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International Council for
the Exploration of the Sea

C.M 1978/C:51
Hydrography Committee

IN/OUT-FLOW OF COASTAL WATER IN VESTFJORDEN

by

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Abstract

Hydrographic sections in Vestfjorden, Northern Norway, during winter 1977 showed strong horizontal temperature gradients on the west side of the fjord indicating an outflow of cold coastal water. Analysis of sea thermograph records from the ship route crossing the fjord between Stamsund and Bodø in the years back to 1936 shows that this hydrographic structure is a permanent phenomenon in the wintertime. Mean temperatures along the thermograph section for February, March and April are presented. A method is suggested for the estimation of the residence time of coastal water in the fjord by using data from standard meteorological stations combined with the thermograph data and data from a fixed hydrographic station.

The outflow of coastal water is of vital importance to the transport and mixing of egg and larvae from the cod spawning areas in Lofoten.

Introduction

Vestfjorden in Northern Norway is the most important spawning area for Arcto-Norwegian cod. The fjord is in fact more like an ocean bay, about 50 n.m wide at the mouth. One branch of the Norwegian Coastal Current turns into the fjord on the east side and comes out on the west side. Fig. 1 shows surface currents 19-11 April 1924 based on dynamic computation by Eggvin (1931). The vertical distribution of the hydrographic parameters in the winter is described by EGGVIN (1938, 1939). The upper layer is a more or less homogeneous layer of cold coastal water. The thickness of the layer varies from 30 to 90 m. The warm deep water is of Atlantic origin. The transition layer between the Coastal and Atlantic water has strong temperature gradients.

In connection with cod larvae surveys during winter 1977 in the spawning areas on the west side of the fjord hydrographic sections with stations very close to the shore were taken. The distance between the stations was 0.5 n.m in the near-shore areas. The sections showed egg and larvae concentrated close to the shore. This also corresponded to an area of cold coastal water with strong horizontal temperature gradients (SUNDBY 1977) (Fig. 2). Moored current meter stations confirmed the out-flow of coastal water along a narrow zone on the west side of the fjord.

This led to the examination of thermograph records from the ship route crossing between Stamsund on the west side and Bodø on the east side of the fjord (Fig. 4).

The thermograph recordings were started in 1936 by Jens Eggvin of the Institute of Marine Research. This instrument gives a continuous recording of sea temperature at 4 meters depth with an accuracy of 0.1^{o}C. The recorder is described in detail by EGGVIN (1940).

Horizontal temperature distribution

All thermograph records, in all 420, for February, March and April in the periods 1936-40, 1946-1978 were examined. The temperature at 14 fixed points between Stamsund and Bodø was digitized. Mean values and standard deviation for February, March and April for each year and for the mean year were computed.

Fig. 3 shows the temperature sections for the mean year during the wintermonths. This shows that the cold coastal water is concentrated in a region about 8 n.m. wide on the west side of the fjord with the strongest horizontal gradient in the innermost 5 n.m. in February and March.
The coldest month is March. The decrease in temperature from February to March is greatest in the central part of Vestfjorden, while the increase from March to April is greatest in the nearshore areas. This last effect is due to the fact that the stratification, which is initiated by fresh-water runoff and increasing radiation from the sun, starts in the nearshore areas.

As already mentioned the current meter stations and hydrographic sections from winter 1977 show, together with the thermograph records, that the outflowing cold water is concentrated in the innermost 5-8 n.m. Outside there is most probably an area of weak and variable currents, while the dominating inflow occurs between 15 and 35 n.m. off Stamsund. This circulation is indicated in Fig. 4.

The cooling of the coastal water is caused by meteorological factors, particularly in the inner parts of the fjord, and is not a result of local cooling on the west side. Fig. 5 shows the mean air temperature and cloudiness for the wintermonths for the meteorological stations along the coast of Vestfjorden. In the figure the head of the fjord is indicated by the meteorological station Evenskjær. The lefthand side of the ordinate indicates the distance outwards along the east side of the fjord. The right hand side indicates the distance outwards along the west side. Thus the x-axis from left to right shows how the meteorological parameters vary while following a parcel of Coastal water into the fjord and out of it as indicated in Fig. 4. There is no significant difference between the air temperature on the west side and the east side, but the temperature decreases towards the head. Fig. 5 also shows that the cloudiness and relative humidity are higher on the west side and particularly low in the inner parts on the east side. Thus the result will be that the loss of heat by longwave radiation and evaporation from the surface is less on the west side. This shows that the cooling of the Coastal water starts when it enters the fjord on the east side, and increases towards the head.

As indicated in Fig. 3 the temperature difference between the inflowing and outflowing water is greatest in February. This can be explained by the fact that February has the lowest air temperature of the year, and the temperature of the inflowing water is higher than in March and April. Thus the longwave back radiation from the sea surface and the turbulent flux of sensible heat to the atmosphere is at a maximum.

Exceptions to the normal temperature distribution

Although the temperature structure described above is dominant, there are some few examples of a negative temperature gradient on the west side of the fjord. In these cases the cold water is displaced some miles off the coast as shown in Fig. 6 from

April 1978. The table below shows the frequency of negative mean monthly temperature gradients on the west side for the different months.

	Feb	Mar	Apr
Number of negative mean monthly temperature gradients	0	1	6
Total number of months	36	36	36

Since this situation is most frequent in April, it possibly is due to an early start of the summer heating which is first noticeable in the nearshore areas, but the reason can also be upwelling as was the case in April 1978. Fig. 7 shows a vertical hydrographic section approximately along the thermograph section on April 12 1978 after a 5 day period with southwesterly winds of 10-20 m/s. The wind conditions resulted in upwelling along the west side and brought the cold water masses into the central part of the fjord.

Vertical temperature distribution

The fresh water run-off is very low in the winter. Fig. 8 shows the yearly amplitude of fresh water run-off to one of the fjords in the inner parts of Vestfjorden. Thus the action of forced mixing by wind and free convection by cooling of the sea surface results in a very homogeneous upper layer. This is illustrated in Fig. 9 which shows the temperature and salinity distribution at hydrographic station Skrova (Fig. 4) throughout winter 1978. The homogeneous layer of coastal water is separated from the Atlantic water below by a transition layer with strong gradients. Stratification of the upper layer is not detectable before the end of May.

Residence time

It is possible to estimate the residence time of coastal water inside a line from Bodø to Stamsund using the following assumptions:

i) homogeneous upper layer
ii) horizontal circulation as indicated in Fig. 4.

The residence time, D, is given by

$$D = \rho_c K \frac{\Delta T\ h}{Q_c}$$

where

ΔT : mean temperature difference between the inflowing and outflowing water
h : depth of the homogeneous coastal water
Q_c : total loss of heat per unit area per unit time from the coastal water behind the Bodø-Stamsund line
K : specific heat of the coastal water
ρ_c : density of the coastal water

Q_c can be expressed by

$$Q_c = Q_S - Q_R + Q_{L1} - Q_{L2} - Q_E - Q_H + Q_A$$

where

Q_S : shortwave radiation from the sun
Q_R : shortwave back radiation from the sea surface
Q_{L1}: longwave radiation from the atmosphere
Q_{L2}: longwave back radiation from the sea surface
Q_E : loss of heat by evaporation from the sea surface
Q_H : turbulent flux of sensible heat from the sea surface
Q_A : turbulent flux of heat from the Atlantic water to the Coastal water

Q_A is neglected. Estimates of the other terms on the righthand side of this equation are made by using observations of air temperature, cloudiness, relative humidity and wind speed from standard meteorological stations together with observations of sea surface temperature.

Table 1 gives mean monthly values of the residence time for the last four years based on the equations above. This agrees well with drift measurements and current meter station measurements.

The estimates are relatively rough. The residence time is particularly sensitive to variations in Δ T and h, and further efforts will be made to obtain better estimates of these parameters.

Table 1. Residence time in days.

	1975	1976	1977	1978
FEB	10.8	7.1	13.1	10.8
MAR	10.4	7.3	11.6	11.3
APR	15.0	12.6	16.7	10.5

The residence time seems to be longer in April than in the previous two months. This is possibly a result of decreasing wind activity in April. In February and March, in particular, the drainage of cold air from the landmasses around Vestfjorden and into the fjord is dominant. Thus the wind conditions, together with the Coriolis force may be an important factor in maintaining the circulations in the fjord.

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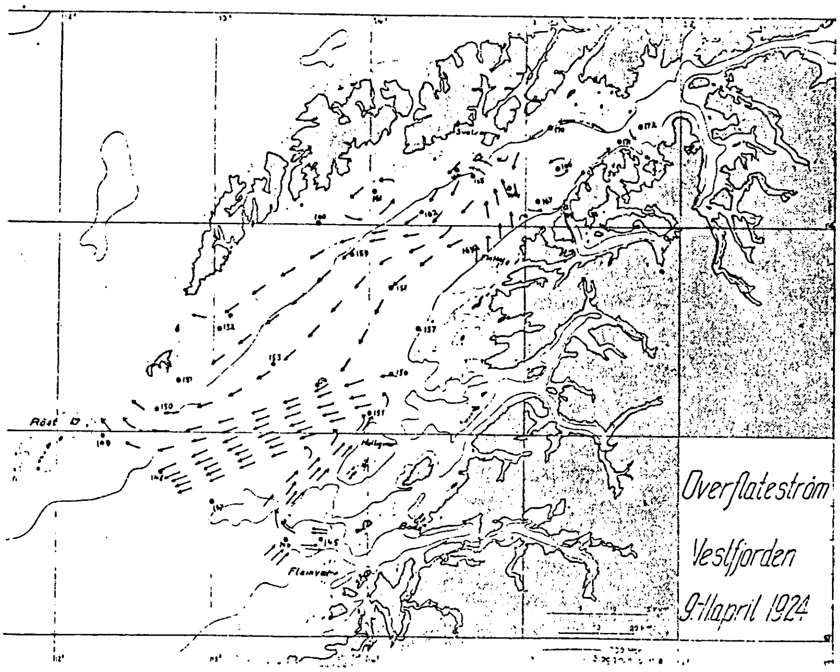


Fig. 1. Surface current in Vestfjorden.
After Eggvin 1931.

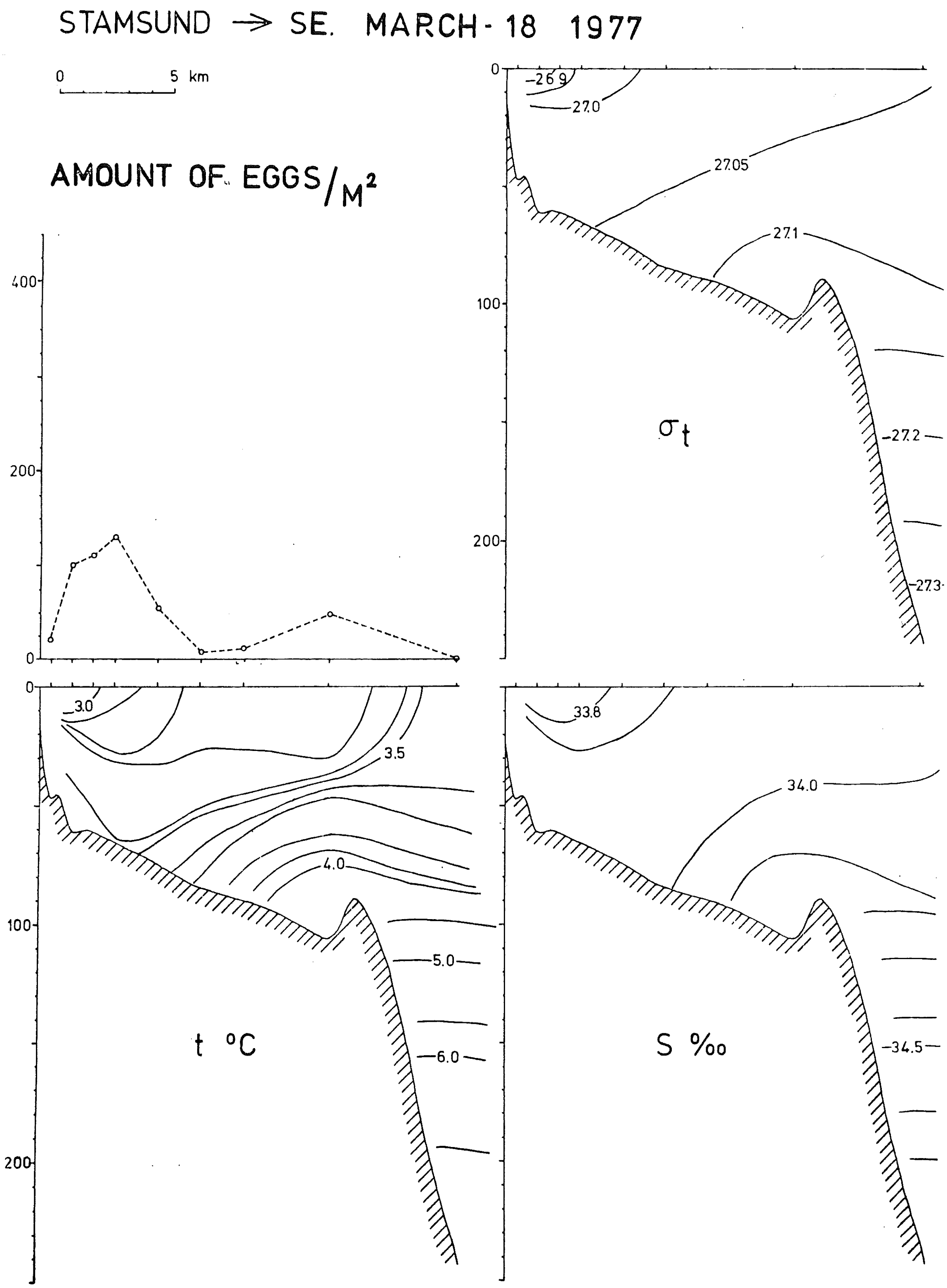


Fig. 2. Hydrographic section from the west side of the fjord.

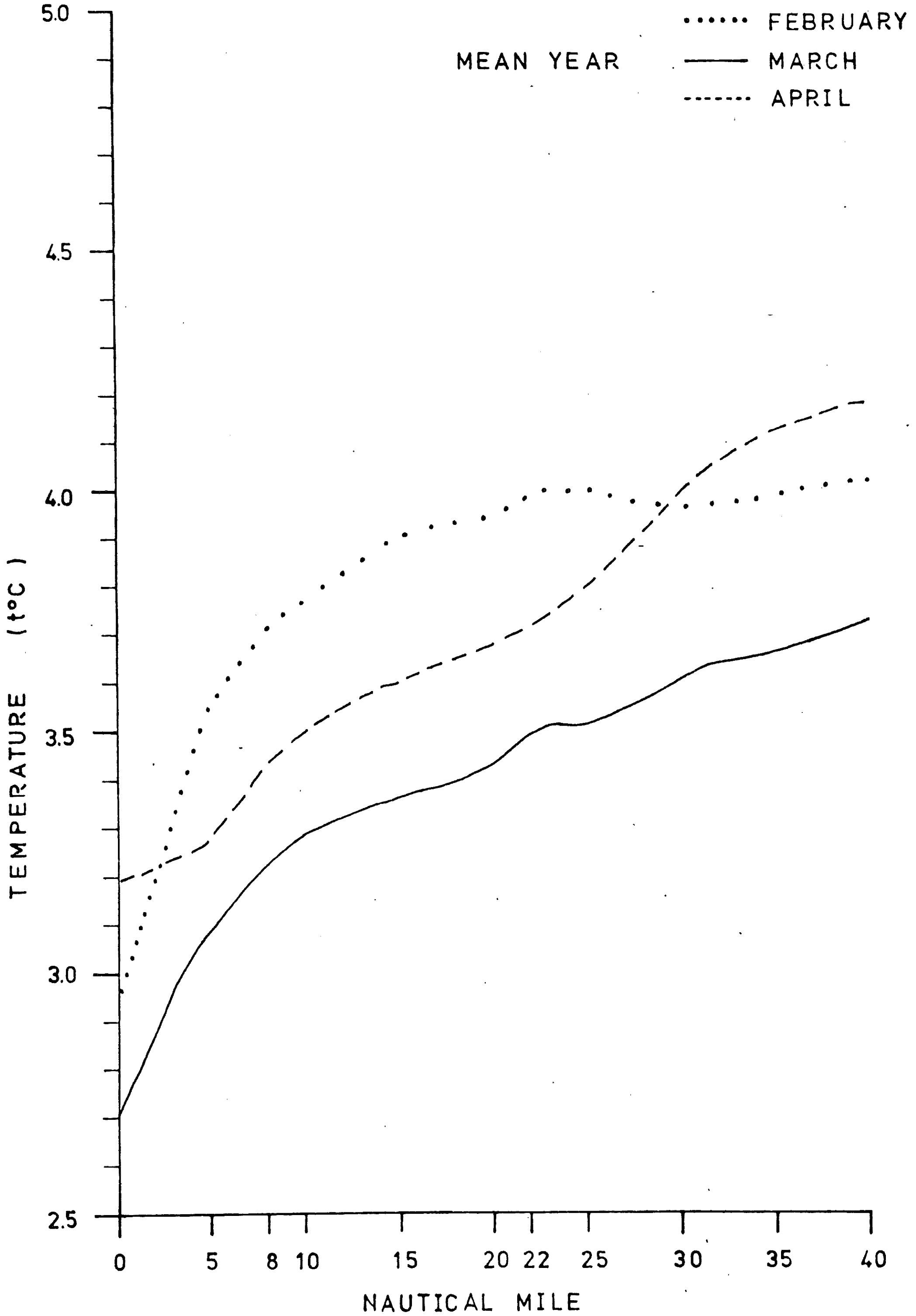


Fig. 3. Sea temperature 4 m depth along the ship route Stamsund - Bodø.

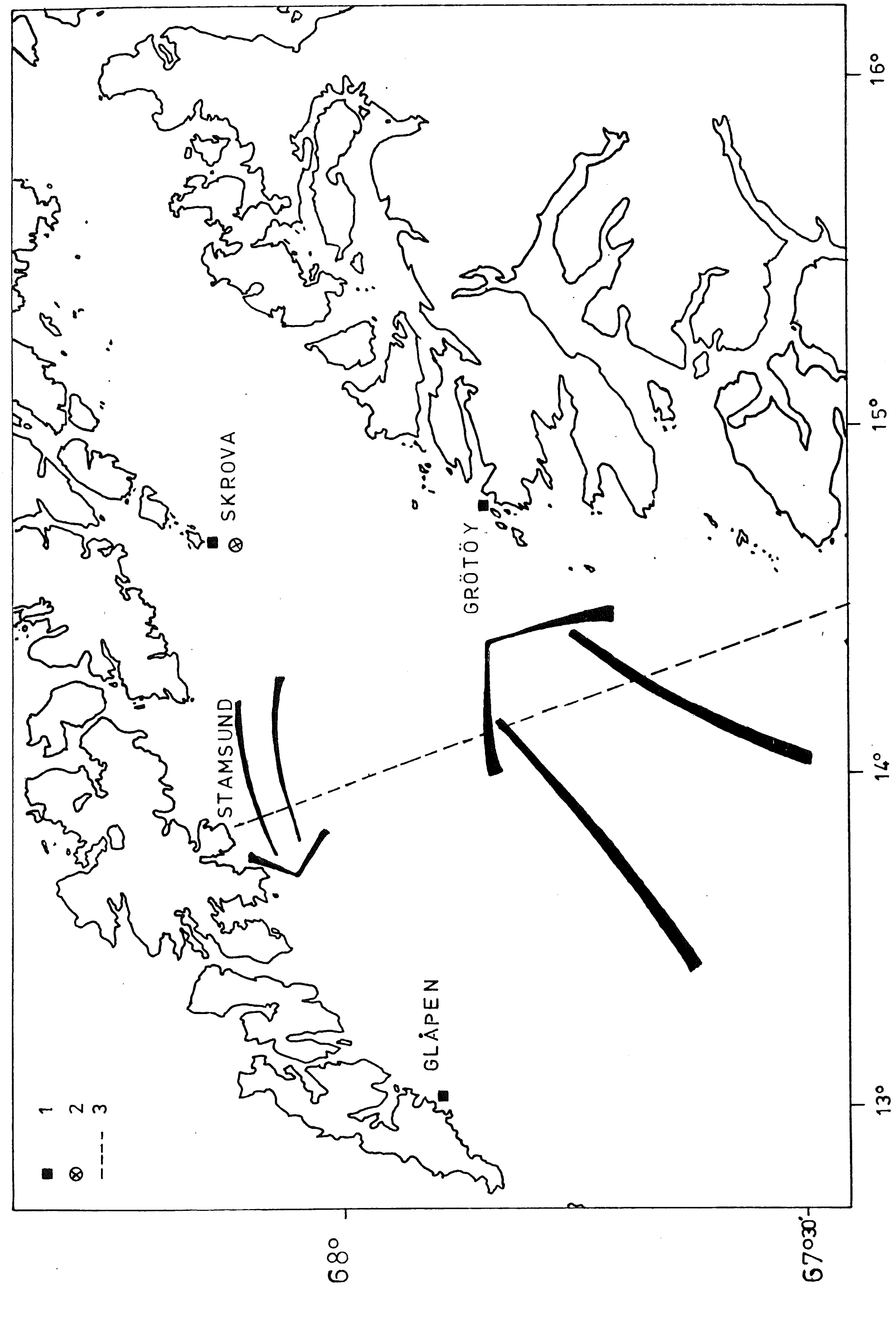


Fig. 4. 1. Meteorological station.
2. Hydrographic station.
3. Thermograph section.

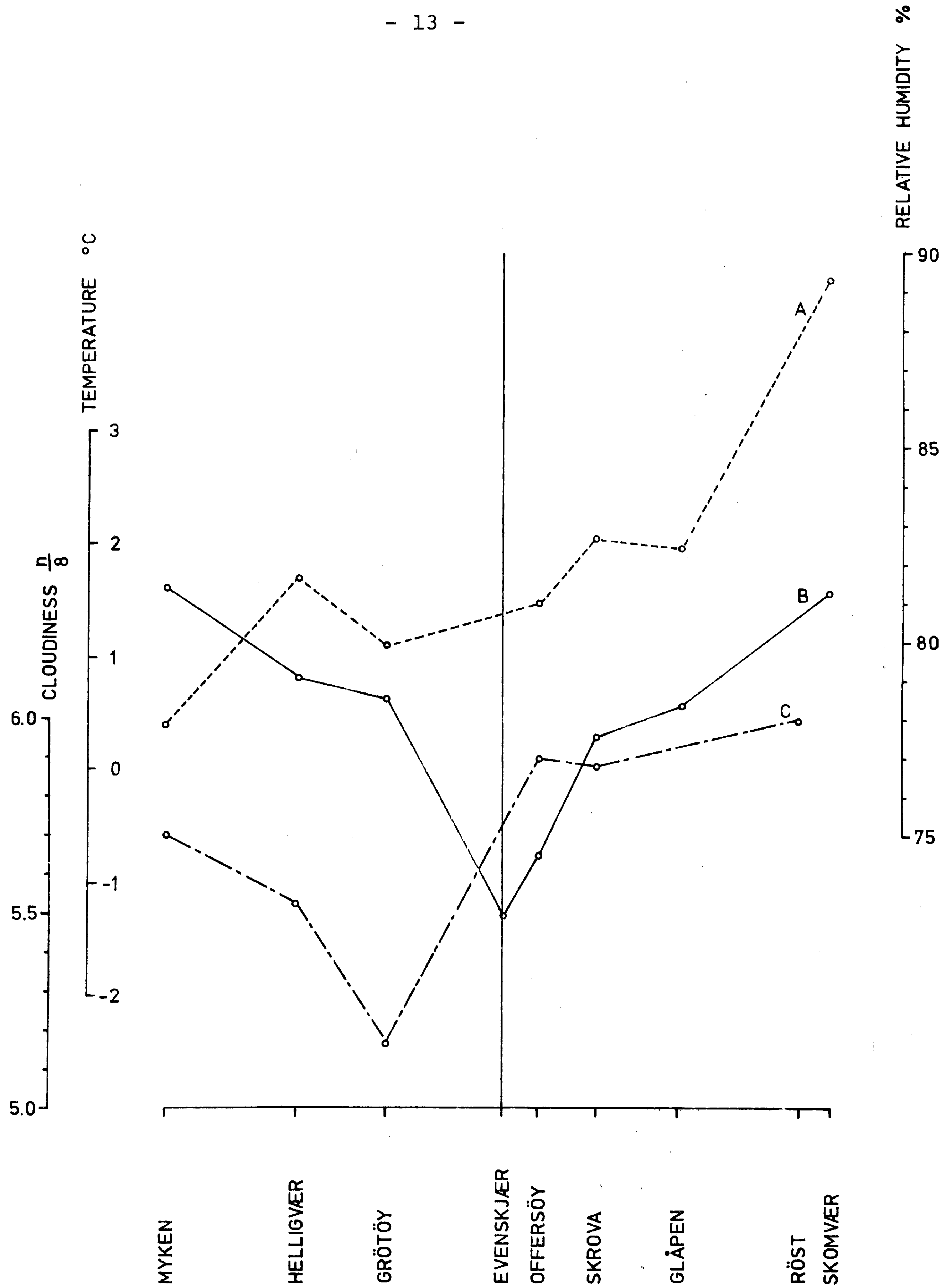


Fig. 5. Relative humidity A, air temperature B, and cloudiness C for the mean year 1931-60 at meteorological stations around Vestfjorden.

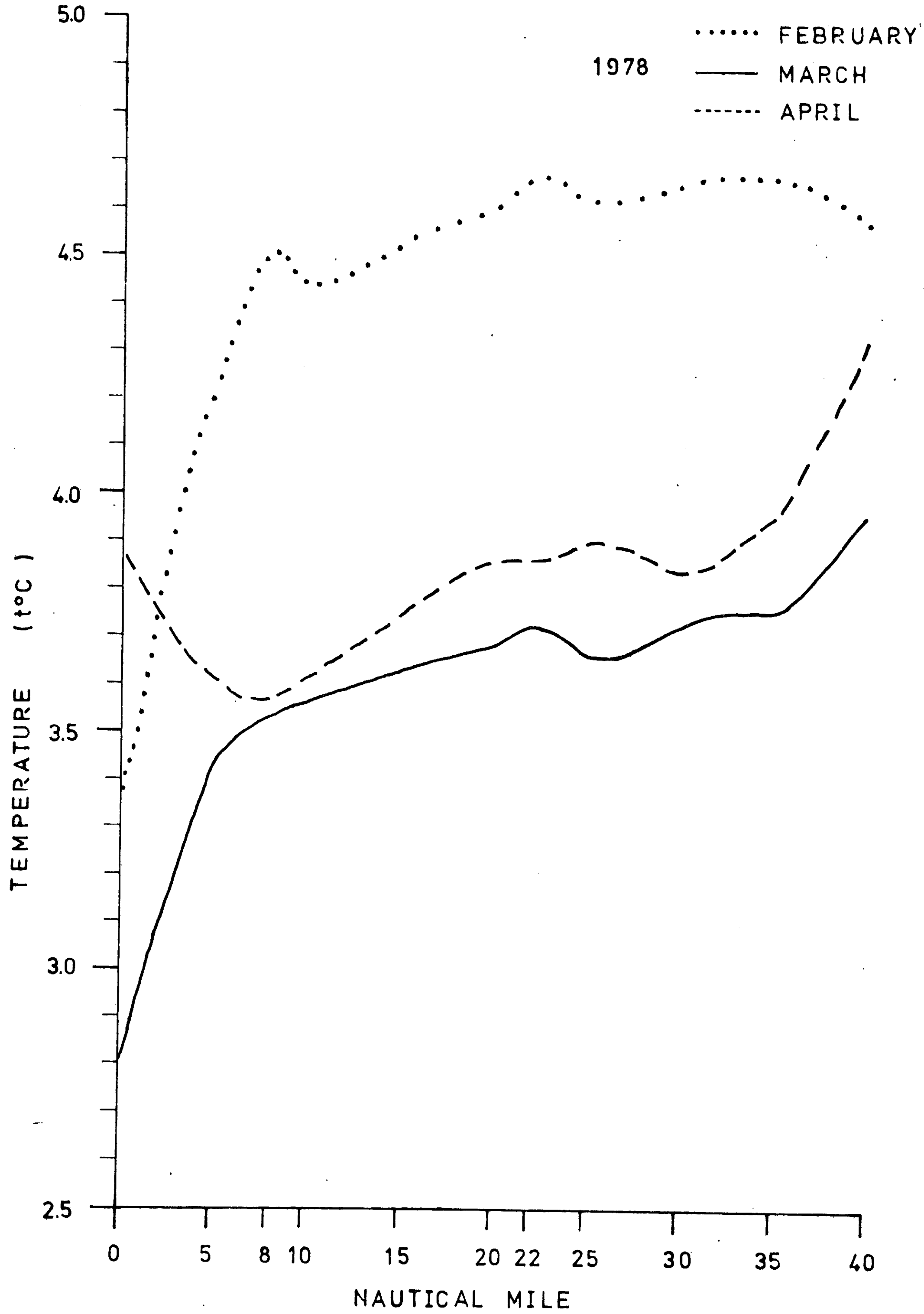


Fig. 6. Sea temperature 4 m depth along the ship route Stamsund - Bodø.1978.

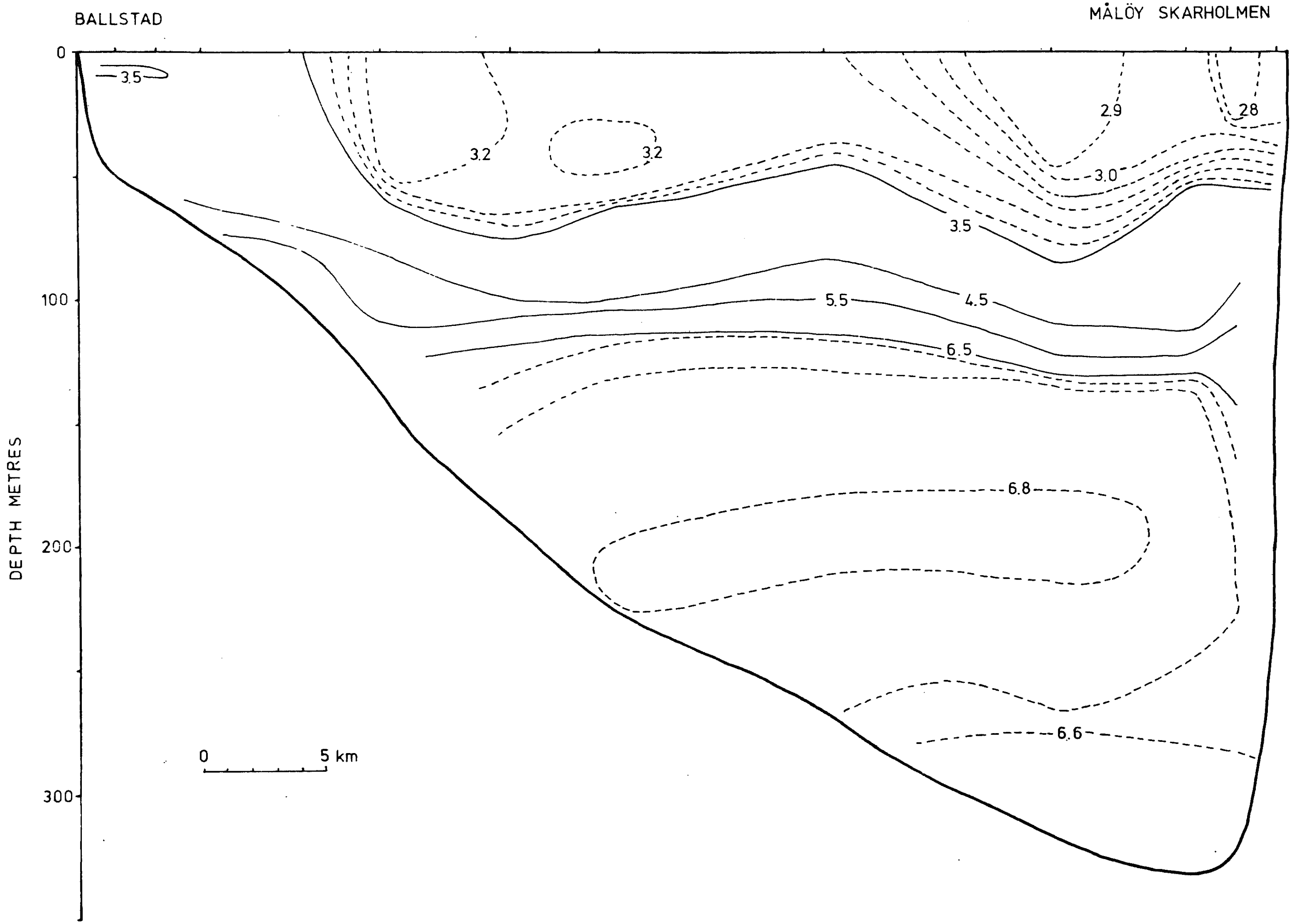


Fig. 7. Temperature in the section Ballstad - Måløy / Skarholmen
April 12 1978.

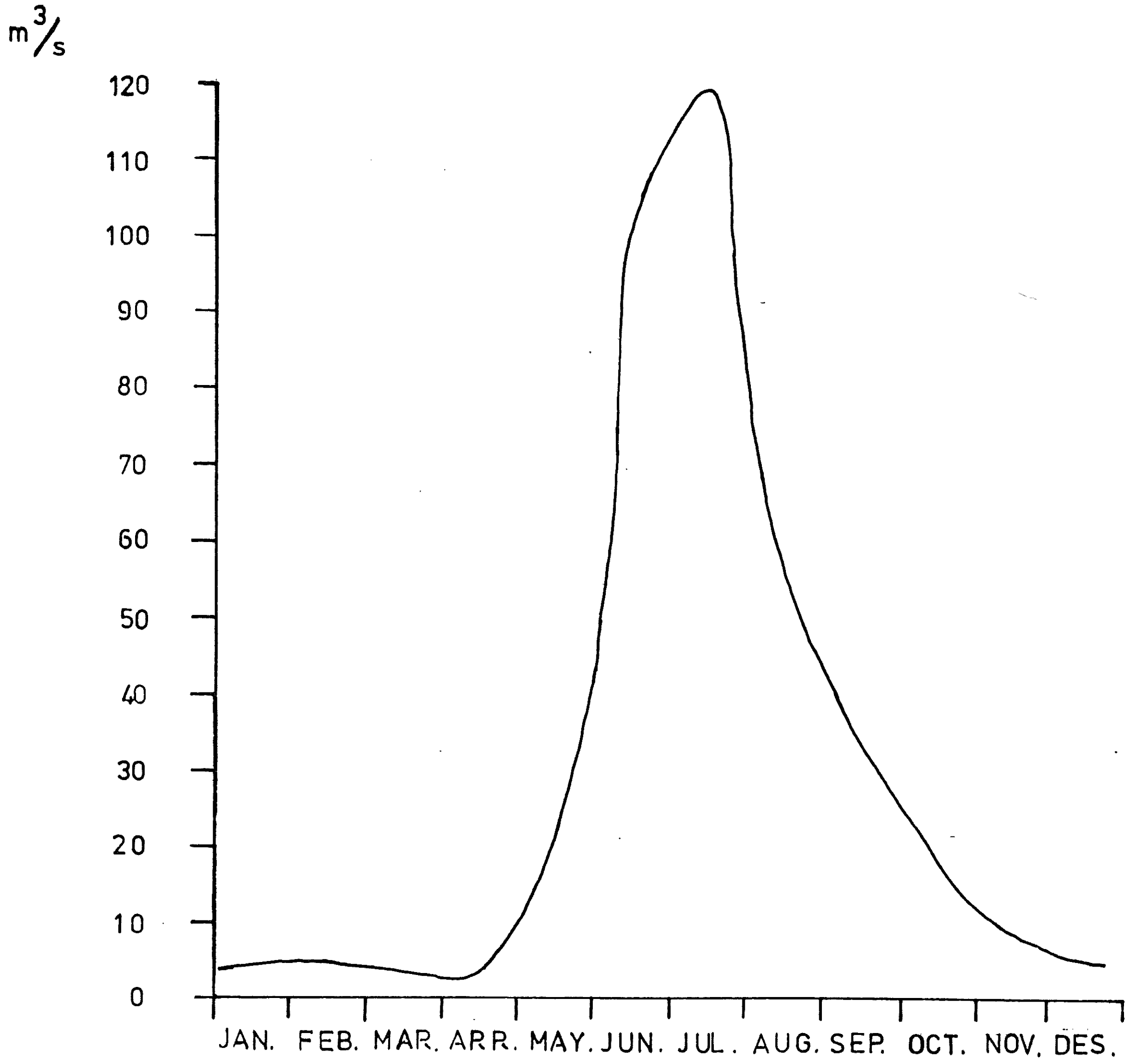
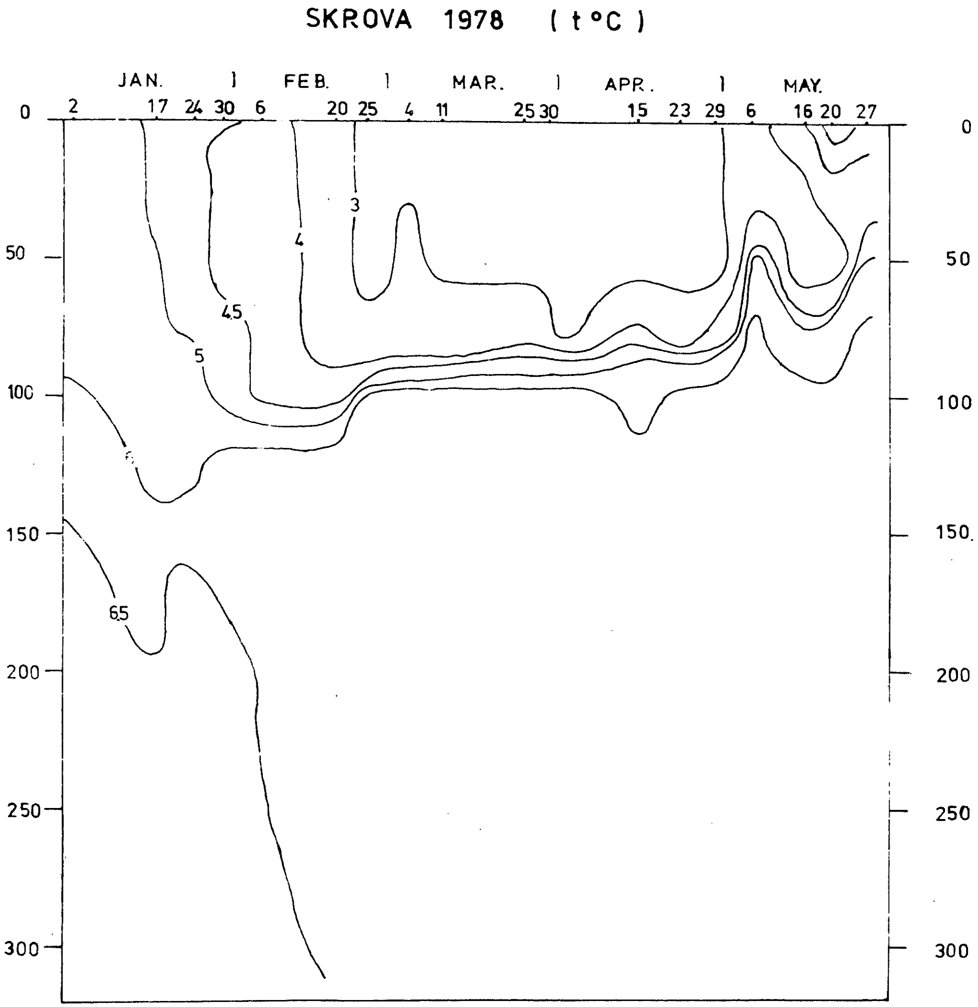


Fig. 8. Fresh water runoff to Skjomen Fjord. Mean year.



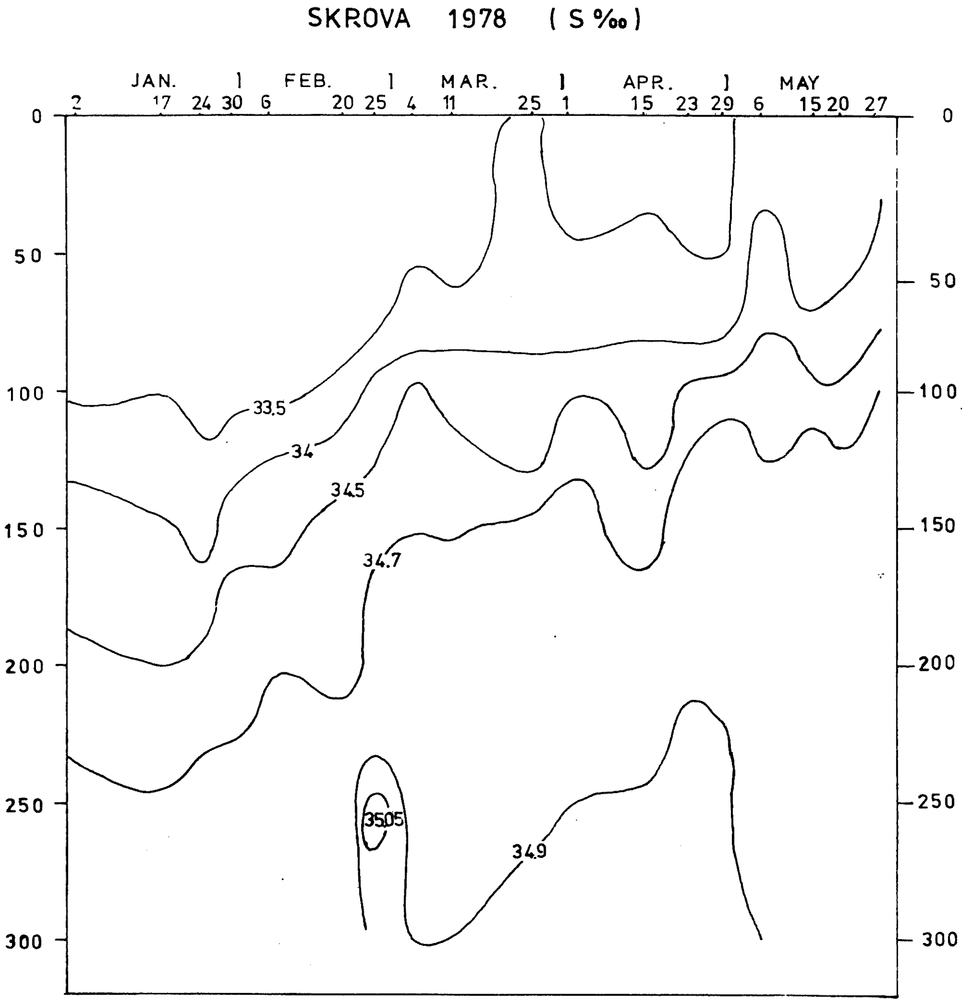


Fig. 9. Salinity and temperature from hydrographic station Skrova.