Ödsmål, Kville sn, Bohuslän

Hällristning
Fiskare från
bronsåldern

Rock carving
Bronze age
fishermen

MEDDELANDE från
HAVSFISKELABORATORIET LYSEKIL Nr 255

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THE BALTIC ENTRANCE PROJECT: Preliminary transport computations of water, salt and nutrients through the Göteborg - Frederikshavn (GF) section in the northern Kattegat, based on measurements 1975 - 1977.

by

Jan Szaron

Contribution to ICES C.M. 1979 Warsaw October 1979

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Water transport computations using currents measured with gelatin pendulum current meters, lead to a net outflow of 1253 km^3/year instead of the desired 457 km^3/year. The computations are therefore modified under som alternative assumptions. Transports are also computed for salt and nutrients. The modified computations lead to a mean net outflow of water of 310-460 km^3/year. The corresponding figures for tot P and tot N are mean net outflows of 6500-14000 ton P/year resp 115000-145000 ton N/year.

Vattentransportberäkningar baserade på strömmar mätta med gelatinpendelmätare leder till ett nettoutflöde om 1253 km^3/år istället för de förväntade 457 km^3/år. Beräkningarna modifieras därför under olika antaganden. Transporter beräknas också för salt och närsalter. De modifierade beräkningarna ger ett nettoutflöde av vatten om 310-460 km^3/år. Motsvarande siffror för tot P och tot N är 6500-14000 ton P/år 115000-145000 ton N/år.

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Preliminary transport computations of water, salt and nutrients through the Göteborg - Frederikshavn (GF) section in the northern Kattegat, based on measurements 1975 - 1977.

by

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Abstract

Water transport computations using currents measured with gelatin pendulum current meters, lead to a net outflow of 1253 km^3/year instead of the desired 457 km^3/year, which is the fresh water discharge into the Baltic, Belt Sea and Kattegat (south of Göta älv). The transport computations are therefore modified under some alternative assumptions. Transports are also computed for salt and nutrients. A dynamic method, using density differences to compute transports, is presented. The modified computations lead to a mean net outflow of water of 310 - 460 km^3/year. The corresponding figures for tot P and tot N are mean net outflows of 6500 - 14000 ton P/year resp. 115000 - 145000 ton N/year. These figures are compared with figures presented by other authors.

Introduction

During August 1974 - December 1977 a section Göteborg - Frederikshavn (Fig. 1) was surveyed 75 times. At 10 stations, and at altogether 55 sampling points (Fig. 2), measurements were made of current, temperature, salinity, oxygen, tot P, PO_4, tot N, NO_2, NO_3, NH_4 and total organic carbon (TOC). The current velocity and direction were determined with a gelatin pendulum device (Haamer, 1973), which gives an instantaneous picture of the current.

In this article total mean transports of water, salt, tot P and tot N, computed in some alternative ways, are presented and discussed. The transports are computed with data collected during 63 expeditions in 1975 - 1977.

Something about the current

Fig. 3 shows what is, uptil now, known about the surface currents in the Kattegat. Our knowledge about what happens in the deeper parts, though, is scarce. Fig. 4 shows mean values of instantaneous measured currents between 1975 - 1977. The figure shows features that were expected, but there are some surprises. (To avoid confusion; the current measurements are drawn in the xy-dimension.)

Let us look a little at the "surprises".

a. The mean currents are ingoing at station 4 and 5 already at 10 meter depth.
b. At station 4, 60 meters, the figure shows an outgoing mean current. This is probably wrong. A closer look at the measurements shows that at 3 occasions outgoing currents greater than 50 cm/s were measured, and this was enough to "spoil" the mean value.
c. The influence of the topography is very clearly seen at stations 6, 7 and 8, although the section is relatively far away from the island of Läsö (will be discussed later).
d. We have an ingoing mean current in the whole watercolumn at station 8. No extreme values are responsible for that. This ingoing current can also be seen in Davies´ numerical model (Fig. 5). We can only regret now that we, for financial and practical reasons,abolished the planned station between station 7 and 8.

Automatically recording instruments (Aanderaa) moored (see Fig. 1) in the vicinity of L/V Läsö Nord (15 and 30 meters), L/V Läsö Trindel (15 and 30 meters) and south of station 4 (8, 15 and 30 meters) confirm the general features in Fig. 4.
At station 6 the mean value of the surface current's north component (actually we have measured the current somewhat below the surface) was 10 cm/s with a standard deviation of 22 cm/s, while 8760 measurements of surface current made on board L/V Läsö (Nord and Trindel) gave a mean value of the north component of 7 cm/s with a standard deviation of 24 cm/s. (See also the maps in "Oceanographical Observations from Danish Lightvessels and Coastal Stations" 1975 and 1976.)

It must be remembered that we have used a very simple instrument to determine the current and that Fig. 4 is based on 63 expeditions. Nevertheless it looks as if we have managed to get a fairly good picture of the elusive parameter "current".

Water transport computations

When we try to compute mean water exchange (-transports) between the North Sea and the Baltic we know that the result should be a mean net outflow from the Baltic of about 457 km^3/year, which is the fresh water discharge into the Baltic, Belt Sea and Kattegat south of Göta älv (Mikulski 1972, Svansson 1975). All the alternative ways, presented below, of computing water transports have as their goal to reach this figure. The alternatives also have in common that we divide the GF-section into rectangular subsections (except where the bottom topography interferes) and that we assume a sampling point to be representative for a whole subsection (Fig. 2).

The "straight-forward-way" (alternative 1)

The cross-section area is divided half-way between the stations and sampling depths. We then get the figures shown in Table 1. The net outflow of 1253 km^3/year is too high, either because the inflow is too small or the outflow too high. The table reveals that 50 % of the outflowing water passes station 6 and 7. If we consider the direction and strength of the currents (Fig. 4) and the current pattern in Fig. 5 we might ask if these currents aren't a combination of the circulation around Läsö, the eddy that can be hinted north of Läsö and outflowing Baltic water.

"Add inflowing water between station 7 and 8"(alternative 2 and 3)

Since the net outflow of water is too high, let us assume that we in our measurements have missed some inflowing water. Fig. 5 suggests that we should add inflowing water between station 7 and 8. We further assume that the water (all or part) later flows out at station 6 and 7, or, in other words, we assume, relaying on Fig. 5, that we have a circulation of water around the island Läsö. Rough calculations immediately show that it is not enough to modify the transport computations above by letting station 8 represent a larger section, and hence station 7 a smaller.

Let us choose two alternatives to quantify the inflow, one resulting in the net outflow of 457 km^3/year (alt 2), the other in saltbalance (alt 3). Table 1 then shows that of the 1075 km^3/year flowing out at station 6 and 7, 796 km^3/year must return between station 7 and 8 to change the net outflow of 1253 km^3/year to the desired 457 km^3/year. In the case of saltbalance the computed outward salttransport at station 6 and 7 of $28.3 \cdot 10^9$ tons/year should be multiplied by a factor x/1075 to equalize the measured net outflow of $24.8 \cdot 10^9$ tons/year. We then end up with $x = 940$ km^3/year.

Fig. 6 shows a possible extrapolation of Fig:s 4, 5 and the discussion above (the figure 1200 km^3/year is composed of measured 260 and of added 940 km^3/year). Some arrows in the NW part have been drawn in accordance with the fact that North Sea water algae appear earlier in the western part of the GF-section than on the Swedish side (Brita Eklund, personal communication).

"The water north of Läsö does not take part in the exchange between the Baltic and the North Sea" (alternative 4)

Let us now assume, looking at Fig:s 1, 4 and 5, that the currents measured at station 6 and 7 belong to the eddy north of Läsö that can be hinted in Fig. 5. In that case we should exclude the water transport they cause since they don't contribute to the water exchange between the Baltic and the North Sea. So, if we exclude the area between station 6 and half-way to station 8, except that we allow the water at station 7, 30 meter, to penetrate inwards, we get a net outflow of 460 km^3/year (Table 1).

The computed water transports for the alternatives 1 - 4 are summarized in Table 2. These alternatives represent some sort of extremes of the assumption made earlier that the currents at station 6 and 7 derives from a combination of the circulation around Läsö (alt 2 and 3), the eddy north of Läsö (alt 4) and outflowing Baltic water (alt 1).

Geostrophic computations for a hypothetical 2-layer flow

The mean density distribution at the GF-section may be roughly described by an inclined pycnocline being deepest on the Swedish side. We start by a Margules' approach

$$M = -\frac{g \cdot H}{f} \cdot \Delta h$$

$$M' = -\frac{g}{f} \cdot \frac{\rho}{\rho'} \cdot H' \cdot \Delta h - \frac{g}{f} \cdot \frac{\Delta \rho}{\rho'} \cdot H' \cdot \Delta h'$$

with

M = total water transport in the surface layer (depth H, density ρ), positive southwards

g = acceleration of gravity = 9.81 m/s^2

f = Coriolis parameter = $1.3 \cdot 10^{-4}$ s^{-1}

Δh = sea level difference

M' = total water transport in the lower layer (depth H' = 25 meter and density ρ')

$\Delta \rho = \rho' - \rho$ = 0.005 ton/m^3

$\Delta h'$ = pycnocline depth difference

$M + M'$ = -457 km^3/year

We then find that the sea level is 8 cm higher on the Swedish side, and further that the outflow is 1950 km^3/year and the inflow 1465 km^3/year.

Also a more detailed dynamical computation was made:

For each expedition that part of the current which depends upon density differences only was computed by the geostrophy formula. Thereafter the mean was taken and two alternative conditions were added, a net outflow of 457 km^3/year (alt 1a) resp saltbalance (alt 2a). We then got the figures shown in Table 2.

Sticking to the saltbalance case we find the outflow to be 4.8 times the net outflow compared with 5.3 computed by Knudsen (Schulz 1930). The geostrophically computed outflow has a mean salinity of 25.8 ‰, the inflow 32.8 ‰.

The two geostrophic computations do not differ much, but they both give slightly lower water transports than alt 2 resp 3. There are many reasons for discrepancies, especially in the detailed pattern. In the dynamic method calculation only a linear variation from Denmark to Sweden is possible. If, however, the additional cyclonic circulation around Läsö is a reality it must be combined with an adverse sea level gradient.

Transports of salt and nutrients

When we now deal with yet another independant variable, the mean transport through each section is computed with the formula

$\frac{1}{N}\sum_{i=1}^{N} u_i \cdot P_i \cdot A_i$ were

N = number of expeditions

A_i = the area of subsection i

u_i = the current's component perpendicular to the cross-section

P_i = salt or nutrient

When we compute salt transports it should be remembered that salinity is defined as g/kg. What we need, though, is the unit g/l=10^6 ton/km^3. This could be named salosity, as the unit corresponding to chlorinity is called chlorosity. The difference beween salinity and salosity is small, e.g. if the salinity is 35 g/kg, the salosity is about 35.9 g/l.

Alt 1 gives an outward transport of tot P at station 6 and 7 of 23380 ton/year. According to alt 2, 796/1075 of this amount returns. The tot N transports are computed analogous. In alt 3 the factor is 940/1075. Table 2 is a summary of transport computations according to the different alternatives.

Fig. 7 shows the time development of temperature at station 4 as measured 1975 - 1977. The figure reveals that we have measured often enough to get a clear picture of how the temperature varies with the seasons, although we have measured unproportionally often in some months. Tot P and tot N are also seasonally dependant, and to counteract the uneven sampling frequency some kind of weighting of the measured nutrients could be desirable. Let us choose the easiest way and compute nutrient transports with linearly weighted values and then, as in alt 3, impose the saltbalance condition. The result is shown in Table 2 as alt 5.

The Phosporus Budget

When the oxygen situation in the deeps of the Baltic began to be discussed in 1967 in Sweden, a first phosphorus budget was made. Human phosphorus was assumed to be most responsible for the observed oxygen decline. In a governmental investigation (Miljövårdsforskning. Statens offentliga utredningar 1967:43) it was assumed that there is a net inflow to the Baltic of 3500 ton P/year from the Kattegat. Fonselius (1969), however, computed, using a box model with 3 boxes on top of each other, a net outtransport of 1500 ton P/year. Sjöberg et al. (1972) simultated various cases in a time-dependant 2-box (on top of each other) model of Baltic proper. First a natural situation was investigated, with 7100 ton P/year as river input and an inward transport through the Belt Sea of 9900 ton P/year (same as Fonselius). The simultation then resulted in an outflow through the Belt Sea of 8700 ton P/year, and hence a net inflow to the Baltic of 1200 ton P/year. Thereafter the supply of "river" phosphorus was increased to 20000 ton P/year. The model now showed, in a new steady state, a net outflow of 3400 ton P/year.
Table 3 shows the P-budget, as presented in ICES (1979), for the Baltic and the Belt Sea. For nitrogen the figures range a lot but they are, in general, one order of magnitude larger than those for P.

The Kattegat values are found in ICES (1978), where the subdivision is somewhat different from that one in Table 3. A total value for Kattegat of 3130 ton P/year is composed by Rivers 2050, Domestic Sewage 835 and Industrial Waste 245 ton P/year. For nitrogen the total figure for the Kattegat is 36400 ton N/year. ICES' P-figures are higher than those obtained by Fonselius. Let us dwell a little about Fonselius 1500 ton P/year - figure. He assumed that measurements in the Skagerrak had shown that at 35 ‰ salinity level, the tot P was 1.25 µgat/l (=38.75 µg/l=38.75 ton/km^3). According to the assumption that the water, flowing from Kattegat to Baltic, is 1/3 Skagerrak water and 2/3 old Baltic water (conc. = 0.34 µgat/l = 12.1 ton/km^3), he found 11400 ton P/year flowing out and 9900 ton P/year flowing in to the Baltic. But there are now better mean values of total phosphorus than Fonselius could use 1969. Table 4 shows mean values of tot P, measured some 4 times a year by the National Board of Fisheries, 1968 - 1975. Let us therefore repeate Fonselius' computation with these updated figures. Instead of 38.75 ton P/year for the Skagerrak we will use 22 ton P/year (=0.7 µgat/l), partly since it is the P mean value of the inflowing water in the deeper part of GF-section 1975 - 1977, partly since this value is found at 30 meter depth (Table 4) at station M6 in the middle of Skagerrak. For the Baltic water we chose 0.54 µgat/l (=16 ton P/year) from Bornholm surface water (Table 4). We then derive an outflow of 15000 ton P/year and an inflow of 8500 ton P/year, with 6500 ton P/year as difference. This difference is of the same order as the difference at the GF-section (Table 2), and as ICES' figures (Table 3).

Summary and discussion

To compute transports of water and matter is quite a formidable task in a dynamic area like the northern Kattegat. The computations must be based on measurements and these measurements must describe the events quite accurately if we hope to get reliable results. The most important parameter in transport computations is the current. It is the current that transports water and matter, but it is also the parameter that varies most in time and space. Since our measurements only give an instantaneous picture of a dynamic course of events, we have to make assumptions to get an overall impression. All the alternative ways, presented above, are the first attempts to reach this goal. Table 2 shows that the resulting net outflows of total phosphorus and total nitrogen accord well with the relevant literature figures and this is an indication that we are on the right way.

The next obvious step should be to try to determine the in- and outgoing transports of water and matter as accurately as possible.

This paper has not dealt with the quality of the measurements, but these considerations shall, of course, be included in the future work with these transport computations.

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Other published papers within the project are:

"Tidal and Spectral Analysis of Kattegat Time Series of Current and Salinity" by H. Bieler and A. Svansson, Meddelande från Havsfiskelaboratoriet no 209, January 1977.

"Investigations in the Northern Kattegat during the International JONSDAP-76 Period INOUT, March - April 1976 (JONSDAP-76 Contribution no 15)" by P. Möller and A. Svansson, Meddelande från Havsfiskelaboratoriet no 243, December 1978.

"The influence of Sampling Frequency on the Study of Time Variations of Hydrographic Parameters" by S. Lööf, Meddelande från Havsfiskelaboratoriet no 244, January 1979.

"The Baltic Entrance Project: Analysis of Currents Measured at Läsö Nord/Trindel Lightvessel 1974-1977" by S. Lööf and A. Svansson, Meddelande från Havsfiskelaboratoriet no 252, October 1979.

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Water Transports, km^3/year, determined by pendulum current meters

Mean Values 1975-77

Station	10	9	8	7	6	5	4	3	2	1
Depth m										
2.5	-95	-131	+45	-82	-64	-17	-21	-93	-9	-16
5	-123	-212	+68	-124	-106	-28	-29	-147	-14	-38
10	-35	-83	+18	-181	-105	+9	+8	-60	0	-14
15	Σ -253	-15	+7	-60	-90	+32	+78	-23	Σ -23	Σ -68
20		-13	+6	-65	-128	+65	+123	-27		
		Σ -454								
30			+60	+55	-70	+71	+148	-5		
			Σ +204	Σ -512 Σ +55	Σ -563			Σ -355		
40	Σ -707		Σ +259	Σ -1075		+70 Σ -45 Σ +247	+126			
50							+86			
60							-11			
70							+6 Σ -50 Σ +575 -11=+564			
						Σ -541 Σ +811				

Inwards : 1070

Outwards : 2323

Difference :-1253

Table 1.

Table 2.

Mean transports of water, salt and nutrients computed in some alternative ways.

		Water (km^3/y)	Salt (ton/y)	tot P (ton/y)	tot N (ton/y)
	in	1070	$35.6 \cdot 10^9$	22800	182000
Alt 1	out	2323	60.4	49800	477000
	diff	-1253	-24.8	-27000	-295000
	in	1866	$56.6 \cdot 10^9$	40100	334000
Alt 2	out	2323	60.4	49800	477000
	diff	-457	-3.8	-9700	-143000
	in	2010	$60.4 \cdot 10^9$	43300	362000
Alt 3	out	2323	60.4	49800	477000
	diff	-313	0	-6500	-115000
	in	1070	$35.6 \cdot 10^9$	22800	182000
Alt 4	out	1530	39.8	32400	322000
	diff	-460	-4.2	-9600	-140000
	in	2010	$60.4 \cdot 10^9$	41300	356000
Alt 5	out	2323	60.4	55400	501000
	diff	-313	0	-14100	-145000

Geostrophic computation

	in	1443	$48.5 \cdot 10^9$	24000	232000
Alt 1a	out	1900	50.6	35400	391000
	diff	-457	-2.1	-11400	-159000
	in	1471	$49.5 \cdot 10^9$	24600	238000
Alt 2a	out	1862	49.5	34700	383000
	diff	-391	0	-10100	-145000

Table 3.

(ICES, 1979)

Phosphorus budget (ton/year)
for the Baltic and the Belt Sea

Input	Highest values		Lowest values	
Domestic and industrial waste	33 000		22 000	
Atmosphere	9 000		3 000	
Natural input	3 000		500	
Danish Straits	6 000		0	
	51 000		25 500	
Outflow				
Danish Straits	(low) 7 000	(high)10 000	7 000	10 000
Net Supply	44 000	41 000	18 500	15 500

Table 4.

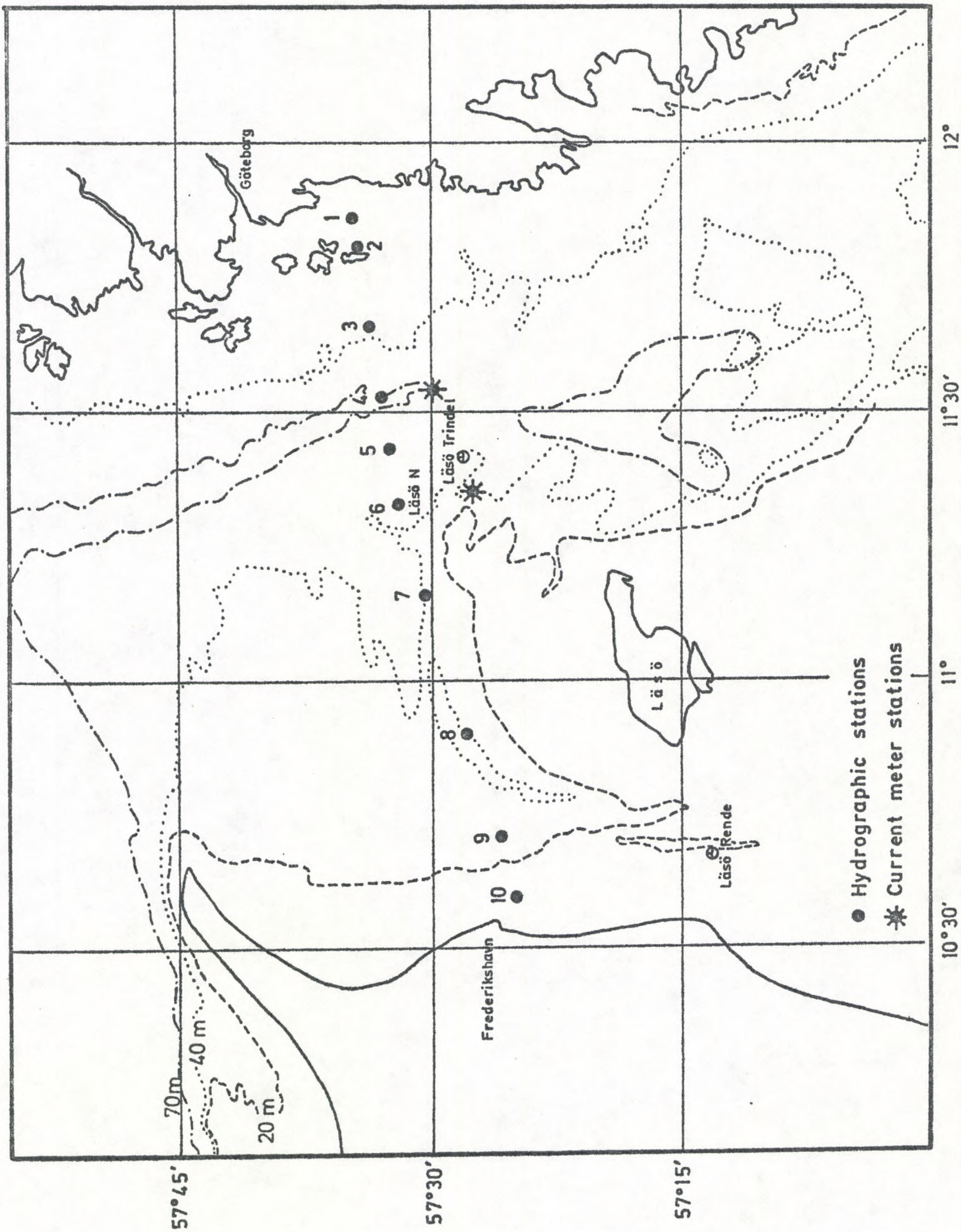
Mean Values of tot P µgat/l (Measured by the National Board of Fisheries 1968-75).

Depth	Ulvö-Deep (GB)	Landsort-Deep (BP)	Gotland-Deep (BP)	Bornholm-Deep (BP)	Landskrona-Deep (S)	Kullen (K)	Fladen (K)	M6 (SK)
0	0.47	0.57	0.46	0.54	0.81	0.80	0.59	0.51
10	0.45	0.54	0.47	0.54	1.24	0.76	0.60	0.56
20	0.41	0.51	0.49	0.53	1.46	1.06	0.59	0.63
30		0.53	0.45	0.56	1.55		0.65	0.74
40	0.35	0.59	0.51	0.56			0.74	0.74
50		0.88	0.53	0.71			0.82	0.76
60	0.40	1.45	0.68	1.07			0.90	
70		2.03	1.29	1.60			0.89	0.82
75								0.82
80	0.50	2.56	2.00	2.45				
90		2.80	2.35	3.20				
100	0.61	2.83	2.34					0.83

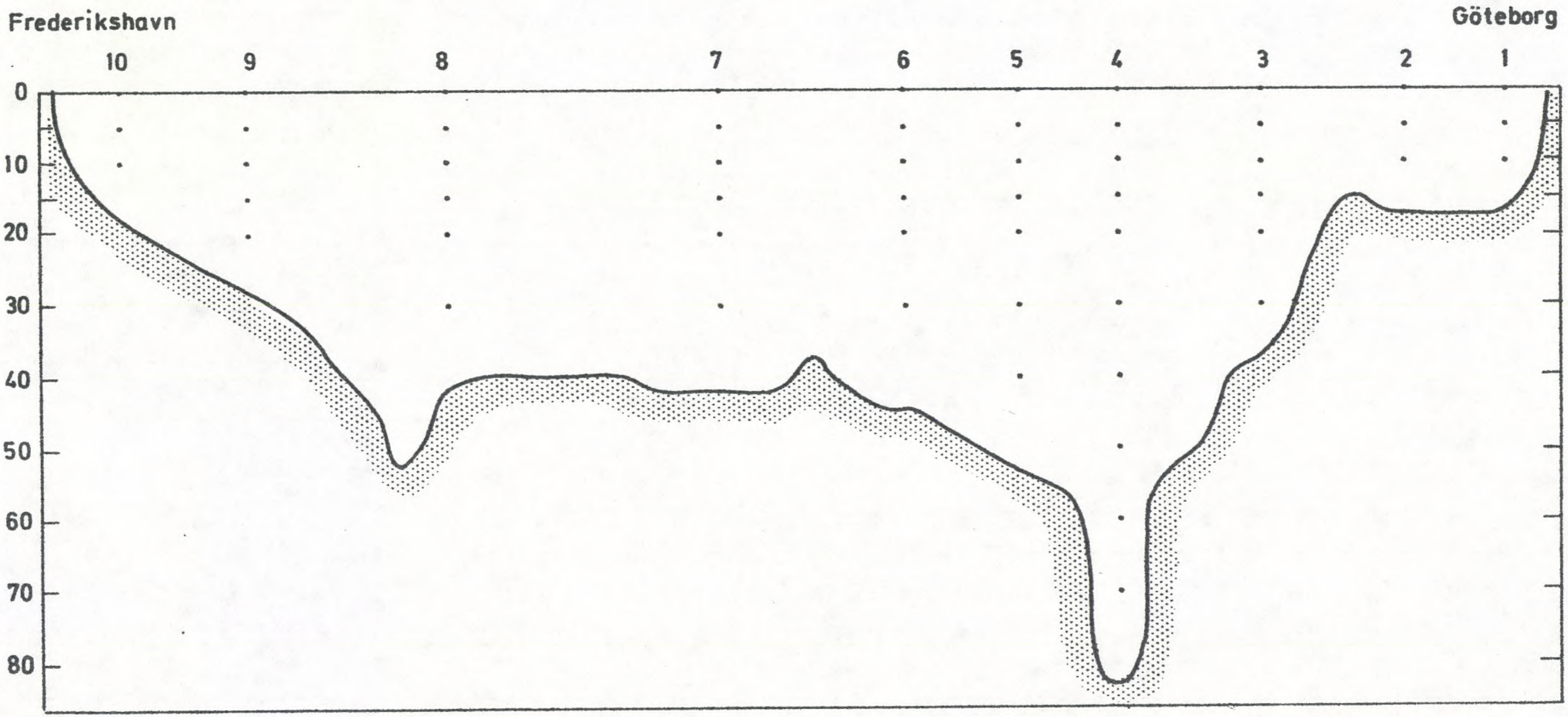
GB = Gulf of Bothnia, BP = Baltic Proper, S = the Sound,
K = Kattegat, SK = Skagerrak

Table 4.

FIG. 1



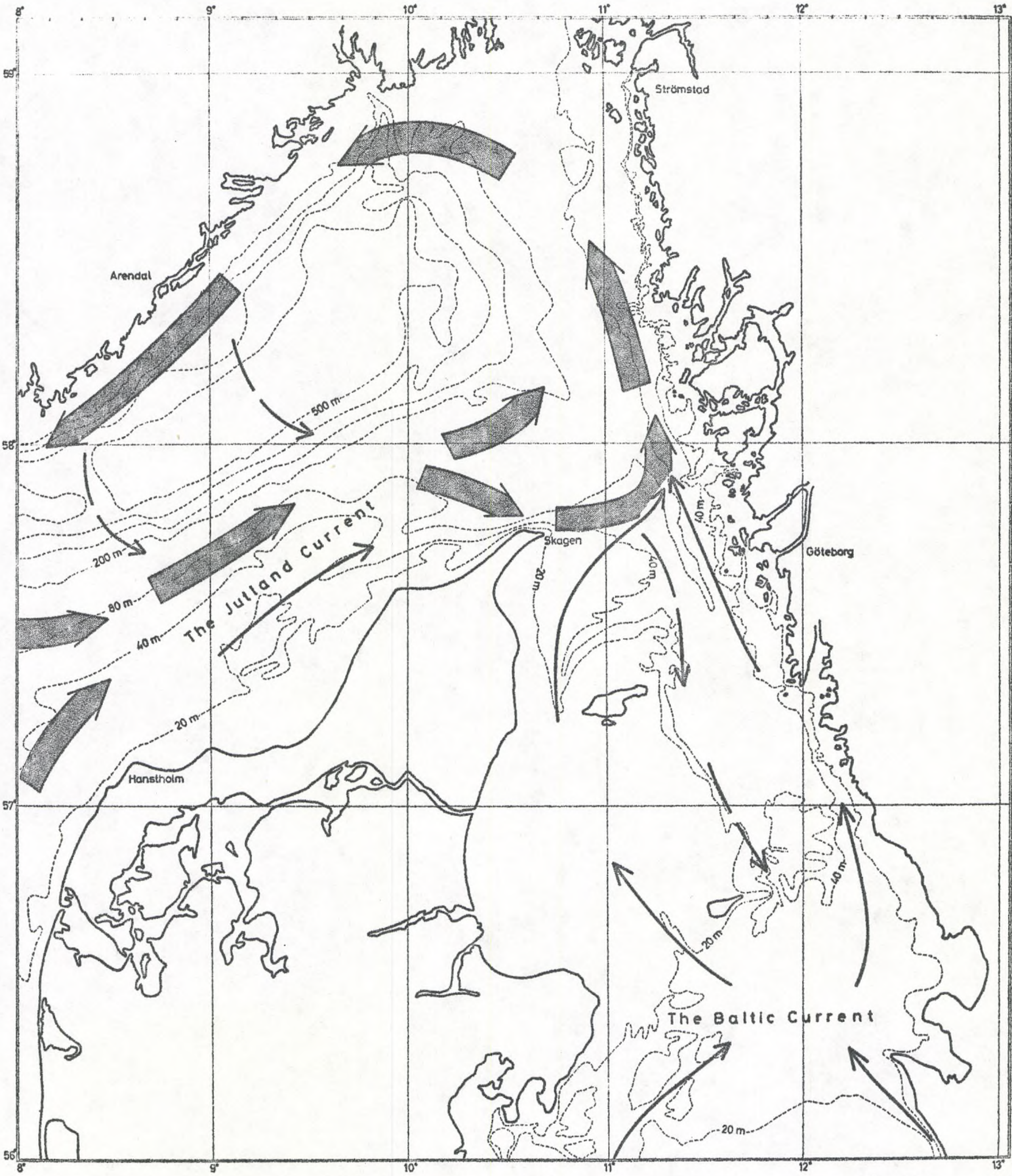
Göteborg
Läsö N
Läsö Trindel
Läsö
Läsö Rende
Frederikshavn
70m
40 m
20 m
Hydrographic stations
Current meter stations
57°45'
57°30'
57°15'
10°30'
11°
11°30'
12°



Topography and sampling points at the Göteborg - Frederikshavn section

FIG. 2

FIG. 3



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GF-SECTION

CURRENT MEASUREMENTS WITH GELATIN PENDULUMS

MEAN VALUES 1975 - 1977

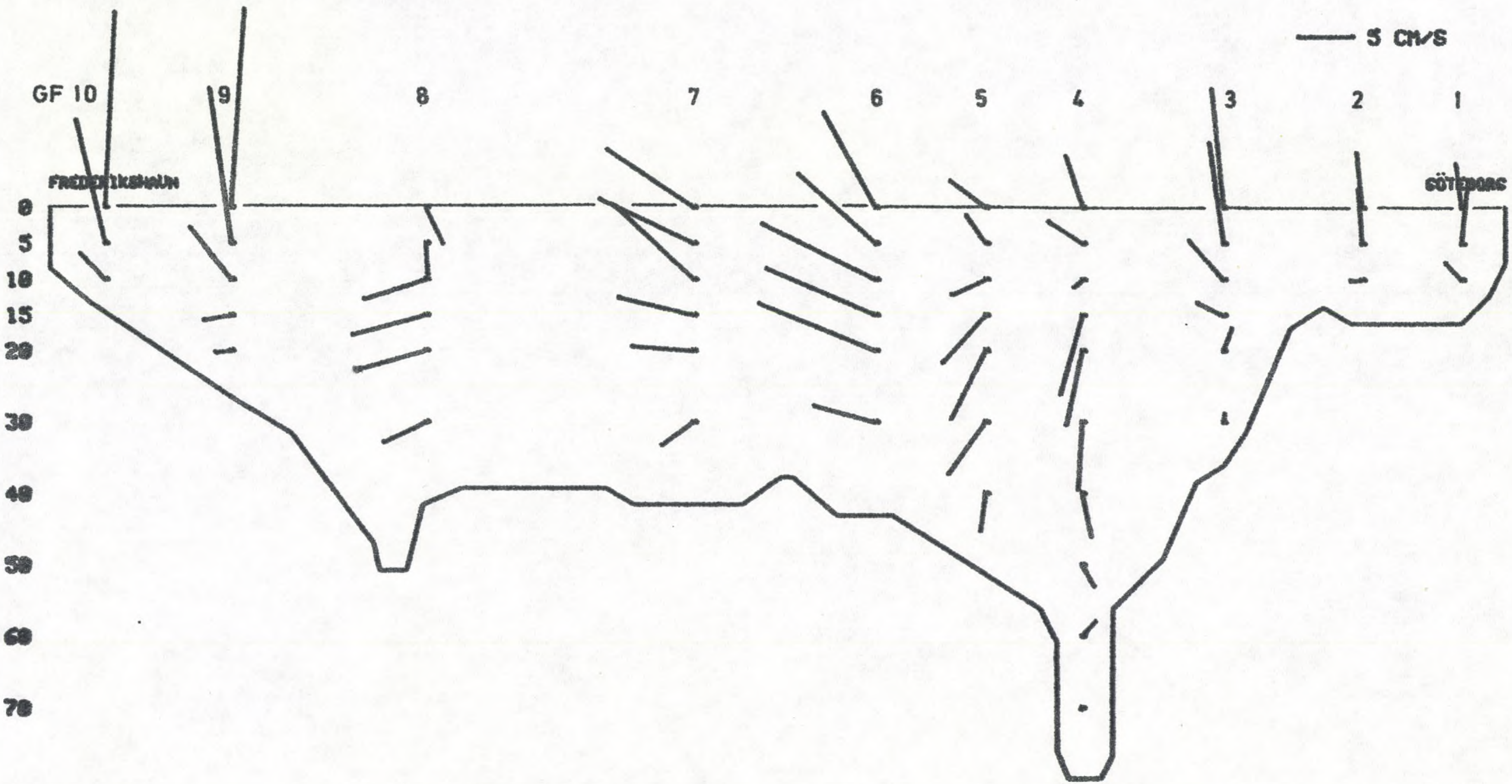
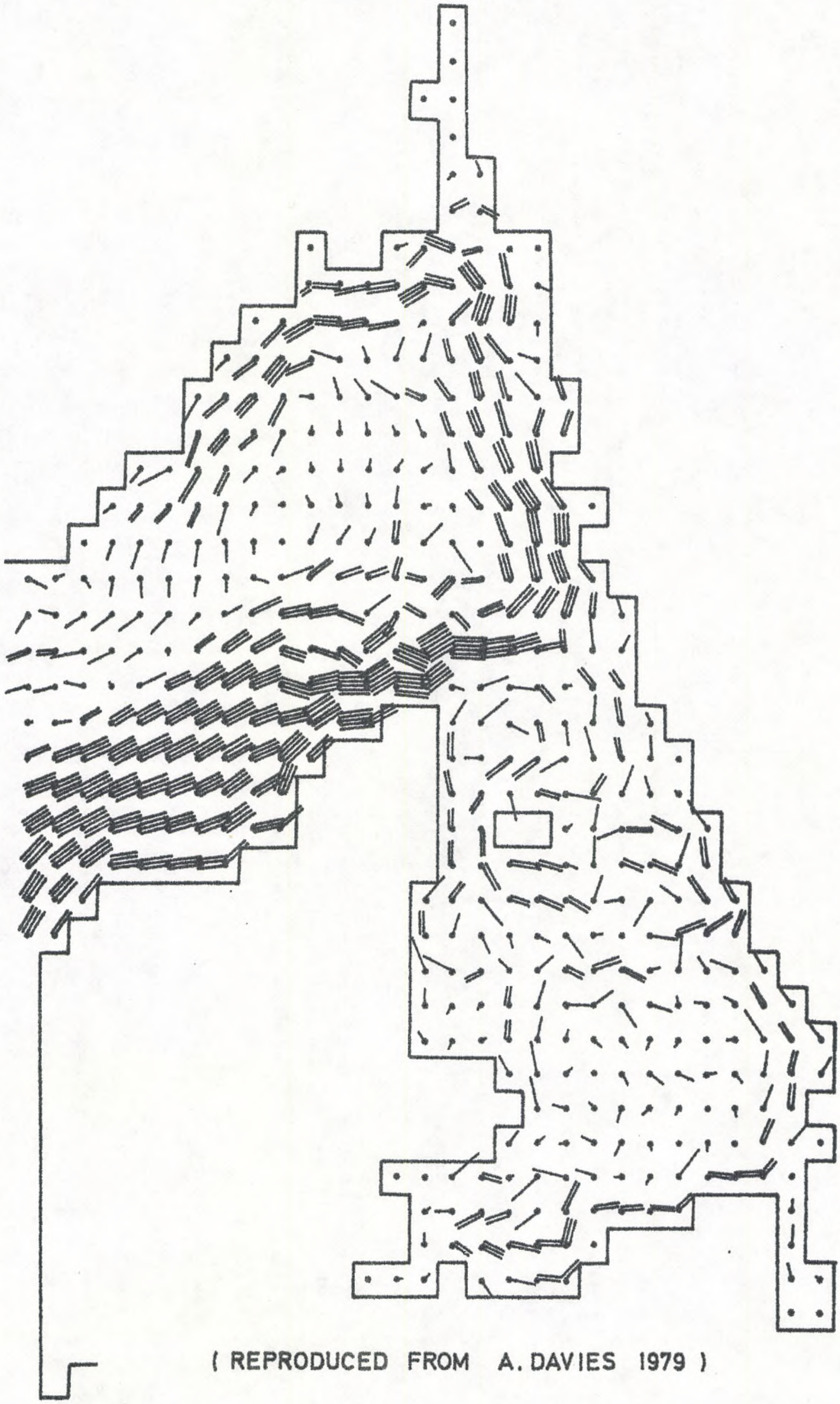


FIG. 4

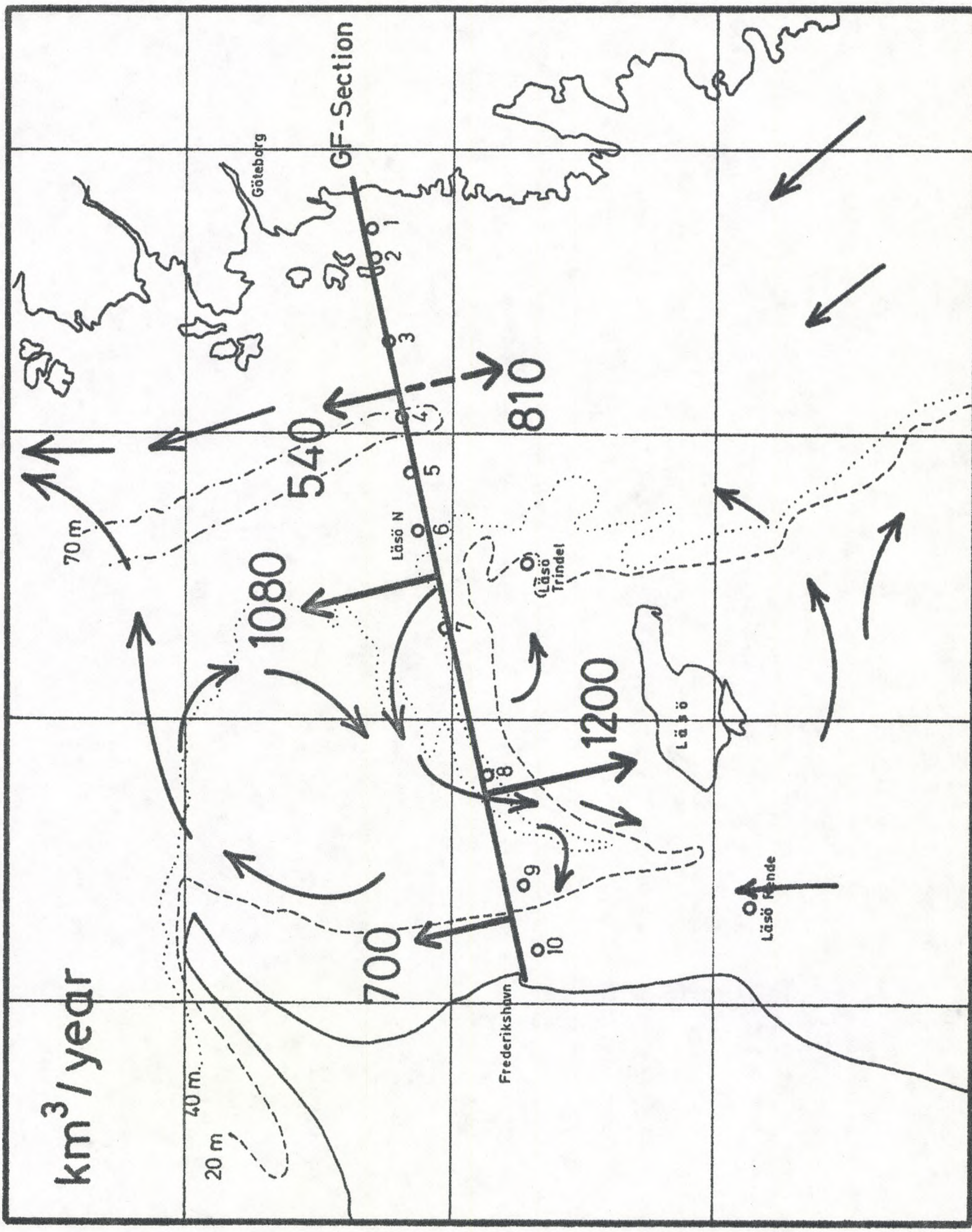
Computed Wind Induced Residual
Currents for the period 76 03 15 – 76 04 15

FIG. 5



(REPRODUCED FROM A. DAVIES 1979)

FIG. 6



Watertransports based on corrected current measurements to bring saltbalance

Temperature t°C 1975 – 1977

Station GF-4

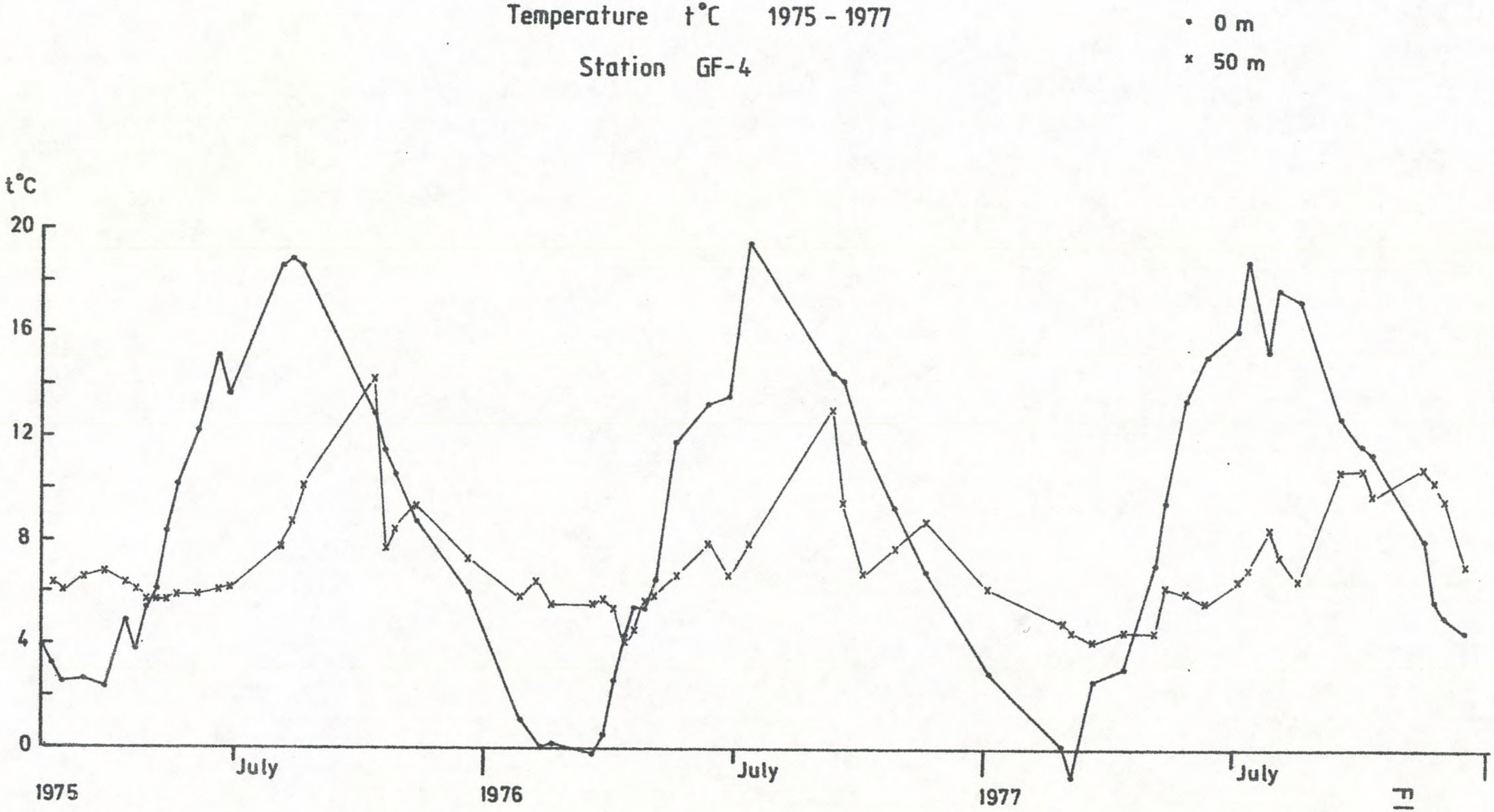


FIG. 7