PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

THE NORWEGIAN COASTAL CURRENT.

R. Sætre and R. Ljøen Institute of Marine Research Bergen, Norway

Introduction.

The first general view of the Norwegian Coastal Current was presented in 1909 by Helland-Hansen and Nansen. (6). Since then several observations and some publications concerning this current have appeared. The current has obtained increased interest in the last years as its importance in the recruitment mechanism of fish stocks has been better understood, and as the problem of pollution has grown. It is the aim of this lecture to give a very brief review of some main features concerning the Norwegian Coastal Current.

One of the most conspicious features of a coastal current at higher latitudes is its inclined boundary surface towards the surrounding water masses. The light coastal water will spread out in a wedgeform above the heavier underlaying water as seen in Fig. 1. The boundary surface will be a discontinuity surface for most of the oceanographic parameters.

Given certain assumptions the slope angle of the boundary surface can be expressed as seen from the following equation:

$$\tan \gamma = \frac{f(\rho_2 v_2 - \rho_1 v_1)}{g(\rho_2 - \rho_1)} + \frac{\rho_2 v_2^2 - \rho_1 v_1^2}{R \cdot g(\rho_2 - \rho_1)} \qquad (1)$$

Here f is the Coriolis parameter, v_1, ρ_1 and v_2, ρ_2 are the velocity and density of the upper and lower layers respectively, g is the gravitation constant and R the radius of the curved trajectories. If straight trajectories are presupposed, R will be infinite and the last term of the equation can be ommitted.

As seen from equation (1) variations in the density difference between the two water masses will result in variations of the slope angle γ . Along the Norwegian coast considerable fluctuations in the slope angle are due to density variations in the coastal water.

Variability in the inclination of the boundary surface can also be attributed to changes in the relative velocity between the two water masses.

Vortices with vertical axes are likely to occur along a boundary surface. In this case the water masses will be subject to centrifugal forces in addition to gradient -and Coriolis forces. As seen from the last term of equation (1) this will result in modifications of the slope angle.

The material.

The positions of the observations dealt with are shown in Fig. 2. Since 1936 the surface temperature and salinity has been observed at fixed positions along the Norwegian coast. A mean year of temperature and salinity as well as standard deviation for some of these positions have been published by L. Midttun. (12).

In the deeper layer along the coast the hydrographic conditions have been observed by means of several fixed oceanographic stations since 1935. These observations are now being worked on. In order to elucidate the temperature variations in the subsurface layers a mean year has been computed for four of these stations. That is Utsira 1946-1965, Sognesjøen and Eggum 1935-1943 and Ingøy 1936-1943.

Along the route Bergen-Newcastle a 10 years mean of the salinity for the period 1960-1970 have been worked out. A brief analysis of the current measurements along the coast of Norway has been carried out in addition to those already published (5, 6, 7, 9, 13).

Observations and results from previous investigations are used and to some extent more recent hydrographic material.

General description of the coastal current.

The most conspicious feature of the bathymetric conditions along the coast is the Norwegian channel, the depth of which exceeds 700 m in the Skagerrak, and the extensive continental shelf between Stad and Eggum. This shelf consists of several shallow banks separated by deeper channels which probably act as a propagation way for Atlantic waters towards the Norwegian coast. Outside Finnmark the ocean is shallow.

As seen in Fig. 3 two water masses are dominating along the coast of Norway, namely the Atlantic water and the coastal water. According to a general accepted definition, water of salinity above 35‰ is designated Atlantic water and that of salinity below 35‰ coastal water.

The Atlantic water enters the Norwegian Sea through the Faeroe-Shetland Channel. The movement of this water mass is mainly based on the map of A.P.Alekseev and B.V. Istoshin. (1). The Norwegian Coastal Current is a continuation of the Baltic Current and the map shows the most probable movement of the upper layer of this water in summer. This season has been chosen as most of the observations are referred to this time. The main features of the map are probably also representative for the winter situation.

The surplus of fresh water carried out from the Baltic is on average approximately $15 \cdot 10^4 m^3 \cdot sec^{-1}$ (2), and the fresh water run-off along the coast of Norway amounts to about $12 \cdot 10^4 m^3 \cdot sec^{-1}$ (14). This fresh water will mix with Atlantic and North Sea water to form the Norwegian Coastal Current. Calculations of the volume transport in the coastal current are few, but at the southern coast $0.5 \cdot 10^6 m^3 \cdot sec^{-1}$ (8) seems to be a reasonable estimate for the summer months.

The current velocity of the coastal water can reach considerable values. Off the southern and southwestern coast velocities exceeding 100 cm $\cdot$ sec^{-1} are frequently observed. The residual current along the coast varies between 15 and 40 cm $\cdot$ sec^{-1}.

The zone of maximum velocity usually occurs at some distance from the coast except off Bergen and Ingøy where the maximum velocities are found close to the coast. The highest current velocities usually are found at the surface and decrease with increasing depth. Along the most northern coast it seems that maximum current velocity occurs in about 50 m.

Ocean currents at higher latitudes will have a tendency to follow the bathymetric curves and this quality will increase with increasing latitude. The apparent splitting up in branches of the coastal current is most likely due to a bathymetric effect. There seems to be a dividing of the current north of Stad where the western branch gradually looses its characteritics due to mixing with the surrounding Atlantic water. (11). South of Lofoten another splitting-up seems to appear.

Fig. 4 shows the seasonal maximum and minimum in temperature and salinity in the surface layer along the coast. As seen from the upper part of the figure the maximum temperature decreases northward. The minimum temperature has its highest value off Møre. This is due to the fact that Møre is the area of the first contact between the Atlantic water and that of the coast. Due to intensive vertical and lateral mixing with the Atlantic water, the salinity of the coastal water will increase along the route of the current as seen from the lower part of Fig. 4. At the southeastern part of the coast the salinity is mostly below 30‰ and at the coast of Finnmark it reaches a value of about 34‰.

The mixing between the Atlantic and the coastal water along the western and northern coast will reduce the density difference between the two water masses, resulting in a reduction of the stability. The termohaline strucure thus created will prevent ice formation in northern Norway.

Variations.

The dynamic field of the coastal current can be considered as consisting of two parts. The first one is the stationary or quasi-stationary part just described. The second is the field of variations which is superposed on the first one. The field of variations can be divided into three main parts:

a) Short-term variations
b) Seasonal variations
c) Long-term variations

The short-term variations are detectable in temperature, salinity, current velocity and direction, the slope of the boundary surface and the lateral extension of the coastal water. The main causes of these fluctuations are variations in the air/sea energy exchange, in discharge of fresh water, vorticies and meteorological factors. The greatest variations are most likely due to changes in the atmospheric pressure field.

Fig. 5 shows the maximum and minimum standard deviation in surface temperature and salinity along the coast. The maximum values of standard deviation are found in summer and minimum in winter. This parameter can be considered as measurement of the magnitude of the short-term variations. As seen from the upper part of the figure there is a maximum temperature deviation in summer off Jæren. This is most likely due to local wind conditions. In winter the values decrease along the coast. The standard deviation in salinity however, decreases along the coast both in summer and in winter.

An analysis of the effect of wind at the coastal current will be presented to this conference by R. Ljøen. (10).

A seaward displacement of the coastal water can also be attributed to factors other than wind. Fig. 6 shows salinity variations at an anchor station in the Atlantic water, west of Stadt as reported by R. Leinebø. (9). The station was occupied during 8 days under favourable weather conditions in August 1969. We see "dots" of coastal water passing the station at August 1st. This is probably due to a vortice propagating seawards.

Coastal water has for some years been observed at Ocean Weather Station M situated about 250 n.miles from the coast of Norway. (4). If this represents a contiuous layer of coastal water or only loose "dots" is not known.

Seasonal variations.

The average seasonal variation in temperature and salinity at the surface along the coast of Norway is visualized in Fig. 7. The time for occurrence of the temperature extremes is delayed along the coast as can be seen in fig. 7. At Færder on the southeastern coast, maximum temperature occurs July 25th, and at Vardø August 25th. The time of minimum temperature will be delayed by approximately one month from February 25th to March 25th.

The yearly temperature curves appear to be assymmetric as the time of cooling is longer then the time of heating. If the average slope angle during the heating period is designated α_s and that of the cooling period α_a then $\beta = \frac{\tan \alpha_s}{\tan \alpha_a}$ is a measure of this assymmetry. As seen from Fig. 7 the value of β has its minimum at Stadt and increases both northward and soutward. This distribution is probably linked to the incoming Atlantic water as mentioned earlier. The maximum salinity along the coast is found in winter. The time of this maximum is delayed about three months from south to north. The minimum salinity is found in summer from June to September, and is mainly due to maximum run-off of fresh water at that time. At Jæren there seems to be two salinity minimums. We will return to this later.

The seasonal variation of the surface salinity along the shipping route Bergen-Newcastle is presented in Fig. 8. A horizontal displacement of the coastal water is obvious. The coastal water has its most seaward extension during the summer. If water of salinity below 34‰ is designated coastal water, the seaward extension of this in summer is approximately 50n.miles more than in winter. The density of the coastal water is low during summer due to heating and low salinity. The water therefore spreads out in a broader and thinner wedge in summer. For the same reason the boundary surface given by a certain isohaline will reach higher in the sea during the summer. This effect is quite marked along the western coast. Due to lack of data we are not able to analyse the lateral movement in detail, but it is generally supposed to be less pronounced in northern Norway.

There appears to be two salinity minimums along the southern coast, one in May-June and an other in September. As maximum discharge of fresh water from the rivers occurs in June and the double minimum is not noticeable north of Stad, it seems reasonable to attribute this phenomenon to variations in the out-flow form the Baltic. Investigation of the seasonal variation of this out-flow shows a marked retardation of the outgoing water in June and July. There is a maximum out-flow in May and in August-September. (15).

It is a well known fact that the yearly amplitude of the sea temperature is decreasing with increasing depth, and that the occurrence of the yearly periodic extremes is delayed with depth. The progation time of the extreme values is a function of stability. As seen from Fig. 9 the progagation time of the periodic extremes down to 200 m is decreasing northward.

The lower part of Fig. 9 shows the yearly amplitude in the subsurface layer. In the upper 50 m the yearly amplitude is decreasing northward. In the deeper layer below 200 m the opposite seems to be the case.

In the summermonths there is a water exchange between the fjords and the water outside the sill. Fig. 10 is an attempt to elucidate this. The river discharge of fresh water will move out of the fjord and gradually mix with the under-laying water. The transport of salt from the fjord has to be compensated by an undercurrent bringing coastal water into the fjord. This is the so-called estuarine circulations.

As previously mentioned elevation of the boundary surface in summer will also give possibilities of the renewal of deep water. On some of the fjords such renewal of deep water occurs annual and in others more intermittent. This depends on the sill depth.

Long-term variations.

In order to study the long-term variation consecutive annual means of temperature have been computed for the stations along the coast and is presented in Fig. 11. By this procedure the seasonal fluctuation is eliminated. As seen from this figure the annual mean temperature is subject to rather great variations. It is striking that such a high degree of conformity exists between the different localities. The same method has been applied with data from Ocean Weather Station M situated in the Norwegian Atlantic Current and with data from the Kola section in the Barent Sea. The main feature of the variations from all the localities is the same. Even in the Byfjord at Bergen the same feature is noticeable.

It seems to be an obvious conclusion that the sea surface temperature is influenced by the general atmospheric circulation. An investigation of the relationship between the water temperature north of Norway and the most probable causal factors in the heat budget indicate that the dominant causal factor appears to be the horizontal advection of heat. (3). At particular times during the year other factors become of great importance. Cloud amount and wind velocity show particularly high negative correlation with water temperature in summer, whilst air temperature and cloud amount show similarly high positive correlation with the water temperature in winter.

The causal relation between the water temperature and the meteorological conditions is probably very complicated. There is also a possibility of an external factor influencing both the atmospheric and oceanic circulations.

Relation to biology.

The reaction of fish distribution and behaviour on variation in the physical environment of the coastal current is various and not fully understood. However, as a "highway" for eggs and larvae from spawning grounds to feeding areas the current's role is undoubted. Various commercial important fish species have their spawning grounds along the coast and successful spawning and hatching partly depends upon favourable hydrographic conditions at the right place and time. The further fate of the 0-group very often depends on which part of the current regime the larvae and fry are initially brought into.

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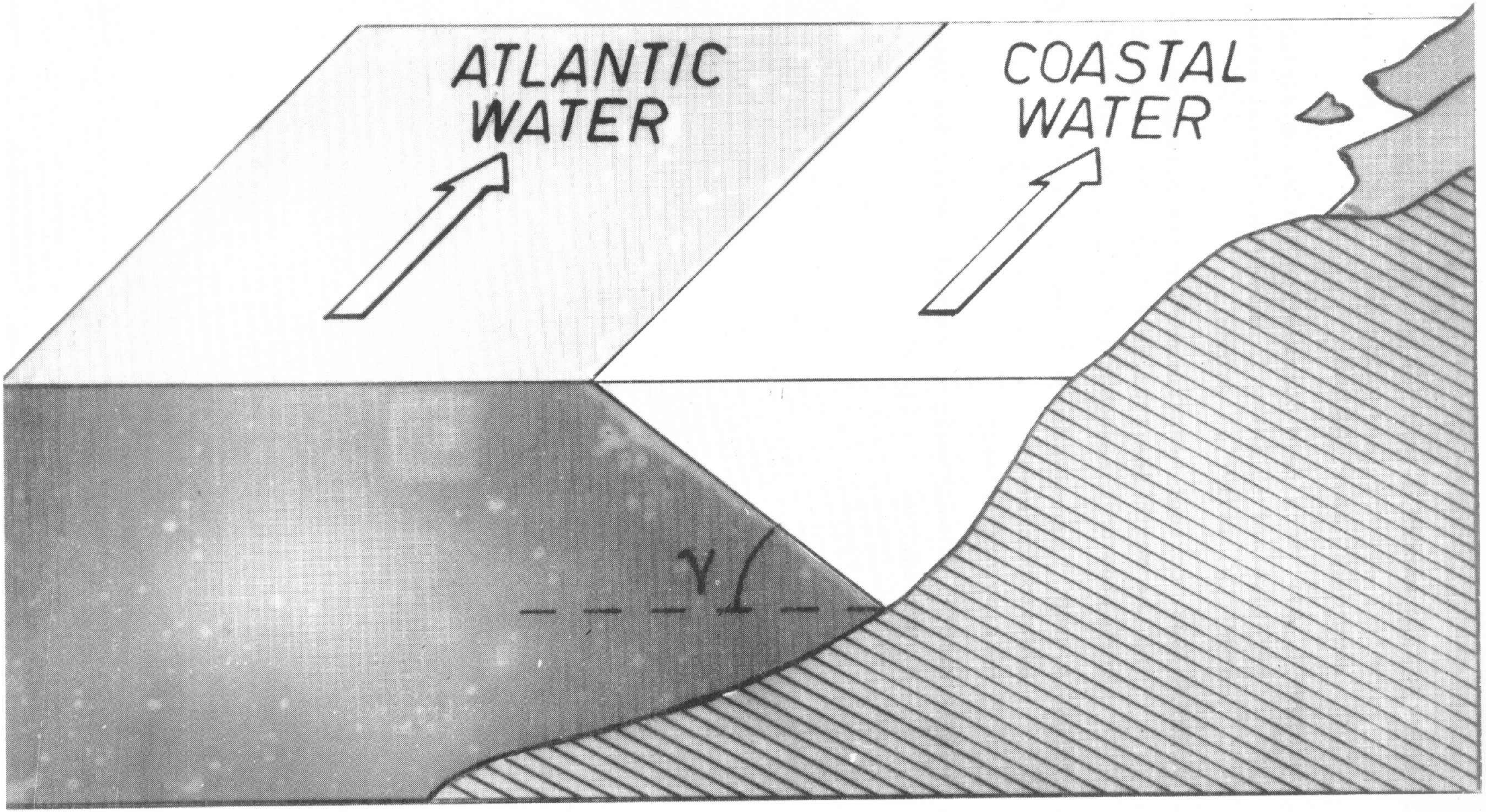


FIGURE 1.

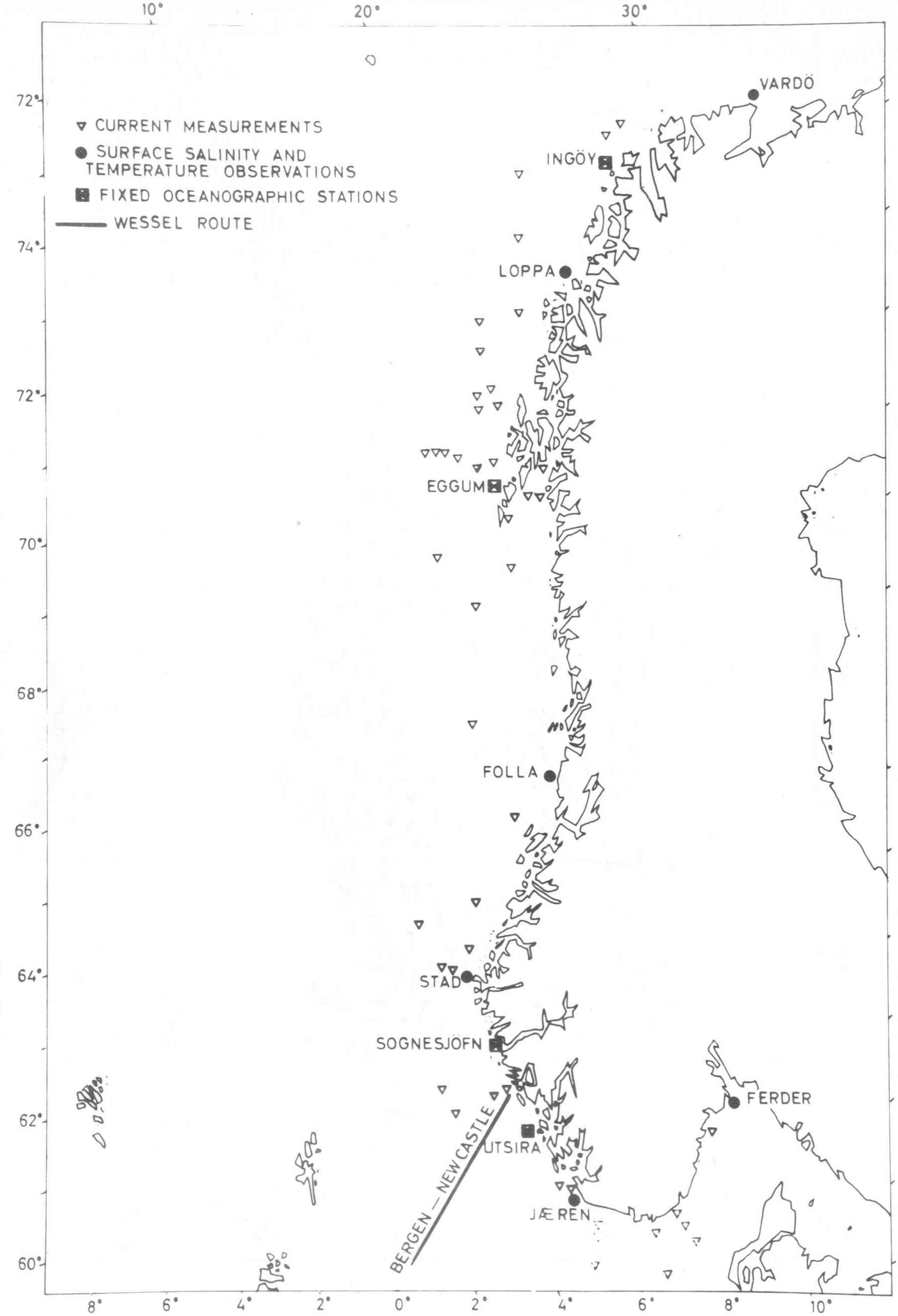

10°
20°
30°
72°
74°
72°
70°
68°
66°
64°
62°
60°
▽ CURRENT MEASUREMENTS
● SURFACE SALINITY AND TEMPERATURE OBSERVATIONS
▣ FIXED OCEANOGRAPHIC STATIONS
WESSEL ROUTE
VARDÖ
INGÖY
LOPPA
EGGUM
FOLLA
STAD
SOGNESJÖFN
FERDER
UTSIRA
JÆREN
BERGEN — NEWCASTLE
8°
6°
4°
2°
0°
2°
4°
6°
8°
10°

FIGURE 2.

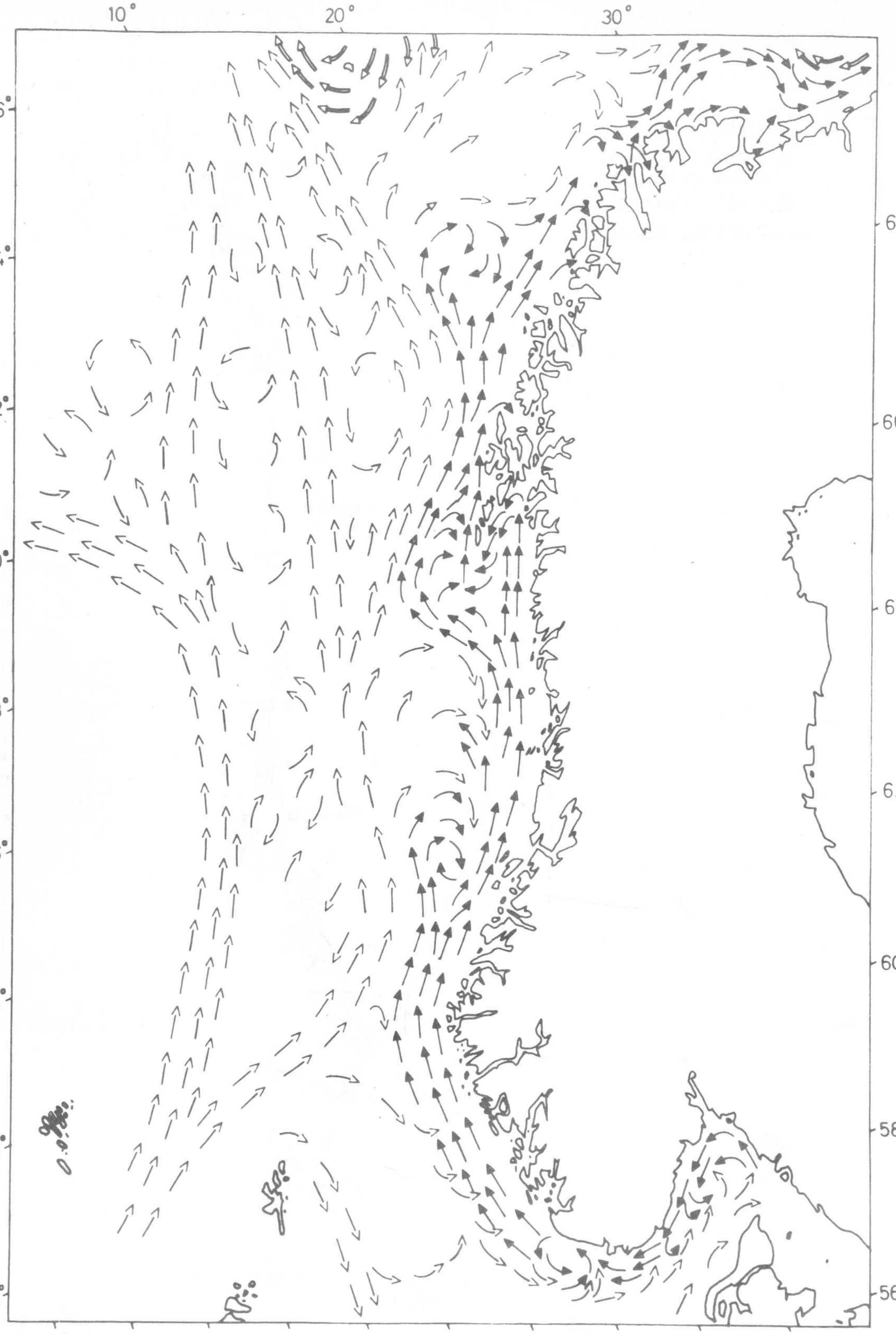


FIGURE 3.

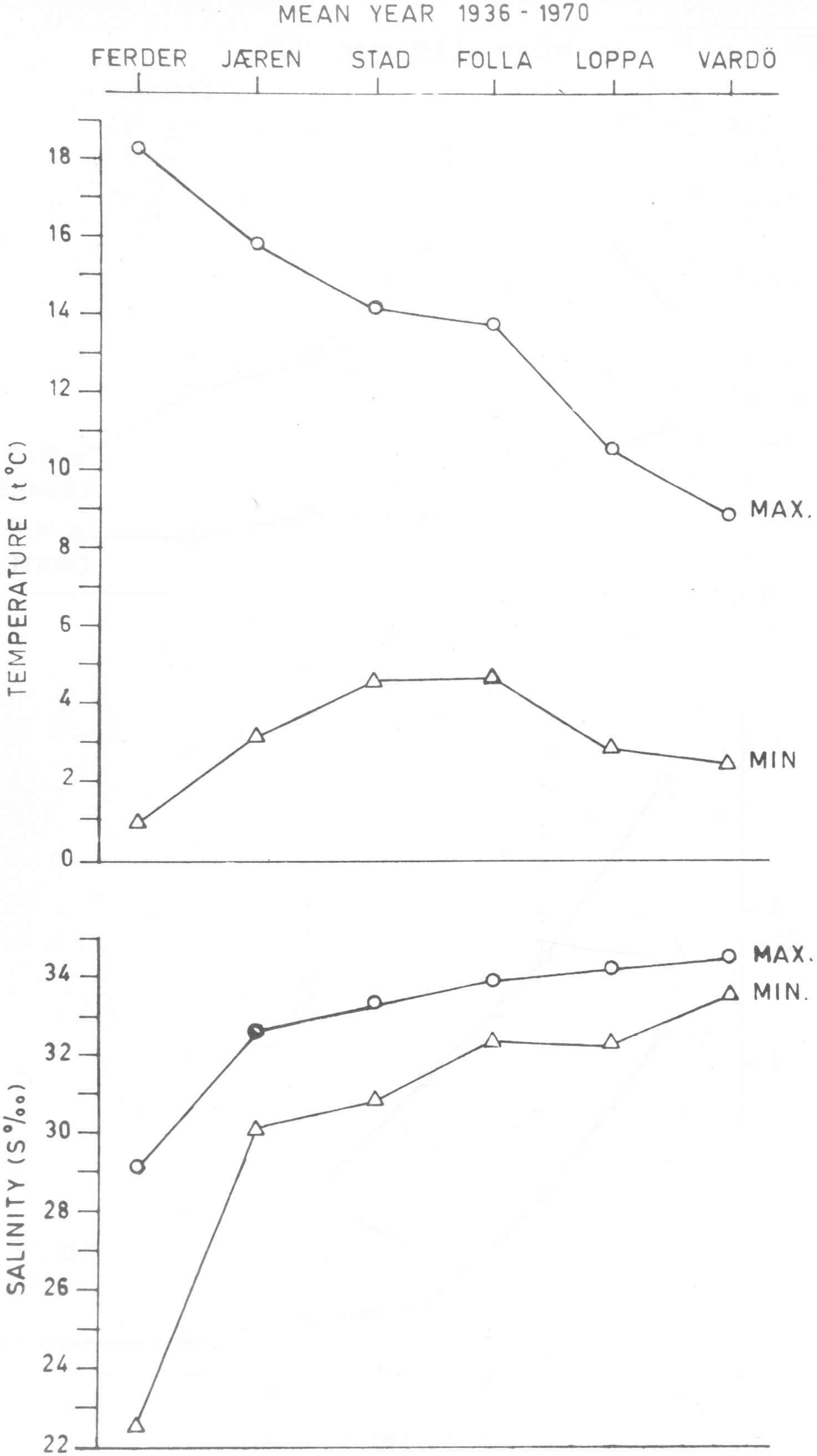

MEAN YEAR 1936 - 1970
FERDER
JÆREN
STAD
FOLLA
LOPPA
VARDÖ
TEMPERATURE (t °C)
18
16
14
12
10
8
6
4
2
0
MAX.
MIN
SALINITY (S ‰)
34
32
30
28
26
24
22
MAX.
MIN.

FIGURE 4.

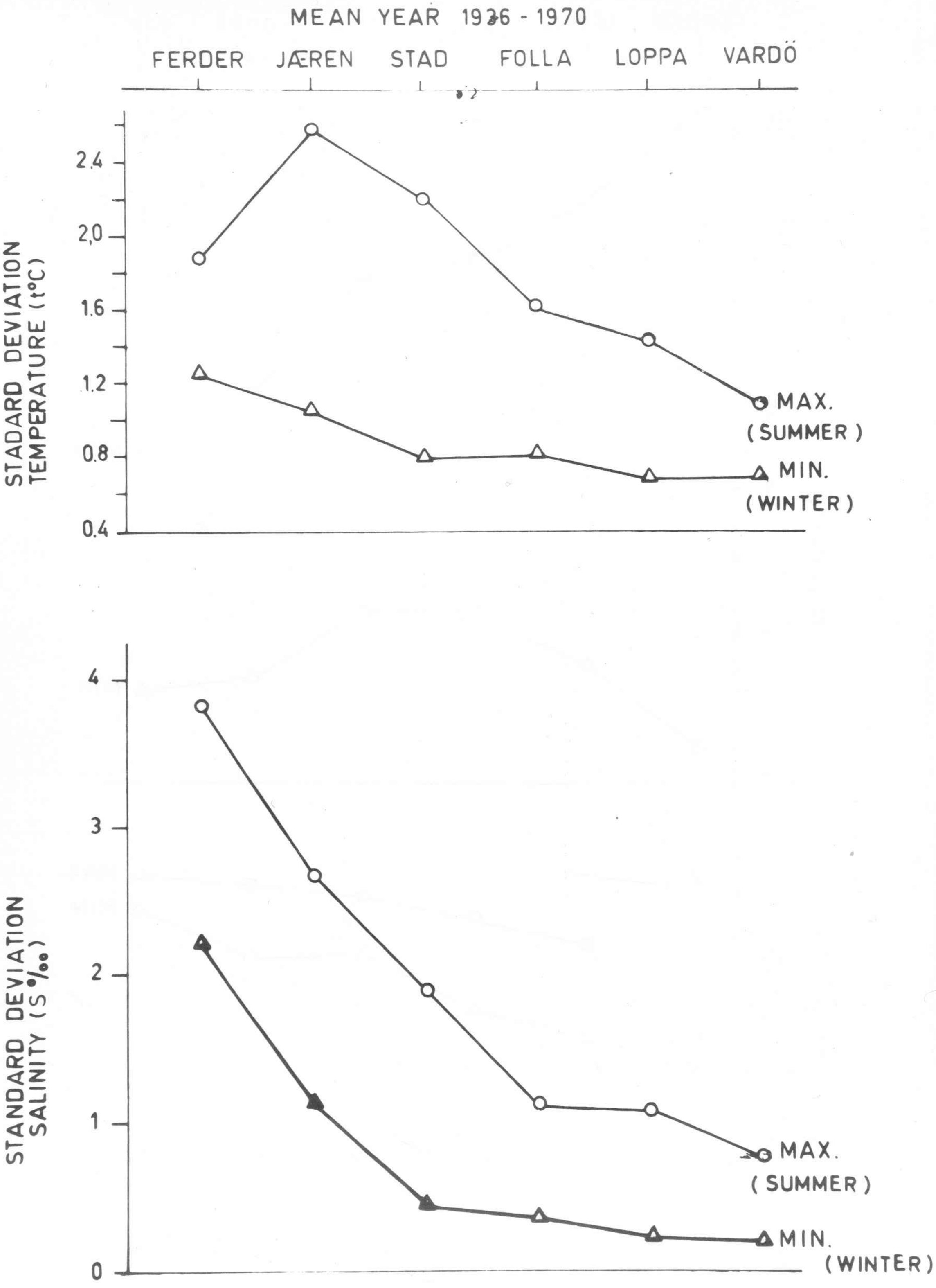

MEAN YEAR 1936 - 1970
FERDER
JÆREN
STAD
FOLLA
LOPPA
VARDÖ
STADARD DEVIATION
TEMPERATURE (t°C)
2.4
2,0
1.6
1.2
0.8
0.4
MAX.
(SUMMER)
MIN.
(WINTER)
STANDARD DEVIATION
SALINITY (S ‰)
4
3
2
1
0
MAX.
(SUMMER)
MIN.
(WINTER)

FIGURE 5.

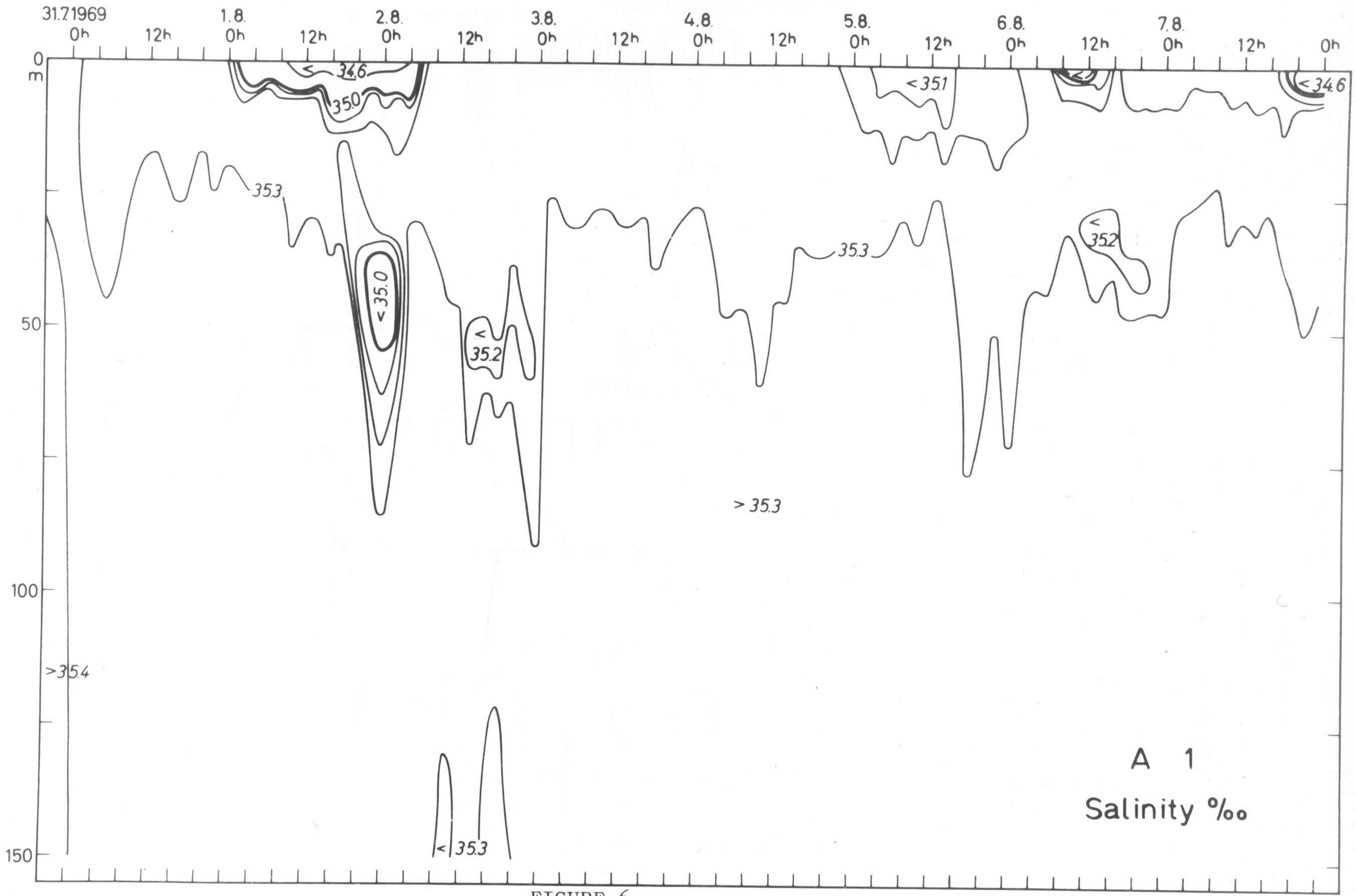
31.7.1969
1.8.
2.8.
3.8.
4.8.
5.8.
6.8.
7.8.
0h
12h
0
m
50
100
150
<34.6
35.0
35.3
<35.0
<35.2
<35.1
<35.2
>35.3
>35.4
<35.3
A 1
Salinity ‰

FIGURE 6.

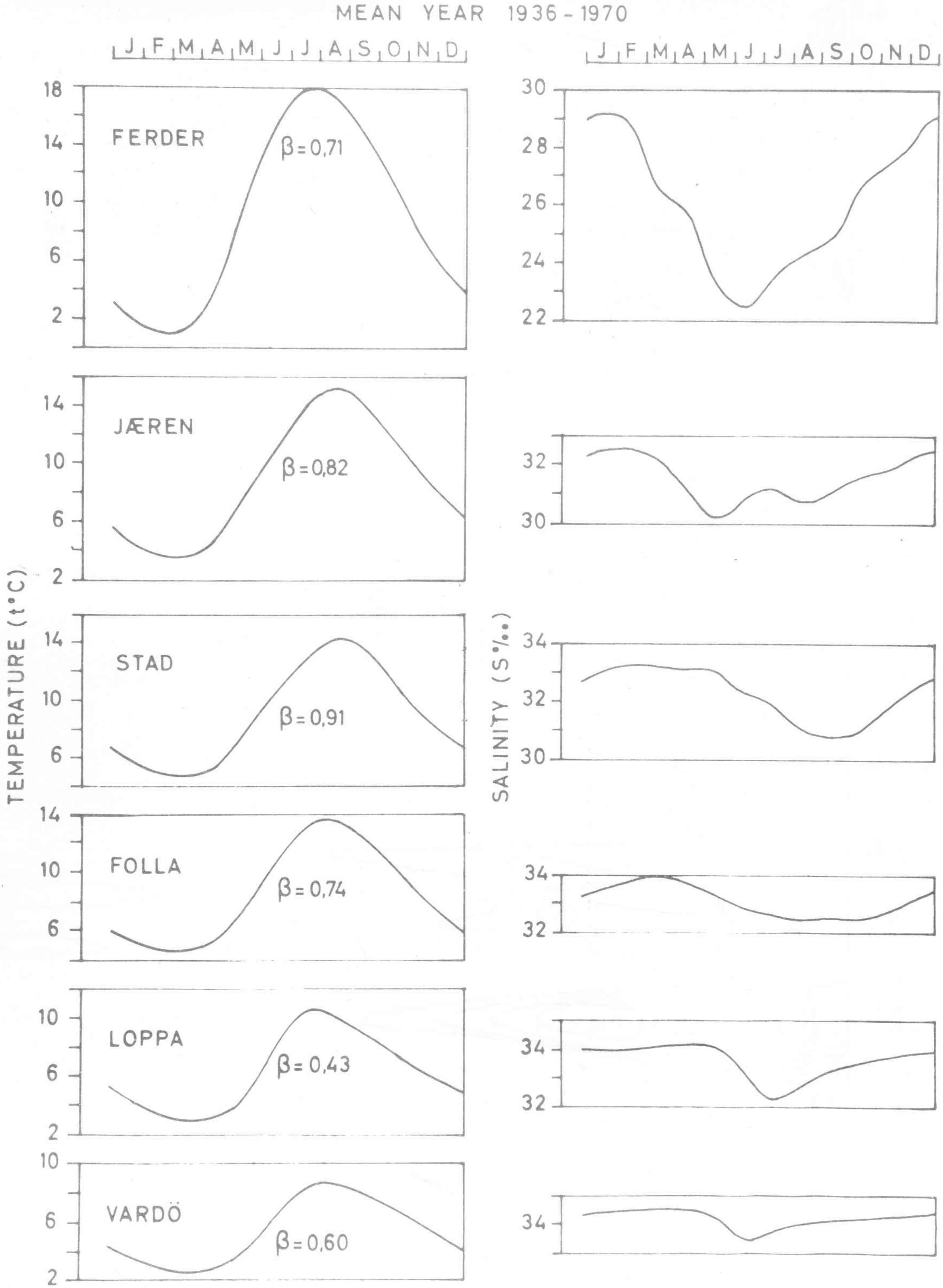
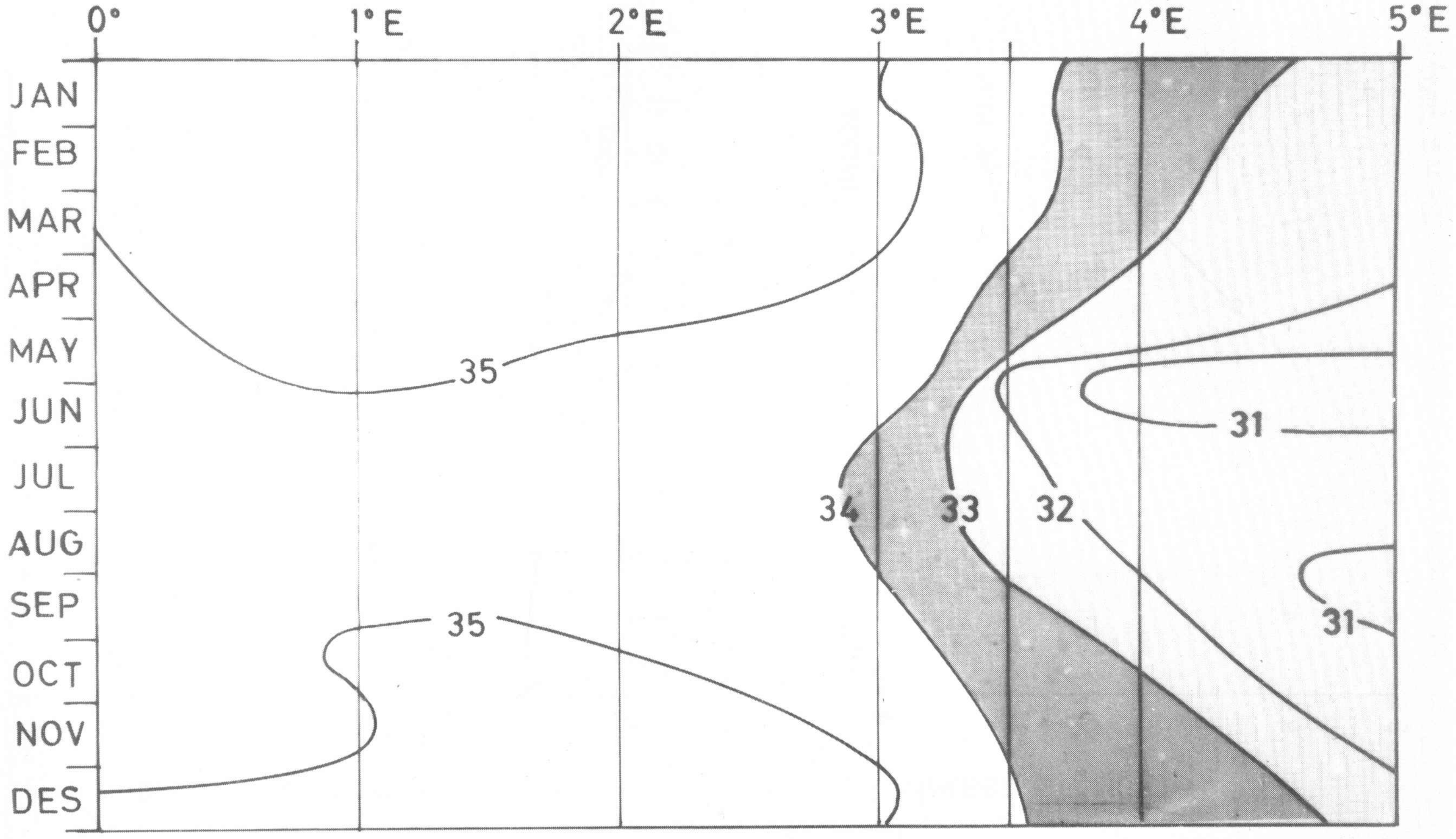
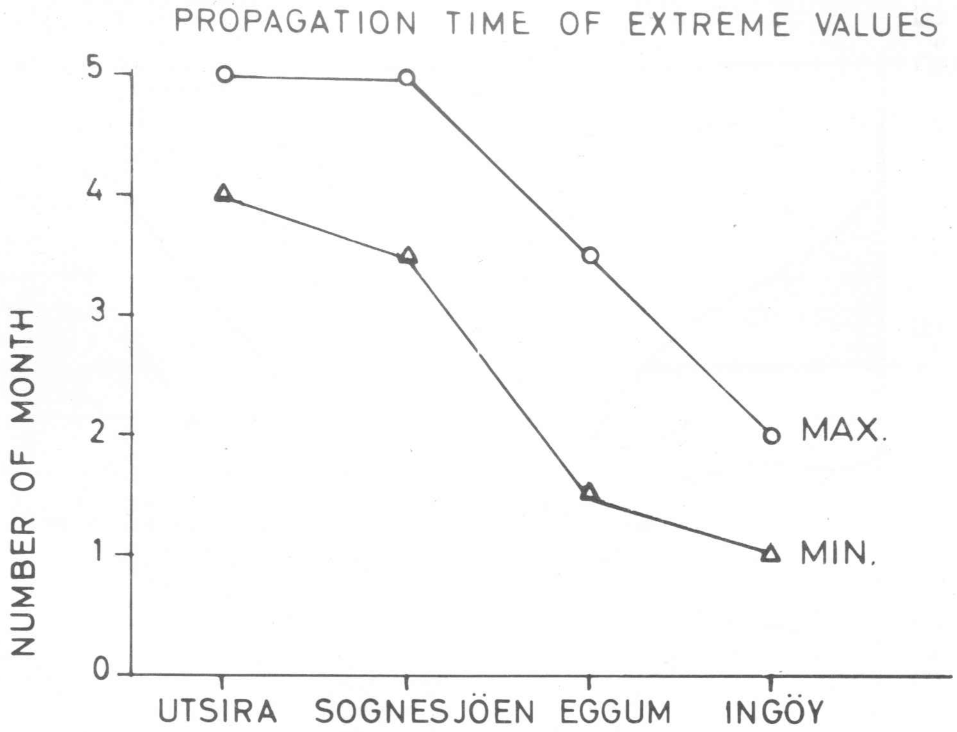

MEAN YEAR 1936 - 1970
J F M A M J J A S O N D
J F M A M J J A S O N D
TEMPERATURE (t°C)
SALINITY (S‰)
FERDER
β=0,71
18
14
10
6
2
30
28
26
24
22
JÆREN
β=0,82
14
10
6
2
32
30
STAD
β=0,91
14
10
6
34
32
30
FOLLA
β=0,74
14
10
6
34
32
LOPPA
β=0,43
10
6
2
34
32
VARDÖ
β=0,60
10
6
2
34

FIGURE 7.

S‰ MEAN YEAR 1961 - 1970



NEWCASTLE — BERGEN


PROPAGATION TIME OF EXTREME VALUES
NUMBER OF MONTH
0
1
2
3
4
5
MAX.
MIN.
UTSIRA
SOGNESJÖEN
EGGUM
INGÖY

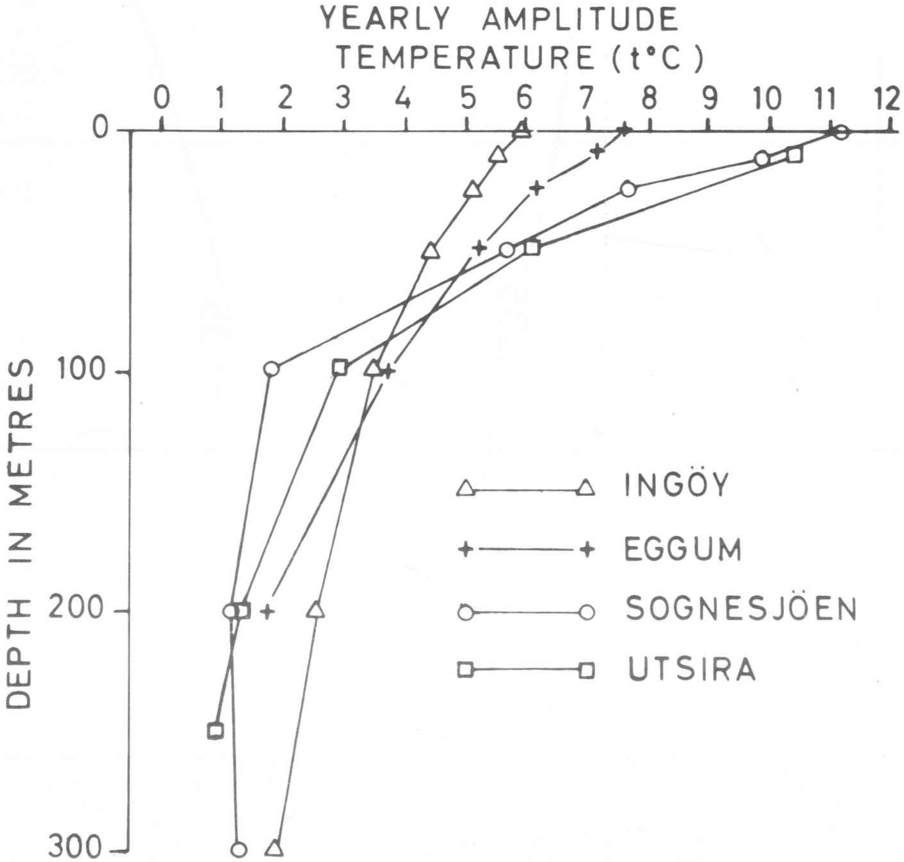

YEARLY AMPLITUDE
TEMPERATURE (t°C)
0
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH IN METRES
0
100
200
300
INGÖY
EGGUM
SOGNESJÖEN
UTSIRA

FIGURE 9.

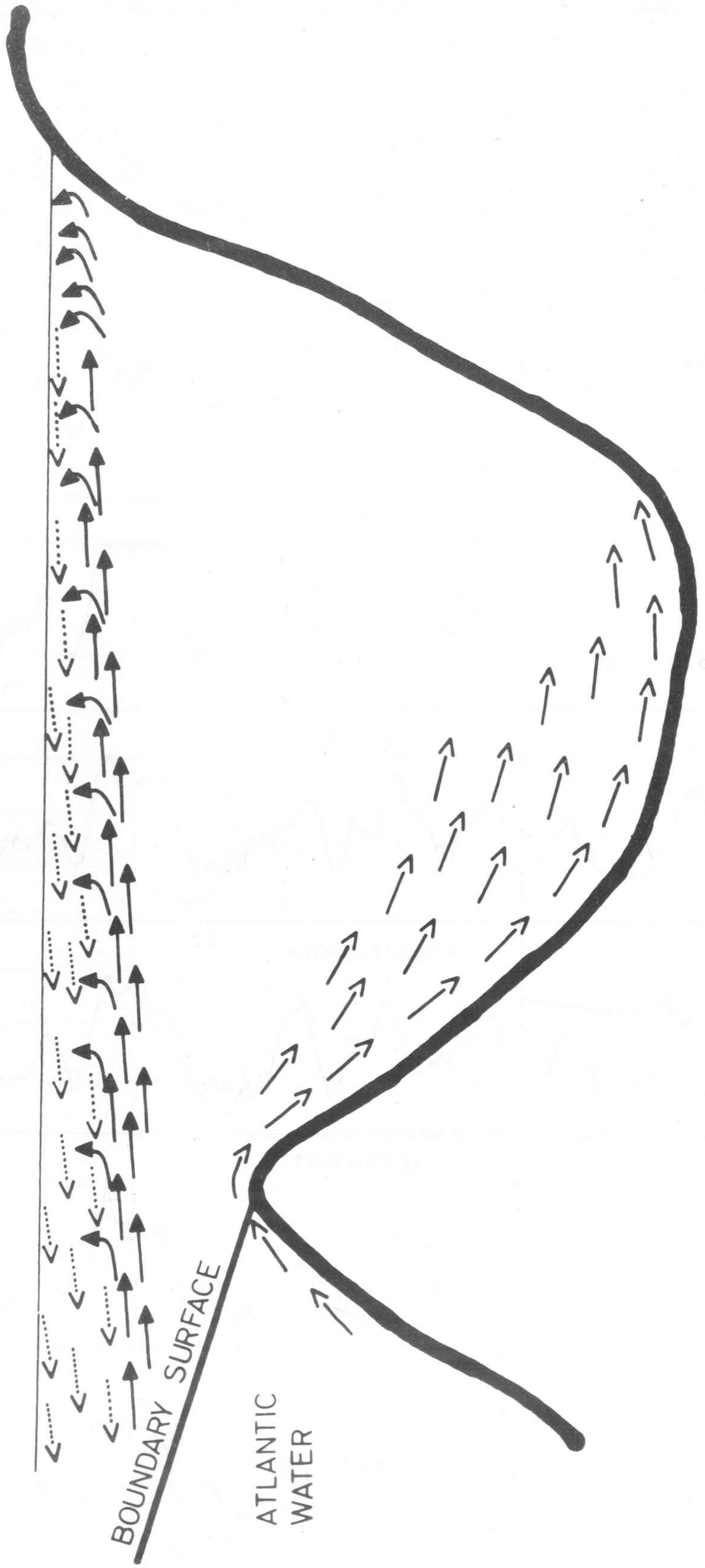


FIGURE 10.

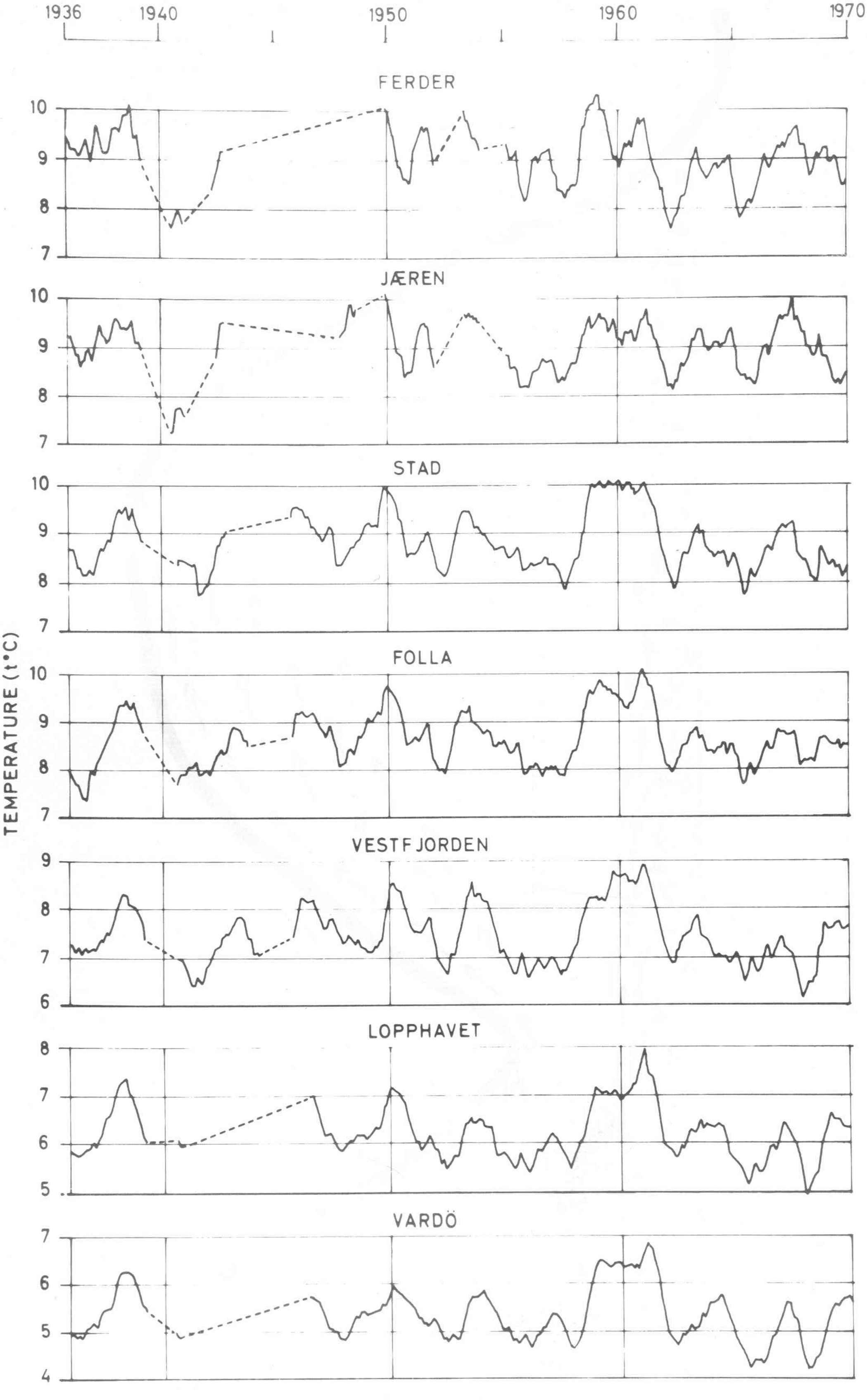

1936
1940
1950
1960
1970
FERDER
JÆREN
STAD
FOLLA
VESTFJORDEN
LOPPHAVET
VARDÖ
TEMPERATURE (t°C)
10
9
8
7
6
5
4

FIGURE 11