AN ATTEMPT TO DETERMINE THE MAGNETIC DECLINATION AT SEA ON BOARD AN ORDINARY MOTOR BOAT.

by

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It is a well known fact that all Fenno-Scandia and the surrounding Baltic waters are extremely disturbed from a magnetic point of view. Some greater anomalies, such as that of Jussarö for instance, have been known for hundreds of years, but not until our days it has been fully recognized how very large the number and how great the extent of the anomalies in this part of the world really are.

The first systematic investigation of a magnetic anomaly at sea seems to be that of HAMMER in the vicinity of Bornholm, in 1892 (1). Here the declination was determined with the aid of a liquid compass on board a raft consisting of two launches put together.

Afterwards the declination was measured in a great number of anomalous areas in the Baltic Sea, partly from steamships and partly from a motor boat. In all these instances, for natural reasons, the larger disturbances only could be determined.

The next, more accurate, magnetic investigation over a greater area was made in 1924 in the Gulf of Finland and adjacent waters by VON GERNET on board the Estonian non-magnetic yacht *Cecilie* (2). During the next two years, 1925-1926, the same yacht was employed by the Hydrographic Service (Kungl. Sjökarteverket), Stockholm, and the Meteorological Central Office, Helsingfors, in collaboration, for the measurement of magnetic declination, horizontal force and vertical force, at 117 stations at sea (3). Later on, further work was carried out with the *Cecilie* in the southeastern parts of the Baltic (4).

During the last winters, Dr. KERÄNEN has successfully determined all the magnetic elements on the ice, in several places not far from the Finnish coasts. He used ordinary land instruments (5).

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(1) HAMMER, Misviisings Undersögelser vid Bornholms Kyster, Foretagne fra Opmaalingsfartöiet "Krieger" i Sommeren 1892. Tidskrift for Sövaesen, Ny Raekke, 27 Bind, Kjöbenhavn 1892, p. 329.

(2) VON GERNET, Die magnetische Aufnahme Estlands und der umliegenden Gewässer, Heft 1, Topo-Hüdrograafia Aastaraamatu 1926 Lisa, No 8, Tallinna, 1927.

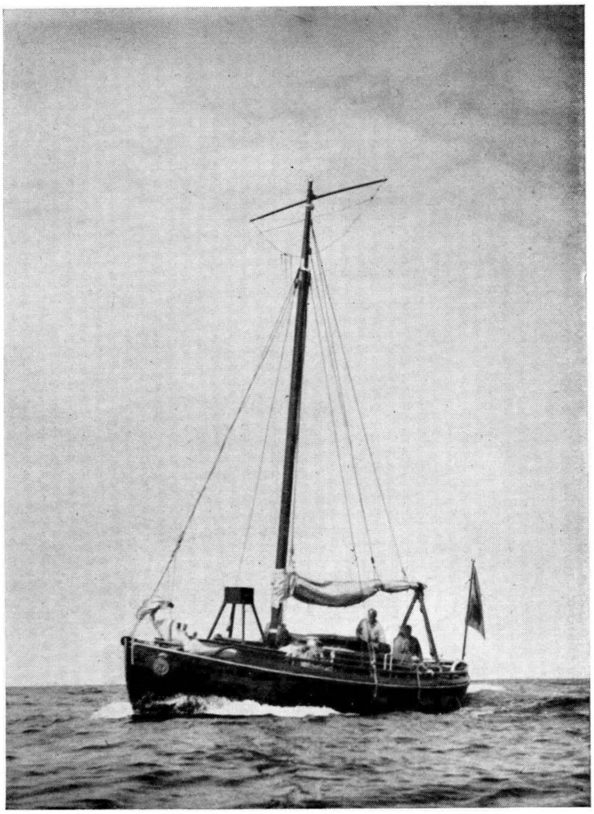
(3) KERÄNEN and ODELSIÖ, Magnetic Measurements in the Baltic Sea, South Quarken and Northern coast of the Baltic Sea, Kungl. Sjökarteverket Jordmagn. Publ. Nr. 5-6; Suomen Valtion Meteorol. Keskuslaitos, Maamagneettisia Tutkimuksia Nr. 14, 16, Helsingfors 1926 and 1927.

(4) VON GERNET, Die Ergebnisse der magnetischen Messungen in der Ostsee in den Jahren 1924 bis 1929, Zeitschr. f. Geophysik, VI, 1929, p. 216; SLAUCITAJS, Magnetic Measurements in the Baltic Sea along the Latvian Coast, Riga 1930, *etc.*

(5) KERÄNEN, On the Earth Magnetic Observations on the Ice, Report of the 18th Scandinavian Naturalist Congress in Copenhagen, 26-31 Aug. 1929.

Determination of Magnetic Declination at Sea

Détermination de la Déclinaison magnétique à la mer



The motor boat — *Le canot à moteur*

The compass stand is seen before the mast

Le support du compas est visible en avant du mât

The local variations of the magnetic elements in detail are, however, still unknown over the greater part of the Baltic Sea.

THE SURVEY IN 1932.

In 1932 the Director of the Kungl. Sjökarteverket, Stockholm, Captain E. Bouveng, suggested that the writer should endeavour to carry on the measurements of 1925 and 1926 in South Quarken by determining the magnetic declination North and South of the area surveyed in those years. Furthermore, determinations of D, H and I were to be carried out at the same time at land stations.

Contrary to expectations, the results proved to be fairly satisfactory. It might, therefore, be of some interest to present a report on the work, including a description of the method and an investigation of the accuracy of the measurements.

The survey was made from the (*not non-magnetic*) motor boat N° 1 of the Kungl. Sjökarteverket. This craft, which is shown in the illustration, is about 11 metres (36 ft.) in length, and is driven by a 15 H.P. crude-oil engine. Unfortunately, the conditions on board did not permit determinations of magnetic elements other than the declination.

The crew at the first 17 sea-stations consisted of two observers and one "all round man", and during the rest of the survey of the writer and the "all round man" only.

THE COMPASS.

The compass used for the determinations of the declination at sea was a liquid compass with a shadow pin, N° 15602, manufactured by Messrs. Lyth, Stockholm. The card was graduated in degrees from 0° (North) clockwise to 360°. The inner diameter of the bowl was 192 m/m (7.56 ins.), the diameter of the card 150 m/m (5.91 ins.). The diameter of the shadow pin was equal to the distance between two adjacent lines of the graduation on the card.

The compass was tested at the Compass Department of the Kungl. Sjökarteverket. The magnetic moment was found to be 2470 c.g.s. before the expedition, and 2390 c.g.s. afterwards.

The magnet system consisted of 6 magnets of cobalt steel, 90 m/m., 75 m/m., and 60 m/m. (3.54, 2.95 and 2.36 ins.) in length respectively, placed according to the Thomson system.

The collimation correction was $-8' \pm 5'$.

The errors of graduation did not exceed $+10'$ and $-10'$, respectively. All the observations were corrected for error of graduation.

EXCENTRICITY AND INCLINATION OF THE SHADOW PIN.

The errors due to eccentricity of the shadow pin were eliminated by turning the compass bowl through 180° after each set of observations. In practice, this was done in the following way: first, the shadow of the shadow pin cast by the sun was read at 8 different positions of the ship's head, *viz.*, N, NE, E, SE, *etc.*, clockwise, and then — after turning the compass bowl — at the same 8 positions of the ship's head counter-clockwise.

The influence of the inclination of the shadow pin was eliminated also by this operation. Therefore, great care was taken always not to touch or move the shadow pin during a series of observations. Nevertheless, the elimination was not perfect, for the compass bowl was suspended in gimbals with cylindrical trunnions. Due to the friction of these trunnions, the levelling was not always satisfactory, especially in a quiet sea when the compass bowl did not swing at all in the gimbals. In future, these cylindrical trunnions should be changed for knife-edges.

DEVIATION.

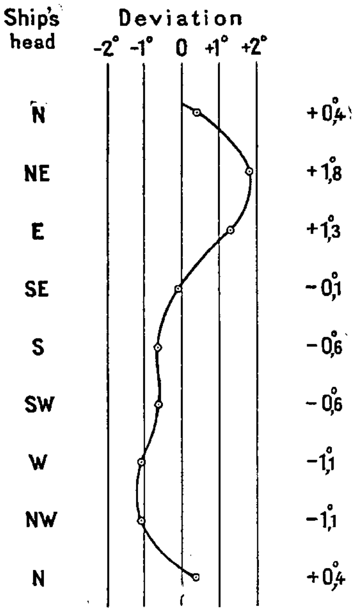
During the observations the compass was placed on a wooden stand in the bow. This place seems to be the most favourable on board with regard to deviation, although it is much affected by the movements of the boat. All iron was, if possible, maintained in the same place. Thus, the large anchor was always lashed to the capstan in the same position, with its chain in the box. The smaller anchor with its chain, and also all loose iron were stowed in the stern, *i. e.* about 8 metres (26 ft.) distant from the compass. The motor also was in the stern. As a matter of fact, the main part of the deviation would be caused by the large anchor, the capstan, the forestay and the shrouds.

With a single exception, *viz.*, Station Nº 5, all the observations were made as determinations of deviation with readings at the 8 main positions of the ship's head, N, NE, E, *etc.*, by swinging clockwise as well as in the opposite direction. At each position of the ship's head, the boat was steered with as little yawing as possible for at least one minute before the reading was taken.

The divergencies from an average, taken from these 8 positions of the ship's head, were assumed to be caused by deviation (as well as by the inevitable errors of observation). At the first 40 stations these divergencies were tabulated, and the means were worked out for each position of the ship's head. These means are taken to be the real values of the deviations. (When the observational material was definitely treated the values from the 26 best stations only were taken into account). The analysis of the compass deviations gives the following formula:

$$\text{Deviation} = \textit{Constant correction} + 73.4' \sin\psi + 29.0' \cos\psi + 34.2' \sin 2\psi - 5.4' \cos 2\psi.$$
Probable error $= \pm 1.7'$

The *constant correction* refers not only to the collimating error, *i. e.*, the angle between the magnetic axis of the magnet system and the North line of the card, but also, perhaps, to dynamic deviation, *viz.*, that due to the theore-



Courbe de déviation du compas de déclinaison

tical possibility that the regular vibrations of the single-cylinder motor might produce periodical fore-and-aft and athwartship oscillations of the fore part of the boat which, in turn, might cause the compass to swing in small circles or ellipses (6). In order to reduce the corresponding hypothetical rotation of the compass fluid, and the ensuing deflection of the card, to as small and as constant a value as possible, all the observations were taken at the lowest possible speed of the motor. It was only at the first "experimental stations" that full speed was used. To determine the *constant correction*, a number of *control measurements* were made (See Table below). Thus, the first station, N° 0, is situated only a few kilometres north of a land station. Stations 27, 37 and 44 are situated in the neigbourhood of land repeat-stations. *At all of these control stations the possibility exists, of course, that the declination is not exactly the same at the sea station and the corresponding land station* (7).

DECLINATION.

SEA STATION N°	0	27	37	44
Land Station 1932.5.	—2° 37'	—2° 06'	—1° 40'	—2° 23'
Sea Station 1932.5...	—2° 24' ± 11'	—1° 24' ± 4'	—1° 12' ± 6'	—2° 09' ± 8'
Difference..........	— 13' ± 11'	— 42' ± 4'	— 28' ± 6'	— 14' ± 8'

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(6) Dynamic deviations, due to rotating vibrations, have been noticed before; *cf.*, for instance, FIELD, *The Navigational Magnetic Compass considered as an instrument of precision. Journ. of the Inst. of Electrical Engineers*, Vol. 57, N° 282, 1919, p. 376: "An instance of marked friction due to vibration came to my notice in the case of a liquid compass recently supplied. The bowl was spring supported and in a position on the ship where considerable vibration existed. Under ordinary conditions the compass behaved quite normally and was entirely free of friction, but at a certain speed the compass deviated fully 10° and remained steady at this deviation. It was suspected that the bowl was in a state of rapid circular vibration, the spring suspension was modified and the trouble entirely cured".

(7) *Cf.* KERÄNEN and ODELSIÖ, *Magnetic Measurements in the Baltic Sea, Second Report*, "*Results, reduced to the Epoch* 1925.5":

Land Station 22,	Lat. 59°50.3' N.,	Long. 19°05.6' E. Gr.,	$D =$ 3°17'.
Sea Station 109,	» 59 49.8' N.,	» 19 05.5' E. Gr.,	$D =$ 3°06'.

The difference is, on an average, = —28.1', the values being given a weight inversely proportional to the mean error of the compass measurements at each station. The great mutual discrepancies are probably due to the above-mentioned difference of the declination at the land stations and the sea stations.

Furthermore, Sea Station N° 14 was made at the same place as the *Cecilie's* station 20/1925, and Sea Station N° 27 very close to the place of the *Cecilie's* station 109/1925. The following results are obtained by comparisons between these measurements.

DECLINATION.

According to	N° 14	N° 27
CECILIE 1925.5	— 1° 30'	— 3° 06'
CECILIE 1932.5	— 0° 19'	— 1° 55'
OBSERVATIONS TAKEN 1932.5	+ 0° 12' ± 7'	— 1° 24' ± 4'
DIFFERENCE	— 31' ± 7'	— 31' ± 4'

The value —30' = —0°.5 *is adopted as the "constant correction".* This correction is applied to the results given later.

INFLUENCE OF MOTION OF THE SEA.

It is evident that the general accuracy of the observations is diminished by the motion of the sea and it seems, also, *that, in certain cases, the compass card may deviate principally in one direction,* especially when the seas strike the vessel broad on the bow at fairly regular intervals. When the vessel lies fairly still for a few moments, the reading of the card wanders towards a certain limit, but as soon as the roll begins again, the first movement of the card is rather frequently back in the same direction (8). Owing to the impossibility of correctly estimating the true limit, which would correspond to a reading when the compass-card is undeviated, observations taken during the above conditions should be rejected.

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(8) The existence of compass-deviations caused by the rolling motion of ships is, in fact, verified theoretically as well as experimentally. (*Cf.* PETERS, *Tilting deviations in magnetic deviations.* Terr. Magn., 34, p. 93, 1929, where, also, further references are to be found). Therefore the utmost care should be taken always to find the reading that would correspond to the non-deviated card. When the craft is rolling, a reading is always doubtful. The best moment for reading seems to be when the vessel lies fairly motionless for a sufficiently long interval of time. Thus the compass-card should be capable of adjusting itself as rapidly as possible. The more rapid the adjustment, the greater the chances of obtaining correct readings.

An extract from the record of Station 42 is given below as an illustration of this case. The measurements were made in 1932, 9th September, from 12 h. 04.4 m. to 13 h. 03.5 m, local apparent time. No wind, but some swell. The azimuth of the shadow varied from 1.4° to 19.6° from North, eastwards. The difference between the computed azimuth of the shadow and the reading of the shadow on the card is given in the following table. Series 1 is made with the boat swinging clockwise, Series 2 in the opposite direction after turning the compass bowl 180°; Series 3 is clockwise, and Series 4 counter-clockwise after again turning the compass bowl.

Ship's head.	1	2	3	4	Mean	Dev.	*Decl.*	Δ
N	—0.2°	—2.5°	—2.0°	—1.5°	—1.6°	+0.4°	—2.0°	+0.1°
NE	+0.7	—1.7	—0.8	0.0	—0.5	+1.8	—2.3	—0.2
E	0.0	—1.2	—0.8	—1.5	—0.9	+1.3	—2.2	—0.1
SE	—2.4	—2.1	—1.8	—3.4	—2.4	—0.1	—2.3	—0.2
S	—2.9	—1.8	—1.0	—4.4	—2.5	—0.6	—1.9	+0.2
SW	—4.2	—4.3	—1.2	—5.0	—3.7	—0.6	(—3.1)	(—1.0)
W	—4.2	—3.6	—3.1	—4.8	—3.9	—1.1	(—2.8)	(—0.7)
NW	—2.2	—4.2	—3.0	—3.0	—3.1	—1.1	—2.0	+0.1
Means...............	—1.9°	—2.7°	—1.7°	—3.0°	*—2.3°*	0.0°	**—2.1°**	**±0.07°**×

Provided that all the observations are free from systematic errors, the same results ought to be obtained at all positions of the ship's head, with only such small variations as are always caused by the inevitable errors of observation. From the column "*Decl.*" in the above Table, however, the ship's heads SW and W have been rejected. The average is thereby altered from —2.3° to —2.1°. After adding the "constant correction" and reducing to the annual mean, the value of the declination is —2.6°.

In cases where discrepant ship's heads are rejected, the mean error is computed from the remaining ship's heads only. These mean errors are denoted by an ×.

Such procedure may be considered arbitrary, but as a matter of fact it corresponds to that used on board the *Cecilie*. The difference is, mainly, that the observations of the *Cecilie* were taken at that position of the ship's head only which was considered to be best with regard to sea and swell, and that in 1932 observations were taken at 8 positions of the ship's head, the selection being made during the subsequent computations.

The influence of the errors of reading was considered to be sufficiently minimized by the great number (generally 32) of observations taken, during which the shadow's azimuth changed about 20°. Thus, an error of ± 1° in a single reading influences the average by ± 1/32 degree = ± 2'.

REDUCTION TO A COMMON EPOCH.

All the observations were reduced to the common epoch 1932.5 with the aid of data from the Magnetic Observatory at Lovö (Stockholm).

OBSERVATION OF TIME.

Time was taken with an ordinary watch, the error of which was checked every day by radio.

POSITIONS.

Before determining the declination at a station, a buoy was anchored on the spot. The measurements were made within a few hundreds of metres of the buoy, the boat moving polygonally around it. At stations in depths greater than 80 metres (44 fms.), the buoy was not anchored to the bottom, but attached to a drift-anchor at a depth of 20 metres (11 fms.). The drift during an observation was not great, due to the absence of tides in the waters in question.

The position of the buoy could generally be determined by two angles to terrestrial objects which could be positively identified on the charts on a scale of 1:100,000 or 1:200,000. At some stations it was possible to get an angle between two terrestrial objects only. In such cases, the azimuths of these objects were determined, and the position fixed in this way. At Stations 16, 22 and 38, the position was determined by one distance and one azimuth and at Stations 34, 35, 39, 41 and 43 by dead reckoning.

RESULTS OF THE DETERMINATIONS IN 1932.

The absolute error of observation seems to exceed ± 0.2° in exceptional cases only. This appears both from the relative mean error, calculated from the observations at separate positions of the ship's head, and from a re-determination of the declination at two of the sea stations measured in 1925 by the *Cecilie*. The method of striking an average of 32 readings at 8 different positions of the ship's head seems to be quite satisfactory. In some cases, however, it seems doubtful whether a determination is affected by systematic errors or not, due to sea and swell.

The results are to be found in the Table below.

CHART OF MAGNETIC DECLINATION FOR THE YEAR 1935.

On the chart of magnetic declination for the year 1935, as shown below, the values of declinations determined in 1932 as well as the values from a number of older determinations are given reduced to the common epoch 1935.5.

The material used consists of determinations both at land stations and at sea stations. The land stations are denoted by a *circular spot,* with the declination value above it. At the sea stations the places of observation are situated in the middle of the *black figures* denoting the declination. *Grey figures* indicate the numbers of the sea stations made in 1932, corresponding to the numbers in the Table below showing the results for that year (Sea Station 37/1932 is situated farther south, beyong the limits of the chart).

The results of most of the older observations were known previously. Thus, the observational material at the land stations as well as at the sea stations made in the years 1925 and 1926, is already wholly published (3).

DETERMINATIONS OF THE MAGNETIC DECLINATION, 1932, REDUCED TO THE EPOCH 1932.5.

Observers : LJUNGDAHL (L), ASLUND (A)

Station.	*Lat. N.*	*Long. E. Gr.*	*Observer.*	*D* 1932.5	*Mean Error.*	*Depth.*	
						M.	fms.
0	58°52.0'	18°01.0'	A	−2.9°	± 11'	40	22
1	58 47.5	18 11.5	A	−2.3	8*	40	22
2	58 49.0	18 26.5	A	−1.8	5*	50	27.5
3	58 51.8	18 36.5	A	−2.7	5	60	33
4	58 51.4	18 46.0	A	−2.4	9*	80	44
5	60 41.8	17 26.5	A	−2.7	21*	25	13.7
6	60 43.7	17 43.2	L	−2.3	12	50	27.5
7	60 38.8	17 47.4	A	−2.7	7*	30	16.5
8	60 43.1	17 52.6	L	−2.7	7*	45	26.7
9	60 38.2	18 21.7	A	−2.4	8*	40	22
10	60 39.0	18 10.6	A	−2.2	5	50	27.5
11	60 30.8	18 44.1	A	−1.8	11	30	16.5
12	60 35.2	18 47.8	A	−1.1	8	40	22
13	60 36.1	18 57.3	A	−0.8	8	40	22
14	60 28.9	19 02.7	A	−0.3	7	60	33
15	60 31.5	18 54.5	A	−1.0	6	50	27.5
16	60 33.3	19 07.2	A	0.0	8	60	33
17	60 34.3	18 14.6	A	−2.2	5	30	16.5
18	60 32.3	18 36.3	L	−2.5	7*	25	13.7
19	60 37.0	18 38.7	L	−2.5	10	30	16.5
20	60 39.8	18 31.3	L	−2.7	7	50	27.5
21	60 34.9	18 29.5	L	−2.5	5	30	16.5
22	60 43.4	18 21.0	L	−2.4	3*	50	27.5
23	60 44.5	18 11.1	L	−2.3	5*	60	33
24	60 30.0	18 15.5	L	−2.2	4	15	8.2
25	60 53.8	18 26.7	L	−2.9	2*	60	33
26	60 56.8	18 36.2	L	−2.5	5	30	16.5
27	59 49.8	19 05.2	L	−1.9	4	30	16.5
28	58 43.9	18 04.4	L	−2.8	7*	50	27.5
29	58 38.7	17 59.4	L	−2.9	10*	70	38
30	58 39.9	18 09.6	L	−1.7	8	50	27.5
31	58 43.6	18 17.2	L	−1.6	11	60	33
32	58 48.4	17 57.8	L	(−4.1)	14*	60	33
33	58 43.1	17 54.4	L	−2.9	11	50	27.5
34	58 47.9	18 50.3	L	−2.2	8	130	71
35	58 43.1	18 58.1	L	−2.4	7	140	76.5
36	58 36.1	19 08.6	L	−2.5	5*	55	30
37	57 24.1	19 12.2	L	−1.7	6	7	4
38	58 34.5	18 56.5	L	−2.8	13	100	54.7
39	58 41.1	18 46.4	L	−2.7	7	180	98.5
40	58 46.2	18 38.8	L	−2.5	7	120	65.5
41	58 38.9	18 20.2	L	−2.4	5	300	131
42	58 37.4	18 33.0	L	−2.6	4*	200	109
43	58 43.0	18 31.5	L	−2.2	4	300	131
44	58 58.0	18 34.5	L	−2.6	8	10	5.5

The mean error signifies merely the relative accuracy of the observations, obtained from 8 positions of the ship's head by compass.

* indicates that the mean error, as well as the corresponding mean value of the declination, were computed from less than 8 positions of the ship's head.

— indicates westerly declination.

Note. The declination is given in degrees, the mean error in minutes of arc.

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With few exceptions, all the values from the land stations west of Stockholm and those north of 60° Latitude refer to measurements made in 1920 (9), and those east of 19° Longitude to measurements made in 1919 (10).

Most of the older values as yet unpublished are from the land stations, east, southeast and south of Stockholm, determined by the writer in 1924. A few still older observations also are taken into account.

In 1932, the net of older land stations was completed by making some new stations, and a sufficient number of the former was re-measured in order to secure the reduction of the whole material to the common epoch 1932.5.

In reducing from 1932.5 to the epoch 1935.5, the value + 30', corresponding to an annual change of + 10', was generally used.

Considering that most of the Fenno-Scandian anomalies, obviously due to irregularities in the mineral composition of the Earth's crust, seem to have local significance only, these anomalies have been neglected in constructing the *lines of equal magnetic declination.* Accordingly, these lines should be considered as approximate only.

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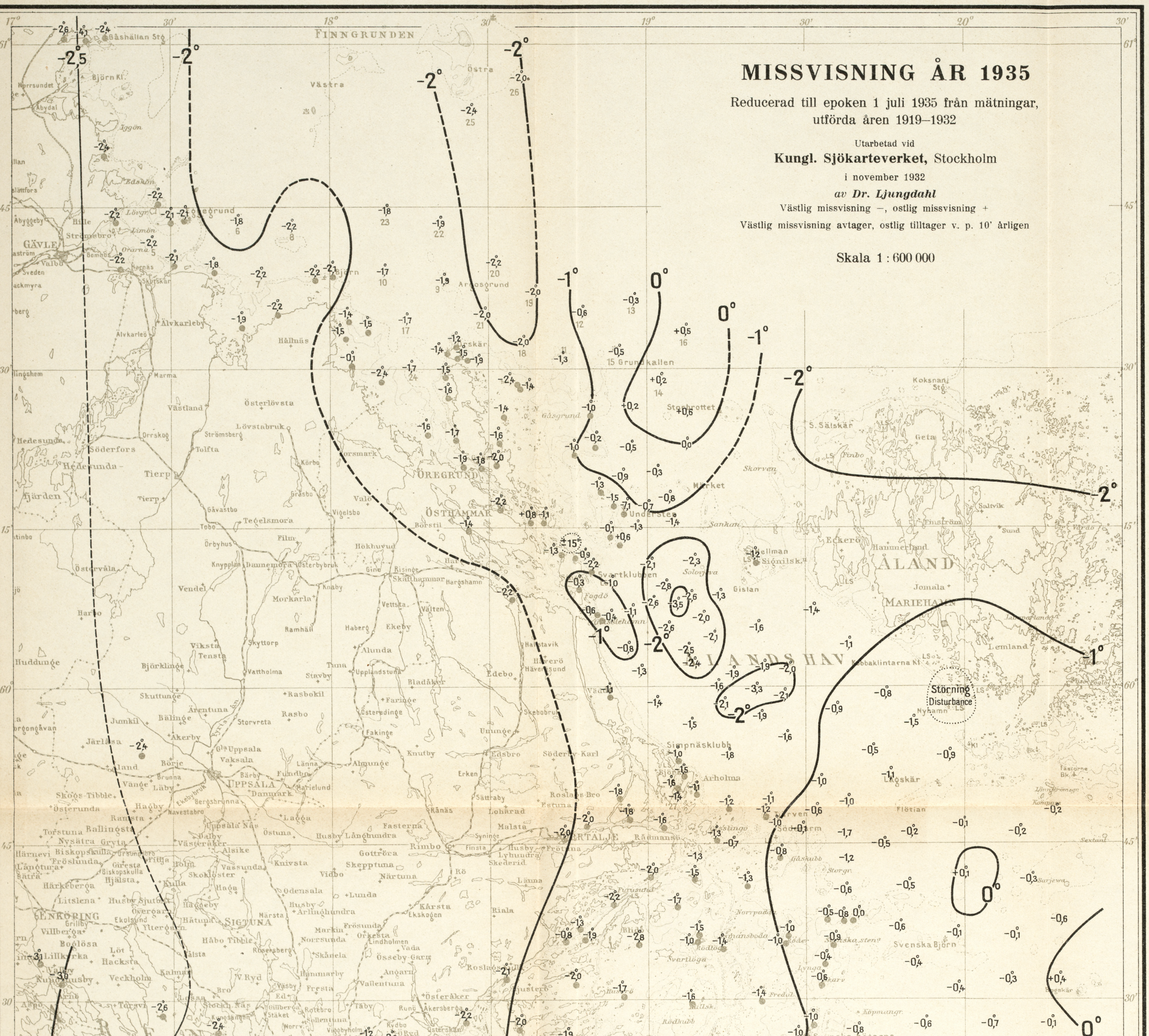
(9) LJUNGDAHL, Jordmagnetiska undersökningar i norra och mellersta Sverige åren 1913-1931, Kungl. Sjökarteverket, Jordmagn. Publ. Nr. 4, Stockholm, 1925.

(10) LJUNGDAHL, Magnetiska deklinationsbestämningar år 1919 i Stockholms norra skärgård, Kungl. nautisk-meteorologiska byrån, Jordmagnetism, Nr. 1, Stockholm, 1920.



MISSVISNING ÅR 1935

Reducerad till epoken 1 juli 1935 från mätningar, utförda åren 1919–1932

Utarbetad vid
Kungl. Sjökarteverket, Stockholm
i november 1932
av Dr. Ljungdahl
Västlig missvisning –, ostlig missvisning +
Västlig missvisning avtager, ostlig tilltager v. p. 10' årligen

Skala 1 : 600 000

MAGNETIC DECLINATION
FOR THE YEAR 1935

Reduced to the epoch 1935,5 from observations during the years 1919–1932

Compiled at the
Kungl. Sjökarteverket, Stockholm,
November, 1932
by Dr. Ljungdahl
Westerly Declination –, Easterly Declination +
Annual change + 10'

Scale 1 : 600 000

Grey figures indicate the numbers of the sea-stations in 1932

STATENS REPRODUKTIONSANSTALT 1932