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Mean Surface Velocities on Southern Bothnian Bay Determined by an Indirect Method

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by

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Abstract

A method has been developed to derive mean velocities from two surface isotherm charts given with a known time lapse. The method is based on the idea that the temperature change of the water surface takes place relatively evenly and that the isotherm pattern changes smoothly from one situation to another.

Introduction

A research programme was planned by the Institute of Marine Research in 1972 to clarify the behaviour of water flowed through the Kvarken to the southern Bothnian Bay and was completed between Nov. 8 and Nov. 22. As a first step, the speed and direction of water masses were to be found. A number of detailed temperature charts became available through the observations made from the air (cf. Fig. 2). Using the idea to follow the changes of the isotherm pattern during a fixed interval (cf. Palosuo /5/), we succeeded in determining the velocity field in the southern Bothnian Bay. Tracing water masses takes place normally by TS-diagrams but also methods similar to ours has been used (cf. Ahlnäs /1/, Voipio /6/). This work is a continuation of direct current measurements in Kvarken, which gave the rate at which volume of water was entering the region (Grönvall /2/). Later on, the mixing processes in the area concerned will be clarified by using data collected during the experiment mentioned.

Observations

The activity of the Institute of Marine Research to collect material was divided into two simultaneous parts. The first mission, conducted by Erkki Palosuo, (cf. Palosuo /5/) was planned to record surface water from the air, and the other one, conducted by Hannu Grönvall, used R/V Aranda for sampling the sea surface and the deeper waters.

The airplane had an infrared thermometer PTR-5 installed into the rear part of the plane. As a navigational aid a Decca Navigator was used. To make the orientation easier, a number of main Decca lines was chosen and a total of seven flights were performed between the dates from Nov. 8 to Nov. 17, 1972. About half of these flights were shorter covering the southern Bothnian Bay with a relatively dense network, but the remainder of the flights were longer, extending over the whole Bothnian Bay. The number of flights in the crosswise direction of the bay was mainly from two to three, but in lengthwise direction mostly four.

Because the infrared thermometer shows only relative temperature values, absolute reference measurements were necessary. These were provided by R/V Aranda, which collected samples during 11 cruises in the southern Bothnian Bay during the dates from Nov. 9 to Nov. 22. The cruises consisted in general of four cross sections, but some of them were incomplete and only a few stations were sampled during a cruise. The northernmost section lied between Blackkallen and Tankar and the southernmost one between Stora Fjäderägg and Helsingkallan (or Stubben). Temperatures and salinities were determined from the samples. For the present work, surface temperatures from three days, namely Nov. 10, 13 and 16, were chosen. The area of the study was the southern Bothnian Bay (cf. Figs. 2a, 2b, 2c).

Preparation of the charts

For each day treated, the surface temperatures from R/V Aranda were plotted on the charts. Then the temperature values from the infrared thermometer were compared in several corresponding points and differences were determined. Normally, these figures were invariable during a flight and so the temperatures of the infrared thermometer could be corrected and added to the main chart. If the differences did not stay quite unchanged, then there was presumably a disturbance present in the instruments, say the battery (ie. the accumulator) for the infrared thermometer could have been depleted due to cold weather. In such a case a linear interpolation was used to minimise the error caused by the failure appeared.

After all data had been properly treated and added to the charts, isotherms were drawn. Naturally, there are spots where the data are sparse and therefore the isotherms themselves possibly not very exactly determined.

Winds in the southern Bothnian Bay

No good wind observations have been made in the circumference of Bothnian Bay, but a good weather station is nearby, namely Valassaaret, which lies some 50 km to the southwest of the center of our region. Wind observations [1)] have been made there seven times a day. During the first period, from Nov. 10 to Nov. 13, wind blew from directions between SSE and SW, except for two observations from NE. Therefore a vectorial mean from the wind velocity was calculated to give 194^{o} for direction and 5.1 ms^{-1} for speed. The winds for our next period from Nov. 13 to Nov. 16 were more irregular and the direction turned in a counterclockwise direction. To get some idea of the wind, means for three subperiods were calculated. The wind blew at first for some 24 hours from a direction of 109^{o} with a speed of 6 ms^{-1}, then for some 12 hours from a direction of 43^{o} with a speed of 14 ms^{-1} and for some 36 hours from a direction of 332^{o} with a speed of 10 ms^{-1}. This irregularity of the wind may be the reason for the specific isotherm pattern of Fig. 2c.

The method

The basic idea is to track certain water masses using the temperature pattern of the surface water when flows from one place to another during a certain interval of time. It is assumed that the temperature changes are somehow regular, this means that main characteristics, for example the minimum or maximum properties of water masses, are preserved in broad outlines during the movement. We studied at first the three day period of Figs. 2a and 2b. The letters A, B, C and D denote points with maximum temperature. (In the case of C and D in Fig. 2a this may not be quite clear.) From the isotherms it can be deduced

1) Wind data were collected from the archives of the Finnish Meteorological Institute, Helsinki, Finland.

that the temperature of the point A has been lowered by about 0.3 °C and that of points B, C and D by some 0.2 °C. Also water masses with minimum temperatures may move without loosing the minimum property. This may be true with the point E with a temperature loss of some 0.4 °C. Extending the idea of smooth temperature change to more general situations, it is found that ridges and troughs are, practically taken, preserved. As a ridge we call lines which run through the points with highest curvature of the isotherms and where the horizontal temperature gradient shows toward the center of curvature of the isotherm. The troughs are similar, but the horizontal temperature gradient shows away from the center of curvature of the isotherm. Some ridges and troughs are shown in the figures by dotted and dashed lines respectively. One ridge runs from A via B and C to D and then will be divided into three main branches. Troughs can be used in a similar way. It is found for example that a trough runs between B and C almost in a north-south direction. Similarly a number of corresponding ridges and troughs can be found in the two figures. When we take into account that in a certain area the temperature has fallen by a known amount, say 0.2 °C, we can follow the march of the corresponding water masses on a ridge or on a trough during the three day interval in question. When the origins and termini of these identified points are connected by arrows, we obtain a vector field (Fig. 3a), where the mean velocities between points in concern readily can be observed. A scale for this purpose is provided. In the case concerned the field is relatively complete, but in some other cases identifying of the corresponding water masses in different figures creates unsurmountable difficulties. This is true for example for the following three day interval, where the eastern part of the observation area is quite well covered by matching point pairs, but in the western or northwestern part there are almost none. The tacit assumption that the motion of water particles takes place almost without mixing and that there is practically no upwelling at all, is naturally not always true and the method therefore cannot be applied without consideration. The result is that mistakes in trying to match the corresponding water particles is possible.

Some observations of the velocity fields

The current in the southern parts of the figures floes to the east and north east. In Fig. 3a, there seems to be a large eddy with a center near the point 64°N, 22°E. Another eddy is found at 63°50'N, 21°25'E. This eddy can be observed also in the Fig. 3b. Except for these eddies, some divergence areas can be observed. One such area lies near the connecting line of the two eddies mentioned. When we compare this with the figures 2a and 2b, we observe that it lies near a trough. This may be indicative of an upwelling area. A not so clear divergence area lies west and north of Helsingkallan and a look at the temperature maps shows rather clearly an upwelling area.

The calculated mean speed corresponding to the arrows of Fig. 3a is 4.5 cms^{-1} and the maximum speed is 9.5 cms^{-1}. The nearshore current west of Kallan has a speed 6.7 cms^{-1}. For the speed of Fig. 3b no mean value is calculated, but for the maximum speed a value 11.0 cms^{-1} is obtained. The nearshore current west of Kallan has a speed about 7.3 cms^{-1}.

Discussion

No direct current measurements have been made in the area in question. Some indirect arguments can indeed be mentioned to support the results presented.

The speed of the surface water varies considerably depending on a few factors, primarily the wind. A natural speed range is from 0 to 20 cms^{-1}, but also larger values have been observed. Speeds derived from isotherm charts show values between 0 and 9.5 cms^{-1}. A histogram has been made from speeds represented in figure 3a, cf. Fig. 4. Most speeds fall in the range 3...7.5 cms^{-1}. If we make a histogram of velocities measured by Grönvall (cf. Grönvall /2/) in a specific site in Kvarken during a longer time spell (1970-09-10--10-04), it is observed that the general shape of the two histograms show some similarities irrespective of the fact that they have been constructed in a different way.

Another test for the method is provided by the water level changes.[1)] The water table between Pori and Kemi was treated as a plane and changes of the volume in the Bothnian Bay north of a demarcation line running northwest and southeast through a point north of Helsingkallan were obtained from the water level changes of the center of gravity of the area. The rate of change of the volume in question was calculated to be 308000 m^3s^{-1} during the time 1972-11-10--11-13. The standard deviation of the rate of change of the volume calculated in intervals of six hours was indeed 530000 m^3s^{-1} and therefore the value obtained may not be very conclusive. The volume of water running through the cross section at the demarcation line per unit time was determined from the interpolated velocity components normal to the demarcation line and the bottom topography to be 340000 m^3s^{-1}. This figure is some 10 % higher than the figure based on volume changes and is thus rather good. We have indeed tacitly assumed that the speed is constant from bottom to surface. In a real case the speed is reduced somewhat toward the bottom and therefore the flow is also smaller in reality. A certain uncertainty is due to the fact that isotherms were not available on the Swedish side and a rough guess for the currents had to be made. The corresponding normal components were simply put equal to zero.

Divergences and vorticities were determined using velocities of Fig. 3a. A mean values of 23 divergencies was $0.52 \cdot 10^{-6}s^{-1}$ with a standard deviation of $2.15 \cdot 10^{-6}s^{-1}$. As a comparison a mean value off the Swedish coast south of Stockholm was $0.3 \cdot 10^{-5}s^{-1}$ with a standard deviation of $0.5 \cdot 10^{-5}s^{-1}$ (Mälkki /3/). The mean vorticity of the velocities of Fig. 3a was found to be $0.76 \cdot 10^{-6}s^{-1}$ with a standard deviation of $3.6 \cdot 10^{-6}s^{-1}$. Published values of measured vorticities are not known to the author but a few hypothetical ones, (Murty et al /4/). The mean and standard deviation of them are respectively $16 \cdot 10^{-5}s^{-1}$ and $16 \cdot 10^{-5}s^{-1}$.

Although the arguments given are not very conclusive, they do not prevent the velocities obtained of being rather plausible and thus the method of deriving the velocity field of being acceptable.

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1) Water elevations used in this paper were collecter from archives of the Institute of Marine Research, Helsinki.

Conclusion

The experiment performed shows that it is possible to construct a surface current field from two detailed temperature fields with a known time lapse by matching corresponding points of these fields.

Although the method may not be quite accurate, some properties of the currents can be derived. Anyhow, this method is much easier to perform than direct current measurements are.

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F i g u r e s

Fig. 1. Isotherms in the southern Bothnian Bay on 1972-11-08. Made by Dr. Erkki Palosuo.

Fig. 2. Surface temperature measurements for the days Nov. 10, Nov. 13 and Nov. 16, 1972. Absolute values (circled) were obtained by R/V Aranda and relative ones from PTR-5 recordings. These values were corrected by using the Aranda values and denoted into the chart (uncircled). From the collected temperature data isotherms were drawn. Thereafter some ridges (dotted lines) and troughs (dashed lines) were plotted (see text).

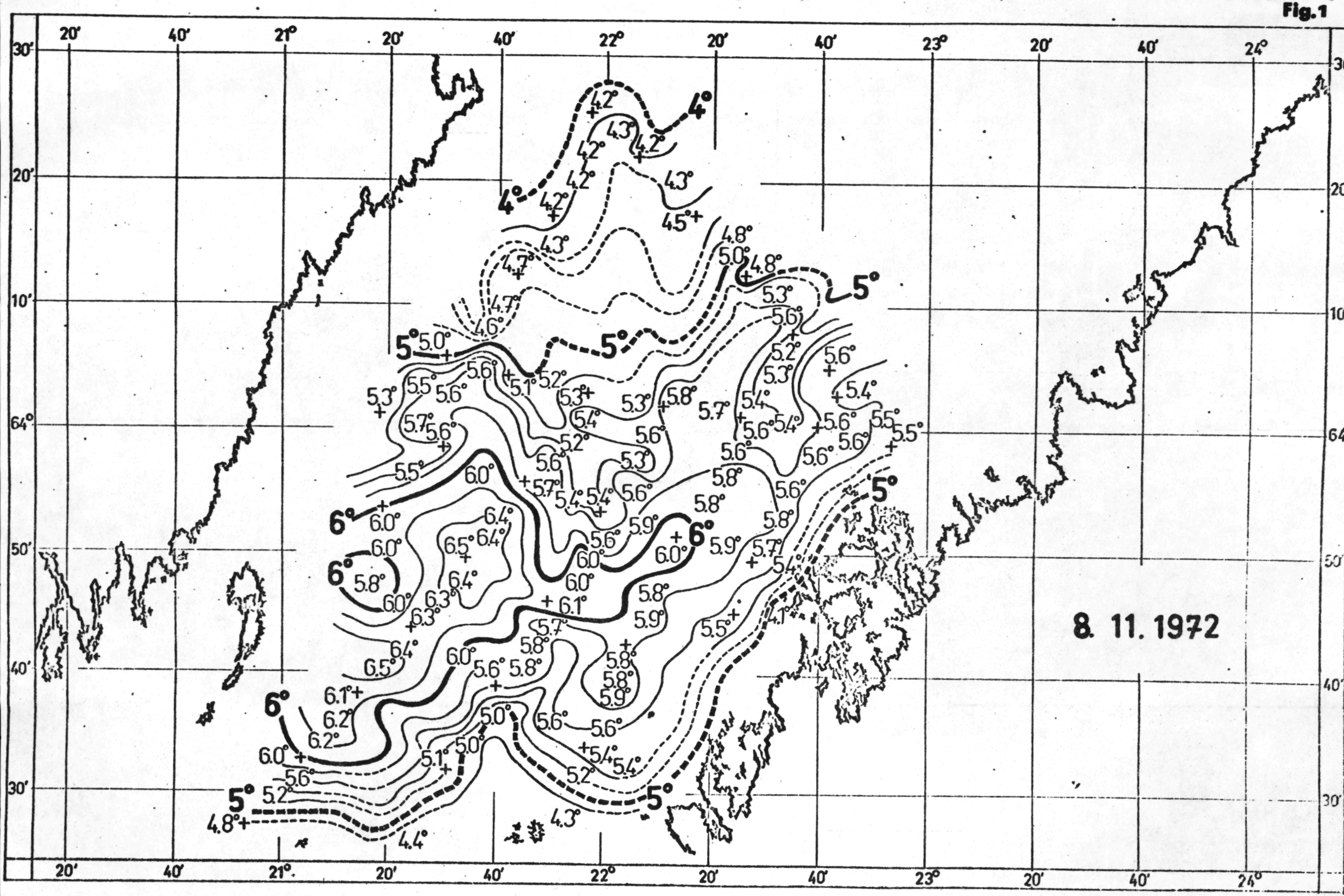
Fig. 2a. Nov. 10, 1972.
Fig. 2b. Nov. 13, 1972.
Fig. 2c. Nov. 16, 1972.

Fig. 3. Points, where the same water masses were beleaved to reside, were connected with arrows. They represent the marching lengths of water particles during the intervals in question.

Fig. 3a. Nov. 10 ... Nov. 13, 1972.
Fig. 3b. Nov. 13 ... Nov. 16, 1972.

Fig. 4. Histograms of speeds found by the isotherm method during 1972-11-10--11-13.

Fig.1



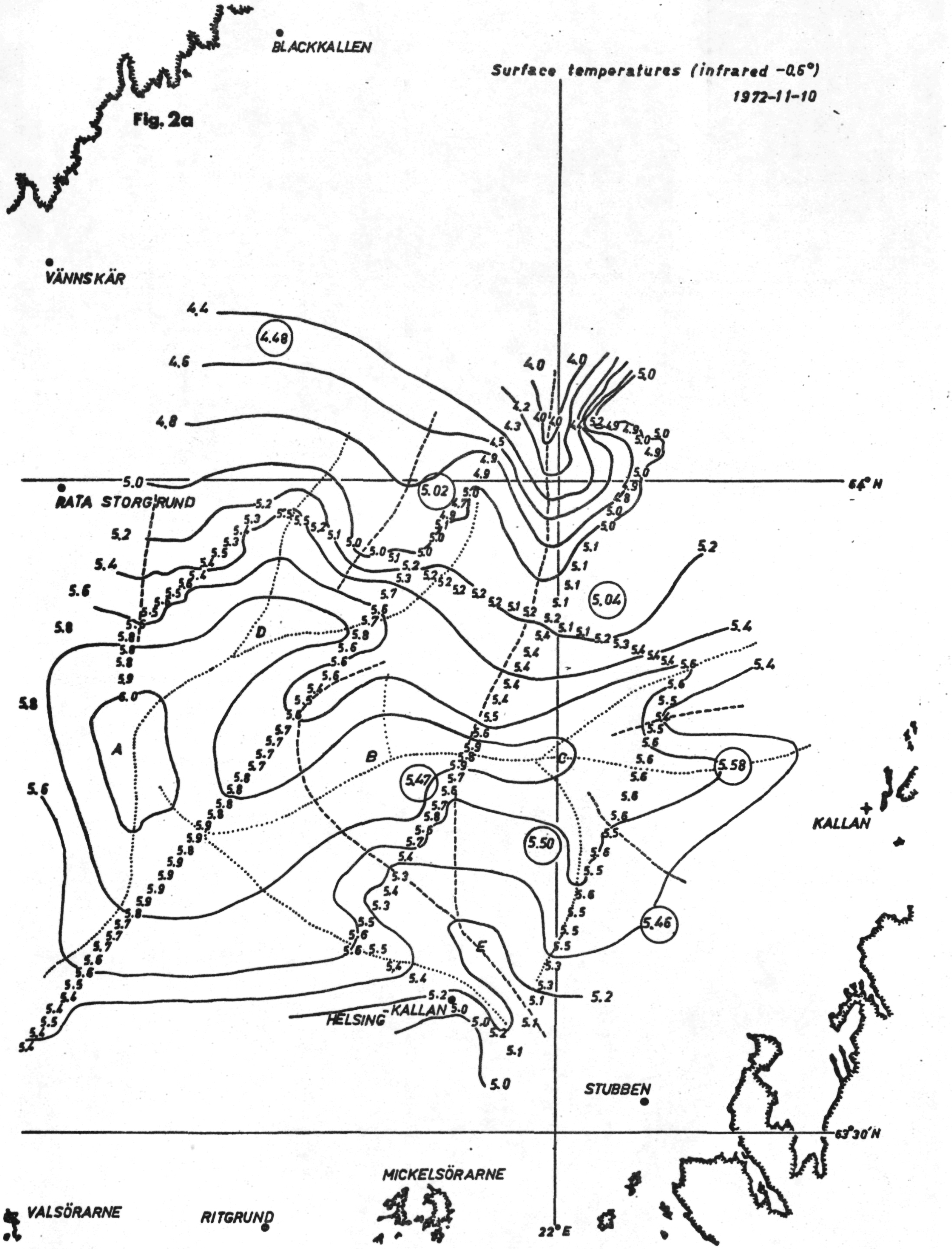


Fig. 2a
Surface temperatures (infrared -0.6°)
1972-11-10
BLACKKALLEN
VÄNNSKÄR
RATA STORGRUND
HELSING-KALLAN
KALLAN
STUBBEN
MICKELSÖRARNE
VALSÖRARNE
RITGRUND
64° N
63°30' N
22° E
A
B
C
D
E
4.48
5.02
5.04
5.47
5.50
5.58
5.46

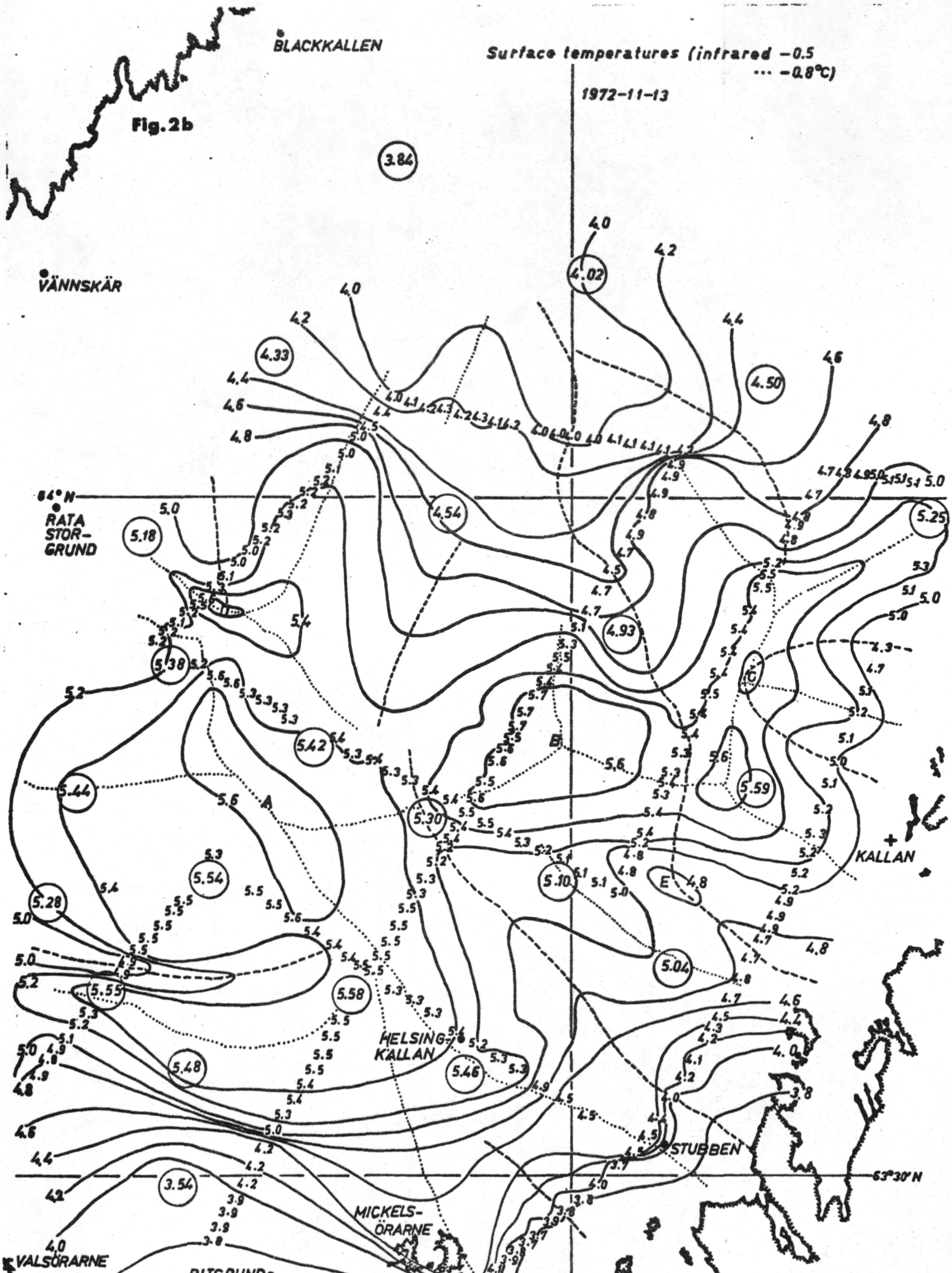

BLACKKALLEN
Surface temperatures (infrared -0.5
... -0.8°C)
1972-11-13
VÄNNSKÄR
64° N
RATA STOR-GRUND
KALLAN
HELSING-KALLAN
STUBBEN
MICKELS-ÖRARNE
VALSÖRARNE
RITGRUND
63°30' N
22° E

Fig.2b

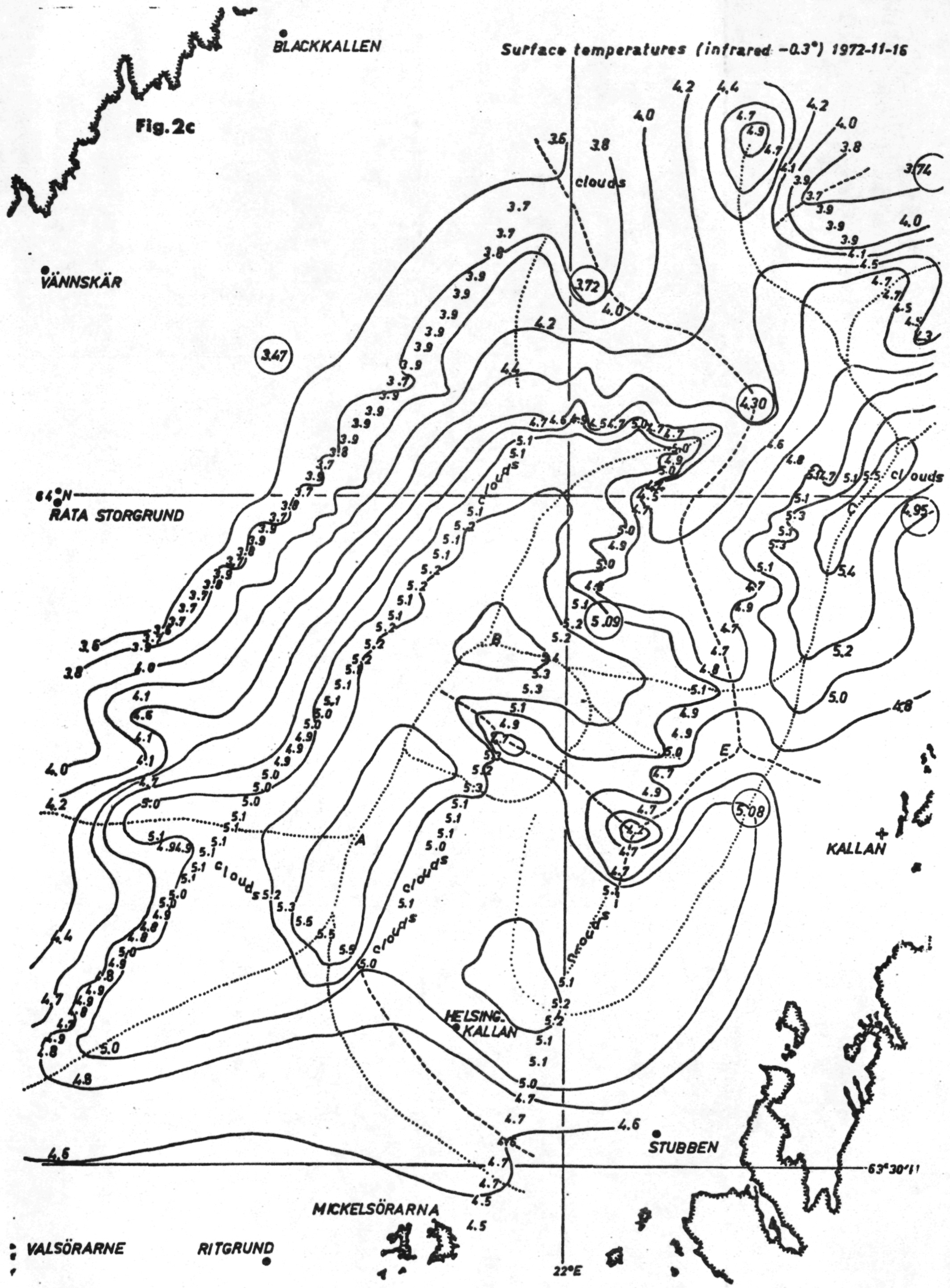
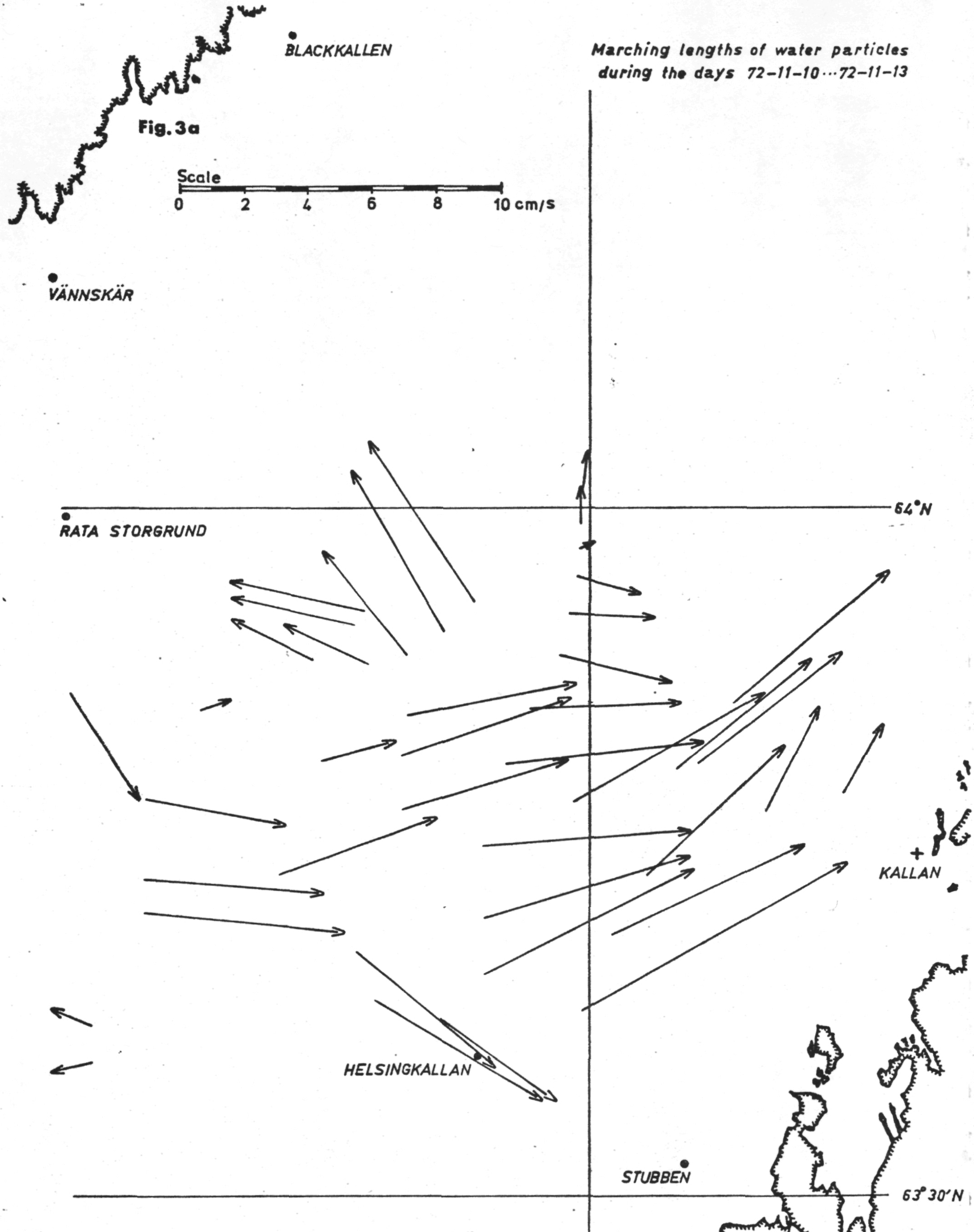
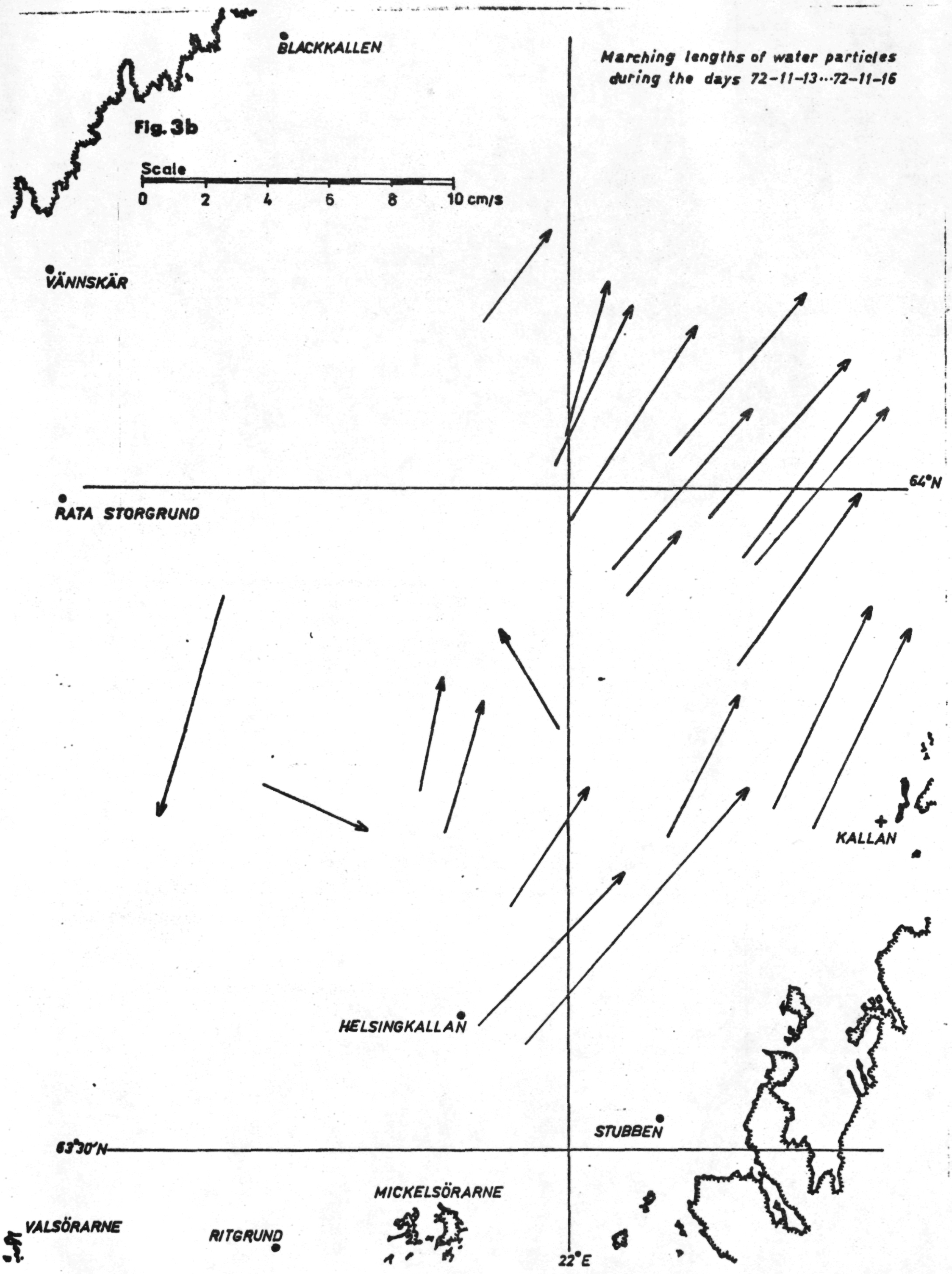

Surface temperatures (infrared -0.3°) 1972-11-16
BLACKKALLEN
VÄNNSKÄR
64°N
RATA STORGRUND
KALLAN
HELSING. KALLAN
STUBBEN
63°30'11
MICKELSÖRARNA
VALSÖRARNE
RITGRUND
22°E
clouds

Fig.2c



Points, where the same water masses were believed to reside, were connected with arrows. They represent the marching lengths of water particles during the interval from Nov. 10 to Nov. 13, 1972.



Points, where the same water masses were believed to reside, were connected with arrows. They represent the marching lengths of water particles during the interval from Nov. 13 to Nov. 16, 1972.

Fig.4