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Translation

OCEANOGRAPHIC WORK IN POLAR REGIONS OF WORLD OCEAN

By

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CONTENTS

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[Text] Introduction. The polar areas of the world ocean and especially the Arctic and Antarctic Oceans are being investigated as a physical medium whose parameters and regime must be known in order to solve many scientific and practical problems: development of the theory and methods for sea hydrometeorological forecasts for different times in advance, scientific-operational support of navigation along the Northern Sea Route and navigation in the Antarctic, planning, construction and rational operation of ports and hydraulic structures.

A knowledge of the natural conditions in a particular region is of fundamental importance when using its mineral, biological, chemical and energy resources, which are acquiring exceptional importance in the economic mastery of the regions of the Arctic and for the country as a whole. A study of the nature of the polar regions is also necessary for an understanding of the physical essence of the processes and mechanisms forming the earth's climate and controlling its variations on both regional and global scales.

Up to the late 1960's oceanographic work in the Arctic and Antarctic Oceans was directed to a multisided investigation of their hydrometeorological and ice regimes, to establishing the spatial-temporal scales of variability of hydrometeorological processes, clarification of the natural patterns and cause-and-effect relationships among the different phenomena transpiring in them. At the same time, it was found to be necessary to increase attention to the solution of fundamental problems directed to study of the extremal states of the earth's dynamic shells, their explanation and prediction.

Accordingly, in 1970 a group of scientists of the Order of Lenin Arctic and Antarctic Scientific Research Institute, under the direction of A. F. Treshnikov, corresponding member USSR Academy of Sciences, developed the scientific program of the Polar Experiment (POLEX), bringing together a number of major scientific problems related to study of the oceanic waters and climate of the Arctic (POLEX-North) and

Antarctica (POLEX-South). This program provides, in particular, for an investigation of the processes of macroscale interaction between the atmosphere and ocean in the polar regions, a quantitative evaluation of their role in formation of the energy balance of the ocean-atmosphere system, study of the mechanisms forming macroscale long-period variations of hydrometeorological processes in the Arctic and Antarctica.

The Arctic and Antarctic Scientific Research Institute proceeded to the implementation of theoretical and experimental studies under the POLEX program in 1971-1972. In 1973 the implementation of the program in the Arctic Ocean was initiated by the carrying out of macroscale oceanographic surveys in the Arctic Basin. In 1974 similar studies were initiated in the Antarctic Ocean.

The carrying out of multisided in situ experiments under the POLEX program is accomplished on scientific research ships, on "Severnyy Polyus" drifting stations, in the network of polar stations and at the observatories of the Arctic administrations of the State Committee on Hydrometeorology and Environmental Monitoring and the "Sever" aerial expeditions.

The solution of major scientific problems and global problems in hydrometeorology should be accomplished with broad international cooperation. For this reason the POLEX program as a national scientific program of the USSR was included in the international Program for Investigation of Global Atmospheric Processes (GARP).

The implementation of oceanographic work in the polar areas of the world ocean under the programs of major in situ experiments required improvements in the methods for their organization, the employment and creation of new technical apparatus, instruments and equipment, development and improvement of measurement methods and processing of the collected information on an electronic computer.

The most promising direction in work for the creation of new technical apparatus and methods for oceanographic investigations is the systemic approach, that is, the combining of the principal stages in the collection of data (collection-processing-accumulation of data), realized in the form of an automated data system.

An example of such a system, used on the scientific research ships of the State Committee on Hydrometeorology and Environmental Monitoring, is a shipboard automated hydrometeorological measurement system which is used in the collection, registry, computer processing, accumulation and dissemination of a considerable number of hydrometeorological parameters.

In oceanographic work from the ice on the "Sever" expeditions and at the "Severnyy Polyus" stations use is made of specific research methods, instruments and technical gear in whose creation allowance is made for the need for using them under special climatic conditions (low air temperature, wind loads, frequent fracturing of floes, etc.). An important role in the planning and implementation of this work is played by proper allowance for living conditions and adherence to safety measures.

The implementation of expeditionary work is a costly measure. Accordingly, it is important to solve the problems of their optimum planning. Only on the basis of such planning is it possible to obtain the maximum effect from scientific research.

The planning of work from drifting and fixed ice, supported by aircraft, must take into account the possibilities for aviation and provide for those changes in weather and the state of ice which frequently to a decisive degree exert an influence on the success in carrying out the principal tasks of the expedition.

The optimum planning of oceanographic work from ships provides for solution of the following problems: discrimination of quasihomogeneous regions of the ocean; choice of rational discreteness and total duration of measurements; determination of time scales of variability of hydrophysical fields; spatial distribution of observations; choice of corresponding equipment, instruments and technical means for expeditionary work; allowance for weather conditions in the observation region.

In the Arctic and Antarctica considerable experience has now been accumulated in carrying out oceanographic work at polar stations, on the "Severnyy Polyus" drifting scientific research stations, on the "Sever" high-latitude aerial expeditions and on expeditionary ships. This article is devoted to a generalization of this experience.

In this book special attention is devoted to a description of technical means, instruments, methods for oceanographic measurements and processing of information on an electronic computer, which are used in oceanographic investigations from ships and the ice cover.

Chapters 1-3 were written by N. I. Blinov, Chapters 4-6 by V. V. Dremlyug, Chapters 7-9 by V. A. Romantsov. The section devoted to exposition of the experience in using electronic computers in work on drifting ice was written by V. A. Volkov, Yu. A. Grodetskiy and V. V. Lukin. Chapter 10 gives the prospects for development of methods for oceanographic research in the polar countries in the form in which they are visualized by the authors.

OCEANOGRAPHIC WORK FROM ICE IN ARCTIC BASIN

CHAPTER I. ORGANIZATIONAL-METHODOLOGICAL PRINCIPLES FOR IMPLEMENTING OCEANOGRAPHIC WORK FROM ICE IN ARCTIC BASIN

1.1. Features of Arctic Basin as Object of Investigation

The Arctic Basin of the Arctic Ocean is the region of the world ocean which is the most inaccessible and complex for investigation because of its climatic and physiographic features, such as drifting ice, covering the entire area during the entire year in an almost continuous armor, the desertlike character of its expanses, the severity of weather conditions, and the polar day and polar night.* Any of these factors makes difficult the implementation of oceanographic work. However, the totality of these factors can constitute the most serious obstacle for carrying out investigations, which require considerable expenditures of material and technical resources, organizational and physical efforts.

The presence of thick and strongly hummocked drifting ice in the Arctic Basin, even with the present-day level of technology, is a serious obstacle to the penetration of researchers into the high latitudes by means of sea (including icebreakers) or surface transport. Air and underwater transport is an exception. However, the effectiveness of its use for investigation of the Arctic Basin is limited by both its natural features (polar night, thawing and hummocking of ice) and by the technical possibilities of the means of transport themselves. And nevertheless, the aircraft is at the present time precisely the principal means of transport for implementation of such work.

The Arctic Basin has an area greater than 5 million square kilometers. All this enormous ocean area is virtually deserted. When undertaking expeditionary work there researchers are forced to take everything with them, down to the smallest detail. With modern scales of expeditionary work and present-day requirements on living conditions the mass of expeditionary equipment and gear amounts to tens and sometimes even hundreds of tons. The deserted nature of the Arctic Basin and its severe climatic conditions require the creation and use of corresponding means and methods for the life support of people and their safety during oceanographic work.

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* Since Soviet researchers are not carrying out work over the entire area of the Arctic Basin, but only in its parts located to the north of Greenland, the Canadian Arctic Archipelago, Alaska and the Eurasian coast, in this monograph it is precisely these areas which are given the name "Arctic Basin."

The severity of climate in the Arctic Basin is governed for the most part by the low air temperature, high humidity and relatively strong winds. The low air temperature not only favors the formation of thick ice in the Arctic Basin, but also exerts a considerable influence on man's conditions of life and performance, physical-mechanical qualities of materials, operation and servicing of equipment in the open air, etc.

It is rather difficult to move and work in the severe cold because the slightest carelessness can be dangerous for health (for example, when there is severe cold it is dangerous to come into contact with metal with unprotected parts of the body). In particular, the efficiency of man's activity in the open air is sharply reduced at temperatures below -30,...-35°C. Accordingly, when carrying out work in the Arctic Basin appropriate warm clothing is worn and shelters are heated year-round.

At a low air temperature many materials change their properties. Metals and even rubber become brittle, articles of skin become hard and break and tear easily. Some types of plastics become brittle in the cold (for example, photographic film becomes fragile and breaks easily), whereas ordinary types of lubricating oils lose viscosity (thicken). Equipment and gear kept in the open air are covered with frost.

The wind in the Arctic Basin, where there are virtually no serious natural obstacles for reducing its effect, is rather significant, especially at a negative air temperature exerting an important influence on the conditions for implementing work (Table 1.1).

Wind is one of the principal reasons for ice drift in the Arctic Basin. A strong and persistent wind causes an intensive movement of the ice, accompanied by the fracturing and hummocking of ice, especially significant when there are abrupt changes in its direction and velocity.

A strong wind causes high and low blizzards which are dangerous in the polar night when any movement of man (especially beyond the limits of camp) is very difficult and risky due to poor visibility and the lack of characteristic natural landmarks.

Increased air humidity, especially during summer during the melting of snow and ice, is also a considerable problem when carrying out work in the Arctic Basin. The unfavorable effect of moisture on clothing and gear is aggravated by the presence of salts in the moist air. Penetrating into the instruments, equipment and gear, the moisture and salt can put them out of operation, and penetrating into clothing (especially footgear), lessen the heat-insulating qualities and make difficult its drying.

The high air humidity at a negative temperature favors the formation of glaze, hoarfrost and frost on the surface of objects exposed in the open air. Sometimes the glaze or frost are so thick that they put structures out of operation (the guys of masts break, the supports of radio antennas snap, etc.), meteorological, actinometric and other instruments malfunction.

Table 1.1

Cooling Effect of Wind as Function of Its Velocity and Air Temperature [121]

1) Скорость ветра		2) Температура воздуха, °C												
3) км/ч	4) м/с	8	4	0	−4	−8	−12	−16	−20	−24	−28	−32	−36	−40
0	0	8	4	0	−4	−8	−12	−16	−20	−24	−28	−32	−36	−40
6	1,7	8	4	0	−4	−8	−12	−16	−20	−24	−28	−32	−36	−40
10	2,8	5	0	−4	−8	−13	−17	−22	−26	−31	−35	−40	−44	−49
20	5,6	0	−5	−10	−15	−21	−26	−31	−36	−42	−47	−52	−57	−63
30	8,3	−3	−8	−14	−20	−25	−31	−37	−43	−48	−54	−60	−65	−71
40	11,1	−5	−11	−17	−23	−29	−35	−41	−47	−53	−59	−65	−71	−77
50	14,0	−6	−12	−18	−25	−31	−37	−43	−49	−56	−62	−68	−74	−80
60	16,7	−7	−13	−19	−26	−32	−39	−45	−51	−58	−64	−70	−77	−83
70	19,4	−7	−14	−20	−27	−33	−40	−46	−52	−59	−65	−72	−78	−85

Notes. 1. In the cited table the equivalent cooling effect of the wind was computed for a temperature of the human skin of about 33°C. 2. With wind velocities greater than 70 km/hour its cooling effect increases insignificantly.

KEY:

1) Wind velocity
2) Air temperature, °C
3) km/hour
4) m/sec

The polar night exerts a rather serious influence on working conditions in the Arctic Basin. Around-the-clock darkness, even at the modern level of power and technical facilities, sometimes does not make it possible to carry out oceanographic work actively over the entire area of the Arctic Basin. In addition, the very gloomy monotony of the polar night in many cases exerts a negative psychological effect on people. During this time man's visible world is limited to a small area illuminated by an artificial light source and sometimes only the room in which he is situated. Polar travelers even in the not distant past have written that the most frightful thing is "...not so much the eternal darkness, as the monotony and deadly boredom paralyzing the mind" [78, 95]. In addition to psychological effects, this polar night exerts on the human body a negative physiological effect which has not yet been adequately studied [43, 44]. Light starvation leads to disruptions of mineral metabolism in the human body, which in the past in many cases was one of the principal causes (together with inadequate nutrition) of disease among polar workers.

During the polar day in the Arctic Basin there is a rather intensive light and UV irradiation which under definite conditions can lead to affliction with "snow blindness." The reason for this disease is the great albedo of the snow surface, reflecting the blinding rays of the sun. The probability of affliction with "snow blindness" is especially great in April and May when the greatest number of cloudless days occurs.

Table 1.2 gives generalized data on the nature of the effect of different climatic factors on people and equipment when working in the Arctic Basin in the open air.

Table 1.2

Nature of Effect of Principal Climatic Factors on Persons and Equipment During Work in Arctic Basin

Factor	Effect	
	on people	on materials, equipment, work-life conditions
Low air temperature	1. Reduces mobility and performance 2. Increases energy expenditures by body in maintaining normal functioning conditions 3. Can lead under unfavorable conditions to frostbite and even lethal outcome 4. Reduces body resistance to unfavorable effects of other meteorological factors	1. Changes properties of some types of materials 2. Worsens operational characteristics of technical apparatus 3. Reduces work productivity 4. Worsens production and living conditions 5. Reduces heat-insulating properties of clothing, shoes, materials 6. Complicates servicing and operation of equipment 7. Increases energy expenditures for maintaining life support conditions
High air humidity	1. Reduces performance 2. Reduces body resistance to unfavorable effects of other meteorological factors 3. Increases body energy expenditures on maintaining normal functioning conditions	1. Worsens operational reliability of equipment 2. Worsens production and living conditions 3. Worsens insulation properties of materials 4. Worsens heat insulation properties of clothing, shoes, materials
Strong wind, high and low blizzard	1. Reduces performance and complicates (worsens) movement conditions 2. Reduces body resistance to unfavorable effects of other meteorological factors	1. Worsens (complicates) production and living conditions 2. Reduces work productivity 3. Complicates (worsens) servicing and operation of equipment 4. Reduces heat insulation properties of clothing, shoes, materials

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Table 1.2 (continued)

Factor	Effect on people	Effect on materials, equipment, work-life conditions
	3. Increases body energy expenditures on maintaining normal functioning conditions 4. Increases negative psychological symptoms	5. Increase in energy expenditures on maintaining normal life support conditions 6. Worsens operational reliability of some types of gear
Polar night	1. Reduces performance, complicates (worsens) movement conditions 2. Causes negative psychological symptoms 3. Increases unfavorable effects of a number of meteorological factors 4. Exerts negative physiological effect (favors development of avitaminosis)	1. Complicates conditions for servicing and operating equipment 2. Worsens production and complicates living conditions 3. Reduces work productivity 4. Intensifies negative effects of some meteorological factors on work and living conditions
Polar day	1. Exerts negative physiological effect (excitation processes predominate) 2. Under unfavorable conditions favors "snow blindness"	
Fracturing and hummocking of ice	1. Favors appearance of situations threatening life 2. Causes negative psychological symptoms	1. Favors appearance of emergency situations leading to loss of instruments, materials and equipment 2. Complicates production and living conditions 3. Intensifies negative effects of some meteorological factors on life support conditions

During 1901-1903 a participant on a Swedish Antarctic expedition, Baudman, carried out a number of experiments for the purpose of evaluating the effect of air temperature and wind velocity on the human body and proposed that the severity of climate and weather be evaluated using the severity coefficient:

$$C = (1-0.04T)(1+0.272v),$$

where C is the severity coefficient; T is air temperature, °C; v is wind velocity, m/sec.

P. A. Gordiyenko generalized numerous data from his daily observations of weather severity during drift on the SP-4 (1955-1956) and recommended some limitations when working in the open air with corresponding severity coefficients C (Table 1.3) [129].

The examined climatic and physiographic features of the Arctic Basin, exerting an influence on the implementation of oceanographic work (on the personnel of expeditions, equipment, instruments, gear, transport and other technical facilities, fuels and lubricants, etc.), determine the specific nature of this work.

Table 1.3

C coefficient	Limitations when working in open air and precautionary measures
0.0-2.5	No restrictions
2.5-4.0	Duration of continuous work not more than 3-4 hours; 1 hour break. Gloves or mittens worn for protecting hands
4.0-5.5	Duration of continuous work not more than 2-3 hours; hourly breaks with mandatory retirement to shelter for 5-10 minutes. Fur mittens worn on hands; face best covered with special ointment
5.5-7.0	Duration of continuous work not more than 1 hour. Smearing of face mandatory. Warm suit impermeable to wind
Above 7.0	Best not to work in open air. In extreme cases work place should be sheltered from wind. Clothing -- down suit with hood impermeable to wind. Mandatory that face be carefully smeared

Note: K. Rodal' [94], on the basis of experience among natives in the North, is of the opinion that smearing of open parts of the face and hands with fat or special ointment during work in the open air not only does not give a positive effect, but is even harmful.

1.2. General Description of Research Methods

In our country, in connection with the vigorous development of the economy in the Far North and the development of navigation along the Northern Sea Route, the study and exploitation of the Arctic Ocean is a highly important national economic task.

Already beginning in the late 1930's Soviet polar workers, taking into account the practical and scientific problems to be solved and relying on the experience of many expeditions and the attained level of technology, have been developing and introducing into practical use two methods for the effective study of the Arctic Basin: 1) organization of long-term scientific research stations on the drifting ice and 2) implementation of oceanographic and geophysical surveys over the entire area of the basin using so-called "flying observatories" [113]. The basic means of transport in both methods is becoming the aircraft, which is demonstrating its effectiveness in work under the severe climatic conditions of the Arctic Basin. The use of aircraft as "flying observatories" has become the basis for the "Sever" high-latitude expeditions, since an aircraft with a group of researchers aboard can fly into the necessary region and in case of necessity repeat flights [25, 78].

In the early 1950's, for observations of the drift of ice and hydrometeorological and ice conditions in the Arctic Basin, in addition to the SP stations, the "Sever" expeditions and ice aerial reconnaissance, drifting automatic radiometeorological stations came into use (DARMS -- dreyfuyushchiye avtomaticheskiye radiometeorologicheskiye stantsii).

It goes without saying that time has introduced definite corrections into these observation methods and nevertheless at the present time they remain the most effective in the multisided study of the nature of the Arctic Basin.

1.3. Macroscale Oceanographic Surveys

1.3.1. The principal tasks of macroscale oceanographic surveys are the implementation of multisided oceanographic, ice, meteorological and other observations in the Arctic Basin and in arctic seas, as well as scientific-methodological studies in situ by the polygon method.

The makeup, volume and direction of oceanographic and geophysical work in such surveys vary in dependence on the practical and scientific problems which can be solved in a definite stage in study of the Arctic Basin. For example, during the course of the 1950's (from 1948 through 1960) the principal scientific task of macroscale oceanographic surveys was obtaining a sufficiently complete idea concerning bottom relief of the Arctic Basin, concerning the vertical and spatial structure of the thermochemical and dynamic fields of its water masses, etc., which is reflected in some increase in the number of oceanographic stations [38, 39] occupied by the "Sever" expeditions.

Beginning in 1973 the scientific task of the "Sever" expedition was implementation of in situ investigations under the POLEKS (POLEX) program. This program provides for study of extremal states of moving media in the polar regions of the earth, their explanation and prediction [13, 115]. Within the framework of the expedition the formulated problem is solved by means of an oceanographic survey, including oceanographic, meteorological and ice observations at definite points uniformly distributed over the entire area of the Arctic Basin at a distance of 150 or 300 km from one another.

1.3.2. Methodological principles and organizational structure of macroscale surveys. At the present time macroscale oceanographic surveys are being carried out during the spring period and organizationally these can be subdivided into three stages: preparatory, field, and report.

In the preliminary (or organizational) stage all types of organizational-economic measures are taken directed to a timely and careful preparation for the expedition. In this stage the program of scientific research and the working plan of the expedition are prepared, discussed and approved; the personnel of the expedition is selected; expeditionary gear and instruments are received from warehouses.

The field stage of expeditionary work is continued from March through June because in February (especially during the first half) the polar night still continues over the greater part of the Arctic Basin, but in June the melting of snow and ice is already beginning. [It is not impossible that with the introduction of helicopters into expeditionary work this period can be expanded.]

During the field period the organizational structure of the expedition provides for the separation of personnel into two groups: operational and scientific, which in turn are broken down into detachments.

The operational group, directed by the head of the expedition, ensures engineering-technical support of the scientific detachments of the expedition. The personnel of this group are situated at all the shore and island bases of the expedition where they are engaged in preparing and dispatching expeditionary freight to the SP ("Severnyy Polyus") stations, ice bases and polygons, etc.

The scientific group is engaged in the direct implementation of the scientific program of the expedition. The number of detachments in this group is determined by the makeup and volume of the work provided for in the scientific program.

The report period is the final stage in the expedition, during which the participants prepare a scientific-technical report on the work which has been done and reduce the field observational data to good order.

1.3.3. Method for implementing oceanographic survey. Such a survey involves the implementation during a relatively short period (1 1/2-2 months) of sporadic hydrological, meteorological, ice and other observations at stipulated points quite uniformly covering the area of the Arctic Basin and the arctic seas. Depending on the area of the investigated ocean sector the survey can be carried out simultaneously by several detachments which are supplied with aircraft with skis. [Up to 1977 such surveys were made with Li-2 aircraft, whereas in later years they were made with An-2 aircraft.] The aircraft are equipped and outfitted with emergency supplies (food, tents, fuels, equipment for preparing and heating food, sleeping bags, etc.). Surveys in the arctic seas and adjacent regions of the Arctic Basin are carried out from shore bases. A survey of the high-latitude part of the Arctic Basin is carried out from temporary bases specially organized for these purposes on the drifting ice (Fig. 1.1). The SP stations are commonly used as such bases. The organization of temporary bases on the drifting ice is very complex. Accordingly, sometimes when carrying out an oceanographic survey aircraft are refueled on the ice by aircraft tankers, this making it possible to increase the work radius. Bases (both on the shore and on the ice) are used for resting of the aircraft crews and scientific personnel of the detachments, for the fueling and inspection of aircraft, for hydrochemical analysis of sea water samples, for critical examination of observational data and their primary processing. At one of the bases there is a synoptic group supporting the work of the expedition's detachments with meteorological forecasts.

The specific conditions for implementing an oceanographic survey required the creation of special light and portable instruments and other expeditionary gear [13, [89].

The principal complexity in the work of the oceanographic flight detachments is the choice of landing areas from the air for sites where observations are planned and the actual landing on them. Therefore, each aircraft participating in the implementation of an oceanographic survey carries an experienced hydrologist - ice scout. Knowing well how to determine the characteristics of ice from aboard an aircraft, in addition to in-flight ice observations he helps the crew to select landing areas and prepare a sketch map of the locality at the landing point.

After carrying out the observations and landings at two or three points or more (their number is dependent on the fuel supply aboard the aircraft) the flight detachment returns to base. After refueling the aircraft and resting, the detachment takes off to investigate the next points. The duration of the stay of the scientific group on the ice at each survey point is determined by the volume and time required for carrying out the observations and can be from several hours to several days.

The aircraft (one or more), after delivering the scientific detachment to the survey point, while the work is being done remains the entire time on the ice in readiness for a takeoff. After completing the planned complex of observations at a point the aircraft proceeds to the next planned point. These "jumps" from point to point and return to the base continue until observations have been made at all the points planned in a stipulated region.

Emergency situations can arise when carrying out an oceanographic survey; they must always be kept in mind and appropriate precautionary measures must be taken.

Such situations include:

-- the aircraft breaking through the ice during landing on a floe with a thickness less than that admissible for a particular type of aircraft;
-- entry of the aircraft skis into fissures which are filled with snow or covered with young ice;
-- fracturing of floes on which the aircraft is situated caused by movement of the ice in a particular region;
-- collision of the aircraft with high hummocks during its landing or takeoff, which can lead to the crashing of the aircraft and even the death of people;
-- falling of people into fissures or under the ice during their movement along the ice, which can lead to different kinds of serious traumas;
-- fire in the aircraft during refueling, heating and starting of motors;
-- fire in living and work tents when using gas heaters and stoves for their heating or food preparation;

-- poisoning by propane or carbon monoxide gas fumes when using gas heaters and solar stoves in tents and also by exhaust gases from motors operating in tents;
-- frostbite and colds;
-- getting lost when moving on a floe at the time of poor visibility (in blizzards, fog, etc.);
-- sudden appearance and attack of a polar bear.

Since assistance cannot always be rendered in time due to the lack of flight weather, duration of the search, etc., the mentioned and many other contingencies can lead to more serious consequences. Taking these circumstances into account, the operation of aircraft in an oceanographic survey, involving landing on the drifting ice, is usually carried out "in pairs" (that is, two aircraft operate simultaneously and keep watch over one another). This safety procedure is executed in two ways: either both aircraft go to the same point or go to a number of near-lying points. In the first case one aircraft lands on a selected floe, whereas the second circles nearby, monitoring its landing either visually or by radio. After a successful landing of the first aircraft the second lands on this same floe, but when parking proceeds to the opposite end of the floe so that in the event of a sudden fracturing of the floe both aircraft will not be in the same region.

In the event that the aircraft go to points which are near one another they maintain constant radio communication with one another. If they both reach the neighborhood of their destinations simultaneously, one of them (by instructions from the group leader) mandatorily awaits communication from the other that it has landed, after which it also lands. The crew of the aircraft already on the ice monitors its landing by radio. It is not without reason that such close attention is given to landing conditions, since despite more than 40 years of experience in the working of fliers and scientists in the Arctic, no one is safe from all kinds of accidents and errors caused by complex natural conditions. After all, the landing is accomplished on a floe, which the flier sees for the first time and at that, from a flying aircraft. The flier and hydrologist-ice scout, determining the suitability of the floe for landing, rely for the most part on their experience. In order to lessen the possibility of error in evaluation of the suitability of a floe for landing, the landing is made only when there is good visibility.

A successful landing is still no guarantee against further emergency situations. The floe on which the aircraft is situated can split apart at any time. It is dangerous if the fissure lies beneath the aircraft skis. In this case all measures are taken for an immediate takeoff or (if the size of the floe allows) the aircraft is moved to a different place. Accordingly, in work on a floe one of the members of the crew continuously monitors the ice conditions.

When making oceanographic surveys the expedition participants must live and work on the drifting ice. Accordingly, in the organization of such work much attention must be devoted to the problem of living quarters, heating and clothing. As living and working quarters in oceanographic flight detachments use is made of tents of the Shaposhnikov design (KAPSh-1, KAPSh-2 and KAPSh-3), ensuring normal conditions for the work and life of people in them. The tent design is such that two persons can assemble each in 20-30 minutes and in case of necessity they can be transported to a safe place in assembled form (Fig. 1.2). The heating of the tents (and also food preparation) in the expedition's flight detachments is accomplished using gas stoves, propane being used as the fuel.

1.4. Oceanographic Work on Drifting Stations

The successful completion of the work of the SP-1 station in 1937 confirmed the viability and effectiveness of the method for studying the nature of the Arctic Basin by the use of drifting stations. Beginning from 1954 and to the present time in the Arctic Basin two and sometimes three drifting stations of the "Severnyy Polyus" type have been operating there year-round. When the drifting station moves out beyond the limits of the Arctic Basin its personnel are evacuated, the station is shut down and a new station is organized to the north of the Chukchi and East Siberian Seas to replace it.

1.4.1. Principal tasks. The SP ("Severnyy Polyus") stations are used for long-term (year-round) multisided oceanographic investigations and related meteorological, aerological, geophysical and other observations. They also serve as bases for carrying out experimental scientific research and scientific-methodological studies under clear-cut specialized programs related to the solution of specific problems following from the scientific program of the sections of the Arctic and Antarctic Scientific Research Institute.

Among the principal scientific problems in the field of oceanography subject to study by observations made on the SP stations are: determination of the principal patterns of hydrological and ice regimes of the Arctic Ocean and their variability; study of the principal patterns of circulation of water and ice in the Arctic Basin and their changes; study of the mechanism and physical essence of processes of interaction between the ocean and the atmosphere through the ice cover; clarification of the conditions for the formation of long-period (climatic) oceanic processes in the polar regions of the earth and elsewhere.

The modern Soviet SP drifting station with respect to its tasks, breadth and volume of investigations carried out, technical outfitting with equipment and instruments, is a full-scale scientific research observatory. The SP stations are the most important (and for the time being the only) source of year-round information on natural processes and phenomena transpiring over enormous expanses in the high-latitude Arctic Ocean.

The principal shortcomings of operation of the SP stations are the following: the passive position of the SP stations during the period of drift, precluding the carrying out of oceanographic observations over a long period of time in one and the same region; vulnerability of the stations during the movement of ice (compression, fracturing, hummocking) and other dangerous phenomena (Fig. 1.3); complexity of organization and support of the SP stations.

1.4.2. Means and methods for organizing work. Two methods are used for landing on the ice of the SP scientific research stations: by air and by ship. For the time being the aerial method remains the most important. Among the 24 stations organized by the Arctic and Antarctic Scientific Research Institute in the Arctic Basin, 20 have been occupied by means of aircraft and only 4 (SP-10, SP-19, SP-22, SP-24) have been occupied by icebreakers and sea ships. An evacuation of SP stations is accomplished only by aircraft (except for the SP-1 station, which was evacuated from the floe by means of the "Murman" and "Taymyr" icebreakers.

Aerial method for organizing SP stations. Transport aircraft (Li-2, Il-14, Il-18, An-2, An-26, An-12) are used for delivery to the ice and organization of the SP stations. One or two aircraft participating in the expedition must have skis in order to land the first group of people on the floe selected for the future station, having the task of preparing a landing strip and receiving transport aircraft (usually the flight group leader). The organization of the drifting stations by means of aviation is accomplished primarily in April, when the weather most favorable for flights appears in the Arctic.

The setting up of a new SP station on the ice is preceded by a search for and choice of a suitable floe in the region where the station is planned.

The choice of a floe is a complex and highly responsible matter. The laws governing the fracturing of ice have not yet been established. In some cases a perennial floe which outwardly is very solid will fracture, whereas in other cases even a weak ice field drifts across the entire Arctic Basin almost without being destroyed.

In organizing the SP stations a search is made for the strongest floe, which is determined by its age. The older the floe, the thicker, more monolithic and stronger it is. When selecting a floe for an SP its size is also of importance. It is undesirable that the station be established on a solid small floe (area less than 1-1.5 km^2) since even with partial fracturing its remaining parts will have a size inadequate for safety and the people will have to be transferred to a new floe. It is also recommended that a floe of excessively great size not be used for establishing a station due to the high probability that some part of it will be subject to fracturing.

For the siting of a station it is best to select isolated pack-ice floes of a circular or oval configuration with an optimum area of 5-10 km^2, situated in the neighborhood of younger (one-year or winter) ice, which can serve as a sort of shock absorber against the pressure of adjacent pack-ice fields [12].

The external feature of pack-ice floes is a slightly hilly (smoothed) surface. Such floes as a rule are monolithic and have a quite great thickness. The ideal floe for the organization of a drifting station is an ice island.

In the organization of a station it is important not only to select a durable floe but also that a landing strip can be prepared on it (or in its immediate neighborhood) relatively simply for the reception of transport aircraft with wheels. Aircraft with skis first deliver the flight leader group to a floe suitable for construction of a flight strip, together with equipment and gear, and also the specialists of the "Sever" expedition operations group. One of the aircraft, delivering the flight leader group to this floe, in order to ensure its safety remains there until the tents or huts are set up, together with heating facilities and a radio station. Only then does the aircraft depart from the floe.

The tasks of the flight leader group include: preparation of the landing strip; its maintenance in a working state during the entire period of organization of the new drifting station; assurance of reception and unloading of transport aircraft delivering station freight to the floe.

In preparation of the floe for a new SP station it may happen that neither on the selected floe nor in its immediate neighborhood will there be a sector suitable for laying out the flightstrip for transport aircraft having only wheeled undercarriages. In such cases the setting out of the station is accomplished through an intermediate base (or a so-called "jumpoff" airdrome), organized at a minimum distance from the ice field selected for the SP. Floes formed during the course of late autumn or winter are best suited for the "jumpoff" airdrome. They have a thickness adequate for the landing of transport aircraft (as a rule, not less than 120 cm) and must be even and have little snow on the surface. But since with movements of the ice such floes fracture more frequently, the "jumpoff" airdrome is organized in a region where there are several near-lying floes suitable for the construction of flightstrips. In the event of fracturing of the first "jumpoff" airdrome it will be possible to transfer the intermediate base to a near-lying floe on which the reception of aircraft will be continued.

The negative aspect of setting up a station through a "jumpoff" airdrome is not only the complexity and great amount of work involved, but also the double handling of the freight delivered for it (the station freight is delivered from a shore point first to the "jumpoff," and from there, in small aircraft, helicopters or tractor trains, is transported to the station floe). The station personnel in this case are divided into two groups. One group is at the "jumpoff" point and unloads the aircraft arriving from shore bases and loads An-2 aircraft or helicopters and maintains the airdrome in a working state. The second is located at the station on the floe and is occupied with the construction of the camp and making scientific observations, as well as unloading the An-2 aircraft (or helicopters). [Sometimes the freight from the "jumpoff" airdrome can be transported by tractor, for which ice roads are laid out on the drifting floes from the airdrome to the SP station.] In the organization of a station through a "jumpoff" point, among the negative aspects we should include the fact that during fracturing of a floe part of the station freight is lost, tumbling into fissures. In order to reduce such losses to a minimum the supplies delivered to the "jumpoff" point must be immediately transferred to the main SP floe. However, if this is impossible for one reason or another, the delivered freight is deconcentrated on the "jumpoff" floe, which reduces the probability of its loss in fissures; in the event of fracturing of the landing strip floe a small quantity of freight is always easier drawn away from the emergency zone into a safe place.

If the region of organization of a new SP station is situated not far from shore bases, for landing the flight leader group on a floe helicopters can be used instead of an aircraft with skis.

Ship method for organizing SP stations. For the time being the setting-out and organization of a new SP station by means of sea ships has been accomplished only in the autumn. Transport ships of the ice class or icebreakers have been used for this purpose. In some cases both have been used simultaneously. The type of ship or ships which should be used for the delivery of personnel of the new SP station and its impedimenta to the floe is determined by the ice conditions on the approaches and in the neighborhood of this floe. The gear and personnel for the new station are delivered by aircraft from Leningrad to the sea port nearest the site of its organization, where they are loaded aboard ships. The floe for the new station is subjected to reconnaissance from an aircraft. The selection of a floe is accomplished the same as in the aerial method for organizing the SP station. During the search for the floe an ice reconnaissance is made along the path of the probable course of the ships from the port to the place where the station is to be situated. This reconnaissance also determines the need for the ship to be accompanied by an icebreaker. The movement of the ship carrying the cargo and personnel for the station is accompanied by an ice reconnaissance aircraft and the ship's helicopter, especially with approach to the floe for the new SP station. The ships advance right up to the floe, moor to it and proceed to unloading. They depart from the floe only after normal life has been established at the new station and stable radio communication with the continent has been initiated.

1.4.3. SP station camp and its siting on floe. The camp of a drifting station is a singular settlement of huts, tents, plywood pavilions and other engineering structures. The camp shelters can be classified as residential, service and laboratory, as pavilions, warehouses, garages, etc., which depending on their purpose are located either in prefabricated-panel huts of the Kanaki-Ovsyannikov design or in KAPSh-1, KAPSh-2 and KAPSh-3 tents. Since the thickness, and accordingly, the load-carrying capacity of perennial sea floes and ice islands differ greatly, the character of the siting of SP station camps and individual structures on them has some fundamental differences.

On a perennial floe the SP camp is sited taking the following requirements into account. First of all, it must not be congested because in winter this leads to its increased snow accumulation and a considerable bending of the floe, and in summer it causes the accumulation of an enormous volume of melt water in the territory of the camp. The great weight loads concentrated due to the crowding of the camp in a small area of the floe cause considerable additional stresses in this place which can favor deformation of the floe or even its fracturing. In addition, in the case of passage of a fissure through the territory of a crowded camp many of its structures may be in its zone. It is desirable that the heaviest equipment of the station (such as aerological theodolite, tractor, diesel, etc.) be uniformly distributed over the territory of the camp.

The following can be said on the basis of the long-term experience in rational layout of the SP station camp (which is the arrangement adhered to in recent years). At the center of the camp there is an electric power station and 10-15 m away there is a recreation and meeting room. All the other structures in the camp are arranged around them, taking into account the mentioned requirements. The aerological pavilion and the radio station are situated at opposite sides of the camp so that the masts and antennas of the latter do not interfere with the launching of radiosondes. The meteorological site is situated alongside the radio station, but no closer than 100-150 m. With the placement of the electric power station at the center of the camp the extent of the cable lines from it to the users is optimum. The positioning of the wardroom alongside the electric power station, in addition to convenience in day-to-day living, makes possible its heating by utilizing the heat of the diesel cooling system. Fresh water is also fed from there to the galley; the fresh water is melted from the snow also due to the heat from the diesel cooling system.

The positioning of the station camp on the floe itself also is of more than a little importance. It has been established by experience that the camp should not be sited at the center of the floe because if the floe is fractured during movements of the ice, most commonly breaking in half, there is an increased probability that the territory of the camp will be in the zone of the fissure or break. For this reason the station camp is usually situated closer to one of the edges of the floe in the strongest, that is, the thickest, part.

On an ice island the station camp is usually situated no closer than 150-200 m from its edge, in that part where it is possible to form a hole through the ice to be used for hydrological measurements (usually near the edge, where there is shore ice).

1.4.4. Advantages and disadvantages of aerial and shipboard methods for establishing SP ("Severnyy Polyus") stations. With the availability of aircraft with skis with a sufficiently great flight range and payload the advantage of the aerial method is the possibility of organizing an SP station in virtually any region of the Arctic Basin.

The shortcomings of the aerial method are: organizational complexity and great time input in all types of work (ice reconnaissance, construction of airdromes on ice and their maintenance in a working state, landing of flight leader groups, loading and unloading of aircraft, supplying of aircraft flights with current and prognostic meteorological data, etc.); small economic efficiency of the aircraft used in this work (small payloads during distant flights); limited use of aircraft during the greater part of the year (due to the polar night and the summer melting of ice); high degree of danger of all types and stages of work (flights, landings, loading and unloading), presence at ice airdromes, etc.); rather prolonged period for setting up the station; great dependence on weather conditions (necessity for flight weather simultaneously over a considerable territory).

The advantages of the ship method are as follows: high economic effectiveness (on a single voyage the ship can deliver to the floe virtually everything necessary for the life and work of station personnel over a long period of time); all the organizational measures are relatively simpler; low dependence on weather conditions; considerably lesser degree of danger in carrying out all types of work; relatively short period for construction of camp and establishing scientific work at the station.

Among the shortcomings of the ship method are the following: period of use limited in course of year (August-September); possibility of setting up stations only in those regions which ships can reach under specific ice conditions; need for using aviation during subsequent years of station operation.

On the basis of a comparison of the advantages and disadvantages of the considered methods it can be assumed that with an increase in the power of icebreakers and thereby broadening of their possibilities for overcoming great ice masses the practice of using ships for organizing the "Severnyy Polyus" stations will be expanded.

1.4.5. Material-technical support of SP stations. The annual consumption of different materials and fuel by an SP station (with the average number of personnel being 15-18) is at the present time about 100 tons. If all this volume of freight is completely unloaded on the floe, together with the mass of all the station structures and its technical facilities, this figure increases by a value of approximately 150%. In different emergency situations associated with fracturing of floes, the station personnel has a very difficult time in saving all the property from the vices of the calamity and resiting it. And if there is a supply of expendable materials at the station for several years, with fracturing of the floe a small group is simply incapable of saving it or moving it to a safe place.

In addition, the great weight loads concentrated on a relatively small area of the floe cause its flexure in this place and an increase in stresses in the ice capable of exerting a negative effect on its strength. At some SP stations under the weight of the load and snow accumulating between the structures by the end of winter the floe bends in the region of the camp to such an extent that sea water penetrates up through the hydrological measurement hole and flows out over the surface of the floe.

For this reason the supplying of the SP stations with all types of expendable materials is accomplished by aircraft twice a year -- in spring and autumn. This supplying of the stations twice a year makes it possible, in addition, to replenish the personnel twice annually with fresh foods (vegetables, fruits, etc.) and thereby (which is very important) bring about a reduction of preserved foods in the diet of the polar specialists. In addition, with deliveries to the station twice a year it is easier to organize the storage of a relatively small quantity of food and other materials.

The material-technical supply of operating SP stations both in spring and in the autumn is accomplished by aerial methods through shore stations situated close to the SP station. Accordingly, the station personnel construct airdromes on their floes which are maintained in an operational state during the entire lifetime of the station.

1.5. Field Oceanographic Work

So-called field oceanographic observations are made for studying the hydrometeorological and ice regimes of arctic seas at some Soviet polar stations and observatories situated on the coast and islands. Such observations are made either at one permanent point (station) or on an oceanographic profile. The places for field stations and profiles for each polar station (observatory, etc.) are constant and are established taking into account the physiographic and hydrological characteristics of the region. The distance of field stations from shore points is different and can be from several kilometers to tens and even up to a hundred kilometers.

During the summer period, if ice conditions permit, field oceanographic observations are made from small boats or whaleboats, and in winter exclusively from the shore ice.

The makeup and frequency of the field oceanographic work are determined both by the number of corresponding specialists at a particular polar station and by the availability of instruments, gear and transportation facilities.

At field stations or on profiles observations are made of the physicochemical and dynamic characteristics of waters, meteorological (and at some places also actinometric) elements and state of the ice cover.

In the field studies of observatories, in addition to standard observations, there can be observations of a scientific-methodological character. The duration of observations at field stations is determined by scientific programs and can be from one day to a month or more.

In work at field stations at the present time use is made for the most part of the same instruments and equipment as at SP stations and on the "Sever" expeditions. During recent years the transport vehicles employed for the delivery of people with the necessary gear and equipment to a field station has been cross-country vehicles and tractors. In the case of a considerable distance between the field station and the SP the delivery of people and gear to the work region is accomplished either by an An-2 aircraft or a helicopter. At some stations sledge dogs are used for this purpose.

1.5.1. Organization of field oceanographic observations from ice. A continuous motionless ice cover (shore ice), whose width, depending on local conditions can be from several to hundreds of kilometers, is formed from autumn through the end of spring (September-June) along the shores of arctic seas.

The beginning of field observations from the ice is determined by the times when the ice cover attains a thickness guaranteeing the safety of movement and work on it.

The data in Table 1.4 [21] are used as guidance in planning and organizing field work from the ice using surface and aerial transport facilities.

In addition to the data in this table, making it possible to judge what thickness of sea ice is capable of supporting definite weight and dynamic (moving) loads over a prolonged time, in the planning of field work an allowance is also made for the stability of the shore ice, determined by the character of local conditions. The most favorable regions for the existence of shore ice over a long time are bays, gulfs, islands, sectors of the coast with very incised shorelines, protected against strong winds capable of smashing the shore ice.

The site in the ice for making field observations is selected where there are no underthrusts and other major irregularities of its lower surface and also nearby there must be no hummocks or other floes which have a greater degree of settling.

The positioning of field stations (and also stations on the profile) within the range of visibility of the shoreline is determined using reference points situated on the land by means of optical geodetic instruments (theodolite, compass, etc.). Beyond the limits of shore visibility their position is determined either by an astronomical method or using appropriate instruments (theodolites, sextants, etc.) or by the route plotting method (using azimuth and the route covered). On field oceanographic profiles the method of oceanographic observations (including preparation of the hole for hydrological measurements) for the most part is identical to that in an oceanographic survey on the "Sever" expedition, and at field stations is identical to that at the SP stations (see Chapter 2). The requirements on instruments and equipment remain the same as when working with them at field stations.

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Table 1.4

Minimum Thickness of Sea Ice Ensuring Safety of Movement and Work at a Stable Negative Air Temperature

Transport	Total mass, tons	Minimum ice thickness, mm	Minimum admissible distance to outer edge of ice of given thickness, m
Man in hiking gear	Up to 0.1	12	5
Loaded sledges with sledge dogs	Up to 1.0	20–25	12
Car or cross-country vehicle	Up to 3.0	40	20
	Up to 8.0	50	25
Tractor with treads	Up to 10.0	60	30
Aircraft or helicopter with skis (wheels)	Up to 6.0	40(50)	50
	Up to 12.0	60(90)	100

Note 1. With the appearance of snowfields on the ice movement and work on it are possible with thicknesses 1.5 times greater than those indicated in this table. 2. With the appearance of through fissures, washed-out hollows and thawed patches in the ice the use of cars, airplanes (helicopters) or other transport vehicles cannot be allowed.

The hydrological pavilion over the measurement hole at field stations, in contrast to at SP stations, can be set up not only in a KAPSh-1 tent, but also in a plywood hut, which inside is lined with felt or other heat-insulating material. In the hut, as in the tent, there is a work table for the titration of samples, shelves, lockers for instruments, a winch with a cable and other gear. On the hut floor there is a hatch which folds back, over which, beneath the ceiling, a block-and-tackle is placed. During work the block-and-tackle is set over the measurement hole in such a way that the hatch opening coincides with it. The hut is also used when running field oceanographic profiles. In this case it is constructed on sledges which are towed by a tractor or a cross-country vehicle. When using cross-country vehicles the pavilions are sometimes mounted in their bodies. In this case the observations are made in light tents of the KAPSh-3 type which can be dismantled.

1.5.2. Features of the organization of field oceanographic observations on ice. The organization and implementation of field work from the shore ice are in many respects identical to the methods for carrying out work from the drifting ice. In the organization of oceanographic work at the SP stations and on the "Sever" expeditions, as well as on the Soviet Antarctic Expeditions, extensive use has been made of the experience in carrying out coastal and field hydrometeorological work at polar stations. In turn, many organizational and technical (instruments, gear, etc.) attainments of the SP stations and "Sever" expeditions are being introduced at polar stations into the practice of field oceanographic work. For example, such oceanographic instruments and equipment as the BPV current meter, AANII bathometers, "Severnyy Polyus" winch, KAPSh tent, PDKO hut and others have come into use in field work.

A special feature of field work is the delivery of specialists and supplies to field stations and to oceanographic profiles on the ice by use of surface vehicles. Only at individual stations is use made of aircraft or helicopters. Such excursions on the ice for field work are made each month during the course of the entire winter and spring. When making field oceanographic observations it is necessary to adhere to some safety rules [88]:

-- it must be taken into account that after the shore ice attains a thickness adequate for movements and repeated crossings in individual places there can be sectors of thin and weak ice;

-- constant weather and ice condition observations must be made;

-- movements must be avoided during blizzards. The storm must be waited out in a tent, the body of a cross-country vehicle or in a snow shelter;

-- crossings through hummocked sectors of ice (especially fresh hummocks) must be avoided;

-- there must be special care taken when there are fissures and seal holes. Broad fissure (0.5 m or more) are best avoided. If this is impossible, for their crossing it is necessary to lay down floors or bridges of logs and boards;

-- there must be no movement along the ice during darkness along an unchecked route;

-- when making any crossing of the ice, regardless of the type of transportation or remoteness of the field station it is necessary to carry along an emergency supply of food, means of signaling and way to communicate with the station, fuel and means of heating, compass, etc.;

-- it is necessary to check carefully the furnishing of personnel with the necessary gear prior to every trip to the site of field work or oceanographic survey.

During oceanographic work on the shore ice, especially not far from its edge, a part of it can be detached with the people still on it. In such a case it is first of all necessary to make use of available means of rescue (small boats, rafts, etc.) in an effort to make one's way to the intact part of the shore ice, taking along primarily food, means of heating (and fuel), signaling and communication, and observational data. If the evacuation of personnel and gear to the main part of the shore ice is impossible, a temporary camp is organized on the detached part of the shore ice (if there is a necessity for this), in its most durable part; everything is transported there which will be necessary for the life support of personnel (tents, food, fuel, etc.). All the supplies of food, fuel and clothing are distributed in such a way that they will last as long as possible. Serious attention is devoted to means for communication and signaling for the speediest possible detection of this camp.

OCEANOGRAPHIC STUDIES FROM SHIPS

CHAPTER 4. TECHNICAL APPARATUS FOR SEA EXPEDITIONS

4.1. Expeditionary Ships

General requirements imposed on expeditionary ships. The specifics of oceanographic work carried out in polar seas imposes the following requirements on expeditionary ships:
-- high navigational qualities, that is, the capacity for carrying out safe and effective voyages in any season of the year, at any latitudes and under the most complex hydrometeorological conditions;
-- presence of adaptations ensuring anchoring at considerable depths (to several thousand meters);
-- presence of special apparatus for the setting-out of self-contained buoy stations and also winches and auxiliary mechanisms for the lowering and raising of instruments. In the designing of the ship the number, type and characteristics of the winches, block-and-tackle, special platforms and other deck equipment should be designed with allowance for the specific purposes of the expeditionary ship and the technology adopted for work with the scientific equipment;
-- presence of laboratories containing recording apparatus, for preparation and repair of equipment, as well as for primary processing of observational data. These laboratories must be of the necessary size and be conveniently placed on the corresponding decks.

The typical laboratories on expeditionary ships, carrying out a complex of hydrometeorological investigations, are: a) meteorological, b) oceanographic, c) hydrochemical, d) hydroacoustic and geophysical, e) interchangeable purpose (dependent on the purpose of the investigations). Ice laboratories must be present on ships carrying out oceanographic work in the polar regions.

The presence of a shipboard electronic computer center is extremely desirable.

Expeditionary ships are complex engineering complexes consisting of several subsystems organically linked to one another and interacting with one another (Fig. 4.1).

The complex consists of the following subsystems:
-- Navigational control of ship 1. Includes navigation instruments and equipment for plotting and determining the position of a ship, control panel and also connection with other subsystems.

Control of the ship's engines 2. There is apparatus for monitoring and regulating the principal and auxiliary engines of the ship, electric motors and other auxiliary mechanisms (active rudder, rudder controls).

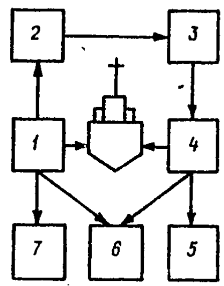

Fig. 4.1. Engineering complex of scientific research ship. 1) navigational control of ship; 2) control of ship movement; 3) stabilization control; 4) control of elements for data collection and processing; 5) control of auxiliary apparatus; 6) control of external communication; 7) control of auxiliary equipment.

Control of ship stabilization 3. This includes different systems for the damping of rolling and stabilizing apparatus. It makes it possible to maintain an invariable spatial position of individual instruments or groups of instruments during rolling.

Control of elements for data collection and processing 4. It includes complexes of systems of sensors and recorders for hydrometeorological and other parameters. Such complexes can be situated directly on shipboard, can be lowered over the side on an electrical or supporting cable, and can also be placed autonomously in the sea (buoy stations). In certain cases they are carried aloft in rockets, balloons and helicopters from the ship's deck. In addition, provision is made for the reception of hydrometeorological information from aircraft observatories and artificial earth satellites. The processing of observational data is with small mechanical calculators or electronic computers, and in the case of large ships -- in a special electronic computer center.

Control of auxiliary apparatus and instruments 5 for supporting hydrometeorological and other observations: special winches, booms, cranes and platforms.

Control of external communication 6. Includes apparatus for radio communication, teletype communication, radar, hydroacoustic instruments, etc.

Control of auxiliary equipment 7 -- shipboard booms, fire systems, rafts and small boats present aboard the ship.

Principal types of ships employed in expeditionary work in polar regions of the world ocean. Special ships of a so-called "ice class" (Table 4.1) are used in icy seas.

The most promising are the following types of ships, intended for expeditionary work in the polar regions of the world ocean.

Table 4.1.

Technical-operational characteristics	Type of ship		
	"Issledovatel'"	"Dmitriy Ovtsyn"	"Professor Vise"
Length, m	54.7	67.0	123.9
Width, m	9.3	11.8	17.0
Draft, m	4.1	4.6	6.1
Displacement, tons	1125	1600	6930
Engine power, HP	1000	2000	8000
Speed in open water, knots	11.5	14.0	17.0
Length of autonomous voyage, days	35	----	50
Ice class	L-1	UL	L-2
Crew, persons	25	30	85
Scientific personnel, persons	15	12	50

1. Ships of the "Issledovatel'" type. These are used in conducting a patrol hydrometeorological service, investigations of the interaction between the ocean and the atmosphere, and also for carrying out geological and radiological investigations. The sailing time and region are unlimited, with allowance for entry into broken ice. It is assumed that in the coming years this type of ship will become the most important for the State Committee on Hydrometeorology and Environmental Monitoring.

The ship has provision for the damping of rolling, making it possible to carry out work even when there are considerable waves, and also a rudder control apparatus.

For scientific research work the following winches are installed on the main deck: LEROK-1,2 (cable length 12,000 m) with a controller and crane; LE-55 (cable length 1,200 m). In addition, there is a manual damper for work with the EMIT (GM-15) current meter.

An LETR-7 winch is installed on the ship for the placement of abyssal buoy stations.

The ship is outfitted with two hydrological, a hydrochemical, an aerological, a radiosynoptic and a meteorological laboratory. There is a special apparatus room for the "Meteorit" radar, the "Musson" system and the "Berezka" apparatus, which makes it possible to carry out a full complex of radar aerometeorological observations.

2. Ships of the "Dmitriy Ovtsyn" type. These are intended for carrying out hydrographic and oceanographic investigations both in the Arctic and in other regions of the world ocean. The ship is reinforced at the ice level and has means for the damping of rolling.

The ship has hydrographic, geological and other laboratories outfitted with everything necessary for carrying out scientific investigations.

3. Ships of the type of the scientific research vessel "Professor Vize." These are intended for carrying out multisided scientific investigations in any regions of the world ocean.

The ship carries the latest radionavigation equipment: radars, echo sounders, LORAN and DECCA apparatus. The ship has means for damping rolling, an active rudder and rudder control apparatus.

The deep-water anchoring apparatus consists of two drums holding about 20,000 m of 8-mm cable and a powerful winch ensuring the anchoring of the ship at virtually any depths.

This same system, in combination with two loading booms, can be employed in the setting-out of self-contained buoy stations in the ocean.

The ship has more than 20 different laboratories. The aerometeorological complex includes meteorological and aerological laboratories and stabilized radar systems, even during rolling of the ship making it possible to use radar in ascertaining the precise position of observed objects. The primary converters of the actinometric instruments are extended by means of a special boom for a distance of 8 m in front of the stem, thereby precluding the influence of the ship's hull on their readings. The weather bureau is situated in the meteorological synoptic laboratory and in the radiosynoptic laboratory, outfitted with radio receivers and "Ladoga" phototelegraphic apparatus. An apparatus for the launching of meteorological rockets is situated on the stern deck. There is a shipboard electronic computer center. Powerful radio transmitters ensure the transmission of the collected information from any point in the world ocean to reception centers.

The ship carries equipment for carrying out a full complex of oceanographic investigations (Fig. 4.2). There are six electrified winches for working with bathometers, bathythermographs, photothermographs and instruments for measurements of currents.

In the vertical sounding of water masses use is made of sounding bathometers for automatic measurement of water temperature and salinity at drift to a depth of 2,000 m. While the ship is proceeding on course the current velocity and direction are measured with an electromagnetic current meter (EMIT). The three hydrological laboratories contain EMIT recorders, a wave meter, ATsIT apparatus and other instruments, as well as equipment for a hydrochemical analysis of sea water.

4.2. Navigation of Expeditionary Ship in Ice

When implementing expeditionary work in the polar regions of the world ocean the navigation of ships occurs amidst the drifting ice, constituting concentrations of individual fields and floes, which under the influence of the wind and currents change their continuity, and also amidst a continuous fixed ice cover -- shore ice. Navigation in a region of concentration of icebergs is a special case.

The passability through ice is dependent on the type, properties and continuity of the ice cover and on the technical-operational characteristics of the ships -- strength and reinforcement of the hull and engine power.

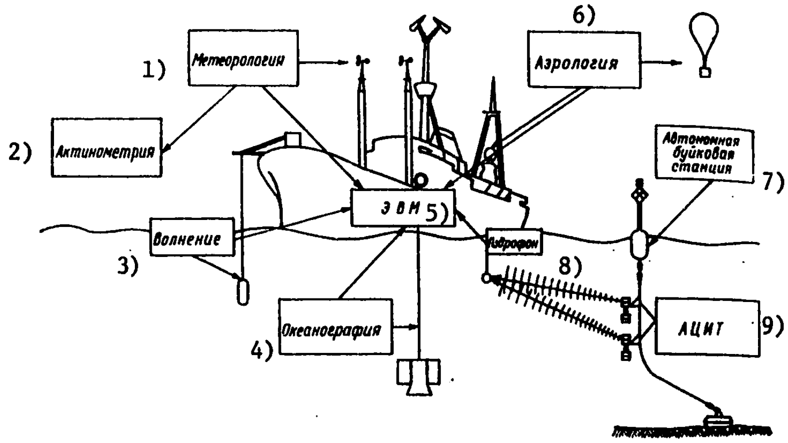

Fig. 4.2. Basic hydrometeorological equipment of ships of the type of the scientific research ship "Professor Vize."

KEY:

1. Meteorology
2. Actinometry
3. Waves
4. Oceanography
5. Electronic computer
6. Aerology
7. Automatic buoy station
8. Hydrophone
9. ATsIT apparatus

Depending on the type and continuity of the ice cover the navigation of ships is in three regimes of movement: 1) on variable courses in order to avoid concentrations of continuous ice or individual large ice formations (extensive hummocky ice fields, icebergs); 2) forcing of the drifting ice along the stipulated course with a forced decrease in the speed of movement for safeguarding the hull at the time of collisions with the ice; 3) overcoming continuous drifting ice or shore ice in a thrusting regime.

We will examine two rates of ship movement which are used in ensuring safe navigation in the ice [81]:

maximum attainable speed -- the speed which the ship can develop under definite ice conditions with use of total engine power (with given reinforcement of the hull); maximum admissible speed -- the speed which is determined by the designed strength of the ship's hull, for the most part its prow (under the condition of damage-free collision of the ship with the ice).

For safe operation of the ship in ice it is desirable that the admissible speed somewhat exceed the attainable speed.

The determination of the maximum safe speed at which a ship can move in drifting ice of different thickness h and extent r (or mass D_r = rh) is accomplished using the graph (Fig. 4.3). For this purpose $V_{adm} = f(D_r)$ and $V_{adm} = \rho(D_r)$ are compared on the graph. If the curve of attainable speed lies below the curve of admissible speed the ship can fully use its power for movement in broken ice without fear of

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inflicting damage; if the curve of attainable speed lies above the curve of admissible speed the ship cannot use the full power of its power plant.

As a convenience the lg D_r values are plotted on the x-axis in place of the absolute value D_r.

The change in the speed of ships is primarily dependent on the type and continuity of ice cover (Fig. 4.4).

With an ice continuity up to 4 scale units the greatest speed losses are observed during navigation in large broken ice, and with an ice continuity above 5 scale units -- during movement amidst ice fields.

The general character of decrease in the speed of movement of the scientific research ship "Professor Vize" in the ice is determined by the equation

$$V_{ice} = aB^2 + bB + c, \tag{4.1}$$

where B is ice continuity, in scale units, a, b, c are empirical coefficients dependent on the type of ice and the technical characteristics of the ship.

During movement in the wake of a powerful icebreaker the decrease in speed in the ice is less than when moving alone. With an increase in ice continuity there is an increase in the difference in speeds when proceeding alone and in the wake of an icebreaker (Fig. 4.5).

The navigation of ships in the ice when they perform expeditionary work has its specific features. For example, ships of the "Dmitriy Ovtsyn" type first of all carry out expeditionary work in ice with a continuity of not more than five scale units, which in most cases makes it possible to move along a stipulated run or section. Second, movement of the ships occurs at a stipulated speed V_{stip}, which satisfies the most effective operation of the instruments (echo sounders, EMIT apparatus, etc.). With such a speed the engine power is not fully used and the decrease in speed in the ice occurs more intensively than during free navigation.

The forcing of continuous ice occurs in a thrusting regime [20] and is determined by the expression

[BP = ult(imate)]

$$\frac{R(1-\Delta)}{\mu B} = k_2 \sigma_{\text{вр}} i + k_3 i^2, \tag{4.2}$$

where R is the actual thrust of the screws, H; Δ is the coefficient of suction of the screws; μ is a coefficient characterizing the configuration of the hull; B is the ship's width, m; k_2 and k_3 are empirical coefficients for each type of ship; σ_{ult} is the ultimate bending strength of the ice, N/m^2; i is ice thickness, m.

P. A. Gordiyenko, A. Ya. Buzuyev and G. N. Sergeyev [35], analyzing in detail the degree of influence of the principal parameters of the state of ice on the rate of movement of ships of the ice class and icebreakers, established that the rate of movement of ships in hummocky ice decreases the greater relative to the speed in even ice the greater the degree of hummocking of the ice; during the period of melting the speed increases with an increase in the degree of ice destruction; in continuous even ice of one and the same thickness during the period of its melting the speed is considerably greater than in the developing ice during the autumn-winter months; an increase in ice destruction by 1 scale unit leads to an increase in the speed of ship's movement on the average by 20% in comparison with the speed of movement in the ice with a degree of destruction of 1-2 scale units.

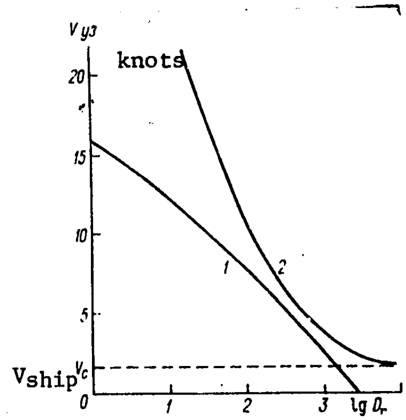

Fig. 4.3. Dependence of admissible (1) and attainable (2) speeds of ship of the class UL on extent of drifting ice. V_{ship} -- speed at which ship can safely impact on edge of ice field.

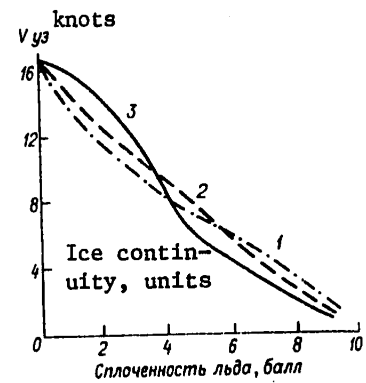

Fig. 4.4. Losses in speed of movement during navigation amidst ice of different types and continuity for ships of the type of the scientific research ship "Professor Vize." 1) large broken ice; 2) small broken ice; 3) ice fields.

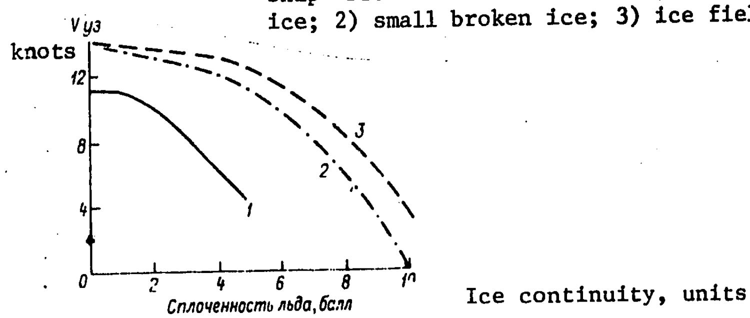

Fig. 4.5. Losses of speed for ships of the "Dmitriy Ovtsyn" type. 1) when carrying out expeditionary work; 2) during autonomous navigation; 3) in wake of icebreaker.

In an examination of the influence of the principal parameters of ice on the speed of ship movement it is necessary to take into account some difference in the characteristics of Antarctic and Arctic ice. D. D. Maksutov [81] notes that in autumn and winter in Antarctica the broken ice rapidly freezes together, heavy snowfalls and blizzards level its surface with the formation of fields rising 100-150 cm above the water surface, with a snow layer of 100 cm or more. It is difficult even for icebreakers to force such ice and it is frequently impassable for the transport ships generally employed for navigation in the ice.

Shore ice, under the weight of snow saturated with water, sinks somewhat. These unconsolidated layers constitute a considerable impediment to splitting of the shore ice during its forcing by a ship. In addition, the "cushion" of sea ice and snow forming along the sides and stem also creates additional resistances. Sometimes even in operation in "runs" at the time of forcing of the shore ice the ship advances only insignificantly. These qualities of Antarctic ice are not taken into account by formula (4.2).

The icebergs in Antarctic seas make difficult the navigation of ships and constitute a serious danger for them. During navigation in Antarctic ice the ships must have radar systems making possible the timely detection of different types of icebergs and they must have adequate engine power and maneuverability in order to avoid collision with icebergs.

As a unified index of ice navigation conditions, P. A. Gordiyenko and A. Yu. Buzuyev introduced the concept of the coefficient of difficulty of ice navigation K_{dif}, which determines the ratio of the time expended on movement of the ship along the track under specific ice conditions to the time expended on movement along this same track through open water.

The general expression for the K_{dif} parameter is

[Пр = shore; ЧВ = open]

$$K_{dif} = \frac{V_0}{V_{\text{пр}}}\frac{S_{\text{пр}}}{S_0} + \frac{V_0}{V_{9-10}}\frac{S_{9-10}}{S_0} + \cdots + \frac{V_0}{V_{1-3}}\frac{S_{1-3}}{S_0} + \frac{S_{\text{чв}}}{S_0}, \qquad (4.3)$$

where V_0 is the speed of a ship of a particular type in open water, knots; S_0 is the total extent of the considered track, miles; S_{shore}, S_{9-10}, S_{open} is the extent of sectors with different (uniform) ice conditions (shore ice, continuity of 9-10 scale units, open water respectively), miles; V_{shore}, V_{9-10} are the ship's speeds under stipulated ice conditions during an individual voyage, knots.

Table 4.2 gives an example of computations of movement of the scientific research ship "Professor Vize" in different kinds of ice and gives the corresponding coefficients of difficulty in ice navigation.

Features of implementation of oceanographic work during navigation in ice. Among the expeditionary ships it is ice-hydrological patrol (IHP) ships which most frequently must enter into the ice. The principal tasks of the IHP are observations of changes in the ice and hydrological regime of the ice edge zone and the operational transmission of this information to the sea operations staffs along the Northern Sea Route. For solving these problems the IHP ships determine the geographical position of the ice edge or individual concentrations of ice, ice continuity, form, extent and age of drifting ice, and also the form of the fixed ice. During recent years the tasks of the IHP include oceanographic studies which are carried out in hydrological surveys and along profiles, such work being done along prestipulated routes. When carrying out oceanographic work amidst ice of different continuity it is necessary that the following circumstance be taken into account. Drifting ice, even thin ice, makes difficult the lowering and raising of instruments on a cable lowered over the side. For this reason the instruments must be lowered on the side on which the ice has the least continuity. During calm weather the rate of ship movement occurs due to the current operative at the entire depth equal to the ship's draft. This speed is usually less than the speed of movement of the ice in the surface layer of water. Accordingly, the more continuous ice is situated on the side on which the current is operative. In the presence of a wind the rate of ship drift is greater than the rate of ice drift and as a result on the windward side there is a thinning of the ice and on the leeward side it is less continuous.

Table 4.2

Computation of Coefficient of Difficulty of Ice Navigation of Scientific Research Ship "Professor Vize"

Number of route segment	Time during which route segment is covered, in hours/minutes	Length of route segment, miles	Average speed in particular segment, knots	Ice continuity in particular segment, units	Ice form	K_{dif}
1-2	06 10	29.8	4.8	8	MBL*	3.54
2-3	01 45	3.5	2.0	9	KBL**	8.50
3-4	02 40	4.8	1.8	8	KBL	9.40
4-5	01 52	35.2	16.5	4	MBL	1.03
		S_0 = 73.3				$K_{dif_{av}}$ = 3.02

*Small broken ice
** Large broken ice

If the oceanographic work is carried out in continuous ice it can be recommended that the ship be anchored to the ice alongside a large floe.

It is best that the cable with the instruments be lowered over the ship's side in a hole specially prepared in a floe. During summer this can be done using places where melt water lies on solid ice or in large fissures. It is not recommended that a cable with instruments attached be lowered into leads since they frequently change their width and can close up completely.

The sounding lead or base methods, described in detail in [103], are used for determining the joint drift of the ship and floe.

When navigating amidst the ice it is always necessary to take into account the influence of low air and water temperature on the implementation of oceanographic work. For example, with supercooling of the current meters in the open air (at a negative temperature) after their lowering into the water ice overgrowths are formed on the instruments which make difficult the rotation of the current meter blades and sometimes completely stop them. With supercooling of bathometers it is common to observe cases of nonactivation of the triggering mechanism of the bathometers. It is difficult to take samples from the bathometer as a result of freezing of the barrel of the discharge cock. At a negative air temperture the glass of the thermometers is covered with an ice crust, which makes difficult readings on the thermometer scales.

As a rule there is a decrease in the speed and quality of observations when working with the supercooled metal parts of instruments -- more frequent cases of loss of weights attached to the cable and poor attachment of the instruments to the cable, as a result of which they move along the cable and in individual cases break off.

In the case of a low ambient temperature it is possible to recommend the following measures for improving the conditions for the implementation of oceanographic measurements. The instruments prior to suspension on a cable must be in a warm room. In those cases when the hydrological and hydrochemical laboratories are at a considerable distance from the hydrological winches it is recommended that use be made of portable heated boxes for safeguarding bathometers and current meters. The heating of such apparatus is accomplished by placement of containers of hot water in them. After raising the instruments from the water they must immediately be placed in rooms where the water samples are taken and readings are made of deep-water thermometers and current meters.

4.5. Buoy Oceanographic Stations

At the present time extensive use is being made of the placement of oceanographic instruments on buoy stations for long-term operation.

One ship can service several buoy stations, which broadens the region of simultaneous work. For example, even a small ship (with a displacement of 500-800 tons) can set out 5-8 buoy stations with 30-40 instruments. The equipment of any buoy station includes: basic (supporting) and signaling buoys, cables, anchor and signaling equipment, and also individual or standard-produced oceanographic instruments.

Buoy stations can be a component part of an oceanographic section when they are set out at control points for detecting changes in the oceanographic characteristics during the time when work is being carried out along the entire section. They are also set out for prolonged work at sea during specialized observations in an oceanographic polygon.

It is common to use a scheme of a buoy polygon in which there is a self-contained buoy station at the center of a square with sides 10-15 miles. At the site of its placement and at the corners of the square (Fig. 4.7) the ship at definite time intervals makes one or more abyssal standard observations of temperature, salinity and other oceanographic characteristics.

When the stations are placed in the open sea their position can be determined most precisely by radio apparatus. When there is no possibility for such a determination it is possible to obtain the observed position of the station by astronomical methods. If the buoy stations are set out within the range of visibility of the shore, their coordinates are determined by ordinary navigation methods (radar, direction finding).

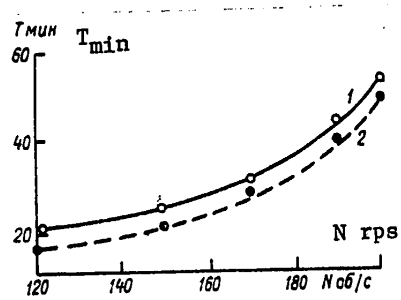

Fig. 4.6. Dependence of duration of acceleration S_{acc} (1) and slowing S_{slow} (2) on number of rpm for ships of the "Professor Vize" scientific research ship type. 1) acceleration; 2) slowing.

The search for the stations can be successful with satisfaction of the following conditions: the coordinates of the stations at the time of their placement have been determined with the maximum possible accuracy; the viability of above-water signaling buoys and markers has been ensured; a precise reckoning of the course of the ship at the time of search has been accomplished; favorable weather conditions have been selected.

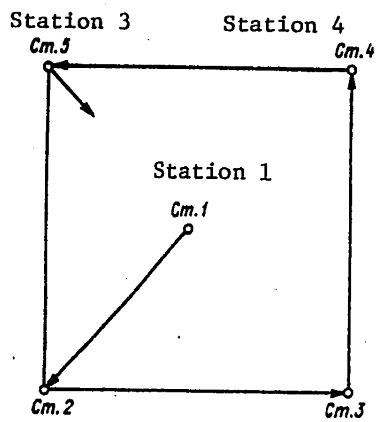

Fig. 4.7. Diagram of buoy polygon.

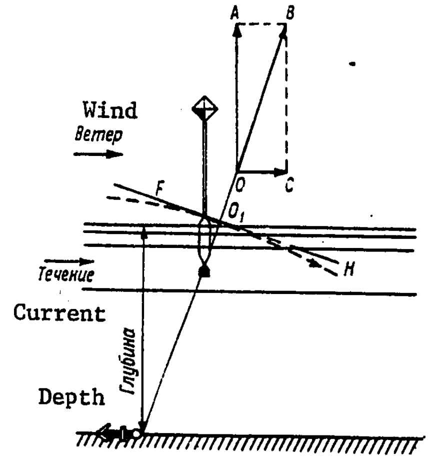

Fig. 4.8. Diagram of forces with exposure of buoy to wind and current.

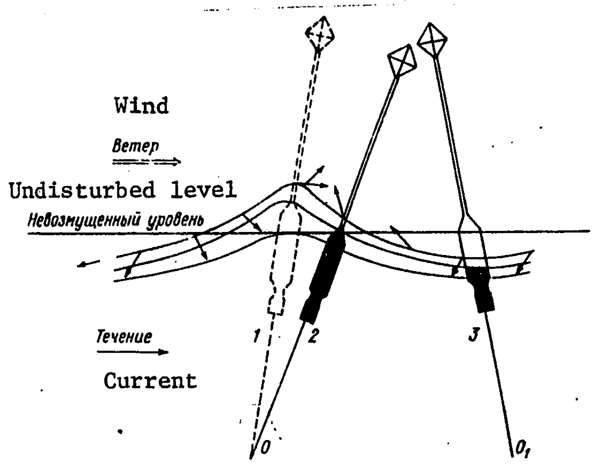

Fig. 4.9. Diagram of forces with exposure of buoy to waves. Position of buoy: 1) with undisturbed level; 2) at wave crest; 3) at foot of wave.

Effect of current, wind and waves on component parts of buoy stations. A self-contained buoy station is subjected to the influence of the wind, waves and currents creating aerohydrodynamic and mechanical loads on its component parts (Fig. 4.8).

After positioning, the cable connecting the buoy to an anchor is drawn out along the direction of the current and is deflected from the vertical by the angle α. When the angle of deviation becomes constant, the joint pressure of the wind and current, determined by the OC vector, begins to be operative, and this will tend to submerge the buoy. In the case of a great buoyancy of the buoy (vector OA) the beacon remains at the surface even when there are considerable wind and current velocities. In the case of a low buoyancy of the buoy and with a strong pressure of the wind and current the buoy can disappear under the water along the arc of the circle FH.

With a direction of the waves coinciding with the direction of the wind and current the maximum pressure of the wave on a buoy and cable will be observed with the passage of a crest (Fig. 4.9.1). In this case the pressure can be so great that the buoy will be submerged under the water along a curve with its center at the point O_1. With the passage of the wave slope the beacon occupies the position 2.

If during the passage of the wave its pressure exceeds the pressure of the wind and current, but is less than with passage of the crest, the beacon and buoy are deflected in the opposite direction relative to the position 2.

With appreciable wave pressure there is a nodding of the beacon -- a deepening of the beacon on the crest and its emergence from the water at the foot of the wave.

For the proper placement of buoy stations and their normal operation under storm conditions it is necessary to compute the loads on them in accordance with [103].

Displacement of deep-water stations under influence of wind, waves and current. Buoy stations set out at great depths in the open sea can be displaced considerable distances from the point of their initial placement under the influence of the wind, waves and currents.

Such displacements of buoy stations cause considerable errors in determining current parameters from the records of automatic recorders placed on the stations.

For computing the aerohydrodynamic loads operative on the buoy station, outfitted with the most frequently used GM-51 or "Pinch" buoys, use is made of the expressions:

for the GM-51 buoy

$$F_{ar} = 0{,}18u^2 \frac{H}{L} d + 0{,}15w^2 + 40{,}8\left(u + \frac{\pi h}{\tau}\right); \quad (4.25)$$

[ar = ah = aerohydrodynamic]

for the "Pinch" buoy

$$F_{ar} = 0{,}18u^2 \frac{H}{L} d + 0{,}23w^2 + 61{,}2\left(u + \frac{\pi h}{\tau}\right), \quad (4.26)$$

where F_{ah} is aerohydrodynamic pressure, H; H is the depth of placement of the buoy station, m; L is the length of the let-out cable, m; d is the cable diameter, m; u is current velocity, m/sec; w is wind velocity, m/sec; h is wave height, m; τ is wave period, sec.

Under the influence of aerohydrodynamic loads the buoy station is displaced from the point where the anchor touches the ground. Computations of displacement of the buoy station with exposure to the wind, waves and currents are made using the formula

$$D = \frac{F_{ar}}{P} \ln\left\{\left[\frac{L^2 - H^2}{2\left(\frac{F_{ar}}{P}\right)^2} + 1\right] + \sqrt{\left[\frac{L^2 - H^2}{2\left(\frac{F_{ar}}{P}\right)^2}\right]^2 - 1}\right\}, \quad (4.27)$$

[ar = aerohydrodynamic]

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where D is buoy station displacement, m; P is the mass of a running meter of cable, kg/m.

The aerohydrodynamic load with an increase in wind velocity and wave height increases nonlinearly (Fig. 4.10a).

The displacement D of the buoy station increases rapidly to definite wind velocities and then with a further increase in wind velocity the displacement of the station is slowed.

With an increase in current velocity the aerohydrodynamic load F_{ah} gradually increases (Fig. 4.10b); it is also dependent on wind velocity.

The displacement D of the buoys in the case of low wind velocities (w = 10 m/sec) occurs more intensively than in the case of high wind velocities (w = 20 m/sec).

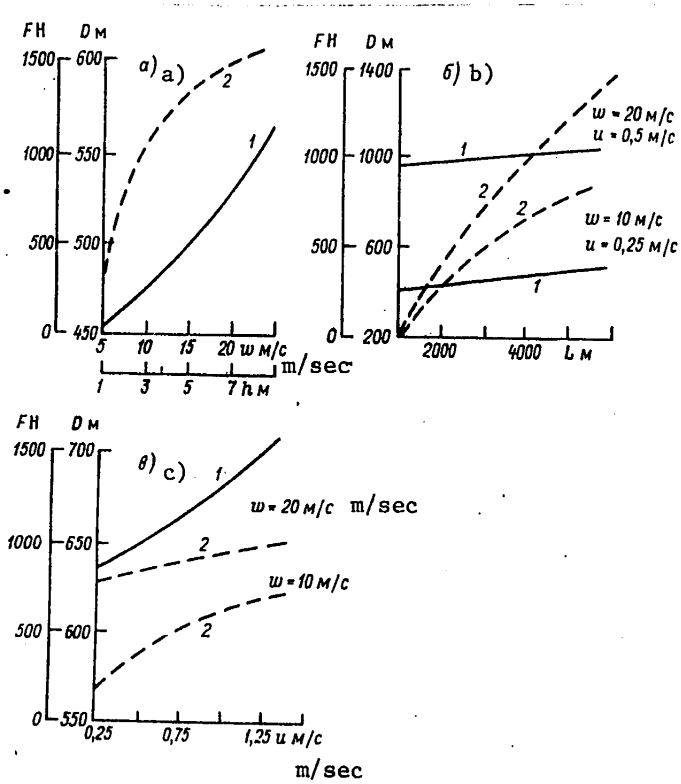

Fig. 4.10. Influence of wind, currents, waves and length of let-out cable on the aerohydrodynamic load F and displacement D of buoy station. 1) aerohydrodynamic load; 2) displacement of buoy station.

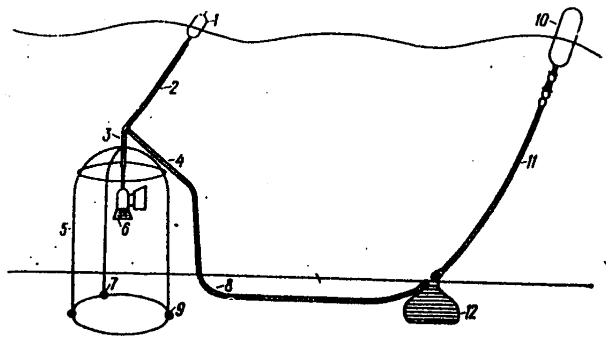

Fig. 4.11. Buoy station of "Kolokol" type. 1) float; 2) metallic cable; 3) tube with bracket; 4) metallic tube; 5) framework; 6) instrument-automatic recorder; 7) metal weights; 8) base cable; 9) lower ring of framework; 10) signaling buoy; 11) buoy line; 12) anchor.

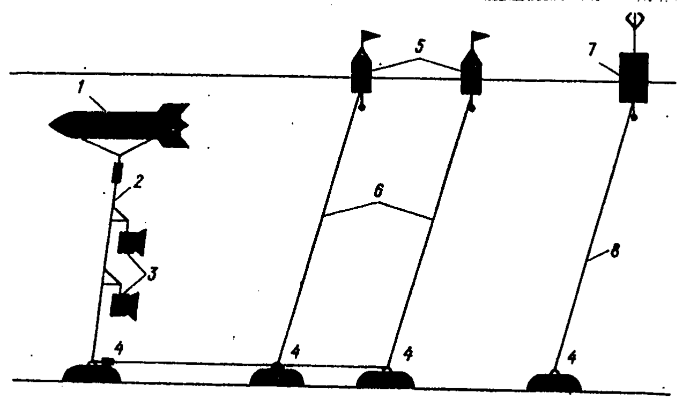

Fig. 4.12. Arctic and Antarctic Scientific Research Institute buoy station. 1) supporting buoy; 2) main cable; 3) bracket with instruments; 4) anchor; 5) signaling buoy; 6) lines connecting signaling buoys; 7) additional signaling beacon; 8) lines connecting signaling beacon.

With constant wind, waves and currents the aerohydrodynamic load F_{ah} and displacement D increase with an increase in station depth H and cable length L.

The aerohydrodynamic load F_{ah} increases proportionally to the increase in the total length L of the cable and the displacement D of the buoy increases nonlinearly (Fig. 4.10c).

At the same time it can be seen that with an increase in wind and current velocities and wave height the absolute values of the aerohydrodynamic load F_{ah} and displacement D increase.

The aerohydrodynamic load F_{ah} and the displacement D are dependent on buoy parameters. For one and the same wind velocity and current velocity and wave heights the aerohydrodynamic load F_{ah} and displacement D for the "Pinch" buoy will be greater than for the GM-51 buoy (especially with a cable length greater than 1,500 m).

Specifics of operation with buoy stations in seas with ice cover. Special designs of buoy stations are used in regions where drifting ice may appear during the period of implementation of oceanographic work.

Bottom apparatus of the "Kolokol" type can be used in the case of insignificant depths (not greater than 10 m) (Fig. 4.11).

At depths greater than 20 m and with the need for suspending of instruments at several horizons it is recommended that use be made of systems of buoy stations with a main submerged buoy (Fig. 4.12).

The fundamental features of this scheme are: increased strength of all station components; presence of a sunken main buoy and two or three surface signaling buoys; placement of an additional signaling beacon at some distance from the site of placement of the buoy station; inclusion in the station system of an automatic cable disconnector for releasing the connecting line from the anchor prior to the floating up of the submerged buoy.

With the placement of buoy stations with above-water buoys in icy seas it is recommended that the following basic requirements be met: during the period of station placement the distance to the ice edge must be not less than 30-60 miles; with approach of the ice edge to a distance of less than 15 miles the self-contained station must be raised with the first opportunity; when the ship is in the immediate neighborhood of the station it is raised at once with the appearance of any threat from drifting ice.

The checking of proper operation of self-contained buoy stations in icy seas must be accomplished at least each 10-30 days, depending on specific ice conditions.

CHAPTER 5. OPTIMAL PLANNING AND ORGANIZATION OF OCEAN EXPEDITIONS

5.4. Evaluation of Effectiveness of Technical Apparatus Used in Oceanographic Work

The optimum planning and organization of oceanographic work must provide for the use of such technical apparatus as can be regarded as efficient.

The choice of the corresponding technical apparatus is determined by:
1) technical efficiency, by which is meant the possibility of carrying out of oceanographic work at set times in a full volume under different hydrometeorological conditions;
2) economic efficiency, which determines the excess of the cost of the results of oceanographic work over the expenditures on the creation and operation of technical apparatus.

In a general case a technical apparatus or complex of apparatus, which under the condition of implementation of planned oceanographic work requires minimum expenditures, is economically more efficient.

One of the factors in increasing the economy of oceanographic work is a shortening of its duration, since the operating expenditures on the use of technical apparatus increase proportionally to the time of its use.

However, in the planning of sea expeditions for the purpose of more efficient use of technical apparatus it is necessary to take into account the specifics of implementation of different kinds of oceanographic work.

For example, it is possible to reduce the duration of work along an oceanographic run by a decrease in the time expenditure in making measurements at each station, but at a multiseries station the total duration of observations cannot be reduced.

A reduction in the duration of an expeditionary voyage, and accordingly, an increase in its efficiency, can be obtained by means of:

a) cruising along the most advantageous routes, with hydrometeorological conditions taken into account;
b) use of automated modern equipment and instruments, making it possible to carry out a stipulated volume of measurements during a shorter time interval.

Efficiency of voyage of expeditionary ship along most advantageous route. Modern expeditionary ships make voyages to a region of oceanographic work and back to the port of origin reckoned in the hundreds and at times in the thousands of miles.

In this case it is recommended that the voyage be made along the most advantageous route by which is meant the route which can be covered in the shortest time, selected taking into account the probable hydrometeorological conditions ensuring safety of the voyage.

If we use t_{ord} for denoting the travel time on an ordinary voyage and t_{most} for denoting the travel time during the most advantageous voyage, the gain in travel time Δt_{most} is determined by the expression

$$\Delta t_{most} = t_{ord} - t_{most}. \quad (5.40)$$

The travel time along the most advantageous route in days is determined as

[T = current,
B = wind-waves]

$$t_{most} = \frac{1}{24} \frac{S}{\sum_{i=1}^{m} K_{T_i} V_{(wh B)_i}}, \quad (5.41)$$

where S is the total route of the ship, miles; $K_{cur_1}, \ldots, K_{cur_i}$ are the coefficients of the ship's speed, taking into account the effect of the current on individual segments of the route; $V_{(wh\ wave)_1}, \ldots, V_{(wh\ wave)_i}$ is the ship's speed in the presence of wind and waves on segments of the track with different hydrometeorological conditions, knots.

Accordingly, if the main task is a reduction in travel time in the region of oceanographic work, it is necessary to select such a route for the ship in whose individual segments there will be minimum total wind-wave losses in navigation speed and an accompanying current with a considerable velocity.

Now we will examine in greater detail the effect which can be obtained for an expeditionary voyage in the case of navigation along the most advantageous route.

With navigation along the most advantageous route in the region of oceanographic work and return from it to port we obtain a time gain Δt_{most}, which makes it possible to increase the time of presence in the stipulated region by Δt_{ocean}, and accordingly, also increase the volume of expeditionary investigations or carry out investigations of a stipulated volume during a shorter time.

The operational expenditures R per one ship in the case of free navigation without allowance for hydrometeorological conditions are determined as follows:

$$R_{ord} = C_{move} t_{ord} + C_{ocean} t_{ocean} + C_{stop} t_{stop}, \quad (5.42)$$

in the case of navigation along the most advantageous route as

$$R_{most} = C_{move}(t_{ord} - \Delta t_{most}) + C_{ocean}(t_{ocean} + \Delta t_{ocean}) + C_{stop} t_{stop}, \quad (5.43)$$

where C_{move}, C_{ocean}, C_{stop} are the daily expenditures on operation of a ship during movement, during oceanographic work and during stopping, rubles; t_{move}, t_{ocean}, t_{stop} are the durations of movement, oceanographic work, stopping, days.

The change in operating expenditures during navigation along the most advantageous route in comparison with ordinary navigation is equal to

$$\Delta R = R_{most} - R_{ord} = (C_{ocean} - C_{move})\Delta t_{most}. \qquad (5.44)$$

If the volume of scientific information per day is q arbitrary units, during the time $t_{ocean\ ord}$ it will be equal to

$$Q_{ocean\ ord} = t_{ocean\ ord}q. \qquad (5.45)$$

The volume of scientific information during the time $t_{ocean\ most}$ is

$$Q_{ocean\ most} = (t_{ocean\ move} + \Delta t_{ocean})q = t_{ocean\ most}q \qquad (5.46)$$

The increment in scientific information during a voyage along the most advantageous route is

$$\Delta Q_{most} = Q_{ocean\ most} - Q_{ocean\ ord} = \Delta t_{ocean\ most}q \qquad (5.47)$$

The ratio of the increment of information during navigation along the most advantageous route ΔQ_{most} to the volume of information in the case of free voyaging Q_{ocean} is determined by the coefficient of increment of scientific information

$$K_Q = q\Delta t_{ocean\ most}/Q_{ocean\ ord}. \qquad (5.48)$$

The difference in the daily expenditures on operation of the ship when carrying out oceanographic work and during free movement is

$$C_{ocean} - C_{move} = \Delta C_{ocean\ move}. \qquad (5.49)$$

The final annual economic effect of navigation of an expeditionary ship when moving along the most advantageous route is determined by the expression

$$\ni_{most} = (R_{most} - \Delta C_{ocean\ move}t_{ocean\ most} + KE)K_Q, \qquad (5.50)$$

where K is the specific capital investments; E is the coefficient of efficiency of capital investments.

It follows from (5.50) that the annual economic effect is proportional to the coefficient of increase in scientific production K_Q.

Efficiency of use of automated instruments. During vertical sounding of water masses as a rule use is made of three groups of instruments:

1) series of discretely operating instruments, triggered by means of signaling weights;
2) series of instruments with an autonomous triggering device;
3) individual instruments with discrete or continuous action.

The duration of measurements with these instruments at a single-series oceanographic station is determined by the formulas (5.10), (5.16), (5.17).

We will examine what time gain can be obtained when in uniform oceanographic measurements use is made of instruments in groups 2 and 3 instead of 1 and instruments in group 3 instead of 2.

We will use the following notations for instrument groups 1, 2 and 3 respectively: $t_{low-raise\ 1}$, $t_{low-raise\ 2}$, $t_{low-raise\ 3}$ -- time of lowering and raising the instruments, $t_{exp\ 1}$, $t_{exp\ 2}$ -- duration of instrument exposure at the horizon; t_{weight} -- duration of falling of signaling weight; t_{L1}, t_{L2}, t_{L3} -- duration of letting-out and drawing-in of cable with instruments; $\Delta t_{L1,2}$, $\Delta L_{1,3}$, $\Delta t_{L2,3}$ is time difference in letting-out and drawing-in the instruments for each of two compared groups.

Then for a single oceanographic station of n horizons we will have the following computation formulas:

$$\Delta T_{m1,2} = T_{m1} - T_{m2} = n\Delta t_{low-raise1,2} + \Delta t_{exp\ 1,2} + \Delta t_{L1,2} + t_{weight}; \qquad (5.51)$$

$$\Delta T_{m1,3} = T_{m1} - T_{m3} = nt_{low-raise1} - t_{low-raise3} + t_{exp1} + \Delta t_{L1,3} + t_{weight}; \qquad (5.52)$$

$$\Delta T_{m2,3} = T_{m2} - T_{m3} = nt_{low-raise2} - t_{low-raise3} + t_{exp2} + \Delta t_{L2,3}. \qquad (5.53)$$

For an oceanographic station of m series at n horizons the computation of change in the duration of measurements is made using the formulas

$$\Delta T_{m1,2} = T_{m1} - T_{m2} = m(nt_{low-raise1} + t_{L1}) - (nt_{low-raise2} + t_{L2}); \qquad (5.54)$$

$$\Delta T_{m1,3} = T_{m1} - T_{m3} = [(nt_{low-raise1} + t_{exp}) + t_{L1} - t_{L3}] - t_{low-raise3}; \qquad (5.55)$$

$$\Delta T_{m2,3} = T_{m2} - T_{m3} = nt_{low-raise2} - t_{low-raise3} + mt_{exp2} + t_{L2} - mt_{L3}. \qquad (5.56)$$

The advantage of instruments in group 2 over group 1 is that when making multiseries oceanographic stations no time is lost in lowering and raising the instruments, letting-out and drawing-in the cable, and also in lowering the signaling weight. In each series of measurements of instrument group 3 there is a greater time gain in comparison with groups 1 and 2 both at single-series stations and at multiseries stations because for group 3 no time is lost in lowering each instrument to the stipulated horizon, exposure of the instrument series and dropping the signaling weight.

6.2. SORC Apparatus and Instruments

The shipboard oceanographic radar complex consists of a radar station operating in the centimeter or millimeter range, an additional linear sweep indicator, photo-attachment, and also radar beacons and buoys.

The principal components of the radar station are: transmitter, antenna, receiver and PPI (plan-position indicator).

In measurements of oceanographic characteristics it is necessary to know the following radar characteristics.

The maximum effective range is determined using the theoretical formula

$$D_{max} = \sqrt{\frac{P_{pulse} G S_A S_{irr} \sigma^0}{P_{min}(4\pi)^2}}, \qquad (6.16)$$

where P_{pulse} is the pulse power irradiated by the radar antenna, W; G is a coefficient characterizing the radar antenna directivity; P_{min} is the minimum power at the radar receiver input, W; S_A is antenna surface, m^2; S_{irr} is the surface of the irradiated object, m^2; σ^0 is the specific effective area of scattering of the object, m^2.

The dead zone is the area around the ship within which it is impossible to detect objects. This area is dependent on antenna height h_A, the width of the radar ray in the vertical plane β. The radius of the dead zone is determined as:

$$D_{min} = h_A \operatorname{ctg} \beta. \qquad (6.17)$$

The time of antenna revolution during which a fixed image of the object is registered on the radar indicator screen is ≈ 4 sec for shipboard radars.

When determining the parameters of ice, waves and currents the observer must work with the PPI.

The purpose of the PPI is the transmission to the observer of a clear and precise image of the observed objects and a determination of their position in azimuth and distance relative to the ship's position.

The bearings of the echo signal pips are determined using the azimuth circle framing the PPI screen by means of a rotating line.

There are fixed and moving range circles for measuring distances; there is a counter for measuring distances.

It must be remembered that the distance from the center of the screen to the echo signal pip is dependent not only on the distance to the object, but also on the range scale used, that is, on the maximum distance which can be registered on the screen during particular observations.

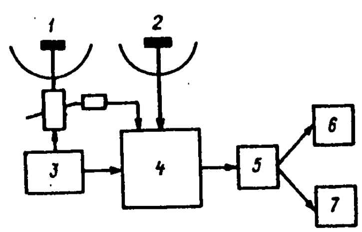

Fig. 6.1. Pulse-coherent phase meter. 1) transmitting antenna; 2) receiving antenna; 3) transmitter; 4) main radio block; 5) phase detector; 6) spectrum analyzer; 7) registry block.

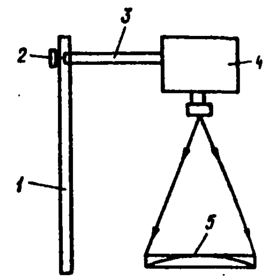

Fig. 6.2. Photoattachment of PPI screen. 1) angle bracket; 2) slots in vertical wall of bracket; 3) fork; 4) camera; 5) radar screen.

The following range scales apply for the radars most commonly used on Soviet ships:

Type of radar	Range scales, miles						
"Okean"	1	2	4	8	16	32	64
"Don"	0.8	2.5	5	15	30	50	
"Lotsiya"	0.5	1	2	4	8	16	

The additional linear sweep indicator makes it possible to register echo signals from objects in the form of pulses whose size and frequency correspond to the reflectivity of the objects.

In some cases the linear sweep indicator is used in determining the energy, frequency and width of the reflected spectrum from the oceanographic object.

A pulse-coherent phase meter (Fig. 6.1) was developed for investigating the change in the spectrum of radiation with scattering by ice or the wave-covered sea surface. The frequency spectrum of the reflected signal can be determined from the instrument by two procedures -- from photographs of the spectrum analyzer screen and by means of computations from a simultaneous record of voltage from the phase detector output.

The photoattachment for photographing the PPI screen by small cameras is a detachable tube in the form of a truncated cone made of sheet aluminum. The lower end of the tube is set on the outer ring of the PPI and the camera is attached to the upper end.

In the upper part of the tube there is a slot for observing the PPI screen. When photographs are taken this opening is covered by a flap of closely woven black fabric.

A photoattachment (Fig. 6.2) can be employed for photographing the PPI screen. A camera 2 is attached by means of a special angle bracket 1. The camera, by means of the fork 3 and the slot in the vertical wall of the bracket 4, can be moved in the horizontal and vertical planes. The basis of the photoattachment is a large-format camera of the FK type (frame size 13 x 18 cm) which with a diameter of the matching block screen 210 mm makes it possible to obtain photographs at a scale 1:2.

It is necessary to adhere to two principal requirements when installing any photoattachment. First, the photograph plane must be rigorously parallel to the plane of the radar image. Second, the center of the negative must coincide with the center of scanning of the PPI screen.

An important consideration in such work is the choice of the image scale and the photosurvey time intervals.

When using small cameras (FED, Zenit, Kiev) the image of the radar screen is obtained at a considerably reduced size. For example, with a radar PPI diameter of 300 mm when surveying on a frame measuring 24 x 30 mm its image will measure 24 mm. In order to obtain an image from a frame at a scale of 1:25,000 when working with a 1.5-mile radar range scale it is necessary to enlarge the negative 11^x, which results in a marked decrease in the clarity of the photoimage.

When using cameras with a frame width 6 cm it is necessary to enlarge the negative 3.7^x and with use of wide-film cameras with the frame measuring 13 x 18 cm an enlargement of 1.85^x is necessary.

Taking these considerations into account, in a radar survey of oceanographic objects it is possible to recommend the use of wide-film cameras.

Types of radar beacons and buoys used in determining currents. In radar observations of currents it is possible to use beacons and buoys which consist of the following principal parts: carrier buoy, latticework corner reflector, underwater sail.

In order for the radar beacon to be visible on the radar screen with any position of the beacon relative to the radar ray it carries sets of several triangular reflectors. Experience has shown that rhombic latticed reflectors are most convenient in work (Fig. 6.3). Such reflectors, with small dimensions, have an adequately great reflectivity but at the same time an insignificant sail effect.

The size and the shape of the underwater sail for the radar beacon should be such that despite a relatively small area the sail has an adequately great "water" drag. An indicated by experience, the best shape of sail is one in the form of four panels, arranged at an angle of 90° to one another. The panels can be attached rigidly. In this case the sail has constant dimensions. In the case of a soft attachment the sail can be folded. The most successful dimensions of the sail are those for which the relationship of the above- and below-water parts of the beacon will be 1:15-1:20.

When working from ships it is possible to use a beacon of the T-2 type (Fig. 6.4).

The beacon is easily dismantled. All parts can be replaced by similar parts but of a different size. Thus, it is possible to change the length of the shaft and the size of the reflector. It is also possible to install an underwater sail of different size, with the buoy buoyancy factor taken into account.

The height of the above-water part of the beacon and the size of the latticed "rhombic" corner reflector were selected in such a way that the radar visibility of the beacon with a height of the radar antenna above sea level was ≈5 miles. In addition, it was taken into account that the beacon must, insofar as possible, rise insignificantly above the water in order to reduce the wind drift of the beacon and for better stability. The optimum ratio is $S_{above}/S_{below} = 1/15$.

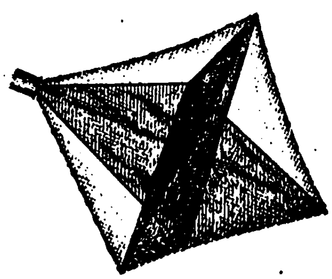

Fig. 6.3. Rhombic latticed reflectors.

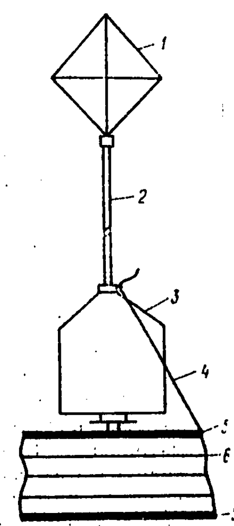

Fig. 6.4. T-2 radar beacon. 1) latticed corner reflector; 2) Dural jointed shaft; 3) carrier buoy; 4) guide cable; 5) sail crosspiece; 6) folded sail

The lowering and raising of the beacon can be accomplished manually by two observers from a small boat or from aboard ship by means of a boom. In individual cases portable buoys of the M-2 type can be used [103, Fig. 18.2]. Such a radar buoy has an adequate buoyancy factor and rises above the water to the height of the reflector plus 1/4 part of the float. The ratio of the above- and below-water parts of the M-2 buoy is 1:8. With a pyramidal reflector (30 cm side) the reflectivity is $S_{eff} = 37\ m^2$. In observing M-2 buoys with such reflectors a radar with a 10-m antenna tracks buoys for 3 miles. But with waves over class 3 the reflected pulses from such buoys are cluttered on the radar screen by echo signals from waves.

6.3. Method for Radar Survey of Ice

Three procedures are used in a radar survey of ice: visual observations of ice on the PPI with subsequent plotting of the ice on a blank map; photographing of the PPI screen and mosaicing of the photographs; determination of the sea area occupied by ice and its continuity within the limits of the range of visibility of the corresponding radar scale.

In making observations of ice on the PPI screen it must be remembered that sea ice, depending on extent and hummocking, gives a reflected signal which varies in intensity. As a result, there will be extremely different ice images on the radar screen.

Low, smooth floes are very poor objects for detection as a result of their small vertical dimensions and unfavorable configuration. For example, even continuous ice does not give images on the radar screen. This is attributable to the fact that the radio ray is almost tangentially incident on such ice and the radar receiver receives so little energy that there will be no echo signal on the screen. Such an ice field can create a pattern on the radar screen which is similar to the image of a polynia.

Thus, during a calm, when there are no signals from waves on the radar screen, it is impossible to be sure what is responsible for the absence of echo signals -- whether because there are no waves or because there is continuous ice cover near the ship. In this case it is necessary to take into account a number of additional indirect criteria (decrease in water and air temperature with approach to large ice masses).

The clarity of the signals reflected from the ice is increased with an increase in its unevenness and with its rise above the water. Individual small and large broken floes of different extent give clear echo signals on the radar screen.

On the PPI screen it is easy to see the edge of the continuous ice from the direction of the open water.

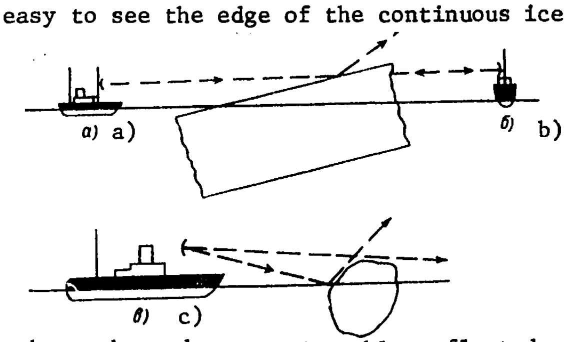

Fig. 6.5. Detection of icebergs by radar. a, c) weakly reflected signals, b) strongly reflected signals.

Floating fields and fragments of fields give strong reflections, which as a result of their movement change their position and form. If the broken ice again freezes together, numerous "flanges" are formed where the ice freezes together. Such ice gives a great many echo signals nonuniformly arranged over the screen.

Large icebergs with almost precipitous sides are usually good objects for detection. Icebergs with gentle sides give a mirror reflection in definite directions, as a result of which the echo signals from them are weak (Fig. 6.5). Such icebergs, even of very considerable extent, are not readily detected. Icebergs which have partially gently sloping, partially steep slopes, may be poor or good objects of detection, depending on the slope facing the radar.

With a calm sea in a fog high and large icebergs are detected at a distance up to 15-20 miles, whereas their fragments, depending on extent, are detected at a distance up to 2 miles.

Waves on the sea exert an influence on the detection of individual hummocked floes on the screen. When there are moderate waves individual large ice fragments give clear echo signals; at a distance up to 1.5 miles it is even possible to differentiate the form of the individual floes. With an intensification of waves above class 4 the images from individual large ice fragments are cluttered with echo signals from waves.

Photographing of PPI. A radar survey can be carried out by photographing of the radar image of ice on the PPI screen. At the time of photographing of the PPI screen a special ice radar survey log is used for entry of the characteristics of the particular ice formation, observed visually, the distance to it, the course angle or bearing to the object of the survey and radar scale. Each of these photographs gives some idea concerning the nature and quantity of ice in a particular region of the sea.

A radar can be used in the mapping of ice conditions in the region of expeditionary ship navigation by the successive photographing of the selected sector of the sea surface.

It must be taken into account that since the radar image on a moving ship constantly changes, one photograph gives only a static picture corresponding to some one point at which the ship is situated at a definite moment in time.

Experience has shown that a necessary and adequate condition for carrying out this work is photography, carried out successively from three position points of the ship. Accordingly, the photographs must have a triple overlap. Depending on the distance between the boundary of the zone of observations and the ship's track it is necessary to select the radar range scale which should be used in carrying out the photographic work. It is recommended that the working surface of the PPI screen be limited to 4/5 of its radius.

The photographic base between successive photographs and the PPI range scale is determined as

$$B_{ph} = 0.5D_{max} \cos CA, \tag{6.18}$$

where D_{max} is the maximum range of visibility at a given radar scale, miles; CA is the course angle at the boundary of the zone along the edge of the PPI screen, °.

The time interval in minutes between two successive photographs can be computed using the expression

$$t = 60B_{ph}/V, \tag{6.19}$$

where V is the ship's speed, knots.

The mosaicing of the photographs is accomplished by the matching of the course plotted on the photograph and on the basis of the distance covered by the ship between the moments of two successive photographings of the object.

Determination of ice continuity. When determining ice continuity K it must be taken into account that in connection with the peculiarities of the image of the echo signals on the PPI screen there is a so-called "apparent" ice continuity K_{app} [106].

The sea surface, covered with ice S_{ice}, within the limits of the area of radar station resolution S_{res}, is determined by the dependence

$$S_{ice} = KS_{res} = K\frac{c\tau}{2}\frac{\pi\varphi}{180}D\sec\theta, \tag{6.20}$$

where c is the velocity of radio wave propagation, m/sec; τ is duration of the radar pulse, sec; φ is the width of the antenna directional diagram in the horizontal plane, °; D is the distance from the ship to the observed object, m; θ is the inclination of the radar beam to the horizon, °.

With a mean cross-section of the floe d_{mean} the apparent continuity within the limits of the area of radar station resolution is

[cp = mean; Л = ice]

$$K_{app} = \frac{S_{л}}{\frac{\pi d_{cp}^2}{4}} = \frac{K c\tau\varphi}{90 d_{cp}^2} D\sec\theta. \tag{6.21}$$

It follows from formula 6.21 that the "apparent" ice continuity K_{app} in the case of real continuity K changes in dependence on pulse duration τ, determining the used radar range scale and the distance D at which ice continuity is determined.

Since with a change in the θ angle in the range 0-20° the sec θ value changes from 1.0 to 1.1; in formula (6.21) we will assume that $\sec\theta \approx 1$, then the actual continuity is determined using the formula

$$K = \frac{K_{app} 90 d_{mean}^2}{c\tau\varphi} \tag{6.22}$$

Figure 6.7 is a graph for determining the actual ice continuity on the basis of the "apparent" continuity with different pulse durations τ and changing distance D. Using formulas (6.20), (6.21) and (6.22), as well as Fig. 6.6, it is possible to draw the following practical conclusions:

It is evident that $K = K_{app}$ only at the distance

$$D_{app} = \frac{90 d_{mean}^2}{c\tau\varphi}. \tag{6.23}$$

Proceeding on this basis, when making radar observations of ice it is necessary to set the movable range circle at the distance $D = D_{app}$ in such a way as to be able to estimate continuity within the limits of the zone where the error in determining K is minimum.

In determining the continuity of finely broken ice it is necessary to use large-scale radar scales (with a pulse duration $\tau = 0.1\mu$ sec).

For large broken ice a sufficiently reliable determination of continuity is possible only with large scales, but with a pulse duration $\tau = 0.5\mu$sec.

A determination of continuity of field fragments requires the use of small scales with a pulse duration $\tau = 0.5\mu$sec.

For fragments of fields with d_{mean} greater than 400 m and ice fields a determination of the actual continuity gives extremely approximate results.

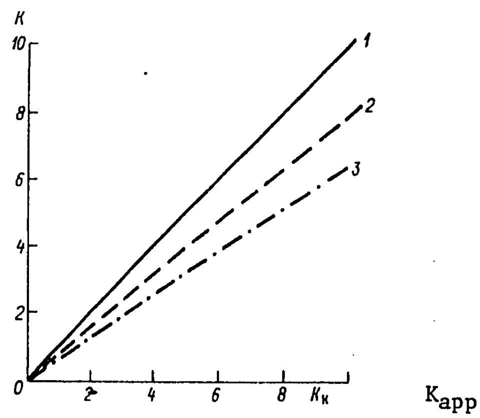

Fig. 6.6. Determination of actual continuity K of ice with d_{mean} = 100 m on the basis of "apparent" continuity K_{app} for different pulse durations and varying distance D. 1) $\tau = 0.12\mu$sec, D = 0.5...1.5 mile; $\tau = 0.5\mu$ sec, D = 3 miles; 2) $\tau = 0.5\mu$sec, D = 4 miles; 3) $\tau = 0.5\mu$ sec, D = 5 miles.

6.4. Use of Shipboard Radar for Measuring Static Characteristics of Waves

At the present time it is possible to define two methods for observing waves by means of a shipboard radar.

Wave observations on PPI screen. In this method the image of waves is photographed on the radar PPI screen. A camera of any model is mounted over the radar screen at a constant focal length by means of a special tube. The exposure time should correspond to the period of one antenna rotation. In this case there will be a full circular scan of the wave-covered sea surface. If the exposure time exceeds the period of radar antenna rotation there will be double exposure on the photograph.

The course line and the azimuth circle must be present on the radar screen for orientation when taking photographs. Observations of the statistical characteristics of waves are made at the times when photographs are taken.

When using this method it is important to know what minimum and maximum lengths of sea waves can be observed, taking into account the technical parameters of the specific shipboard radar station.

Table 6.2

Minimum Lengths of Waves λ_{min} Observed at Different Radar Scales as Function of Distance, m

Distance from ship to wave D, miles	Radar scales, miles			
	0.8	2.5	5.0	15; 30; 50
"Don" radar	δ_D = 25 m	δ_D = 35 m	δ_D = 80 m	δ_D = 150-200 m
0.2	26	36	80	200
0.5	30	39	82	---
0.8	36	--	--	---
1.0	--	48	86	203
1.5	--	60	94	---
2.0	--	74	103	210
2.5	--	89	114	---
3.0	--	--	127	223
4.0	--	--	153	239
5.0	--	--	182	258

Continuation

Distance from ship to wave D, miles	Radar scales, miles			
	1.0	2.0	4.0	8.0
"Okean" radar	δ_D = 20 m	δ_D = 24 m	δ_D = 33 m	δ_D = 150 m
0.2	22	27	40	168
0.5	27	32	45	---
0.8	31	37	49	178
1.0	37	39	53	181
1.5	--	48	62	---
2.0	--	59	72	199
2.5	--	--	82	---
3.0	--	--	90	218
4.0	--	--	112	240
5.0	--	--	---	260

The minimum dimensions of sea waves, which can be determined using a radar, are computed using the formula

$$\delta_l = \sqrt{\delta_D^2 + \alpha_D^2}, \tag{6.24}$$

where δ_l is the minimum distance between two crests of a sea wave at which the pulses reflected from them are still visible separately on the radar screen, m; δ_D is the minimum distance at which the wave crests are visible separately in dependence on resolution in distance l, and the distance D from the radar to the wave, m; α_D is the minimum distance at which two wave crests are still visible separately as a function of resolution in angle α, m.

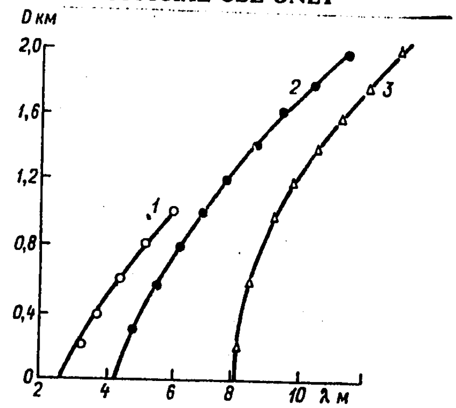

Fig. 6.7. Minimum dimensions of waves observed with LPr radar. 1) scale I -- 1 km; 2) scale II -- 2 km; 3) scale III -- 8 km.

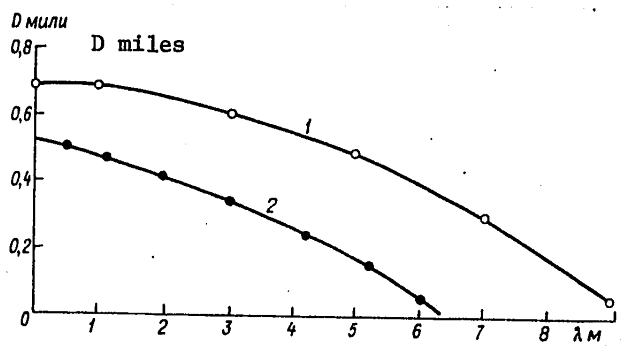

Fig. 6.8. Dependence between wavelength λ and distance D. 1) "Don" radar, scale 0.8 mile; 2) LPr radar, scale 0.54 mile.

Table 6.3

Maximum Wavelengths λ_{max} as Function of Distance D Between Radar Set and Wave Crest

D miles	"Don" scale 0.8 mile	"Okean" scale 1.0 mile	LPr scale 0.54 mile	D miles	"Don" scale 0.8 mile	"Okean" scale 1.0 mile	LPr scale 0.54 mile
0.08	--	--	600	0.48	480	815	105
0.12	890	1150	560	0.50	440	800	65
0.24	780	1050	420	0.60	260	690	--
0.36	630	912	270	0.72	70	505	--

Formula (6.24) is used in computing the minimum wave dimensions λ_{min} which it is possible to observe for different scales of "Don" and "Okean" radars (Table 6.2). Computations indicate that the minimum wave lengths which it is possible to observe using these radars increase with increasing distance of the waves from the radar and with transition from large to smaller scales.

Hence the practical conclusion can be drawn that in observations of sea waves using the "Don" and "Okean" radars it is necessary to use large scales 0.8, 1.0, 2.0 and 2.5 miles, and also make observations near the ship.

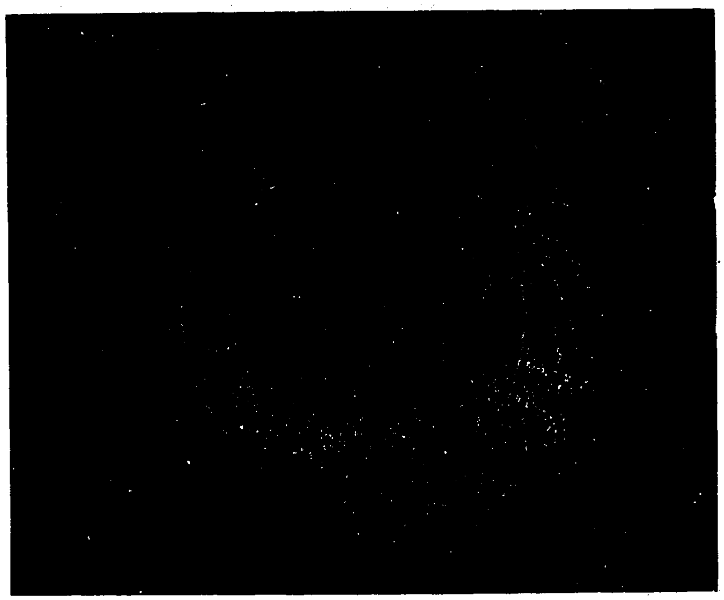

Fig. 6.9. Photograph of radar image of wave-covered sea surface, n = 4 m, λ =60 m.

The use of the LPr (pilot's guidance) radar for determining the characteristics of sea waves (Fig. 6.7) is highly promising. Its high resolution, about 0.3° in angle, and with a range of 5-6 m, makes it possible to observe the minimum dimensions of waves with a length of 5-8 m, that is, virtually from the moment of their development in the sea.

In computations of the maximum wave lengths which can be observed at different scales of the shipboard radar it is necessary to take into account the circumstance that the height of the crest along the wave front is different and accordingly, the intensity of the pulses reflected from individual parts of the crest is not the same. Therefore, in order to obtain an objective picture it is necessary to trace a wave along the entire length of the crest on the radar screen.

In order to compute the maximum length of a wave whose crest is completely visible on the radar screen the distance D and the wavelength λ are expressed in fractions of the radius R of the radar screen. Then the dependence (Fig. 6.8) between these parameters is determined by an equation of the type:

$$\lambda^2 + 0{,}49D - 0{,}42 = 0. \qquad (6.25)$$

Equation (6.25) is used in computing the maximum lengths of the waves which can be observed at the greatest scales of the "Don," "Okean" and LPr radars as a function of the distance between the radar and the wave crest (Table 6.3).

Since even in the open sea the wave lengths rarely exceed 200 m, on the basis of computations it can be concluded that using the "Don," "Okean" and LPr scales it is possible to observe the largest waves along the entire extent of the crest. However, it must be remembered that with $D > 0.75$ R there can be cases when the the largest waves cannot be registered along the entire length of the crest. In order to observe such waves it is necessary to adhere to the distance $D < 0.75$ R.

Thus, a mandatory condition for use of the two-dimensional method for observing the statistical characteristics of the waves by a shipboard radar is the separate representation of pulses on the screen from two adjacent wave crests. It is also desirable to trace the reflected pulses along the entire length of the wave crest. The interpretation of the radar photographs of waves and the determination of the statistical characteristics of the waves is accomplished in the following way.

First the photograph is used in determining the general direction of wave propagation on the basis of the form and radar screen position of the so-called oval of wave reflections. Such an oval usually has an asymmetric position relative to the center of the radar screen and its more elongated part is situated on the windward side (Fig. 6.9).

The direction of the waves is determined along a line which divides the elongated part of the "oval of wave reflections" in half. The accuracy in determining the direction of waves is assumed to be ±5°.

The wave length is determined by measuring the distance between the wave crests directly on the radar screen photograph with the image scale taken into account. For this purpose segments of straight lines are drawn; these are perpendicular to the direction of wave propagation, through the brightest reflected pulses. The distances between the segments is measured with an accuracy to 0.2 mm on the basis of the zones between the scale range circles; then the distances are averaged by zones and with allowance for the image scale are converted to wave lengths in meters.

Fig. 6.10. Echo signals from waves on radar linear sweep screen.

The mean values of the wave lengths, obtained on the basis of data from a radar survey of sea waves, can be used in computing the mean period of the waves using the formulas of spectral theory [24]:

a) for unsteady waves

$$\bar{\tau}=\sqrt{\frac{\bar{\lambda}}{1,04}}; \qquad (6.26)$$

b) for well-developed waves

$$\tau=\sqrt{\frac{\bar{\lambda}}{1,40}}; \qquad (6.27)$$

c) for swell

$$\bar{\tau}=\sqrt{\frac{\bar{\lambda}}{1,56}}. \qquad (6.28)$$

Determination of statistical characteristics of waves on radar linear sweep screen. In this method the echo signals reflected from the waves are studied on the linear sweep screen of the radar (Fig. 6.10).

It is assumed that the distance between the pulses on the scale corresponds to the length of a sea wave. It is also possible to measure the velocity of propagation of waves which move along the marker sweep in the course of 10-15 sec.

A modification of this method has been developed in the Soviet Union. In this method it is not the shape of the reflected signal which is studied on the linear sweep, but its energy, frequency and spectral width.

The spectral width of the reflected signal is related to the parameters of sea waves, as pointed out by N. M. Fuks [122], by the expression

$$\Delta f=\frac{\sqrt{2}\,\bar{h}}{g\bar{\tau}}, \qquad (6.29)$$

where Δf is the spectral width of the reflected signal, Hz; g is the acceleration of free falling, m/sec^2; $\bar{h}$ is the mean square height of sea waves, m; τ is the mean period of sea waves, sec.

It can be seen from formula 6.29 that the spectral width Δf of a reflected signal increases with an increase in the height and frequency of sea waves.

The spectral width of the reflected signal is measured using a special attachment connected at the input of the radar videochannel. The attachment indicator makes it possible to make observations of change in voltage, which is proportional to the spectral width of the reflected signal.

6.5. Radar Method for Determining Currents

Makeup and sequence of observations of currents using radar beacons. The range of observations includes: 1) determination of ship's position by reckoning or observation; 2) registry of beacon position at a particular moment in time; 3) observation of wind and waves.

The ship's position is determined by the usual procedures employed in navigation. In each specific case the procedure selected is that which gives the maximum accuracy in determination.

Individual positions of the radar beacons are registered on the PPI scales with subsequent plotting on work sheets or a map. The bearing is read from the circular radar screen with an accuracy to 0.5° and distance is read from the movable range circle with an accuracy to 0.01 mile. At the same time the ship's course is read from the PPI scale.

The time intervals between successive readings on the radar scales are selected taking into account the velocity of the registered current and the employed radar range scale. The minimum time interval between two readings must be such that two successive pulses from the beacons will be visible separately. It is evident that the time intervals are considerably reduced with an increase in current velocity and increase with transition from one range scale to another.

In addition to the readings on the radar scales during observations of movement of the beacons each half-hour a determination is made of the wind velocity and direction, as well as the direction and height of waves. All the data from radar observation of currents are plotted in a special log "Radar Observations of Currents."

The following work procedures have been developed for determining currents by the radar method from a ship: 1) determination of current elements using a single radar beacon and 2) determination of current elements using several radar beacons.

The details of the method for determining currents by different procedures have been set forth in [50, 103].

Determination of vector of currents using data obtained by radar observation of movement of beacon. If observations of radar beacons are made under conditions of considerable wind drift (relationship $w/u > 10\%$) the total drift of the beacon is v_{drift}.

The vector of total drift v_{drift} during the observation period is obtained in the following way. The individual positions of the radar beacon are plotted on the work sheet or map on the basis of the distance and direction at the moments of their determination. By connecting the initial and final points it is possible to obtain the total drift vector during the time of observation.

A number of procedures have been proposed for discriminating the current vector from the total drift vector [30, 77]. However, in order to solve the problem of discriminating the current vector by the method proposed by these authors it is necessary to know the coefficient of beacon drift.

The following procedure can be used successfully in the mass processing of data from radar observations of currents.

It follows from expression (6.8) that $u_{cur} = v_{drift} - v_{drift}'$ [here v_{drift} is the velocity of angular drift, v_{drift}' is the velocity of general drift]. The wind drift vector can be determined from expression (6.9). In this case the direction of wind drift is assumed to coincide with the wind direction ($\alpha_{drift} = \alpha_w$). By finding the values v_{drift}' and α_{drift} it is possible to determine the current velocity u_{cur} by use of a vector circle or using the "Tables for Processing Observations of Currents at Sea" [79].

Photosurvey of radar images of beacons for determining currents. Observations of surface currents with use of radar beacons can be made by the method of a photosurvey on the radar screen.

The essence of such observations is as follows. Individual positions of the radar beacon moving in the current are registered by a photosurvey of the radar screen at definite time intervals on a single frame, which makes it possible to obtain the pattern of successive movement.

In order to obtain the vectors of the surface current on the photograph, and not the vector of total angular drift, it is necessary to carry out detailed observations using beacons for which the ratio of the above- and below-water parts is not less than 1:15.

Only under such conditions will the wind drift of the radar beacons be absent or not exceed 10% of the angular drift of the beacon in the current.

The size of the image on the radar screen is also dependent on what radar range scale is used in making the observations. However, the choice of the radar range scale is dependent on the duration of observations of movement of the radar beacons and on the velocity of their movement. It is evident that the range scale should be selected in such a way that the length of the hourly current vector does not exceed the limits of the radar screen.

Table 6.4

Range Scales of "Don" Radar Used in a Photosurvey as Function of Observed Current Velocities

Current velocity, knots	0.5	1.0	2.0	3.0	4.0	5.0
Scale	I	I	II	II	II	III

For selecting the scales it is customary to use special tables (Table 6.4).

When photographing the radar screen it is necessary to predetermine the minimum time intervals between successive exposures on one and the same frame. These time intervals are determined taking into account the minimum resolution with respect to bearing and distance to the edge of the radar screen for the corresponding scales. The time intervals between successive exposures on one and the same frame must be such that on the photographs it is easy to see individual pulses from radar beacons. These time intervals are obviously dependent on the scale of the photosurvey and the current velocity (Table 6.5).

The duration of exposure for each successive photograph is usually 1-2 revolutions of the radar antenna (about 4-8 sec).

In order to obtain clearer images of reflected pulses on a single frame it is necessary to take the first photograph of the radar screen with range circles and a course scale.

Table 6.5

Minimum Time Intervals Between Individual Photographs on Single Frame as Function of Current Velocity and Photosurvey Scales on Screens of "Don" Radar, minutes

Current velocity, knots	Radar scale			
	I	II	III	IV
0.5	6	20	60	90
1.0	3	10	30	45
2.0	2	5	15	20
3.0	1	3	10	15
4.0	-	3	6	10

Subsequent photographs on the same frame are made through black paper with a small aperture (1-2 mm) which is moved under the necessary reflected pulse from the radar beacon. In this case the radar conditions are quite clearly depicted on the screen.

If such a radar survey is made at many points over some water surface and then such photographs are mounted, it is possible to obtain a map of surface currents in the region of interest.

The mounting of individual photographs is accomplished by matching one and the same reference points and positions of the ship on successive frames, which must be accomplished with some overlap. The central points of the survey and the time interval between exposures are marked on the next frame for accomplishing the overlapping of the photographs; this is done in advance, in dependence on the map scale and the scale of the radar survey.

Accuracy in determining current and observation error. The accuracy in determining a current when using radar beacons is dependent on the scale of the radar and on what distance the observations are made from the ship.

For example, the "Don" radar ensures a determination of direction to the object with an accuracy to 1° and a determination of distance on scale I of 0.20 cab, on scale II -- 0.35 cab and on scale III -- 1.5 cab.

The probable error in determining current velocity is determined by the expression

$$\Delta u = \frac{2}{3} \frac{(r_1 + r_2)}{t}, \tag{6.30}$$

where Δu is the probable error in computing current velocity, knots; r_1 and r_2 are the radii of the circle of error in the first and second determinations of the position of radar beacons, miles; t is observation time, hours.

The positions of the radar beacons are registered by the radar with respect to bearing and distance. Accordingly, the radius r of the circle of error can be determined using the formula

$$r = \sqrt{\left(\frac{D\varepsilon}{60}\right)^2 + \Delta D^2}, \qquad (6.31)$$

where D is the distance to the radar beacon, miles; ΔD is the error in the measured distance, miles; ε is the error in the true bearing, °.

If in the first and second measurements the position of the radar beacon is determined by the distances D_1 and D_2 respectively, the error in determining current velocity is determined:

$$\Delta u = \frac{2t-1}{3}\sqrt{\left(\frac{\varepsilon}{60}\right)^2 (D_1 + D_2)^2 + 2\Delta D^2}. \qquad (6.32)$$

Using this formula it is possible to determine the probable error in determining current velocity when observing radar beacons.

For example, for the "Don" radar the error in determining current velocity using scale I does not exceed 0.07 knot, on scale II -- 0.1 knot with a distance from the ship up to 2.5 miles and with a distance from the ship between 2.5 and 5 miles is not greater than 0.2 knot.

An important practical conclusion can therefore be drawn: it is advantageous to make observations of currents near the ship. This also governs the duration of observations: insofar as possible it must be reduced to the minimum time interval during which it is possible to obtain reliable information concerning the current vector.

AUTOMATION OF COLLECTION OF OCEANOGRAPHIC DATA AND MATHEMATICAL SUPPORT FOR DATA PROCESSING ON ELECTRONIC COMPUTERS

CHAPTER 7. SIGMA-S SHIPBOARD INFORMATION HYDROMETEOROLOGICAL AUTOMATED SYSTEM (SUDOVAYA INFORMATSIONNAYA GIROMETEOROLOGICHESKAYA AVTOMATIZIROVANNAYA SISTEMA)

7.1. Purpose and General Principles of Structuring of System for Scientific Research Ships

The key role in oceanographic investigations in the ice-free polar regions is played by the scientific research fleet, the scales of whose use during recent years have increased appreciably. The need for increasing the efficiency of use of ships in the solution of scientific problems of polar hydrometeorology and a sharp increase in the volumes of collected primary information have advanced new requirements on the methods for carrying out experiments and the instrumental base of investigations; this has led to the need for automation of the collection and processing of data from shipboard observations. It has been necessary to create an automated information measurement system for scientific research ships as a local link in the branch automated hydrometeorological system [116].

In the creation of an automated system it is possible to achieve a reduction in the productive cycle for the collection of hydrometeorological information, an increase in the productivity of labor and efficiency of scientific research, as well as the possibility for obtaining qualitatively new data on the natural processes transpiring in the hydrosphere and atmosphere.

The development of the system was proceeded by an analysis of available experience in the construction and organization of shipboard automated systems aboard the scientific research ships "Akademik Vernadskiy" and "Mikhail Lomonosov" and also aboard ships of the United States, Great Britain, Canada and Norway. A review of these systems is evidence of the diversity of principles of their design (in the structure of the systems and makeup of the measurement and computer apparatus), which is a reflection of the differences in the level of technical apparatus for collection of information. As common features in the organizational structure of the systems one can mention that they contain measurement complexes linked in informational and technical respects with the electronic computer of the shipboard computation center (SCC) either directly through communication channels or through an intermediate buffer unit. The SCC electronic computer is linked to an on-shore computation center (OCC).
Research ships carry different types of computers -- from intermediate-class electronic computers to minicomputers.

In the case of centralized data processing the SCC has one intermediate-class electronic computer. In a decentralized variant there are several computers servicing self-contained groups of equipment. The systems have a hierarchical structure [14].

It must be noted that there are two trends in the creation of automated systems. One of these involves the creation of narrowly specialized systems for studying microscale phenomena in the ocean (turbulence, fine structure, etc.), similar to the systems of the Marine Hydrophysical Institute, Ukrainian Academy of Sciences. Another trend involves the development of systems oriented to solution of a broad range of research, so-called standard problems. Such systems function, for example, aboard the scientific research ships "Discovery" and "Oceanographer" (NOAA, United States), belonging to the multipurpose or universal class of ships [9, 14, 19]. But it can be noted that such a classification has an extremely arbitrary character.

Worthy of note is the experience in creating self-contained measurement links with minicomputers, in general forming an automated system for data collection and processing, aboard the scientific research ship "Atlantic II." A distinguishing characteristic of this system is that it is at two levels and is decentralized [132]. With respect to organizational scheme, the experience in automating observations aboard NOAA ships in the United States is useful; this indicates the desirability of creating shipboard automated systems with their division into classes in dependence on the displacement of the vessels [130].

The application of the principles for creating a shipboard automated system is determined by the specific characteristics of the investigated object, by the level of technical outfitting (makeup of the measurement complexes, role of computer equipment in the process of processing, accumulation, exchange and use of collected information) and is dependent on the technological scheme of the process of experimental observations and further movement of information. It is desirable that the process as a whole be automated, not individual technological operations or types of investigations [19, 70].

Within the framework of the problem of automation of standard shipboard hydrometeorological observations the technological process of collection, checking, processing, accumulation (storage) and dissemination (exchange) of data can be arbitrarily divided into the following stages.

1. Collection of primary data. There is automatic measurement of parameters of the medium, registry of the results of measurements (in digital form -- on a technical carrier and digital print-out units; in graphic form -- on visual display units; in analog form -- using curve plotters and automatic recorders [14, 19]). In this stage the initial information is obtained, it is prepared for input into shipboard computers, a visual critical checking of data is carried out, routine conclusions are drawn concerning the course of experimental investigations.

2. Input of results of observations on a technical carrier into the electronic computer of a SCC for checking the quality of information, partial computer processing and conversion of data in accordance with the computation model.

3. Output of data from the SCC computers, registry of the results of computations in representative form for carrying out a speedy analysis of the results of investigations, registry of the true values of the parameters on a technical carrier for exchange, dissemination and incorporation in the data bank. In this stage there is also assurance of control of the experiment and active intervention in methods and apparatus used in measurements.

4. The transmission of data on a technical carrier to the SCC of another scientific research ship or OCC [14, 19, 53, 55].

5. Input of data on a technical carrier to the electronic computer of the OCC, full mathematical processing of the results of observations with use of information from the data retrieval system (data bank); registry of initial data on a technical carrier.

In this stage provision is made for an objective analysis and generalization of the results of experimental investigations; documenting of data in graphic form and long-term data storage; exchange and dissemination of data on a computer carrier; coordination, planning and optimization of control of a field experiment.

The cited generalized description of the technology of collection, checking, processing, dissemination and storage of hydrometeorological data for scientific research ships shows that for the entire process of movement of information from the moment of its receipt to the time of its use there is a characteristic hierarchical succession and sequence. The initial stage in the scheme is a measurement process using shipboard apparatus and the final stage is the process of complete analysis and storage of data at the OCC in the presence of feedbacks to the initial levels, whose intensity increases with movement of information to the final stage. The existence of feedbacks makes the technological process of collection and processing of information closed, in definite stages giving it the character of an interaction. It is evident that the level of technological collection, conversion and use of the results of the observations for a specific type of scientific research vessel is determined by the volume and degree of complexity of the problems to be solved [19, 53, 55].

The organized bringing together of the sources for the collection of information with conversion and computation facilities of the research ship in some definite way at some stage in implementation of the technological process leads to the formation of a data measurement system (DMS). The joining together and interaction of the measurement and computation links of the system are attained by a unification of the digital representation of information at the output, equivalence of the formats of registry of data on a computer carrier, as well as the compatability of the technical apparatus used in the collection and processing of data.

It is possible to automate the collection and processing of scientific information on ships by three methods [19].

1. By outfitting research ships with electronic computers and measurement complexes (MC) in which the registry of data is accomplished on a technical carrier in a computer code. The data are fed into the electronic computer from a technical carrier through the computer input unit (IU).

2. The measurement complex is joined to the electronic computer with the addition of a central control unit and a standard time unit to the system. In this case due to the diversity of the output characteristics of the measurement converters and the apparatus for linking the measurement complex and the computer it is necessary to use matching devices for tie-in of the measurement complex, which leads to a complexity of the system as a whole.

3. By developing standardized measurement and information apparatus for the system. By joining all the measurement complexes with the shipboard electronic computer, and if necessary, with one another. The requirement of a unified form of data representation is retained. The system also includes an electronic computer with which the measurement complexes are joined by the so-called KIOSK complex (KIOSK -- complex for data exchange of shipboard complexes), an apparatus for buffer storage of data.

Taking into account the necessity for the forming of complex data masses from diversified hydrometeorological information and compression of data, in the apparatus for the linking of measurement instruments and the processor provision is made for a complex of technical devices for the collection and processing of hydrometeorological information.

The multisided processing of information and the preparation of results for documentation are accomplished in an electronic computer in the shipboard computation center.

The third method for creating a system is the most promising. Without question, in the future the problem will arise of a feedback between the electronic computer and measurement complexes due to the need for automating the processes of regulation of regimes of the measuring and recording apparatus and the creation of computer methods for monitoring observations in the ocean. However, with the existing level of development of technical devices the development of the KIOSK complex was a complex task, technically difficult to accomplish. Nevertheless, the practical application of the principles embodied in the third method is extremely useful.

As a result of transformation of the first and second methods for system development it was decided to create an aggregated built-up system with a variable make-up of the equipment which is determined by the functions performed by the system [14, 16].

The SIGMA-S (Fig 7.1) includes a subsystem for the collection and storage of data (measurement complexes, recorders for one or two levels of representation of data); a subsystem for standard processing on an electronic computer in the shipboard computation center ensuring the processing, checking and documentation of information; a subsystem for the analysis, storage and regulation of data by means of which the highest level of processing, scientific analysis, incorporation of data in the information system and monitoring of research is attained in the computers at the on-shore computation center. The subsystems are functionally interrelated to one another.

The algorithm for operation of each automated complex was prepared in such a way that without precluding the autonomous operation of the measurement instruments it is possible to join all the automated complexes together in a system [14, 15]. The use of a universal computer with an adequate storage unit and external memory having a high speed at the level 10^4-10^5 operations per second in the shipboard computation center makes possible the routine reworking of the collected data. The KTS ASOGI complex ensures a linking of the peripheral data collection units with the electronic computers in the shipboard and on-shore computation centers.

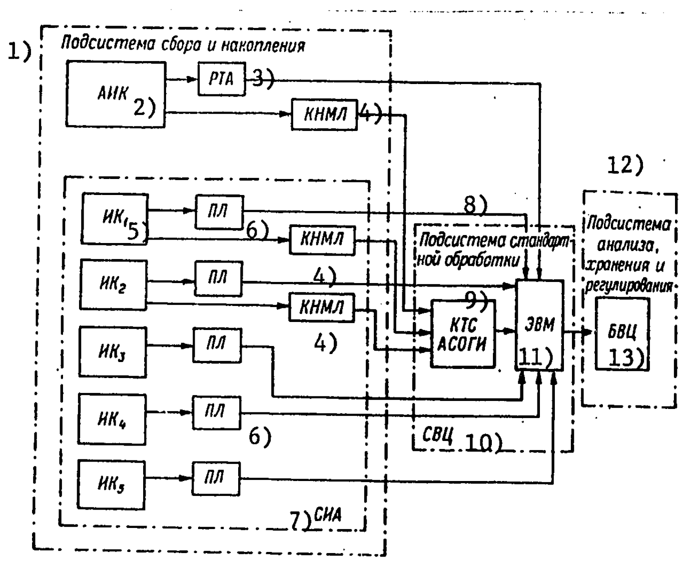

Fig. 7.1. Structural-functional diagram of SIGMA-S shipboard automated system.

KEY:

1) Collection and storage subsystem
2) Autonomous measurement complex
3) Reel telegraphic apparatus
4) Cassette-type magnetic tape storage unit
5) Measurement complexes
6) Tape puncher
7) Shipboard measurement apparatus
8) Standard processing subsystem
9) KTS ASOGI
10) Shipboard computation center
11) Electronic computer
12) Subsystem for analysis, storage and regulation
13) On-shore computation center

In oceanographic investigations the specialization of research ships is based on their scientific purpose, displacement, degree of outfitting with measurement and computation apparatus, physiographic characteristics of the regions investigated, methods for the organization of in situ experiments, etc. As a result, the realization of the principles for development of an information-measurement system for a specific ship can be limited to some definite stage in the technological scheme ensuring the necessary autonomy of a particular equipment group and accomplishment of the actual volume of data processing.

Thus, in connection with the specifics of use of scientific research ships it is desirable to introduce a classification of information-measurement systems, dividing them into three ranks corresponding to three relatively independent stages in the technological scheme for the collection and processing of data.

A shipboard information-measurement system of rank III is intended for outfitting research ships with a displacement up to 800-1000 tons with limited scientific tasks and ships carrying out research work en route (for example, ships of the USSR Maritime Fleet, USSR Ministry of the Fishing Industry). The information-measurement system consists of one or more automated measurement complexes; it ensures the collection and registry of data on the technical carrier of a standard storage unit and informational compatibility with the on-shore computation center. The combining of automated measurement complexes is accomplished for the purpose of solving the task in the first stage of the technological scheme. Data are processed in a minimum volume, for which a rank-III system includes a program-controlled minicomputer.

A rank-II shipboard information-measurement system is intended for outfitting research ships with a displacement from approximately 1000 to 4000 tons. It includes the apparatus of a rank-III system and a small electronic computer. Rank-II information-measurement systems ensure a compatability of the shipboard electronic computer with the computation devices of rank-III information-measurement systems and the on-shore computation center, the implementation of the first and second stages in the technological scheme for the collection and processing of data.

A rank-I shipboard information-measurement system is intended for outfitting research ships with a displacement of 5000 tons or more, which can be categorized as multipurpose, in which the volume of data is most significant. It includes rank-III apparatus and an intermediate-class electronic computer. A rank-I system ensures compatibility of a shipboard computer with the computation devices in rank-III and rank-II information-measurement systems and the on-shore computation center and can perform the functions of the first, second, third and fourth stages in the technological scheme [14].

The problem of building-up individual groups of equipment in relation to a ranking system has been solved most completely for actinometric systems and has been examined in [16].

7.2. Makeup and Structure of System and Features of Its Functioning

The SIGMA-S incorporates the totality of technical measurement and computation devices joined together for common purposes and by a common functioning algorithm and intended for the automation of the collection of shipboard hydrometeorological information, checking, processing and its representation in a form convenient for further use [14].

Taking into account the purpose of the system, the measurement apparatus is combined into independent complexes automating the process of standard measurements and storing data in the following scientific fields: meteorology, actinometry, temperature-wind sounding of the atmosphere and oceanography. The most rational set of complexes has been developed and is the basis of a subsystem for the collection and storage of hydrometeorological information, to wit:

1) marine automatic recording station (MARS -- morskaya avtomaticheskaya registriruyushchaya stantsiya);
2) automatic shipboard actinometric system (ASAS -- avtomaticheskaya sudovaya aktinometricheskaya sistema);
3) unit for the readout and punching of temperature-wind sounding data (in the RKZ-"Meteor" system) "OKA-3";
4) wave measurement complex;

5) oceanographic bathometer-sonde complex;
6) autonomous digital current meter (ATsIT -- avtonomnyy tsifrovoy izmeritel' techeniy);
7) submergible buoy station (PBS -- pritaplivayemaya buykovaya stantsiya) with hydroacoustic signaling and search.

The first five complexes form a shipboard measurement group of apparatus. The ATsIT complex, together with the submergible buoy station, forms an autonomous measurement group of apparatus. Assurance of an informational compatability of individual links in the measurement subsystem is attained by the development of a single level for the representation of information at the output of the automated complexes. The means adopted for this purpose is an intermediate data technical carrier -- the punch tape. This technical carrier is a linkup between the measurement complexes and the main computation system. The mathematical support of the measurement complexes for the processing of the arriving data in an electronic computer is designed for the use of a punched tape.

Storage in the form of a magnetic tape in a minicassette has been selected as the standard intermediate means for data storage. The informational interaction of different technical means or processors in the common system at the necessary time scale in this case is attained in a second, higher level -- the level of minicassette data storage (KNML) -- through a special unit for the reregistry of the contents of the minicassette onto a magnetic tape compatible with the electronic computer at the shipboard computation center. The use of this technical carrier makes it possible to optimize the joint processing and analysis of the results of observations made at different levels and by different elements of the system.

Some measurement complexes of the system, such as the bathometer-sonde and the ATsIT, include the cassette storage on magnetic tape feature. Encouraging results have been obtained with the use of the minicassette storage unit for the collection and storage of meteorological and actinometric information.

The dominating computation link in the system is the processor, whose type is determined by the rank of the system. For rank-I systems the principal computers are now the "Minsk-32" and YeS-1020 computers, in whose regime a mathematical support of the measurement complexes has been created.

For solving the problem of a logical organization of joint work, the computation system of different units at a higher level than the level of the punched tape of the shipboard computation center includes a complex of technical devices for the collection and processing of hydrometeorological information -- the KTS ASOGI (kompleks tekhnicheskikh sredstv apparatura sbora i obrabotki gidrometeorologicheskoy informatsii). The principal purpose of the complex is providing a linking of the peripheral devices for the collection of information with the electronic computer of the shipboard or on-shore computation center.

Thus, the subsystem for the processing of data in the shipboard SIGMA-S automated system structurally consists of a universal electronic computer and the KTS ASOGI. These two elements, with the matching of some functions, and at the same time with adherence to a definite hierarchy in the organization of the computation process, solve the problem of checking, processing, documentation, storage, dissemination of hydrometeorological information and its storage in a memory bank.

The final link in the setup for the collection and use of information in the SIGMA-S system is the on-shore computation center. The technical outfitting of the on-shore computation center includes a "Minsk-32" electronic computer and a considerable array of servicing devices. A data bank is an integral part of the on-shore computation center; it has the elements of a data retrieval system. The task of the on-shore computation center in the subsystem for the analysis, storage and regulation of data is the collection, total processing and generalization of the results of observations made by different research ships in the waters of the Arctic and Antarctic Oceans. The collected information is the basis for carrying out an objective analysis of oceanic and atmospheric processes and fields for the purpose of obtaining valid ideas concerning the spatial-temporal variability of natural processes and phenomena. A scientific analysis is made drawing upon information from the data bank. An important task of the on-shore computation center is the coordination of investigations and the formulation of recommendations on a scientifically valid organization and implementation of experiments in specific regions of the ocean [15].

The long-term storage of the collected information completes the technological process of collecting and using the results of experimental investigations.

7.3. Complex of Technical Devices for Collection and Processing of Hydrometeorological Information (KTS ASOGI)

The complex of technical devices for the collection and processing of hydrometeorological information (KTS ASOGI -- kompleks tekhnicheskikh sredstv apparatury sbora i obrabotki gidrometeorologicheskoy informatsii) as a structural part of the SIGMA-S system is intended for the organization of joint work and the linkup of the measurement systems of the shipboard information-measurement system with the computation facilities at the shipboard computation center and at the on-shore computation center [71, 108].

The KTS ASOGI (Fig. 7.2) can be employed in shipboard information-measurement systems of all ranks for solution of the following problems:
-- automated collection and registry of hydrometeorological information arriving from shipboard measurement complexes on the magnetic tape of a cassette storage element;
-- primary processing of observational data;
-- output of the results of primary processing to the magnetic tape of a cassette storage element, digital printout unit and digital indicator based on a cathode ray tube;
-- reregistry of data from the magnetic tape of a cassette storage element onto a compatible tape 12.7 mm wide for subsequent processing of the data on electronic computers of the "Minsk-32" and YeS types. The possibilities of the KTS ASOGI make possible its use as the basic link in the collection and primary processing of information at hydrometeorological stations, observatories and observation platforms not supplied with an electronic computer [14].

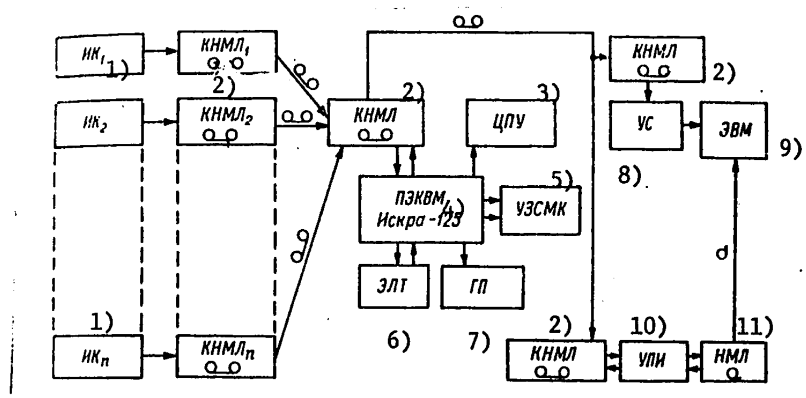

Fig. 7.2. Generalized block diagram of complex of technical devices for collection and processing of hydrometeorological information (KTS ASOGI).

KEY:

1) Measurement complexes
2) Cassette elements for storage on magnetic tape
3) Printout unit
4) PEKVM "Iskra-125"
5) UZSMK
6) Cathode-ray tube
7) Curve plotter
8) Linkup
9) Electronic computer
10) Unit for reregistry of data
11) Storage on magnetic tape

The complex is aggregated and in the above-mentioned makeup is designated as the "Iskra-1251" -- computer complex for the processing of hydrometeorological information. With a change in makeup -- in the complex the reregistry of data unit can be replaced by a conversion block and a unit for the output of graphic information (curve plotter) -- the complex is designated the "Iskra-1252" -- computer complex for the routine and continuous solution of scientific-technical and engineering problems. The possibilities of the complex are increased by including in its makeup units for linkup with analog sensors and a cathode-ray tube, an external storage unit, enhancing the memory volume, devices for direct input of data into the electronic computer, etc.

The informational linkup of the shipboard measurement complexes with the KTS ASOGI is accomplished by means of the KNML elements. The procedure for processing the results of observations is described in the generalized structural diagram of the algorithm for the processing of hydrometeorological information.

The individual independent algorithm blocks have the following content:
1) registry of information from the shipboard measurement complex in the KNML;
2) programmed control of the accumulated information;
3) primary processing and scaling of readings of the primary converters into real physical values with introduction of the necessary calibration coefficients;
4) display and registry of the results of processing in a decimal form on rolled tape of the printout unit or on the screen of a cathode-ray tube for checking and drawing operational conclusions and in the KNML for data storage and exchange. In the latter case, if necessary the data are reorganized into the necessary sequence;
5) reregistry of the KNML data masses on a magnetic tape compatible with the electronic computers in the shipboard computation center or at the on-shore computation center (using the data reregistry unit) for full mathematical processing, statistical analysis, documentation and storage.

The KTS ASOGI processor is a program-controllable electronic keyboard computer (PEKVM -- programmoupravlyayemaya elektronnaya klavishnaya vychislitel'naya mashina) "Iskra-125," which is intended for making computations in a regime of manual and programmed control of different characteristics of hydrometeorological series introduced from the KNML and keyboard, the output of the results to the KNML and other servicing devices [108].

The makeup and technical specifications of the KTS ASOGI make it possible to carry out the collection and processing of data by several methods.

1. The collection and storage of data from the measurement complexes is accomplished in the KNML. The processing of data follows the replacement of the cassettes. Such a scheme can be employed if data processing is carried out with a time shift. In this way it is possible to attain a maximum economic effect because a single PEKVM can be used for processing information from several measurement complexes.

2. The measurement complex is connected directly to the PEKVM. The collection and processing of data are carried out simultaneously. It is desirable that the scheme be used with the operational use of the collected information.

3. After primary processing the data can be stored in the minicassettes of one of the KNML constituting part of the PEKVM. With subsequent processing of data on a more powerful electronic computer the information through the data reregistry unit is reregistered from the KNML tapes onto a 12.7-mm magnetic tape.

The KTS ASOGI complex makes it possible to unify the systems for data registry in automated complexes by means of employing a single interface and employing standard storage of data on magnetic tape in a minicassette.

The incorporation of the complex in the shipboard automated system ensures an increase in the informational level of the system from an intermediate technical carrier, a punched tape, to a magnetic tape, which considerably increases the possibilities of storage of great masses of data and long series, as well as their reproduction.

The ATsIT autonomous measurement system and the bathometer-sonde complex include a KNML component and the processing of oceanographic information can be accomplished using the "Iskra-125" PEKVM.

On the 18th voyage of the scientific research ship "Professor Zubov" (December 1975-February 1976) and the SP-22 (1976) under real conditions for carrying out experimental investigations it was possible to obtain positive results with the linkup of the KTS ASOGI with analog actinometric and meteorological primary converters.

Thus, the high technical qualities and broad functional possibilities characteristic of the KTS ASOGI ensure that the complex will play the role of a local computation element of the shipboard automated system, including for research ships not outfitted with an electronic computer.

7.4. Mathematical Support of System

The mathematical support of the SIGMA-S system is determined as some combination of specially organized and functionally related programmed computer elements used in the processing and converting of input hydrometeorological information, in accordance with the special purpose of the system.

In its most general representation the mathematical support consists of universal elements and special programs. The universal programmed means ensure an effective use of a processor and peripheral servicing units. The special programs are intended for computer processing of the measurement results obtained by means of the automated complexes [15].

The universal elements are dependent on the parameters of the processor (speed, volume of internal and external memory), its architecture, which in turn are determined by the class of electronic computer. For example, the "Minsk-22" computer has an adequately diversified general mathematical support for control of operation of the input and output units, the organization of interaction of different technical components and the checking of the correctness of functioning of the equipment by use of test programs, translation of programs from algorithmic languages, solution of different standard problems, etc. At the same time, the systemic servicing of the "Minsk-22" computer, intended for the formulation of programs from individual modules (reregistry of information from some carriers to others, etc.), is inadequately perfect.

The known advantages of the "Minsk-32" and YeS computers make it possible to create a mathematical support with a better-developed automation level.

Adhering to the materials in [15], we will describe the mathematical support for a system based on the "Minsk-32" electronic computer.

In its general part the support includes:
1) an operational system -- the totality of programmed elements controlling the solution of problems in the electronic computer in different regimes (multiprogram, with separation of time, compatibility, etc.).

The central part of this system is a program-dispatcher; it includes an archives of standard programs in the load language;
2) an automated control system -- computer tests and a system for the linkup of the computer with automated data measurement complexes;
3) a general programming system -- wide-purpose languages, translators, special archives of standard programs for translators and program debuggers.

The special part of the mathematical support includes:
-- the AIS -- automated information system;
-- the SPU -- programmed control system;
-- the SKZ -- problem complex system.

The AIS is a complex of systemic programs intended for the collection, storage, revision, retrieval, processing and output of data. The shipboard AIS is factographic, that is, it performs the storage of data on the characteristics of hydrometeorological objects. The AIS includes an automated data retrieval system (AIPS -- avtomatizirovannaya informatsionno-poiskovaya sistema) and a system for the display and correction of data (SOI -- sistema otobrazheniya i korrektirovki informatsii).

The AIPS is a translator-interpreter which accomplishes conversion of communications (inquiries) from the input information language into the computer information language and back. It also performs instruction concerning the character of data processing. The AIPS operates in the following principal regimes:
-- initial input and revision of the main data masses;
-- "reconstruction" of hydrometeorological elements on the basis of measurements in a spatial discrete grid;
-- data support for computation problems;
-- data retrieval for nonstandard formalized inquiries.

The data display system is a set of programs for standard printout of data to the ATsPU and for its output to the display screens. This complex provides for the programmed servicing of corrections of materials.

The SPU is a set of programs intended for organizing interaction among all the mathematical support components. It includes the dispatcher of the operational system, as well as programs for commutation of the measurement complexes in an automatic interrogation regime.

The SKZ (problem complex system) is the largest in volume. It includes:
-- packets of programs for primary and standard processing of observations;
-- programs for the statistical analysis of data;
-- special programs (nonstandard data processing, navigational and auxiliary problems).

Programs for primary and standard processing are prepared for all measurement complexes, combined into a system. Examples of programs of the first kind are, for example, programs for the processing of data from the bathometer-sonde, ATsIT complex, "OKA" attachment, etc. [7, 69]. The concept of primary processing, common for all the measurement complexes, is formulated in accordance with [54]. That source includes a block diagram of primary processing in a series of blocks.

First block. Subprograms for input and technical control, created applicable to codes and models in accordance with which the information is automatically registered on a technical carrier. The control is to check correspondence of the data masses to the codes (syntactical control), the use of alogisms, etc.

Second block. The sorting and introduction of corrections and calibration coefficients. The distribution of data is accomplished by different elements and the true values of the measured parameters are obtained.

Third block. Smoothing of the data arriving from the primary converters. There is correction of the series necessitated by the negative effect of different random disturbances (for example, in the depth readings of a descending sonde under the influence of drift and waves, etc.), making use of different approximation and averaging procedures.

Fourth block. Discrimination of special points and layers. The position of the portions of the record of greatest interest is refined more precisely. For example, the position of the thermocline, inversion layers and intrusions in the ocean, tropopause and special points in the atmosphere.

Fifth block. Obtaining derivative characteristics. The parameters necessary for further processing and documentation of information.

Sixth block. Critical analysis. Here there is an evaluation of quality and rejection of erroneous data by statistical methods based on available information concerning the law of distribution of natural variability of a particular element, confidence interval of variability of the parameter within quasihomogeneous regions; the matching of the results of measurements of different parameters is accomplished.

Seventh block. Obtaining and printout of forms of representation. Printout of different generalizing tables and graphs graphically representing the results of measurements and processing and constituting report documents for data collection by storage centers and ship owners. Data are entered on storage punched tapes and magnetic tapes determining the level of dissemination and exchange of data on computer data carriers at both national and international scales.

Eighth block. Preparation and registry of information on long-term data carriers for the storage and organization of banks of hydrometeorological data. Data are filtered for eliminating excess and made more compact -- for accumulation of data subject to storage. Definite information, collected with large spatial-temporal averaging scales, is subject to storage.

Random information, characterizing small-scale structure of variability, is incorporated in the data bank only in the form of extremal records.

CHAPTER 8. TECHNICAL APPARATUS FOR THE COLLECTION AND REGISTRY OF DATA -- SIGMA-S

8.1. On-board Data Measuring Complexes

8.1.1. MARS automatic registry system. [MARS = morskaya avtomaticheskaya registrir-uyushchaya stantsiya] The station is intended for the automatic measurement of hydrometeorological parameters in a cyclic program, their primary processing and registry on a computer carrier; graphic registry of actinometer parameters; output of data to the operator's central display and to a remote display which can be placed in different positions on the ship; transmission of data from meteorological-actinometric observations along a communication line to the shipboard computation center [102].

The station ensures automation of standard hydrometeorological observations carried out on scientific research ships.

The MARS station includes the following apparatus:
-- an array of primary converters;
-- central automation unit;
-- operator's central panel;
-- remote display;
-- unit for registry and control (telegraphic apparatus, automatically registering instruments).

The conversion of the hydrometeorological and actinometric information into an electrical signal is accomplished using the corresponding primary converters, which operate on different physical principles and have different output characteristics.

The diversity of output characteristics of the primary converters required that in the design of the station use be made of matching devices, separately for discrete and analog primary converters, which convert different output signals into a single electric signal, and also are responsible for the preliminary processing and storage of measurement data.

The data are fed from the matching devices to a conversion unit in which the information is converted into a decimal code for visual display on a central display and into an MTK-2 code for registry with the RTA telegraphic apparatus. In addition, the actinometric information is fed to the KSP-4 automatic recorder.

Visually observed information from the manual input panel is also fed to the operator's central display.

Any information from the central display is fed to the unit for forming and subtracting information in which it is converted into the MTK-2 code and is fed to the RTA, and in case of necessity, through the communication channel to the shipboard computation center.

From the RTA the information on the punch tape is fed tc an electronic computer. The unit for forming and subtracting the information organizes the output of the telegram text to the remote display.

Time reckoning is with a time unit which produces commands for cutting-in the station and cutting in the primary converters for preparing for measurements at a fixed times; it accomplishes synchronization of operation of all the units and registers and shows the date and time of measurements.

The control unit is cut into operation by commands from the time unit. The control unit cuts in the measurement channels and ensures registry of the measurement parameters on a teletype and the operator's display.

The unit for selecting the primary converters connects to the corresponding matching devices those converters best suited for making measurements.

The principal operating regime of the station is automatic, in which it automatically selects the corresponding primary converters, measures, registers and feeds out information into the line from the shipboard computation center.

8.1.2. Automatic shipboard actinometric system (ASAS -- avtomaticheskaya sudovaya aktinometricheskaya sistema). The actinometric system is intended for the stabilization of actinometric instruments in the plane of the horizon, automatic pointing of the receiving surfaces of these instruments on the sun for the purpose of obtaining high-quality and comparable data from actinometric observations under shipboard conditions despite the disturbing effects of rolling [64].

The ASAS system ensures a multisided solution of the problems involved in the automation of sea actinometric observations carried out for the purpose of measuring elements of the radiation balance and makes it possible to obtain all the information with any discreteness and on any carrier: EPP-09 or KSP-4 tape, magnetic tape or using the MARS-1 automatic station. The use of the system makes it possible to improve the quality of the primary information and broaden the complex of observations, as well as to optimize observations. It affords definite prospects for the implementation of a number of special measurements, whose implementation under oceanic conditions involves difficulties. The programs for processing on "Minsk-22" and "Minsk-32" computers make it possible to compute the elements of the radiation balance and the final results are printed out in tabulated form.

It is desirable that the ASAS system be used simultaneously with the MARS-1 station. Upon receiving signals from the ASAS system the unit for representative selection of the primary converters of the MARS-1 station can cut in the unshaded actinometric converters on the port and starboard sides, depending on the position of the sun relative to the ship. The ASAS system sends to the unit for the representative choice of the primary converters a signal in the form of a voltage corresponding to the cut-in sector.

The ASAS system consists of several units which are electrically coupled to one another and which form, depending on the type of scientific research ship on which it is installed, different configurations [16].

The complete ASAS outfit consists of the following units:
-- stabilized central post which includes a biaxial gyrostabilizer and system with phototracking of the sun;
-- stabilized posts, each of which includes a repeater indicator unit with systems having phototracking of the sun and a remote control panel. The repeater indicator unit stabilizes the instruments in the horizontal plane and the phototracking system automatically tracks the sun;
-- remote stabilizers, each of which consists of a power gyrohorizon and a control panel. They are intended for the stabilization of the actinometric instruments placed on them.

The ASAS system is controlled from a central post and from remote control panels.

The operation of the system is based on use of the possibilities of power gyroscopic stabilization of instruments and systems on moving vehicles and continuous automatic direction-finding of the sun using special phototracking systems.

The central post biaxial gyrostabilizer stabilizes the actinometric instruments and system for phototracking of the sun in the plane of the horizon.

In turn the central post gyrostabilizer is corrected by a pendulum correction system, maintaining a horizontal position with allowance for the local vertical.

The extensible stabilizers operate autonomously. The stabilization of the actinometric instruments in power gyrohorizons is accomplished by means of the stabilizing properties of the gyroscopes.

The ASAS system makes possible the simultaneous accomplishment of actinometric observations of the following elements, with continuous registry on automatic recorders:
-- reflected radiation and the radiation balance (using an albedometer and balance meter, mounted on the gyrohorizon of the remote stabilizer (RS_2), placed on a boom extending over the water surface);

Tests and operation indicated the operability of system components and their suitability for stabilizing actinometric instruments in the plane of the horizon and automatic heliotracking of the sensing surfaces of these instruments under conditions of rolling and movement of the ship with an accuracy adequate for observational practice. A comparison of the result of observations made using the standard method and employing the ASAS-MARS system indicates their satisfactory convergence.

8.1.3. Complex for automatic processing of data from radiosonde measurements of the atmosphere ("OKA-3"). The "OKA-3" unit is included in the outfit for automatic processing of data obtained with the RKZ-"Meteorit" sounding system and is intended for transformation of the spherical coordinates of the radiosonde (elevation angle, azimuth, range) into a digital code, together with the frequencies of meteorological parameters, and also their output to a punch tape for subsequent processing on "Minsk-22" and "Minsk-32" electronic computers in accordance with a special program [118]. The apparatus consists of elements for the conversion of coordinates and frequencies into a binary code, storage register, punching unit based on a T-51 teletype, unit for control summation of the data to be punched, unit for input of initial data for punching and a control unit. The input data for the apparatus are telemetric data on the spherical coordinates of the radiosonde and the frequencies of the meteorological parameters arriving from the output of the radar receiver and also the initial and calibration information necessary for processing on an electronic computer.

The processing program ensures the possibility of automatic input of data from the "OKA-3" complex into a "Minsk-32" electronic computer through a special unit for the graphic representation of information, standard processing of data and their registry on magnetic tape.

8.1.4. Automated wave measurement complex. The complex is intended for measuring and registry of wind waves. It ensures the collection and representation of data on waves in a form convenient for input into an electronic computer employing a GM-62 wave recorder and an analog-recording unit (ATsRU). This apparatus ensures analog and digital registry of fluctuations of the wave-covered sea surface at a real time scale. The digital representation of data on a technical carrier in combination with mathematical support of the complex makes possible direct input of data and their processing in "Minsk-22" and "Minsk-32" electronic computers.

The operating principle of the complex is based on measurement of the resistance of a wire vertically submerged in the water in front of the ship's stem with the simultaneous readout of variations of the ship's rolling by means of the primary rolling converter, lowered into the water at the point of suspension of the wire wave converter.

The registry of the output signal of the GM-62 wave recorder proper in analog form is accomplished using a KSP-4 electronic potentiometer. At the same time the signal is converted into a discrete digital form, the instantaneous state of whose code is displayed on the display panel of the decoding unit and which is registered on a punch tape by means of a PL-80 puncher.

The organization and control of operation of all units of the analog-digital conversion system, interrogation and commutation regime, are accomplished by a control unit. The control unit ensures the operation of the system in three code interrogation regimes: 1) automatic and fixed interrogation frequencies; 2) in a regime with triggering from an external generator with a preset interrogation frequency; 3) in a regime of single code interrogation at moments in time selected by the operator. In each specific case the choice of the necessary interrogation frequency is determined by the maximum admissible interval of discreteness in readings for the greatest frequency of the process to be registered.

For solving a wide range of problems for investigating waves the complex has a mathematical support, including several programs for checking the measured data and obtaining the characteristics of the probabilistic-statistical description of waves as a random process [69].

The full cycle of processing the measurement results provides for three stages: 1) checking of the initial data mass; 2) computation of statistical characteristics; 3) spectral-statistical analysis.

8.1.5. Oceanographic automated bathometer-sonde sounding complex. The bathometer-sonde complex [63] is intended for the remote measurement, transmission and registry of the principal oceanographic characteristics: temperature, specific conductivity, hydrostatic pressure in regimes of vertical sounding or exposure at fixed horizons in the depth range from 0 to 2000 m (Fig. 8.1).

The complex makes possible the taking of samples of sea water by means of a bathometric section outfitted with bathometers of the BM-48 type. The operation of the bathometers is accomplished automatically upon reaching the standard horizons or by command of the operator.

The sounding data are registered in analog form and also discrete form on a technical carrier adapted for input into an electronic computer for subsequent computer processing.

The bathometer-sonde complex is carried aboard scientific research ships equipped with a cable winch and makes it possible to automate the process of collection and processing of oceanographic data.

The complex includes:
-- lowered apparatus with primary converters and bathometric section with 18 bathometers;
-- shipboard apparatus, including an instrument cabinet, control panel, remote display, telephone and registry apparatus system (PL-80 tape puncher, EUM-23 printout machine, cassette-type unit for storage on magnetic tape (KNML), KSP-4 single-coordinate automatic recorder, PDS-021 two-coordinate potentiometer);
-- LK-2 cable winch.

The shipboard apparatus controls the operation of the sonde and bathometric section, converts the received information and displays it on an illuminated display panel, remote display alongside the winch, at a real time scale -- in decimal form, and also registers the data on different technical carriers: in a binary-octal form on a punch tape by means of a punch; in decimal form on the digital printout unit through an electrically controlled machine; in a special format on the magnetic tape of a minicassette storage unit for the output of data to a specialized computer for the reregistry of data on the magnetic tape of an electronic computer, such as the "Minsk-32." In analog form the information obtained via one measurement channel is fed out as a function of time on the graph paper of the KSP-4 automatic recorder and as a function of depth on the tape of a PDS-021M two-coordinate automatic recorder. Such a choice of recorders is desirable and optimum because it makes it possible to perform any possible operations with data -- from checking of the quality, speedy analysis, processing on an electronic computer up to their inclusion in the memory units of the shipboard computation center or the on-shore computation center.

A necessary element in work with the bathometer-sonde is its programmed (mathematical) support, making it possible to process the measured information on an electronic computer, obtain the true values of parameters of the sea medium and their derivatives used in the subsequent scientific analysis.

The authors of [7] describe one of the first programs for a "Minsk-22" electronic computer which can characterize the level of computer processing of data from the bathometer-sonde attained by 1974. The program has now been improved and includes the following structural blocks:
1) computation of calibration equations;
2) input of primary data, calibration coefficients, syntactical, logical control and elimination of punched tape gaps or control block malfunctions [7, 101].
3) computation of true values of depth, temperature and salinity;
4) computation of derivative parameters;
5) printout of table;
6) plotting of data on magnetic storage tape.

*****

In the archives of shipboard computation centers of the Arctic and Antarctic Scientific Research Center there are programs for the processing of bathometer-sonde data on "Minsk-22," "Minsk-32" and YeS-120 electronic computers.

The first temperature-salinity sondes of original designs were developed at the Marine Hydrophysical Institute, USSR Academy of Sciences (ISTOK), and at the Institute of Oceanology, USSR Academy of Sciences (AIST) [120]. In contrast to the bathometer-sonde the ISTOK and AIST complexes are intended for the most part for work in investigating the fine thermohaline structure of the ocean and therefore do not have a bathometric section. Despite some diversity in the design and circuitry the ISTOK and AIST sondes do not fundamentally differ from one another. In evaluating the possibilities of the bathometer-sonde this makes it possible to limit ourselves only to the characteristics of the AIST sonde.

For the AIST sonde there is a somewhat greater response of the temperature channel, a lesser mean square error in measuring temperature under static conditions σ^{st}_{Tw}, a lesser total random error in measuring temperature σ^{Σ}_{Tw}, a lesser mean square error in determining salinity σ_S. However, the differences in the evaluations of accuracy in measuring temperature and in determining salinity for the AIST sonde and bathometer-sonde occur only in the third decimal place and therefore for the most part they are not of fundamental character.

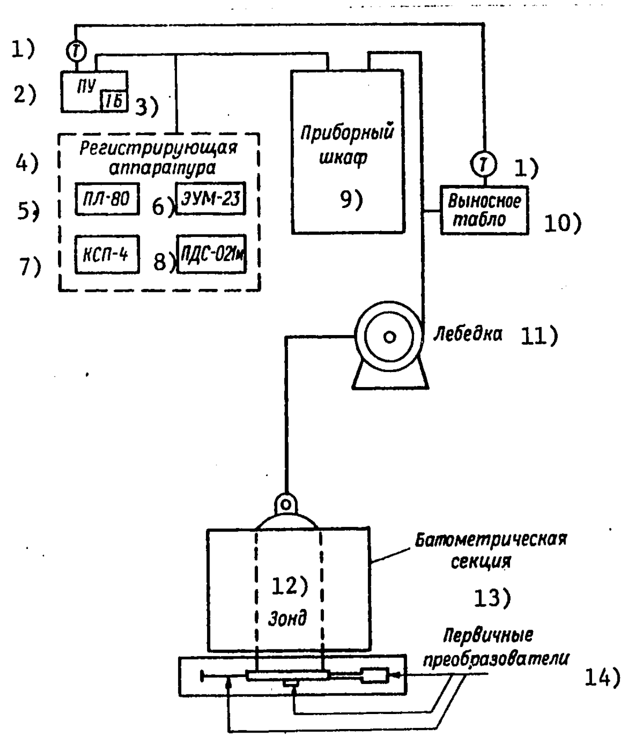

Fig. 8.1. Oceanographic bathometer-sonde.

KEY:

1) Telephone	8) PDS-021m
2) Control panel	9) Instrument closet
3) Control panel display	10) Remote display
4) Registry apparatus	11) Winch
5) PL-80	12) Sonde
6) EUM-23	13) Bathometric section
7) KSP-4	14) Primary converters

There is an extremely significant difference in the accuracy in measuring hydrostatic pressure. The use of a vibrational-frequency converter (vibrotone of the DDV-200 type) in the AIST sonde as a pressure converter made it possible to attain a high accuracy in measuring the depth of instrument submergence and preclude the appearance of hysteresis, which is an obvious design advantage. We also note that the time constant of the temperature sensor is close to half that of the AIST sonde. Accordingly, the dynamic error in sounding with the bathometer-sonde will be half as great.

Principal Technical Specifications of Sounding Complexes

	AIST	Bathometer-sonde
1. Temperature measurement range, °C	-2...30	-2...32
Conductivity measurement range, mmho/cm	30...71	17...71
Pressure measurement range, MPa	0...20	0...2.24 2.24...20
2. Response		
temperature, °C	0.008	0.01
conductivity, mmho/cm	0.01	0.01
3. Time constant of temperature sensor, sec	0.35	0.2
4. Error in measuring water temperature, °C		
static	0.013	0.025
dynamic	0.020	0.010
total	0.024	0.027
Error in determining salinity, °/oo	0.028	0.030
Error in determining static pressure, %	0.25	1.5 of upper limit
5. Discreteness in measuring pressure, MPa	0.003	0.1
6. Interrogation cycle, sec	1.24	1.2; 2.4; 4.8 9.6
	2.48	1.6; 3.2; 6.4; 12.8 (with bathometric section)
7. Registry and display		
PL-80 tape puncher	Yes	Yes
KNML digital magnetic recorder	Yes	Yes
EUM-23 digital printout mechanism	No	Yes
PDS-21 and KSP-4 curve plotters	Yes	Yes
Control panel display	Yes	Yes
Remote display	No	Yes
8. Presence of bathometric section	No	Yes

Among the merits of bathometer-sonde design we should also include the presence of a bathometric section which ensures the taking of samples and also a broader possibility of registry and display of the results of measurements, which involves an optimum set of servicing devices, including a remote display and a digital printout machine. The lack of a bathometric section in the AIST sonde precludes its use for the automation of abyssal oceanographic observations. The representation of the registered information in decimal form (for the bathometer-sonde) favors the carrying out of calibration work and also purposeful control of the measurement regime.

Another merit of the bathometer-sonde is the possibility of its standard production because the complex is made of standard components. Such a possibility probably does not exist for the AIST sonde because some components of the complex are produced in limited quantity and are unique, such as the primary salinity converter.

The use of high-response, high-speed sounding apparatus for the purpose of studying hydrophysical fields has now come into wide use. Experience in such investigations, presented in [84, 120], indicates that it has become possible to obtain qualitatively new data concerning the thermohaline fine structure of the ocean, the origin, spatial-temporal variability of different forms of microstructure of physical processes in the ocean. K. N. Fedorov correctly compares the results of such investigations with the results of use of a microscope in biology. However, the practical use of the apparatus involved different kinds of difficulties of a methodological nature. Complexities arose in the interpretation of data measured using a moving low-inertia instrument and subjected to rapid changes in a stratified medium, especially during rolling and nonuniform drift of a ship [45, 73, 95]. The need appeared for evaluating the accuracy of characteristics of the new apparatus and accordingly developing calibration work methods. Finally, it was necessary to proceed from the creation of individual algorithms and programs to the organization of a flexible mathematical support facilitating processing on an electronic computer and assimilation of a great volume of data.

Below we examine some results of development of the methodological principles for measuring temperature, conductivity and hydrostatic pressure in the ocean by means of the bathometer-sonde, the problems involved in the interpretation of the collected data and some aspects of use of the complex in oceanographic investigations.

A mandatory initial condition for working with the complex is the carrying out of calibration of the primary pressure, temperature and conductivity converters since the peculiarities of apparatus design do not make it possible to carry out direct measurements of hydrophysical parameters at a real time scale. This problem has been solved under laboratory conditions for all measurement channels.

Despite definite difficulties, the calibration of the measurement channels can be accomplished under in situ conditions, as is indicated by the experience of investigations carried out on the scientific research ships "Professor Vize" and "Professor Zubov," and also similar studies with the AIST temperature-salinity sonde [120]. The calibration studies make it possible not only to determine the transfer functions from the readings of the sonde to the true values of parameters of the sea medium, but also to evaluate the accuracy, threshold characteristics, and ascertain the time scales of instability of the measurement channels directly during the period of the investigations.

The content of the work involves carrying out comparative observations with the primary converters of the sonde and with standard instruments in quasihomogeneous or low-gradient layers, under similar metrological conditions in the entire range of actual change in parameters of sea water. In the final stage of the work the functional dependences between the readings of the sonde and the true values of the measured elements are computed.

Potentiometric primary converters of the DTM-25 type (for depths 0-250 m) and MD-200T (for depths 250-2000 m) were used as hydrostatic pressure detectors.

The calibration of a precise converter is accomplished using the readings of a counter unit with a known coefficient under calm weather conditions and in the absence of a cable slope. The upper limit of the measurement range (180-250 m) is refined by a determination of depth using temperature-depth meters in the bathymetric section. The approximate primary converter is calibrated for the most part by using the readings of the temperature-depth meters.

Typical calibration curves of the DTM-25 and MD-200T primary converters are shown in Fig. 8.2. The graphs show that the calibration curves of both converters are by nature nonlinear; the nonlinearity, appearing at the upper limit of depths, attains 15% of the measurement range. The calibration curve, with an adequate degree of accuracy, is approximated by a polynomial in the form

$$H = a + bP + cP^2, \quad (8.1)$$

where H is the true depth according to the temperature-depth meters or the counter unit; P is pressure determined with the bathometer-sonde; a, b, c are coefficients determined by the least squares method.

Accordingly, the problem of calibrating the bathometer-sonde relative to depth essentially involves a determination of the coefficients a, b, c in equations (8.1).

Frequently [26, 62] the calibration curve of the pressure measurement channel is determined by a piecewise-linear function. Within the selected depth interval, within which H = f(P) is linear, the true depth value is determined using a linear interpolation formula.

The standard deviation, computed using a great number of measurements at horizons spaced each 20 m, during lowering and raising is on the average equal for the entire depth range 0.5-2.8 m.

The indicated values characterize the random error in measuring depth with a precise primary pressure converter in the range 0-220 m, which in general corresponds to the technical specifications.

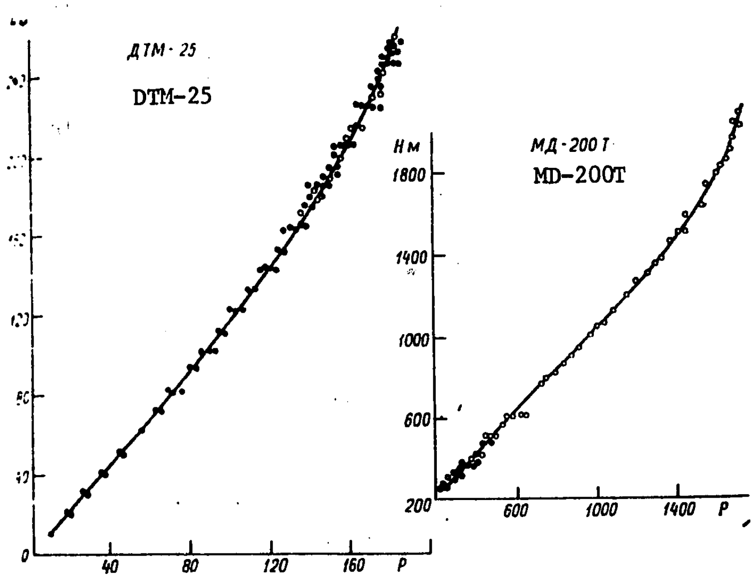

Fig. 8.2. Calibration curves of primary depth converters in bathometer-sonde complex.

The fact of a systematic shift in depth readings during the lowering and raising of the instrument, on the average attaining 2 m, should be noted. It was demonstrated in [101] by use of the Student test that this difference is significant and cannot be attributed to random factors. Accordingly, the readings of the precise primary depth converter during the lowering and raising of the instrument are not identical. This conclusion is of considerable importance. A depth dispersion of 2 m in the presence of high temperature and salinity gradients can be one of the possible reasons for the appearance of hysteresis in the registry of the vertical profiles of observed characteristics of sea water.

The following expression can be used for determining the number of observations necessary for calibrating the pressure channel with the stipulated error

$$\sigma_{\bar{H}} = \frac{\sigma}{\sqrt{n-1}}, \tag{8.2}$$

and also the magnitude of the admissible error in measuring depth, which are cited in [103]. It appears that in order to obtain information on depth with the error admissible in oceanographic work it is sufficient to make 1-3 measurements which are made under favorable hydrometeorological conditions.

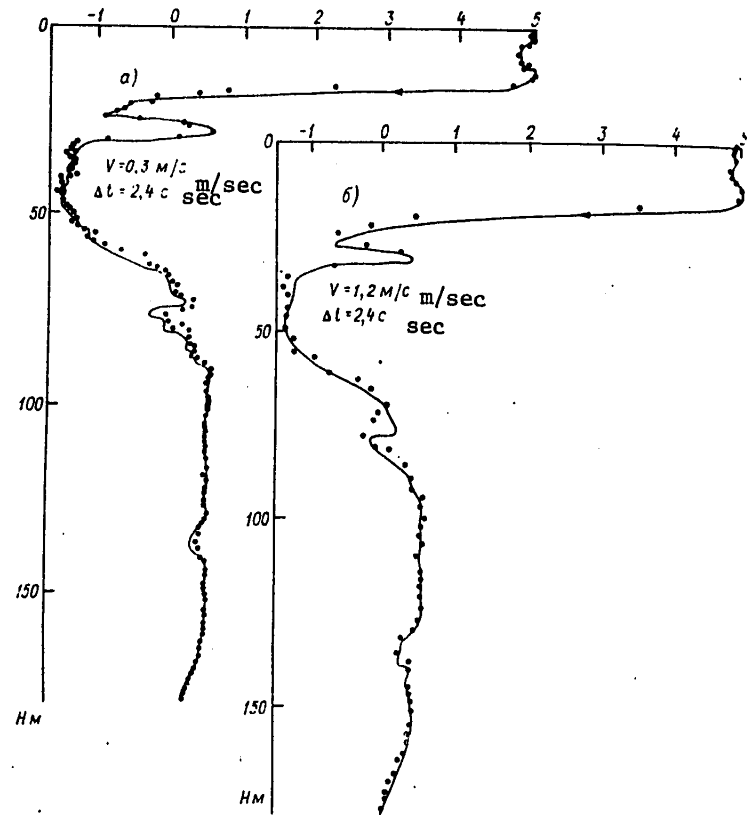

Fig. 8.3. Hysteresis of water temperature profile according to bathometer-sonde data.

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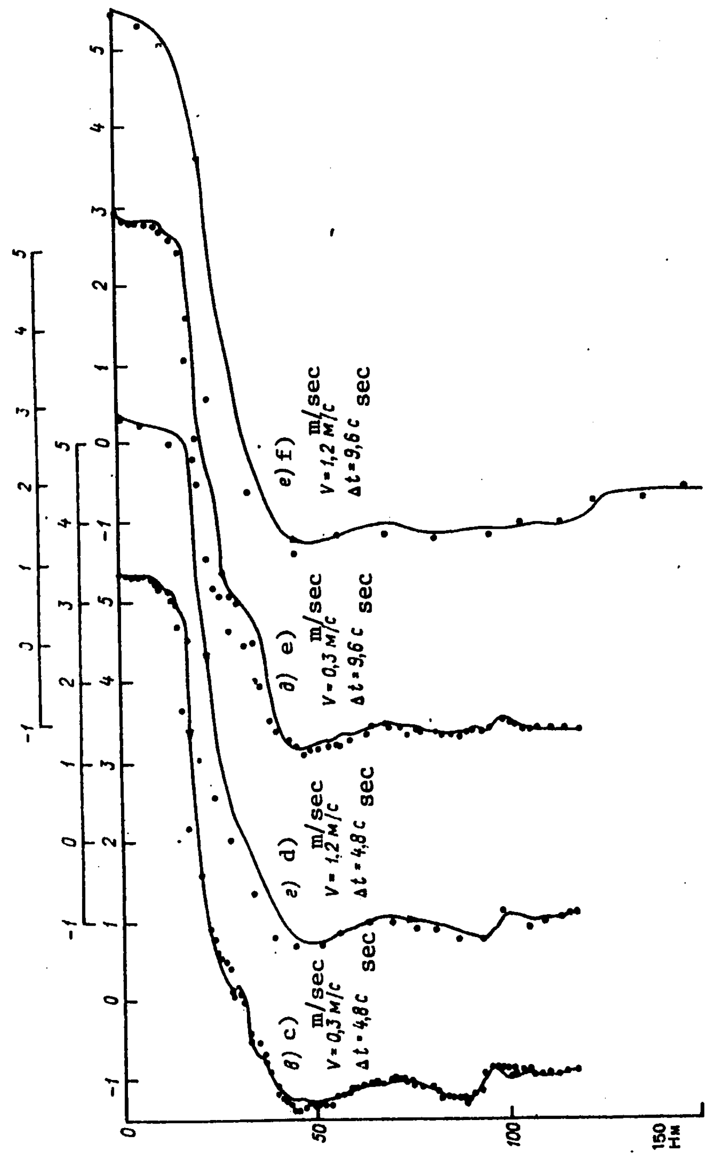

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In the depth range from 200 to 1000 m (MD-200T primary converter) the random error in measuring depth is 3-12 m, which is 1.2-1.5% of the depth and corresponds to the technical specifications of the instrument.

With an increase in depth the measurement error increases, probably due to an increase in scale nonlinearity. However, it is difficult to judge specific errors without special investigations. Using temperature-depth recorders it is impossible to register precisely the true depth of sonde submergence because during the time of exposure of the thermometers the horizon where the instrument is located under the influence of drift, even under favorable hydrometeorological conditions, can decrease by 50-100 m. However, the conclusion can be drawn that the approximate depth converter is of inadequate accuracy. For example, temperature-depth recorders register depth at the horizons from 300 to 2000 m [103] with an accuracy exceeding the accuracy of the approximate depth converter by roughly a factor of 1.5-3. During the ship's rolling and irregular changes in drift (especially under the conditions prevailing in the thermohalocline) an inadequate accuracy in measuring the true depth of probe submergence leads to the appearance of considerable disturbances in the registry of oceanographic characteristics which in the subsequent analysis cannot be interpreted validly [94].

The difference in the readings of the MD-200T primary converter during lowering and raising is manifested more sharply:

$$\overline{\Delta H}_{\downarrow\uparrow} = 10\ \text{м};\ \sigma_{\Delta H_{\downarrow\uparrow}} = 6\ \text{м}. \tag{8.3}$$

These discrepancies are also statistically significant.

As the primary temperature converter in the bathometer-sonde use is made of a copper resistance thermometer (ETS-2u) with a fundamental error ±0.027°C. In the course of operation, due to temporal instability of the parameters of the sensor and elements of the compensation circuit, there is an additional error in measuring temperature, which, however, does not exceed the fundamental error. The nature of the temporal distribution of this additional error is not known.

In order to determine the calibration curve of the temperature measurement channel a series of comparative observations is made using a lowering apparatus and deep-water thermometers of the bathometric section. The observations are made in quasi-homogeneous layers or layers with a small variability in temperature. It has been established that the curve for the temperature measurement channel is linear and has the form

$$T = a + bt, \tag{8.4}$$

where T is the true temperature value according to the deep-water thermometer; t are the readings of the primary temperature converter of the bathometer-sonde; a,b are coefficients determined by the least squares method or in any other way.

The mean square error in measuring temperature on the basis of a long series of observations is 0.025°C, which corresponds to the technical specifications of the complex. The number of measurements with thermometers necessary for obtaining temperature of a stipulated accuracy is 2-3. An investigation was made in [101] whose purpose was a more precise determination of the scales of the temporal effect of destabilizing factors on the results of calibration of the temperature converters and determination of the desirable interval between calibrations. It was found that the results of calibrations carried out each 100 and 200 hours of work are virtually identical and the coefficients of the polynomials differ by not more than 0.01° for all cases. This is an indication of the stability of the temperature converter curve and the slowness of aging of primary converter parameters.

An inductive-type converter (transducer) is used in measuring conductivity. It consists of two toroidal transformers connected inductively through the sea water. The voltage across the transformer windings determines the specific conductivity of the water.

In general, the calibration of the conductivity primary converter is accomplished similar to calibration of the temperature channel, but due to the complex dependence by which conductivity, temperature and pressure are related it differs in being more time-consuming and requires very precise and synchronous measurements. An analysis of the degree of influence of each oceanographic characteristic on the computed salinity values was accomplished in [26]. It was found that a change in conductivity in the third place leads to a change in salinity by $\sim 1^{o}/oo$. A temperature change leads to a salinity change by the same order of magnitude. To be more precise [120], within the range 5-25° the following expression is correct

$$\Delta S \approx 0.86 \Delta T,$$

that is, the deviation of the measured temperature from the true temperature by 1°C causes an error in determining salinity of $0.86^{o}/oo$ Pressure changes water conductivity by 12% and in the depth range from 0 to 1000 m this is 1-2.5%. In the case of deep-water measurements the influence of pressure can become decisive [26].

In order to carry out calibration three samples are taken using a bathometric section in the layer which is quasihomogeneous with respect to salinity. The use of the GM-65 electrosalinometer (or use of titration) makes it possible to determine the true (mean) salinity value at a particular horizon. Then, using data on salinity, temperature and pressure a determination is made of specific conductivity, which can be obtained, for example, using the nomograms in [31]. On the basis of the measured and computed specific conductivity it is possible to solve the equation

$$E = a\varkappa + b, \tag{8.5}$$

where E is the true conductivity value; $\varkappa$ are readings of the bathometer-sonde; a,b are coefficients determined by the least squares method or by a different method.

The conversion from conductivity in situ to salinity is accomplished using a known system of formulas, on the basis of which a special program is prepared for the processing of data on "Minsk-22, -32" and YeS-1020 electronic computers. The mean square error in computing salinity on the basis of conductivity under static conditions usually does not exceed $0.02-0.03^{o}/oo$.

Comparative observations with the primary converters of the complex and standard instruments, carried out synchronously in quasihomogeneous layers and under similar (static) metrological conditions, indicate a high degree of similarity of the results. However, comparison with the data from bathometric series, as a result of the asynchronous nature of the observations in space and time, as well as the different inertia of the primary converters, does not yield positive results, in any case, in the upper 300-m layer, where the natural variability of hydrophysical values is great. These data can be used only for the qualitative checking of sonde readings. Source [101] gives an analysis of matched vertical temperature and salinity profiles in the layer 0-600 m on the basis of observations with the bathometer-sonde and standard instruments at two stations in the Atlantic. It is indicated that the discrepancies in the layers 40-300 m for water temperature can attain 0.3-1.5°C, for water salinity 0.03-0.15°/oo. In the upper quasihomogeneous layer and in the lower low-gradient layer they are small. Evidently, in the case of parallel measurements with low-inertia sondes and standard instruments it is impossible to achieve a complete correspondence of their readings due to fundamental design differences involved in the two methods. The substantially different inertia, the dynamic error in sounding and the effect of spatial-temporal inhomogeneity of the sea medium -- all this favors the appearance of a difference between the readings of the bathometer-sonde and observational data at the oceanographic station.

The proper interpretation of the results of measurements with the bathometer-probe was impossible without thorough allowance for different distortions introduced in the observation process. The distortions can be of different nature. For example, they can be caused by design features of the instrument (geometrical dimensions, inertia, discrete representation of the information at the output), variability of the oceanographic characteristics or disturbance of the structure of flow by the moving instrument. The output signal of the complex is a result of averaging of the field at definite spatial-temporal scales and its primary converters are low-frequency filters.

Accordingly, all the measurements are accompanied by a dynamic error of low-frequency filtering which is a result of transformation of the random hydrophysical process by a low-frequency filter [95].

The water temperature, measured with an inertial primary converter, differs from the actual temperature and is determined [96] by the expression

$$T(z) = T'(z) + \tau V \frac{dT'(z)}{dz}, \qquad (8.6)$$

where T(z) is the actual temperature; T'(z) is the measured temperature; τ is the time constant of the primary converter; V is the rate of sounding; dT'(z)/dz is the vertical temperature gradient.

The second term in expression (8.6) $\delta_t = \tau VG_t$ determines the dynamic error. For the surface layer the dynamic error can exceed the random error.

Under average oceanic conditions in the polar regions the vertical temperature gradient characteristic for the layer 0-100 m usually does not exceed 0.1°C/m. With V_{min} = 0.3-0.5 the minimum value δ_t = 0.006-0.01°. In actuality, in local sectors of the thermocline the vertical temperature gradient can be substantially greater, which results in an increase δ_t by several times, especially since sounding with a minimum rate is not always possible due to technical considerations. This value of the constant (determined) component δ_t can be excluded, taking this into account in the processing program.

The random part δ_t arises during the ship's rolling, which can increase the rate of lowering of the instrument due to the periodic component, equal to about 0.3-0.5 m/sec, and also due to the nonuniformity of winch speed. This error has the same value as the constant δ_t, but it is difficult to take into account. In general, allowance for rolling is important in interpreting the results of sounding. It is noted in [73] that under some conditions the influence of rolling is more important than the spatial averaging of the primary converter and its inertia. Thus, the actual error in measuring temperature with the bathometer-sonde is

$$\sigma_T^{\Sigma} = \sqrt{(\sigma_t)^2 + (\delta_t)^2} = 0{,}027. \quad (8.7)$$

There is no dynamic error in measuring salinity since the primary salinity converter is virtually inertialess. But the distortions caused by the dynamic error in measuring temperature can lead to considerable errors in computing salinity. Distortions in the determination of salinity due to the inertia of the primary temperature converter can be manifested in the appearance of characteristic wedges in the salinity profile in sectors with high temperature gradients. However, if the water temperature is measured later than the measurement of conductivity by a time close to the inertia of the primary temperature converter, the error in computing salinity, caused by the latter, is compensated. This conclusion can probably be extended to the bathometer-sonde [123]. In a study of the thermohaline structure of a stratified fluid it is necessary to organize a system of constant monitoring and control of bathometer-sonde operation (the rate of its movement, frequency of interrogation of measurement channels). Without this the investigations carried out will not be adequately effective.

There must be optimum matching of the parameters of the moving instrument. In the case of a high speed the sounding is accomplished rapidly, but (under conditions of sea stratification due to the distorting effect of inertia of the primary temperature converter) distortions arise in the vertical profiles of temperature and especially salinity, which make it difficult to interpret the collected data. At a low speed the influence of the dynamic error can be avoided, but in this case the time required for implementing the observations substantially increases. An increase in the interrogation cycle reduces the vertical resolution of the measurements, as a result of which it is possible to overlook interesting structural features of the physical processes (inversions, "steps," etc.), whereas a decrease in the discreteness of the measurements in a definite situation can lead to an excess of information.

Source [62] gives a description of a variant of an automatic unit developed on the basis of a bathometer-sonde and an M-6000 electronic computer. The unit makes it possible to determine the gradients of water characteristics and shapes commands for change in the rate of movement and discreteness of measurements for the purpose of optimizing the sounding regimes. It can be postulated that in the future such a unit will become an indispensable component of the automated system on shipboard.

The thermal inertia of the primary converter and the lowering apparatus, the different conditions for flow around the measuring instrument and the spatial-temporal variability of the parameters of the water medium lead to hysteresis -- a deviation of the vertical profiles of the characteristic during the lowering and raising of the sonde.

We will mention the principal distortions arising in this work. The measured depth of the layers with a high gradient is greater than the true depth during lowering of the sonde and less than the true depth during its raising. This difference is proportional to the product $V\tau$. The measured field distribution is smoothed and the registered gradients are less than the real gradients. The latter distortion also decreases with a decrease in $V\tau$, but its minimum value is limited by the volume of spatial averaging of the primary converter. The totality of these characteristics, including the geometrical dimensions of the primary converter and the lowering apparatus as a whole, determines the temporal and spatial resolution of the instrument. The minimum dimension of the registered inhomogeneities and the spatial resolution of the bathometer-sonde vertically can be determined using the formula

$$h_{min} = V2\Delta t, \tag{8.8}$$

where Δt is the discreteness of measurement; V is the rate of sounding [120].

With V = 0.5 m/sec and different values of the discreteness of measurements we find that depending on the cycle of measurements the bathometer-sonde registers the sea water inhomogeneities having vertical dimensions exceeding 1.2 m, 2.4 m, 4.8 m, 9.6 m. The spatial (and temporal) resolution characterizes an important quality of the measurement system, especially in an investigation of small-scale phenomena when a fictitious nonuniformity can be interpreted as a really existing detail of oceanic microstructure.

It was demonstrated in [73], for example, how it is easy to take as the limiting value of the period of internal waves possible in the investigated layer of the ocean the minimum value of the period, which is dictated by the tactical-technical specifications of the instrument, its spatial resolution.

The evaluation of the theoretically possible hysteresis has the form:

$$\Delta T(z) = \frac{V_{\downarrow} + V_{\uparrow}}{2} \tau G_t. \tag{8.9}$$

Now we will examine Fig. 8.3. All the curves are characterized by a hysteresis, which is noted in the seasonal thermocline, whereas beyond its limits it is for the most part absent. It can be noted that in the case of great sounding rates (1.2 m/sec) the sonde understates the thickness of the upper quasihomogeneous layer by 2-4 m during raising versus lowering. Naturally, a minimum $\Delta T(z)$ value is noted in those cases when the rate of sounding and the interrogation cycle are less. Substituting the actual values of the parameters into expression (8.9), it is easy to confirm that for the cases (a, c, e) the computed $\Delta T(z)$ values are close to the values taken from the graph, but somewhat less than the latter. The difference can in part be attributed to the effect of short-period internal waves, which during the time of sounding change the vertical position of water layers with different characteristics. K. N. Fedorov [120], for establishing the real degree of hysteresis, recommends the use of a TS diagram on which there is exclusion of the dependence of temperature and salinity on depth, and accordingly, the influence of internal waves. Another reason for the exaggerated $\Delta T(z)$ values may be an inadequately correct design and construction of the instrument, as was the case for a model copy of the bathometer-sonde, when the large volume and nonidentical conditions for flow around the primary converters during the lowering and raising led to an exceedingly great hysteresis. In this problem it is also important to know the precise value of the time constant for the primary converter, whose temperature is frequently greater than that indicated in the certificate due to the influence of the inertia of the recorders and the thermal effect of the instrument mass. However, in standard production the design of the bathometer-sonde has been substantially improved, its dimensions have been considerably reduced and the primary converters have been moved to the lateral surface, which led to a definite increase in the reliability of instrument readings due to a decrease in its hysteresis [101].

Therefore, the most probable reason for the relatively small hysteresis in the bathometer-sonde is hysteresis of the DTM-25 primary depth converter, which is a characteristic property of the potentiometric pressure converters in general.

Now we will briefly discuss the problems of reliability and effectiveness of operation of the bathometer-sonde under expeditionary conditions. By the term "reliability" is meant the probability of faultless operation of the instrument for 200 hours

$$F = F_{lowering}F_{shipboard}, \tag{8.10}$$

where F is the probability of fault-free operation of the complex as a whole; $F_{shipboard}$ is the probability of fault-free operation of the on-board apparatus, including the data recorders; $F_{lowering}$ is the probability of fault-free operation of the lowering apparatus with the bathometric section.

For the standard-produced model of the instrument $F \geqslant 0.90-0.95$.

The electronic part of the sonde has a high reliability. The control unit, bathometric section and automatic recorders operate virtually without malfunctions. The EUM-23 digital printout unit has a rather high frequency of recurrence of malfunctions and the reliability of the data on the punched tape of the PL-80 punch-tape unit is inadequate. The latter required the development of a special program for checking and correcting data with input into an electronic computer.

The automation of observations of temperature and salinity at an oceanographic station with the use of a bathometer-sonde leads to an increase in the efficiency of work by a factor of about 3. The bathometer-sonde is a more effective instrument for hydrophysical investigations than standard instruments. Its use made it possible to shed light on some processes of fine structure of fields in the ocean. The volume of collected information increases by two orders of magnitude.

The use of the bathometer-sonde in oceanographic investigations on the scientific research ships of the Arctic and Antarctic Scientific Research Institute has become extensive. The principal scientific problems solved using the bathometer-sonde can be represented in the following form:

-- Study of the thermohaline structure and evolution of waters in a wide range of spatial and temporal scales.
-- Study of the internal fluctuations of temperature and salinity in the oceanic thermocline in the region of short and mesoscale processes.

For the first time in oceanographic work the bathometer-sonde was used in an investigation of the high-frequency fluctuations of water temperature in the neighborhood of the pycnocline on the 11th voyage of the scientific research ship "Professor Vize" in 1971 when a cycle of measurements was made of fluctuations of characteristics of the pycnocline at the scale of short-period internal waves [94].

In carrying out expeditionary investigations for improving the method for multisided study of hydrophysical fields and their spatial-temporal variability, provided for under the Polar Experiment program, the bathometer-probe was used on the 14th voyage of the scientific research ship "Professor Vize" and the 9th voyage of the scientific research ship "Professor Zubov" in 1972 for investigating the fine thermohaline structure of the active layer in the ocean [4]. Then data were obtained on the short-period variability of the temperature field, the stepped structure and centers of small-scale hydrostatic instability in the oceanic thermocline were investigated and a method was proposed making it possible to exclude the influence of rolling and nonuniformities of drift on the results of a statistical description of the measurements made with the bathometer-sonde.

Source [83] gives an analysis of the mesoscale variability of water temperature in Drake Passage on the basis of the results of observations with the bathometer-sonde at a multiday station. On the basis of a statistical analysis of the results of measurements a description is given of the structure of variability and composition of water temperature variations in the range of periods from 4 hours to 2.5 days. The conclusion is drawn that the structure of mesoscale variability has a complex multimode oscillatory character. The principal energy-bearing periods are two-day, semidiurnal and diurnal. The semidiurnal period in the spectrum of fluctuations is attributable to the effect of internal gravitational waves of a tidal origin on the density stratification of the ocean. The two-day and diurnal disturbances in the temperature field are related to the advection of waters, the periodicity of whose change has a meteorological nature. The vertical structure of the fluctuations is characterized by irregularity and spatial and temporal intermittence.

Source [93] is devoted to a similar problem. In that study data obtained with the bathometer-sonde, also collected in the region of Drake Passage, were used in an investigation of the high-frequency fluctuations of water temperature.

Also of unquestionable interest are the investigations with the bathometer-sonde carried out for the purpose of studying the fine structure of hydrophysical fields, devoted to the problems of mixing and turbulence, the characteristics of formation of water masses and their interaction in the regions of oceanic fronts and eddy structures.

The authors of [111] investigated the thermal structure of waters of the Antarctic Ocean over the continental slope of the Antarctic continent in connection with a discussion of the possible mechanisms of the vertical mixing of warm deep waters with the above-lying cold winter surface waters and the subsequent formation of bottom Antarctic waters on the continental shelf. The hypothesis of destruction of internal waves with periods less than 70 hours on the continental shelf was expressed and partially checked. As a result of this process conditions are created for the mixing of surface and deep waters, with formation of denser and colder water, which flows downward along the continental slope.

The authors of [3] investigated the structure of water masses in the neighborhood of the Antarctic polar front and the features of development of processes leading to the formation of thermohaline and dynamic inhomogeneities. They also presented a classification of the vertical profiles of temperature and salinity with intersection of the hydrological frontal zone.

The 21st and 23d voyages of the scientific research ship "Professor Zubov" (1977 and 1978) were devoted to a study of the polar frontal zone in the Norwegian and Greenland Seas. During these voyages a major complex of observations (a total of about 400 stations) was carried out using the bathometer-sonde. An analysis of the extensive data collected made it possible to obtain new information on the physical processes transpiring in the region of a local sector of the polar hydrological front and its effect on the formation and variability of thermodynamic anomalies in the ocean;
-- a study was made of the state and dynamics of water masses of polar and Atlantic origin, interacting in the frontal zone;
-- a classification was made of the vertical profiles of temperature and salinity directly on the front and on its northern and southern peripheries; zones of instability and intensive mixing were detected;
-- a study was made of the spatial-temporal structure and dynamics of eddy formations responsible for the formation of mesoscale disturbances in the temperature and salinity fields;
-- data were obtained for investigating the relationships between the fine structure of the thermocline and mesoscale thermohaline inhomogeneities;
-- a study was made of the advective nature of exchange of energy and mass between polar and Atlantic waters in the form of a cyclonic eddy, breaking through the zone of the hydrological front in a direction from north to south;
-- the spectral composition of high-frequency temperature and salinity oscillations in the seasonal thermocline near the frontal zone was determined more precisely.

8.1.6. Automatic digital unit for measuring current direction and velocity, temperature, conductivity and hydrostatic pressure of sea water (ATsIT instrument). The ATsIT unit for self-contained digital measurement of current velocity and direction, temperature, conductivity and hydrostatic pressure of sea water is intended for operation on an underwater buoy station and from aboard a ship in a self-contained regime. The registry of data is with a magazine-type magnetic recorder placed in the body of the instrument. The ATsIT (Table 8.1) is an automated technical apparatus for the collection of hydrophysical information in the oceans and seas [8].

The data obtained on the state of the studied medium, recorded in the course of measurement, averaged in time and volume, are registered periodically at equal time intervals in accordance with the selected operating regime. The time constant of the primary converter for current velocity, temperature and the magnetic compass can be regulated in definite ranges, taking into account the requirements on the frequency characteristics of the instrument. Provision is made for the following regimes of periodicity of instrument operation: 3 sec and 30 sec during sounding

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or brief exposure at a fixed horizon from aboard the ship; 5, 15, 30, 60 minutes -- during prolonged operation on the underwater buoy station. The supply of magnetic tape and the capacity of the battery source of electric current were reckoned at 10^4 measurement cycles. The processing of the measurement results, registered in a magnetic minicassette, involves the printout of a table of true values of the measured parameters. This is accomplished using "Minsk-32," YeS-1020 electronic computers or with the "Iskra-125" PEKVM system by the input of data through a special buffer magnetic recorder of the data conversion unit. The monitoring of the correctness of functioning of the instrument under laboratory conditions is accomplished through an on-board unit connected to the ATsIT. Provision is made for the possibility of connecting a T-51 telegraphic apparatus to the unit for the output of data to a punch tape for storage purposes or for their printout on a rolled tape. A hydroacoustic communication channel is provided for in the instrument for checking the proper operation of the instrument in an underwater position and also for possible future relaying of data by radio via a buoy floating on the sea surface. The communication channel consists of a radiating hydrophone and a hydroacoustic receiver, situated on shipboard, which is connected to the data conversion unit. The registry of data in a reception regime is accomplished on a visual screen and with the telegraphic apparatus. The effective range of the acoustic communication channel under the optimum hydrometeorological conditions is 2000 m [8].

With respect to design, the instrument is a sealed cylinder with a protective latticed framework in its upper and lower parts (Fig. 8.4). The body of the instrument is fabricated from a titanium alloy and is intended for a depth of submergence 6000 m.

Table 8.1

Principal Technical Specifications of ATsIT Complex [8]

Parameter	Measurement range	Measurement discreteness	Principal error
Current			
velocity, cm/sec	3-200	1	±3
direction, °	0-360	1	5
Water temperature, °C	-2-+38	0.01	±0.03
Specific conductivity, mho/m	0-3.4	$8 \cdot 10^{-4}$	$\pm 3 \cdot 10^{-3}$
mho/m	2.6-6		
Hydrostatic pressure, MPa	0-600	0.005	0.5% of upper limit in range 0-30; 1% in range 0-600
Angle of deviation of instrument axis from vertical, °	0-±30	0.1	±1
Error in rate of programming clock, sec/day	--	--	±0.1

The ATsIT complex includes the following sensors:
-- current velocity measurement converter;
-- magnetic compass;

-- temperature measurement converter;
-- conductivity measurement converter;
-- hydrostatic pressure measurement converter;
-- angle of slope measurement converter [8].

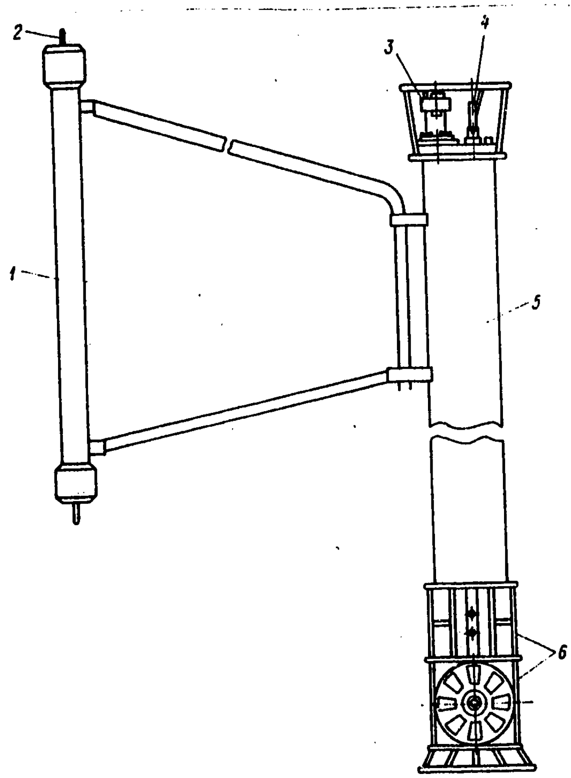


Fig. 8.4. General appearance of ATsIT measurement complex with support [8]. 1) suspension support; 2) cable; 3) conductivity sensor; 4) temperature sensor; 5) housing of measurement complex; 6) propeller-type current meter.

The instrument contains a two-component current velocity measurement converter of the propeller type which is formed by two mutually perpendicular current meters with a horizontal axis, making possible separate measurement of both projections of the current velocity vector, and then, during the processing of data, taking into account the orientation of the instrument relative to the magnetic meridian, computation of total current vector. The reversibility of the propeller-type current meters makes it possible to filter out the sign-variable wave component of the current and improve the quality of the information when making measurements in the surface layer, subject to the influence of wind waves [42].

The two-component measurement method allows an arbitrary orientation of the axes of the current meters relative to the direction of flow and therefore the angular stabilization of the housing in a stipulated direction is not required and a steady moment is absent. However, it is necessary that during the time between two successive cycles of reckoning the angular position of the potentiometers and mean direction of instrument orientation relative to the directions of the compass be known. This position is measured with a magnetic compass having integrating properties. In order to decrease the integration errors of both the current meters and the compass it is important that in the fluctuating flow the angle of orientation of this instrument should be changed in the smallest possible range [8].

The magnetic compass is intended for measuring the angle of orientation of the instrument housing relative to the magnetic meridian. The compass is used with a fluid (electrolytic) converter of the angle of rotation of the compass card into an electric signal.

A platinum wire resistance thermometer with an inertia of 3 sec was used as the water temperature measurement converter. With such a time constant the primary temperature converter is used in a sounding regime or with a brief exposure at a fixed horizon with an interrogation cycle of 3 sec and 30 sec. In order to register mesoscale processes at the selected horizon the thermal inertia can be increased to 180 sec by means of installing an interchangeable heat-insulating bushing.

The instrument includes an induction-type primary conductivity converter.

Water salinity is computed by a solution of well-known equations unambiguously determining water salinity as a function of conductivity, temperature and depth.

The depth of instrument submergence is measured on the basis of hydrostatic pressure, taking into account corrections for the vertical distribution of water density. The primary pressure converter is a spring-type manometer (Bourdon tube) with an induction-type converter of the sensing element value into an electric signal.

The function of registry of the vertical angle and the introduction of such a correction is performed by a primary angle-measuring converter of the deviation of the housing from the vertical in the plane of inclination of the cable. The information (Fig. 8.5) registered by the complex is recorded directly in the course of the measurements in a magnetic tape storage cassette.

The readout of data from the magnetic cassette, input of data into "Minsk-32," YeS-1020 or PKVM "Iskra 125" electronic computers, output of data to a display or teletype, is all accomplished by means of an on-board data conversion and processing unit. Depending on whether the ship carries a large electronic computer or the KTS ASOGI complex, or whether there are peripheral units for the output and display of data, there can be several variants of the technology for machine processing of ATsIT data. One of these is based on use of the "Minsk-32" and YeS-1020 computers, which makes possible the readout of data in a continuous regime. In this case the data are printed out in the form of a table and also can be registered in a systematized form in the format used by the processor. The use of the mentioned KTS ASOGI apparatus (including on ships not outfitted with electronic computers) also makes it possible to carry out primary processing of the information and accomplish printout of orderly output of masses of data in decimal form through a digital printout unit in a narrow format; a curve plotter is employed for the graphic representation of data; a linkup makes possible the output of data to the teletype (in a broad format) and, finally, by means of a reregistry unit the data content of the minicassettes is transferred to a combined magnetic tape in the formats for the "Minsk-32" and YeS-1020 electronic computers.

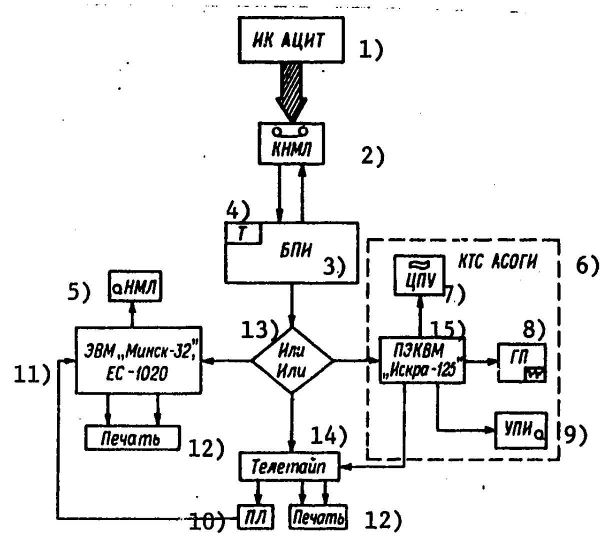


Fig. 8.5. Block diagram of data processing for ATsIT measurement complex.

KEY:

1) ATsIT measurement complex;
2) Cassette-type magnetic tape storage;
3) Data conversion unit;
4) Display of data conversion unit;
5) Storage on magnetic tape;
6) KTS ASOGI complex (complex of means for collection and processing of hydrometeorological data);
7) Digital printout unit;
8) Curve plotter;
9) Data reregistry unit;
10) tape puncher.

The use of a teletype makes it possible, simultaneously with the printout of the codes, to plot information on an intermediate machine carrier for its subsequent input and processing on an electronic computer which has a photoreadout unit.

Principles of method for calibration work. The specifics of the complex and its design features make it necessary to develop a special verification method and determine the particular types of required technical and special means for performing such checking under both laboratory and expeditionary conditions [8].

The problem of carrying out calibration work under real experimental conditions has not yet found an adequately complete solution due to the complexity in organizing such work due to technical reasons and the difficulties in choosing the optimum conditions for state of the medium. However, it is difficult to reproduce in situ conditions in the basin sufficiently completely. Precisely for this reason the results of calibration carried out in a sea medium characterize the real metrological possibilities of the apparatus.

The calibration of the two-component primary current velocity converter is carried out in a linear hydrometric basin in which well-known procedures are used in modeling the range of current velocities stipulated by the technical specifications of the ATsIT. Experimental data are used in constructing the calibration curve of the dependence of the number of revolutions of each current meter on current velocity with subsequent scaling of the collected data into the angles of rotation of the potentiometers and into the instrument output code. The current velocity modulus V is equal to

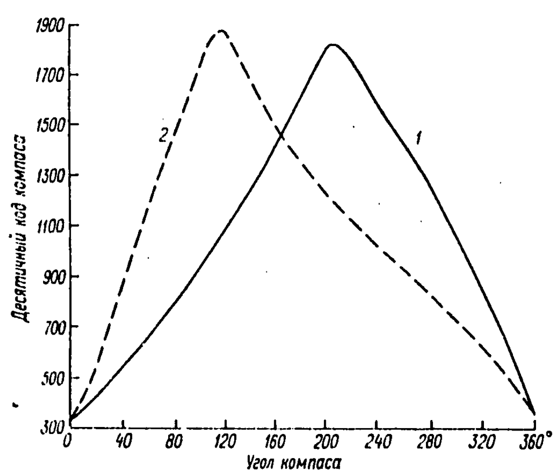
$$V = \sqrt{(m_1 \Delta k_1)^2 + (m_2 \Delta k_2)^2}, \tag{8.11}$$

where $\Delta k_1 = k_i^1 - k_{i-1}^1$ is the code increment for the first velocity component; $\Delta k_2 = k_i^2 - k_{i-1}^2$ is the code increment for the second velocity component; m_1, m_2 are the values of the graduation per code unit for the first and second velocity components,

$$m = \frac{7{,}258}{\Delta t} \frac{V}{n}, \tag{8.12}$$

where Δt is the discreteness of measurements, in sec; n is the number of revolutions of the blade screw corresponding to a particular velocity V.

Decimal compass code



Compass angle

Fig. 8.6. Calibration curve for magnetic compass in ATsIT complex. 1) first pair of emitting electrodes; 2) second pair of emitting electrodes.

Then a dependence is established between the number of revolutions of the current meters on the angle of orientation of their axes relative to the flow and a directional diagram is constructed. With a proper geometrical configuration of the current meter-fairings profile the directional diagram has a cosinusoidal form within the limits of the established tolerances of 5% for the velocity range 100-200 cm/sec and 10% with velocities 3-15 cm/sec.

During the carrying out of the calibrations and during subsequent work with the complex it must be taken into account that the principal error in measuring current velocity with a two-component primary converter is caused primarily by the unit for conversion of the number of current meter revolutions into an electric signal and also a mechanism ensuring the initial response of the primary converter. The operating principle of the ATsIT primary velocity converter requires its single calibration after manufacture.

The magnetic compass is calibrated by rotating the body of the instrument in a turning circle by stipulated angles under conditions of absence of magnetic disturbances. The normal operability of the compass is checked in the range of a total working angle of 360° and corrections for deviation are eliminated. The calibration is carried out twice for each pair of emitting electrodes (Fig. 8.6). The shape of the compass characteristic is virtually linear with a sharp bend at the point of lead-in of the emitting electrode. The existence of a bend in the curve creates an ambiguity in readout of the angle which is eliminated with the use of two readings on the two curves with "inflection" points spaced in angle (that is, for each component it is necessary to find two angles corresponding to the read-out code of the corresponding component). From the two pairs of angles one angle is selected from each which are closest to one another. The average of these two values of the angles is used as the compass reading.

The fluid primary converter of the angle of deviation of the instrument axis from the vertical is calibrated by means of an angle-measuring device supplied with a plumb line in the range 0-30°. The angle of inclination γ of the instrument in the vertical plane is determined using the expression

$$\gamma = (k - k_0)\frac{60}{k_{-30} - k_{+30}}, \tag{8.13}$$

where k is the code of the computed angle; k_0 is a code corresponding to $\gamma = 0°$; k_{-30} is a code corresponding to $\gamma = -30°$; k_{+30} is a code corresponding to $\gamma = +30°$.

The k_0, k_{-30}, k_{+30} values are given in the instrument logbook.

The statistical characteristic of the platinum resistance thermometer is determined from the expression

$$R_t = R_{k_0}\frac{0{,}5 + 1{,}0175\cdot 10^{-5}k}{0{,}5 - 1{,}0175\cdot 10^{-5}k}, \tag{8.14}$$

where R_t is thermometer resistance with the measured temperature, t ohms; R_{k0} is thermometer resistance with k = 0; k is the value of the decimal code at the output of the measurement converter.

The measured value of the resistance of the platinum resistance thermometer is scaled into the temperature value using the formula

$$R_t = R_0(1 + 3{,}096847 \cdot 10^{-3} t - 5{,}847 \cdot 10^{-7} t^2), \tag{8.15}$$

where t is medium temperature, °C; R_0 is resistance of the platinum resistance thermometer at 0°C.

Accordingly, for calibrating the temperature channel it is necessary to compute R_{k0} and R_0. The R_{k0} value can be determined using a resistance box introduced in place of the platinum resistance thermometer into the temperature measurement channel, for which it is necessary to select such a resistance of the box with which the read-out temperature code is equal to zero. The R_0 value can be determined from expression (8.15) with known R_t and t corresponding to one another. As the temperature t it is possible to use the readings of abyssal thermometers obtained in parallel measurements with the ATsIT under identical meteorological conditions of thermostable layers in the sea. The temperature value is substituted into expression (8.15) and the ATsIT temperature code and the R_{k0} value are introduced into expression (8.14). The R_0 value is determined by joint solution of (8.14) and (8.15). The measured temperature value with known R_0, R_{k0} and k is determined by computation of R_t from expression (8.14) and by solution of expression (8.15) relative to t.

The primary water conductivity converter makes it possible to measure the absolute value of the total resistance of the water washing the coil. Using the measured resistance of the coil, water conductivity is determined by computations, taking the dimensions of the primary converter into account.

In analytical form the static characteristic curve for the primary converter has the form for the first subrange

$$\varkappa_1 = C \cdot 0{,}0154 \frac{k}{4095}, \tag{8.16}$$

and for the second subrange

$$\varkappa_2 = C\left(0{,}0154 \frac{k}{4095} + 0{,}01155\right), \tag{8.17}$$

where $\varkappa_1$, $\varkappa_2$ are the conductivities for the first and second subranges respectively, mho/m; k is the digital value of the code at the converter output; C is the geometrical constant of the converter, m^{-1}.

The geometrical constant of the primary converter is determined as the ratio of the total resistance, measured with the primary converter, to the specific resistance. The stability of this parameter with time and nondependence on the ambient medium is the principal criterion of primary converter quality. The geometrical constant of the primary converter is measured under laboratory conditions using standard solutions of a specific conductivity. Relative conductivity is determined using the formula

$$\varkappa_{rel} = \frac{\varkappa}{\varkappa_{35,\,15,\,0}} = \frac{\varkappa}{4{,}2896}, \tag{8.18}$$

where $\varkappa_{35,\ 15,\ 0}$ is the conductivity of normal water.

Water salinity is determined proceeding on the basis of a well-known algorithm, using data on $\varkappa_{rel}$, temperature and water pressure.

Thus, the calibration of the conductivity channel essentially involves determination of the C parameter. Under expeditionary conditions the true salinity, temperature and pressure values and the conductivity code value can be obtained from parallel observations with the ATsIT and bathometer-probe. Then, using expressions (8.16), (8.17), (8.18), by the successive approximations method it is possible to select the corresponding value of the C constant with which the computed salinity coincides with the salinity determined by titration.

The primary hydrostatic pressure converter is calibrated by employing a separate apparatus including a hydraulic compressor and a standard piston-type manometer. The characteristic curve is determined with a smooth rise and fall of pressure on the scale for the entire range from 0 to $58.86 \cdot 10^4$ GPa.

Under expeditionary conditions the calibration of the primary pressure converter is usually accomplished by the method of parallel measurements of depth using the ATsIT and temperature-depth meter, as well as the readings of a counter unit (in the upper 300-m layer) under favorable meteorological conditions and in the absence of the ship's drift. The code-depth dependence is represented by a straight line and therefore is successfully approximated by a piecewise-linear function whose parameters are introduced into the program for the processing of data on an electronic computer.

Some scientific results of use of ATsIT complex. The scientific research ships of the Arctic and Antarctic Scientific Research Institute have now employed the ATsIT in situ and considerable experience has been accumulated. A considerable volume of observational data has been obtained, which makes it possible to analyze the measurement principles employed in the instrument. Conclusions have been drawn concerning the peculiarities of instrument design, the reality of the metrological characteristics obtained and the possibilities of employing the complex in oceanographic practice.

Observations were made for solution of scientific problems:

1) study of the spectral composition of short-period thermohaline fluctuations in the neighborhood of the seasonal thermocline;
2) study of mesoscale variability of variations of temperature, salinity, current vector at the northern periphery of the polar hydrofront;
3) investigations of the peculiarities of vertical structure of thermodynamic inhomogeneities in the regions of probable formation of eddy formations.

We will examine some results of use of the ATsIT complex for study of a definite class of physical phenomena and processes in the ocean.

During the period of the 21st voyage of the scientific research ship "Professor Zubov" in making an oceanographic survey of the frontal zone of the Mohns Ridge the southeastern periphery of the hydrofront during the period 2-4 August 1977 a system of formation of three eddies was discovered. Two of these were anticyclonic and one was cyclonic, the diameter being about 15-20 miles. The existence of eddy structures was clearly traced in the field of temperature and geostrophic currents from depths of 800-1000 m to the surface.

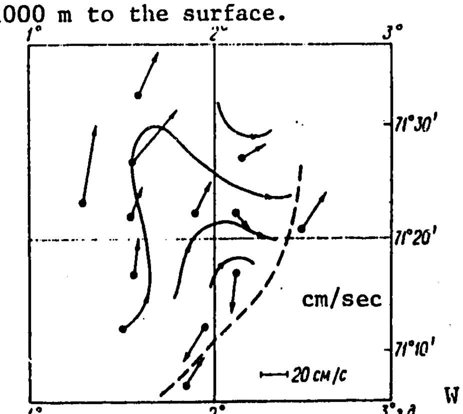


Fig. 8.7. Instrumental and geostrophic currents at 50-m horizon. 15-18 August 1977. Norwegian Sea. Region of Mohns Ridge.

During the period 15-18 August an attempt was made at a detailed investigation of the central cyclonic eddy with the use of the ATsIT and bathometer-sonde complexes. In the region where the eddy was situated the plans called for a regular grid of 18 oceanographic stations with distances of 5 miles between them. The following observations were made at each station:

-- sounding of the layer 0-2000 m with the bathometer-sonde;
-- measurement of the total vector current + drift using the ATsIT measurement complex at the horizons 50 and 100 m;
-- determination of the true drift by means of the "Transit" SNS (satellite navigation system) (ensuring an accuracy in determination of coordinates of 200-220 m) during the entire period of observations at each station.

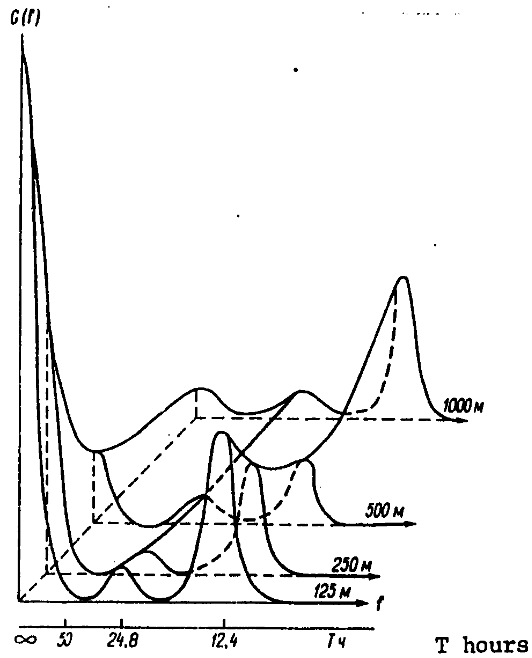


Fig. 8.8. Characteristic spectrum of temporal variability of current vector. Norwegian Sea. Neighborhood of Mohns Ridge.

On the basis of observational data B. G. Borisov and B. A. Vasil'yev constructed maps of the horizontal distribution of water temperature and maps of dynamic topography. Vectors of true currents were computed. An analysis of the collected data (Fig. 8.7), carried out by B. G. Borisov and B. A. Vasil'yev, demonstrated that in comparison with the survey of 2-4 August there was a change in the sign of circulation in the investigated region. In place of the cyclonic eddy an anticyclonic meander was formed, clearly expressed in the field of currents obtained by the instrumental method and indirectly confirming the general warming and salinization of waters in the layer 100-1000 m (caused by descending movements of waters at the center of the meander) and general vorticity of the same sign in the field of geostrophic currents. In the region of the meander there were considerable current velocities (up to 62 cm/sec), not corresponding to the small gradients of density and velocities of geostrophic currents (about 12 cm/sec), which is evidence of a strong influence of ageostrophic forces on the dynamics of the investigated formations.

In a specific situation, due to the inadequacy of initial data, it is difficult to draw valid judgments concerning the path of movement and the possible evolution of the detected cyclonic eddy. It is only possible to postulate that it was displaced in a northeasterly direction and was replaced by an anticyclonic formation arriving from the southwest, which moved with a mean velocity of about 10 $cm \cdot sec^{-1}$, close to the velocity of mean movement.

The cited example shows that the method employed for investigation of local regions of the frontal zone with the use of the ATsIT complex in all probability will make it possible to describe the real pattern of formation of thermodynamic inhomogeneities, although, without question, it requires an analysis of the accuracy of the method employed.

The principal purpose of the ATsIT complex is self-contained measurements of the parameters of state and dynamics of the sea medium at a buoy station [8]. Figure 8.8 shows the characteristic spectrum of temporal variability of the vector of currents on the basis of the results of observations using BPV-2 and ATsIT automatic recorders at six buoy stations in the neighborhood of the frontal zone in the neighborhood of Mohns Ridge. The ATsIT registered currents at the 250-m horizon. The duration of the observations was from 20 to 30 days and the discreteness was 30 minutes. The results of observations of currents make it possible with a sufficient reliability and detail to compute the validated evaluations of the spectral density functions in the range of periods from 1 hour to 2-3 (sometimes 3-4) days and thereby describe the temporal variability of the current vector, draw conclusions concerning the spectral composition of the oscillations, and also interpret the nature of their appearance.

On the spectral curves everywhere there are energy bursts with characteristic time scales of about 12.4 and 24.8 hours, and also a high energy level of the long-wave part of the spectrum, indicating the presence in the series of currents of low-frequency components with scales exceeding the length of the observation series. These components make the principal contribution to the general dispersion of fluctuations in the current field. The energy of the trend as a rule rapidly decreases with depth, especially sharply at the upper horizons (for all practical purposes by an order of magnitude) and more slowly in the deep layer (from 500 to 1000 m).

Some part of the energy is concentrated in the region of diurnal variations which also have an obvious tidal origin. The spectrum of these variations is not subject to deformations with an increase in depth.

8.2. Submerged Buoy Station

The submerged buoy station with hydroacoustic search and signaling is intended for placement at sea for long-term self-contained operation of different recorders of characteristics of the sea medium [110]. The complex of technical instrumentation with which the station is outfitted, in combination with the units placed aboard the scientific research ship, makes it possible to conduct a search, detect it and send a signal for the floating-up of the carrier and instrumentation.

The submerged buoy station was developed for replacement of traditional buoy stations with above-water buoys (autonomous buoy stations) for the purpose of increasing the viability and duration of operation of self-contained apparatus in the open sea or beneath ice, and also for enhancing the quality of the information received by means of the measurement instruments which it carries.

Figure 8.9 is a schematic representation of the submerged buoy station. All the apparatus in the technical complex and the makeup of the equipment used on the station can be classified as on-board and underwater. The on-board apparatus is located in the laboratory of the scientific research ship. It consists of a transmitter, receiver, signal indicator and an array of hydrophones for the sound sources and is intended for use in search and signaling the station to float up.

The underwater part consists of a supporting float with bracings and attachment elements, hydroacoustic beacon with primary depth converter, two paired cable releases, self-contained oceanographic instruments, supporting cable and anchor system.

A basic feature of the submerged buoy station is the submergence of a supporting float to a depth of about 100 m. This is fitted with instruments. An appropriate choice is made of the length of the supporting cable, which is reckoned in dependence on the depth of the point of placement, with current velocity taken into account. The absence of significant movements, usually caused by movements of a surface buoy under the influence of the waves and other hydrometeorological factors, makes it possible to increase the viability of the station and exerts a positive influence on the readings of the instruments attached for work.

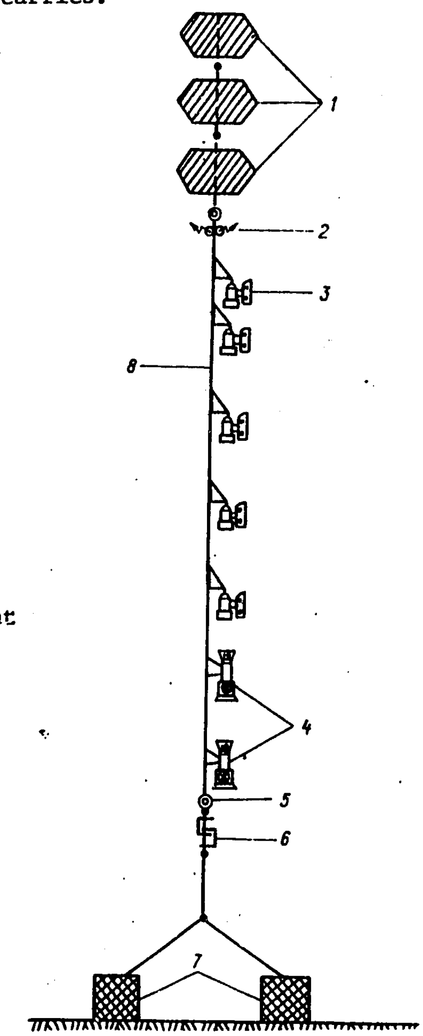


Fig. 8.9. Schematic diagram of underwater part of submerged buoy station. 1) supporting floats; 2) hydroacoustic beacon; 3, 4) BPV-2 and ATsIT measurement complexes; 5) pivot; 6) hydroacoustic releases; 7) bottom anchors; 8) buoy line

The search for and detection of the station is accomplished by means of a hydroacoustic signal of a definite periodicity and power which is shaped and sent into the water by a hydroacoustic beacon at a fixed frequency. The arrival of the ship at a point with the stipulated coordinates is ensured by some navigational systems of the satellite navigation system "Transit," radar navigation systems "Omega," "Loran" and "Decca," with which scientific research ships are usually outfitted. The beacon signals are received by the shipboard sonar and if the ship does not have such a system -- by the "Poisk" hydroacoustic direction-finding system, specially developed at the Arctic and Antarctic Scientific Research Institute, by means of which it is possible to ascertain the bearing and distance to the station with constant tracking of the latter. In the immediate neighborhood of the station there is a signaling device which through a hydrophone-emitter sends coded call signals into the water at a definite frequency. The signals are received by the submerged buoy station, the station receiver cuts in an actuating mechanism, after which the cable releases are triggered. As a result the connecting cable breaks loose at a stipulated depth, usually near the anchor system. The anchor remains at the bottom, but the framework and cable with the attached instruments rise to the surface under the influence of positive buoyancy where they are hauled aboard by the usual method. An indicator for bringing the station to the surface is a decrease in the pulse repetition rate from the acoustic beacon.

The submerged buoy station complex has undergone successful in situ tests on a number of voyages of scientific research ships of the Arctic and Antarctic Scientific Research Institute and beginning with the 15th voyage of the scientific research ship "Professor Zubov" (1976) has been used systematically for placement of BPV-2 and ELT automatic current meters, photothermographs and ATsIT complexes in position for long-term autonomous operation. The experience gained in work with the submerged buoy station has made it possible to formulate the principles of methods and apparatus for setting out the station under real oceanographic conditions.

Prior to setting out the submerged buoy station in the stipulated region the depths to the bottom are measured at the site of occupance of the oceanographic station; a work chart is prepared showing true measurement depths.

The supporting float complex is usually assembled from three frameworks with attachment elements, each with a lift of about 400 kg. The number of float units is determined by the mass of the connecting cable with the instruments, which may be more than 1 ton. These float units are concentrated in the upper part of the connecting cable, one directly above the other in such a way that the lower one is situated at a depth of about 75-100 m. In order to avoid dangerous loads due to inertia and drag the float units are allowed free movement on segments of cable with a diameter of 10-12 mm.

Two hydroacoustic beacons are suspended on a bracket somewhat below the last float unit. Instruments are arranged on brackets, at the horizons recommended by the observation program, lower on the connecting cable, depending on the purposes of the investigations. The upper horizon at which the instruments are placed most frequently is the horizon 100-125 m. Since a considerable static load is concentrated in the upper part of the connecting line, the upper segment of the connecting cable is separated into an independent unit and is positioned from an individual winch.

The connecting cable supports all the instruments and apparatus and connects the load-carrying floats and the anchor into a unified system. The connecting cable set consists of cables with a diameter from 8.7 to 4.9 mm with the necessary fittings (pivots, hooks, eyes, etc.).

Instruments and pairs of acoustic cable releases are placed along the length of the connecting cable at stipulated horizons. This pair of cable releases is fabricated in the form of a unified rigid device. The latter are placed at a distance of 300-400 m from the bottom. Such a depth of submergence ensures a guarantee against the releases sinking to the bottom due to possible errors in determining the depth of the site due to complex bottom topography or failure to reach the intended depths in the case of a considerable drift. In case of necessity for correcting the length of the connecting cable (due to a constantly changing depth of placement) the anchor system and a segment of the connecting cable is also separated into an individual link and is placed independently from an individual winch. As a result of experimentation it has been established that an anchor system of two reinforced concrete anchors with a total weight of 340 kg in the water reliably holds the station in the position where it has been placed.

Computations of submerged buoy stations with depths of placement up to 4000 m and with a safety factor along the entire length of the connecting cable amounting to not less than 2 indicate that the static load, with allowance for mass of the anchors, can attain 1.5 tons.

Full computations of the static and dynamic loads on the station, full and residual buoyancy, restraining force of the anchors and depression of the float units under the influence of the current are carried out in accordance with the recommendations set forth in [103]. It has been determined experimentally that a positive buoyancy of 150 kg reliably ensures the surfacing of the station after the triggering of the releases and setting-free of the anchors. An increase in positive buoyancy can result in a decrease in the restraining force of the anchors, and as a result, to scraping of the station on irregularities of underwater relief or to drifting under the influence of the current. A decrease in positive buoyancy is a cause of a considerable submerging of the float units (and accordingly, the instruments) in a strong current.

The in situ placement of a submerged buoy station is one of the most complex and time-consuming tasks in oceanographic work. A great accuracy in computations of the weight characteristics and buoyancy of the submerged buoy station is required. In case of necessity, all the instruments, equipment and fittings mounted on the station are weighed and measured. Precise data are required concerning the length of the connecting cable and the forces holding the station in a stipulated place. Inadequate allowance for any station parameter can result in uncorrectable consequences. Jerkings of the connecting cable and inertial loads on it as a result of the effect of the float unit mass and the entrained mass of water, due to a considerable drag in the waves, involve a constant risk of losing the station. An unmonitorable depression of the horizons at which the float units are situated under the influence of the current and sinking of the beacons below the admissible limit precludes the possibility of detecting the station in the ocean. Other aspects of work with submerged buoy stations, requiring precise allowance, have been indicated above. Unfortunately, the methods for designing submerged buoy stations do not provide reliable methods for determining deepening of the station in dependence on residual buoyancy, drag and current velocity, as well as the restraining force of the anchors in dependence on their shape, mass and nature of the bottom. Improvement in methods for in situ placement of submerged buoy stations should probably proceed along the lines of increasing accuracy in computing the parameters of the station and the most probable exclusion of random factors exerting a negative influence on its reliability.

The submerged buoy station is a modern technical means for the placement of different instruments for long-term autonomous operation. A submerged buoy station has a number of obvious advantages over a traditional buoy station with a surface buoy and is free of the shortcomings characteristic of automatic buoy stations. First of all, the submerged buoy station has a longer lifetime than an automatic buoy station since it is influenced to a lesser degree by external factors. Another advantage is a substantial increase in the accuracy of measurements of current elements. The results of statistical processing of the results of current measurements at three submerged buoy stations (8 horizons) and four automatic buoy stations (16 horizons) on the 21st voyage of the scientific research ship "Professor Zubov" are clear evidence of a substantial increase in the quality of primary information when working with automatic current meters on submerged buoy stations. When registering currents at a submerged buoy station the dispersion of the random measurement error, determined by extrapolation of the structural function to zero, in the layer 125-1000 m is insignificant and at the upper horizons is 0-0.1 of the natural variability of currents and at the lower horizons is totally absent. At automatic buoy stations the measurement errors for the horizons 50, 125, 250, 500 and 1000 m average 0.70, 0.30, 0.15 and 0.10 of the current vector dispersion respectively and can very substantially distort the really existing pattern. Earlier researchers [109] have repeatedly pointed out the inadequate accuracy in measuring the current vector in the surface layers at automatic buoy stations, which introduces a considerable "noise" component into the dispersion and mean values. It must be added that the errors in measuring the current vector exert a strong influence on the accuracy in computing different derivative values, including those for the slope of the frontal surface in the ocean and the index of the degree of geostrophicity of real flows, which frequently leads to unstable and contradictory results.

9.4. Use of Automated Systems and Electronic Computers in Oceanographic Work From Ice Cover

The specific conditions for the work of expeditions on the ice of the Arctic Basin make difficult the carrying out of automation in the same way as on scientific research ships.

These conditions include:
-- the transporting of automatic equipment (AE) by air or sea transport at low temperatures;
-- instability of temperature and air humidity during operation of AE in working places;
-- relative reliability of viability of the observation platform (sea ice) and the associated impossibility of stationary placement of AE;
-- limited possibilities of the power of expeditionary electric power stations;
-- need for rapid deployment and removal of AE associated with the possible appearance of emergency situations at working places in the ice camp;
-- limited number of specialists -- members of the expedition responsible for the operation and technical monitoring of AE.

Without question, the basis for the AE on such expeditions should be, the same as in the KTS ASOGI [complex of technical means for the collection and processing of data], the use of a program-controllable electronic keyboard computer (PEKVM -- programmno-upravlyayemaya elektronnaya klavishnaya vychislitel'naya mashina), having the necessary characteristics [119]. The most important of these are the following: adequate computation capabilities; simplicity in operation; possibility for connection of a great number of external devices, including measurement systems; small mass and size.

Beginning in 1975, on the high-latitude aerial expedition "Sever" of the Arctic and Antarctic Scientific Research Institute, for the purpose of primary processing of observational data and speedy analysis, use has been made of the "Elektronika S-50" and "Iskra-125" PEKVM; a special packet of programs was prepared for this purpose. Despite the limitations in solving the formulated problems, this automation in the processing of oceanographic observations, carried out both on the SP drifting stations and on sea arctic expeditions on ships of the "Mayak" type, has found its use. At the present time, in the processing of data use is made of the DZ-28 PEKVM, which is more modern and program-compatible with the "Elektronika-50" PEKVM.

In 1977 the "Sever" expedition carried out tests showing convincing results of an expeditionary computer complex created on the basis of the "Iskra-125" PEKVM. It included a magazine-type unit for storage on magnetic tape (KNML -- kassetnyy nakopitel' na magnitnoy lente), an FS-1500 photoreadout unit, a T-51 teletype and an LKD-4 two-coordinate curve plotter [29]. The joining of the latter three external devices to the PEKVM is accomplished by an input-output widener. In this complex the KNML is used exclusively for registry and input of programs and reference data. The teletype is used for the control of problems, input of primary data, printout of the results and transfer of the data to a punch tape. The photoreadout unit is intended for the repeated input of data into the PEKVM in the subsequent processing stages. The curve plotter is used for the graphic representation of the collected data and plotting profiles of the measured parameters and derivative values.

It can be seen that as the technical carrier, in contrast to the KTS ASOGI, use is made of a punch tape, not a magnetic tape. The choice of the punch tape was dictated by the greater reliability of this carrier and the fact that the collected data are relatively graphic, as is especially important under the conditions of arctic expeditions. The punched tape is ready for direct input into the on-board computation center computer and additional reregistry on a wide magnetic tape is not required for this.

The punched tape obtained after primary processing through the FS-1500 can again be introduced into the PEKVM and thereby the stages of both systematization and analysis can be accomplished in this expeditionary computation complex.

The use of the KNML only for the registry and input of the program makes it possible to solve rather complex problems by means of segment-by-segment loading of the programs, whose length can exceed by an order of magnitude or more the volume of the operational memory unit of the PEKVM, and this considerably broadens the possibilities of a scientific analysis of data [119]. An additional KNML must be introduced into the KTS ASOGI for these purposes.

The introduction of the teletype into the expeditionary computation complex made it possible not only to obtain standard processing and systematization documents -- observation data books and tables in the form close to that usually employed, but also to organize all the programs in a dialogue regime. This simplifies the operator's work and reduces the probability of the appearance of errors.

The punched tape can serve as a component in the archives of oceanographic observations. Using the punched tape in both the PEKVM and with the large computer in the shipboard computation center it is possible to obtain a composite TGM-3M table, organize an archives of data from this expedition and carry out computations related to an analysis of the observations.

The organization of work in the expeditionary computation complex is governed by the different regimes of receipt of data. The primary processing can be carried out directly after the measurements (for example, when working on an SP drifting station) or after the accumulation of some volume of data by the mobile detachments of the "Sever" high-latitude expedition, when during one takeoff several oceanographic stations are occupied. A nonuniformity in the receipt of data is also characteristic for the work of different research detachments.

The expeditionary computation complex has proven itself under the difficult operating conditions of the "Sever" high-latitude expedition, which specifically involves a frequent rebasing of the expeditionary computation center, which in turn involves its repeated deployment and repacking of the equipment and its transport. Thus, in the course of 2.5-3 months the computation center operates at five or six different arctic points: on shore, on islands and on drifting stations; its route in the air is more than 20,000 km.

In the considered expeditionary computation complex there is no automation of observations. However, this problem is solved quite simply for any primary converters having an electric signal at the output.

The linking of such converters as temperature-salinity sondes, strings of temperature sensors, etc. with the PEKVM is accomplished through interfaces specially developed for this purpose, cut in through the "input-output widener."

Such an organization of automated systems makes it possible to create programmed instrument complexes in which by programming, as the results are obtained and analyzed, without man's intervention, it is possible to bring about changes in different research investigations, such as a change in the spatial and temporal discreteness of observations. The latter is especially important in study of rarely repeating phenomena existing a short time.

An example of such a programmed instrument complex is the automated actinometric complex created at the Arctic and Antarctic Scientific Research Institute and which has functioned well on the SP-22 drifting station [6].

Modern trends in investigations of natural processes are tied-in to synchronous measurement of several medium parameters at the same time. An extremely timely task is now the creation of a multichannel recorder of data obtained at one and the same time from different primary converters with the simultaneous entry of data on a technical carrier. Such a recorder has been created at the Arctic and Antarctic Scientific Research Institute. This is a cassette magnetic tape storage unit [29]. The design of the KNML itself is extremely reliable, as is especially important for work on Arctic expeditions.

Thus, the use of complexes created on the basis of the PEKVM opens up broad prospects not only for investigations carried out on drifting ice. They can be used in solving many other problems on different expeditions: on small ships not outfitted with electronic computers, in the network of polar stations, at sea ice operations headquarters, etc. Their possibilities are especially widening with an increase in PEKVM computational capabilities.

Such a machine, meeting the greater part of the requirements imposed on it, has already been created -- the "Iskra-1256." This PEKVM and the complex created on its basis will already find extensive use in investigation of the Arctic in the coming years.

CHAPTER 10. PROSPECTS FOR DEVELOPMENT OF METHODS FOR OCEANOGRAPHIC RESEARCH IN ICE-COVERED REGIONS OF THE WORLD OCEAN

10.1. General principles. Oceanographic surveys, studies in polygons and along individual profiles, carried out from ships and the ice cover, roadstead observations and observations of the state of the sea from shore, work with the use of aviation and artificial earth satellites, constitute the necessary information base for studying the Arctic and Antarctic Oceans. During recent decades the area of such observations has been continuously and actively expanded. The qualitative side of observations is also increasing due to the use of new methodology for investigations and modern technology.

Nevertheless, it must be admitted that the degree of study of the polar regions is inadequate and knowledge concerning hydrophysical processes and the patterns of the water regime frequently have a fragmentary character even from a microscale point of view.

One of the reasons for such a status of study of the polar regions is the considerable extent of the ocean areas and the volumes of their waters, as well as the climatic conditions making difficult the expeditionary hydrometeorological study of the Arctic and Antarctica.

It can be assumed that even with the use of new technology, sharply increasing the information yield of observations and the effectiveness of research, the inadequacy in study of polar areas will still for a long time stimulate the development of oceanographic investigations of the Arctic and Antarctica.

The development of research is dictated by the interests of society, which are inseparably linked to study of the ocean and the use of its resources (energy, biological, geological, etc.), with the economic exploitation of its regions. These interests will also increase with a deepening of our knowledge and comprehension of the role of the polar regions in the processes which in general determine the global state of the environment.

Without question, the expansion of investigations will be accompanied by a further improvement in both the transportation base, observation platforms and technical means of collecting information, as well as the methodology for planning, organization and implementation of in situ experiments, including methods for processing and transforming information by means of electronic computers.

In this section we present some prospects and and specific tasks of development and improvement of technical means and methods for oceanographic work applicable to investigation of the polar regions of the world ocean.

The exposition of the prospects reflects the ideas of the authors relying on the generalized experience in expeditionary investigations accumulated by the Arctic and Antarctic Scientific Research Institute and takes into account modern tendencies in the development of the instrumental base, machine technology, transportation facilities and methods for experimental investigations in the ocean. The method for conducting some types of oceanographic work from drifting ice in the Arctic Basin is one of the possible variants for realizing their development.

10.2. Oceanographic Work in the Arctic Basin

The results of investigations in the field of oceanography of the Arctic Ocean are evidence that despite definite successes in the multisided study of the regime and in the development of methods for long-range hydrometeorological and ice forecasts, inadequate work has been done on many problems relating to fundamental comprehension of the nature of the ocean relating to explanation and prediction of extremal states in the atmosphere-ocean-ice system and to a comprehension of the physical essence of the mechanisms of energy transformation in this system.

Long-range ice and hydrometeorological forecasting is still based in most cases solely on allowance for the external sequence of change of events and does not always take into account the internal factors and mechanisms responsible for such a sequence. This applies, in particular, to variations on a climatic scale (including prolonged changes in the forms of circulation, ice content and hydrological regime). As an example, it is possible to cite the appreciable warming of climate in the northern hemisphere observed during the period 1921-1960. This phenomenon has not yet been adequately explained. Moreover, science still cannot predict the climatic background in this region of the earth even in the coming decades. However, all the physicostatistical relationships and methods for selecting predictors for the regime characteristics of the arctic zone have been established precisely on the basis of data for the mentioned period. Whether these correlations will retain their stability in the future or will begin to be "disrupted," this problem is primary and is directly related to the needs of the national economy. The need has arisen for creating a system of investigations which at the same time would be of an adequate scale and sufficiently detailed, with wide coverage, operational, automated and economically optimum [115].

In the light of the discussed problems, the available materials from oceanographic observations and the methods for their collection in the Arctic Basin at the present time do not adequately completely satisfy either science or practical needs. First, because an oceanographic survey of the area of the ocean basin and seas, carried out by the "Sever" expedition, is made only once a year (April-May), not supplying data for other seasons of the year. Second, the observational data obtained at the SP drifting stations, despite their great value and importance, suffer a substantial shortcoming -- the drift of each SP station during one and the same months and seasons of the year occurs in different regions and in the analysis they are difficult to compare in time and space. For science, however, as in practical work, it is desirable to have long-term year-round observations in the very same regions of the Arctic Basin and seas.

The task of the immediate future will be the development of such new methods, and with them technical and transportation means for oceanographic investigations in the Arctic Basin which would be capable of ensuring observations in the necessary regions over a long period in time and a great spatial resolution.

The vigorous development of technical means for making observations (artificial earth satellites, automatic stations, buoys, instruments, etc.), even with their remote control, does not preclude the direct presence and participation of the researcher himself in carrying out observations of natural processes and phenomena in their natural manifestation. The principal method for further many-sided scientific-productive study of the Arctic Ocean and especially its inaccessible part -- the Arctic Basin, in our opinion, as before, remains expeditionary.

The most promising methods for study of the Arctic Basin and arctic seas are synchronous oceanographic surveys and stationary long-term oceanographic observations at constant reference points and at drifting stations of the SP type.

The further most effective study of all aspects of the regime of the Arctic Basin and its seas will possibly involve a desirable combination of these methods.

Below we will examine some of the methodological principles of these methods for oceanographic research, the means for carrying them out with allowance for the requirements on them following from the physiographic and natural characteristics of the basin.

10.2.1. Synchronous oceanographic surveys. This sort of survey has as its purpose the synchronous (or near-synchronous) implementation of sporadic oceanographic and other observations in definite regions of the Arctic Basin with the required spatial frequency of stations. These surveys must be carried out not less than once each season and observations in each such survey should be carried out at one and the same points. It is proposed that the duration of a synchronous survey completely taking in the area of the Arctic Basin should not exceed one month.

The observational data obtained as a result of synchronous oceanographic surveys will afford the possibility for creating a map of the state of waters in the Arctic Basin during the period of the survey. The possibility of studying the dynamic processes transpiring in the investigated regions in this case will be still extremely limited and tidal processes in general can be completely neglected. Therefore, in addition to synchronous surveys, and in some cases in place of them, it is desirable to carry out so-called autonomous-automatic surveys. In such surveys, at a sufficiently great number of points, with the required frequency covering the investigated ocean area, automatic recording instruments will be placed out on the ice and will regularly transmit hydrometeorological information. The automatic instrument complexes set out on the ice must operate for a sufficiently long period of time. Automatic means for the collection of oceanographic and hydrometeorological information will make it possible to have maps of the oceanographic elements which similar to synoptic maps constitute an "instantaneous" picture of physical fields in the ocean at different depths simultaneously with meteorological conditions.

In examining the two variants of "surveys" as the possible immediate prospects for the development of oceanographic investigations in the Arctic Basin, it is necessary to evaluate the real conditions. Such "surveys" in the Arctic Basin are time consuming, expensive and organizationally quite complex. Most importantly, there is a need for appropriate transportation facilities, equipment and gear, which for the most part does not yet exist and which must be developed.

In order to carry out oceanographic surveys it is necessary to use special transportation facilities (sea scientific research vessels, icebreakers or submarines, aircraft or helicopters), as well as instruments and gear.

Synchronous autonomous-automatic surveys, together with the necessary number of automatic instruments and corresponding transport vehicles for their delivery and placement on the ice, require the presence of a well-operating system for determining position and the collection of information arriving from them. This system can operate either via a special artificial earth satellite or via radio tracking stations.

The practical implementation of such surveys, by virtue of the physiographic and climatic characteristics of the Arctic Basin, requires transport vehicles which at any season of the year are capable of delivering scientists to the regions of interest to them and ensuring the safety of personnel and the possibility of carrying out oceanographic work either directly from transport platforms or from the ice. A transport vehicle intended for such surveys should have the following qualities: high effectiveness in active overcoming of thick drifting ice, adequately great autonomy or radius of action, high speeds of movement in the region of implementation of a survey, possibility of operating at any season of the year.

Among all the known sea and air transport vehicles, having to an adequate degree the mentioned qualities, taking into account the possible prospects of their development, the use of either a scientific research submarine or dirigible will evidently make it possible to solve the formulated problem [35, 38]. Even powerful atomic icebreakers, having a high effectiveness in actively overcoming perennial ice and a great autonomy, are ineffective in areal oceanographic surveys. Due to the relatively small rates of movement in the ice this sort of survey of the Arctic Basin and arctic seas (even when using several icebreakers) will occupy a considerable period of time commensurable with a season of the year.

When using for an oceanographic survey either a scientific research submarine or a dirigible it will be possible not only to make the necessary observations throughout the year, but also to set up laboratories on them which are supplied with the corresponding instruments, including electronic computers. For example, instrumentation aboard transport vehicles will make it possible not only to broaden the number of elements which can be determined in sea water, but also to make an in situ analysis of sea water samples, which at the present time are transported by aircraft from one oceanographic station to another prior to arrival at a base, which is a substantial methodological shortcoming in operation of the "Sever" expedition.

The use of aircraft or helicopters for oceanographic surveys in the Arctic Basin and arctic seas, with their year-round employment taken into account, is possible under the condition that they, in addition to the requirements indicated above, will also have such design and flight-technical qualities as would enable them:
-- at any season of the year (including during the polar night) to make primary landings on the drifting ice with the choice of a landing strip from the air (for an aircraft a ski undercarriage is required);

-- to use for the landing strip a floe of relatively small size (600-800 m is the most frequently encountered extent of even and sufficiently thick floes);
-- with a flight range of 3000-4000 km have a payload of not less than 1000 kg;
-- have a relatively small flight mass (about 15-17 tons), which will make it possible to use for the landing a floe with a relatively small thickness (60-80 cm).

A factor of more than a little importance is the hourly expenditure of fuels and lubricants, especially when the aircraft or helicopter must be used in carrying out work from bases organized on drifting ice for which the delivery of fuels and lubricants involves complexities of an organizational, technical and economic character.

Unfortunately, at the present time there are still neither aircraft nor helicopters with such (or close) flight-technical characteristics. Even if aircraft or helicopters with such qualities are created, for the considered work the helicopter must be regarded as preferable because the possibility of using an aircraft is limited to February-June. During the remaining part of the year the landing of an aircraft on the ice is virtually impossible either due to melting of the ice (summer-autumn period) or due to the polar night.

10.2.3. Stationary long-term oceanographic observations at constant points (or regions). Such observations in essence are identical to the observations of weather ships, which during the entire year at one and the same points in the world ocean make continuous oceanographic and other investigations. Regular oceanographic observations made together with meteorological and other observations over a period of years at several representative points in the Arctic Basin will afford the possibility of obtaining data on the annual and long-term course of hydrometeorological characteristics and its variability. In addition, the availability of year-round materials in the "key" regions of the basin will make it possible to tie in data from seasonal surveys. Stationary long-term observations at such points in the long run will possibly replace the oceanographic investigations made on the SP drifting stations.

In order to carry out such observations under the conditions prevailing in the Arctic Ocean it is necessary to develop a method which would make it possible to exclude the effect of the principal obstacle hindering its implementation -- the drift of ice. The constant movement of the ice does not allow the above-water transport vehicle from which oceanographic work is carried out in the basin to maintain its position in constant geographical coordinates.

One of the promising methods for carrying out long-term observations at a constant point (or region) can be as follows.

A transport vehicle with scientific personnel aboard, supplied with everything necessary for a prolonged (year or more) stay in the research region, arrives at the stipulated point and is moored (with its technical characteristics taken into account) to one of the floes, after which the scientific personnel proceed to implementing the planned program of observations. It is assumed that some of the observations are made directly from aboard this transport vehicle and some from the ice. The necessary living and laboratory rooms are situated directly on the transport vehicle.

Since the rate of general drift of ice in the Arctic Basin per day averages 3-5 km, the transport vehicle in the course of 10-15 days can remain moored to the floe. As soon as the transport vehicle withdraws from the stipulated point by 50-75 km, the instruments and gear situated on the ice are disassembled and loaded on it and it returns to the initial point. The movement to the new place together with disassembly, loading, unloading and installation of instruments should require no more than a day. Such movements of the transport vehicle will take place regularly during the entire period of observations at the stipulated point.

The implementation of such a method for carrying out oceanographic work in the Arctic Basin requires a corresponding transport vehicle capable of withstanding (or avoiding) the effect exerted upon it by compressive forces of continuous perennial ice, relatively rapidly moving in it (or outside it), even under the conditions of the polar night, or have a quite great autonomy. Among the most promising transport vehicles for this purpose are: a powerful icebreaker or scientific research atomic submarine. A dirigible is also not excluded.

On drifting stations of the SP type, the practical introduction of new methods for regular oceanographic investigations will transpire as individual elements continue to be perfected, with the use of different technical and transport facilities. Accordingly, the importance of the SP stations in the study of natural processes in the Arctic Basin will persist for a long time, despite the already mentioned negative characteristics of their operation.

Oceanographic work at the SP stations will be directed to a further investigation of the problems of thermodynamic interaction between the ocean and the atmosphere: structure and dynamics of waters, including mixing processes, stability, internal waves, etc.

The continuation of the key role of SP stations in the investigation of the Arctic Basin in the immediate future, however, does not preclude a further improvement in definite organizational-methodological principles of their operation.

In order to increase the viability of the stations, as the platform for their installation it is possible to use special ships whose hull would be capable for a long time to withstand any effect upon it by the compressive forces of continuous perennial ice [75]. The use of such ships will make it possible to install on them laboratories which are outfitted with special automated measurement apparatus and computers, something which cannot be done in full measure on drifting stations. On a ship it is possible to create far more convenient working and living conditions than is possible on modern SP stations.

With the retention of the existing method for station operation (use of perennial floes or ice islands for their placement) it is better that their organization be accomplished using powerful icebreakers. There has been successful experience in organizing SP stations by means of icebreakers. [The SP-10 station was established on the ice by the atomic icebreaker "Lenin," and the SP-22 by the diesel-electric icebreaker "Vladivostok." The material-technical support of the SP-24 station was accomplished by the "Sibir'" atomic motor ship.] The use of ships and icebreakers simplifies the organization of stations since by employing them it is then possible during this period to avoid primarily time-consuming work on construction of a landing strip on the ice for heavy transport aircraft (which is inevitable in the aerial method for organizing a modern SP station to which it is necessary to deliver more than 150-200 tons of different cargo).

10.3. Oceanographic Work From Ships

The presently existing technical facilities, instruments and equipment used on sea expeditions do not make it possible in full measure to solve the scientific problems provided for in national and international programs for investigation of the polar regions of the world ocean.

In this connection the question has been repeatedly raised of creating special types of expeditionary ships capable of carrying out a voyage and executing work not only in the marginal zone and amidst open pack ice, but also penetrating into the mass of continuous ice or into shore ice.

Such expeditionary ships must be supplied with such laboratory rooms and special equipment as will make it possible to carry out oceanographic work at low air temperatures without danger of icing over of the instruments.

Evidently the prototype of such ships is the scientific research icebreaker "Otto Shmidt" and new ships of the ice class of the "Ovtsyn" type, intended for ice expeditions. It is not impossible that scientific research submarines will be used on a broader basis for oceanographic work in oceanic regions. It can be assumed that at long-term stations scientific research submarines will operate in combination with surface vessels which will perform the functions of an aerometeorological observatory and supply observations in the meteorological complex synchronous with oceanographic observations from scientific research submarines.

Accordingly, there should also be improvement in the method for carrying out oceanographic work from ships of a new type. It is evident that automated instruments must be used more widely (for example, of the bathythermosonde type); these will reduce the working time at a single point, which is of very great importance in working amidst the drifting ice. There must be a further improvement in methods for setting out buoy stations when there is an ice cover.

10.4. Prospects and Tasks for Improvement in Shipboard Automated System

Positive results have now been obtained in the field of automation of collection and processing of information on scientific research ships. Scientific-methodological principles and concepts have been developed for the automation of shipboard observations which are realized in the form of a local shipboard automated hydrometeorological system of the first class in the stage of individual measurement complexes linked to electronic computers. The introduction of the new instrumental base favored the more effective implementation of investigations under the POLEKS (POLEX) program, as a result of which interesting information was obtained on the structure and characteristics of the natural processes transpiring in the hydrosphere and atmosphere in the polar regions.

However, the implementation of multisided in situ experiments on a global scale and the rapid growth in the volume of collected hydrometeorological information make inadequate the attained level in automation of shipboard observations and impose new increased requirements on the subsystem for the collection, monitoring, processing, accumulation and dissemination of information from the oceans and seas [116]. In examining the work of scientific research ships as an important form of fundamental study of the ocean, we arrive at the conclusion that it is necessary to improve the developed automated complexes, taking into account the shortcomings detected as a result of operation. There is need for refining individual methodological problems involved in the use of technical apparatus under field conditions. There must be a broadening of the field of automation by including new measurement complexes in the system, increasing the set of registered parameters. Finally, it is necessary to proceed from available types of mathematical support for individual complexes to the organization of a data control system and specialized on-shore and shipboard data banks. In connection with the above, and with [116] taken into account, the immediate prospects for the development and improvement of the SIGMA-S shipboard system during 1980-1985 are definitely related to the development of experimental investigations in the polar regions under the "POLEKS-Sever" and "POLEKS-Yug" (POLEX-North and POLEX-South) programs. Below we give the principal tasks in automation of shipboard observations in the immediate future.

10.4.1. Tasks in improving individual measurement complexes and broadening of automation regimes.

1. Constructive and schematic reworking of the MARS meteorological station and creation on its basis of a complex with a simplified electronic part, reduced dimensions and more reliable sensors. There is a need for an increase in the accuracy of measurement of meteorological parameters.

2. Realization of the technical design in an improved variant of the ASAS actinometric system and its industrial production. The ASAS must be developed in an assembly-unit principle, making it possible to build up the system from outfit III (installed on class-III scientific research ships) to outfit I (installed on scientific research ships of class I) without design and schematic changes in the assembly units entering into the outfits.

3. Constructive and schematic improvement in the bathometer-sonde complex, which involves an increase in the depth of submergence of the descent complex to 5000-6000 m and changes in the principle for measuring depth to the vibrational-frequency principle for the purpose of increasing measurement accuracy.

It is known that obtaining a quantitative estimate of the relative contribution of the ocean and atmosphere to the heat balance of the polar regions is one of the principal tasks of the POLEKS (POLEX) program [115]. The solution of this problem requires the greatest possible accuracy in determining the components of the heat balance of the ocean and atmosphere. However, the determination of energy and mass exchange near the ocean-atmosphere discontinuity on the basis of data from standard measurements involves great errors. Accordingly, the realization of direct measurements of the flows of heat, moisture and momentum over a water surface from aboard a scientific research ship by use of an automated complex is an extremely important prospect for the development of a shipboard automated system. The creation of such

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a complex will also make it possible to develop investigations of the problem of the heat and dynamic interaction between the atmosphere and ocean, consisting of the necessity for parameterization of the principal physical processes transpiring at the air-water discontinuity, clarifying the relationships of the parameters of turbulence and mean background conditions and the determining external factors, refining the patterns of formation of the thermocline, etc.

As the basis for developing the new complex it will probably be feasible to use the experimental apparatus developed at the Institute of Physics of the Atmosphere, USSR Academy of Sciences and successfully employed on the expedition TROPEKS-72 (TROPEX-72) [28].

It is known that the method for temperature sounding of the active layer of the ocean used in oceanographic practice by means of a bathythermograph has serious shortcomings, attributable to the poor metrological indices of standard-produced instruments and the need for a substantial reduction in the rate of movement of the ship when making measurements. In addition, the character of movement of the bathythermograph in the water also worsens the quality of the data, whereas manual processing complicates the operational use of information. However, such observations are important for investigating both brief processes and phenomena and synoptic variability in the ocean, including under the conditions prevailing in 200-mile economic zones, introduced by a number of countries where the stopping of foreign ships is forbidden.

The use of a bathythermograph with a special sensor of the type of the American-type XBT thermosonde eliminates the above-mentioned complexities and limitations [92]. Encouraging results of work with the use of freely falling XBT probes for measuring the thermocline profile were obtained on the 20th voyage of the scientific research vessel "Professor Zubov" (1976-1977) during joint Soviet-American investigations in the Antarctic Ocean.

The USSR has analogues of freely falling probes. The thermosonde is of the XBT type; an experimental consignment was fabricated and tested at the GUNiO MO SSSR and ensures registry of the vertical distribution of water temperature while the ship is proceeding on course. But this instrument requires improvement in its metrological characteristics. On the basis of experience in developing the thermosonde it is desirable to create a thermosonde of the XBT type with parameters not inferior to the best foreign models.

A study of the forms of oceanic variability caused by turbulent processes of different scales occupies a special place in the problem of investigating the distribution of energy of movements in different spatial-temporal intervals, investigations of the mechanisms of generation, redistribution and dissipation of energy arriving from external sources. For this purpose it is necessary to develop an automated complex for investigating turbulent processes in the ocean. As the basis for such development it is possible to use a complex created at the Marine Hydrophysical Institute, Ukrainian Academy of Sciences [1]. The recorders of the complex are submergible self-contained instruments for studying the three-dimensional velocity field and the temperature field in a broad range of frequencies (wave numbers). The complex must also meet all the requirements imposed on the automated system as a whole.

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A shortcoming of the information on the state and distribution of different hydrochemical fields in the ocean makes difficult the investigation of different thermodynamic processes in the water layer associated with the formation and dynamics of water masses and the development of biological life. This shortcoming of the data must be at least partially filled by the development of measurement apparatus based on principles making it possible to obtain information on the vertical hydrochemical structure with a high resolution [2]. The development should be carried out on the basis of a sonde-bathometer with the inclusion in the complex of: measurement converters for dissolved oxygen and the hydrogen index, whose technical realization is possible at the present time.

The development of the computation element of the shipboard automated system is represented in the form:
-- creation of an organizational-technical subsystem for the accumulation and long-term storage of regime hydrometeorological information in noise-immune form with high densities of the record and rate of exchange with the electronic computer, that is, a specialized bank of hydrometeorological data for the polar regions.

Some of the basic principles of mathematical and technical methods for the practical organization of a data bank are described in [27]. The stages in the realization of measures for the development of an automated reference-data bank have been set forth in [53, 54];
-- creation for first-class scientific research ships of a computer data bank on magnetic disks (tapes) as an individual independent link in a specialized data bank for the organization of a speedy analysis of data and testing of the control elements of the subsystem for measurements and carrying out of in situ experiments;
-- creation, in an expanded form, of a subsystem for the mathematical support of a third-generation electronic computer on scientific research ships for the checking of the collected information, its standard and scientific processing, compression, transformation of data, statistical processing and model computations, accumulation on equivalent formats of magnetic tapes for the purpose of exchange and dissemination.
-- practical testing of the role of the complex of technical apparatus for the collection and processing of hydrometeorological information (KTS ASOGI -- kompleks tekhnicheskikh sredstv apparatury sbora i obrabotki gidrometeorologicheskoy informatsii) on scientific research ships (classes I, II, III);
-- introduction of programmed checking and correction of the information received from measurement complexes.

Improvement in the overall organization and structure of the system evidently must be carried out in the following directions:
-- determination of the degree of complexity and refinement of the principles of operation of a local shipboard automated system of different classes in accordance with the specific features of the scientific tasks facing the scientific research fleet when it is used in the Arctic and Antarctica [116]; solution of problems involved in the logical organization of joint work in the makeup of a system of different recorders of information and technical support of the data link between the data complex and the electronic computer;
-- increase in the level of automation with exclusion of the registry of initial information on an intermediate carrier prior to its checking and primary processing [56];

-- formulation of requirements and design of elements for regulating the controlling effect on the measurement apparatus and its operating regimes for the purpose of "closing" the Arctic and Antarctic Scientific Research Institute automated sea expedition computation data retrieval control system [53].

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