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Translation

PHYSICAL METHODS FOR INVESTIGATING ICE AND SNOW

Ed. by

V.V. Bogorodskiy and V.A. Spitsyn

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PHYSICAL METHODS FOR INVESTIGATING ICE AND SNOW

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 2-23, 51-54, 74-79, 90-93, 104-120, 143-146

[Annotation, table of contents and selected articles from collection "Physical Methods for Investigating Ice and Snow", edited by V.V. Bogorodskiy, doctor of physical and mathematical sciences, and V.A. Spitsyn, candidate of physical and mathematical sciences, Gidrometeoizdat]

CONTENTS

[Text] Annotation. This collection of articles includes materials from a scientific symposium organized by the Order of Lenin Arctic and Antarctic Scientific Research Institute and the Interdepartmental Commission on Study of Antarctica, Earth Sciences Section, Presidium, USSR Academy of Sciences, held in Leningrad, 1-5 October 1973. The articles by Soviet and foreign scientists reflect the results of investigations of recent years in the following directions: 1. Electromagnetic methods for investigating snow and ice, active and passive radar observations of ice and snow surfaces. 2. Optical methods for investigating snow, ice and water. Dynamic and static methods for investigating the dynamic properties of ice and snow.

Contents Original page

PREFACE

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'-SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 7-8

[Unsigned article]

[Text] This collection of articles contains studies devoted to physical methods for the investigation of ice and snow. It can now be assumed that a new direction has already been formed in glaciology -- the physics of ice.

Taking into account the increasing interest in physical methods for investigating ice, the Arctic and Antarctic Scientific Research Institute and the Interdepartmental Commission on Study of Antarctica organized a special symposium which was held in October 1973 at Leningrad. Most of the reports presented at the symposium were finalized in the form of articles which have been published in this collection of articles.

The articles presented in the collection reflect the results of investigations of recent years in the following directions:

1. Electromagnetic methods for investigating snow and ice. Active and passive radar of ice and snow covers.
2. Optical methods for investigating snow, ice and water.
3. Dynamic and static methods for investigating the mechanical properties of ice and snow.

Many of the articles are devoted to the results and methods for investigating the mechanico-acoustical properties of ice and snow. The importance of further investigations in this direction is demonstrated, especially determination of the characteristics of internal friction, the coefficients of absorption, viscosity, velocities of propagation of wave processes, reflecting and scattering properties in a broad range of amplitudes of deformations and frequencies of elastic and visco-elastic oscillations (seismic range, infralow-frequency, acoustic and ultrasonic frequencies -10^{-2}-10^{6}Hz).

Recently investigations have been initiated of dynamic phenomena and the stressed state of the ice covers of different ocean areas by seismoacoustic methods and also methods based on the use of lasers.

The studies made in these three directions reflected new results of investigations which are a considerable contribution to the physics of ice. These results bring considerably closer the solution of highly important physicotechnical problems related to artificial modification of ice and snow (radar observation of sea ice, problems of ice destruction, evaluation of the stressed states of the ice covers by the laser and seismoacoustic method, remote determination of large moisture reserves in the snow cover, etc.).

RADIOPHYSICAL METHODS FOR INVESTIGATING ICE AND SNOW

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 9-16

[Article by V. V. Bogorodskiy]

[Text] Ice, one of the physical bodies occurring most widely over the surface of our planet, is an example of a proton dielectric, a viscoelastic body, capable with a relatively small change in external conditions of changing its micro- and macrostructure, electric and mechanical properties.

Continental and mountain glaciers are sources of pure water and the principal water resources for irrigation in arid regions. The glaciers and ice covers to a considerable degree are regulators of weather and climate. At the same time, glaciers and ice covers on the seas are features creating dangerous natural phenomena.

The shelf of arctic seas and regions of permafrost in Siberia constitute rich warehouses of natural resources. Their exploitation is determined by the possibility of overcoming of the ice, that is, its destruction, or use as a material. Both these aspects lead to the need for studying all the properties of ice and snow. The diversity of problems favored the formation of an independent direction in ice investigations (not only as a substance, but also as a geophysical feature), ice physics.

The physics of ice as a science has already attained considerable successes in the study of the atomic-molecular structure of ice, the behavior of protons in hydrogen bonds and lattice dynamics. This has been facilitated by the work of Professor Granicher (Switzerland) and Doctor Wall (Canada). Important investigations have been carried out for studying the growth of ice crystals and their orientation by N. P. Cherepanov and P. A. Shumskiy (USSR), Doctor Hobbs and Doctor Kitcham (United States).

However, in ice physics there are a number of problems which until now have only been formulated. From our point of view such important problems include the thermoelectric effect of ice, potential jump at the boundary of development of phases and precipitation of impurities during the growth of ice crystals from a melt and solution. The investigation of the processes of thermoelectricity and potential jump, to be sure, in the long run will lead to an evaluation of the possibility of using the energy of the discussed phenomena. At the present time quantitative estimates are already being given for the thermoelectric potential gradient and the potential gradient at the ice-water discontinuity, attaining several tens of volts. Primary laboratory investigations show that these phenomena are in fact singular natural generators of electric energy.

Investigations of the influence of impurities on ice structure are very interesting. It has been established that exceedingly small quantities of impurities (F, HF) in virtually every case bring fresh-water ice close in its properties to sea ice. Penetrating between the crystals, in many cases they give a complex structure with variable salinity and the presence of small volumes of saline water. Such a structure is the subject of intensive study by physicists: it is responsible for the mechanical and electrical properties of ice. A comprehension of the physical principles of the growth of crystals in the presence of impurities is of great importance in developing reliable methods for obtaining drinking water from the sea by means of its freezing. The problems of atomic-molecular physics of ice were discussed more completely in [4].

In this article we examine some problems related to study of the electromagnetic characteristics of snow and ice (including the optical and mechanical properties of snow and ice and dynamics of the ice covers).

The availability of these data makes it possible to solve a number of serious practical problems: creation of radio equipment for sounding ice covers, study of the functional dependence of the mechanical characteristics of ice, conditions for the transfer of radiant energy through ice covers, measurement of the rate of movement of ice covers and evaluation of their stressed state.

Electromagnetic Characteristics of Ice and Radio Probing of Ice Covers

During recent years specialists in the USSR, United States, Denmark, Canada and Japan have carried out extensive laboratory and field investigations of the electromagnetic characteristics ε and tg δ of glacier, fresh-water and sea ice in a broad range of frequencies from 100 Hz, including optical.

The generalization and analysis of theoretical and experimental data on electromagnetic characteristics made it possible to create reliable radio apparatus for study of the structure (thickness, layering, inhomogeneity) and state (mean effective temperature) of cold, moderate and warm glaciers. Using radio apparatus created in Great Britain, Denmark, USSR and the United States and installed on different carriers, new possibilities appeared for the study of the ice shields of Antarctica, Greenland, the Arctic and other glaciers of our planet.

An important conclusion drawn as a result of radio measurements is a new idea concerning the thickness of glaciers and the structure of Antarctic relief beneath the ice. Figure 1 shows that the relief of Antarctica beneath the ice is not smoothed (for example, in the zone of the Soviet investigations), as was speculated before, but instead has abrupt dropoffs and mountains with sharp peaks. Radar makes it possible to refine maps of Antarctic relief. It is interesting that a detailed radar survey of the polygons also revealed a very great diversity of relief. Interesting results from radar probing of this type were obtained by researchers at the Scott

Institute (Cambridge) and the Professor Gudmandsun Laboratory (Denmark).

Table 1

Electromagnetic Characteristics of Some Media

Medium	Velocity, m/μsec	Specific absorption f = 30 MHz	Measurement conditions
Cold glaciers	169	0.065	at -40°C
	169	0.025	at -10°C
Warm glaciers	169	0.05	at -1°C
	169	0.035	at -5°C
Perennial permafrost	110	1-8	at -5°C
		0.4-2.5	at -15°C
Fresh water bodies	33	0.5-2.5	---
Sandy ground	170	0.05	dry
	55	2	moisture content 30%
Sea pack ice	150	1-2	at -20°C thickness 2-9 m
Young sea ice	100	3-5	at -20°C thickness 0.9-1 m

A more complex cycle of measurements of the electromagnetic characteristics of sea ice in the SHF range led to the solution of an equally important problem -- the fundamental possibility of remote measurement of thickness of drifting sea ice. In the USSR this problem was solved by the scientific personnel of the Arctic and Antarctic Scientific Research Institute and the Institute of Civil Aviation Engineers (Riga). At the same time this same problem was solved by researchers in the United States, Canada and Denmark.

Radio sounding of glaciers and sea ice was facilitated to a considerable degree by radio sounding of highly absorbing media: desert sands for the detection of water-bearing layers, fresh-water bodies and permafrost.

Table 1 gives the electromagnetic characteristics of highly absorbing media. They show that it is possible to employ radio apparatus for sounding these media.

Fluctuations of Radio Signals in Probing of Ice Covers. Depolarization of Radio Waves in Glaciers

The nonuniformity of ice covers and the complex structure of the underlying bed change the amplitude, phase, shape of envelope, lag and polarization of the studied radio signals. A statistical analysis of the random process of change in the signal amplitude, which is determined by the different influence of scattering on the surface of the glacier and its bed, is of interest in estimating the rate of its movement. A mass of data on fluctuations of amplitudes made it possible to compute the autocorrelation radius and demonstrate its direct dependence on the radiated frequency.

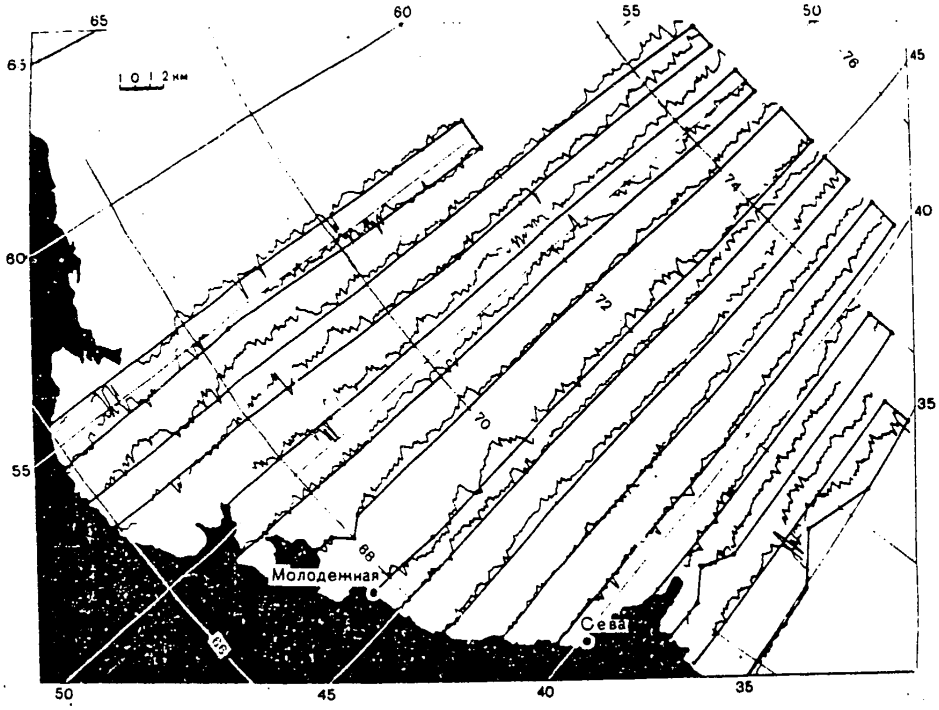

Fig. 1. Profiles of relief under ice along radio sounding profiles. In upper left corner -- vertical scale.

Figure 2 illustrates the fluctuations of signals reflected by the glacier bed for frequencies of 440, 213 and 60 MHz. These frequencies correspond to autocorrelation radii of 0.8, 1.6 and 6.1 m respectively. The frequency dependence of the autocorrelation radius of fluctuations of amplitudes can be used in measuring the rate of movement of glaciers in any regions of Antarctica.

In the USSR much work has been done on studying the phenomenon of depolarization of electromagnetic waves during their vertical propagation in a glacier. Similar investigations are being made by Clough (in the United States). Our studies indicated that one of the principal reasons for depolarization is double refraction.

Ice Optics

Recently extensive use has been made of optical methods for investigating ice. This has been dictated by the timeliness of those scientific and practical problems which they make it possible to solve. Investigations of the interaction of optical radiation with ice are being carried out in a wide range of wavelengths, including both the visible and IR parts of the spectrum. Infrared spectroscopy of ice made it possible to take a considerable step forward in the study of its molecular structure and to reveal a great diversity of structural forms.

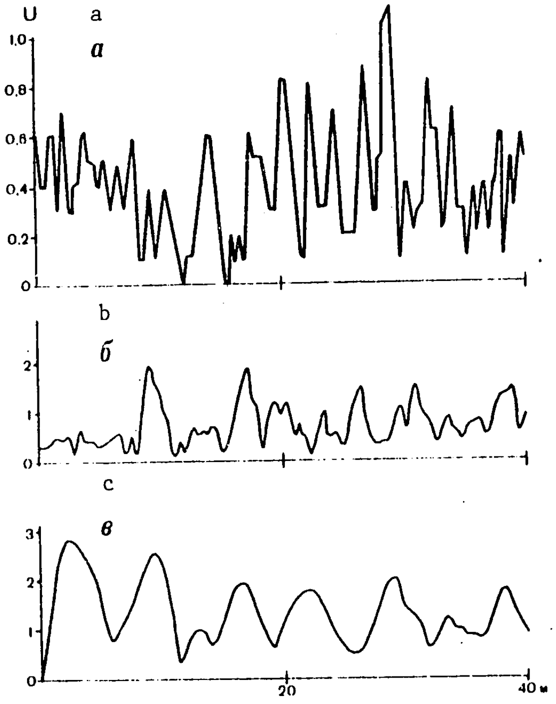

Fig. 2. Distribution of amplitudes of reflected signals for frequencies 440 MHz (a), 213 MHz (b) and 60 MHz (c).

The problem of radiation transfer through the snow and ice cover of water areas is acquiring particular importance. The energy penetrating through the ice is considerably attenuated and greatly changes the character of the underwater light field, and accordingly, biological activity and the conditions for the use of different optical systems for underice visibility and other problems.

It should be noted that an estimate of the total attenuation of optical radiation during transmission through the ice involves great difficulties. The scattering indicatrices for ice are very diverse. They are indicative of the complex scattering properties of ice structure.

Mechanical Characteristics of Ice and Stressed State of Ice Covers. Movement of Glaciers

The study of the mechanical properties of ice and snow is an important problem which is now being solved by the scientists of Canada, USSR, United States, Great Britain and Japan. The increased interest in this problem is obvious: in the study or exploitation of polar territories and ocean areas it is necessary to improve the types of transportation and either destroy the ice or use it as a construction material. In both aspects the success is determined by a knowledge of the mechanical characteristics of the ice and snow obtained by dynamic and static methods. A study of the mechanical properties of ice in combination with the packing of its macrocrystalline structure made it possible to estimate the strength characteristics of sea and fresh-water ice freezing under different hydrometeorological conditions.

The acoustic method for studying the mechanical characteristics of ice has been found to be promising. This method, not destroying the investigated medium, makes it possible to make measurements in individual crystals, blocks and the ice cover. The mechanical characteristics obtained by an acoustic method made it possible to develop a method for predicting their distribution in the thickness of the ice cover, knowing the air temperature.

At the present time for further progress in this field it is necessary to have new theoretical models reflecting the state of ice in response to rapid and slow effects and taking into account the thermal oscillations of atoms and molecules, and also the developing changes in the structure of the bonds among them during deformation.

An equally important problem is study of the stressed state of ice covers. At the Arctic and Antarctic Scientific Research Institute specialists are developing two directions toward its solution: study of the sound emission of deforming ice and use of special Doppler laser systems. Similar work is being carried out by Professor Bentley in the United States. The principal aspect of this problem is a determination of the numerical values of the developing pressures and their quantitative and qualitative correlation with hydrometeorological conditions. Information of this character would facilitate prediction of the stressed state of ice and especially the moments of its destruction. However, this problem is considerably complicated by the strong dependence of the physical properties of ice on many factors, the strong variability of the thickness of drifting ice, the absence of satisfactory models for prediction of macroscale deformations and the drift of ice on the basis of the measured hydrometeorological parameters. The intensity of the acoustic emission and the parameters of the acoustic signals radiated during the deformation of ice can be a key to solution of the problem.

It has now been established that the amplitudes of the oscillations, the spectral composition of waves, their velocity, duration of pulses and their repetition rate are objective criteria determining the general character of stages of the stressed state. It was also found that this information is carried by oscillations with a broad spectrum of frequencies from 10^{-2} to 10^{6} Hz. However, there is also a definite selectivity: at the temperatures of critical stresses the maximum of the acoustic emission spectrum for ice falls in the band 100-400 Hz. The first in situ experiments revealed the good prospects of the acoustic method for determining the stressed state of the ice cover. The correlation coefficient between the registered acoustic emission and air temperature fluctuation was about 0.8 [1, 2].

The use of lasers also makes it possible to make estimates of the stressed state of ice covers. The preliminary experiments carried out on the ice of Lake Ladoga in the winter of 1972 made it possible to obtain the numerical values of stresses in the ice [3]. The physical basis for estimating stressed state by this method is the possibility of determining the deformation of ice under the influence of some factors. The Doppler laser method applicable to this problem shows that the determined deformation, multiplied by the dynamic modulus, leads to an evaluation of the stressed state. The study of glacier movement is a timely problem for whose solution there is a good theoretical basis [5, 6].

Some progress has also been noted in the experimental investigation of glacier movement: the basis for this progress is laser Doppler systems, the scattering properties of the glacier bed and a detailed radio survey of oriented polygons.

The Arctic and Antarctic Scientific Research Institute, in collaboration with the State Optical Institute imeni Academician S. I. Vavilov, has developed special laser systems known as deformographs; these have undergone testing in Antarctica. These tests revealed that laser apparatus with a high degree of accuracy can register the absolute and relative rates of glacier movement.

At the Arctic and Antarctic Scientific Research Institute experiments have begun on study of the movement of glaciers relative to irregularities of the bed under the ice. We already have qualitative confirmations of a partial realization of this idea. The essence of the method is a repeated (with a definite time interval) detailed radio survey of the relief under the ice in polygons whose coordinates were determined with a high accuracy. A survey of these polygons repeated after a year demonstrated the presence of a complex displacement of the glacier.

BIBLIOGRAPHY

1. Bogorodskiy, V. V. and Gavrilo, V. P., "Physical Methods for Investigating the Stressed State of the Ice Cover," TRUDY AANII (Transactions of the Arctic and Antarctic Scientific Research Institute), Vol 316, pp 59-69, 1974.

2. Bogorodskiy, V. V., Gavrilo, V. P. and Gusev, A. V., "Acoustic Effects in the Friction of Ice," TRUDY AANII, Vol 324, pp 97-103, 1975.

3. Bogorodskiy, V. V., Gavrilo, V. P. and Ivanov, I. P., "Use of the Doppler Effect in Lasers for Investigating the Stressed State of Ice," TRUDY AANII, Vol 324, pp 114-117, 1975.

4. FIZIKA L'DA. OBZOR DOKLADOV MEZHDUNARODNOGO SIMPOZIUMA PO FIZIKE L'DA, SOSTOYAVSHEGOSYA 9-14 SENTYABRYA 1968 V MYUNKHENE (Ice Physics. Review of Reports at the International Symposium on Ice Physics Held at Munich 9-14 September 1968), Leningrad, Gidrometeoizdat, 1973, 154 pages.

5. Shumskiy, P. A., DINAMICHESKAYA GLYATSIOLOGIYA (Dynamic Glaciology), Moscow, Izd-vo AN SSSR, 1970, 200 pages.

6. Budd, W. F., THE DYNAMICS OF ICE MASSES, issued by the Antarctic Division, Department of Supply, Melbourne, 1969, 216 pages.

RADAR FM SIGNALS REFLECTED FROM ICE SURFACES AND POSSIBILITIES OF THEIR MODELING

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 17-20

[Article by A. B. Babayev, V. P. Logachev, V. N. Parfent'yev, V. A. Fedorov and G. P. Shelomanova]

[Text] This article gives some results of experimental investigations of the physical properties of ice surfaces and the radio signals reflected from them. Experimental investigations of the rangefinder signal were made with smooth and hummocky ice of different salinity with a thickness of about 2 m.

In rangefinding it is important that saline sea ice at its lower edge has a transitional unconsolidated layer attenuating the reflection of the sounding signal. A source of radiosignal loss is also the unevenness of both edges of the ice layer. With a roughness parameter greater than 0.2 the periodicity of change in the mirror reflection coefficient K_{f0}, characteristic of the layer, disappears and K_{f0} becomes a random value [1].

In the course of making the experiment, on the basis of the measurements computations are made of the specific effective area of reflection for ice with different degrees of unevenness of the edges. The computations were made using the formula

$$\sigma_0 = \frac{(16\pi)^2 \cdot H^2 \sin\varphi}{D^2 \cdot \lambda^2 \cdot \Delta\beta \cdot \Delta\gamma} \cdot \frac{P_{\text{пр}}}{P_0}, \tag{1}$$

where H is the range; φ is the angle of surface irradiation; D is the antenna amplification factor; λ is the radiation wavelength; $\Delta\beta, \Delta\gamma$ is the width of the antenna directional diagram in the orthogonal planes; P_{rec} is the power received in the antenna; P_0 is the radiated power.

Figure 1 shows the dependence of σ_0 on the angle of irradiation of ice surfaces. The accuracy in measurements is (1.5-2.0 db). Using the proportional relationship

[K = refl]

$$\frac{K_{f_{01}}}{U_{\text{к}1}\exp\left|\frac{1}{2}\left(\frac{4\pi\sigma h_1}{\lambda}\right)^2\right|} = \frac{K_{f_{02}}}{U_{\text{к}2}\exp\left|\frac{1}{2}\left(\frac{4\pi\sigma h_2}{\lambda}\right)^2\right|}, \tag{2}$$

where K_{f0} is the mirror reflection coefficient, U_{refl} is the amplitude of the reflected signal, σ_h is the standard deviation of height of the irregularity, we obtained the values for saline ice and ice with low salinity.

The results of the computations are given in Table 1, from which it can be seen that K_{f0} for ice with a low salinity is approximately twice as great as K_{f0} for sea ice. It can be postulated that this increase in the reflection coefficient occurs due to reflection from the lower edge of the ice layer with a low salinity content.

Table 1

Coefficients of Mirror Reflection as Function of Type of Surface

Type of surface	Sea water	Fresh water	Sea ice	Fresh ice	Asphalt
$\Delta h \approx \sigma_h$	0	0	0.3	0	0
K_{f0}	0.85	0.78	0.35	0.68	0.49

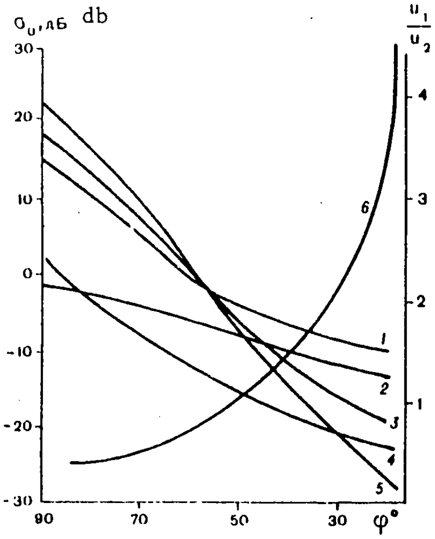

Fig. 1. Dependence of specific effective area of reflection σ_0 of different surfaces. (1 -- ice cover with presence of small hummocks on surface; 2) same with large hummocks; 3) smooth surface of fresh-water ice; 4) snow field; 5) smooth water surface); 6) dependence of u_1 and u_2 on angle of irradiation φ_0.

An investigation of the accuracy characteristics of rangefinders operating in the centimeter range indicates that they all give exaggerated readings in the case of measurement over an ice layer. An analysis of structure of the reflected signal revealed that there are two maxima in the signal spectrum corresponding to reflection from the upper and lower edges of the ice layer.

The ratio $U_1/U_2(\varphi)$ with a change in the angle of irradiation of the ice layer is of interest. The experimental curve $U_1/U_2(\varphi)$ is also shown in Fig. 1 (ice with a low salinity, $\Delta H_{ice} = 2$ m). The figure shows that with a change in the irradiation angle φ the relationship of the signals from the two edges changes to a considerable degree. The mechanism of this change can be attributed to the different angles of refraction at the discontinuity of the two media and signal scattering on the uneven boundaries of the layer.

The results of the experiment cited above indicate that the accuracy of the readings of the rangefinders over a layered ice surface deteriorates. In addition, the experiment revealed that anomalous phenomena at the time of radio signal reflection from the ice layer can be used in obtaining information from the reflecting surface.

The problem of reflection from a layer with uneven discontinuities is complex and for the time being no rigorous solution has been obtained. For this reason for the special problems of radar observation of ice it is desirable to use a model based on representation of the layer in the form of a set of independent elementary reflectors distributed in space.

The basis of the model considered below is the results of experimental investigations of the operation of frequency rangefinders in the centimeter range and some results which were mentioned above. The radio signal reflected from the ice layer can be written in the form of the equation

$$u(t)=\sum_{\theta}\sum_{\varphi}\sum_{H}u(\theta,\ \varphi,\ H), \tag{3}$$

where θ, φ, H are the spherical coordinates of the spatial position of elementary reflectors. Assuming the antenna diagrams to be axisymmetric and the reflecting medium to be isotropic with respect to azimuth φ, the signal at the output of the balanced mixer can be determined using the formula

$$u_{б}(t)=\sum_{\theta}\sum_{H}E(\theta,\ H,\ t)\cos[\Phi(\theta,\ H,\ t)+\Psi(\theta,\ H)], \tag{4}$$

where $\Psi(\theta$, H) is the equiprobable initial random phase. After the necessary computations it is possible to obtain the time-averaged correlation function of this signal [1,2]

[б = bal]

$$R_{б}(t,\ \tau)=\sum_{\theta}\sum_{H}D^2(\theta,\ H)\sum_{k=1}^{\infty}\xi_k(\theta,\ H)\cos 2\pi\tau_k F_{м}, \tag{5}$$

where $\xi_k(\theta$, H) is dependent on the type of modulating function; $D^2(\theta$, H) is the dispersion of an elementary signal.

The averaged energy spectrum of the signal of beats in this case is written in the form of the equation

$$\overline{S_{б}(f,\ t)}=\sum_{\theta}\sum_{H}D^2(\theta,\ H)\sum_{k=1}^{\infty}\delta(f-kF_{м})\xi_k(\theta,\ H). \tag{6}$$

In the case of a pencil-beam antenna the broadening of the spectrum will occur only due to the thickness of the reflecting layer. The factor $D^2(\theta$, H) includes the normalized function f(θ, H) characterizing the reflecting properties of the ice. In the case of a pencil-beam antenna

$$f(\theta,\ H)=f_{\theta}(H)|_{\theta=\mathrm{const}}. \tag{7}$$

For ice with a low salinity and fresh ice in the centimeter range the function f_{θ} (H), as demonstrated by the experiment, is approximated well by the expression

$$f_{\text{н}}(H) = A_1\delta(H-H_1) + A_2\delta(H-H_2), \tag{8}$$

where δ (z) is a delta function; A_1, A_2 are coefficients dependent on the electrophysical parameters of the reflecting layer of ice.

With expression (8) taken into account, the readings of the frequency rangefinder in the case of narrow antenna directional diagrams can be written in the form

$$F_{\text{л}} = \frac{4\Delta f \cdot F_{\text{м}} \cdot H_1}{c} + \frac{1}{1 + \dfrac{A_1}{A_2} \cdot \dfrac{(H_1 + \Delta H_1)^2}{H_1^2}} \times \\ \times \frac{4\Delta f F_{\text{м}} \Delta H_{\text{л}} \sqrt{\bar{\varepsilon}_{\text{л}}}}{c}, \tag{9}$$

where $\bar{\varepsilon}_{ice}$ is the mean value of the dielectric constant in the thickness of the ice; F_M is the modulation frequency; Δ f is the frequency deviation; c is the speed of light.

For practical computations a major role is played by the values of the electrophysical parameters of ice in the SHF range. We used the results of measurement of ε_{ice} and tg δ_{ice} obtained by B. T. Kapitkin.

All the experimental results and computations cited above indicate that rangefinder FM apparatus can be used with some modernization for determining the parameters of the ice layer, for example, its thickness ΔH_{ice}. A simplified block diagram of one of the possible methods for processing the rangefinder signal for determining the thickness of the ice layer should contain an envelope detector and a unit for measuring the mean modulation of signal frequency, averaged for the period, at the output of the envelope detector.

With expressions (6) and (8) taken into account, it can be shown that the mean modulation of signal frequency, averaged for the period, at the detector output in the case of a narrow antenna directional diagram is proportional to the ice thickness ΔH_{ice}.

In conclusion we should note the following facts:

1. The results of experimental investigations of the reflecting properties of ice surfaces make it possible to find new methods for obtaining information on the reflecting surfaces.
2. It is fundamentally possible to determine the thickness of a thin ice layer on the basis of use of radio rangefinding FM apparatus.

BIBLIOGRAPHY

1. Zubkovich, S. G., STATISTICHESKIYE KHARAKTERISTIKI RADIOSIGNALOV, OTRAZHENNYKH OT ZEMNOY POVERKHNOSTI (Statistical Characteristics of Radio Signals Reflected From the Earth's Surface), Moscow, "Sovetskoye Radio," 1968, 223 pages.

2. Tsvetnov, V. V., "Statistical Properties of Radar Signals From Extended Surfaces in Systems With Internal Coherence," TR. MAI (Transactions of the Moscow Aviation Institute), No 1, pp 5-26, 1966.

INFLUENCE OF ICE STRUCTURE ON ITS RADIATION CHARACTERISTICS IN THE SHF RANGE

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'-SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 21-23

[Article by A. Ye. Basharinov and A. A. Kurskaya]

[Text] Experimental investigations of radiothermal radiation of sea and continental ice carried out in the Soviet Union and the United States have revealed the spectral characteristics associated with the nature of ice, its age, degree of salinity and microstructure [1-4]. In this article we describe the influence exerted on the SHF radiation characteristics of sea ice by the effects of scattering on air bubbles and small inhomogeneities.

The microstructure of sea ice experiences changes dependent on the conditions of ice formation and age. Young ice with a thickness of the layer of several decimeters has increased moisture content and salinity. With an increase in ice age the moisture and salinity content decrease. In the upper layers of the perennial ice there is an increased content of air bubbles. With a strong degree of porosity the air content increases to 100 cm^3/kg.

According to data from measurements made on the artificial earth satellite "Cosmos-243" over the Antarctic zone, in the region of perennial ice there is an appreciable decrease in radiobrightness temperature for the short-wave parts of the range. Figure 1 shows experimental data for the spectral dependences of the degree of blackness for young and perennial ice obtained in processing the results of observations cited in [1, 4]. The transfer of radiation in the upper layers of perennial sea ice is accompanied by the effects of scattering on inhomogeneities of the dielectric constant. The emissivity of ice formations is determined by the value of the dielectric constant and the thickness of the ice layer [2].

The effect of the influence of internal scatterings, dependent on the relationship of the sizes of the inhomogeneities, wavelength and degree of ice porosity, is reflected in the form of the spectrum of radiobrightness temperatures and on the angular characteristics of the radiation field. The degree of blackness of the emitting layer of ice, with internal scatterings taken into account, is evaluated using the expression

$$\varkappa \simeq 1 - |R_{\epsilon} + \rho_{\lambda}(1 - R_{\epsilon})|, \qquad (1)$$

where R_ε is the reflection coefficient at the boundary of the ice layer, determined without allowance for internal scatterings; ρ_λ is a coefficient characterizing the fraction of the power scattered on inhomogeneities; $\varphi_{ice}(1 - R_\varepsilon)$ is a coefficient characterizing the fraction of the power scattered in the upper half-space.

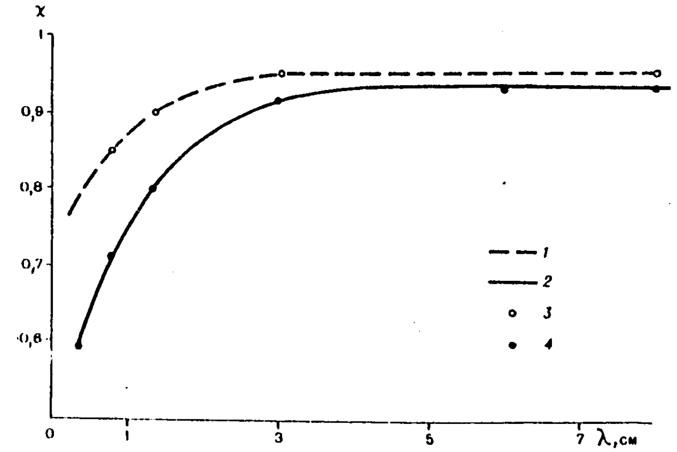

Fig. 1. Computed and experimental spectral dependences of degree of blackness for "young" and "old" ice obtained in processing the results of observations on the "Cosmos-243" artificial earth satellite and from "Convair-990."

With allowance for the effects of single scattering from randomly distributed small inhomogeneities the mean value of the coefficient of reflection from an elementary volume is determined by summation of the partial scattering fields

$$\bar{\rho}_\lambda = \overline{\sum \sigma_i} = \overline{\frac{dN}{dV}}\,\bar{\sigma}, \qquad (2)$$

where σ_i is the scattering section of the inhomogeneities; dN/dV is the spatial density of the inhomogeneities.

The mean value of the reflection coefficient from a layer with a depth corresponding to the skin layer is determined using the formula $\rho_\lambda = \frac{dN}{dV}\bar{\sigma}(\lambda) l_{э\lambda}$,

[э = elem(entary)]

where $l_{elem\,\lambda} = \lambda/2\pi\sqrt{\varepsilon}\,\mathrm{tg}\,\delta$ is the depth of the skin layer.

is the depth of the skin layer.

The spectral dependence of the scattering section, determined by the relationship of the sizes of the inhomogeneities and the wavelength, is manifested in the form of a decrease in the degree of blackness with a shortening of the wavelength.

Model computations of the spectral dependence of the degree of blackness of the ice cover were carried out taking into account the contribution of the effects of scattering on bubble inhomogeneities of a spherical form on the assumption of a uniformity of the structure of the upper layer to a depth of 30-60 cm. A comparison of the computed and experimental values of the spectrum of the degree of blackness for long-term sea ice makes it possible to evaluate the degree of porosity of ice samples (see Fig. 1). Thus, an evaluation of the content of air inclusions for the sounded ice fields gives 30-50 cm^3/kg with a mean diameter of the bubbles of about 1 mm. The difference in the SHF spectral characteristics of one-year and perennial ice can be used in the diagnosis of sea ice.

BIBLIOGRAPHY

1. Basharinov, A. Ye., Gurvich, A. S., Yegorov, S. T., Zhukov, V. I. and Kurskaya, A. A., "Results of Observation of Thermal Radio Emission of the Earth's Surface According to Data of the Experiment on the AES 'Cosmos-243'," KOSMICHESKIYE ISSLEDOVANIYA (Space Research), Vol IX, No 2, pp 268-279, 1971.

2. Tuchkov, L. T., YESTESTVENNYYE SHUMOVYYE IZLUCHENIYA V RADIOKANALAKH (Natural Noise Radiations in Radio Channels), Moscow, "Sovetskoye Radio," 1968, 152 pages.

3. Tuchkov, L. T., Basharinov, A. Ye., Kolosov, M. A. and Kurskaya, A. A., "Thermal Radio Emission of the Ice Cover in the SHF Range," TRUDY GGO (Transactions of the Main Geophysical Observatory), No 222, pp 159-161, 1968.

4. Wilheit, T., Nordberg, W., Blinn, J., et al., "Aircraft Measurements of Microwave Emission From Arctic Sea Ice," REMOTE SENSING OF ENVIRONMENT, No 2, pp 25-28, 1972.

REMOTE MEASUREMENT OF SEA ICE THICKNESS BY RADAR METHODS

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 51-54

[Article by M. I. Finkel'shteyn, V. A. Kutev, V. G. Glushnev and E. I. Lazarev]

[Text] Introduction. The radar method, based on measurement of the time interval between separately observed signals reflected from the ice boundaries, is widely used in measuring the thickness of glaciers, for example, in Antarctica [1]. Due to the successes of nanosecond pulsed apparatus and the technique for the processing of signals the method can be applied to thinner sea ice whose thickness usually does not exceed 2 m. However, a great attenuation occurs in this case.

In order to compute the ratio of the amplitudes of signals reflected from the boundaries of sea ice it is possible to use the data of J. Addison [7], which are confirmed by our radar sounding of sea ice. There is a definite "frequency window" lying in the meter and partially in the short-wave wavelength ranges [6].

Method of Individual Radio Pulses

A radio pulse is characterized by the presence of at least several, for example, three periods of high-frequency oscillations, so that the minimum activity is $\tau_{u_{min}} = 3/f$, where f is the frequency of high-frequency oscillations. This corresponds to the minimum thickness of the homogeneous layer of ice $h_{ice_{min}} = v_{ice}\tau_{u_{min}}/2$, where $v_{ice} = \_ \mathrm{Re}\sqrt{\dot{\varepsilon}_{ice}}$ is the velocity of radio wave propagation in ice ($\dot{\varepsilon}_{ice}$ is the complex dielectric constant).

Table 1 gives the limiting $h_{ice_{min}}$ values and the ratio r of the bottom/top amplitudes [2]. The salinity of ice was selected so as to be characteristic for sea ice of the corresponding thickness (ice temperature -30°C).

The table shows that of the three frequencies only for f = 40 MHz is the ratio of the bottom/top amplitudes acceptable for measurement from the point of view of resolution of signals with a limited ice thickness. However, in this case $h_{ice_{min}} = 5.9$ m. With higher frequencies the bottom/top ratio $\leqslant 0.1$, which makes the process of measurement of the time interval between two reflected pulses, being at the limit of resolution, virtually impossible. Only a frequency f = 300 MHz makes a resolution of 0.8 m acceptable for practical purposes, but in order to ensure measurements there must be an increase in the r ratio by two orders of magnitude, for which the salinity of ice must be approximately three times less.

Table 1

Dependence of Kesolution and $h_{ice_{min}}$ Value on Frequency of Sounding Signal

f, MHz	$\tau_{u_{min}}$, nanosec	S,%	$h_{ice_{min}}$, m	r
40	75	1-1.5	5.9	0.38
100	30	5-6	2	0.1
300	10	12-13	0.8	0.03

Method for Shock Excitation of Antenna

In 1960 J. Cook proposed the use of a monopulse in the form of one period of a high-frequency oscillation for ensuring the contradictory requirements of use of the above-mentioned frequency window and maintenance of the necessary resolution [8]. The shock excitation of an antenna was proposed in order to obtain a monopulse. It should be noted that the optimum shape of a pulse from the point of view of the best resolution in the case of shock excitation differs from a monopulse [3].

This method was checked by M. Meyer, using horn antennas having a frequency band from 150 MHz to 600 MHz [10]. In our experiments (in 1969 from a beacon and in 1970 from aboard a helicopter) the shock excitation method was used by us in apparatus for the shaping of short radio pulses. Using wind-band vibrator antennas it was possible to obtain radio pulses with a duration of 6, 12, 20 nanoseconds corresponding to the central frequencies 440, 300, 140 MHz. In addition, using more low-frequency antennas with a central frequency of 70 MHz it was possible to obtain pulses with a duration of 40 nanoseconds. In addition to measurement of ice thickness, the inverse problem was solved: determination of the ice parameters from the ratio of the amplitudes of the signals and the time interval between them [4].

These experiments confirmed the possibility of using the method for fresh-water and slightly saline ice and its inapplicability for highly saline sea ice. This is associated with a strong nonuniformity of the frequency characteristic of real antennas, especially in the low-frequency region, which leads to the "ringing" phenomenon. This was mentioned by S. Evans as an important technical problem [9].

Videoimpulse Method (Method of Shock Excitation With Correction)

We proposed and from aboard a helicopter (1971) and aircraft (1972, 1973) made practical use of a method for the compensation of ringing based on the use in the receiving channel of narrow-band channels for the multiple frequencies F, 2F,..., nF, which jointly with the frequency characteristic of the antenna form a uniform comblike filter [5]. The signal with which a particular comblike filter is matched is a packet of video pulses with the repetition rate F. Measurements can be made from one of the pulses in the packet.

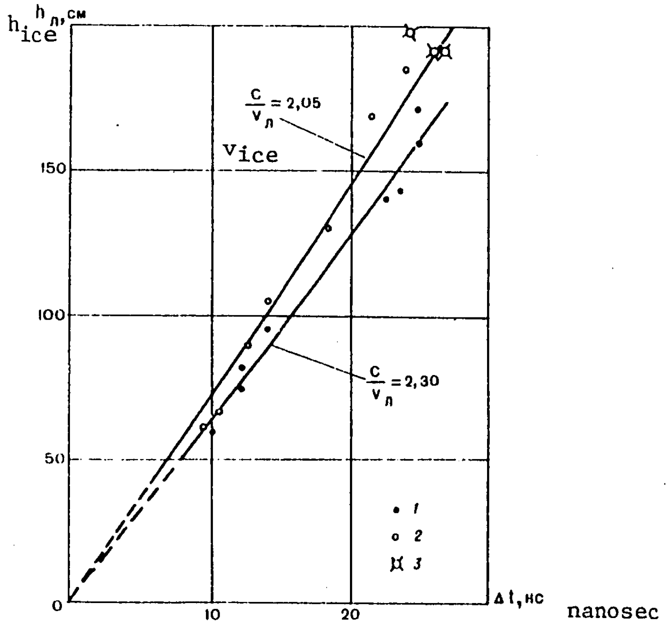

Fig. 1. Dependence of true thickness of ice h_{ice} on time interval between pulse maxima Δt. 1) S_{ice} = 4.5-13°/oo, t_{water} = -22 - -36°C; 2) 1.5-2.5°/oo, t_{water} = -8--18°C; 3) perennial ice.

Our experiments revealed the possibility of measuring the thickness of sea ice beginning with 50-60 cm. The presence of an adequate stability of the mean velocity of radio wave propagation in ice of different thickness was demonstrated for several gradations of the state of ice (Fig. 1). For one-year sea ice at an air temperature t_{air} -20°C and a mean ice salinity S = 4.5-13°/oo the velocity of radio wave propagation in the ice is 2.3 times less than in the air. With a decrease in salinity this ratio decreases to 2 or more to the known value 1.79 for fresh ice. An increase in air temperature t_{air} above -20°C exerts a considerable influence on the attenuation of radio waves in ice. In this case for young highly saline ice and perennial ice the signal does not attain the lower layers, which makes it difficult to determine the velocity of radio waves in the ice and also calibration when measuring the thickness of such ice.

BIBLIOGRAPHY

1. Bogorodskiy, V. V., FIZICHESKIYE METODY ISSLEDOVANIYA LEDNIKOV (Physical Methods for Investigating Glaciers), Leningrad, Gidrometeoizdat, pp 3-211, 1968.

2. Mendel'son, V. L., Kozlov, A. I. and Finkel'shteyn, M. I., "Investigation of Some Electrodynamic Models of Ice in Radar Sounding Problems," IZV. AN SSSR: FIZIKA ATMOSFERY I OKEANA, Vol VIII, No 4, pp 396-402, 1972.

3. Finkel'shteyn, M. I., "Optimum Shape of Pulse in Radar Sounding of Sea Ice," RADIOTEKHNIKA I ELEKTRONIKA (Radio Engineering and Electronics), Vol 25, XV, No 12, pp 2468-2472, 1970.

4. Finkel'shteyn, M. I. and Glushnev, V. G., "Some Electrophysical Characteristics of Sea Ice Measured by Radar Sounding in the Meter Wavelength Range," DOKLADY AN SSSR (Reports of the USSR Academy of Sciences), Vol 203, No 3, pp 577-580, 1972.

5. Finkel'shteyn, M. I. and Kutev, V. A., "Sounding of Sea Ice Using a Series of Videopulses," RADIOTEKHNIKA I ELEKTRONIKA, Vol XVII, No 10, pp 2107-2112, 1972.

6. Finkel'shteyn, M. I., Kozlov, A. I. and Mendel'son, V. L., "Modeling of Reflection of Radio Waves From Sea Ice," RADIOTEKHNIKA I ELEKTRONIKA, Vol XV, No 11, pp 2282-2288, 1970.

7. Addison, J. R., "Electrical Properties of Saline Ice," J. OF APPLIED PHYS., Vol 40, No 8, pp 3105-3114, 1969.

8. Cook, J. C., "Proposed Monocycle Pulse Very-High-Frequency Radar for Airborne Ice and Snow Measurement," TRANS. AMER. TEE. P 1 (Commun. and Electronics), Vol 79, No 51, p 588, 1960.

9. Evans, S., "Progress Report on Radio Echo Sounding," THE POLAR RECORD, Vol 13, No 85, pp 413-420, 1966.

10. Meyer, M. A., "Remote Sensing of Ice and Snow Thickness," PROC. OF THE FOURTH SYMPOSIUM OF REMOTE SENSING OF ENVIRONMENT, The University of Michigan, pp 183-192, 1966.

INSTRUMENTATION FOR INVESTIGATING SPECTRAL REFLECTION OF LIQUID WATER IN THE WAVELENGTH REGION 1-50μm

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'-SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 74-79

[Article by M. A. Kropotkin]

[Text] Remote sensing methods, based on use of radiations in the IR range, are now being used more and more extensively in measuring the temperature of a water surface. In interpreting the results obtained by remote sensing methods it is necessary to know such optical characteristics of the water surface as the coefficients of spectral reflection, spectral and integral radiation in the visible and especially in the IR part of the spectrum, and also the dependence of the optical parameters of water on such factors as salinity and temperature.

Investigations for study of the reflection of liquid water in the IR range have already been carried out over the course of several decades. During recent years the reflection properties of liquid water are being investigated especially intensively. Work on investigation of the reflective properties of liquid water has also been carried out at the Department of Principles of Electrovacuum Technology at the Leningrad Electrotechnical Institute.

In this article we describe instrumentation used at the Leningrad Electrotechnical Institute for measuring the spectral coefficients of reflection of liquid water in the wavelength range from 1 to 50μm [2, 3] and give some results of the investigations made.

The study of the spectral reflection of liquid water is complicated by the fact that, first of all, the coefficients of reflection of liquid water, especially in the case of small angles of incidence, in the IR range are small, and second, the surface of the liquid water does not remain plane due to vibrations of the ground. Accordingly, sometimes reflection at the air-liquid water discontinuity is not investigated, but instead at a dielectric-water discontinuity. The coefficients of reflection of the latter are then determined by computations. In experimental respects such a method is very convenient, but due to the absence of materials transparent in the IR region and insoluble in water, such a method can be used only in the region of wavelengths less than 12-15μm.

At the Leningrad Electrotechnical Institute the investigation of the spectral reflection of liquid water has been accomplished using instrumentation in which a mirror hemisphere is used for focusing the radiation reflected by the water.

Due to the use of this hemisphere there is a considerable reduction in the harmful influence of ground vibration.

In the wavelength region up to 20 μm the measurements were made with an attachment to a standard single-ray IR spectrometer, whose optical diagram is shown as Fig. 1. In this attachment the cell with the water to be investigated and the radiation detector are situated under the mirror hemisphere at an identical distance from the center of the hemisphere in the plane of its great circle. The plane mirror M_4 can be rotated. When making measurements of reflected radiation this mirror directs monochromatic radiation onto the water surface to be investigated. The reflected radiation is focused by the mirror hemisphere onto a radiation detector.

When measuring the incident radiation the mirror M_4 is turned into a second position, in which it directs the radiation directly onto the detector. Thus, if the reflection coefficient of the mirror surfacing of the hemisphere is known, by means of this attachment it is possible to measure the absolute reflection coefficient of water.

The reflection coefficient of the mirror surfacing of the hemisphere was determined with an accuracy to ±1% by measuring the reflection coefficient of a plane mirror which was sprayed simultaneously with the hemisphere. The possibility of measuring the absolute reflection coefficient is an important advantage of this measurement method since in the measurement of the relative reflection coefficient it is necessary to use a comparison mirror. In this procedure it is necessary to take into account the difference in the character of the polarization of the radiation reflected by the water and comparison mirror, especially with angles of incidence close to the Brewster angle.

As the radiation detector use was made of a radiation thermoelement with a window RRS = 5. In measurements in the wavelength region up to 10 μm the recording instrument was an M 195/2 multilimit galvanometer, in parallel with which a 1.7-kilohm resistor was connected. The response of the measurement system could therefore be varied: it was maximum when measuring reflected energy and 10 times less when measuring incident energy. With measurements in the wavelength region 12-20 μm, where the source energy is small, the galvanometer was replaced by a d-c amplifier and an EPP-09 automatic recorder.

In the wavelength zone from 20 to 50 μm the measurement of spectral reflection of liquid water was accomplished using an apparatus consisting of a long-wave single-ray IR spectrometer designed using a Pfund autocollimation scheme in which the dispersing element used was interchangeable diffraction gratings and an optical system focusing the monochromatic radiation either on the sample or on the detector. The optical system and the diffraction gratings are situated under the mirror hemisphere. The switching of the ray from the sample to the detector is accomplished using the rotatable spherical mirror.

The source in this apparatus is a globar (lamp); the detector is a radiation thermoelement with a KRS-5 window operating in combination with a d-c amplifier and an EPP-09 electronic automatic recorder. In order to suppress the scattered short-wave radiation the optical system of the monochromator has two fluorite reflecting filters and a transmission filter of smoked polyethylene. In addition, in the measurements use was made of a cutting slide of sodium fluoride. All the enumerated measures made it possible to reduce the level of scattered interfering short-wave radiation to 1-2%.

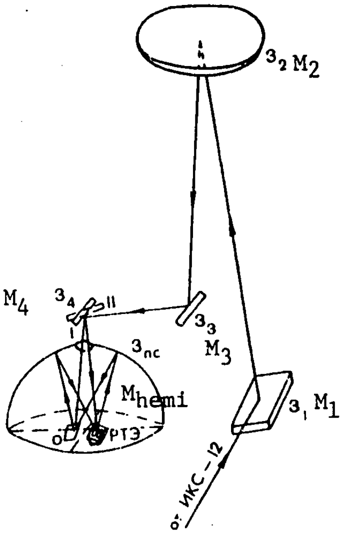

Fig. 1. Optical diagram of attachment.

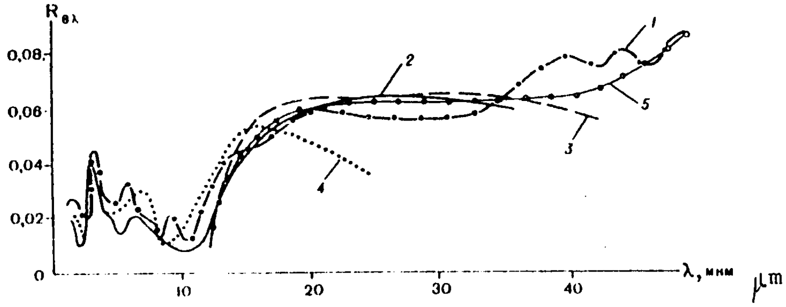

Fig. 2. Reflection spectrum of liquid water.

During the measurements the water was poured into a special cell which was divided into a number of sections by several horizontal and vertical partitions. The water layer over the upper horizontal partition was 1.5 mm. Adjustment was accomplished by use of a flat mirror whose reflecting surface was placed at the level of the upper section of the cell. Upon completion of adjustment the mirror is removed and the cell is filled to the edges with water.

In all the measurements a convergent beam of rays with an angle at the vertex in the plane of incidence of 5° was incident on the investigated surface. The angle of incidence for the central ray of this beam was 17°. The nonparallel nature of the incident beam is a source of additional errors, but with a change in the angle of incidence in the range ±5° it is possible to assume that the change in the coefficient of reflection of water as a function of the angle of incidence is linear; therefore, the error in determining the reflection coefficient, caused by the nonparallel nature of the incident beam, is small. According to our estimate it is not greater than 1%.

The nonlinearity of the radiation detector, d-c amplifier and electronic potentiometer can exert a substantial influence on measurement accuracy. The influence of nonlinearity of the thermoelectric detector in this case is insignificant since the measurements are made twice at each wavelength: for incident and reflected radiation. From this point of view the presence of some selectivity of the thermoelement is also unimportant.

The nonlinearity of the d-c amplifier (an FEOU-18 was used for this purpose) was caused by the nonuniformity of illumination and response over the surface of the photoelements. If prior to each measurement a zero position of the boundary between the light and shadow is set strictly in the middle of the second stage grids, the FEOU is linear with an accuracy to 1%. In order to decrease the influence of nonlinearity of the EPP-09 electronic potentiometer on the measurement accuracy, in this work use was made of a specially selected automatic recorder the nonlinearity of whose scale did not exceed 2%.

Thus, it is extremely difficult to make a precise evaluation of the error possible when determining the absolute values of the reflection coefficients. It is evidently a value not greater than 4-5%. The checking of the reproducibility of the results indicated that in the case of repeated measurements the scatter of the determined values does not exceed 2.5%.

Figure 2 shows the reflection spectrum of distilled water (curve 1) which we obtained using the described apparatus. As a comparison, this same figure shows the reflection spectra of water obtained by other researchers. Curve 2 was taken from [7], curve 3 -- from [8], and curve 4 -- from [9]. Curve 5 was computed from the values of the optical constants of liquid water cited in [1].

Figure 2 shows that the reflection spectrum of liquid water which we obtained is characterized by the selective reflection bands at 2.93 and 6.1μm, and also at 44 and 48μm. A somewhat greater value of the reflection coefficient in the region of wavelengths less than 12μm is attributable to the fact that the data of other authors were obtained with lesser angles of incidence (curves 2, 3 with a normal angle of incidence, and curve 4 with an angle of incidence 10°). In the more long-range spectral region our results also satisfactorily agree with the results of other authors. The selective reflection bands which we discovered at 44 and 48μm agree well with the absorption bands in the spectrum of liquid water obtained by N. G. Yaroslavskiy and A. Ye. Stanevich [5]. True, in a later publication dealing with the investigation of the transmission of liquid water in the long-wave IR spectral region [6] the mentioned bands are absent. In [6] the absorption spectrum was determined using a two-component spectrometer. The authors of this article assume that the bands discovered by N. G. Yaroslavskiy and A. Ye. Stanevich were caused by the absorption of the water vapor present in the volume of the spectrometer. However, the DIKS-1 used by N. G. Yaroslavskiy and A. Ye. Stanevich was of the vacuum type, so that this cause is improbable.

The described apparatus can also be used in studying the reflection spectra of snow and ice. However, in an investigation of snow and ice in order to preserve the natural state of their surface it is necessary to use special refrigeration apparatus. For this purpose it is convenient to use miniaturized semiconductor condensers produced by our industry. In the case of use of refrigeration apparatus it is difficult to ensure a small distance between the investigated sample and the radiation detector. If a mirror hemisphere is used, this distance cannot be great since its increase is linked to a sharp increase in aberration of the hemispherical mirror. There is a particularly strong increase in aberration in the case of a diffuse or mixed character of reflection from the investigated object, such as snow.

In the case of considerable aberrations of the optical system in order to measure the entire reflected flux it is necessary to have an indicator with a large receiving area. Such an indicator has a low sensitivity.

It can be shown that a mirror semiellipsoid (half of a mirror whose surface is formed by the rotation of the ellipse about the semi-major axis) has considerably lesser aberrations. With the use of a mirror semiellipsoid for measuring the reflection coefficients a sample is placed in one of its foci. This sample is irradiated through an aperture in the upper part of the semiellipsoid, whereas the radiation detector is placed in its other focus.

In the Department of the Principles of Electrovacuum Technology at the Leningrad Electrotechnical Institute a new variant of an attachment has been developed for the IR spectrometer. Here a mirror hemisphere is used in place of a mirror semiellipsoid [4]. Work is also being done on replacing the mirror semiellipsoid in the apparatus intended for measuring the reflection coefficients in the region of wavelengths 20-50μ m.

The described apparatus is now being used at the present time at the Leningrad Electrotechnical Institute for studying the influence of salinity and temperature on the spectral reflection of water, and also for investigating the optical properties of snow and ice in the IR range.

BIBLIOGRAPHY

1. Zolotarev, V. M., Mikhaylov, B. A., Al'perovich, L. I. and Popova, S. I., "Dispersion and Absorption of Liquid Water in the IR and Radiowave Spectral Regions," OPTIKA I SPEKTROSKOPIYA (Optics and Spectroscopy), Vyp 27, No 5, pp 790-795, 1969.

2. Kropotkin, M. A. and Kozyrev, B. P., "Determination of the Spectral Coefficients of Reflection of Bulk Materials in the Wavelength Region 0.7-15μ m," IZV. VYSSHIKH UCHEBNYKH ZAVEDENIY: FIZIKA (News of Higher Institutes of Education: Physics), No 3, pp 27-29, 1965.

3. Kropotkin, M. A. and Kozyrev, B. P., "Apparatus for Investigating Spectral Reflection of Scattering Materials in the Long-Wave IR Part of the Spectrum," IZV. VYSSHIKH UCHEBNYKH ZAVEDENIY-PRIBOROSTROYENIYE (News of Higher Institutes of Education: Instrument Making), No 6, pp 123-130, 1963.

4. Kropotkin, M. A., Kutilina, N. B. and Sheveleva, T. Yu., "Apparatus for Measuring the Transmission and Reflection Coefficients of Scattering Materials in the Wavelength Region From 1 to 20μm," IZV. LETI (News of the Leningrad Electrotechnical Institute), No 161, pp 110-114, 1975.

5. Stanevich, A. Ye. and Yaroslavskiy, N. G., "Absorption of Liquid Water in the Long-Wave Region of the IR Spectrum," OPTIKA I SPEKTROSKOPIYA (Optics and Spectroscopy), No 10, pp 278-281, 1961.

6. Draequert, D. A., Stone, N. W., Williams, D. and Curnutte, B., "Far IR Spectrum of Liquid Water," J. OPT. SOC. AMER., Vol 56, No 1, pp 64-69, 1966.

7. Pontier, L. and Dechambenoy, C., "Determination des constantes optiques de l'eau liquide entre 1 et 40 mkm. Application an calcul de son pouvoir reflecteur et de son emissivite," ANN. GEOPHYS., Vol 22, No 4, pp 633-641, 1966.

8. Rusk, A. N., Williams, D. and Querry, M. R., "Optical Constants of Water in the Infrared," J. OPT. SOC. AMER., Vol 61, No 7, pp 895-903, 1971.

9. Querry, M. R., Curnutte, B., and Williams, D., "Refractive Index of Water in the Infrared," J. OPT. SOC. AMER., Vol 59, No 10, pp 1299-1305, 1969.

ICE BEHAVIOR IN HIGH-STRENGTH RAPIDLY VARYING ELECTROMAGNETIC FIELDS

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 90-93

[Article by L. B. Nekrasov]

[Text] Theoretical and experimental investigations of recent years indicate the existence of a fluid or quasifluid water film on the ice surface. The hypothesis of existence of a thin water film on the ice surface at temperatures below its melting point was expressed for the first time by Faraday in 1860 in [6]. The matter of the energetically stable existence of a water film on an ice surface at negative temperatures was the subject of a discussion between Faraday, Thomson and Tyndall [5]. The hypothesis of a quasifluid film on the ice surface was further developed by Weyl, who attempted to explain the existence of film water on the ice surface on the basis of the concept of an impaired structure of the surface layers of solids.

There are now experimental data [7, 8] indirectly confirming the presence of a water film on the basis of measurement of the tensile strength and shearing strength of ice, especially that frozen on a plate of stainless steel and optical quartz. Experiments for studying shearing strength gave values which could be expected if one accepts the hypothesis of the existence of a quasifluid layer between the ice and the surface of these materials.

Dilatation experiments give rise to fractures in the ice mass. There were no fractures of the material (quartz plate) at the ice-surface contact. The author postulates that the factor responsible for this is surface tension forces in the quasifluid layer existing between the ice surface and the plate.

The existence of a fluid film on the ice surface is indicated by investigations of nuclear magnetic resonance, making it possible to obtain information on the degree of mobility of molecules. Due to the inadequate response of the nuclear magnetic resonance method data were obtained [3] confirming the existence of film water only in highly disperse ice (hoarfrost on the walls of a Dewar vessel with liquid nitrogen).

These data once again confirm the widely held opinion that the adsorbed state of water in the form of a quasifluid film is a common property of the disperse state of matter. Nevertheless, nuclear magnetic resonance data do not give a convincing answer to the question as to whether there is a water film in monolithic semicrystalline ice -- the most interesting case for practical purposes.

Studies for investigation of the adhesion properties of ice, in our opinion, make the problem of the existence of a quasifluid film in monolithic ice still more debatable. We made an attempt at experimental confirmation of the fact of existence of film water in semicrystalline ice on the basis of its behavior in highly variable high-strength electromagnetic fields.

It is well known that ice, especially pure ice, being a good dielectric, is virtually not heated in highly variable fields even of a very high strength. However, as indicated by our experiments carried out in the Problems Laboratory of Destruction of Rocks by Powerful Electromagnetic Fields of the Leningrad Mining Institute, semicrystalline ice at negative temperatures is extremely effectively destroyed in a high-strength HF electromagnetic field.

The experiments were carried out with strongly mineralized ice (prepared from sea water), ice with slight mineralization (distillate) and ice prepared from chemically pure water (subjected to anion-cation purification and degassing). The destruction of ice in all cases developed approximately identically: after 1.5-2 sec from the time of exposure to an electromagnetic field (E = 4 KV/cm; f = 40.68 MHz) the ice (weakly mineralized) loses its optical and mechanical homogeneity; after 3-4 sec poorly distinguishable inclusions of volume water and voids appear in the sample; after 7-8 sec there is a stage of intensive fracturing of the sample, ending with complete disintegration into individual crystals.

As is well known, dielectric heating is determined by the loss factor $\varepsilon'' = \varepsilon' \mathrm{tg}\,\delta$. The value of this characteristic for quasifluid films at the ice surface is not mentioned in the literature. However, there is basis for assuming that the value of the loss factor ε'' for film water at the ice surface must not differ greatly from the adsorbed water on other substances at the corresponding temperatures and frequencies. We will compare ε'' for the ice and water adsorbed on silica gel at negative temperatures and also for ice and volume water at positive temperatures.

For adsorbed water at frequencies of hundreds of MHz at a temperature to -70°C $\mathrm{tg}\,\delta = 5 \cdot 10^{-2}$ and $\varepsilon' = 4$ [1]; ε' is slightly dependent on frequency and temperature [2]. At frequencies of about 2 MHz and with a temperature of about -30°C $\mathrm{tg}\,\delta = 0.3$ [2]. There are far more data on the electric properties of volume water and ice. Since the rate of dielectric heating is dependent primarily on the factor of losses of the heated material and on field frequency, it is desirable to examine the behavior of volume water in high-frequency fields in dependence on these characteristics. Source [4] gives the dependence of $\varepsilon' \mathrm{tg}\,\delta f = \varepsilon'' f$ on field frequency for volume water and ice in a broad frequency range.

The value $\varepsilon'' f$ for water in the range of high and especially superhigh frequencies greatly exceeds this same value for ice. For example, at a frequency of 2375 MHz (the frequency of industrial technological apparatus) this value for water is $3.6 \cdot 10^{10}$, whereas for ice (with t = 20°C) it is equal to only $4.3 \cdot 10^{6}$.

We will compare the electric characteristics of ice, film and volume water at negative and positive temperatures. It was demonstrated in [1] that at a frequency of 213 MHz $\mathrm{tg}\,\delta$ for ice is $(4.2\text{-}7) \cdot 10^{-4}$, whereas the dielectric constant is 3.2.

In other words, the loss factor ε'' for ice at a frequency of 213 MHz is equal to $1.5 \cdot 10^{-3}$. For adsorbed water at negative temperatures at this same frequency $\varepsilon'' = 2 \cdot 10^{-1}$, for volume water at positive temperatures -- $\varepsilon'' = 2.4$.

Scaled to the value $\varepsilon' \operatorname{tg} \delta f$ (determining the capacity of the material to absorb HF energy) for ice, film water (at a temperature corresponding to the temperature of ice) and volume water (at a temperature close to 0°C) we obtain the values $3.2 \cdot 10^5$; $4.3 \cdot 10^7$ and $5.1 \cdot 10^8$. Thus, the intensity of absorption of the HF energy by the film water at a frequency of 213 MHz exceeds by two orders of magnitude (to be more precise, by a factor of 111) the intensity of absorption of HF energy by ice at this same frequency.

The intensity of absorption of HF energy by volume water in comparison with ice is still greater (by a factor of 160). In the light of these data the behavior of the polycrystalline ice in rapidly variable high-strength fields can be explained in the following way. Under the influence of a high-frequency field on the ice the absorption of energy occurs for the most part at the surface and at the boundaries of the grains. As a result, the liquid layer will increase and the mechanical strength of the ice will decrease. From the moment of appearance of the volume water the process of ice destruction will be accelerated still more (avalanchelike process). With some critical thickness of the water layers between the individual crystals the ice monolith breaks apart under its own weight.

For highly mineralized ice it is also possible to give other explanations of the behavior of ice in an electromagnetic field. The admixtures dissolved in the water at the time of phase transitions are squeezed toward the boundaries of the crystals and can be the source of local losses leading to the fracturing of the ice without melting in its entire mass.

However, such a mechanism can scarcely explain the similar pattern of behavior of ice prepared from distilled water. In any case, for ice which is virtually completely deprived of chemical admixtures, the explanation of the observed pattern of destruction is obviously different. Evidently, the only possible source of increased dielectric losses in the semicrystalline ice may be film water, whose ε' and $\operatorname{tg} \delta$ parameters, according to available data, are much greater than for ice.

BIBLIOGRAPHY

1. Bogorodskiy, V. V. and Fedorov, B. A., "Radar Sounding of Glaciers," ZHURN. TEKHN. FIZ. (Journal of Technical Physics), Vol 37, No 4, pp 781-788, 1967.

2. Zhilenkov, I. V., "Debye Dispersion of Adsorbed Water at Low Temperatures," IZV. AN SSSR: OKhN (News of the USSR Academy of Sciences: Division of Chemical Sciences), No 2, pp 232-234, 1957.

3. Kvlividze, V. I., Kiselev, V. F. and Ushakova, L. A., "Existence of a Quasi-fluid Film on an Ice Surface," DOKLADY AN SSSR (Reports of the USSR Academy of Sciences), No 191(5), pp 1088-1090, 1970.

4. Nekrasov, L. B. and Ivanov, V. G., "Destruction of Ice in Strong HF Electromagnetic Fields," FIZIKO-TEKHNICHESKIYE PROBLEMY RAZRABOTKI POLEZNYKH ISKOPAYEMYKH (Physicotechnical Problems in Mineral Output), No 5, pp 26-28, 1971.

5. Ushakova, L. A., Kvlividze, V. I. and Sklyankin, A. A., "Surface Properties of Snow and the Metamorphism Process," GIDROLOGIYA SUSHI. GLYATSIOLOGIYA. ITOGI NAUKI (Hydrology of the Land. Glaciology. Results of Science), Moscow, Izd-vo AN SSSR, pp 9-39, 1968.

6. Faraday, M., "Note on Regelation," PROC. ROY. SOC. LONDON, No 10, p 440, 1860.

7. Jellinek, H. H. G., "Liquid-like Layer on Ice," J. APPL. PHYS., No 32, p 1793, 1961.

8. Jellinek, H. H. G., "Liquid-like (Transition) Layer on Ice," J. COLL. AND INTERFACE SCI., No 25, pp 192-205, 1967.

DYNAMICS OF ICE IN COASTAL REGIONS ACCORDING TO DATA FROM SIDE-LOOKING RADAR SURVEY FROM AIRCRAFT

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 104-113

[Article by S. M. Losev and Yu. A. Gorbunov]

[Text] Among the new noncontact methods for investigating the ice cover which have come into practical use during the last decade is a side-looking radar survey from an aircraft [1, 3, 5, 7]. In this article the emphasis is on those possibilities which are afforded by a radar image in a study of the drift of ice and some phenomena associated with it.

Experience in work with the films of an electronic photorecording unit of a side-looking radar station convinces us that they contain much important information which can be used successfully for a deeper investigation of the kinematics and dynamics of the ice cover.

The materials from surveys with a side-looking radar in arctic seas during the period from 1968 through 1972 were used by us in investigating the following problems: influence of the land on the forming of drift in the coastal regions, spatial variability of the field of velocity of ice movement, mobility of ice fields relative to one another and their rotation, compression and thinning of the continuous drifting ice.

Much of the materials used here were obtained in ice aerial reconnaissance. The surveys were carried out both along individual flight alines and along parallel runs with coverage of a considerable area of the sea. The time interval between observations in one and the same region for the most part was two days.

A knowledge of the peculiarities of ice drift in the coastal regions is of great importance for ensuring navigation and also for the designing and operation of different kinds of hydraulic structures. However, there have been no effective methods for investigating the patterns of movement of ice under the real conditions prevailing in arctic seas with simultaneous coverage of quite extensive zones. In turn, attempts at an analytical solution of the problem of ice cover drift have not always been successful due to the difficulties in correct allowance for influence of the land. In this respect the data obtained using a side-looking radar can give much which is highly valuable for both practical work and for theory.

The material which we had at our disposal made it possible to analyze several schemes of the fields of velocity of drift of packed ice in the neighborhood of the islands. It was established that as a result of the transfer of the normal pressure forces in the ice cover on the drift side of the islands there is formation of zones of compression within which the normal drift component v_n decreases with approach to the shore.

As the extent of the nondrift zone of influence of the island we will use the distance L_f in the direction of the general drift from the point where a decrease in velocities to the central part of the island begins. Then the extent of the zone of influence of the island can be expressed by the value

$$\frac{L_f}{h},$$

where h is the section of the island along the normal to L_f. According to the collected data this ratio was close to 5 (Table 1).

Table 1

Characteristics of Field of Ice Drift Velocity on Drift Side of Island (Summertime)

Measurement series	Length of island, km	Section of island along normal to drift h, km	v_{max}, km/day	Extent of zone of fixed ice L_0, km	Extent of zone of island influence L_f, km	L_f/h	L_0/h
1	11.1	9.6	11.8	8.1	50.4	5.25	0.84
2	12.0	12.0	10.5	11.1	58.1	4.84	0.92
3	14.5	11.5	14.7	10.8	61.4	5.34	0.94
					mean	5.14	0.90

The change in the component v_n in the direction of the general drift as a function of distance to the shore L is characterized by a regularity which in general form can be represented by the equation

$$\frac{v_n}{v_{n_{max}}} = f\left(\frac{L}{L_z}\right),$$

where $v_{n_{max}}$ is the normal component of drift velocity at the boundary of the zone of influence of the island; L_z is the distance from the shore to the boundary of this zone.

Directly near the island on the drift side there is formation of a zone of fixed ice in the form of a wedge directed toward the drift and giving the island a streamlined shape. In summer the ratio of the length of the wedge L_0, measured from the section h, to the value of the section itself on the average is equal to 0.9. In winter as a result of freezing together of the ice the wedge can be more elongated. According to data from one of the surveys made during this period the L_0/h value was 1.51.

On the approaches to the wedge the drift divided and the ice, bending around the island on both sides, again converges on the opposite side. The zone of open pack ice developing beyond the island disappears at a distance from 0.4 to 2h. The zone of influence of the island on the field of velocity of movement of the ice on the sheltered side is approximately half as great as on the drift side. The increase in velocity beyond the island ceases on the average at a distance of 2.5 h (Table 2).

Table 2

Characteristics of Field of Ice Drift Velocity on Sheltered Side of Ialand (Summer)

Measurement series	Length of island, km	Section of island along normal to drift h, km	Extent of zone of influence of island L_b, km	L_b/h
2	12.0	12.0	32.0	2.67
3	14.5	11.5	32.0	2.78
4	37.0	26.0	62.0	2.38
5	22.0	16.5	35.5	2.15
			mean	2.50

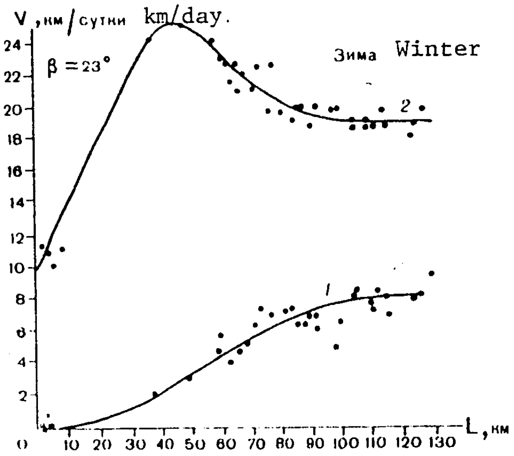

Fig. 1. Change in drift velocity components of packed ice as function of distance to shore. 1) normal component; 2) tangential component.

The use of films for the photorecording unit in a study of ice drift in straits between two islands or between an island and the mainland made it possible to establish that the formation of zones of compression and fixed ice on the drift side of the islands creates the effect of an "increase" in the length of the strait. For this reason the zone of increase in the velocity of ice movement at the entry into a strait is 1.2-2 times longer than the zone of decrease in velocity at the exit from the strait. The profiles of the velocity of the tangential component of drift across the central part of the strait and between the zone of compression and the shore of the mainland to all practical purposes are similar to one another.

It is known from observations that the shore exerts a different influence on the normal and tangential drift components. However, traditional methods for the study of ice drift under real conditions (radio beacons, DARMS stations, drifting stations) have not given simultaneous data for a detailed spatial analysis of change of these components. Surveys made using the side-looking radar make it possible to carry out such an analysis.

Figure 1 shows the change in ice drift velocity components for ice with a continuity of 9-10 units. The surveys were made in winter. In this case at a distance of 130-140 km from the land, where the drift components for all practical purposes no longer changed, the general direction of ice movement was at an angle $\beta = 23°$ to the boundary of the shore ice (the width of the shore ice was about 15 km).

It follows from the cited data that with approach to the shore the tangential component v_{ℓ} first increases, whereas the v_n component decreases. This is attributable to the fact that in this sector the value of the drift velocity vectors virtually does not change. At the same time, they rotate and in direction they gradually approach the direction of the shore ice boundary.

At a distance of 40-45 km from the fixed ice the influence of boundary zone friction begins to be reflected. Within its limits the v_{ℓ} values intensively decrease and at the boundary of the shore ice this component is only 0.4 of its maximum value.

The normal drift component v_n within the limits of the boundary zone is usually less than the v_{ℓ} component. In the immediate neighborhood of the shore or shore ice in a zone with a width of 10-15 km it is close to zero. Beyond the limits of the boundary zone the relationship between the v_{ℓ} and v_n values can be different and be determined completely by the value of the β angle.

In summer the change in the ice drift components in general is characterized by the same regularities. This is indicated by the data obtained in the neighborhood of the islands. However, the width of the boundary zone in the presence of packed ice during this period decreases to 10-15 km. The reaction of the normal drift component to the influence of the shore is transmitted within the region of the ice cover the same, evidently, as over shorter distances. At this time we have not been able to obtain any specific data on this problem.

The drift of the ice cover is accompanied by relative movements of the floes. The intensity of movement of the floes relative to one another has already been investigated on the basis of an aerial photographic survey with averaging of velocity during time intervals of about one hour [2, 4]. Using films from the photorecording unit we analyzed the velocities of relative movement of the ice with time averaging of two days. The mobility of the floes was examined in the direction of the mean drift and along the normal to it. For this we used the mean square values of the longitudinal v'_{ℓ} and transverse v'_n deviations of the velocity vector of each floe from the vector of mean ice drift velocity. The areas of the zones for which the drift was averaged were 600-800 km^2. It follows from these results that the relative displacements of the floes along the general drift increase with an increase in the mean velocity modulus v for movement of the ice cover (Table 3).

Table 3

Mean Square Values of Longitudinal Deviations $\overline{v}'_\ell$ of Ice Drift Velocity Vector, in km/day

Ice continuity, units	Mean ice drift velocity, km/day				
	7-9	9-11	11-13	13-15	15-17
4-6	1.81	2.43	2.69	2.98	3.56
7	1.20	1.55	1.72	2.06	2.35
8-10	0.62	0.74	0.86	1.11	1.30

The dependence of the v'_ℓ value on the $\overline{v}$ and C parameters is entirely satisfactorily approximated by the expression

$$\overline{v}_l = (0{,}41 - 0{,}037C)\,\overline{v}.$$

The mean square values of the transverse displacements of floes $\overline{v}'_n$ also increase with an acceleration of the general movement of the ice cover (Table 4). At the same time it is impossible to note any significant influence of ice continuity with its change from 4 to 9-10 units. In general, the deviations $\overline{v}'_n$ are comparable with the longitudinal deviations of the drift velocity vectors for packed ice.

The mean deviation between $\overline{v}'_n$ and $\overline{v}$ is 0.102.

It should be noted that in a coastal zone with a width of 15-20 km the fluctuations of the drift velocity vector are greater than in the more seaward zone. For example, with an ice continuity of 4-6 units the longitudinal deviations exceed the values cited in Table 2 on the average by a factor of 1.5. The values of the transverse deviations near the shore increase by a factor of 2-3.

Table 4

Mean Square Values of Transverse Deviations $\overline{v}'_n$ of Ice Drift Velocity Vector, km/day

$\overline{v}$, km/day	$\overline{v}'_n$, km/day	$\overline{v}$, km/day	$\overline{v}'_n$, km/day
7-9	0.78	13-15	1.21
9-11	1.13	15-17	1.73
11-13	1.10	17-19	1.95

A joint analysis of the deviations $\overline{v}'_\ell$ and $\overline{v}'_n$ makes it possible to establish a change in the nature of the distribution of the velocity vectors for movement of floes relative to the mean vector with an increase in continuity of the ice cover. It was found that in open pack ice the longitudinal displacements of the floes predominate over the transverse displacements, that is, $\overline{v}'_n/\overline{v}'_\ell < 1$ (Fig. 2). With an ice continuity of about 8 units the deviations on the average become equal. In more continuous ice the transverse displacements of the floes are greater than the longitudinal displacements. The dependence of the ratio $\overline{v}'_n/v'_\ell$ on ice continuity is determined approximately using the formula

$$\frac{v'_n}{v'_l} = \frac{1}{4{,}02 - 0{,}353C}.$$

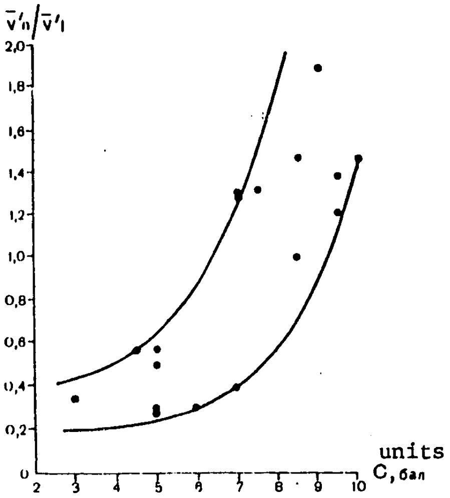

Fig. 2. Change in ratio $\bar{v}_n'/\bar{v}_l'$ as function of ice continuity (in units).

Interesting results were obtained in an analysis of the position of the axes of the ellipses of scattering of the deviations v'_l and v'_n. If the resultant drift is directed in the direction of any obstacle (toward the shore or zone of stranded ice), limiting the movements of the ice cover, the longer axis of the ellipse of scattering rotates relative to the mean velocity vector, tending to be oriented along the general direction of the obstacle. The very same occurs in the case of drift of open pack ice in the direction of the ice mass. For example, with a direction of the mean velocity vector at an angle of 50° to the boundary of the ice mass the greater axis of the ellipse was deflected from this boundary by only 15°, that is, it was turned relative to the mean drift by 35°. In the ice mass itself, near its boundary, with a similar direction of the resultant movement of the ice, the ellipses of scattering were also oriented along the boundary of the pack ice.

It was established earlier on the basis of materials from an aerial photographic survey that with the drift of open pack ice, uniformly distributed in space, and in the absence of obstacles the greater axis of the ellipses is usually deflected from the direction of the averaged drift by not more than 10° [4]. Now it has been found that in the presence of an ice continuity gradient the displacement of the floes relative to the mean velocity vector occurs differently. The velocity vectors are distributed in such a way that there is a predominance of drift fluctuations in the region of lesser ice continuity. Evidently, this peculiarity is attributable to internal processes transpiring in the ice cover as a result of both contact and hydrodynamic interaction of ice [6].

On the basis of materials from a radar survey it is possible to investigate the spatial variability of the field of ice drift velocity. As a characteristic of the correlation between the velocities of ice movement at individual points in the drift field we computed the normalized spatial correlation functions:

$$R(l) = \frac{\frac{1}{n-l}\sum_{i=1}^{n-l} v'(L_i)\, v'(L_i + l)}{\sigma_v^2},$$

where $v'(L_i)$ and $v'(L_i + \ell)$ are the deviations from the mean drift velocity at the points L_i and $L_i + \ell$; ℓ is the interval in which the correlation function was determined; σ_v^2 is the dispersion of drift velocity.

In computations we used a scheme of ice drift taking in an area of about 110,000 km^2 and averaged during a time interval of two days. The analysis was made in the direction of the general drift and along the normal to it.

The values of the mean velocity of ice movement and the standard deviations along the general drift were equal to $\bar{v}$ = 9.2 km/day; σ_v = 0.02 km/day, and along the normal to the drift -- $\bar{v}$ = 9.4 km/day; σ_v = 2.90 km/day.

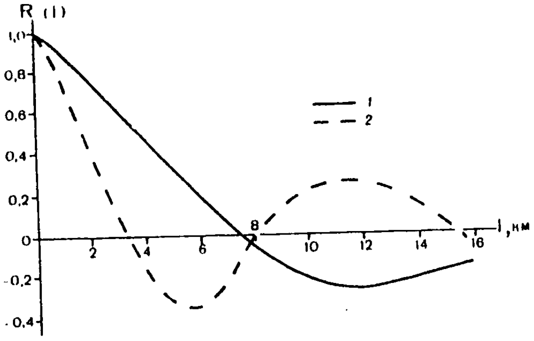

Fig. 3. Normalized spatial correlation functions of drift velocity of pack ice. 1) along direction of general drift; 2) along normal to general drift.

It can be seen from Fig. 3, which shows the results of computations, that the difference in the normalized correlation functions in the directions mentioned above is extremely significant. A substantial linear correlation between the drift velocities across the movement of ice (with $R(\ell) \leqslant 0.5$) is observed at points distant from one another by not more than 18 km, whereas along the drift this distance increases to 39 km. The first intersection of the axis of distances with the curve of the correlation function along the normal to the drift is observed with ℓ = 35 km. The correlation function along the direction of drift attains zero with ℓ = 75 km. Thus, the mean values of the maximum size of the structural formations of the field of drift velocity in the direction of ice movement and along the normal to it differ by a factor of approximately 2. This means that the structural formations of drift velocity, that is, zones of increased and decreased velocities of ice movement, have an elliptical shape and are drawn out in the direction of the general movement of ice.

One of the peculiarities of ice drift is rotation of floes during their translational movement. The floes can rotate both as a result of random interactions between them and under the influence of the general nonuniformity of the field of velocity of ice movement. It is evident that the rotation of large ice fields for the most part is attributable to the nonuniformity of drift and to a lesser degree is dependent on random factors. For a clarification of this circumstance we analyzed the rotation of 65 ice fields measuring from 2 to 8 km with an ice continuity of 9-10 units, making use of electronic photoregistry films. The velocity of rotation of the floes was compared with the local transverse drift velocity gradient in the sector of movement of each field. It was discovered that there is a direct correlation between these values, that is, with an increase in the absolute value of the transverse drift gradient the intensity of rotation of floes also increases. This dependence is expressed approximately by the equation

$$\omega = 24{,}5 \frac{\partial v}{\partial n} - 2,$$

where the transverse drift velocity gradient $\partial v/\partial n$ is expressed in km/day / km, and the velocity of rotation ω -- in degrees per day.

A study of deformation of the ice surface is of great importance, that is, an investigation of the compressions and dilatations arising in it. For a quantitative evaluation of these phenomena we used the change in area ΔS of a "surface element," discriminated from the characteristic points on individual floes. Since the electronic photoregistry films make it possible to establish the relative position of the floes at the times of the first and second surveys, it is also possible to determine the deformation ΔS of the contour during the interval between observations Δt. The intensity of deformation is expressed most simply by the relative change in the area of a surface element in a unit time

$$\mu = \frac{S_2 - S_1}{S_1 \Delta t},$$

where S_1 and S_2 are the areas of the contour during the first and second surveys. The relative deformation value is identical to the divergence of the ice drift velocity field.

A total of 134 μ values were obtained by the described method using data from summer surveys of pack ice. Seventy of these were with a plus sign and 64 were with a minus. In the computations for the most part we discriminated rectangular contours. The areas of the figures on the average were 100-120 km^2. It was established as a result of a careful analysis of the materials that the deformation of figures of such a scale is determined by the changes of both the velocity and direction of drift.

The mean positive μ value was +0.142; the mean negative value was -0.136; the mean for the entire sample was +0.009; the standard deviation was 0.186. The extreme μ values were +0.95 and -0.38. The curve of μ distribution is characterized by a positive asymmetry and a positive excess. The totality of these data makes it possible to assume that in the studied situation the deformations of the surface of the continuous ice cover during compression were manifested less intensively than during dilatation.

Spatially the μ values were not distributed unsystematically, but form individual zones with positive and negative values. In such zones during the period between surveys there were dilatations or compressions of the ice respectively. The zones of compression, elongated along the normal to the general drift, alternate with zones of dilatation. The width of the first on the average is 30 km; the width of the second on the average is 40 km. The maximum negative μ values were observed on the drift side of the islands, that is, in zones of intensive decrease in the velocity of ice movement. The maximum positive μ values were observed at the entrances to straits, where, on the other hand, the velocity increases were considerable. In zones of positive μ values it was usually possible to observe the forming of channels or chains of leads.

In this article we have by no means examined all the aspects of use of side-looking radar for study of the dynamics of the ice cover in the coastal regions of arctic seas. Nevertheless, we hope that the results cited here will be indicative of the possibilities of a multisided application of this method, which is not dependent on such factors as the illumination of the underlying surface and visibility. At the same time, we assume that the method requires further development, which evidently must be directed both along the lines of technical improvement of the radar system and along the lines of broad automation of the procedures of processing and analysis of the collected data.

BIBLIOGRAPHY

1. Gorbunov, Yu. A. and Losev, S. M., "Use of the Side-Looking 'Toros' Radar Set for Investigating Ice Drift," TRUDY AANII (Transactions of the Arctic and Antarctic Scientific Research Institute), Vol 316, pp 153-162, 1974.

2. Gorbunov, Yu. A. and Timokhov, L. A., "Investigation of the Dynamics of Ice," IZV. AN SSSR: SERIYA FIZIKA ATMOSFERY I OKEANA (News of the USSR Academy of Sciences: Physics of the Atmosphere and Ocean), Vol 4, No 10, pp 1086-1091, 1968.

3. Glushkov, V., et al., "New Means for Obtaining Ice Information," MORSKOY FLOT (Navy), No 9, pp 27-28, 1970.

4. Losev, S. M., "Statistical Analysis of Relative Mobility of Ice Cover," TRUDY AANII, Vol 307, pp 28-40, 1973.

5. Loshchilov, V. S. and Voyevodin, V. A., "Determination of Ice Cover Drift Elements and Movements of the Ice Edge Using the 'Toros' Airborne Side-Looking Radar Set," PROBLEMS AR[illegible]TIKI I ANTARKTIKI (Problems of the Arctic and Antarctic), No 40, pp 23-30, 1972.

6. Timokhov, L. A., "Dynamics of the Ice Cover and Changes in Its Continuity," TRUDY AANII, Vol 257, pp 125-134, 1967.

7. Johnson, J. D. and Farmer, L. D., "Use of Side-Looking Airborne Radar for Sea Ice Identification," J. GEOPHYS. RES., Vol 76, No 9, pp 2138-2155, 1971.

OBSERVATIONS OF SEA SURFACE TEMPERATURE USING A RADIATION THERMOMETER FROM AN ICE RECONNAISSANCE AIRCRAFT

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'-SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 114-120

[Article by A. I. Paramonov, Yu. A. Gorbunov and S. M. Losev]

[Text] During August-September 1973 in the eastern region of the Arctic for the first time specialists made regular observations of the temperature of the sea surface using a radiation thermometer. The following problems were solved: determination of the possibility of measuring the temperature of the sea surface in leads amidst thin and scattered ice, the collection of data on the temperature of the surface of ice of different age, evaluation of the accuracy of observations, perfection of the method for aerial temperature surveys from an ice reconnaissance aircraft.

The following apparatus was used in carrying out surveys

Precise Radiation Thermometer, Model PRT-5, Barnes Engineering Co., United States

Range of measured temperatures, °C	-20 - +75
Accuracy, °C	0.5
Response, °C	0.1
Inertia, sec	0.5
Working range of ambient temperatures, °C	-20 - +40
Working range of wavelengths, μm	8-14
Angle of view, degrees	2

Electronic Automatic Recording Potentiometer, Model KSP-4, USSR

Range of measured voltages, mV	0-10
Rate of run of carriage along entire scale, sec	2.5
Input resistance, ohms	1000
Rate of motion of registry tape, mm/hour	20, 60, 240, 720, 1800, 5400 and same values x 10
Accuracy, % of entire scale	0.5

Electronic Automatically Recording Potentiometer (Ankersmit), Model SP-65V, Riken Denshi Co., Japan)

Range of measured voltages	0-5 mV, 0-10 mV to 10 V on fixed and variable scales
Rate of run of carriage along entire scale, sec	1.0
Accuracy, % of entire scale	0.5
Rate of motion of registry tape, mm/hour	75, 150, 300
mm/min	10, 15, 30, 60, 120, 240, 480

Converter of voltage from 27 V d-c current to 220 V 50 Hz a-c current, voltage converter type PO-300, power 600-700 W

Model of IR Thermometer Developed in REVT Laboratory at Leningrad Electrotechnical Institute imeni V. I. Ul'yanov (Lenin) in Portable Variant

Range of measured temperatures, °C	-50 - +100
Accuracy, °C	0.5
Response, °C	0.2
Inertia, sec	2.0
Working range of ambient temperatures, °C	-50 - +50
Working range of wavelengths, μm	2.5-40
Angle of view, degrees	5.0

The checking of the working state of the apparatus was accomplished in the Radiophysical Research Section of the Arctic and Antarctic Scientific Research Institute in Leningrad and at the observatory of the Pevek Administration of the Hydrometeorological Service in Pevek. In carrying out the observations the apparatus was installed aboard an Il-14 aircraft which carried out ice reconnaissance in the eastern region of the Arctic. Methodological studies for checking the accuracy of temperature measurements were carried out during the time of flights for ice reconnaissance and temperature surveys during the period 14 August - 28 September.

Such studies were carried out, in particular, on the Kolyma River, in the neighborhood of Cherskiy station, where simultaneously with measurements with a radiation thermometer from a motor boat a mercury thermometer was used in measuring the temperature of the water surface layer in the river. The discrepancy in water temperature measurements did not exceed 0.2° (Table 1).

During the period of aerial temperature surveys it was also possible twice to carry out joint observations from aboard the expeditionary ship "Mayak." [The oceanographic expedition of the Arctic and Antarctic Scientific Research Institute aboard the expeditionary ship "Mayak" was headed by A. V. Chireykin.] Water temperature at the surface and at the horizons 0.5, 1, 2 and 5 m was measured from shipboard. In both cases the water temperature in the upper 5-m layer was virtually identical. Meteorological observations were made simultaneously (Table 2).

The difference in data obtained when measuring water temperature at the sea surface with a PRT-5 thermometer and the data obtained on the "Mayak" ship in the first case was 0.1 and in the second case 0.4° (see Table 1). An aerial temperature survey of the ice-free sea surface was made on 22 September. The aircraft flight path duplicated the standard hydrological runs made from the ship "Mayak."

Table 1

Temperature of Sea Surface According to Measurements at Polar Stations, "Mayak" Ship and From Aircraft With PRT-5 Radiation Thermometer

Date	Region	Temperature	
		PRT-5	polar station or ship
15/August	Cape Vankarem	2.6; 2.4; 2.1	0.5
	Kolyuchin Island	2.1; 1.6; 2.3	0.8
	Ayon Island	2.5	1.8
	Ambarchik Bay	11.0	9.3
20/August	Ayon Island	1.2	0.6
	Chetyrekhstolbovoy	3.2	2.3
	Kolyma River, Cherskiy	11.0	10.9
30/August	Chukotskoye More ("Mayak")	1.0; 1.0	0.9
31/August	Kolyma River, Cherskiy	8.0	7.8
17/September	Kolyma River, Cherskiy	1.8	1.9
21/September	Kolyma River, Cherskiy	2.2	2.0
22/September	Chukotskoye More "Mayak"	1.7; 1.4; 1.5; 1.4	1.1

Table 2

Meteorological Conditions According to Observational Data Obtained From Aboard the "Mayak" at Time of Joint Work With Aircraft

Date	Air temperature, °C	Relative humidity, %	Wind		State of sea, units
			direction	velocity, m/sec	
30/Aug	3.6	95	S	8	2
22/Sep	1.8	93	W	3	3

Figure 1 presents the results of observations obtained using the PRT-5 and a ship on one such section with an extent of about 200 miles. The expeditionary ship "Mayak" occupied oceanological stations each 30 miles. Readings on the hand indicator were made on the average each 6.5 miles of flight. Registry on the tape of a KSP-4 potentiometer was uninterrupted.

The substantial difference in the data obtained from aboard the ship and using the PRT in individual segments of the profile is attributable to the fact that the observations were made at different times. Due to the considerable time required for running the profile (19-28 September) and the great distance between stations the ship data have a smoothed character. The observational data obtained using the radiation thermometer indicate a more complex structure of the temperature field.

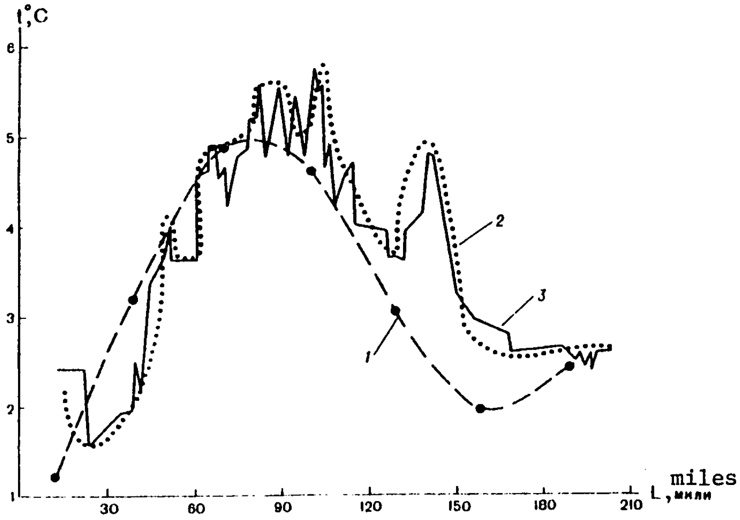

Fig. 1. Change in water temperature at sea surface along standard profile. 1) observational data obtained from aboard "Mayak" ship; 2) discrete readings on hand indicator of IR radiometer; 3) continuous registry on potentiometer tape.

Aircraft sorties were made to polar stations for checking the accuracy of readings of the radiation thermometer. At the time of aircraft approach to the station simultaneous measurements were made of water temperature at the sea surface on the hand indicator of the radiometer and by the polar station observer. The results of measurements of water temperature are communicated by the polar stations to the aircraft. The radiometer measurements had to be made precisely at the time of aircraft flight over the position of polar station observations. This was difficult to achieve. Taking into account that in the coastal regions the horizontal temperature gradients of the water are usually considerable, great discrepancies in the readings of the radiometer and polar station (see Table 1) are entirely natural.

During the execution of ice reconnaissance leads were encountered on almost every flight; these were covered with young ice. If the young ice had the age stage of ice slush or ice crust or older, the radiometer measured the temperature of the surface of this ice. If ice needles were observed in the lead, it could be assumed that the temperature at the surface of the lead has the freezing temperature of water. In this case the radiometer readings were compared with the freezing temperature of water with the mean long-term salinity value for this region.

An analysis of the results of aerial temperature surveys and methodological studies reveals that the instruments used meet the principal requirements of operation on board aircraft under arctic conditions. The PRT-5 precise radiation thermometer has good operational qualities, a high stability, insignificant inertia and stable reading. During the entire operating period the error in measurements with this radiometer did not exceed the value indicated in the certificate.

Among the shortcomings of the PRT-5 we should include the complexity of the circuitry and the great number of highly sensitive elements, which results in a high cost of the instrument and lowers its reliability. With respect to design a radtion thermometer has an inadequate strength of the plugs and contacts and an inadequate hermetic sealing. During the time of operation of the PRT-5 radiometer there was one failure in its operation as a result of increased vibration and entry of moisture from the air into the optical head. This led to disruption of the contacts of the sensing elements. In general, however, the results of the work confirmed the accuracy of its measurements. This made possible extensive use of the PRT-5 radiometer for the collection of important information on temperature of the sea surface. The collected data were used in the scientific-operational support of sea operations.

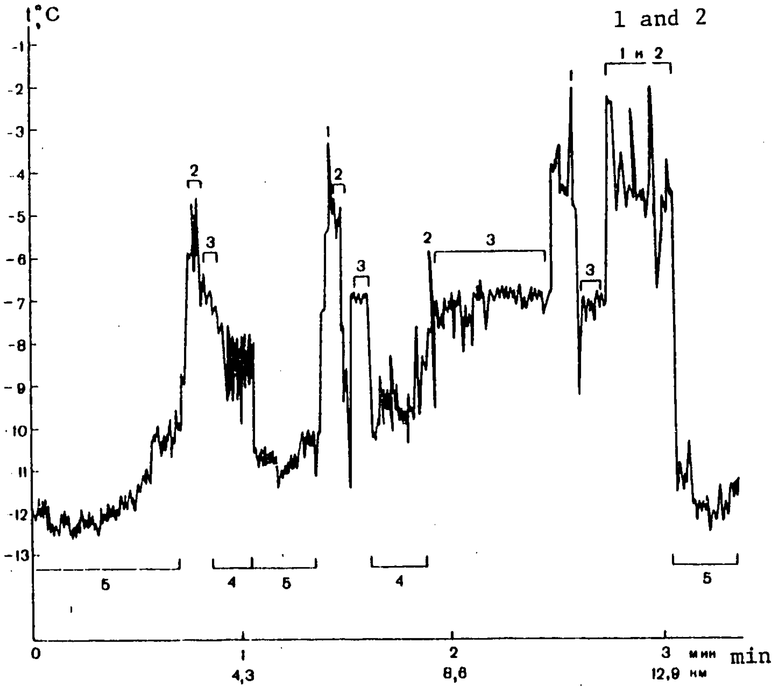

Fig. 2. Fragment of record of surface temperature of ice cover on 28 September 1973. 1) slush ice; 2) dark ice crust; 3) light ice crust; 4) one-year ice; 5) field of perennial ice.

During the flights specialists also made tests of a model of an IR thermometer developed in the REVT laboratory of the Leningrad Electrotechnical Institute in a portable variant. A peculiarity of this instrument is the simplicity of the circuitry, low cost, strength and reliability in operation. The inadequacies include an increased zero drift and a broad transmission band of the optical filters.

The KSP-4 and Ankersmit potentiometers met the requirements of aerial temperature surveys.

In addition to measurements of the water temperature at the sea surface, the radiation thermometer registered the surface temperature of the ice cover. The measurements which were made confirmed the idea expressed in [2] that the temperature of ice of different age is different (Fig. 2). Such a difference is a result of a decrease in the heat flow from the water to the upper surface of the ice with an increase in its thickness. In autumn and in winter at negative air temperatures the young ice is invariably warmer than the perennial ice. This fact is of unquestionable interest and merits the closest attention in further investigations. Such investigations will afford a possibility for study of the peculiarities of heat exchange between the ocean and the atmosphere through the ice cover over a considerable area. At the same time, the temperature contrast at the ice surface, depending on its thickness, will make it possible to solve the inverse problem: use of IR apparatus for determining ice of different age. However, at present there are still no data for any generalizations along these lines. For this reason the collection of data on temperature of the ice cover must be continued. For an objective interpretation of ice and preparation of new standards on the basis of data from IR apparatus it is desirable that such observations be supplemented by an aerial photographic survey along the flight route.

In addition, it is important to clarify how the nature of the correlation between the thermal contrast and ice age changes with transition of air temperature from negative to positive values and also whether there is a sufficiently clear dependence between these characteristics in summer, when the ice surface is covered by a thin water film and patches of snow. The value of the observations is increased if the measurements with the radiometer are supplemented by direct measurements of temperature of the ice surface by highly sensitive contact sensors. Such data are necessary for experimental determination of the optical characteristics of the ice cover surface.

In order to draw final conclusions concerning the correspondence between the temperature of the thin film and the temperature of the sea surface layer it is necessary to carry out special methodological investigations similar to the investigations described in [1]. They also should include parallel measurements with a radiometer and the contact sensors of the expeditionary ship. It is particularly important to carry out such work in leads where there is thin or scattered ice since under these conditions the effect of wind mixing is lessened and as a result of the thawing of ice the stability of the water surface layer is increased. The organization of such observations will also make possible a more precise determination of the influence of state of the atmosphere on radiometer readings.

BIBLIOGRAPHY

1. Vinogradov, V. V., "Some Results of Measurements of Water Temperature Distribution in the Surface Layer of the Northern Part of the Atlantic Ocean," TRUDY OKEANOGRAFICHESKOGO INSTITUTA (Transactions of the Oceanographic Institute), No 100, pp 38-46, 1970.

2. Galkina, A. I. and Spitsyn, V. A., "Measurement of Surface Temperature of Water, Snow and Ice by a Radiation Thermometer," TRUDY AANII (Transactions of the Arctic and Antarctic Scientific Research Institute), Vol 295, pp 64-68, 1970.

STUDY OF DYNAMICS OF GLACIERS USING LASER DEFORMOGRAPH

Leningrad TRUDY. ORDENA LENINA ARKTICHESKIY I ANTARKTICHESKIY NAUCHNO-ISSLEDOVATEL'-SKIY INSTITUT. FIZICHESKIYE METODY ISSLEDOVANIYA L'DA I SNEGA in Russian No 326, 1975 pp 143-146

[Article by I. M. Belousova, I. P. Ivanov and N. G. Firsov]

[Text] This article is a discussion of some characteristics of a laser deformograph and also the results of investigations which were obtained using this instrument on glaciers in the neighborhood of Mirnyy station in Antarctica.

The fundamental possibility of creating such an instrument was mentioned in [1,3]. Laboratory and field investigations carried out using a laboratory model of the instrument in Antarctica, on the ice of Lake Ladoga and on the glaciers of the Caucasus made it possible to formulate the following requirements on individual instrument blocks.

1. Its laser should be: a) single-frequency, since only in this case is the modulation intensity of the output radiation not dependent on the distances to the investigated object; b) single-mode, which ensures the necessary modulation intensity and makes it possible to avoid intermode beats [2]; c) stable with respect to radiation frequency, with adherence to the following condition:

$$\Delta\nu / \nu_0 \ll \Delta L_{eff}/L,$$

where ΔL_{eff} is the measured shift, L is the distance to the measured object, $\Delta\nu$ is the change in the frequency of laser radiation, as a result of system instability, ν_0 is the laser radiation frequency.

2. The optical system of the instrument must include receiving and transmitting telescopes which are selected from the condition of full use of laser radiation with reflection from the investigated object.

3. The registry system must include a photomultiplier (FEU), amplifier and spectrum analyzer, upon which special requirements are not imposed.

Our laboratory investigations made it possible to determine the limits of the rates of movement of the object to be determined, which with respect to the upper limit are determined by the width of the resonance line of the laser and are 1-2 MHz (0.6 m/sec), and which with respect to the lower limit are determined by the width of the generation line, whose theoretical width is determined by the specific conditions of the experiment and is a value about 10^{-3} Hz. Under natural conditions it is dependent on thermal deformations, the microphone effect, fluctuations of the atmosphere on the radiation path.

In addition, by means of laboratory investigations it was possible to determine absolute sensitivity to the shift, whose minimum value in the case of use of a laser with a three-mirror resonator (unmatched) is 0.002μm.

Field tests of a model of the instrument in Antarctica in the neighborhood of Molodezhnaya station during the period of operation of the 15th Soviet Antarctic Expedition [4] indicated that the instrument could perform in severe climatic situations and also that it is possible to determine the rate of movement of objects at distances from 380 m. One of the important conclusions from this study was that the atmosphere over the glacier cover in Antarctica is exceedingly favorable for the carrying out of this type of interferometer measurements. As a result of what has been presented above, we designed and fabricated a laser deformograph.

Laser Deformograph Operating Principle

The laser radiation is directed through the forming optical system to a reflector mounted on the investigated glacier, and being reflected from it, returns to the instrument. The beats arising in the laser are registered by a photodetector; their frequency is determined by the recording apparatus. The instrument consists of three blocks: reflector, recording apparatus together with a power source for the entire apparatus, laser with a photodetector and with the optical system. The instrument uses a specially developed single-frequency ($\lambda = 6328$ A) helium-neodymium laser with frequency stabilization which is created by control of the resonator by an error signal shaped using a neon absorbing cell in a magnetic field and a doubly refracting prism.

The laser deformograph is intended for operation at distances up to 1.5 km. The very same 20^x telescope is used as the transmitting and receiving optical system. The reflector, whose diameter is 200 mm, is a set of triple high-quality prisms (1"-3"). For a methodological comparison, and also for operation with internal frequency stabilization, a Michelson interferometer is incorporated in the instrument. By means of an eyepiece fitted directly into the instrument the laser radiation is visually directed to the reflector. The system operates in a mismatched coupled resonator so that the fraction of light returned to the laser is small and the intensity of this radiation is modulated in conformity to a sinusoidal law. The period of modulation of the radiation corresponds to the Doppler frequency, related to the movement of the object by the formula

[OTP = refl]

$$\Delta I = \frac{T^2\sqrt{R_0 R_{\text{отр}}}}{8la}\cos\left(2\nu\frac{v}{c}t + \varphi\right),$$

where Δ I is the change in laser intensity; ν_0 is the frequency of laser radiation; v is the rate of movement of the object; c is the speed of light; I is the length of the resonator; a is the distance to the object; R_{refl} is the coefficient of reflection within the resonator; $R_0 = 1 - T_0$ is the coefficient of reflection of the reflector.

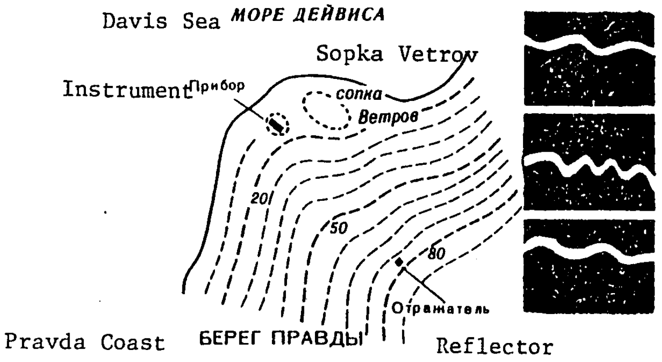

Fig. 1. Diagram of investigated region.

Calibration was accomplished by means of a specially developed simulator of movement based on thermal expansion. By means of the simulator the translational movement along a guide with rates from 0.5μm/sec to 100μm/sec is communicated to the triple prism reflector.

This instrument was tested in operation during the seasonal period of the 18th Soviet Antarctic Expedition in Antarctica in the neighborhood of Mirnyy station. The first step was to determine the instrument's effective range, that is, a determination of the maximum distance at which laser radiation does not lose its coherence property. It was discovered that with the passage of radiation through a layer of the atmosphere with a thickness up to 2 km the coherence of the radiation is not impaired. Measurements of atmospheric transparency were made for radiation with λ = 6328 A.

Atmospheric transparency was determined at different times of day during the period from 20 January through 20 June 1973. A correlation was found between atmospheric transparency for λ = 6328 A and the meteorological range of visibility. It can be concluded from these experiments that atmospheric transparency is very high and virtually all the laser radiation passes through the atmosphere, that is, there is confirmation for the conclusion drawn during the period of operation of the 15th Soviet Antarctic Expedition that the atmosphere over the Antarctic glacier is very favorable for interferometer measurements of this kind. An outlying camp for study of movement of the glacier cover was organized in the neighborhood of the small Hill of the Winds (Sopka Vetrov) (Fig. 1). The instrument was set up directly in the tent on bare rock, together with apparatus for adjusting and checking individual instrument components. All the apparatus was supplied current from a gasolene-powered generator. The rates of movement of different points on the glacier were determined (distant up to 1 km from the rocks).

The registered oscillograms were used in computing the rate of movement of some point on the glacier during the time of observation; this varied in the range from 0.5μm/sec to 1.2μm/sec. In some cases it can be seen from the oscillograms that the rate of movement of this point on the glacier is not constant even during the observation time, that is, during a time of about 10 sec.

Thus, the laser deformograph, successfully undergoing tests under field conditions in Antarctica, makes it possible to obtain new data on the movement of the glacier cover and undoubtedly in the future it can be used in solving many glaciological problems.

BIBLIOGRAPHY

1. Belousova, I.M., Bogorodskiy, V. V. and Ivanov, I. P., "Measurement of the Rate of Movement and Deformation of Glaciers Using Doppler Systems," TEZISY DOKLADOV NA XV GENERAL'NOY ASSAMBLEYE MGGS (Summaries of Reports at the Fifteenth General Assembly of IQSY), Moscow, 1971, 47 pages.

2. Belousova, I.M., Danilov, O. B. and Lyubimov, V. V., "Intermodal Beats in the Low-Frequency Spectral Region," ZHURN. TEKHN. FIZ., No 6, p 1134, 1967.

3. Belousova, I.M., Bogorodskiy, V. V., Danilov, O. B. and Ivanov, I. P., "Investigation of the Dynamics of Movement of Glaciers Using a Laser," DOKLADY AN SSSR (Reports of the USSR Academy of Sciences), Vol 199, No 5, pp 1055-1057, 1970.

4. Ivanov, I. P. and Chudakov, V. I., "Possibility of Determining the Rate of Movement of Glaciers Using the Doppler Effect in a Laser," INFORM. BYULL. SAE (Information Bulletin of the Soviet Antarctic Expedition), No 8, pp 143-146, 1973.

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