DET KONGELIGE DEPARTEMENT
FOR INDUSTRI OG HÅNDVERK

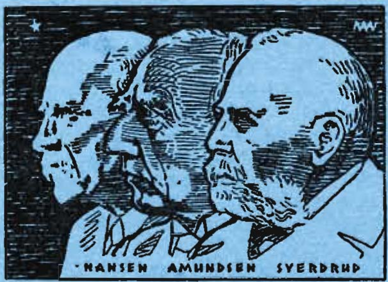
NORSK POLARINSTITUTT

SKRIFTER

Nr. 111

THE STRESS OF THE WIND ON THE ICE OF THE POLAR SEA

BY
H. U. SVERDRUP



I KOMMISJON HOS
FABRITIUS & SØNNERS FORLAG
OSLO 1957

NORSK POLARINSTITUTT

(Formerly Norges Svalbard- og Ishavs-undersøkelser.)

Observatoriegaten 1, Oslo

SKRIFTER

Skrifter 1—50, see numbers of Skrifter previous to No. 100.

Resultater av De Norske statsunderstøttede Spitsbergenekspeditioner.

DET KONGELIGE DEPARTEMENT
FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT

SKRIFTER

Nr. 111

THE STRESS OF THE WIND ON THE ICE OF THE POLAR SEA

BY
H. U. SVERDRUP

I KOMMISJON HOS
FABRITIUS & SØNNERS FORLAG
OSLO 1957

A. W. BRØGGERS BOKTRYKKERI A/S

SUMMARY

The pilot balloon ascents made when the "Maud" in 1922—24 drifted with the ice to the north of Northeastern Siberia have been examined. In only 20 of 375 cases was the wind found to be practically constant through several hundred meters above the layer of frictional resistance. On the assumption that this wind represented the geostrophic wind, the surface stress was computed from the results of these 20 observations.

It was found that on an average the stress $\tau = 6.9 \times 10^{-3} \varrho w^2$ (dyn/sec²) where ϱ is the density of the air and w the surface wind. Under adiabatic conditions $\tau = 5.2 \times 10^{-3} \varrho w^2$. The direction of the stress did not coincide with the wind direction, as should be expected, but the stress was on an average directed 10° to the left of the wind. No great weight can be given to this discrepancy because of the uncertainty of the data.

The results are not conclusive, but it is hoped that they may stimulate further studies of the problems.

1. Introduction.

There exist several meteorological problems that can be dealt with advantageously in the Polar Regions because simple and well defined conditions are encountered. One may expect that this applies to the problem of the stress that the wind exerts on the ice-covered surface of the Polar Sea, for which the following features are characteristic:

The surface can be considered practically unlimited if observations are made at a distance of, say, 50 km or more from the coast or from open water. The surface is level and of a uniform roughness. Pressure ridges or isolated large hummocks may rise to a height of about 5 m above the general level of the ice and, on an average, the height of the "roughness elements" may be estimated at about 1 m. The surface is of uniform thermal character, such that disturbances due to differential heating and cooling are lacking. During the greater part of the year a temperature inversion exists close to the surface. In calm winter weather the inversion begins at the ground, but when a wind blows, it generally begins at some distance from the surface but below a height of a few hundred meters. In the late spring and in the autumn the inversion begins at a slightly greater height, but in the summer it may be lacking. With a low inversion present the layer below the inversion represents the layer of frictional influence. In these circumstances it may be expected that the turbulence in the layer of frictional influence is induced by the flow of the air over the rough ice, and that convective turbulence is lacking. The turbulence must first increase with increasing distance from the surface, but at some greater height, but below the inversion, the turbulence probably decreases because the lapse rate is stable. In the inversion layer the turbulence is probably very small.

The above description of the conditions over the Polar Sea and the conclusions drawn from them are based on experiences gained during the drift of the "Maud", 1922—24 (Sverdrup, 1933), which, as far as I know, have been confirmed by the work of later expeditions.

Conclusions as to the surface stress of the wind can be drawn from measurements of the variation of the wind with height in the lowest 10 to 20 m, but to my knowledge no such measurements have been made over the ice in the Polar Sea. However, on certain assumptions the components of the stress of the wind, τ, at anemometer level, a, can be computed from pilot balloon observations, using the relations:

$$\tau_x = \varrho \lambda \int_a^H v \, dz, \qquad \tau_y = \varrho \lambda \int_a^H (W - u) \, dz \tag{1}$$

Here ϱ is the average density of the air between the levels a and H, $\lambda = 2\omega \sin\varphi$ (ω the angular velocity of the earth, φ the latitude) u and v the components of the wind, w, W the velocity of the geostrophic wind, and H the height at which the wind equals the geostrophic wind.

The assumptions on which the above relations are valid are:

1. Accelerations can be neglected.
2. The geostrophic wind is constant between the levels a and H.
3. The stress vanishes at the level H.

2. Observations.

During the drift of the "Maud", 1922—24, 375 pilot balloon observations were made between latitudes 71° 59′N and 76° 43′N, longitudes 170° 50′W and 138° 06′E. However, only a very small number of these can be used for computing the stress of the wind because no synoptic maps are available from which the geostrophic wind and its variation with height can be determined. Conclusions as to the geostrophic wind have to be drawn from the pilot balloon observations themselves. These are taken as indicating that assumption 2 is satisfied if the observed wind remains constant through several hundred meters above the layer of frictional influence. In these cases assumption 3 can also be expected to be satisfied. Among all the 375 observations only 20 cases are found in which the geostrophic wind remains constant (as to speed and direction) through some hundred meters above a level H to which the integration is performed. For these 20 cases the stress, τ, and the angle between the geostrophic wind and the stress, α_τ, have been determined by numerical integration, using equations (1). The operation was very simple because in the tables of results (Sverdrup, 1930), the average wind in stated layers is entered. In general the wind varied so rapidly with height in the lowest layers that readings were made every minute, thus giving average velocities in layers of thicknesses varying from 120 to 160 m. In some cases readings were made every half minute in order to obtain more details.

The components of the stress have been computed from the results of the pilot balloon observations only, without regard to the wind at anemometer level, 7 m. (In the tables [Sverdrup, 1930], the anemometer level is stated as 5 m, but in the discussion [Sverdrup, 1933], it is entered as 7 m. The later value is correct.) However, the objective must be to find the relationship between the wind at anemometer level and the stress. In the records of the pilot balloon observations the surface wind, that has been entered in each case, has been obtained from the continuous records at a height of about 7 m. The velocity and the direction represent the mean hourly values at the time when the pilot balloon was launched. Cases in which the wind was changing rapidly have been eliminated in order, as far as possible, to satisfy assumption 1. The use of mean hourly values may introduce uncertainties because the actual velocity in the few minutes during which the balloon passed through the layer of frictional influence might have deviated 10 to 20 % from the mean hourly value, and the direction might have deviated 10° or more from the mean hourly direction. Because of the character of the recorder the latter may be $\pm$ 11° in error. These features have to be considered when discussing the results.

3. Discussion.

The pertinent data and the results of the computations are shown in Table 1 which contains the number and date of each pilot observation, the wind at anemometer level, w_a, the estimated geostrophic wind, W, the angle between the geostrophic wind and the surface wind, α_w (positive when the surface wind lies to the left of the geostrophic wind), the angle between the geostrophic wind and the surface stress, α_τ, the numerical value of the stress, and finally, the difference $(\alpha_\tau - \alpha_w)$. When computing the stress the value $\bar{\varrho}\lambda = 1.8 \times 10^{-7}$ has been introduced.

Table 1.

Direction and magnitude of the surface stress of the wind, computed from pilot balloon observations of the "Maud" expedition.

No.	Date	W_a m/sec	W_a From °	W m/sec	W From °	α_w °	α_τ °	τ dyn/cm²	$\alpha_\tau - \alpha_w$ °
102	25. VIII, 1922	4.2	248	6.4	300	52	52	1.2	0
120	28. IX, 1922	5.9	60	12.0	81	21	28	3.1	7
126	8. X, 1922	4.8	37	8.5	60	23	26	2.5	3
177	30. XII, 1922	3.3	2	11.0	50	48	54	1.7	6
195	22. I, 1923	6.0	166	15.0	218	52	59	4.3	7
210	7. II, 1923	4.4	225	12.0	249	24	32	2.3	8
228	19. II, 1923	8.0	111	21.0	156	45	72	5.2	27
238	4. III, 1923	2.9	210	9.5	241	31	20	1.0	−11
256	25. III, 1923	6.7	110	15.0	150	40	66	3.8	26
273	19. IV, 1923	4.2	71	6.8	106	35	57	1.1	22
301	31. V, 1923	5.9	147	13.4	190	43	46	3.2	3
312	16. VII, 1923	3.4	256	6.0	280	24	37	0.8	13
330	17. IX, 1923	5.6	31	15.8	72	41	69	3.1	28
350	25. XI, 1923	1.8	300	7.5	330	30	29	0.4	− 1
386	5. II, 1924	4.4	242	11.5	268	26	50	1.6	24
387	7. II, 1924	3.2	228	11.0	260	32	50	1.2	18
415	19. III, 1924	4.5	66	10.8	102	36	49	1.6	13
426	2. IV, 1924	2.6	155	5.0	190	35	18	0.9	−17
432	10. IV, 1924	7.3	56	12.6	100	44	62	3.8	18
445	26. IV, 1924	3.6	261	8.2	290	29	45	1.2	16

In the lower part of Fig. 1 the values of the stress are plotted against the wind velocity, w_a. The distribution of the values suggests a relationship of the form:

$$\tau = k w^n, \tag{2}$$

where the subscript a has been dropped, or

$$\log \tau = \log k + n \log w, \tag{3}$$

that is, a linear relationship between log τ and log w. The coefficient of correlation between the two quantities is found equal to 0.94, and the two lines of regression are reprented by the equations

$$\tau = 63 \times 10^{-6} w^{1.69} \text{ and } \tau = 16 \times 10^{-6} w^{1.92}$$

Because of the few data and the considerable uncertainty of the single values the relationship may just as well be represented by the equation

$$\tau = 9 \times 10^{-6} w^2 \tag{4}$$

The corresponding curve has been entered in Fig. 1. We may then write

$$\tau = \gamma^2 \varrho w^2 = 6.9 \times 10^{-3} \varrho w^2 \tag{5}$$

where ϱ is the density of the air, in this case equal to 1.3×10^{-3}.

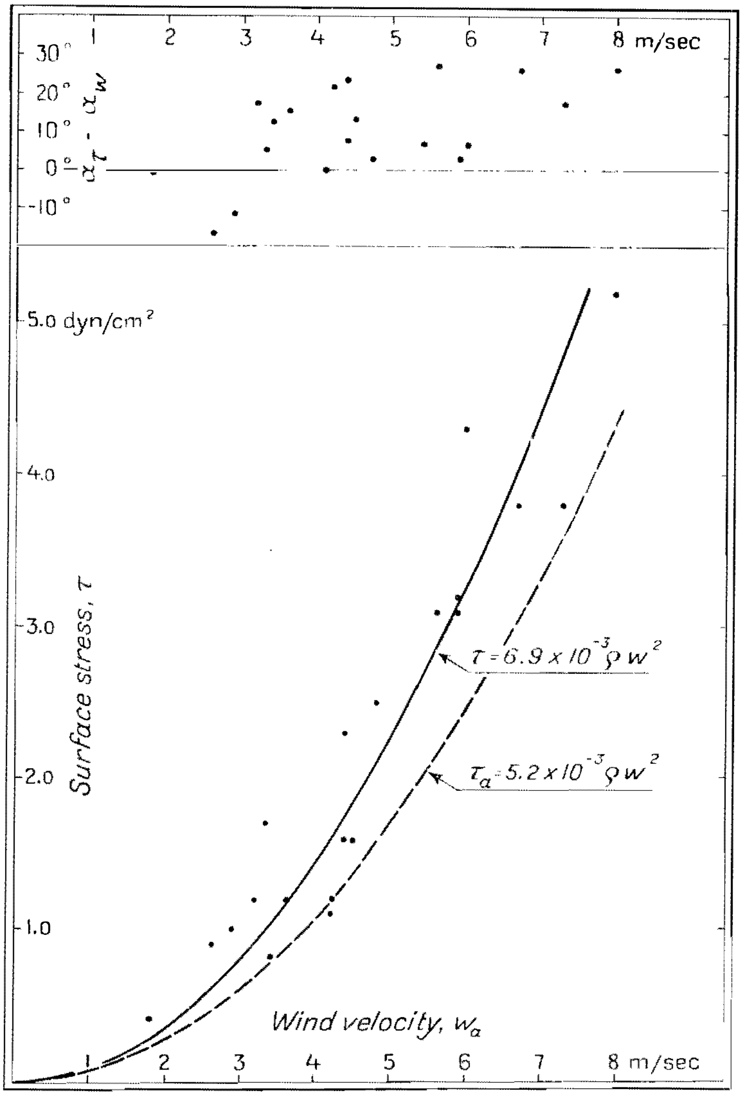


Fig. 1. Lower part: The surface stress, plotted against the wind velocity at anemometer level. Upper part: The deviation of the direction of the surface stress from the direction of the wind at anemometer level. The deviation is positive when the stress is directed to the left of the wind.

Table 2 contains for each case the ratio w/W, the observed stress, τ_{obs}, the stress computed from equation (5), τ_c, and the ratio τ_{obs}/τ_c. In several cases the temperature difference, $(\vartheta_{30}-\vartheta_5)$, is entered on the basis of temperature measurements at the top of the main mast at a height of 30 m and in the meteorological screen at a height of 5 m. The temperature at the mast head was obtained by means of a resistance thermometer which was read only when the sun was below the horizon because the thermometer was not protected against radiation.

Table 2.

Values of the ratio w/W, the observed stress, τ_{obs}, the stress computed from eq. (5), τ_c, and the temperature difference $(\vartheta_{30}-\vartheta_5)$.

No.	w m/sec	w/W	τ_{obs} dyn/cm²	τ_c dyn/cm²	τ_{obs}/τ_c	$\vartheta_{30}-\vartheta_5$
102	4.2	0.66	1.2	1.6	0.75	
120	5.9	0.49	3.1	3.15	1.0	-0.3
126	4.8	0.56	2.5	2.1	1.2	−0.2
177	3.3	0.30	1 7	1.0	1.7	0.3
195	6.0	0.40	4 3	3.25	1.3	−0.2
210	4.4	0.37	2.3	1.7	1.35	0.2
228	8 0	0.38	5.2	5 8	0.9	−0.3
238	2.9	0.31	1.0	0.75	1.3	0.5
256	6.7	0.45	3.8	4.0	0.95	−0.1
273	4 2	0.62	1.1	1.6	0.7	
301	5.9	0.44	3.2	3 15	1.0	
312	3.4	0.57	0.8	1.0	0.8	
330	5.6	0.35	3 1	2.8	1.1	
350	1.8	0.24	0.4	0.3	1.3	1.3
386	4.4	0.38	1.6	1.7	0.95	−0 3
387	3.2	0.29	1.2	0.9	1.3	0.6
415	4.5	0.42	1.6	1.8	0.9	
426	2.6	0.52	0.9	0.6	1.5	
432	7.3	0.58	3.8	4.8	0.8	
445	3.6	0.44	1.2	1.2	1.0	

In Fig. 2 the ratio τ_{obs}/τ_c is plotted against the ratio w/W, and in Fig. 3 the temperature difference $(\vartheta_{30}-\vartheta_5)$ is plotted against w/W. In order to interpret the contents of these figures it is necessary to remember that $\tau=\eta dw/dz$ where η is the eddy viscosity. The value of dw/dz must be expected to be large when w/W is small and vice versa. In agreement with this reasoning we find that τ_{obs}/τ_c is large for w/W small and approaches a value of 0.75 when w/W exceeds 0.5. However, the stress depends also on the eddy viscosity which in turn is related to the stability, being great when the stability is small, and vice versa. The relationship between $\vartheta_{30}-\vartheta_5$ and w/W (Fig. 3) indicates that for w/W small η must be small (great stability) and that for w/W greater than about 0.5, when adiabatic temperature decrease prevails, η must be great. These features should lead to the opposite effect of that which is evident from Fig. 2, and the conclusion must therefore be that the large values of dw/dz which characterize conditions when w/W is small, dominate and suppress the effect of the smaller η-values.

From Figs. 2 and 3 it may be concluded that with w/W greater than about 0.5 adiabatic conditions prevail under which $\tau_{obs}=0.75\tau_c$. This means that with indifferent stratification

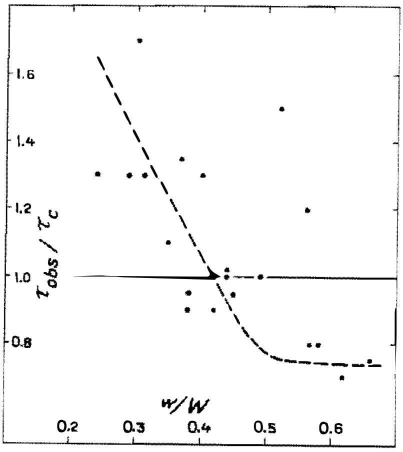


Fig. 2. The ratio τ_{obs}/τ_c plotted against w/W. The dashed line represents the probable relationship, neglecting two values which deviate a great deal from the others.

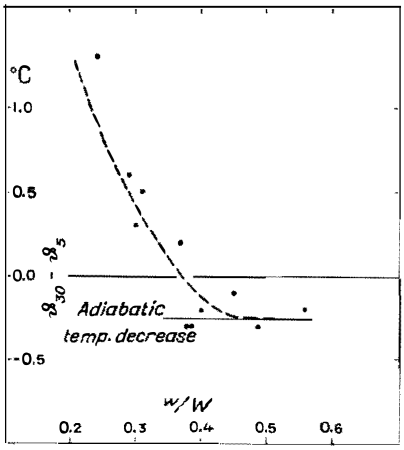


Fig. 3. The temperature difference $(\vartheta_{30}-\vartheta_5)$ plotted against w/W. The dashed line represents the probable relationship.

$$\tau = 5.2 \times 10^{-8} \varrho w^2$$

The corresponding curve is entered in Fig. 1 where it nearly passes through four of the observed values for which w/W equals 0.57, 0.62, 0.66 and 0.58, respectively.

Over a rough surface, and with an adiabatic lapse rate:

$$\gamma^2 = \frac{0.0302}{\left(\log \frac{a+z_0}{z_0}\right)^2}$$

where a is the anemometer level and z_0 the roughness parameter of the surface. With $\gamma^2 = 5.2 \times 10^{-8}$ and with $a = 700$ cm we obtain

$$z_0 = 2.65 \text{ cm.}$$

This value is approximate because it is derived from a small number of observations.

From laboratory experiments Nikuradze found that the average height of the "roughness elements" was equal to 30 z_0. If this result can be applied we obtain:

Average heigh tof the "roughness elements" of the polar ice equals approximately 83 cm.

This conclusion is in good agreement with our expectations, but should not be given a great weight because so far Nikuradze's results have not been applied successfully to atmospheric conditions. However, no surface in nature represents a better large-scale replica of Nikuradze's laboratory surface than does the polar ice. If his results are at all applicable, they should be applicable to the polar ice.

The angle between the geostrophic wind and the surface wind, α_w, varies between 21° and 52°, and is on an average 35°, independent of the ratio w/W. The angle between the geostrophic wind and the stress, α_r, varies between wider limits, from 18 to 72°, and is on an average 45°. It is also independent of w/W.

The difference $\Delta\alpha = (\alpha_r - \alpha_w)$ varies between —17° and 28°. This great scatter is not surprisning in view of the facts that, as stated above, the direction of the surface wind may be $\pm 11°$ or more in error, and that the direction of the stress cannot be expected to be determined with a high degree of accuracy. It is, however, surprising that the stress is directed to the left of the wind in 16 of the 20 cases, and that the average deviation is as great as 10°.

A further examination of the difference $\Delta\alpha$ may not be justified because of the small number of observations, but it seems worth while to draw attention to the following features: In the upper part of Fig. 1 the difference $\Delta\alpha$ is plotted against the wind velocity, w. It appears that $\Delta\alpha$ increases somewhat with increasing wind velocity. For 11 cases with velocity less than 4.5 m/sec the average value of $\Delta\alpha$ equals 7°, whereas for 9 cases with $w >$ 4.5 m/sec, $\Delta\alpha = 15°$. A closer inspection reveals that in 7 of the 9 cases with $w >$ 4.5 m/sec the wind direction is north-easterly or easterly, lying between 30° and 130°. The wind blows from these directions in 8 cases for which $\Delta\alpha = 18°$, whereas for the remaining 12 cases $\Delta\alpha = 5°$. This result suggests that with easterly wind the geostrophic wind turns right with increasing height, or that a thermal wind directed to the north cannot be neglected. In general the thermal wind directed to the north or the northwest was present below a height of 3—4 km because north-easterly or easterly winds were slightly prevalent at the surface, whereas south-westerly winds were prevalent above 3 km. It is also possible that systematically the true geostrophic wind is directed a little to the right of the adopted one. The uncertainties which exist because of the character of the data are such that no great importance can be attributed to the discrepancy between the directions of the surface wind and the surface stress.

In conclusion it is of some interest to examine the energy which is transmitted to the ice by the stress of the wind. According to results from the drifts of the "Fram" and the "Maud" as well as from subsequent expeditions the speed of the wind-drift of the ice is proportional to the wind velocity, $w_i = 1.2 \times 10^{-2} w$, and the direction deviates 30° to the right of the wind direction, $\psi = 30°$. The power of the wind is

$$P = \tau w_i \cos \psi$$

or, introducing τ and w_i as functions of w:

$$P = 10^{-7} \times w^3 \qquad \text{(erg/sec per cm}^2\text{)}$$

With $w = 10^3$ cm/sec we obtain $P = 10^{12}$ erg/sec per $km^2 = 10^2$ kilowatt per km^2. Part of this energy is dissipated in the sea, and part is dissipated by the jamming of the ice. The above numerical value is given in order to indicate the order of magnitude of the energy that enters into play.

Literature

SVERDRUP, H. U. The Norw. N. Polar Exp. with the "Maud", 1918—25, Vol. II, Meteorology, Discussion, Bergen 1933, and Vol. III, Meteorology, Tables, Bergen 1930.

Printed June 1957.

Printed June 1957.

Nr. 78. ORVIN, ANDERS K., *Outline of the Geological History of Spitsbergen.* 1940. Kr. 7,00.
„ 79. LYNGE, B., *Et bidrag til Spitsbergens lavflora.* 1940. Kr. 1.50.
„ 80. *The Place-Names of Svalbard.* 1942. Kr. 50,00.
„ 81. LYNGE, B., *Lichens from North East Greenland.* 1940. Kr. 14,00.

Norges Svalbard- og Ishavs-undersøkelser. Skrifter.

„ 82. NILSSON, TAGE, *The Downtonian and Devonian Vertebrates of Spitsbergen. VII. Order Antiarchi.* 1941. Kr. 11,50.
„ 83. HØEG, OVE ARBO, *The Downt. and Devonian Flora of Spitsbergen.* 1942. Kr. 33,00.
„ 84. FREBOLD, HANS, *Über die Productiden des Brachiopodenkalkes.* 1942. Kr. 6,00.
„ 85. FØYN, SVEN and ANATOL HEINTZ, *The Downtonian and Devonian Vertebrates of Spitsbergen. VIII.* 1943. Kr. 5,00.
„ 86. *The Survey of Bjørnøya (Bear Island) 1922—1931.* 1944. Kr. 9,00.
„ 87. HADAČ, EMIL, *Die Gefäßpflanzen des „Sassengebietes" Vestspitsbergen.* 1944. Kr. 6,00.
„ 88. *Report on the Activities of Norges Svalbard- og Ishavs-undersøkelser 1936—1944.* 1945. Kr. 6,50.
„ 89. ORVIN, ANDERS K., *Bibliography of Literatere about the Geology, Physical Geography, Useful Minerals, and Mining of Svalbard.* 1947. Kr. 12,00.

Norsk Polarinstitutt. Skrifter.

„ 90. HENIE, HANS, *Astronomical Observations on Hopen.* 1948. Kr. 3,00.
„ 91. RODAHL, KÅRE, *Vitamin Sources in Arctic Regions.* 1949. Kr. 6,00.
„ 92. RODAHL, KÅRE, *The Toxic Effect of Polar Bear Liver.* 1949. Kr. 12,50.
„ 93. HAGEN, ASBJØRN, *Notes on Arctic Fungi. I. Fungi from Jan Mayen. II. Fungi collected by Dr. P. F. Scholander on the Swedish-Norwegian Arctic Expedition 1931.* 1950. Kr. 2,00.
„ 94. FEYLING-HANSSEN, ROLF W. and FINN A. JØRSTAD, *Quaternary Fossils.* 1950. Kr. 8,25.
„ 95. RODAHL, KÅRE, *Hypervitaminosis A.* 1950. Kr. 22,50.
„ 96. BUTLER J. R., *Geochemical Affinities of some Coals from Svalbard.* 1953. Kr. 3,00.
„ 97. WÄNGSJÖ, GUSTAV, *The Downtonian and Devonian Vertebrates of Spitsbergen.* Part IX. *Morphologic and Systematic Studies of the Spitsbergen Cephalaspids.* A. Text, and B. Plates. 1952. Kr. 75.00.
„ 98. FEYLING-HANSSEN, ROLF W., *The Barnacle Balanus Balanoides (Linné, 1766) in Spitsbergen.* 1953. Kr. 8,00.
„ 99. RODAHL, KÅRE, *Eskimo Metabolism.* 1954. Kr. 10,00.
„ 100. PADGET, PETER, *Notes on some Corals from Late Paleozoic Rocks of Inner Isfjorden, Spitsbergen.* 1954. Kr. 1,00.
„ 101. MATHISEN, TRYGVE, *Svalbard in International Politics 1871—1925.* 1954. Kr. 18,00.
„ 102. RODAHL, KÅRE, *Studies on the Blood and Blood Pressure in the Eskimo and the Significance of Ketosis under Arctic Conditions.* 1954. Kr. 10,00.
„ 103. LØVENSKIOLD, H. L., *Studies on the Avifauna of Spitsbergen.* 1954. Kr. 16,00.
„ 104. HORNBÆK, HELGE, *Tidal Observations in the Arctic* 1946—52. Kr. 2,50.
„ 105. ABS, OTTO und HANS WALTER SCHMIDT, *Die arktische Trichinose und ihr Verbreitungsweg.* 1954. Kr. 4,00.
„ 106. MAJOR, HARALD and THORE S. WINSNES, *Cambrian and Ordovician Fossils from Sørkapp Land, Spitsbergen.* 1955. Kr. 4,00.
„ 107. FEYLING-HANSSEN, ROLF W., *Stratigraphy of the Marine Late-Pleistocene of Billefjorden, Vestspitsbergen.* 1955. Kr. 22,00.
„ 108. FEYLING-HANSSEN, ROLF W., *Late-Pleistocene Deposits at Kapp Wijk, Vestspitsbergen.* 1955. Kr. 3,00.
„ 109. J. J. DONNER AND R. G. WEST, *The Quaternary Geology of Brageneset, Nordaustlandet, Spitsbergen.* 1957. Kr. 5,00.
„ 110. KAARE Z. LUNDQUIST, *Magnetic Observations in Svalbard 1596—1953.* 1957. Kr. 6,00.
„ 111. H. U. SVERDRUP, *The Stress of the Wind on the Ice of the Polar Sea.* 1957. Kr. 2,00

MAPS AND CHARTS

The following topographical maps and charts have been published separately:

Maps:

Bjørnøya. 1:25 000. 1925. New edition 1944. Kr. 3,00.
Bjørnøya. 1 : 10 000. [In six sheets.] 1925. Kr. 30,00.
Adventfjorden—Braganzavågen. 1 : 100 000. 1941. Kr. 2,00.
Svalbard. 1 : 2 000 000. 1937. New edition 1944. Kr. 1,00.
Topografisk kart over Svalbard. Blad C 13. Sørkapp. 1 : 100 000. 1947. Kr. 3,00.
Topografisk kart over Svalbard. Blad B 10. Van Mijenfjorden. 1 : 100 000. 1948. Kr. 3,00.
Topografisk kart over Svalbard. Blad C 9. Adventdalen. 1 : 100 000. 1950. Kr. 3,00.
Topografisk kart over Svalbard. Blad B 11. Van Keulenfjorden. 1 : 100 000. 1952. Kr. 3,00.
Topografisk kart over Svalbard. Blad B 12. Torellbreen. 1:100 000. 1953. Kr. 3,00.
Austgrønland. Eirik Raudes Land frå Sofiasund til Youngsund. 1 : 200 000. 1932. Kr. 2,00.

Preliminary topographical maps [1 : 50 000] covering claims to land in Svalbard and a preliminary map of Hopen 1 : 100 000 may be obtained separately.

In addition, Norsk Polarinstitutt has prepared a wall map: Norden og Norskehavet, in 4 sheets. This map is to be obtained through H. Aschehoug & Co. (W. Nygaard), Oslo, at a price of kr. 27,80.

Charts

No. 501. Bjørnøya. 1 : 40 000. 1932. Kr. 4,00.
„ 502. Bjørnøyfarvatnet. 1 : 350 000. 1937. Kr. 4,00.
„ 503. Frå Bellsund til Forlandsrevet med Isfjorden. 1 : 200 000. 1932. Kr. 5,00.
„ 504. Frå Sørkapp til Bellsund. 1 : 200 000. 1938. Kr. 5,00.
„ 505. Norge—Svalbard, nordre blad. 1 : 750 000. 1933. Kr. 4,00.
„ 506. Norge—Svalbard, søre blad. 1 : 750 000. 1933. Kr. 4,00.
„ 507. Nordsvalbard. 1 : 600 000. 1934. Kr. 4,00.
„ 508. Kongsfjorden og Krossfjorden. 1 : 100 000. 1934. Kr. 4,00.
„ 509. Frå Storfjordrenna til Forlandsrevet med Isfjorden. 1 : 350 000. 1946. Kr. 4,00.
„ 510. Frå Kapp Linné med Isfjorden til Sorgfjorden. 1 : 350 000. 1946. Kr. 4,00.
„ 511. Austgrønland, frå Liverpoolkysten til Store Koldeweyøya. 1 : 600 000. 1937. Kr. 4,00.

Prices above do not include purchase tax.

Norsk Polarinstitutt Skrifter Nr. 111 H. U. Sverdrup: The Stress of the Wind on the Ice of the Polar Sea