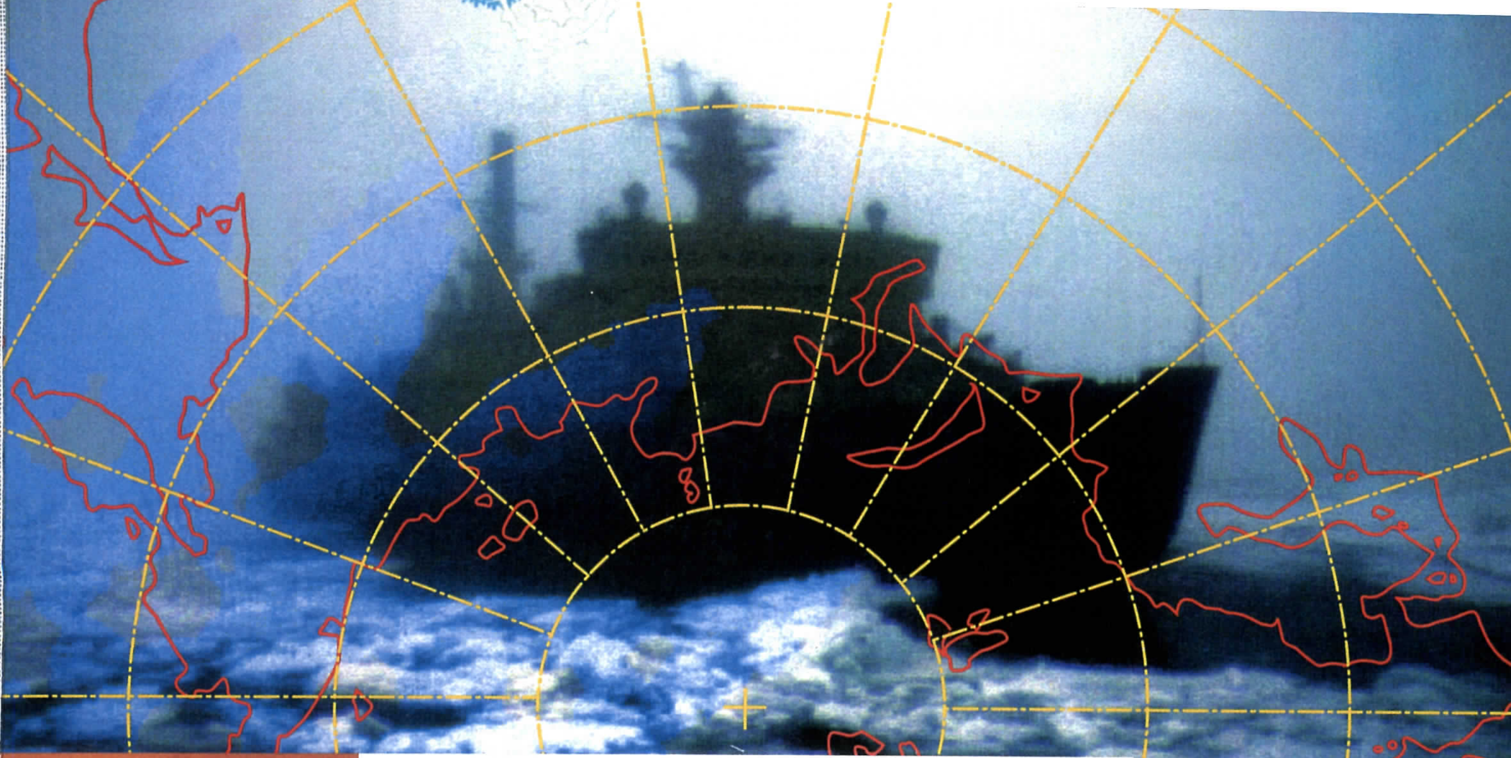


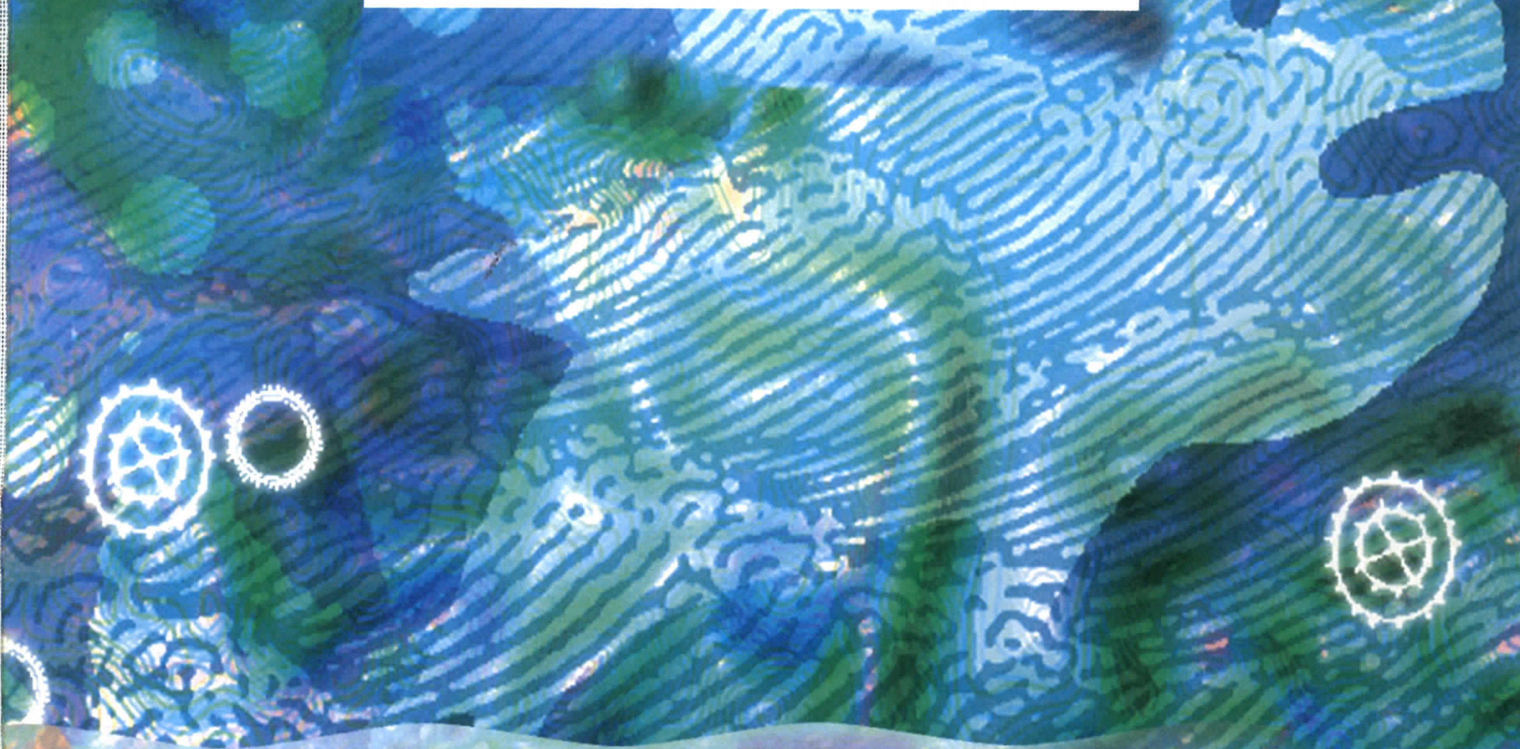
INSROP WORKING PAPER

NO. 29 - 1996, I.7.1

Perspective Research

Volume 1 - 1993 project work

Victor Zacharov and Alexander Baskin 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)

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Sub-programme I: Natural Conditions and Ice Navigation.

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FOREWORD - INSROP WORKING PAPER

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

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

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

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

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PART I:
ICE FORECASTING AND CLIMATE IN THE ARCTIC: CRITICAL REVIEW

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PART I. ICE FORECASTING AND CLIMATE IN THE ARCTIC; CRITICAL REVIEW

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Part I.

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SUMMARY

Natural conditions in the Arctic experience strong seasonal, interannual and multiyear changes, their character, extent and interrelation govern the degree of the environmental counteraction to shipping, i.e. navigation "difficulty". A rational organization of transit transportation is possible in these conditions only if based on knowledge of the current and expected ice state on the route. Essential points for the design, construction and use of long-term off-shore structures, including icebreaking and transport vessels, are the character and depth of future environmental transformations of a climatic scale.

On the basis of study and analysis of the current state of forecasting climate and ice conditions in Arctic waters, this Report concludes that the situation is satisfactory only with regard to the study and description of the phenomenon of the change of the climate and ice conditions. Inadequate progress has been made in understanding the underlying causes of this phenomenon, as well as the knowledge of the advance mechanisms. The situation is aggravated by the fact that the relation between natural and anthropogenic components in climate changes remains unclear, being at the stage of discussion.

Forecasting of future ice conditions along the NSR will need to take into account changes governed by factors of natural origin. Studies here are still based on retrospective data,characterizing the development of climatic and ice conditions in the past. The most important immediate objective in the framework of the Project is to investigate typical spatial-temporal features of changes in climatic conditions along the NSR during the 20th century.

KEY WORDS: climate, ice conditions, forecast, transit transportation.

1 TAKING INTO ACCOUNT FORTHCOMING ENVIRONMENTAL CHANGES - A NECESSARY CONDITION FOR RATIONAL ORGANIZATION OF ARCTIC NAVIGATION

Navigation, like all varying economic activities in the Arctic, is still strongly dependent on natural conditions. Over half a century of regular navigation along the Northern Sea Route provides abundant evidence of such dependence. And although the technical advances of recent decades have reduced this dependence, assessing the environment and taking its state into account remains important for the implementation of marine transport operations.As to planning, design and maintenance of long-term off-shore structures, including multipurpose ships, they are simply impossible without knowledge of the existing and expected natural conditions.

Natural conditions in the Arctic experience large seasonal, interannual and multiyear changes with time. Their character, extent and interrelation govern the medium resistance to shipping, that is, the "difficulty" of navigation. Sea ice appears to be the most important environmental factor here. Thus, the question of in what direction and with what intensity ice conditions will change in the near future attains important practical significance, governing to a considerable extent the strategic operation aspects of the Arctic Marine Transportation System. An analysis of retrospective data indicates both the extent and a close connection of multiyear variations in the sea ice state to the north of the coast of Siberia with climate variations. The climatic variation of the first four decades of the present century, known as the warming of the Arctic, has undoubtedly contributed to the success of the exploration of the Northern Sea Route and its becoming a normally functioning transportation sea passage. The cooling which has replaced it, has similarly been accompanied by a worsening ice situation and more complicated navigation conditions, despite the increased power of the fleet. The extent of the changes in the ice state in Siberian Arctic waters over the last seven decades can be seen from the variations of the anomalous areas of this ice, shown in Fig. 1.

Assessing the future climate and the ice state in the Arctic has become particularly important due to the increased concentration of carbon dioxide and other greenhouse gases in the Earth's atmosphere. Some climatologists believe that the greenhouse effect will have a decisive significance in current and future climate changes. According to their conclusions, based both on theoretical (mathematical models of different levels) and empirical estimates, by the year 2025-2030 the mean global surface air temperature should increase by 1.5-4.5C as a result of the doubling of CO_2 levels (WMO,1986). As the amplitude of climatic variations in the Arctic exceeds the total planetary average by 2.5-3 times, such temperature increase will in high latitudes result in surface air warming of about 10 deg C as compared with current values.

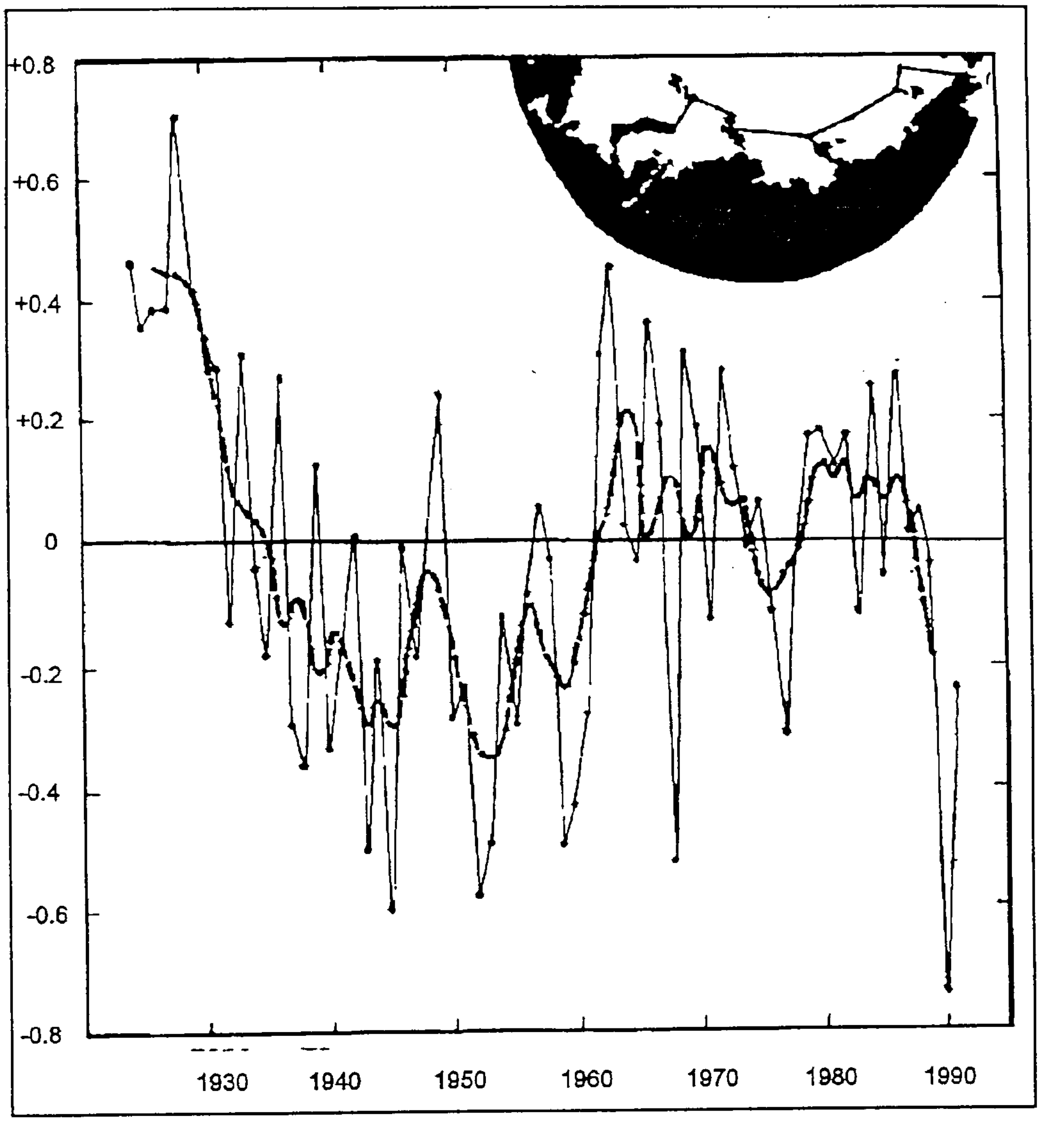

Figure 1. Ice-area anomalies in Siberian Arctic waters in the second half of August.

Siberian Arctic waters include the Kara, Laptev, East-Siberian and Western Chukchi Seas according to the boundaries agreed by the AARI. Total area of these seas - 2.5 . 10^6 km2. The dotted curve is a 5-year running mean. Data from the period 1924-1931 should be considered as approximate, due to poor quality of observations.

The consequences of this will immediately affect the state of the environment, including the Arctic sea ice. A major change of the environmental pattern will in fact take place - a return to those conditions which dominated in the Arctic some two million years ago, at the border of the Pliocene and the Pleistocene. The Arctic Ocean will be free of ice much of the year. In the light of such a prospect, any research and practical projects based on relative stability in the existing climatic regime within time intervals comparable to the lifespan of a human being appear to be rather insignificant.

However, It should also be mentioned that not all scientists share this view of the near future of our planet undergoing an instantaneous (from the geological standpoint) transition into a new qualitative state, with destructive consequences for the life and economy of the peoples. Most scientists are still of the opinion that climate changes have occurred, occur and will occur mainly under effects of natural rather than anthropogenic origin.

Such strong difference of opinion shows a large uncertainty in this extremely important issue. This uncertainty becomes more and more intolerable in view of the increasing economic exploration of the Arctic with the transit marine transportations along the Northern Sea Route an integral part of it. What is needed here is a clear understanding of the phenomenon of climate change phenomenon and its causes, to enable the creation of accurate forecasting methods.

2 FEATURES OF ARCTIC CLIMATE CHANGE

Climate change in the Arctic is seen as only part of the global planetary phenomenon. However, in high latitudes the character of these changes differs in certain important features.

The main characteristic of present-day climatic changes appears to be their strong spatial non-uniformity. Fig. 2 and 3 present the curves of mean annual, winter and summer surface air temperature from 1880 to 1980 in four latitudinal belts of the Northern Hemisphere: 87.5 deg-72.5deg N, 72.5 deg-57.5 deg N, 57.5 deg-37.5 deg N, 37.5 deg -17.5 deg N and on the whole for the entire area outside the equator, i.e. 87.5 deg -17.5 deg N. In order to avoid too much detail which sometimes obscures the most significant features of the secular temperature variations, the values of the latter were calculated as a 5-year running average. The values obtained served as a basis for the diagrams and the ensuing conclusions.

First of all, the large-scale changes of the thermal atmospheric state for the period of instrumental observations differ in consistency both in time and in space. Secondly, the amplitude of temperature fluctuations in the Northern Hemisphere is not constant, depending significantly on the geographical latitude. Comparatively small temperature changes in the equatorial and tropical areas increase several times in polar latitudes. Thirdly, temperature changes within a year differ in intensity, with the most significant changes occurring in winter. The amplitude of summer temperature variations is usually two-three times less than in winter.

The materials presented illustrate that the Arctic occupies a special place in the climatic changes in the Northern Hemisphere. In this area (according to Ye.S.Rubinstein,1973, its southern boundary is located near 55 deg N), where the climatic signal unexpectedly increases, exceeding by several times its global value. In view of the high sensitivity of Arctic nature to all kinds of impacts, one should recognize that such changes of climatic conditions can considerably affect the environment and thereby all human economic activity beyond the Polar Circle.

In the Arctic belt itself the spatial and temporal structure of the climate variations has quite a complex character. Not only the amplitude but also the direction of climatic changes in its sectors are different. Ye.S. Rubinstein and L.G.Polozova (1963) have shown that each latitudinal zone between 40 deg and 80 deg N is divided into two parts, with temperature changes being in the main opposite. There is no complete compensation of the heat excess in one sector of the belt by its deficiency in another during the development of global warming.

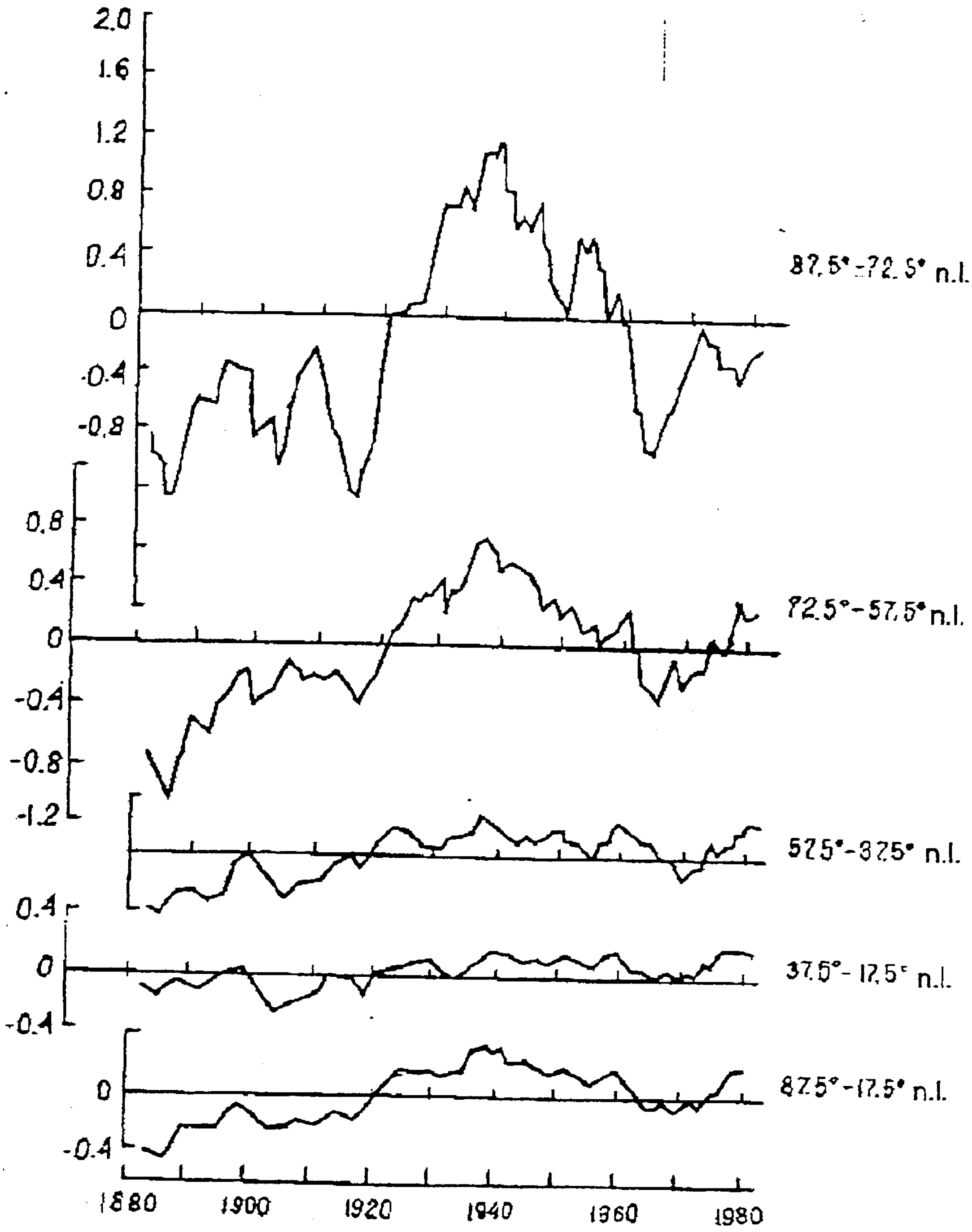

Figure 2. Five-year running mean anomalies of the annual air temperature in different latitudinal zones of the Northern Hemisphere (Vinnikov, 1986).

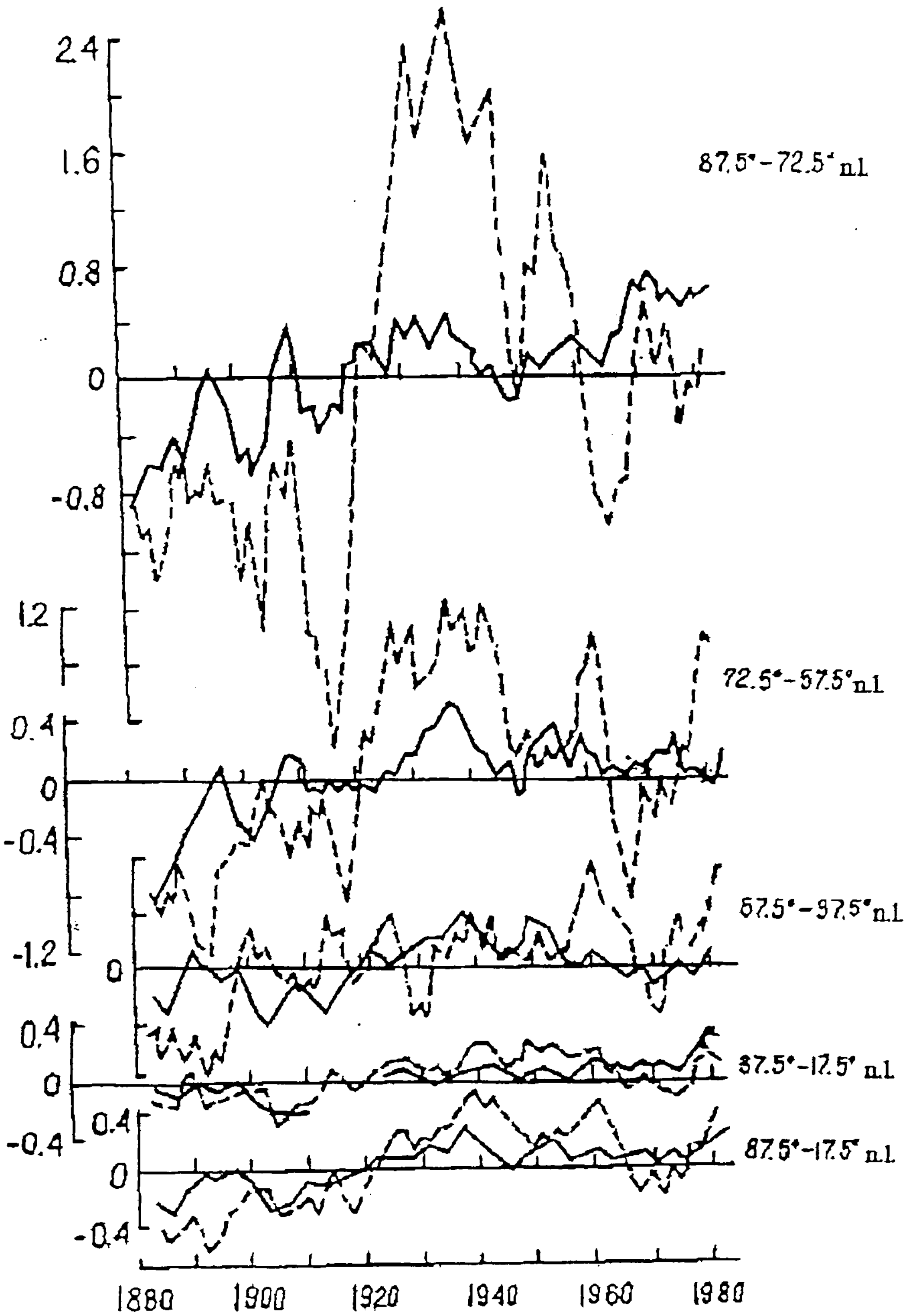

Figure 3. Five-year mean anomalies of zonally averaged air surface temperature in the Northern Hemisphere for winter and summer (-) (Vinnikov, 1986).

The Atlantic sector plays a decisive role in the formation of climatic tendencies in this zone. All investigators concerned with the spatial structure of climate changes in the 20th century have noted that regardless of the direction of these changes - toward warming or cooling - they are most pronounced in the far north of the Atlantic and the adjacent Arctic regions. There is now sufficient evidence that the most significant temperature increase in the Northern Hemisphere during the warming epoch is observed at the archipelagos of the Northern Land, Franz-Josef Land, Spitsbergen, Greenland and the islands of the Canadian Arctic Archipelago (see Viese, 1940; Villett, 1966; Rubinstein and Polozova, 1966). Polozova, basing her work on the analysis of surface temperature of approximately 100 meteorological stations of the Northern Hemisphere, has come to a conclusion that secular variations in this temperature are most pronounced in the regions adjacent to the Atlantic, relating this phenomenon to the effect of the ocean. Many similar opinions indicate the special sensitivity of the North Atlantic and the Atlantic sector of the Arctic. They all show that while high latitude plays a particular role in climate changes in the Hemisphere, the Atlantic sector of the Arctic plays the same role within these latitudes themselves.

3 CURRENT UNDERSTANDING OF THE CAUSES OF NATURALLY GOVERNED AND ANTHROPOGENIC CHANGES IN CLIMATE AND ICE CONDITIONS OF SHIPPING

It is impossible to explain a natural phenomenon, or indeed foresee its future state, until the factors controlling its development become completely clear. Only periodic phenomena whose onset can be forecasted without knowledge of the forces inducing them, appear to be an exception. Obviously, climate changes are not among such phenomena; their scientific forecasting is based on knowledge of these forces and typical features of their development. How far have we advanced today in understanding these forces and what are the prospects of the climate forecast for the near future?

As mentioned, there is a deep difference between those who consider factors of natural origin to be dominating and those who consider the anthropogenic factors to be prevailing in causing climate change. In view of this difference, it is desirable to review the existing understanding of the nature of these changes. Let us begin with the factors of natural origin.

Already in the 1930s, when the character and the extent of the occurring changes had become more or less clear, attempts were undertaken to explain them. At that time most common was the view that atmospheric circulation played a leading role in the development of the climatic warming, beginning from the end of the last century. It was found that simultaneously with the development of this warming there had been an enhancement of the atmospheric circulation in the Arctic, a shift of the trajectories of Atlantic cyclones to the north and their deeper penetration eastward up to the New Siberian Islands. As a result, heat advection to the high latitudes from the south increased, being thus the most immediate cause of the phenomenon initially called the warming of the Arctic. The justification of this point of view is given by Viese (1944).

From the very beginning, this viewpoint needed to be supplemented, as it was unclear what caused the changes in the regime of the atmospheric circulation itself, and how this regime came about. Viese suggested that solar activity was a regulator of this regime. Solar activity, weather and climate characteristics, natural environment : these are the main links of the cause-effect chain, which in his opinion controls the natural-historical process on the Earth. The seeming simplicity and clarity of the idea, and not least the tradition and external obviousness of the fact that everything comes from the Sun, found numerous supporters. The main efforts were then directed to establishing direct correlation relationships between solar activity and various, more often local and regional hydrometeorological phenomena, rather than to the study of the physical mechanism of solar - terrestrial relations. Many authors were not concerned with the need to explain how or why this takes place. Such a situation could not continue for long; the unclear effect mechanism, the unstable relationships and the increasing criticism resulted in a crisis in this approach, combined with loss of interest in the study of solar-terrestrial relationships relative to hydrometeorological phenomena.

Let us, however, return to the atmospheric circulation as a possible cause of today's climate fluctuations.

Air movement by itself is not able to warm or cool the atmosphere, i.e. to distinctly change its thermal state. Shifting air masses from one geographical region to another, the circulation accounts for heat ***redistribution*** over the surface of the globe - not changing its amount. That is why when one speaks about climate changes on the scale of the whole planet, atmospheric circulation as a climate-forming factor becomes senseless.

An analysis of secular temperature variations over approximately the last 100 years leaves no doubts about the global scale of climatic changes. The warming of the Arctic and its subsequent cooling proved only a regional indication of worldwide air temperature fluctuation. That is why it is hardly justified to relate the climate changes on the Earth in this century to the dynamic regime of the atmosphere today.

In addition to the circulation hypothesis various other hypotheses have been suggested to account for natural climate changes. Some of them at present cannot be trusted, while others need stronger arguments. Among them are the hypotheses in which current climate changes are linked with the instability of solar radiation, and changes in the atmospheric transparency for short-wave radiation fluxes.

The idea that climate changes may be connected with the variable regime of solar radiation is, first of all, attractive because of its exceptional clarity and simplicity. During periods of increased solar radiation the Earth's atmosphere is heated, during the periods of attenuation - cooled, inducing the corresponding changes in the other components of the climatic system. For a long time, the reality of this simple scheme could be neither confirmed, nor rejected due to the insufficient technical possibilities for observing the incoming solar radiation to the external atmospheric boundary. This uncertainty was used from time to time as a suitable way out from the unexpectedly arising difficulties. Since "if one cannot explain the long-term fluctuations by any other reasons, - Weyl wrote, - one can always refer to the variability of the Sun" (Weyl, 1970).

With the beginning of the satellite epoch, this situation began to change towards greater certainty. Measurements of the solar constant outside the Earth's atmosphere did not reveal any distinct variations of the latter. Changes within some hundredths of one percent could not give firm assurance that it is the integral solar constant which is responsible for the climate changes which were observed. Quite the contrary: they increased doubts about the decisive role of solar illumination in these changes. It is not by chance that most specialists concerned with the search for the reasons underlying climate change do not connect large hopes with this explanation. Although the last word has not yet been spoken, there is a large probability that the amount of solar energy coming to the external boundary of the atmosphere within the time intervals which we use remains basically stable.

However, measurements of solar radiation coming to the Earth's surface indicate that it is not constant. If solar radiation at the external atmosphere boundary is constant, then a variable radiation flux to the surface of the ocean and the land can be accounted for by changes in atmospheric transparency. The hypothesis of the effect of the atmospheric transparency on the thermal regime is considered to be one of the oldest. In the 1960s it was supported by Budyko

(1971). Taking actinometric observation data for 1880-1965 and comparing them with secular air temperature variations over the Northern Hemisphere he concluded that "the radiation changes, governed by the instability of the atmospheric transparency appear to be a significant factor of the climate change". He further relates transparency variations themselves with volcanic eruptions. It should be, however, noted that the assessment of the contribution of the volcanic aerosole into the solar radiation changes is not still final. Discussing this question, Loginov concludes that "on the whole over the year the temperature of the Northern Hemisphere after volcanic eruptions decreases by 0.08 deg C. If one takes into account only the largest volcanic eruptions then this value should be approximately doubled" (Loginov, 1988). This means that the contribution of volcanic aerosole to climatic temperature changes is not the only one, and even not the major one.

Thus, none of the most popular hypotheses of the present-day climate changes induced by natural causes can be recognized to be satisfactory. Taking into account that climatic events are not even remotely periodic, the absence of clarity concerning this central item of the problem significantly restricts the possibilities to forecast the climate for the near future.

Dissatisfaction with the causes of climate change impelled investigators to renew their attempts. When it was found that economic activity - in particular, the combustion of fossil fuel - results in the accumulation of carbon dioxide in the atmosphere, some climatologists turned to the study of the role of this gas in the Earth's climate. In the USSR it was Budyko who addressed this problem and began to actively work on it. In numerous scientific articles and books, published in the 1970s and 1980s, he and his school substantiated the increasing role of atmospheric carbon dioxide in the climate, and discussed the forecast for climatic changes, ecological, economic and social consequences of the carbon dioxide increase. Already in the early 1970s Budyko developed the first forecast of the change in the thermal state of the atmosphere up to the middle of the next century, based on the increasing role of carbon dioxide in these changes. According to this forecast, air temperature should increase almost by 2.5 deg C in the Northern Hemisphere during the next 25 years as compared with its value in the 1950s. And the warming will be accompanied by a decrease in precipitation in some regions and a reduction of the extent of polar ice. "The warming in high latitudes," - writes Budyko," - can produce a significant effect on the state of sea ice. Multiyear ice in the Northern Hemisphere can turn into first-year ice or disappear completely with a mean global air temperature increase of 2-4 deg C. Paleoclimatic data indicate that during the epoch of the climatic Pliocene optimum, when the mean temperature was 3-4 deg C higher than today, there was no perennial sea ice in the Arctic. In accordance with the above data on the changes of mean global temperature one can conclude that multiyear Arctic ice should disappear in the second quarter of the next century" (Budyko et al.,1978).

As to the causes of the climate change over the last 100 years Budyko believes that the two warmings during this time interval - the first with a maximum in the 1930s, and the second one - in the 1980s - were governed by different factors. While the first warming was induced by an increase in atmospheric transparency as a result of decreased volcanic activity, the second one has anthropogenic nature, directly related to an increase in greenhouse gases in the atmosphere. One should also note here that the warming intensity in the 1980s happened to be quite close to that which had been predicted.

This serves to strengthen the positions of those who argued for the leading role of carbon dioxide in current climate changes. It should also be mentioned that this research direction has been well organized and has managed to publicize its views widely. Possible consequences of the anthropogenic increase of carbon dioxide in the atmosphere are noted in the conclusions of the International UNEP/WMO/ICSU Conference on assessing the role of carbon dioxide and other greenhouse gases in climate variations and associated impacts, held in Villach, Austria in October 1985 (WMO, 1985). Some of these conclusions connected with the topic of our discussion run as follows:

A. Strictly speaking, the elevation of mean global temperature (0.3-0.7 deg C), statistically observed during the last 100 years cannot be attributed to the increase of carbon dioxide and other greenhouse gases. Such temperature change lies within the predicted range (0.3-0.7 deg C).

B. During the 20th century the mean sea level has risen by 12-15 cm.

C. The concentration increase of carbon dioxide and other trace gases may possibly induce a climatic response equivalent to that of doubling of carbon dioxide already by 2020-2030.

D. The results of climate modelling permit the conclusion that the rise in mean global equilibrium air temperature, governed by the atmospheric content of all greenhouse gases, equivalent to the doubling of carbon dioxide, lies within the range of1.5-5.5 deg C. More probably, the temperature increase will be in the lower part of this range, i.e. not more than 3.5 deg C.

E. Empirical estimates made on the basis of sea level observations since the beginning of the 20th century suggest that the rise in mean global temperature within 1.5-5.5 deg C will result in an ocean level rise from 20 to 165 cm. The main factor inducing such a change appears to be thermal water expansion.

Figure 4 shows the change in mean global air temperature due to changes in atmospheric carbon dioxide and other trace gases according to one of the climate models for three different values of an equilibrium temperature change with the carbon dioxide doubling (1.5 deg;3.0 deg;4.5 deg C).

A joint Soviet-US Report on Climate and its changes, prepared under the USSR-US Agreement on Cooperation in Environmental Protection (Working Group VIII) speaks about the increasing certainty that it is changes in atmospheric chemistry that have played the major role in the development of the global warming processes in the past, and that this will hold true in the future. However, it is mentioned in the report that there are considerable differences in assessments of the sensitivity of the thermal state of the atmosphere to the level of green-house gases (Forthcoming Climate Changes, 1991).

The picture for the comparatively near future presented by those who argue for the leading climate-forming role of carbon dioxide is still not so cloudless as it may seem at first glance. First of all, one should remember that so far no distinct proof of this gas in actual climate changes has been found. Many publications have doubted that carbon dioxide plays a major role in these changes. "The conclusion that the results of meteorological observations indicate the beginning of the warming due to carbon dioxide," - writes Kondratyev," - causes contradictory opinions, including the doubts on the rightness of this conclusion. When determining a positive trend (0.5 deg C) of mean global surface air temperature (SAT) in the Northern Hemisphere during the period of instrumental observations one takes into account the warming peak during the period 1920-1940 when the increase of carbon dioxide concentration was small. Likewise, in the years after this warming maximum when an intensive increase of carbon dioxide started unexpectedly, a cooling in the Northern Hemisphere has been observed together with a small warming, especially after the 1960s in the Southern Hemisphere, instead of a further cooling. So far this fact has not been satisfactorily explained. Estimates of climate cooling due to volcanic aerosole, put forward in some works, cannot be considered to be reliable. One can also by means of selecting empirical constants, convincingly attribute the observed change to the effect of solar activity, not recognizing the hypotheses of carbon dioxide or aerosole. That is why one encounters more and more critical estimates about the explanation of climate warming in the middle of the current century due to the effect of carbon dioxide" (Kondratyev, 1987). In another article this author indicates the need "to overcome the rather widespread stereotype of a global warming governed by carbon dioxide increase" (Kondratyev, 1992).

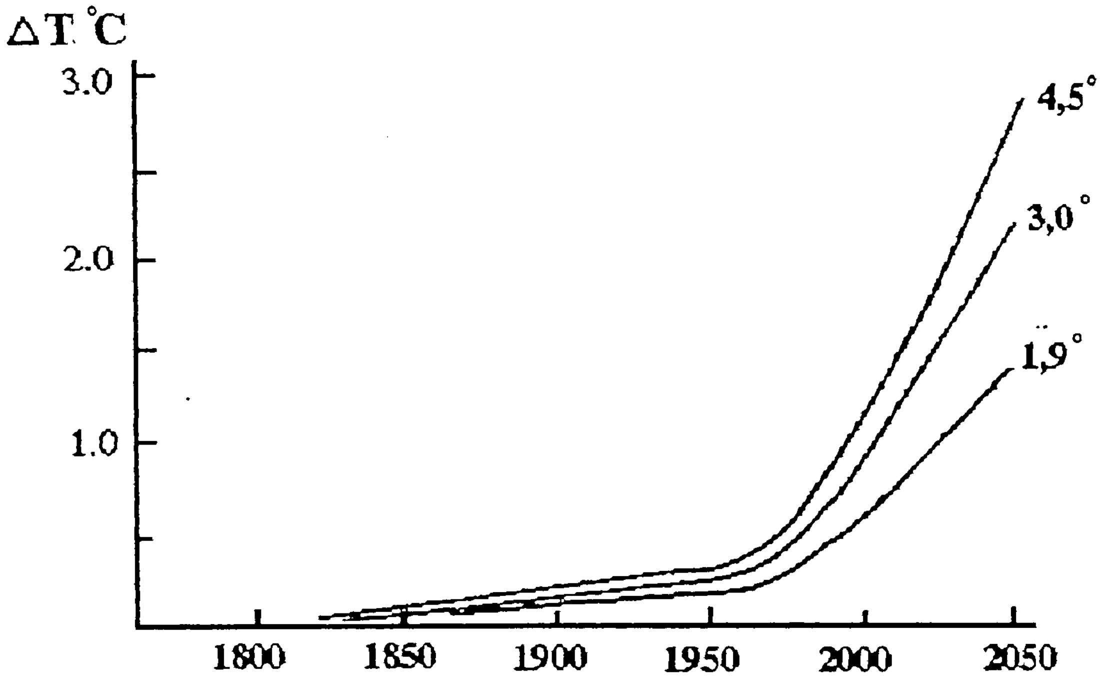

Figure 4. Changes of mean global surface air temperature (base 0 deg.C) in the past and the future as a result of changes in carbon dioxide and other trace gases in the atmosphere, according to the model of a non-stationary response for three different values of equilibrium temperature change with the doubling of carbon dioxode concentration: 1.5; 3.0; 4.5 deg. C.

One should also note that the warmest decade in this century, which was in the 1980s and seemed to confirm the increasing effect of carbon dioxide in the thermal regime of the atmosphere, did not make the debates on the role of carbon dioxide and other greenhouse gases less acute. On the contrary, as White (1990) writes, while one group of scientists persists in saying that the Earth is under threat of coming warming, the other part considers this a classic example of exaggeration born of fear. In accordance with their positions some demand from the governments of the developed countries to stabilize the situation, whereas others stress there is no haste to take measures.

Sea ice is generally considered an excellent indicator of climate changes. That is why, with the acquisition of data on carbon dioxide concentration in air inclusions of the Antarctic Ice Sheet, providing information on changes in the content of this gas in the Earth's atmosphere from the mid-18th century up to present, it became possible to clear up the question on the effect of carbon dioxide on the state of polar ice in the Arctic. In particular, one speaks about the effect of this gas on the ice season duration near the shores of Iceland. As Koch mentioned, this index characterizes changes in ice conditions not only in the waters off this island, but in the entire Atlantic sector of the Arctic outside the present century and back to the "Viking Age"

(Koch,1945).

Figure 5 presents data on the duration of ice season and air temperature off the coast of Iceland according to Bergthorsson (1969), as compared with the carbon dioxide level in the atmosphere on the basis of analysis of air inclusions in the Antarctic Ice Sheet. We may note, on the basis of this diagram, that the greatest variations in thermal and ice conditions in the Atlantic sector of the Arctic during the last two and a half decades are generally not related to the carbon dioxide level in the atmosphere. In any case this relationship cannot be traced at all in secular variations, which are characterized by significant amplitude. There are two curves at the bottom of the diagram. One characterizes temporary variations in carbon dioxide concentration from measurements at Mauna Loa station (on Hawaii), and the other one - variations of sea ice area in the Northern Hemisphere. Obviously, these two phenomena are far from being related. That is why, not denying in principle the carbon dioxide effect on the thermal and ice conditions in the Arctic, one can argue about the scales of this effect. The actual data available at present do not provide clear evidence about the distinct traces of this effect. All this, naturally, poses a question about the justified conclusions on the natural conditions of the future, taking into account the greenhouse effect.

This controversy of opinions on one of the most important problems of the present-day natural science shows the difficulties in finding a solution. Climate science, unfortunately, has not yet reached the level to predict the more or less distant future. The question of climate predictability and its possible limits is still not quite clear. The causes of the climatic changes in the current epoch are not fully known and no complete scientific explanation has been given of these changes in the past. The pessimistic view voiced by Mitchell (1981) is not an exaggeration at all: "it should be recognized that our possibilities are not sufficient to predict the climate for a significant period in advance in the future with an accuracy acceptable for practice". But another extremity is to hold that this objective cannot be resolved at all. There is increasing evidence that efforts undertaken in various countries will be successful at last, providing a reliable basis to predict future natural conditions with high probability.

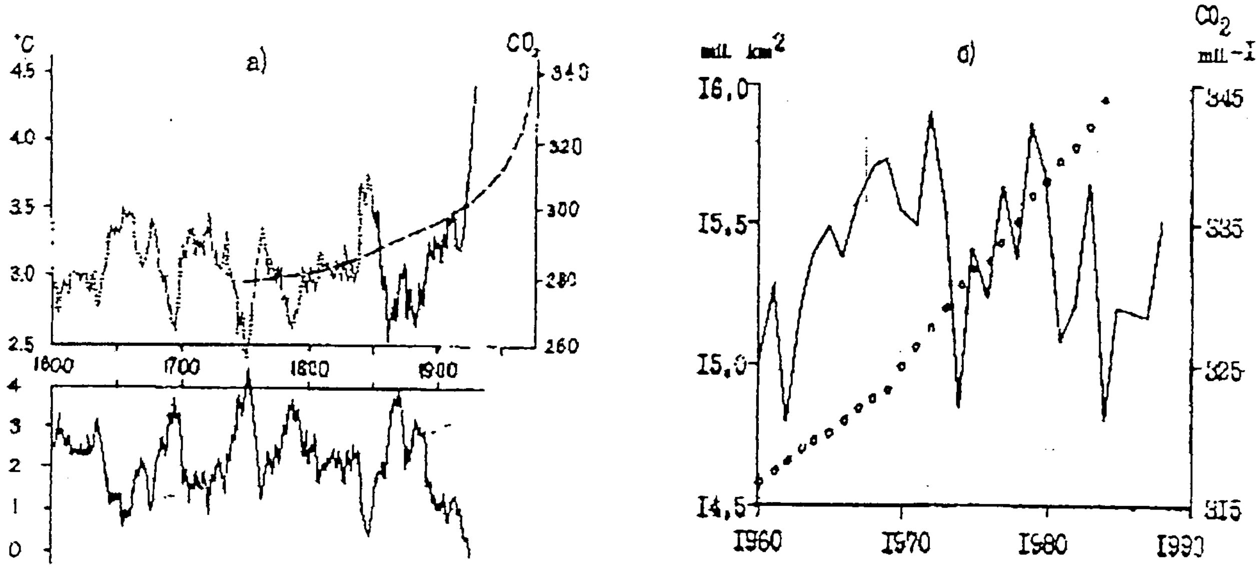

Fig. 5. Air temperature, duration of ice season near the coast of Iceland according to Bergthorsson, as compared with the carbon dioxide content in air inclusions of the Antarctic Ice Sheet (a) as well as the ice area in the Northern Hemisphere and carbon dioxide concentration from Mauna Loa measurements.

4 ASSESSMENT OF EXPERIENCE IN FORECASTING CLIMATIC CHANGES IN ARCTIC ICE NAVIGATION CONDITIONS

The first serious attempt to look into the future of the Arctic and shed some light on ice conditions of the next several decades was made by Maksimov (1955). On the basis of the results of his own studies of fluctuations in ice cover extent in the Atlantic sector of the Arctic (to be more exact, in the Greenland and Icelandic waters) he reached a conclusion about the existence of the secular variations in ice cover extent, governed by changes in solar activity over an 80 - year cycle. In his opinion such a relation exists between ice cover and solar activity when a high level of this activity has a corresponding high index of atmospheric circulation, enhanced air temperature, reduced ice cover extent of the Arctic seas.

The last ridge of the secular wave in ice cover extent connected with an 80-year solar activity cycle was, from his data, found in the 1890s, and the next minimum - in late 1930s-early 1940s. The decrease in solar activity during the secular cycle which started in the 1940s, according to the estimates of Maksimov (1963), was to last approximately up to 1990, while its index would reach by that time the level observed in 1890-1900. "The changes of solar activity will inevitably cause changes of the general atmospheric circulation in polar regions of the Earth. As a result, the ice cover extent of the seas of the Soviet Arctic will be changing in the secular rhythm too, prescribed by the changes of the activity of the Sun. And this means that the total ice cover extent of the seas of the marginal Arctic ... will steadily increase. Navigation conditions on the Northern Sea Route will get worse. As a result, in 1982-1992 the ice cover extent of these seas will reach approximately the level found at the end of the last century" (Maksimov,1979).

All other adherents to the view that climatic changes are governed by the sun have held similar views about the future climatic and ice conditions in the Arctic: Eigenson (1963), Vitels (1960, 1962), Girs (1956), Rubinstein (1973), Nazarov (1963), Kupetsky (1969, 1973). In particular, Vitels wrote that in 1970-2000 the conditions of atmospheric circulation would approach those of the era before the warming of the Arctic. Total atmospheric circulation would significantly weaken, the pathways of cyclones would shift southward, the ice cover extent of the Arctic Seas would increase. And the results of studies in some sea reservoirs also indicated a worsening of ice conditions by the end of the current century (Maksimov et al., 1964; Dunbar, 1971; Lebedev, 1965).

Thus, the aforementioned considerations with regard to future ice conditions in the Arctic indicated a further increase in cooling and ice cover extent up to 1990. All authors sharing this view expected that the climatic and ice conditions would closely approach the level typical of the late 19th and early 20th centuries. Although our knowledge about the latter is quite imperfect, one can with certainty state that conditions were more severe than in the 1930s-1950s. According to Viese (1940) the probability of the appearance of ice in the south-western Kara Sea, i.e. on the initial NSR segment during the navigation to the east, was about 30% in September. With rare exception, ice was found near the eastern coast of Novaya Zemlya, blocking the straits of Matochkin Shar, Yugorsky Shar, Kara Gate and making difficult if not impossible ship entry into the mouths of Ob' and Yenisey. For 1940-1989 this probability was only half as great - 16%.

In connection with the end of the climatic ice forecast period over the Arctic, based on solar activity, it would seem desirable, using actual data, to check its success. Results of comparing forecasted and actual data permit the conclusion that forecasting changes in ice conditions in the second half of this century, developed on the basis of solar activity, proved a failure. This, naturally, resulted in scepticism also with regard to the methods of such forecasts.

Interest in solar activity as a climate-forming factor has started to decrease noticeably, the number of publications devoted to this subject has fallen significantly.

This failure of the adherents to the solar activity theory may have contributed to greater attention being given to the possibility connected with the carbon dioxide problem. Here let us limit ourselves to only a short note. An extended picture of future climate changes governed by changes in the Earth's atmospheric chemistry is presented in the Report of a Mixed Soviet-American Commission for Environmental Protection (Working Group VIII) (Forthcoming Climate Changes, 1991). It confirms the conclusions made before with regard to the direction and scales of the effect of greenhouse gases on climate. Atmospheric heating will be accompanied by a qualitative change in the state of the Arctic sea ice, with the area of multiyear ice, which extends today over the entire near-pole area, reduced drastically. It will be replaced by seasonal ice, which will disappear in summer and appear again in winter over a smaller area, as compared with that occupied at the present time. The notion of open polar seas, which so excited scientists and navigators of past centuries, may become reality already by the end of the first quarter of the 21st century if events develop along these lines. However, the presence of a serious argument in estimating the role of carbon dioxide in modern climate changes does not yet allow one to completely trust this forecast. Most specialists in this field are still of the opinion that the decisive role in the forthcoming changes of this state will be played by factors of natural origin, as has been the case in the past. Our current level of knowledge on the causes of natural climate changes does not yet enable us to create a reliable physical basis for forecasting. The only possibility to "look into tomorrow" is related here to the past, or more precisely to what we know of the regime of the forecasted phenomenon in this past. The main methodological principle of such forecasting is indicated in a simple and clear formula: "the past is a key to the future". The statement about the probable development of the forecasted phenomenon is made on the basis of its behaviour in the past. But it is always assumed that these typical features, established from the retrospective data, will preserve the same values also for the future. This condition does not seem to be excessive, taking into account the restriction of the time intervals covered by the forecast. Within such an interval, the probability of changes in the typical features of natural development is close to zero. In the light of all this, it is quite understandable that forecasters should be interested in studies based on data from the past.

To conclude this discussion of the current state of climatic forecasting of ice conditions in the Arctic, it is necessary to admit the preserved vagueness with regard to possible conditions of ice navigation on the NSR in the near future and the importance of studies that can lead to progress in this area. The hope that such progress can be achieved already in the next few years has been strengthened lately as we learn more about the nature of the moving forces behind the development of the Arctic climatic system.

5 ASSESSMENT OF CLIMATIC CHANGES IN THE DURATION OF TRANSIT NAVIGATION ALONG THE NSR WITHOUT ICEBREAKING ESCORT ON THE BASIS OF SUMMARIZED CHARACTERISTICS OF THE ICE STATE

The climatic ice forecast is defined as a forecast of generalized characteristics of the ice state, such as the extent area. How adequately do these generalized characteristics reflect ice navigation conditions on the route itself? To answer this question let us take such an important indicator of these conditions as the duration of transit navigation along the NSR without icebreaking support.

The duration of unescorted voyage appears to be an important operating characteristic of any shipping route in ice-covered seas, and of particular importance for the Northern Sea Route (NSR). The large extent of the NSR, the presence of ice cover throughout much of the year, as well as the large spatial and temporal variability in ice conditions make the task of optimum stationing of the icebreakers, the choice of the most favourable period and the routes which permit navigation without an escort quite important.

The dates of the beginning and end of unescorted navigation will be governed by the total ice amount in the region of the route, features of its distribution, as well as the type (ice category) and the state of the ships making such a voyage.

This section concerns the duration of unescorted transit navigation of UL ships possible on the basis of natural conditions. The agreed criteria for estimating the dates of the beginning and end of unescorted navigation have been developed on the basis of generalizing the multiyear experience of such ships in the NSR zone (Buzuyev et al., 1982). However, before discussing the results of their application for retrospective analysis of changes of the period of unescorted transit voyage, we need to dwell briefly on the methodology of the study and characteristics of the initial data.

Obviously, experience plays quite an important role in assessing the possibility of unescorted transit voyage. To date several representative publications have accumulated devoted to the description of some transit voyages and generalization of experience (Buzuyev, 1979; Batskikh et al., 1993 etc.). However, due attention is not always paid to the specific features and the reliability of estimates of the possibility of unescorted navigation in this or that region of the NSR (and on the whole on this route) made from onboard a ship.

In fact, shipborne observations cover a comparatively narrow range, indicating the ice distribution features only for the moment of the actual passage of the ship. This can give rise to different and sometimes opposite opinions on the ice cover extent of the region and the possibilities of unescorted navigation. Only from the time of regular airborne reconnaissances, when observations began to cover practically the entire area of the seas of the Siberian shelf did it become possible to choose sufficiently reliable routes for unescorted navigation and the time intervals for such navigation.

Regular airborne reconnaissance covering all transit navigation along the NSR started in 1946, although occasional observations had been carried out earlier (Belov, 1956-1969). This means that we can assess the possibility of unescorted transit navigation sufficiently reliably for the period from 1940 up to the present time. To ascertain climatic changes in the conditions of the voyage it seems interesting to analyse data for a possibly larger period. In this regard some questions arise. First of all, how to combine separate and non-uniform data obtained during the first voyages along the NSR with data from 1940-1992? What climatic changes as the duration of unescorted navigation subjected to in the period when the ice distribution observations covered the entire NSR? Relevant here appears to be the finding of the most difficult part of the transit voyage, which most often governs the dates of the start and the end and, hence, the duration of the navigation type under consideration. Finally, there is the question about the relationship of the duration of the transit navigation possible under natural conditions with the generalized parameters of ice conditions in the Arctic basin and its marginal seas. Such parameters used in climatic studies include total ice cover extent, overall ice-covered area, ice volume, etc. (Viese, 1940; Nazarov, 1969; and other works).

To answer these questions one has to refer to the various materials and publications, which are rather non-uniform in completeness and reliability. It has, however, been possible to reconstruct chronological variations of the changes in the duration of unescorted navigation for the period from 1900 up to the present time (Climatic regime of the Arctic at the border of the XX and XXI centuries, 1991). However, for the time being only the marginal (western and eastern) NSR parts are included here, from which the exploration of the route has started.

To find out the NSR region which delimits unescorted navigation, a comparison of the duration of this route by the main parts and on the whole over the entire route has been made. The possibility of unescorted transit navigation is, as a rule, governed by ice conditions in the B.Vilkitsky Strait and at the approaches to it (Fig. 5).

To find the reasons when this typical feature is not observed should be further studied. The year 1983 can serve as an example, when such unescorted transit navigation was restricted by ice conditions on the easternmost segment of the route (Kovalev et al., 1985).

Discussions of the prospects of regular transit (including international) navigation will inevitably touch on attitudes to current estimates of climate changes, especially in the Arctic and in the NSR zone.

In the early 1980s many publications appeared, which all indicated an impending period of warming in the near future, particularly significant in the Arctic, due to the so called "polar enhancement" (see Forthcoming Climate Changes. A Joint Soviet-American Report on climate

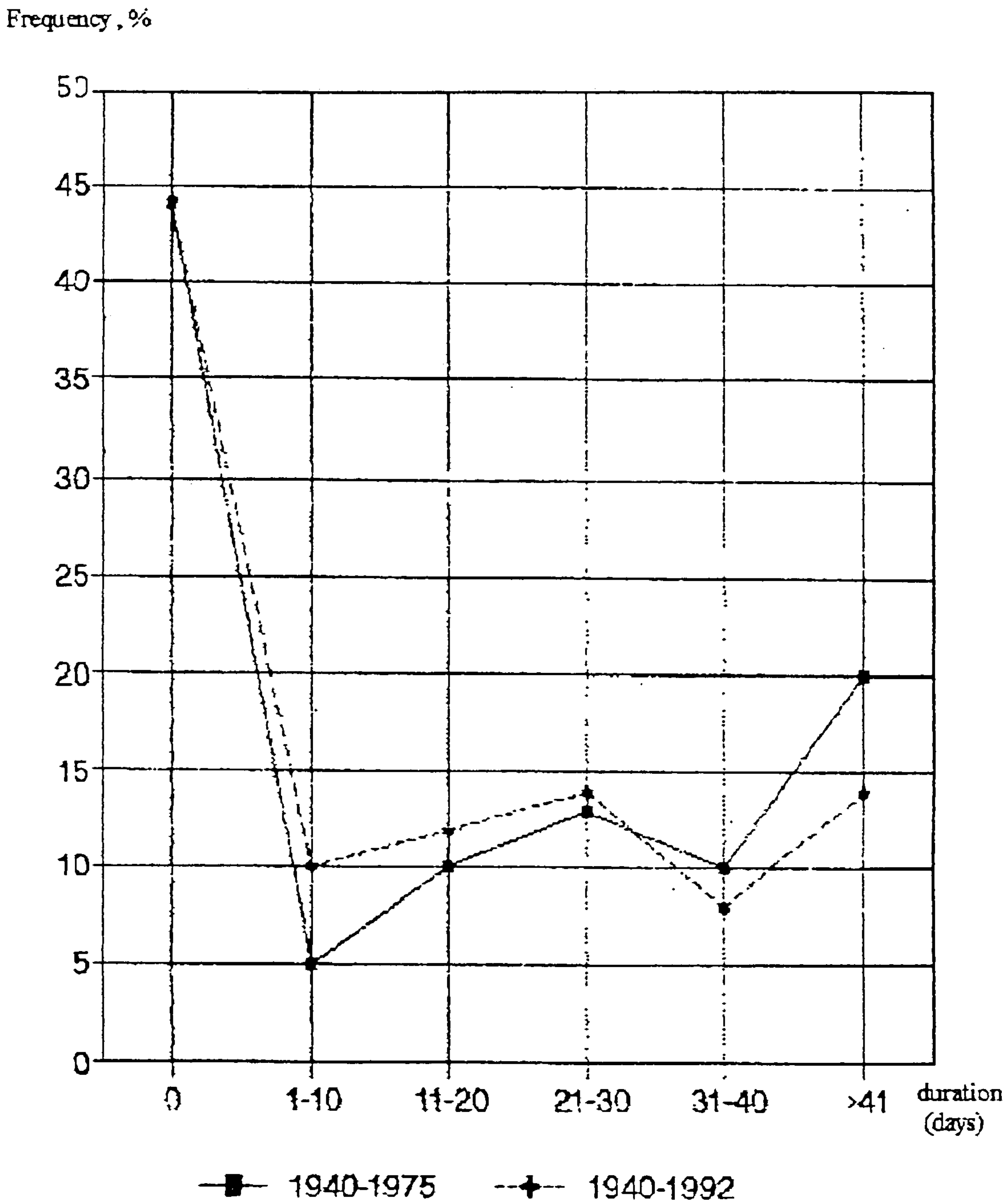

Figure 6. Duration of navigation period of UL class ships without icebreaking support along the Northern Sea Route

and its changes, 1991; Kondratyev, 1987; White, 1990; Budyko et al., 1989). It was predicted that there would be a significant increase in the duration of the period of unescorted transit navigation along the NSR. However, as observation data from 1940-1972 have shown, there was in fact a decrease in the occurrence frequency of favourable navigation conditions (Fig. 6). It still remains to analyse the causes of the above mentioned typical features and find out their relationship with the other generalized indicators of natural conditions in the Arctic basin and its marginal seas. However, there is no doubt that concerning the prospects of developing international transit navigation along the NSR it is desirable to be based on the climatic characteristics of the present-day epoch (Climatic regime of the Arctic at the threshold of the 21st century, 1991).

6 STUDIES OF THE ARCTIC CLIMATE IN THE CONTEXT OF GLOBAL AND REGIONAL PROBLEMS

Over the last decade, the Arctic has become the focus of attention - first of all, in connection with the problems of global and regional climate changes, environmental protection and supply of natural resources.

The key role of the Arctic in the global climatic system is primarily related to the Arctic Ocean, its specific freshwater balance, sea ice and the dependence on water exchange with the adjacent seas and oceans. That is why the Arctic Ocean is still the priority goal for the studies in the framework of international programmes suggested under the aegis of international scientific agencies.

Among them the WMO/ICSU/IOC Program "Arctic Climate System Study" (ACSYS), adopted in 1993 as part of the World Climate Research Program, aimed at studying the circulation of the Arctic Ocean and sea ice, their interaction with the Arctic atmosphere, freshwater balance in the Arctic region with adjacent oceans and seas. Special emphasis has been put on the construction of current models of ocean circulation and ice.

The European Committee for Ocean Polar Science (ECOPS) with the assistance of other European agencies (MAST, AOSB) and the International Arctic Science Committee (IASC) has developed the foundations for the European strategy of Arctic Ocean studies as an important part of the regional climatic system with special interests of the North European and sub-Arctic countries in problems of the role of the Arctic Ocean in changes of regional climate, conservation of renewable resources (in particular, fish supply in the Barents Sea), use of oil and gas on the Arctic continental shelf, development of marine trade shipping along the Northern Sea Route, monitoring and control of environmental pollution and improvement of the models for weather and ice forecasting.

Close international cooperation is important here. This is necessitated by the rather expensive logistics of Arctic studies, the distribution of scientific information, financial possibilities in different Arctic and Nordic countries, the existence of state boundaries in the Arctic, an interregional character of the Arctic processes and common views on the scientific grounds and the ways of addressing Arctic research problems.

The questions of the scientific research and the strategy of planning the studies in polar regions were discussed in 1994 at three large European and international conferences.

2-7 September 1994 the ECOPS jointly with AOSB, IASC and with the support of MAST held a conference "The Arctic Grand Challenge" to discuss and plan the European scientific strategy of the studies in the Arctic for the next 10 years. 12-16 September 1994 "The European Conference on Grand Challenges in Ocean and Polar Science" was arranged in Bremen, where a long-term strategy of the studies in polar regions was discussed jointly by scientists and administrators. 7-10 November 1994 a conference "The Dynamics of the Arctic Climatic System" was held in Gothenburg to discuss and adopt plans for the implementation of the ACSYS Program for 1994-2005.

7 CONCLUSION

Analysis of available studies and the forecasting of changes in climate and ice conditions in the Arctic waters north of the coast of Siberia allows for the following conclusions.

A. Navigation along the NSR is still strongly dependent on natural conditions and,in particular, ice. With ice there are large seasonal, interannual and intraannual variations, and these govern the character of navigation. Rational organization of transit transportation is possible in these conditions only if based on knowledge about the current and expected ice state on the route. This governs the place and the role of scientific forecasting in the marine transport system. For the design, construction and maintenance of long-term engineering constructions, the character and extent of climatic transformations appear to be of interest.The problem of such transformations has particular importance for polar regions due to their great sensitivity to external effects.

B. Scientific forecasting requires the following:

a. knowledge of the forecasted phenomenon as such;
b. knowledge of the causes of the change of its state;
c. knowledge of advance mechanisms.

This knowledge is satisfactory only in the part concerning the study and description of climate change and ice conditions. Progress in understanding the two other points is rather insufficient: the moving force of the development of natural process remains unclear. Today the efforts of a wide range of scientists-geophysicists in many countries are aimed to investigate it. And much of their attention is given now to the study of the internal dynamics of the climatic system.

C. Lately due to the rapid increase in carbon dioxide and other greenhouse gases in the atmosphere, the question of the ratio of natural and anthropogenic components in changes in the climate and the environment has become more and more important. There is no agreement, and as long as this situation continues it seems to be too early to speak about the prevailing role of the "greenhouse effect". Science must be given the necessary time to clear up its own problems. It is hardly advisable to make responsible decisions of major economic importance based on the carbon dioxide factor before finding out its actual role in climate changes.

D. Recognition of the dominance of naturally governed climate changes (as we could see there are insufficient grounds to reconsider this statement) allows one to use the regular features found during the study of retrospective data, to forecast its future state. The main methodological principle of such forecasting is expressed in the simple and extremely clear formula: "the past is a key to the future". If we do not know the past, we are devoid of a possibility to look into the future. Thus, to investigate the spatial-temporal typical features of past changes in climate and ice conditions along the NSR remains the most important immediate objective of studies under Project 7.

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Part II

ELECTRONIC NAVIGATIONAL TECHNOLOGY

I.7.1 PERSPECTIVE RESEARCH ELECTRONIC NAVIGATIONAL TECHNOLOGY

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SUMMARY

According to the project part "Electronic navigation technology" the analysis of last technologic achievements on the usage of new satellite positioning systems and electronic charts in the Arctic was carried out.

The results of marine and indoor trials of GPS NAVSTAR system and electronic chart systems based on IBM compatible personal computers are represented.

KEY WORDS

Satellite navigation system, GPS NAVSTAR, GLONASS, marine trials, ECDIS.

INTRODUCTION

The purpose of researches in 1993 on this theme is the ordering of latest achievements in the science and practice of new navigating technologies, based on usage of satnav systems of the second generation and electronic charts in area of international navigation in the Arctic.

The problem is that neither electronic charts nor satnav receivers have till now had the status of compulsory conventional ship equipment.

At the same time radio and satellite navigational systems receivers have already for many decades been used as gauges of location of vessels in conventional technologies of navigation based on traditional paper chart usage. The same equipment is included in new technologies of navigation in essence distinguished from conventional ones by the application of electronic charts.

Since satnav receivers are compulsory components of electronic navigational technology, on stage 1993 the analysis of in-door and marine tests of latest models satnav GPS NAVSTAR receivers produced by various firms was executed. The tests of navigating complexes, including personal computers, electronic charts and GPS NAVSTAR receivers were conducted simultaneously.

Much help in the realization of tests was rendered by Russian shipowner, in the first place, Northern Shipping Company (Arkhangelsk), manufacturers of ECDIS - TRANSAS MARINE and ALBATROS (St.Petersburg, Russia), St.Petersburg distributors of TRIMBLE (USA) and FURUNO (Japan), which have presented for vessel tests samples of equipment.

The executed work is an initial stage of researches on new navigating technologies, which will be continued in 1994.

HISTORICAL INFORMATION

For a decade of satnav receivers use on transport vessels as well as on ice breakers the sufficient experience was accumulated. At first it was low-orbit satnav systems - American TRANSIT and Soviet TZIKADA (for civil consumers) and PARUS (for military users), and then middle-orbit satnav systems - American NAVSTAR and Soviet GLONASS.

Positioning by satnav systems of first generation has the accuracy 8-12 cbs (probability 0.95) in dependence on accuracy of drift account. Thus the position obtaining interval ranges from 20-25 minutes in Arctic to 12 h in equatorial regions. Satnav systems of second generation in any region of the Earth provide to civil consumers an accuracy of 100 m (probability 0.95) with every-second updating of data. In differential variant GPS NAVSTAR provides the accuracy in general in units of meters.

Keep in mind, that GPS NAVSTAR provides two levels of accuracy: precision (PPS - Precise

Positioning Service) and standard (SPS - Standard Positioning Service). The level PPS is supervised by USA Ministry of Defence and is protected from non-authorized use i.e. civil users receivers do not accept the special frequency and exact code PPS. For civil consumers the standard level of accuracy SPS - 100 m, provided by the use of carrier frequency 1575 MHz, modulated by rough code SA. As far as the standard level of accuracy has appeared, from point of view of USA, too high (by our tests, 35-40 m), it is artificially decreased by special methods down to 100 m.

As far as such accuracy is low for maintenance of navigation in dangerous arctic regions, in narrow passages, on approaches to ports and port waters, solution of the problem was found in the use of the differential operating mode GPS NAVSTAR.

This regime consists in automatic entry in board receiver of differential amendments, determined by the local receiving device and transferred, such as radio beacons. The ground stations of differential subsystems GPS NAVSTAR, using as transmitters of amendments marine radio beacons, already function in a number of regions of USA coast, Denmark, Sweden, Norway, Finland (about 50 stations in total).

GPS NAVSTAR receivers are widely distributed on the vessels due their reliability, high accuracy and simplicity of use. The economic factor also plays its role - usage of satnav receivers excludes the necessity of distant, average and short-range radio navigational systems receivers (OMEGA/MARCHROUTE, LORAN-C/CHAIKA, DECCA/MARS/BRAS), the cost of GPS NAVSTAR receivers ($2000-3000) not much more higher than the cost of replaceable radio navigation systems receivers and is much cheaper than other aids of navigation - log, compass and radar.

The question of the recognition of satnav systems of second generation as a world means of positioning has been the subject of discussion in IMO committees for some years.

With reference to electronic charts one can say that while the international maritime community discussed the idea of Electronic Chart Display and Information System (ECDIS), elaborated its performance standards, tried to find its place in navigational technology and law status, some manufacturers put on the market the low-priced, PC-based, electronic chart systems very suitable for seafarers.

IMO and national Administrations must use the received experience for ECDIS legal support elaboration and the specialists in the navigational theory - elaborate the methods of application of the new technology in practice under various conditions and circumstances of navigation.

1 GPS NAVSTAR RECEIVERS COMPARATIVE TESTS

Statements of task

The expediency of equipment of all vessels, directed in arctic seas, by GPS NAVSTAR, and in the shortest possible terms, gives no cause for doubt in CNIIMF. The operational and economic advantages of GPS NAVSTAR on radio systems of long, middle and short range navigation are too obvious. Moreover the installation of GPS NAVSTAR receivers on board ships opens the way to electronic navigation, based on use of electronic charts, for which such receivers are the unique acceptable gauge of information about current location of vessel and time.

The existing disagreement on the question of terms and the base model of receiver for particular group of vessels, may be removed only on the basis of comparative sea tests.

At present on the navigating equipment market, including the Russian one, are devices of various firms and of diverse models. But the firms of exhibitions, in advertising and prospectuses declare only the positive sides of their productions, without any mention their shortcoming and negative aspects.

Information on this problem received by the Institute in recent years from Russian shipping companies and individual shipowners confirms the necessity of solving these issues.

Concept of comparative tests

From models subjected to comparative tests, the concrete GPS NAVSTAR receiver may be chosen for vessels requiring the optimal characteristics:

a) constructive hardware-software reliability, as well as electromagnetic compatibility with other ship equipment;

b) cost, including the cost of modernization for work in differential variant;

c) number of tracking channels;

d) perspectives, including the ability to work in differential regime with least costs of modernization;

e) quality of software;

f) measurement of speed based as on Doppler effect, as on increasing of observed coordinates;

g) accuracy of output parameters;

h) dimensions and design.

No receiver model actually exists having all best listed parameters. Receivers of each firm have their own particular features and only the consumer knows, what he wants to receive in the first place, taking into account the specific character of work of the various vessels.

In our case, idea of tests consists in the choice from receiver series of such model, which is about equal with other models to price and quality, and:

- could be used as exact and reliable mean of position, time, speed and course fixing, for electronic chart;
- could be in short term and without large additional costs modernized for work in differential regime;
- provide the opportunity of direct connection to ship emergency network without expensive

converter.

Receiver and its software should be simple enough for mastering by navigators. Finally a receiver should be capable of replacing log - conventional device, which does not function on more than half of the vessels, working in the Arctic.

Organizations of tests

In 1991 at the request of some leading Russian Shipping Companies and the Marine Department of the Ministry of Transport, the Laboratory of navigational technology of CNIIMF proposed to manufacturers of electronic charts to conduct comparative in-door test of their production. The consent was received from three firms, two of which - ALBATROS and TRANSAS MARINE - both located in St.Petersburg - have actually participated in tests.

Later ALBATROS dropped out of the cooperation, leaving only TRANSAS MARINE presents for valuation all samples of its production till now. This firm in extremely short terms eliminates the defects, revealed in its software while testing.

Such the approach may be offered to application to all firms - manufacturers of satnav systems receivers. Such firms as FURUNO (Japan), MAGNAVOX (USA), TRIMBLE NAVIGATION (USA) have long term cooperation with Russian shipowner and, intending to enter the Russian market, also presented the devices for tests. Today the large Russian shipowners do not establish on board equipment for navigation and communication without recommendation by CNIIMF.

In the beginning of 1993, choosing the acceptable model of the GPS NAVSTAR receiver on the instructions of Northern Shipping Company (NSC) CNIIMF experts - the head of Laboratory of navigational technology candidate of science A.Baskin and scientific employee I.Sergeev on board the NSC m/v "Pioner Onegi" have conducted the tests of MX 200 receiver (MAGNAVOX). Then the same group of researchers on board the vessel of the same type "Pioner Severodvinska", where MX 200 receiver was already installed, has established in addition NAVTRAC XL (TRIMBLE NAVIGATION) and MARK 90 (RACAL MARINE ELECTRONICS, England) and has executed the comparative tests of three named models in the same operational conditions and following the uniform program and technique.

In 1993 and the beginning of 1994, scientific employees of Laboratory candidate of science V.Vasiljev, diplomaed engineers S.Samonenko and V.Isakov, while sailing on board the vessel of private shipping company "Liko-I" and during the manoeuvering tests of new-made vessels of NORTHERN SHIPYARD (bulker "31") and ADMIRALTY SHIPYARD (tanker "Pulkovo"), conducted the tests of GP-50 (FURUNO), MARK 90, NAVTRAC GPS and ACUTIS (TRIMBLE NAVIGATION) receivers.

Receivers were connected with electronic chart display information systems NAVI MASTER (TRANSAS MARINE) - standard variant for navigation and NAVI DREDGER - special version for high-speed and manoeuvering tests of vessels. All tests were carried out according to the programs and technology, developed by CNIIMF and approved by the Marine Department of the Ministry of Transport and ship-building enterprises.

During tests the satnav receivers were installed in the chart house. The antennas were fixed on spar-deck or vane-deck rails as close as possible to for and aft line of the vessel. The power supply of equipment was executed from board network through blocks - converters, when necessary.

General information on receivers

The satnav receiver MX 200 is produced by the American firm MAGNAVOX. The model appeared on the market of navigational instruments in 1992 and, possibly due to its wide and well organized advertising, became widely known.

MX 200 represents a 6-channel receiver and antenna block. On measure of reception of data the task of choosing between three satellites, which parameters ensure the best accuracy, is decided.

Simultaneously, on the basis of independent measurements of Doppler shift of carrier frequency of satellite, the true speed of vessel over the ground is determined.

The power supply voltage is 10,5 - 32V DC. The consumed power - 7 Wt.

The receiver dimensions 150 x 300 x 51 mm. The possibility of differential corrections receiving may be realized through the installation of a plate with signal processing software.

The receiver is simple to handle.

The satnav receiver MARK 90 have been are produced by English firm RACAL MARINE ELECTRONICS Ltd already for some years.

The receiver has 3-channels (receiver installed on m/v "Pulkovo" was single-channel with sequential interrogation of satellites), antenna, four input/output ports, enabling the usage of receiver as an informational pick-up device for ship navigating equipment. Through input ports it is possible to enter in receiver course from gyrocompass, speed from log, latitude and longitude from independent gauge and corrections of pseudo-distances in case of use in differential operating mode GPS NAVSTAR (if software for correction reception and processing is available).

Power supply: the voltage - from 18 to 36V (nominal - 24V) DC, consumed power - 18 Wt.

Dimensions: - 365 x 230 x 245 mm.

The receiver is executed pursuant to operational conditions of the Department of trade of Great Britain, stated in "General Requirements for Marine Navigational Equipment 1982".

The satnav receiver GP-50 is produced by the Japanese firm FURUNO, whose instruments are well known by Russian navigators.

GP-50 includes the antenna block of with 8-channel receivers, control and indications block, cable of 15 m length, assembly set for fastening and installation.

The display of data is executed on the screen of liquid crystal display with resolution of 16 characters on 4 lines.

GP-50 has one output port for interface with external navigating equipment on standards NMEA0183, NMEA0180S and CIF (FURUNO standard).

The given model does not provide the opportunity of work in differential regime.

Power supply: the voltage - from 10 to 35V DC or 110/220V AC through additional supply unit. The consumed power - 8 Wt.

The dimensions of control and indications block, mm: 208 x 55 x 115. The weight 0.7 kgs.

The satnav receivers NAVTRAC GPS and NAVTRAC XL are various models produced by the American firm TRIMBLE NAVIGATION. The model XL is more modern, has more accomplished software and more extended menu of navigating tasks. However the main difference of the new model is the availability in its software for reception and data processing of corrections for differential regime.

Receivers include the antenna block with 6-channel receiver, control and indications block, antenna cable.

Receivers have two input/output ports for interface with external navigating equipment. The model XL has the port for connection with receiver of differential corrections NavBeaconXL.

Power supply: the voltage - from 12 to 24V DC.

Dimensions, mm: 230 x 100 x 170.

The receiver ACUTIS DGPS is also produced by TRIMBLE NAVIGATION. It differs from described models, in that it represents the antenna and 6 channel receiver, located in one antenna block. The set includes a 15 m antenna cable.

The given model is only the unit producing coordinates data for their reflection by video plotters or ECDIS.

The dimensions of the ACUTIS antenna block are identical to those of NAVTRAC GPS and NAVTRAC XL.

During the tests the receiver ACUTIS was connected to NAVI MASTER (NM-1000).

For all satnav receivers:

- minimum satellite elevations at which the coordinates location is provided - 5°;
- average time of reception of the first observation after turning the receiver on by "hot" start (almanac being recorded in memory) not more than 5 minutes. The least time of initialization of GP-50 receiver - 2.2 minutes;
- average time of reception of the first observation after turning the receiver on by "cold" start (almanac being recorded in memory) - 30-40 minutes;
- receivers have menu of navigating tasks (routing, list of routes, course line, distance to way point, arrival time calculation etc.), quantity and complexity of which depends on the model;
- coordinates, calculated in all GPS NAVSTAR receivers, are presented in system of coordinates WGS-84. All listed models have the possibility to recalculate the displayed coordinates in other systems of coordinates, however each model has own subroutine of recalculation. The subroutines differ in the degree of complexity and quantity of standard geodetic datums.

As is known, distinction of geographical coordinates of the same point on earthly surface, referred to different geodetic systems, can reach about 25" (700 m). Such value has a serious practical significance from the point of view of safety of navigation, especially in narrow passages. The potential accuracy of differential regime - about 10 **M** - can't be reached without taking into account these divergences. A similar situation arises at interface of receivers with ECDIS, working in other geodetic systems.

TECHNICAL RESULTS OF TESTS

Accuracy

The positioning accuracy of all models of GPS NAVSTAR receivers is approximately the same. The main component of observation error is determined not by tool or methodical characteristics of a particular model, but by USA Ministry of Defence teleological actions for prohibition of non-authorized access to exact GPS NAVSTAR information, fixed in appropriate decision of USA Congress.

The receivers tests have shown, that the casual positioning error while standing in ports was about 30-40 m (probability 0.95). The systematic error - divergence of average significance of observed coordinates from accurate coordinates of antenna on navigating chart, corresponded to the divergence of geodetic datums of receivers and those of ports plans.

The error mentioned above defines only the tool accuracy. It doesn't include the 100 m limit of accuracy for civil consumers fixed by USA Congress, for detection of which the long term measurements on the fixed point are necessary. During 20 standings in Arkhangelsk satellite observations received with the help of an MX 200 receiver were fixed continuously by means of NM-1000.

The average square error of GPS observation, received by scope (latitude range - 1.5 cbs, longitude - 0.8 cbs), was equal +/- 0.85 cbs +/- 157 m. Accordingly the positioning error was equal 89 m (probability 0.95).

More continuous supervision (about 12 days) on evaluation of accuracy and stability of satellite observation was conducted in premises of the Laboratory of CNIIMF. The GP-50 receiver was subjected to test. The readout of geographical coordinates were carried out by series with 30 s and 1 min frequency. After processing of supervision data the following results were received:

- the average square error +/- 52 m, the maximal error at regime SA - 112 m (probability 0.95).

The tests have shown, that the error of speed definition amounts to 0.3 knots (probability 0.95) - for the movement with constant propeller's rounds and course and with the same satellite asterism. The change of asterism greatly influences the speed indication. So, the divergence of speed indications in receivers using different asterism is up to 0.6 knots.

While manoeuvering with a rudder hard to board the difference between the compass course and the course indicated by satnav receiver increases with an increasing of turning angle and reaches the maximum (20-40°) on the counter-course (170-210° turn). The maximal divergences were fixed for the receiver MX 200 (68-114°).

Interference resistance and electromagnetic compatibility

Two satnav receiver sets MX 200, as well as MARK 90 and NAVTRAC XL were subjected to effect two VHF-radio emitters "REID" (power of carrier frequency in antenna 75 Om equivalent 15-25 Wt, range of working frequencies 156.05 - 157.95 MHz, antennas installed on the mast at a height of 14 m above the level of the vane-deck) serially on all channels.

The MX 200 receiver showed suppression of satellite signals and loss of observations while the VHF-station worked on channels 23-36, 82-95. The cycle of tests was repeated three times: with installation of MX 200 antenna in left-hand forward corner of vane-deck in right forward corner and in the middle of front the rail. In all cases irrespective of the antenna installation within the limits of cable length, the results were identical. Thus interference resistance and electromagnetic compatibility of MX 200 with ship radio equipment is not provided in due measure, that puts under question the conformity of operational receiver parameters to project standard IEC.

The interference resistance and electromagnetic compatibility of other models of receivers did not provoke censure.

The other radio, radar and electrical ship equipment didn't affect the functions of MX 200, NAVTRAC XL and MARK 90 receivers.

Reliability

All tested satnav receivers are produced by firms, whose production is in long-term constant demand. GP-50, NAVTRAC, ACUTIS DGPS and MARK 90 receivers worked reliably and steadily being tested. It is necessary to note, that GP-50 was installed on board the m/v "31" in the period of manoeuvering tests, during which power shifts and significant voltage changes were observed.

In comparison with the reliable work of other models the extreme concern is caused by the insufficient constructive hardware and software reliability of the MX 200 receiver. Installed on board the m/v "Pioner Onegi", the complete set MX 200 worked satisfactorily for 20 days, after that the equipment failure was fixed. Presumably the managing processor failed. In replaced complete set, in turn, after 36 days of work the control button went out of operation, after that MX 200 was replaced by the third set.

At the time the tests were completed, 13 sets of MX 200 were installed on the vessels of NSC. Failures occurred in 6 sets, during a few months of operation.

Software

The tests have revealed some essential defects of software of different models, limiting their functional use and hindering their inclusion as means of positioning in navigating complexes.

In the NAVTRAC GPS receiver the coordination of geodetic systems of observed and entered coordinates is not stipulated. When changing the system of coordinates with a route loaded (ROUTE), coordinates instantaneously change (regime Position), all regimes work, but at switching in regime of indication of route (geographical grid) receiver "hangs" - does not react on buttons pressure, time stays, any signal or messages are not given out. After switching receiver out and once more in, the work of NAVTRAC GPS is renewed.

The following software and hardware defects of the GP-50 receiver were detected:

- the calculation of bearings and distances is executed only for orthodromy though the majority of navigational tasks requires calculation for Mercator sailing;
- the functional buttons are concurrent with alphanumerical which reduces the operational speed.

In MX 200 receiver software the PLOTTER-program works extremely unstably - the frequently distortions of the route, the unpredictable disappearing of route line or, on the contrary, the displaying of additional route segments are detected. The work in regime TAPE IN/OUT of subroutine

ACCESSORIES frequently causes loss of observations. The NAVIGATE programs stops when calculating the XTE value during navigation on route. Alarming about the observation loss (ALARM task) is unreliable.

The calculation of orthodromy distances is not correct when the latitude difference exceeds 90°.

Only the GP-50 receiver has a self-check program, started by operator. The absence of such program in other models should be counted as a deficiency in their software.

Differential regimes

Only the GP-50 receiver stipulates no facility for the opportunity of additional installation of module with software for processing of differential corrections. Its software does not provide possibility of receiving data and parameters from the interface with receiver of differential corrections

All other models were to a greater or lesser degree developed in view of being able to work in differential regime GPS NAVSTAR. However models of receivers vary greatly. If in MARK 90, MX 200 and NAVTRAC GPS the opportunity of additional installation at additional expense of module for processing of differential corrections, accepted from special receiver is stipulated, NAVTRRAC XL already has the built-in software for work in operative range of basic stations of differential subsystem GPS NAVSTAR. For NAVTRAC XL it remains to establish the receiver and antenna (TRIMBLE manufactures the receiver NavBeaconXL, working in radio beacon range of frequencies).

Approvals by classification company

Whether the particular model of GPS NAVSTAR receiver is approved by some classification company or not - is at the present time an academic question, for this equipment is not conventional.
However the problem of approval by classification company would take another turn after IMO decision about inclusion of GPS NAVSTAR receiver in the class of compulsory means of navigation. Much indicates that the cost of approved models of receivers will doubtless increase.

MARK 90 has the certificate of Marine Register of Russia. The other models have not.

Speed determination

One of the questions, which should be established by tests, is the question of speed determination. The fact is that high-grade GPS NAVSTAR system receivers should not only define the geographical coordinates of the vessel's position, but also execute the determination of speed of the vessel by measurement of Doppler shift of carrier frequency of satellite signal.

The simplified models of receiver also display the speed of vessel, but do not measure it. In this case speed is calculated by increments of coordinates. The manuals of such receivers usually use the expression "the speed determination", which is an attempt to hide the difference between independent measurement of speed and its calculation.

There are also more complex cases e.g. the NavTracXL receiver not only executes the measurement of Doppler shift of frequency, but pursuant to the algorithm, during sharp (more than 15 %) changes of satellite movement dynamic simultaneously uses for speed determination its values calculated by coordinates increments, which are taken into account with small weight factors.

This question is principal since the conventional requirements that the vessel should have log for measurement of speed, this as is known, does not function on majority of vessels, working in Arctic. Therefore just such a device as the GPS NAVSTAR receivers, measuring the speed, may be considered.

Questions of engineering psychology

The modern receivers have a lot of capabilities incorporated. However, as actual practice shows, only 10-20% of the possibilities of numerous navigating tasks decision, provided by latest receiver models, are used by navigators. So, on a few vessels the routes are recorded in memory of receivers, the alarming system about approach to way points, about utmost deviation from line of way, about circulation on anchorage are almost not used.

The responsibility for such use of modern receivers rests not only with navigators and their instructors, but also with developers of software paying little attention to questions of engineering psychology.

The English made MARK 90 receiver is extremely conservative in the ideology of its software, management of work, ways of decision of tasks and representation of information. Navigator must remember a lot of formal codes having no mnemonic. The entering and management of data is executed with the help of sensors, which are very unreliable in practice. The display of information appears on two one-line liquid crystal displays, one of which is navigating, the other serves for indication of codes of processed and entered data. Such displays give little information. mark 90 is rather complex to study.

The best decisions from the engineering psychology point of view are provided by MX 200 and GP-50. The keyboards (buttons instead of sensors) are functional on these models. It is possible not to know the device in general, but simply to press buttons NA, P'S, PLOT or GPS and displayed information to define whether the button is pressed. Pressing of buttons with arrows permits to understand that with their help the program formats change is realized. These receivers are easy to study due to the well organized tasks realization.

The high allowance of matrix liquid-crystal display ensure the perfect visualization of alphanumeric information.

At the same time, GP-50 has the format number indicator in its lower right corner, which is superfluous and may cause navigator's errors.

The existence of "calculator" program in MX 200 receiver is, in our view, simply inadmissible, for it provokes the officer on watch to do things, not connected with the watch duties, which runs counter to international conventions.

NAVTRAC receivers remind MX 200 and almost do not concede them (the speech goes only about questions of engineering psychology). The sizes of NAVTRAC display are somewhat smaller than at MX 200, however graphic decision of program ROUTE is, in our view, the more successful one.

The volume of navigating tasks and auxiliary programs, soluble by all receiver's models, is quite sufficient for automatic check of vessel's route and maintenance of safety of navigation.

Dimensions and design

Even on board the modern vessels the dimensions of satnav receivers have significance. So, MARK 90 was established with difficulties in best location - in the right forward corner of the navigator table, due its big dimensions.

Practically identical in size are the models NAVTRAC and MX 200 (the first is smaller), both are easy to establish in any location.

GP 50 receiver, the smallest in size, can be easily fastened with the help of arm on table, on the bulkhead or on the ceiling.

As to design, MARK 90 is different from all other models, as arithmometer from electronic calculator.

Engineering specifications

The international conventions require from the officer on watch the knowledge and account of equipment possibilities limitations. In the engineering specifications of all models information about their limitations is absent. Neither do any of the firms indicate the shortcomings of their products, for it reduces their competitive opportunities. The restrictions of equipment can be named only by the independent experts.

Engineering specifications of MX 200 do not mention the characteristics of course and speed information smoothing, but the tests have shown, that while turning the indicated course error can reach 114°.

Engineering specifications of MX 200 and mark 90 fail to mention some characteristics of important significance for safety of navigation, e.g. the way of speed determination (SOG) - direct measurement of Doppler shift of frequency or calculation by observed coordinates of vessel position.

The user's guides and manuals of all receivers do not give information on accuracy. Instruction manuals of NAVTRAC lack explanation of work of some tasks, the specification is missing, the erratums are present. But on the whole the engineering specifications of NAVTRAC are less deficient, than documentation of MX 200, the system of search of necessary function or tasks is very successfully organized and includes a key to abbreviations and terms.

The instruction manual of MARK 90 is executed very unsuccessfully, is very bulky, inconvenient and difficult to master.

CONCLUSIONS FROM COMPARATIVE TESTS OF MX RECEIVERS

GPS NAVSTAR restrictions. The major qualitative restriction of GPS NAVSTAR is "the Reliability of information", under which the ability of the system to find out the failure in the work and to notify about it to the user is understood. American issues give information that the reliability of NAVSTAR system data is characterized by 3-hour term, i.e. navigator can use the faulty GPS NAVSTAR observation for 3 hours, without knowledge about it.

Therefore the conventional requirement on the systematic supervision of vessel position and other independent methods of navigation completely preserves the significance for GPS NAVSTAR use.

For navigation in the immediate vicinity of dangers to navigation in the absence of the differential subsystem GPS NAVSTAR control of vessel position should be executed by visual methods (radar-tracking, compass tracking, leading lines, pilotage) using land marks. The reliability of visual methods is independent of the system of coordinates of the chart. On the other hand, satnav receivers give the position in absolute system of coordinates, transition from which to local system is frequently unknown, because of possible local system distortions made for reasons of secrecy.

Therefore near to dangers to navigation the satnav system can be used only as an auxiliary means of navigation.

The comparative marine tests have revealed the following:

1. operational characteristics of the compared receivers are distinguished slightly one from another and satisfy the requirements of project of IEC standard for ship GPS NAVSTAR receivers. MX 200 receiver concedes to other models in interference resistance, reliability and conformity of course to its real values while turning.
2. Comparative valuation of receivers by criteria of efficiency of use, reliability of software, simplicity and convenience of work and service, design, weight and dimensions has shown, that the NAVTRAC XL receiver satisfies to the greatest extent modern requirements.
3. GP-50 receiver is the least expansive (approximately half the price of all the other models).

It is one of its main advantages.

4. Receiver ACUTIS can not be recommended for use as positioning device of ECDIS, because in the case of ECDIS failure the vessel may stay without position indicator, necessary for reserve hand-operated lining.

2 INDOOR AND MARINE TESTS OF ELECTRONIC CHARTS

THE ORGANIZATION

In 1992 CNIIMF employees participated in state commissions executing indoor tests of electronic charts produced by two Russian firms - the "ALBATROS" enterprise and joint-stock company TRANSAS MARINE.

The tests aimed to verify the production of firms on conformity to "Technical and operational requirements to videoplotters with display of electronic charts" (entered by the Department of marine transport of the Ministry of Transport of the Russian Federation on April 07, 1992), as well as to IMO Resolution A.574(14) Recommendation on general requirements to electronic navigating equipment, (accepted on November 20, 1985) and reception of Certificate about general approval.

During the past 18 months the IMO Draft Performance Standard for Electronic Charts Display and Information Systems (ECDIS) has undergone significant changes, their last version having been issued in July 1993. The production of named firms was also modified, due certainly to its wide use on Russian vessels. The new Russian organizations, also developing and producing electronic charts and electronic charts display equipment appeared.

The idea of electronic navigation has advanced from the stage of theoretical development and tests of equipment prototypes to wide industrial use of electronic charts display systems. In real time it is not the technical or software questions that are first and foremost, but questions of training of navigators, questions of technology of the use of this equipment and legal questions. In this plan the results of first indoor and marine tests are of interest, as the listed questions were raised just at that time. Note that it was the very beginning of 1992 that IMO discussed the question about acceptance of GPS NAVSTAR receivers as conventional equipment for certain classes of vessels, as well as the project of USA law (H.R.3969) with requirements for compulsory equip the vessels, visiting the USA ports after January 1 1993, not only by GPS receivers, but also by videoplotters recording the vessel's own trajectory and trajectories of radar auto-tracking aims.

INDOOR TEST OF NAVI MASTER NM-VERSION VIDEOPLOTTER

The tests were carried out on March 6, 1992, according the program and methodic, agreed by main navigation officer of the Baltic Marine Shipping Company captain M.Charushin. The long experimental operation of one set of equipment on ferry "ANNA KARENINA", working on line St.-Petersburg - Kiel.

For consideration by the commission were submitted:

- specialized personal computer of marine performance DRS M-4 produced by MCS (MARINE COMPUTER SYSTEMS, St.-Petersburg), approved by Register of Shipping of Russia;
- specialized software produced by TRANSAS MARINE - NAVI MASTER, version NM;
- a set of electronic charts, equivalent to 30 paper Soviet charts of different scales edited by the Head Department of Navigation and Oceanography of Ministry of Defence;
- satnav receiver GP-500, produced by FURUNO (Japan).

The set delivered included the hardware-software key, excluding non-authorized access to electronic chart, and to its updating. The commission came to the conclusion, that as a whole the submitted sample of videoplotter has passed the indoor tests. The commission statement mentions, that on series of parameters the complex NAVI MASTER surpasses the IMO recommendations.

The following developers merit were noted:

- the possibility of scaling of cartographic information, i.e. opportunity of reception of chart in practically any scale convenient for the navigator, and not just in scale series IHO-IMO, due the programmed choice of information to display by rather complex algorithm from more large scale of initial chart to more small-sized one;
- the opportunity of data input from log and compass, that permits organization of the information filter;
- the opportunity of documenting of navigating information, satisfying many requirements of Rules of management of ship journal and of "black box".

At the same time the commission noted several deficiencies, in particular:

- not total conformity of used symbols to IMO proposals;
- absence of the alarms about the navigational information gauges failures etc.

The final conclusion was assumed to be given after finishing the stage of tests on vessels.

One complete set of NAVI MASTER was handed to Laboratory of navigation and VTS technology of CNIIMF for the following modification trials, aimed at further perfection of software. The special expert conclusion was based on the results of tests carried out in May 1992.

INDOOR TESTS OF FUNCTIONAL SYSTEM "SHTURMAN"

The research-and-production enterprise "ALBATROS" had presented for examination the functional system "SHTURMAN". The tests were carried out on April 22, 1992.

Submitted for consideration by the commission were:

- the software of functional system (FS) "SHTURMAN", installed on IBM PC/AT - compatible computer;
- set of operational documentation;
- technical requirement on delivery of (FS) "SHTURMAN";
- protocol of experimental operation of (FS) "SHTURMAN" on board the nuclear ice breaker "the Soviet Union" of September 30, 1991.

The "ALBATROS" developed the software, enabling transformation of electronic charts made in format DS-90 to format of personal computer IBM PC/AT 286 12 MHz and above.

The PC and navigational gauges have no constructive changes.

The "ALBATROS" software is oriented on interface with TRANSIT receivers FSN-70 (FURUNO, Japan) and GPS NAVSTAR receivers SHIPMATE RS 5300 (Denmark). The opportunity of other receivers use on condition beforehand buyer order was declared.

The orientation on particular receiver models has made the dependence of software from receiver information format. However best, in our view, was the decision to develop an individual format, making software universal.

Taking into account the absence on the market of a catalogue of electronic charts officially produced by state hydrographic services, "ALBATROS" has created separate electronic charts, including the charts for the Arctic. Thus the firm uses as its basis the existing collection of Russian paper charts which is three times bigger than the British Admiralty collection.

At the moment of examination, the (FS) "SHTURMAN" did not meet entirely the requirements of IMO Draft Performance Standard for Electronic Charts Display and Information Systems (ECDIS), regarding in particular the sizes of screen.

The choice of gauges of navigational information was not optimal. The TRANSIT receiver calculates the coordinates of current location of vessel by the compass and relative log data and corrects them by satellite observations with unacceptably large periodicity. For arctic regions such gauge is unsuitable. Obviously, the gauge of coordinates for electronic chart should be GPS NAVSTAR receiver. However GPS receiver SHIPMATE RS 5300 as shown by the comparative tests, is far from the best choice.

FS "SHTURMAN" was not designed for direct interface with ship log and compass, as well as with autopilot, from which it was possible to receive the information about the vessel manoeuver by rate and/or speed. That's why it is impossible to detect the receiver data failure, and such failure is documented as vessel manoeuver.

The problem of graphic plotting of observations received and displayed by receiver on its own panels in various systems of coordinates (FSN-70 on WGS-72, SHIPMATE - on WGS-84 and electronic chart, for example, on Krasovsky ellipsoid) was not resolved by developers. In any case, the potential accuracy of GPS NAVSTAR was not realized.

Despite marked defects, the state commission ascertained, that FS "SHTURMAN" meets in general national "Technic and operational requirements to videoplotters with display of electronic charts" and was recommended for certification.

THE MARINE TESTS OF NAVIGATIONAL SYSTEM NAVI MASTER NM 1000

The marine tests of navigational system NAVI MASTER were conducted in some stages as follows. The TRANSAS MARINE Ltd. transmitted to the Laboratory of navigation and VTS technology of CNIIMF the next version of software, which was installed on the vessel computer for sea tests.

After completion of each stage of tests the report with results of tests, including descriptions of performance of the system on trip, noticed failures , remarks and proposals on navigational programs and electronic charts was transmitted to producer. The firm, in case of consent, made modifications in tested version, whereupon the corrected version of software was subjected to test.

The marine tests were carried out in October 1992 on board the m/v "Urij Avot" of the Latvian Shipping Company; in February - March 1993 on board m/v "Pioner Onegi" and in August 1993 on board m/v "Pioner Severodvinska" of the Northern Shipping Company; in September 1993 on board m/v "Liko 1" of a private Russian shipping company.

THE MAIN RESULTS OF MARINE TESTS OF NAVIGATIONAL SYSTEM NAVI MASTER NM 1000

The tasks

The navigational system NM-1000 serves for execution of a large number of navigational tasks, including:

- display of navigational charts on the screen and allocation of necessary site with its scaling;
- preliminary routing;
- recording the tracks;
- alarming of approach to way point, of deflection from given safety criteria (lateral evasion, displacement from anchorage etc.)and of malfunctions;
- satnav GPS NAVSTAR receiver data (coordinates, speed, bearing) indication;
- automatic plotting and its check to conformity with preliminary plotting;
- documenting of tracks with possibility to list data;
- representation of additional navigational information;
- representation of selected information from navigational allowances;
- electronic chart correction by Notices to Mariners;
- operative position fixing ("Man Overboard" situation).

The legal questions

The IMO Draft Performance Standards for Electronic Chart Display and Information Systems (ECDIS) consider the electronic charts as auxiliary means. Such ranking creates a ridiculous situation: the shipowner should suffer the significant costs of additional equipment, only for its use together with old technology without the right to change it.

Resolving the problem is found in the following organization of navigator service, which should be fixed by appropriate document of shipowner. While navigating at significant distances from navigational dangers, the preliminary plotting is put on small-scale paper chart and is entered in electronic chart by the coordinates of way points. The paper and electronic charts are shared: the operation of vessel is executed on the basis of automatically presented information of the electronic chart. At the same time once or twice each watch, the GPS NAVSTAR position of the vessel is plotted on the paper chart, providing the necessary reservation. In such variant it is simply impossible to say, which chart - electronic or paper - is the auxiliary one. Near to navigational dangers, on approaches to ports and in port waters the updated large-scale paper chart is used as the main source of navigational information, and the electronic chart permits to be oriented in fast changes in the situation. Graphic plotting on paper charts in port waters is not compulsory according to the modern requirements.

The shipowner, expanding vast sums on purchases of system of electronic charts, besides increasing of safety of navigation, receives the opportunity to reduce the ship collection of conventional charts by several times, which is equal to the cost of the electronic equipment. Thus the financing of electronic technology requires no extra costs, and is reduced to redistribution of means on navigational support to shipping with a general reduction in costs.

Installation of the system

The electronic charts are installed on board the vessel and may if necessary be dismantled without labour-consuming assembly or starting-up and adjustment work.

The correct choice of installation site for the electronic chart is in many cases determined by the need of rapid access to its information by the person for whom this information is intended.

The system should in no case be installed on the navigator table. This place is reserved for the conventional navigational chart and the GPS NAVSTAR receiver, intended for vessel position fixing by the navigation officer in case of use of conventional technology.

The electronic chart system is a mean of vessel control and its location must be in the forward right corner of the wheelhouse - the main position of the captain, and in his absence - of the watch captain assistant. The place of installation of the electronic chart system is determined also by minimum distances from front window, radar, telegraph, remote control system and board VHF-transmitter (it is assumed, that, in regions of intensive manoeuvring, the autopilot is switched off).

The tests have confirmed, that the above mentioned installation site of system best meets the requirements.

System operation training

NAVI MASTER system includes several of the electronic devices - satnav GPS NAVSTAR receiver, personal computer, hardware and software of electronic chart system (NM-2000 version includes also digital radar BRIDGE MASTER with interface block), each of which is multifunctional, rather difficult in operation and is not easy to master.

Shipowners of Russia have bad experience of the use of first generation satnav systems receivers, when for many years from their installation on vessel, the functions of receivers were not fully mastered by the navigator. It must be admitted, that the level of acknowledgement with position fixing devices decreases from junior assistants of captain to captains. The installation of a large number of new technological devices on vessels of large companies requires almost the simultaneous retraining of navigators. It is necessary to execute this task in the short term, taking into account the approach of next stage of introduction of electronic technology.

The following ways of solving the problem of training with electronic chart systems in large shipping companies can be recommended:

1. One or two set of the system should be installed in the training center for the training period (about one year).

First 3-5 educational days must be reserved for training of the captains - instructors of training equipment and safety of navigation service staff.

Then the training or the check of knowledge period is reserved for navigators directed on vessel, equipped by new the technology devices and for students on courses of qualification improvement.

2. Captains - instructors, after the training on shore, are directed in short trips on vessel, equipped with the new devices.

3. If the captain and other navigators not familiar with the system are directed on vessel, equipped by new instruments, the training with a 2-3 hour program should be organized directly on board the vessel.

4. Free access of navigators to devices of systems, installed in training center, should be widely announced. The acknowledgement with navigational system should be marked in the personal

chart of the navigator.

Use of the system

Use of the system in the legal sense, as well as in dependencies on installation sites of instruments and preparations of operators was considered above. In shipping process the use of system is connected with decision of several issues.

Centralized organization of preliminary plotting of recommended routes of navigation, in particular on the NSR, with drawing up of sheet of way points coordinates and routing description in shipping company for different types of vessels is rather effective for safety of navigation support and economic expediency. Certainly in ice conditions deviation from recommended routes is very probable. But it is also probable, that a significant part of routes will be used. The preliminary plotting, executed by experienced experts, checked, relieves captains and navigators from executing highly labour-consuming work, with a likelihood of errors. This measure does not restrict captains in route choice.

The efficiency of use of the system depends on the availability on board the vessels of qualitative instructions, containing, as required by international conventions, restriction of navigational equipment. Since the firms - manufacturers in the descriptions don't inform buyers about the defects and limitations of their products, objective instructions for shipowners can be developed only by the independent experts, participating in marine tests of the system.

The efficiency of use of the system essentially depends on the correctness of choosing of gauges of continuous position fixing - GPS NAVSTAR receiver. It is obvious that the receiver model not ensuring the necessary operational characteristics, should not be included in the system. Taking into account the opportunity of international recognition in the nearest future of GPS NAVSTAR system, and the including in International convention SOLAS-74 of requirements of vessels equipment by receivers of the system, which makes the differential variant GPS NAVSTAR legitimate, the installation on vessel of receiver models which will be hereinafter possible to modify for work in differential variant GPS NAVSTAR may be recommended.

The marine tests of instruments NAVI MASTER NM 1000 have confirmed, that the electronic charts systems are the effective means of navigation ensuring the increase of vessels efficiency and safety of navigation.

THE FURTHER RESEARCHES

The concept

The continuity and high accuracy of vessel position fixing, ensured by satnav system differential variant, cannot in essence be realized by hand-operated plotting on conventional paper chart. The effective use GPS NAVSTAR is possible only when utilized in a system with videoplotter and electronic chart.

The navigational system, displaying observed by precision system current position of vessel in real time scale on electronic chart, containing all necessary navigational and hydrographic data, including preliminary routing, alarming about the vessel's deviation from the given route restrictions, documenting the necessary sailing data - represents no new navigational hardware, but the technical base of new navigational technology. The introduction of new technology is no single tactical task, but rather a strategic operation, including technical, legal, organizational, information, economic and many other aspects, largely new, insufficiently developed and, therefore, requiring insight and resolute decisions.

The significance of the tests for the introduction of new technology

The tests of navigational systems during introductions of new electronic technology of navigation are called upon to play an unusual role. Reasons:

First, electronic chart systems have no precedents so there is no experience of previous tests.

Secondly, the complexity of the problem causes the multialternativeness of technological decisions for the construction of navigational electronic chart systems, the comparative efficiency of which is possible to be revealed only by tests under various conditions and circumstances of real navigation. Thus the tests make it possible to have e real influence on the cost, rates of development and entry in operation of new navigational systems, as well as on terms of replacement of defective program decisions by improved versions.

Thirdly, the tests electronic chart permits revealing the defects of GPS NAVSTAR receivers and personal computers which has its independent significance.

The tests permit verification of the organization of navigational watch and of vessel operation.

It is clear that major functional electronic chart use remarks can be established only while sailing.

The introduction of navigational electronic chart systems
(usually indicating the radar information), followed by ice breaker and transport vessel navigators' mastering of personal computers and satnav second generation systems receivers, requiring a new understanding of the "human factor" in arctic navigation, changes the requirements to theoretical and practical training of navigators. In order to solve this problem , it will be necessary to conduct a series of teleological marine tests, results of which should be used operatively in the common interest.

The program of introduction of electronic navigation in the Arctic.

In our opinion, the program of introduction of electronic navigation in the Arctic, should be accepted. This program should provide:

- elaboration of "Recommendations on installation of electronic charts systems";

- elaboration of "Recommendations on navigational use of electronic chart";

- elaboration of order of replacement of navigational electronic chart system software on vessels by improved on results of marine tests versions;

- the rule of periodic (with stipulated interval) replacement of out of date electronic charts by new ones;

- order and short program of navigators training on board the vessel before the first trip with electronic chart system;

- installation in training center of navigational electronic chart systems, including GPS NAVSTAR receivers, for training of ice breakers and vessels of ice navigation navigators and captains;

- elaboration of training program for courses of qualification improvement with simulator use and with compulsory indication of GPS NAVSTAR, electronic chart and new technology restrictions;

- organization of drawing up and support on modern level of additional information file, which includes information about radiocommunications channels of call of pilots, zones of division, points of control communication etc.;

- organization of preliminary routing in companies with drawing up of sheet of routing coordinates and routing description;

- development of proposals on reduction of ship collections of navigational charts and books for accumulation of means for introduction of electronic navigation and essential reduction of correction volumes on vessels;

- choosing of the most acceptable GPS receivers GPS and personal computer models.

APPENDIX

PROJECT REVIEW

11 August 1994

To : Ms Elin Dragland
INSROP Secretary
The Fridtjof Nansen Institute
PO Box 326
N-1324 Lysaker, Norway fax (47) 6712 5047

From : N.Untersteiner
University of Washington, AK-40
Seattle WA 98105 fax (206) 543 0308

Dear Ms Dragland,

the following is a review of INSROP Sub-Programme I, Project I.7.1 by Zakharov et al. entitled "Perspective Research".

1) Part I is appropriately described as "A Review and a Critical Analysis of the Existing Understanding......". The paper does indeed convey a "perspective" of the existing understanding. Even so, it is not possible to call the project "perspective research", and I suggest that the title be changed, perhaps to read "Ice Forecasting and Climate Change - a Critical Review".

2) The authors are clearly familiar with the problem of climate, climate change, climate prediction, and sea ice cover variations. They are also familiar with the modern international literature. They justifiably cite primarily the extensive Russian work on the problems of ice forecasting.

I am personally in favor of the authors's healthy skepticism about our current state of understanding of the sea ice and climate problem, and about the absence of convincing signals in the climate that would indicate anthropogenic effects.

In general, the essay does not contain new material or insights, but it is a fair and informative summary of the current status of the problem.

3) Assuming that these reviews are written for a general, non-expert readership, the quality of the translation must be considered a serious

problem. In many places, syntax and choice of words in this essay are so exotic that the reader has to be intimately familiar with the subject in order to understand the message. In its present form, the essay places such high demands on its reader that, in my opinion, it is of limited value.
I don't know how difficult or expensive it is in Russia to get a competent English translator, but I would recommend that INSROP make the necessary investment to assure that the cost and effort expended in writing this review results in a product of commensurate usefulness.

4) Section 6 describes a somewhat naive view of the various multi-national (e.g ECOPS) and international (e.g. WMO-WCRP) research enterprises in the Arctic. It has become one of the hallmarks of the contemporary scientific establishment that various groups initiate international projects by giving them a name and declaring their existence. This is often done without the support, and even without the knowledge, of the concerned operating and funding agencies in the countries whose participation would be essential to making the plans reality. The result is a bewildering array of overlapping and cross-related research initiatives in various stages of planning and variable national or regional acceptance, not to speak of an avalanche of project descriptions and workshop reports. (For instance, the WMO World Climate Research Programme has recently ceased to publish the reports of the annual workshops of its 13 standing working groups because, apparently, the impact of these publications did not warrant their cost).

I believe it will be important for INSROP to perform periodic "reality checks" on the numerous arctic research projects and initiatives.

5) Part II is concerned with electronic (satellite) methods of navigation. Having no expertise in this field I cannot offer a review of that section, except to say that little emphasis appears to be given to the use of near-real-time satellite data transmitted to ships operating in sea ice areas, for the purposes of safety and routing.

Attention: Dr. E. Dragland
INSROP Secretariat, FNI

Reference: INSROP REPORT REVIEW

FAX Number: (47)-67125047

No. Of pages: [illegible], incl. this

From: A.Baranov

Date: September 7, 1994

Dear Dr. Dragland !

Please find enclosed INSROP report review.

Sincerely yours, [signature] A. Baranov

Captain Alexander Baranov, Ph.D.,
Professor of State Maritime Academy,
St. Petersburg, Russia

Review of INSROP report

I.1.2.7 "Perspective research"

Part II

"Electronic navigation technology"

The reviewed work is devoted to the accurate methods of electronic navigation in the Arctic area. It is based on long-term research work being carried out in the CNIIMF.

The work consists of two main parts. The first one is devoted to the different aspects of use of GPS systems and comparative tests of different types of GPS receivers. GPS is suggested as a main electronic navigational system for the area. There is no detailed analysis of the work of other radionavigational systems but the final idea is based on general knowledge and supported by previous results. There should be no objections against it.

The general idea of the use of GPS is followed by comparative tests of the several worldwide well-known types of GPS receivers. The value of the tests is that mainly they had been carried out aboard vessels of NSC in the conditions very similar to those of the Arctic area.The author of the review had a chance to participate in different tests of GPS receivers in U.K, USA, Russia and it is necessary to mention that the results in the report coincide in whole with the work carried out by other specialists. Moreover there are some unique results, for example-investigation of the influence of noise from VHF radiostations on the work of GPS receiver. The detailed descriptions of all tests are also of great value.

The second part of the report deals with the use of electronic Charts (ECS or ECDIS) together with GPS receivers. This idea should be fully supported as the best way for safe navigation in the Arctic.

Some short remarks however should be made on the text:

- when referring to accuracies a general remark should be made for 95% probability at the very beginning for not-misunderstanding.
- period of reliability of GPS according to the last results should be considered better than 3 hours (UP to 15 minutes by the end of 1994) but some additional research might be necessary.

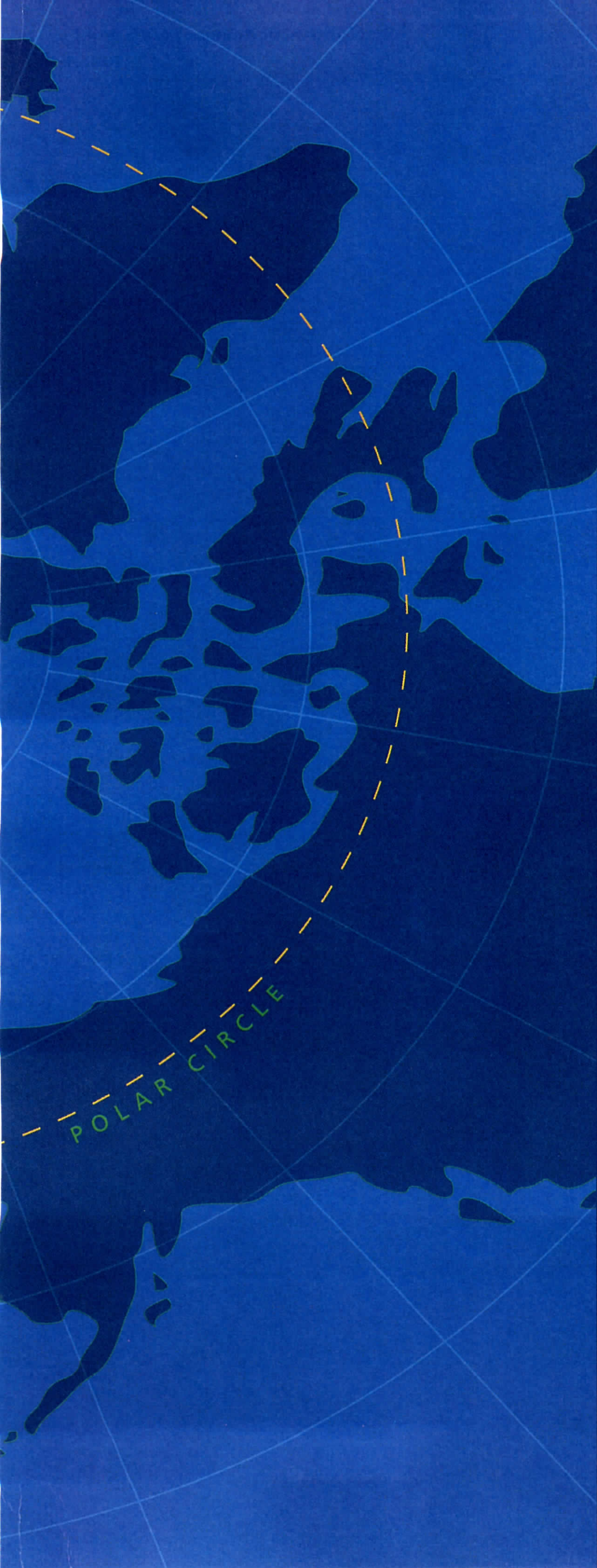
Taken in whole the results of the work seem to be reliable. They are based on good theoretical knowledge and thoroughly carried out practical tests and may be considered as a good base for future work.

To my opinion the work should not be stopped at this stage but additional research may be considered necessary specially in the following areas:

- use of differential GPS in the A,ctic (types of correction, range of coverage of corrections, etc);
- use of electronic charts (improved versions, etc);
- influence of rapid ships' manoeuvres on the work of GPS and differential GPS;
- other items.

The reviewer had a chance to compare both versions, Russian ad English and has to mention that better translation into English in future reports may be appreciated.

A. Baranov



The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.

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

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.

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

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.

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