AD-A041 250 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 8/3
WIND DRIFT OF ANTARCTIC SEA ICE (VETROVOI DREIF MORSKIKH ANTARK--ETC(U)
JUL 77 G I BARANOV, V O IVCHENKO

UNCLASSIFIED CRREL-TL-623 NL

1 OF 1
AD
A041250

END
DATE
FILMED
7-77

TL 623

Draft Translation 623
July 1977

(12)

WIND DRIFT OF ANTARCTIC SEA ICE

G.I. Baronov et al

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Draft Translation 623	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): WIND DRIFT OF ANTARCTIC SEA ICE	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): G.I. Baranov, et al	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: July 1977
	13. NUMBER OF PAGES: 22
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SEA ICE
WIND FACTORS
DRIFT

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Using a hydrodynamic ice drift model which allows for interaction of icebergs among themselves, general schemes for average monthly ice circulation around Antarctica are given. A companion chart of solid and breakup zones is also included. The possibility of drawing up a map of solid ice zones based on the records of the forced drift of the Ob in 1973 is discussed.

(14) CRREL-TL-623

DRAFT TRANSLATION 623

(6)

ENGLISH TITLE: WIND DRIFT OF ANTARCTIC SEA ICE

FOREIGN TITLE: (VETROVOI DREIF MORSKIKH ANTARKTICHESKIKH L'DOV),

(11) Jul 77 (12) 25p.

(10)

AUTHOR: G. I. Baranov, ~~et al~~ V. O. Ivchenko, M. I. Maslovskiy, A. F. Treshnikov, D. E. Kheysin

(21) Draft trans. of

SOURCE: Problemy Arktiki i Antarktiki, No. 47, 1976, p. 118-139, 1976. (USSR)

CRREL BIBLIOGRAPHY NO: 31-256

Translated by Office of the Assistant Chief of Staff for Intelligence for U.S. Army Cold Regions Research and Engineering Laboratory, 1977, 22p.

NOTICE

1473

Ø37100

WIND DRIFT OF ANTARCTIC SEA ICE

PROBLEMY ARKTIKI I ANTARKTIKI in Russian No. 47, 1976 pp 118-139

[Article by G. I. Baranov, V. O. Ivchenko, M. I. Maslovskiy, A. F. Treshnikov, D. E. Kheysin]

The drift of sea ice in arctic seas is mainly due to the wind [2,7,9] and is determined by the nature of the atmospheric circulation. The magnitude of the wind coefficient k and the angle of deviation of the drift from the wind direction α, which are obtained by instrumental observations on ice drift, vary over a wide range. The coefficient k varies from 0.001 to 0.105, and its average values fluctuate from region to region by more than four times (0.010-0.043). The angle α varies in similar fashion. The magnitude of these parameters depends on the direction of the wind relative to the shore and also varies substantially from season to season. Hence the simple and convenient method of N. N. Zubov can only be used for small well-studied regions, where typical pressure fields can be selected and the corresponding drift parameters can be determined for each point of computation.

The magnitude of the mean wind coefficient for antarctic seas (0.030) is significantly larger than the corresponding value for the Arctic Ocean (0.017). The reason for this difference lies in the specific natural conditions that prevail in the Antarctic, particularly the lack of any sort of obstacle to the spread of ice northward. V. Kh. Buynitskiy [3] compiled charts of the isobaric drift of antarctic sea ice from October 1961 to September 1962, where he plotted daily drift values calculated using Zubov's formula and daily charts of pressure near the surface. Smoothed ice drift trajectories for the eleven-month period provided a clear picture of the overall ice circulation in antarctic waters. Nevertheless, because of the deficiencies of this method mentioned above, the quantitative results of the study must be examined critically.

It is stated in reference [6] that the main characteristic of atmospheric circulation in Antarctica is the existence of a system of climatic cyclones around the continent, which form a relatively stable circumpolar zone of low pressure. Hence in four regions of Antarctica climatic cyclones are observed practically year round. These cyclones are located in Riiser-Larsen Sea (20° E long.), the Sea of Cooperation (72° E long.), the Ross Sea (160° E long.), and the Weddell Sea (35° W long.).

O. G. Krichak has set forth his view concerning the overall pattern of sea ice drift in the Antarctic, which can be summarized as follows. Close to the shore of the continent, along the southern periphery of the stationary cyclone, the ice drift is westward. On the back side of the cyclones due to the prevailing outward winds, the ice is moved strongly away from the coasts of the continent northward. On the front side of the cyclones, where the wind direction is opposite, the rate of movement of the ice falls off sharply, and the ice is very compact. The same viewpoint is upheld by A. F. Treshnikov [10,11]. The calculations of V. Kh. Buynitskiy [3] have shown that close to the shore the isobaric drift of sea ice is significantly faster than in the northern part of the zone, close to the outer edge of drifting ice. In addition, the northward movement in the area near the shore of the antarctic continent is very stable.

The formation of leads and areas of solid drift ice is also related to ice drift processes. The formation and persistence of leads in antarctic ice are caused by the movement of sea ice away from the place where it is formed [7]. Since outward winds prevail everywhere along the coasts of Antarctica, persistent leads should form along the western shores of capes and peninsulas extending into the sea. The nature of a bend in the shore line largely determines the existence of persistent open water, since it protects the open area from being filled with ice drifting along the coast.

Persistent leads are widely distributed along the coast of Antarctica, even outside the shore zone. It is worth noting that leads are often formed between very compact concentrations of ice. In addition to the persistent leads in the Antarctic we also find persistent areas of continuous ice. The largest of them are found in the Weddell Sea.

It would be interesting to build a general picture of the drift of antarctic sea ice on the basis of present-day ideas concerning the nature of this process. To solve this problem we shall use a mathematical model of ice drift, which takes into account the interaction of ice floes and which was developed in studies reported in references [4,5, and 13]. Nonsteady-state equations for the movement of the ice cover are solved. These equations take into account the balance of friction forces on the upper and lower surfaces of the ice, inertia, the Coriolis force, lateral transfer of momentum, and quasi-elastic compression forces.

Equations for the dynamics of barotropic quasi-stationary layers of the atmosphere and ocean are used to complete the equations of ice motion. To find the turbulence coefficient we use an equation for the balance of turbulent energy in integral form and semi-empirical hypotheses. Then the closed system of equations is written in the following form:

$$\begin{cases} m\dfrac{\partial u_0}{\partial t}+\lambda m v_0=\rho_1 k_1\dfrac{\partial u_1}{\partial z_1}\Big|_{z_1=0}+\rho_2 k_2\dfrac{\partial u_2}{\partial z_2}\Big|_{z_2=0}+k_r m\nabla^2 u_0+\dfrac{\partial P_{xx}}{\partial x}+\dfrac{\partial P_{xy}}{\partial y},\\ m\dfrac{\partial v_0}{\partial t}-\lambda m u_0=\rho_1 k_1\dfrac{\partial v_1}{\partial z_1}\Big|_{z_1=0}+\rho_2 k_2\dfrac{\partial v_2}{\partial z_2}\Big|_{z_2=0}+k_r m\nabla^2 v_0+\dfrac{\partial P_{yx}}{\partial x}+\dfrac{\partial P_{yy}}{\partial y}, \end{cases} \quad (1)$$

$$P_{ik}=k_P\left(\frac{\partial u_i}{\partial x_k}+\frac{\partial u_k}{\partial x_i}\right), \quad (2)$$

where P_{ik} is the "elastic" tensor of stresses and k_p is the coefficient of compression, which is equal to $3\cdot10^6$ dyn/cm.

The relation between rates of deformation and magnitudes of deformation for short-period processes can be assumed to be linear:

$$\begin{cases} u_0=\dfrac{\partial u_x}{\partial t}\\ v_0=\dfrac{\partial u_y}{\partial t}. \end{cases} \quad (3)$$

We write the equations for the dynamics of the boundary layers of the ocean and the atmosphere in the following form:

$$\begin{cases} k_j\dfrac{\partial^2 u_j}{\partial z_j^2}-\dfrac{1}{\rho_j}\dfrac{\partial P_j}{\partial x}-\lambda v_j=0\\ k_j\dfrac{\partial^2 v_j}{\partial z_j^2}-\dfrac{1}{\rho_j}\dfrac{\partial P_j}{\partial y}+\lambda u_j=0, \end{cases} \quad (4)$$

and the equation for the turbulent energy balance in integral form as follows:

$$\int_0^{H_j} k_j\left[\left(\frac{\partial u_j}{\partial z_j}\right)^2+\left(\frac{\partial v_j}{\partial z_j}\right)^2\right]dz_j-c_1 b_j^{3/2}=0, \quad (5)$$

where the expressions

$$k_j = c_2 H_j \sqrt{b_j}, \tag{6}$$

$$H_j = \pi \sqrt{\frac{k_j}{\lambda}} \tag{7}$$

represent semi-empirical hypotheses.

Here u_0 and v_0 are components of drift velocity; m is the surface density to the ice; u_x and u_y are components of the vector of movement; the subscript j indicates magnitudes related to the boundary layers of the atmosphere (j = 1) and the ocean (j = 2). The origins of the z_1 and z_2 axes are located at the ice-air interface and ice-water interface; z_1 is directed vertically upward, and z_2 vertically downward; p_j and P_j are the density of the medium and the pressure; H_j and b_j are the thickness of the boundary layer and the kinetic energy of turbulent pulsations; λ is the Coriolis parameter; k_j is the coefficient of turbulent viscosity; k_Γ, which is equal to 10^{10} cm^2/sec, is the coefficient of lateral momentum transfer; and c_1 and c_2 are numerical constants. The values of k_Γ and k_p are obtained by numerical experiments.

The system of equations should satisfy the following boundary conditions. At the air-ice and ice-water interface the condition of cementing of velocities is met:

$$z_j = 0: \begin{cases} u_j = u_0; \\ v_j = v_0. \end{cases} \tag{8}$$

At the upper margin of the atmospheric boundary layer, the wind speed coincides with the speed of the geostrophic wind $\vec{G} = (u_g, v_g)$:

$$z_1 = H_1: \begin{cases} u_1 = u_g; \\ v_1 = v_g. \end{cases} \tag{9}$$

At the lower margin of the boundary layer beneath the ice the current speed returns to 0

$$z_2 = H_2: \begin{cases} u_2 = 0; \\ v_2 = 0. \end{cases} \tag{10}$$

At the solid contour $\partial\Gamma$ the condition of adhesion holds for the drift speed:

$$\begin{aligned} u_0 |_{\partial\Gamma} &= 0; \\ v_0 |_{\partial\Gamma} &= 0. \end{aligned} \tag{11}$$

At the liquid boundary $\partial\Gamma$ the condition of free flow should be fulfilled

$$\left.\frac{\partial u_n}{\partial n}\right|_{\partial \Gamma} = 0, \qquad (12)$$

where n is the perpendicular to $\partial\Gamma$.

The isobaric drift $\vec{V}$ = (u,V) is given as the starting point

$$t = 0 : \begin{cases} u_0 = \tilde{u}; \\ v_0 = \tilde{v}. \end{cases} \qquad (13)$$

The method of splitting is applied to the system of equations (1-7) after transformation, and then the method of dispersal.

Analysis of the Results of Calculations

In carrying out numerical computations on the computer for the ice cover of the antarctic seas, difficulties of the following nature were encountered: the ice cover forms a relatively narrow ring around an enormous continent and for this reason it is impossible to use a single computational grid. To take into account the most characteristic outlines of the continental shore, the grid interval should not exceed 30-60km.

It was found possible to handle this problem by dividing the entire region covered by the computations into a series of sectors overlapping one another. The interval of the computational grid was made equal to 55km (0.5° along a meridian), and 110km in the Weddell Sea region (1.0° along a meridian). The calculations were based on the monthly chart of average pressure near the ground in April, as given in the Atlas of the Antarctic [1].

The April position of the ice edge was also based on the Atlas. Maps of the ice drift and the distribution of compression and rarefaction were plotted from the results of the computations. These maps were assembled to give an overall picture of ice drift around the whole of Antarctica.

The use of an average monthly chart for pressure near the ground gives us information on the resultant ice drift, the velocities of which are usually lower than those actually observed. But the existence of the system of quasi-stationary cyclones mentioned above assures that the results obtained will be close to the actual instantaneous drift speeds. Since resultant vectors of ice drift were used in the compression and decompression patterns calculated, they can obviously be treated as a distribution of mean monthly positions of ice compression and relaxation zones (leads).

Charts of ice drift at zones of relaxation are given in Figs. 1a and 1b for the Weddell Sea. The pressure situation shows a cyclone over the sea with its center at 28° E long. At the southern and northern peripheries of the cyclone there are zones of sharp rise in pressure gradients near the surface. Elevated pressure gradients near the surface along the coast of the continent are typical of the whole of the Antarctica and are responsible for the high speed of ice wind drift (up to 1 m/sec) in the shore zone. The distribution of ice drift velocities obtained (Fig. 1a) agrees with existing ideas concerning it in these regions: the drift is close to isobaric and the wind coefficient is approximately equal to 0.032-0.034, i.e. it agrees with the results of other investigators [3,8]. The drift deviates slightly from the isobar (6-10°) in the high-pressure direction. Some change is observed in the drift speed of the ice in the regions near the shore due to the influence of the shore.

The diagram of ice circulation presented shows a relatively narrow zone (up to 200 km wide) along the shore of Coats Land in the eastern part of the sea, where the drift velocities of the ice are from 36-40 cm/sec. The drift is compressive in nature along the Riiser-Larsen and Filchner Ice Shelves, and this is reflected in the distribution of zones of compression and relaxation (Fig. 1b). With this distribution of pressure in April the lead reported by some authors [7,9] at the Filchner Ice Shelf barrier evidently should be covered with ice.

Farther along the Antarctic Peninsula the ice drift velocities are low (10-15 cm/sec), and at the Larsen Shelf it enters the back side of the cyclone, whence it is carried away in the heavy flow northward. In this way the ice is transported from the coastal regions beyond the Antarctic Divergence into the region of the East Wind Drift.

The clearly defined expansive drift at the Larsen Ice Shelf should be responsible for the existence in this region of a stationary lead in the autumn. Fig. 1b confirms this assumption. The actual existence of such a lead is mentioned in a number of studies [3,8,9].

The field of ice drift velocities in the center of the cyclone is characterized by low speeds. At the same time the action of the Coriolis force should cause the ice flow to spread out and result, if not in the appearance of leads, at least in a weakening or disappearance of compression. This zone is indicated on the diagram in question. At 50° E long. there is a region of elevated stress causing the ice to come together as a result of negative divergence of the air flow.

One of the climatic cyclones usually exists also above the Riiser-Larsen Sea (see Fig. 2a). The center of the cyclone is located at

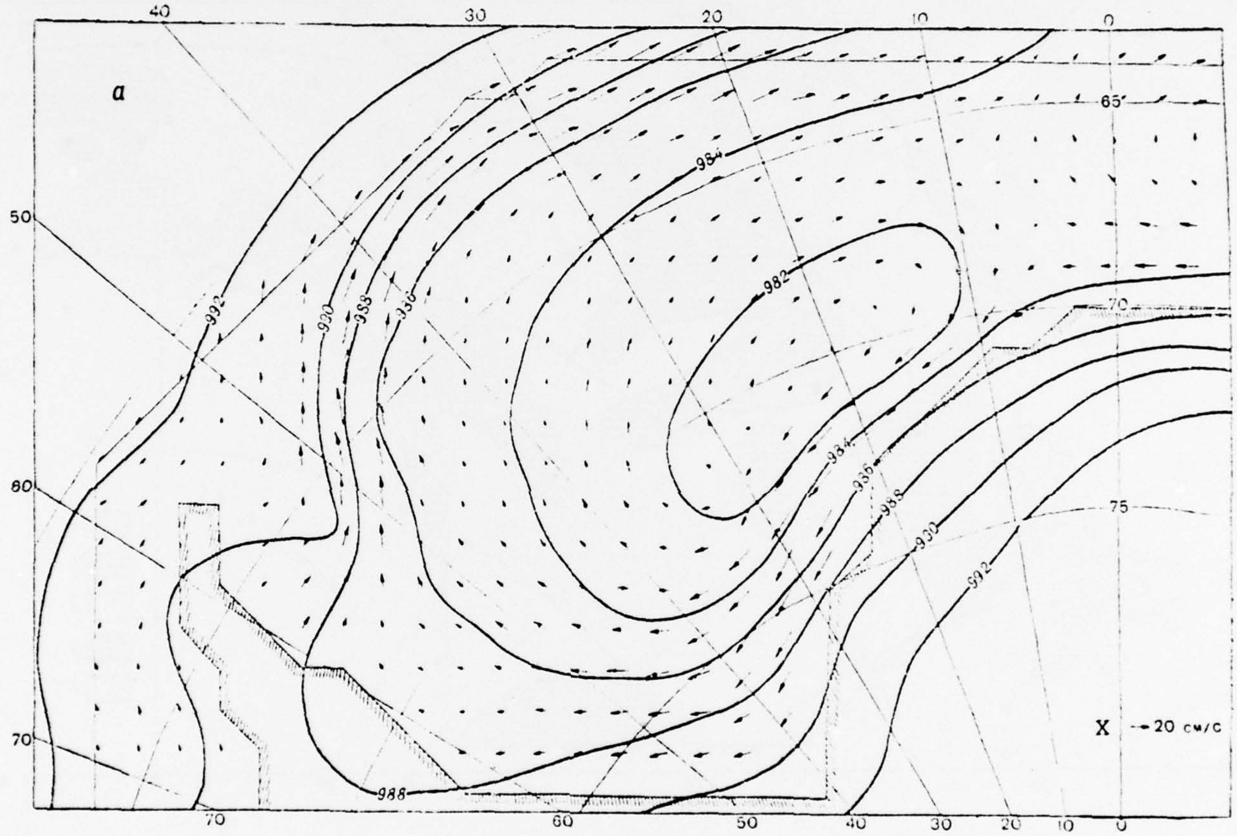
40
30
20
10
0
a
65'
984
982
70
50
992
990
988
986
984
986
988
990
60
75
992
70
X
20 cm/c
988
70
60
50
40
30
20
10
0

Fig. 1

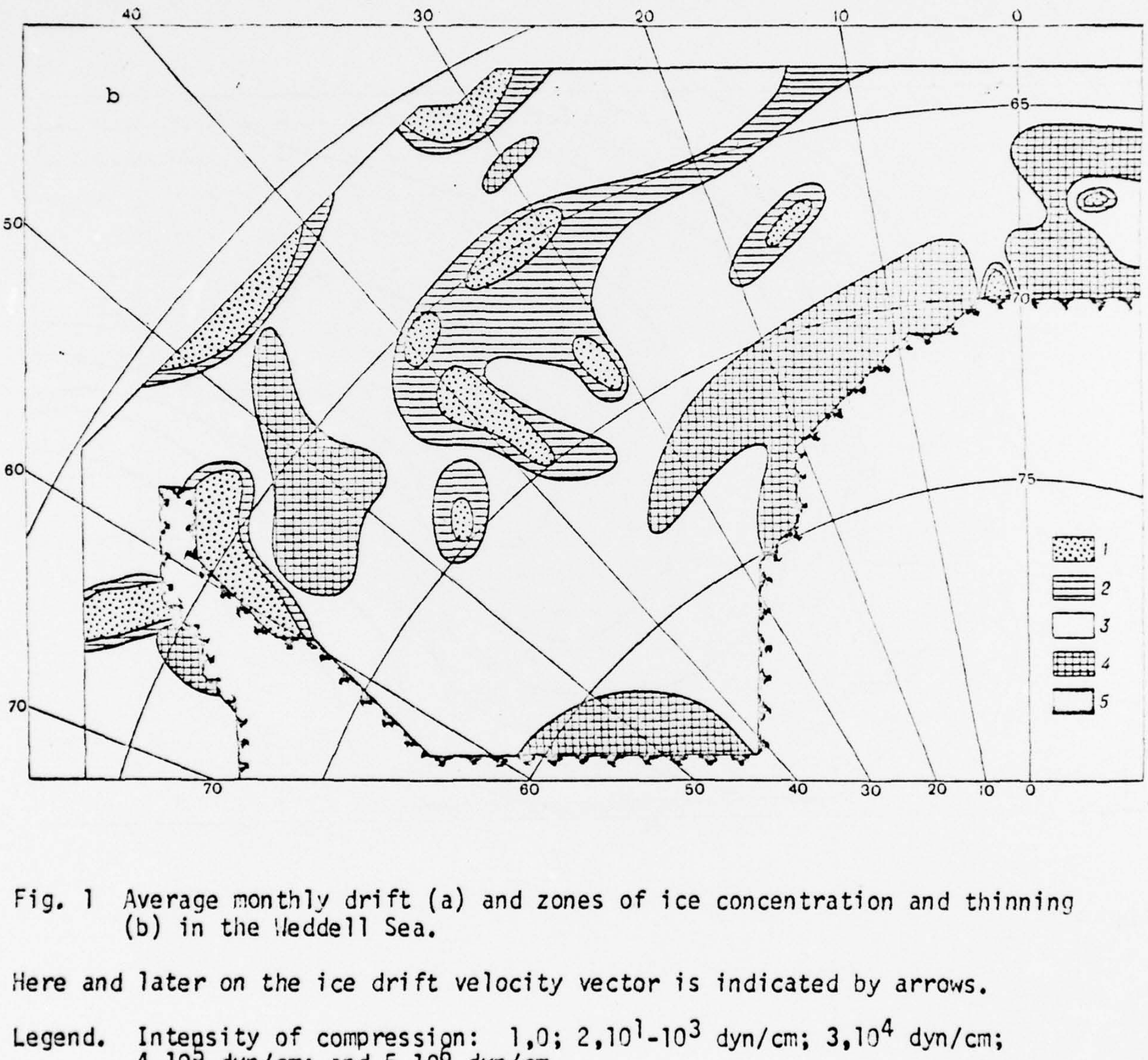

Fig. 1 Average monthly drift (a) and zones of ice concentration and thinning (b) in the Weddell Sea.

Here and later on the ice drift velocity vector is indicated by arrows.

Legend. Intensity of compression: 1,0; 2,10^1-10^3 dyn/cm; 3,10^4 dyn/cm; 4,10^5 dyn/cm; and 5,10^6 dyn/cm.

Key: x-20 cm/sec

23° E long. Even the average monthly ice drift velocities caused by the wind in the southern edge of this cyclone reached 60-65 cm/sec in the region of the shore. The ice drift along almost the entire coast of Queen Maud Land is compressive in nature. This is reflected in the pattern of distribution of compression (see Fig 2b). At the same time, where parts of the continent extend into the sea, we should expect zones of reduced ice concentration on the west and zones of greater compressive concentration on the east. Lützow-Holm Bay is indicative in this respect (40° E long.). The greatest stresses in the whole of Antarctica are observed in the ice cover on the western shore of this bay, and this agrees well with available information on ice conditions in this bay.

The existence of coastal regions of less concentrated ice is typical basically of parts of the continent which extend out into the sea or ice shelves; for instance: the Fimbul Ice Shelf (0°), the ice shelves of Enderby Land, and the West Ice Shelf (80° E long.). The stationary lead on the east shore of Prydz Bay is observed throughout almost the entire year.

Zones without compression are found along the northern edge of the ice cover.

A ridge of high pressure is found in Lazarev Bay caused by an abrupt change in sign in the pressure gradient near the surface. The front part of the quasi-stationary cyclone present above the Sea of Cooperation (80° E long.) causes pressure drift in the western part of the Davis Sea.

The gradient of the pressure field near the surface is typically weak in the regions of the Mawson and D'Urville Seas (Fig. 3a). Strong winds prevail only in the portion of the D'Urville Sea near the shore. The ice-drift velocities at the shore reach 18-22 cm/sec, and are 2-6 cm/sec outside the zone affected by strong winds.

The distribution of zones of ice concentration and rarefaction (Fig. 3b) obeys the laws discussed above. Along the western part of the Shackleton Ice Shelf (90° E long.) there is a zone of rarefaction corresponding to the stationary lead present there for a great part of the year [7]. Zones of rarefaction in Vincennes Bay (110° E long.) and along Adelie Land (145° E long. and 152° E long.) are similar in nature.

Heavy concentrations are found in the Davis Sea and in certain coastal regions; such regions also include the Leningrad Station region, near which the D/E Ob' was ice-bound in April 1973.

The Ross Sea (Fig. 4a) is among the zones with a climatic cyclone constantly present. In April its center is located at 160° E long.

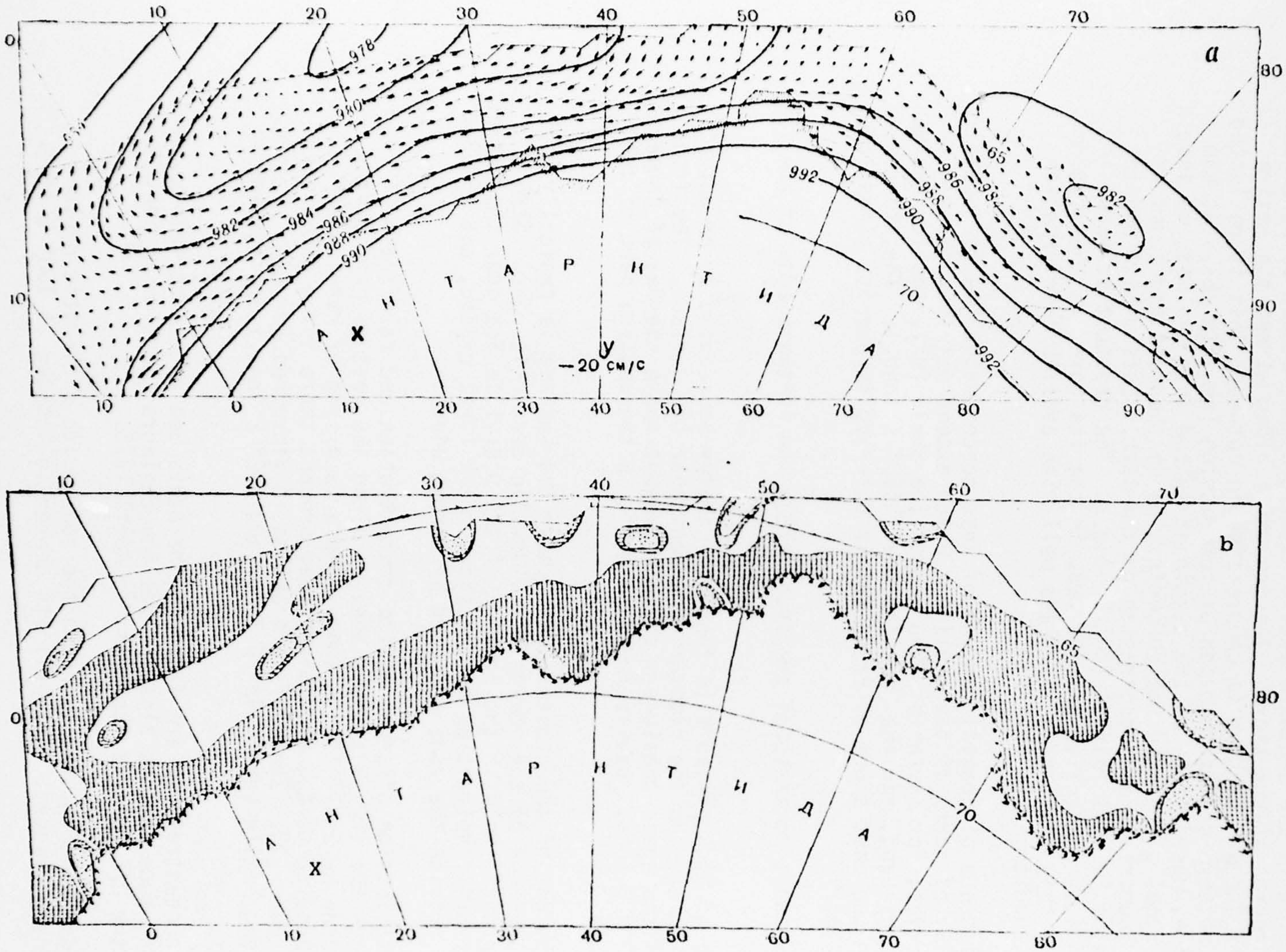

Fig. 2. Average monthly drift (a) and zones of ice concentration and thinning (b) in the 0-90° E long. sector. The legend for compression intensities are given in Fig. 1.

Key: x-Antarctica; y-20 cm/sec.

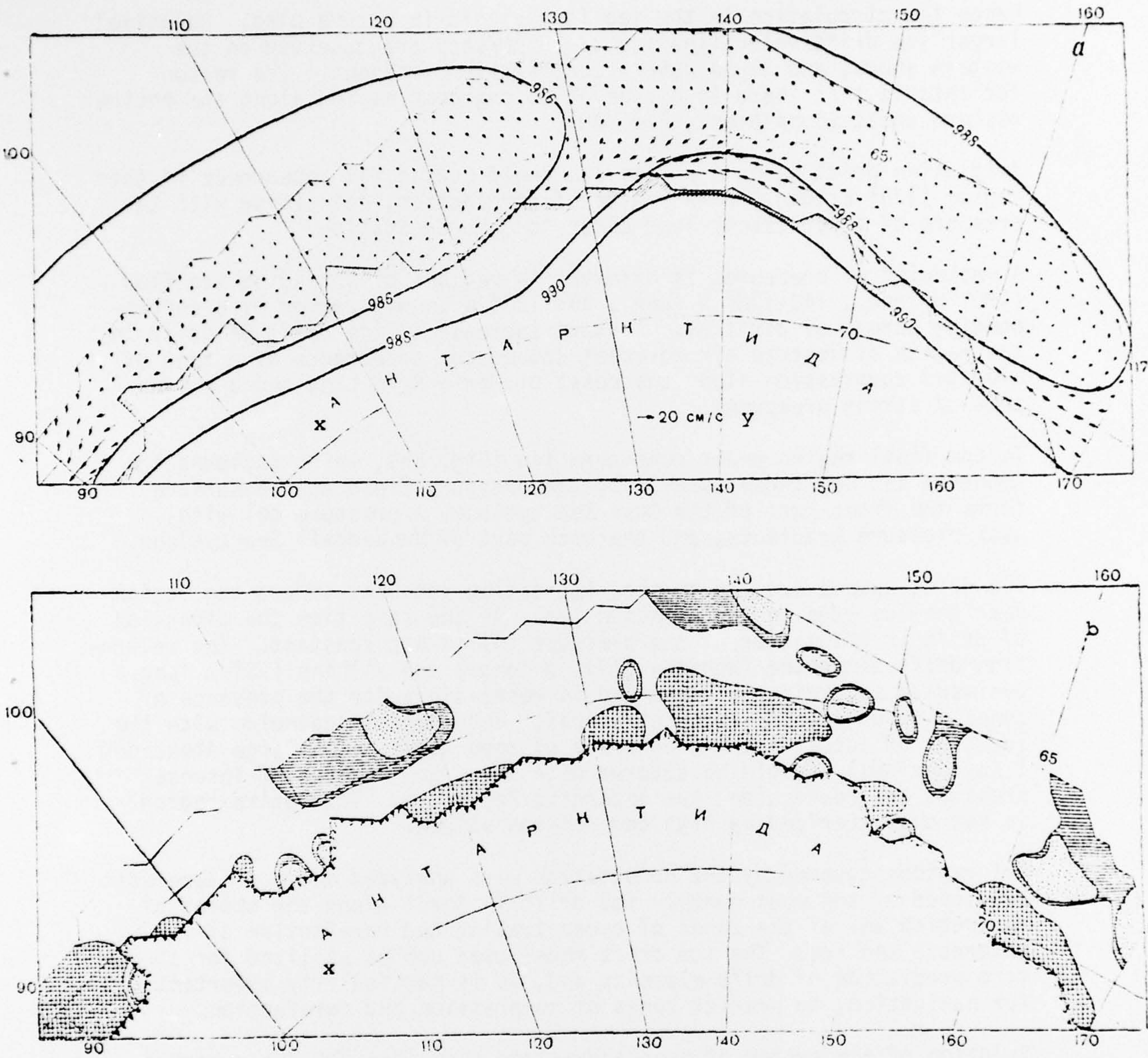

Fig. 3. Mean monthly drift (a) and zones of ice concentration and rarefaction (b) in the 90-170° E long. sector. The legend for intensity of compression is given in Fig. 1.

Key: x-Antarctica; y-20 cm/sec.

Hence the circulation in the sea is cyclonic in nature also. Relatively larger ice drift velocities (to 22-24 cm/sec) are observed on the western shore, and these have a compressive component. The reason for this is that there is a zone of strong compression along the entire western coast (Supplement, Fig. 4b).

Relaxation drift along the Ross Ice Shelf causes the appearance in this region (170° E long.) of a region of rarefaction, coinciding with the presence of a persistent lead close to McMurdo Station.

A weakening of pressures is observed in regions of spreading ice flow (180° W long., 140-130° W long., and 120° W long.) caused by a corresponding spread of air flow. A sharp increase of ice drift velocity in the region of western air movement causes the appearance of a zone of elevated compression along the coast of Marie Byrd Land and a narrow zone of strong pressures.

In the final region under consideration (Fig. 5a), which includes the Amundsen and Bellingshausen Seas, the pressure field at the surface forms the front part of the Ross Sea cyclone, a pressure col with weak pressure gradients, and the back part of the Weddell Sea cyclone.

Ice drift speeds are 2-6 cm/sec, increasing somewhat toward the region near the ice edge in the Amundsen Sea. At the same time the direction of drift in the sector of the pressure col is not constant. The relaxation drift along the Thurston (104° W long.) and Wilkins (75° W long.) peninsulas extending into the sea is responsible for the presence of zones without pressure concentrations. Both regions coincide with the location of actually existing areas of open water. The large Alexander I Bay obviously should be covered with ice. Small zones of intense pressure are found along the Antarctic Peninsula. The entire region is not characterized by high compression values.

All regions covered by the computation were analyzed and a picture was developed of the mean monthly ice drift in April along the shores of Antarctica and of the zones of concentration and rarefaction of antarctic sea ice. The ice drift model used can be utilized for short-term prediction of drift elements and, as is particularly important for navigation, to predict zones of compression and rarefaction.

Solution of the system of nonsteady-state equations for the dynamics of the ice cover, which takes into account the interaction of ice floes with one another, makes it possible to trace the development and displacement of such zones; and the subsequent inclusion of data on changes in the baric situation may extend the interval of time for which the computations are carried out.

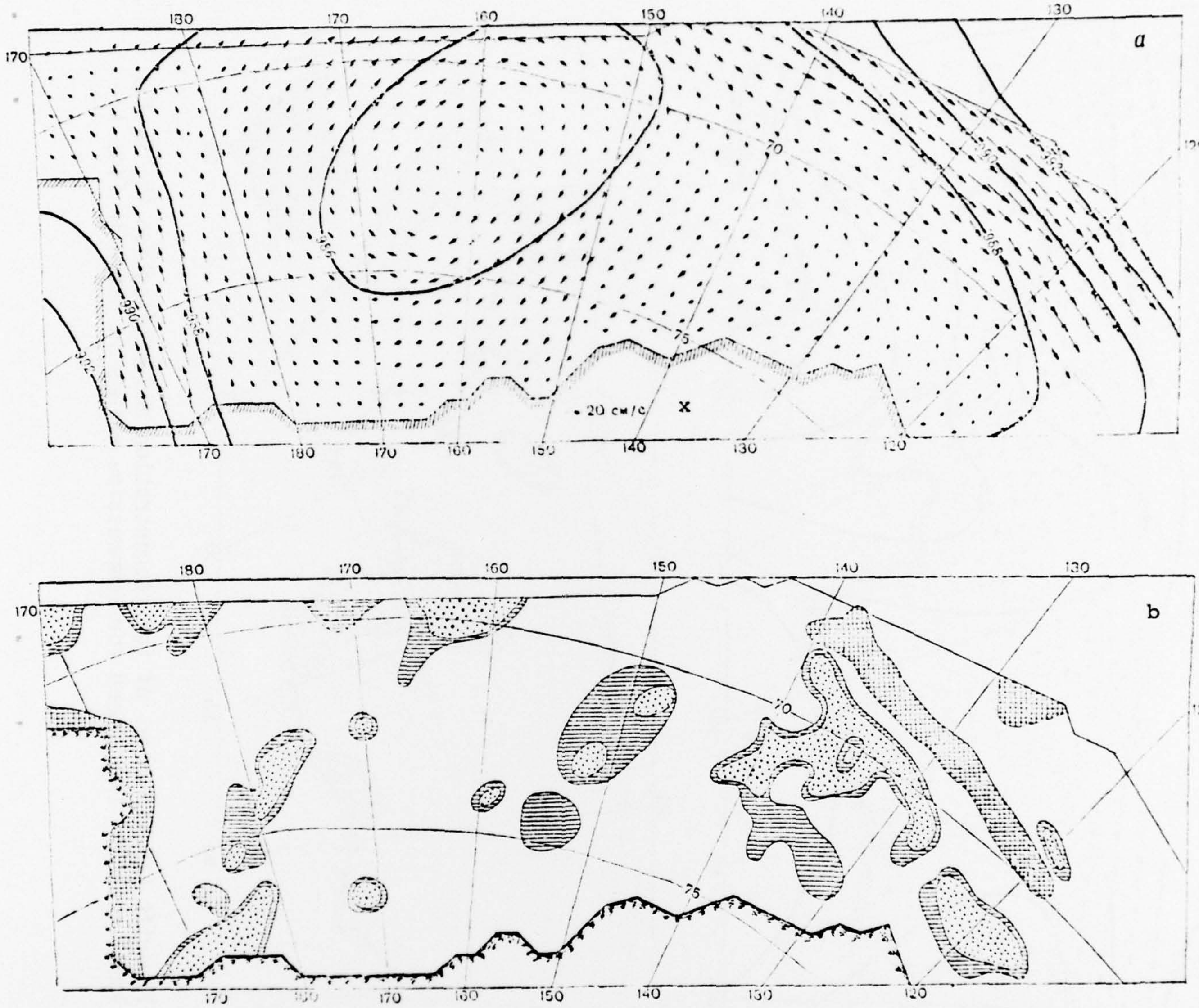

Fig. 4. Mean monthly drift (a) and zones of ice compaction and rarefaction (b) in the sector from 179° E long.-115° W long. The legend for compression values is given in Fig. 1.

Key: x-20 cm/sec.

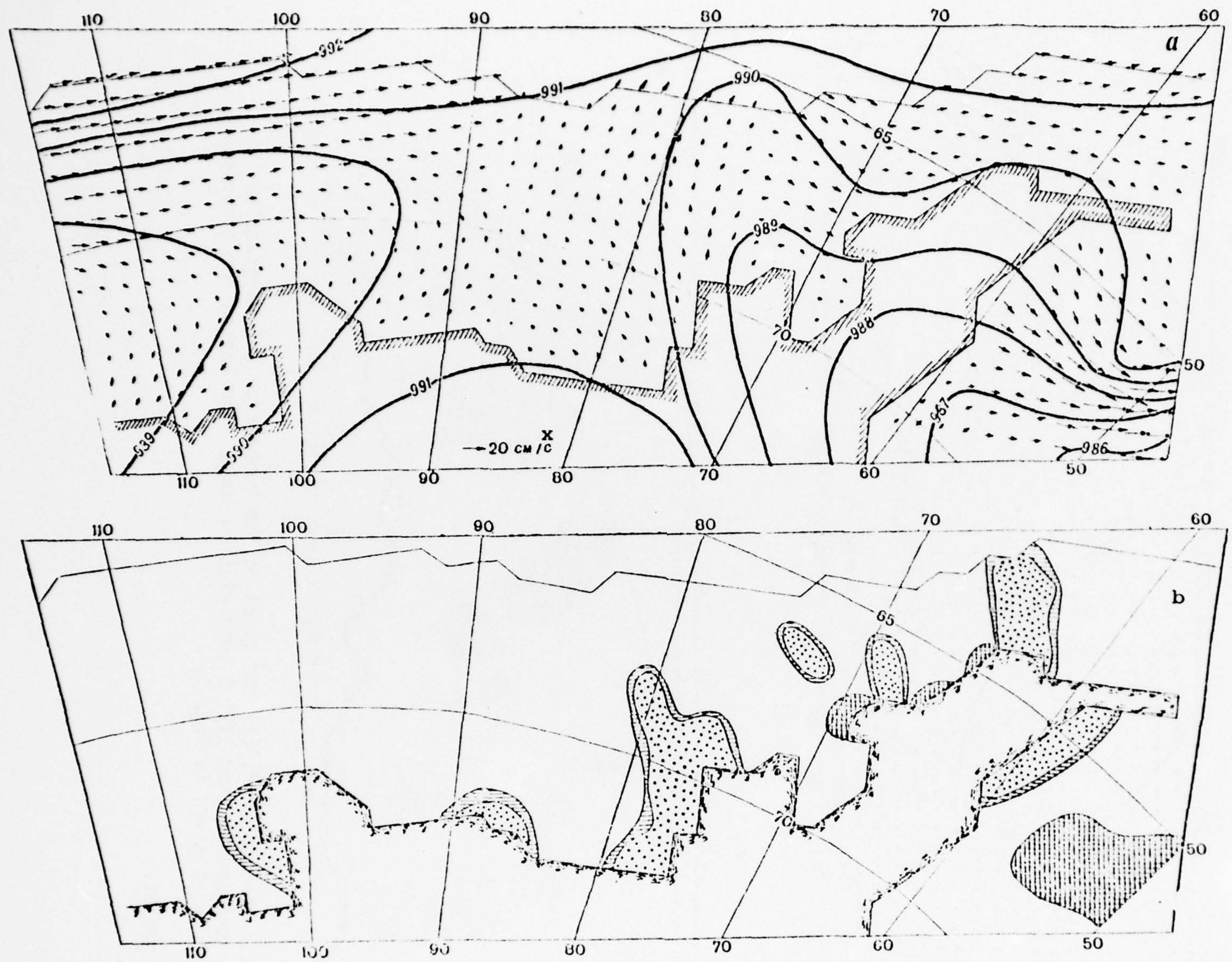

Fig. 5. Mean monthly drift (a) and zones of ice concentration and rarefaction (b) in the 115-65° W long. sector. The legend for compression values is given in Fig. 1.

In order to evaluate the correctness of the information on zones of compression and rarefaction developed using the model, we made calculations for a series of characteristic situations during the drift in the ice of D/E Ob' in 1973.

From March through April 1973 the D/E Ob' attempted to cut its way through to the Leningrad Station. Active cyclonic activity was observed in the region of this station at the beginning and the end of April. Rapid changes in the pressure field near the surface caused the appearance of temporary zones of increased compression and rarefaction. Taking advantage of the zones of rarefaction, the ship attempted to move as close to the shore as possible, often finding itself in zones of compression. On April 23, at a location with coordinates 68°0.5' S lat. and 156°39' E long. the D/E Ob' finally found itself beset in the ice pack [11] and began to drift westward with the ice parallel to the shore.

Fig. 6 shows a map of the calculated zones of compression and rarefaction with the corresponding baric situation at 12:00 noon (Greenwich time) on April 20, 1973. A ridge of high pressure divides the area covered by the calculation into two zones. The drift in the first zone is of the compressive type, and that in the second of the relaxation type. The high drift velocity (up to 40 cm/sec) caused the appearance of regions of high pressures (more than 10^5 dyn/cm) along the western shore of D'Urville Sea. We note a zone without compression centers close to the shore at 146° E long., which appeared in very compact ice with elevated stresses.

In the second zone near the shore the ice was in a weakened state, which could lead to the appearance here of cracks, clear spaces, and leads. The D/E ob' was located at the margin of a zone of low values of compression and rarefaction.

The appearance above the sea of a very deep cyclone on April 23 (Fig. 7) caused a sharp change in the distribution of stresses in the ice and led to the formation of a broad zone of high compressive forces. The D/E Ob' was in this very zone, so that it lost headway. The low air temperatures that prevailed at that time (from -23° to -28°) promoted rapid freezeup of the ice mass, and subsequent changes in the pressure field did not result in a weakening of the ice in this region.

Compression of the ice cover is determined not only by wind drift but also by tidal movements of the ice. But the periodic nature of the tidal compression and rarefaction would lead to rapid reduction (within a day) of stresses and the appearance of openings; and this was not observed.

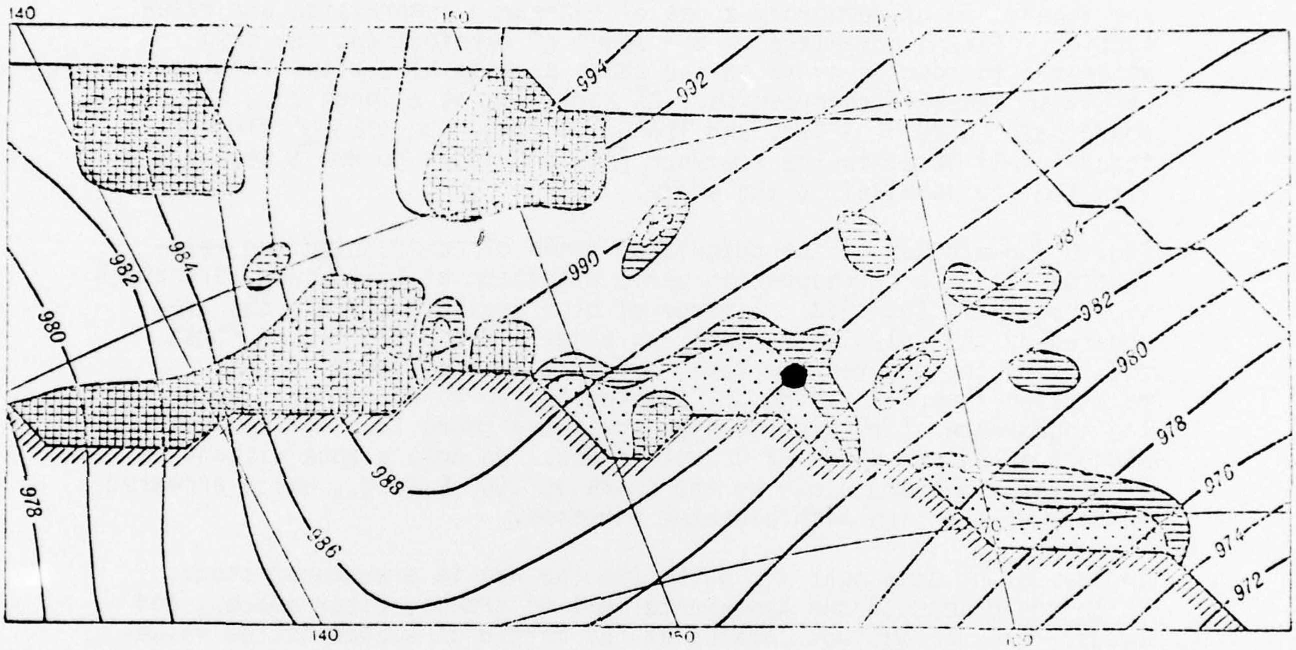

Fig. 6. Distribution of areas of compression and rarefaction at 12:00 noon (Greenwich) on April 20, 1973. Here and later on the position of the D/E Ob' is indicated by a black circle.

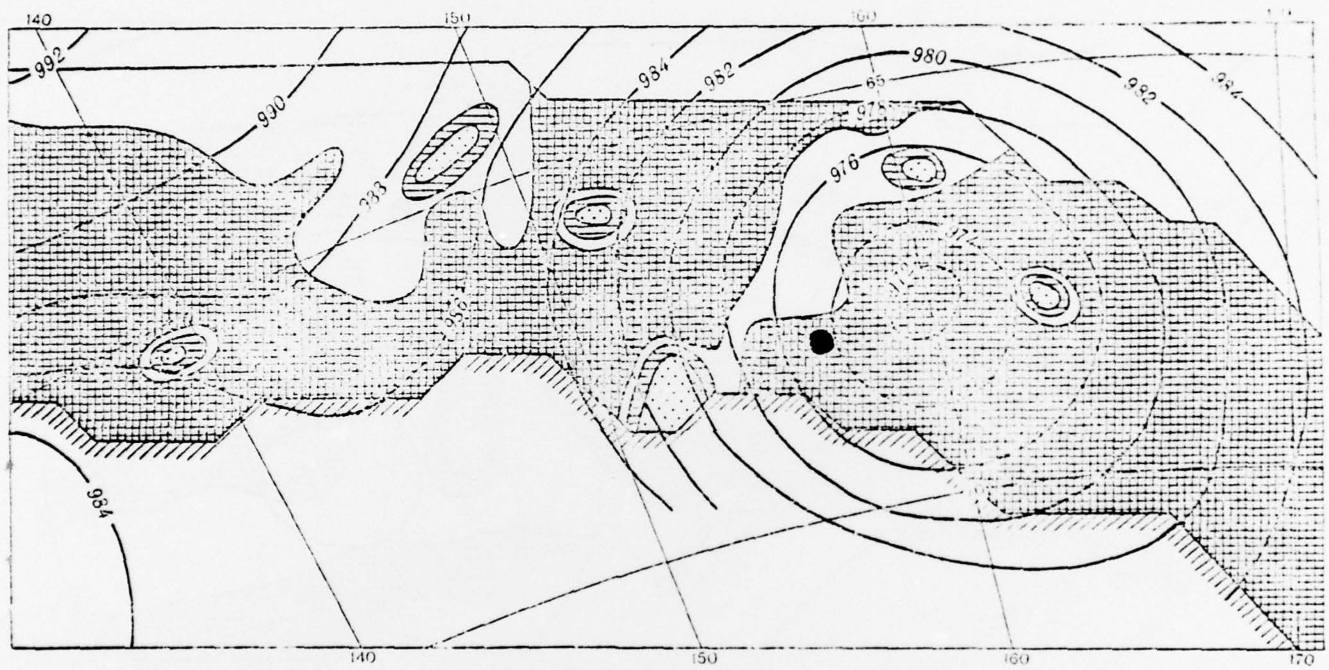

Fig. 7. Distribution of pressure and rarefaction at 12:00 noon on April 23, 1973.

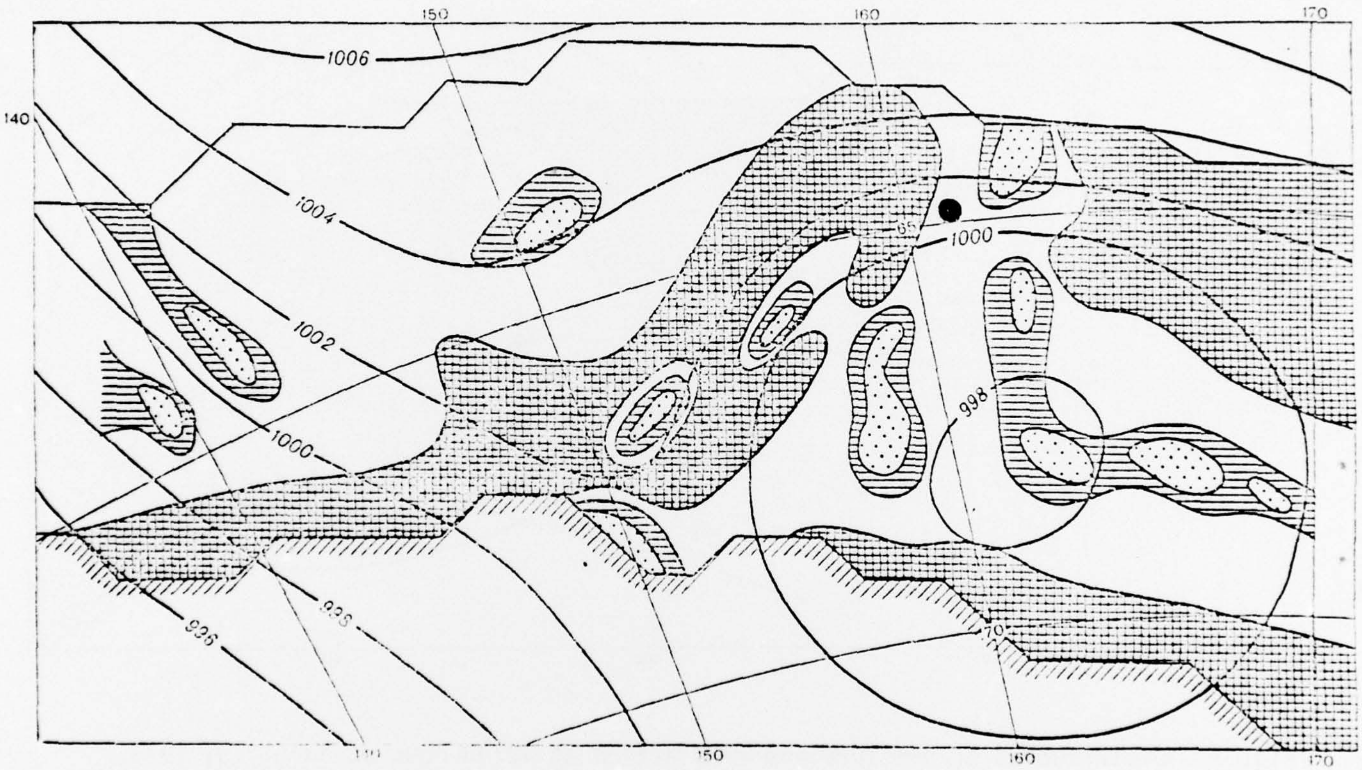

Fig. 8. Distribution of compression and rarefaction at midnight on July 22, 1973.

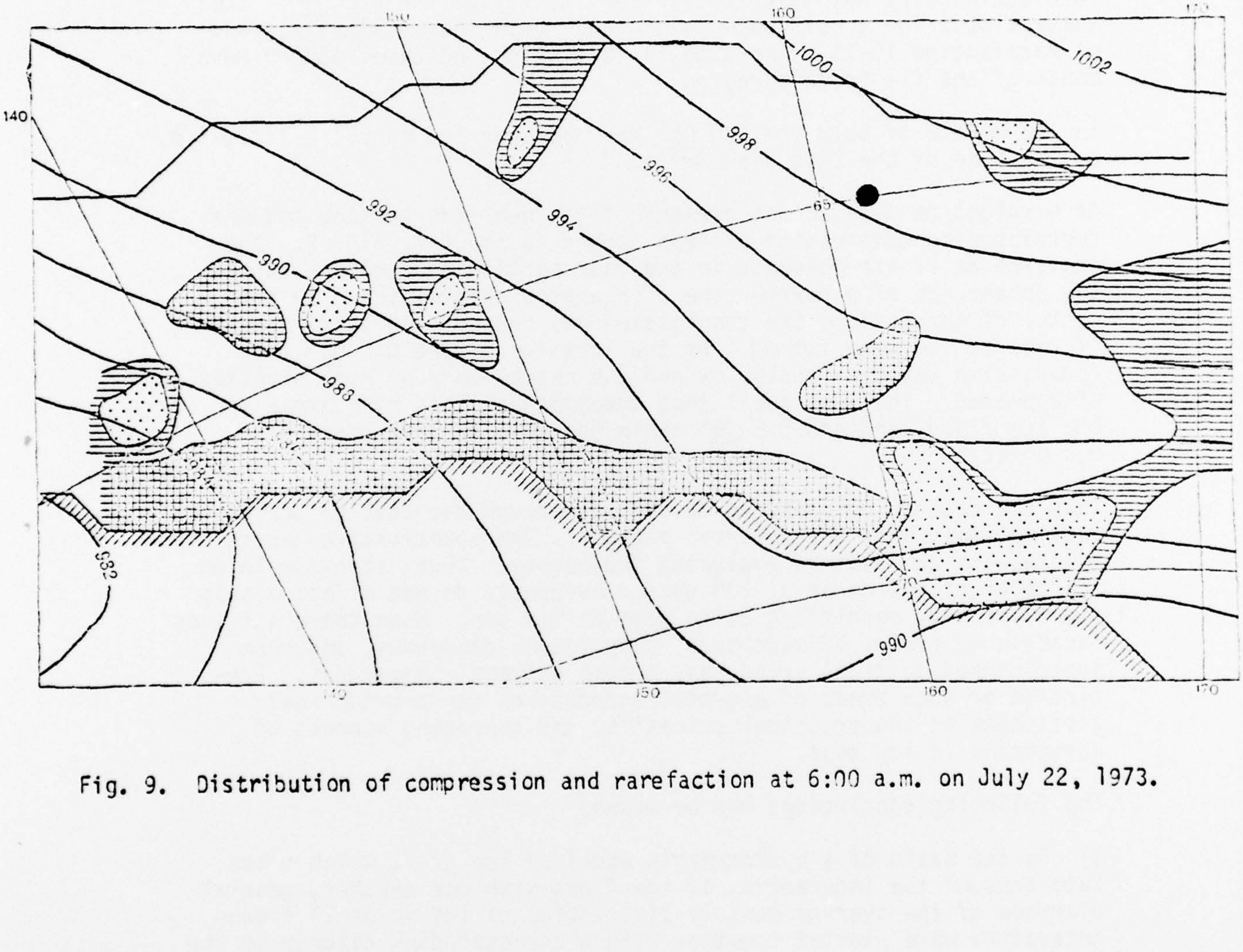

Fig. 9. Distribution of compression and rarefaction at 6:00 a.m. on July 22, 1973.

Thus, compression caused by wind drift of the ice played a critical role in this situation, while tidal pressures superimposed on the wind pressures might have sharply increased the absolute magnitude of the stresses and led to destruction of the ship. Purely tidal compressive forces, obviously, can be hazardous only in the coastal zone or in narrow places.

The D/E Ob' was held captive in the ice for three months. Compression and hummocking of the ice continued all this time, but broad zones of rarefaction were not observed in the vicinity of the D/E Ob'. Ice surveys made fom a helicopter along the route showed local regions of rarefaction 10-15 miles wide, a fact which indicated strong movements of the ice in this region.

In the middle of July the D/E Ob' had been carried to 65° S lat., i.e. to the zone of the East Wind Drift.

At midnight on July 22 the pressure field near the surface and the corresponding compression pattern looked as shown in Fig. 8. The convergence of air currents in the rear portion of cyclones caused the appearance of a narrow zone of elevated compression. In the center of the cyclone the compression was reduced and local zones of rarefaction were formed. At the location of the D/E Ob' the compression was previously low and the nearby zone of high stresses disappeared. The long swell that developed at this time broke up the ice field, and the D/E Ob' again was able to move under its own power.

Thus the data on compression developed through computation correspond qualitatively with the observed picture. The quantitative aspect of the results can also be evaluated indirectly. Thus, stresses in an ice cover of the order of 10^4 dyn/cm evidently do not affect a ship significantly, permitting it to move on its own. When these stresses increase by orders of magnitude, they become dangerous, and when superimposed on tidal pressures, become extremely hazardous. Prediction of such zones of elevated compression may provide real assistance in the practical scientific and operating aspects of navigation in icy seas.

The following conclusions may be drawn.

1) On the basis of a hydrodynamic model of ice drift which takes into account the interaction of ice floes with one another, general diagrams of the average monthly circulation of ice in April around Antarctica were plotted together with a corresponding diagram of the distribution of zones of compression and rarefaction.

2) The values for drift velocity and direction obtained were close to those observed in these regions.

3) The pattern of ice drift in an actual month was refined.

4) The calculated zones of rarefaction agree well with the known locations of persistent leads.

5) The results convincingly demonstrate the possibility of using the proposed mathematical model in support of sea operations in ice fields.

BIBLIOGRAPHY

1. Atlas Antarktidy (Atlas of Antarctica). Vol. 1. Moscow-Leningrad, GUGK, 1966. 225 pl. + 23 p.

2. Buynitskiy, V. Kh. Some principles governing the distribution and formation of drifting sea ice in the Antarctic. Tr. SAE, 1965, 44:27-38.

3. Buynitskiy, V. Kh. Morskiye l'dy i aysbergi Antarktiki (Sea ice and icebergs of the Antarctic). Izd. Leningrad. Gos. Univ., 1973. 225 p.

4. Ivchenko, V. O. and D. Ye. Kheysin. Determination of the internal stresses in an ice cover arising during ice drift. Problemy Arktiki i Antarktiki, 1971, No. 43-44:84-91.

5. Ivchenko, V. O. and D. Ye. Kheysin. The distribution of ice compression in continuous ice. Okeanologiya, 1975, No. 5:803-812.

6. Krichak, O. G. Characteristics of atmospheric circulation over the Antarctic and the Southern Hemisphere. Tr. SAE, 1960, 9:50-62.

7. Kupetskiy, V. N. Stationary leads in seas subject to freezing (causes and distribution). Vestnik LGU, 1958, No. 12:172-190.

8. Romanov, A. A. Characteristics of ice drift in East Antarctica. Inform. byull. SAE, 1963, No. 45:5-16.

9. Treshnikov, A. F. Characteristics of ice conditions in antarctic waters. Tr. SAE, 1963, 5:40-53.

10. Treshnikov, A. F. Circulation of surface waters in the Antarctic Ocean. Inform. byull. SAE, 1964, No. 45:5-21.

11. Treshnikov, A. R. Winter operations in the Antarctic in 1973. Meteorologiya i gidrologiya, 1974, No. 5:40-53.

12. Kheysin, D. Ye. Disturbance of the forces of ice compression at the hydrodynamic stage in the drift of continuous ice. Tr. AANII, 1971, 303:89-97.

13. Kheysin, D. Ye. and V. O. Ivhenko. A numerical model of tidal ice drift which takes into account the interaction between ice floes. Izv. AN SSSR, Ser. Fizika atmosfery i okiana, 1973, 9(4):420-429.