONS:

ATS OI	- Algorithms for OI transformation into a specialized type,
OD OI	- Organization of OI documentation,
MF MO	- MO management functions,
POI	- OI purpose,
EC	- Expert conclusion,
OID	- Objective image distinguishing,
OE	- Objective extrapolation,
CF	- Cartographic forecasting by charts-analogues,
EM CG	- Expert merging and cartographic generalization,
SF M, MD	- Messages, maps-diagrams of specialized forecasts,
MNS	- Maps of the navigation scale,
VMD	- Vector map-diagram,
HSM	- Hydrosynoptical map, including the navigation scale,
GIM	- Kinematic general ice chart of ice limits and its characteristics smaller than the scale of 1:2000000,
NR SMOR	- Navigation recommendations (NR) over the entire NSR, strategic OM regions,
NRS	- NR for the NSR segment,
NR UIR	- NR on uniform ice regions (UIR),
NR UHR	- NR on uniform hydrological regions (UHR),
TIR	- Through icebreaking routing,
IBRS	- Icebreaking routing on the NSR segments,
MIR	- Mass icebreaking routing,
OIB	- Occasional icebreaking routing,
UN	- Unaided navigation.

Let us stress the conclusion following from the results of the presented section of the Report - the conclusion on the principal need for making marine transit operations in the Russian Arctic standard. The existing standards define the present-day Russian Arctic Marine Transport System as a system of mass coastwise transportation. This is most evident in the structure of hydrometeorological support at all levels of its organization. For the purposes and objectives developed and resolved in the framework of this Project, this conclusion forms a strategic direction for the improvement of the subsystem of operational information on natural conditions of ice navigation, their genetic relation to other projects of Subprogram I, fulfilled by Russian investigators or from other countries, as well as the possibility of a fruitful interaction with Subprogram III, specifically in the conditions of field experiments.

Thus, a standard regioning of the NSR into strategic zones of operational management and HMS should be made basing on the interrelation of projects and their sections I.1.2.2 - I.2.3 - I.5.2 - I.5.5.

The interaction of the sections of projects I.2.2 - I.2.5 - I.4 - I.5.4 provides the development of a rational configuration and content of a specialized database supporting the decisionmaking of operational management of transit marine operations.

Joint studies during the formulation of the forecasting problem in the framework of projects - I.2.1 - I.5.3 - I.6 give hope for the successful development of the model for the use of natural information during the management of transit ice navigation.

There is an urgent need for implementing already in 1994 joint studies in projects 1.2.4 - 1.4.2 (Stayn Sandven) - 1.3 which will allow numerical estimates of the economical effectiveness (by their functional and information components) due to the use of high resolution satellite (non-Russian) data (for example, ERS-1).

And, finally, in our opinion the interaction of Subprograms III and I in the framework of Projects I.2 - I.3 is advisable for standardization of the requirements of navigators to the HMS quality for transit navigation and development of criteria for the HMS cost-effectiveness.

REFERENCES

A Handbook for the organization of hydrometeorological support to shipping in the Arctic, (1974), Leningrad, Rotaprint, p. 60

A Handbook for the preparation of short-range ice forecasts for the Arctic Seas, (1977), the AARI archives, p.214

Adamovich N., Makarov E. NIR Report. Study of the possibilities to create an information model of hydrometeorological support to marine operations to supply the regions in the western Arctic and transit shipping along the NSR outside the traditional navigation period, (1991), Leningrad, the AARI archives

Adamovich N. Report of NIR: To elaborate methods of optimal utilization of hydrometeorological and ice information at the formation of forecasting recommendations with a short period in advance for shipping in the Arctic, (1985), the AARI archives, p.233

Arikainen A.I. (1984) Transport artery of the Soviet Arctic, Moskva, Nauka, p.192

Arikainen A.I. (1990) Shipping in the Arctic ice, Moskva, Transport, p. 247

Arikainen A.I., Levit B.Yu. (1987) Features and main elements of the adaptation imitation model of the transport process on the NSR, tr. VNIISI, issue 4, pp.20-33

Atlas of the Arctic. (1985), Moskva, GUGiK, p.204

Atlas of the Oceans. (1980), MO SSSR, VMF, p.201

Belov M.I. (1959) History of the discovery and exploration of the NSR, V. 3, Leningrad, Gidrometeoizdat, p. 510

Belov M.I. (1969) History of the discovery and exploration of the NSR, V. 4, Leningrad, Gidrometeoizdat, p. 613

Belyaev B.N. (1986) Applied oceanology studies, Leningrad, Gidrometeoizdat, p.144

Berg A.E., Chernyak Yu.E. (1966) Information and management, Moskva, Economy, 1966, p. 187

Buzuyev A. NIR Report: To elaborate methodological principles for the preparation of specialized forecasts for shipping on the western segments of the NSR more than one month in advance, (1991), Leningrad, the AARI Proceedings, p.225

Chubakov K.N. The NSR, (1979), Moskva, Znanie, p. 63

Druzhinin V.V., Kontorov D.S. (1976) Questions of the military systems technology, Moskva, Voenizdat, p.224

Druzhinin V.V., Sergeeva I.V. (1990) Quality of information, Moskva, Radio i svyaz, p. 172

Egorov A.G., Spichkin V.A. (1990) Uniform ice regions of the north-eastern Kara Sea, the AARI Proceedings, V.423, pp. 6-14

Gol'cman F.M. (1982) Physical experiment and statistical conclusions, Leningrad, Izd. LGU, p.192

Gorbunov Yu.A., Krutskikh B.A. (1972) Basic elementary hydrological processes in the Arctic seas, the Arctic and Antarctic Seas, issue 40, pp.5-12

Gudkovich Z.M., Kirilov A.A. et al. (1972) A basis for the methods of long-range ice forecasting for the Arctic Seas, Leningrad, Gidrometeoizdat, p.348

A handbook for the formation of short-range ice forecasts for the Arctic Seas, (1977), the AARI archives, p.214

A handbook for the organization of hydrometeorological support to shipping in the Arctic, (1974) Leningrad, Rotaprint, p.60

Itin V. (1936) The Northern Sea Route and the Kara expeditions, Novosibirsk, p.96

Korzhikov A.Ya., Kuznetsov A.V. (1993) Statistic characteristics of the relation between the wind speed and surface pressure in the Arctic, Leningrad, the AARI Proceedings, V.431, pp. 91-98

Krutskikh B.A. (1963) A comprehensive forecasting method of sea level surge fluctuations (by the example of the bar of the Kolyma River), the AARI Proceedings, V. 264, pp.18-30

Krutskikh B.A. (1970) Features of ice formation in the Arctic seas, the AARI Proceedings, V. 292, pp. 106-117

Krutskikh B.A., Gorbunov Yu.A. (1971) Determination of the duration of natural hydrological periods, the Arctic and Antarctic problems, issue 38, pp. 22-28

Krutskikh B.A., Gorbunov Yu.A. (1973) On the relation between elementary hydrological and synoptic processes, the Arctic and Antarctic problems, issue 41, pp.22-28

Krutskikh B.A., Nikiforov Ye.G., Baskakov G.A. at el. (1991) 70 years to the AARI, the Arctic and Antarctic problems, issue 66, pp.7-31

Kupetsky V.N. (1979) Some questions of hydrometeorological forecasting, Tr. DVNIGMI, issue 79, pp.13-22

Kupetsky V.N. (1979) On the hydrosynoptic method of the preparation of sea ice forecasts, Tr. DVNIGMI, issue 79, pp.102-108

Likhtenstein V.V. (1973) Discretion and occurrence in the economic-mathematic problems, Moskva, Nauka, p. 375

Makarov E. A report on scientific-operational hydrometeorological support of summer-fall navigation in 1990 in the western Arctic, (1989), Dikson, the AARI archives, p.178

Makarov E. A report on scientific-operational hydrometeorological support to summer navigation in 1989 in the western Arctic, (1989), Dikson, the AARI archives, p. 198

Makarov E. To systematize data on natural conditions of transit shipping along the NSR in the interests of international cooperation, (1991), the AARI archives.

Melnik N.V. (1990) Analysis and evaluation of the management system at the enterprises, Moskva, Finances and statistics, p. 136

NIR Report: To develop methods for an optimal use of hydro-meteorological and ice information during the preparation of the prognostic recommendations with a short period in advance for shipping in the Arctic, (1985), the AARI archives, p.233

A Report on hydrometeorological support to winter navigation during the period 1987-1988 in the western Arctic, (1988), Dikson, the AARI archives, p.247

A report on scientific-operational hydrometeorological support to winter navigation in 1988-1989 in the western Arctic, (1989), Dikson, the AARI archives, p. 198

A report on scientific-operational hydrometeorological support to winter navigation in 1988-1989 in the western Arctic, (1989), Dikson, the AARI archives, p. 198

A report on scientific-operational hydrometeorological support to summer navigation in 1989 in the western Arctic (1989), Dikson, the AARI archives, p. 198

A report on scientific-operational hydrometeorological support to summer-fall navigation in 1989 in the western Arctic (1989), Dikson, the AARI archives, p.178

Report of the NIR: To elaborate methodological princips of the formation of specialized forecasts for shipping in the western area of the NSR more than one month in advance, (1991), Leningrad, the AARI Proceedings, p.225

The state of scientific-operational hydrometeorological support to Arctic shipping, (1983), Rotp. AARI., p. 45

The state of providing long-range forecasts for the Arctic Seas and the mouth areas of the Siberian rivers to the MMF organizations, (1983), Leningrad, the AARI reprogr., p. 9

Study of the possibilities for creating an information model of hydrometeorological support to marine operations to supply the areas in the western Arctic, to transit shipping during the traditional period and outside it, (1991), Leningrad, the AARI archives

The Instruction on scientific-operational hydrometeorological support to Arctic shipping, (1983), Rotp. AARI., p. 45

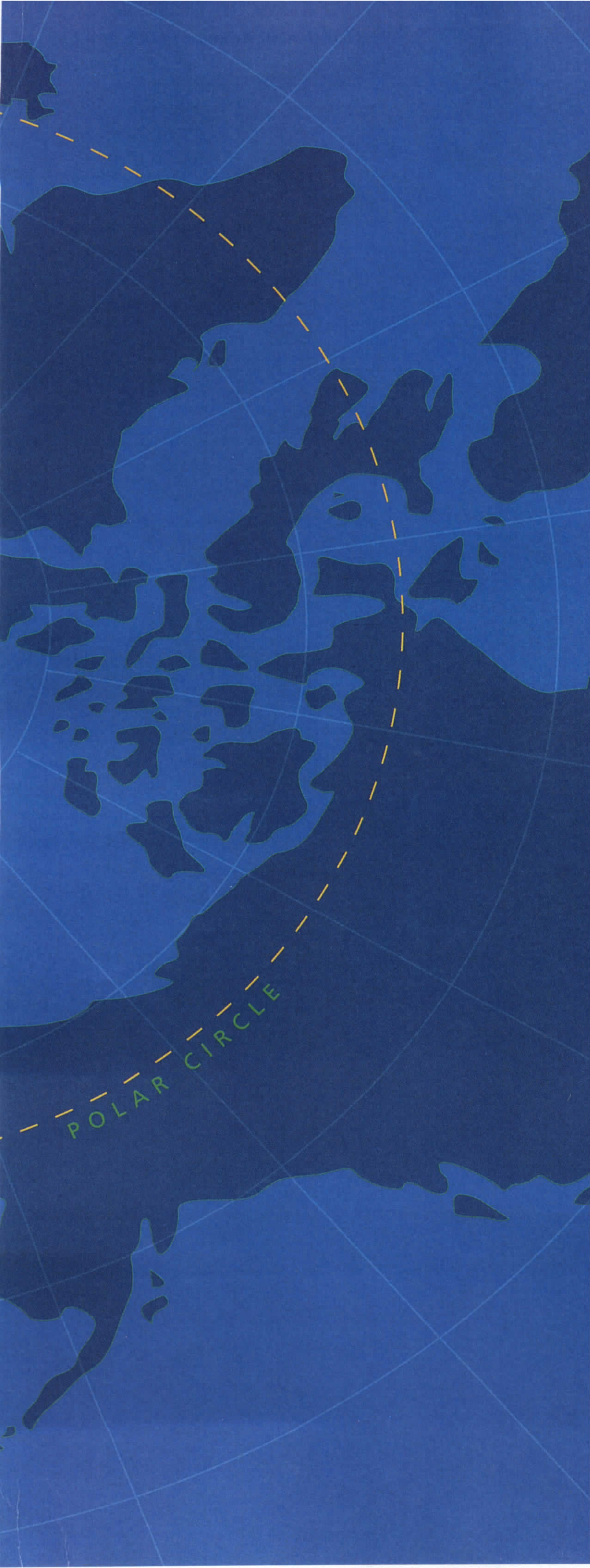
The Instruction on the provision of the MMF institutions with long-range ice forecasts for the Arctic Seas and the mouth areas of the Siberian rivers, (1983), Leningrad, the AARI reprogr., p. 9

To systematize data on natural conditions of transit shipping along the NSR in the interests of international co-operation, (1991), the AARI archives.

Ushakov I.A. Probability models of the reliability of the information -calculation systems, (1991), Radio and Communication, p.132

Ushakov I.A. Probable modes of the stability of information-calculation systems, (1991), Radio and connection, p.132

Zhukovsky Ye.Ye. Meteorological information and economic decisions, Leningrad, Gidrometeoizdat, p.304



The three main cooperating institutions of INSROP

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

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