PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

ON SHORT-TERM VARIATIONS OF THE HYDROGRAPHICAL CONDITIONS IN THE SKAGERRAK AND ADJACENT SEA

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INTRODUCTION

The Baltic current has often been regarded as a relatively narrow flow along the south-east and south-west coast of Norway. It has some seasonal but regular movements. However, the hydrographical conditions of the current are also subjected to short term variations. Such variations may occur periodically or aperiodically. The latter referred to here, are first of all due to changes in the field of wind. The variations are detectable in horizontal and vertical changes of the mass-field and in fluctuations of the current velocity and direction. They are most distinct in areas with sharp vertical and horizontal gradients, as found in the Skagerrak and adjacent seas, where, during the summer, a great multitude of Baltic water gives a significant negative temperature-gradient and a positive salinity-gradient to the water masses below.

The theoretical background for understanding the relation between wind forces and changes in the mass-field is outlined in the theory on drift current (1). The drift current results from the tangential stress produced by the wind on the surface of the sea. At a fixed latitude, the corresponding transport of the water masses of the "surface current layer" is a linear function of this stress and occurs perpendicular cum sole to the wind direction. In layered waters the wind effect is confined essentially to the masses above the boundary surface. Under such conditions the energy of the wind may be conveyed to shallower waters, and thus the modifying effect on other types of movements present, will be increased significantly.

Near a coast or other border there is a secondary effect of wind. By a transport towards the coast the surface water will be piled up along the shore, causing an upward inclination of the physical sea surface and an increase in the slope angle of the boundary surface. Both generate a current parallel to the coast following the wind direction. By a transport away from the border the inclination of the physical sea surface as well as the boundary surface will be reversed. Also in this case the produced current will have the same direction as the wind.

Investigations have also shown that during periods with wind-conditions as described above, a series of convergences and divergences is developed with corresponding cells of circulation in the homogeneous top layer. This configuration is visible in a waveformed appearance of the transition layer.

MATERIAL

In order to map fluctuations of this character a synoptic survey is needed of the whole area under consideration. The investigation must also be repeated under the influence of different external forces. Such conditions were fulfilled by the joint Skagerrak expedition in June-July 1966 (2).

Fig. 1 shows the net of observation points. On each serial station salinity and temperature were recorded at standard depths. A survey was completed in the course of 3 days and repeated three times with intervals of approximately one week. The wind field is presented by recordings from 13 localities. At the meteorological stations on land the wind direction and speed was observed 4 or 6 times a day, whereas the wind conditions at the localities on open sea were traced by the help of six hourly mean isobaric maps.

RESULTS

First run (Fig. 2)

The first run of hydrographical observations were carried out during June 21st. - 23rd. The figure shows the average wind conditions for the time interval June 18th. - 21st.,inclusive. The presentation of the wind field is meant to give the main feature only.

During this period the wind was fairly peristent west of Lindesnes, while in the central part of Skagerrak towards the end of the period, the wind turned more westerly.

The figure also includes the temperature distribution at the uppermost 50 m in a section outside Jæren.

The lower part of the figure shows the bathymetric depth of the surface attached to 30 ‰ isohaline and the average salinity of the watermasses above this depth.

The value 30 ‰ is considered to be the upper salinity limit of the Baltic water, the depth of which is found at the top of or in the uppermost part of the transition layer. The Baltic water, so defined, is thus well limited from the underlaying North Sea water and vertical mixing through the boundary is negligible for the problems discussed.

Evidently the persistent wind from south in the Skagerrak and parallel to the coast west of Lindesnes has had two main effects:

1. The wind stress has developed a series of successive convergences and divergences starting with a significant convergence at the border. In all the sections west of Lindesnes, corresponding wave-like patterns occur in the salinity and the density as well as in the temperature distribution. This indicates longitudinal zones of convergences and divergences.

2. The wind has moved the water mass above the transition layer towards the south-west coast so that Baltic water is found in a relatively narrow zone close to the shore, reaching a thickness of 20 m. In the Skagerrak the dominant southerly component

of the wind has forced great quantities of Baltic water towards the east, covering the major part of the inner basin from 0 to 5 or 10 m depth. At the Swedish coast the thickness has increased to 20 m and the average salinity of this water is as low as 22 ‰.

Second run (Fig. 3)

Between the first and second run the wind changed in the western part of the area from a southerly to a dominantly northerly wind and to a northeasterly in the Skagerrak. In the first area the wind was fairly stable during the period June 27th. - 30th., whereas in Skagerrak there were som variations. However, the strongest winds had the directions indicated.

The series of divergences and convergences this time starts with a significant divergence near the coast. Also, in this case convergence and divergence lines are traceable, parallel to the west-coast.

As evident from the lower part of the figure, the wind has caused a transport of low salinity waters towards the Norwegian Skagerrak coast. The intersection between the surface of 30 ‰ salinity and the sea surface is found further northwards in the central part. The most original Baltic water occurs in a zone close to the Norwegian coast reaching depths of 30 m.

In the North Sea sector the persistent northerly wind has on an average moved the top layer water away from the coast. The Baltic water was found in a trough some distance from the shore as indicated by the lower salinity. The 30 ‰ surface intersects the physical sea surface near the coast.

Third run (Fig. 4)

The third run was carried out during July 5th. - 8th., and this figure shows the wind condition just before and during the first part of the run. There has been some variations both in speed and direction, the latter being indicated by the limiting sectors at some of the localities. However, on an average, the wind has blown parallel to the coast in such a way that surface water should be moved away from the coast in the whole area.

It is also clearly seen that the most of the Skagerrak is now covered by low salinity water. By this action more North Sea water has been forced into the Kattegat and has raised the surface salinity in the northern part by 2-3 ‰.

However, the equilibrium between the external and internal forces is broken down, and probably due to meandering, free vortices are developed. The eddies are both cyclonic and anticyclonic as demonstrated by the lower part of the figure. The vortices are also shown in the temperature section where the convergences and divergences are more pronounced than previously. The convergences here represent the center of cyclonic eddies and are to be interpreted as points rather than lines or zones.

Changes (Fig. 5)

In order to demonstrate the main feature of the changes between two successive hydrographical conditions, differences in the depth of 30 ‰ surface and the average salinity of the water masses above this depth are shown respectively. From the first to the second run, the mass fields have been turned over two axes, one in Skagerrak and one off the western coast of Norway. Baltic water is tipped over from the southern and easternmost part of Skagerrak to the Norwegian coast. Such situations will always give increased current velocity at the coast. Measurements made synoptically to the second run showed speeds of 80-85 cm/sec whereas maximum velocity during the first run was 50 cm/sec. In both cases the current direction was southwesterly (3). The net transport of water out of Skagerrak had increased by 20-25 %. Off western Norway the turn-over axis is parallel to the coast. Part of the great quantity of Baltic water, which during the second run was concentrated in the trough off the coast, has on account of dynamic equilibrium moved to the south. This together with the greater outflow from Skagerrak causes a large accumulation of Baltic water off Lindesnes. It is possible that this accumulation may result in a sudden outflow of Skagerrak water towards the central part of the North Sea. Such occurrences have been reported. (4).

The turn-over axis of the mass-field between the second and third run is located in the central part of Skagerrak. A great quantity of the Baltic water, which before the change was found near the Norwegian coast of the basin and at some distance from the west coast, has probably been moved south and eastward and is concentrated off the coast of Jylland.

DISCUSSION

The meteorological conditions during the 1966 expeditions were not in any way extraordinary. Similar variations in the wind field commonly occur in the summer seasons and indicate that fluctuations of the mass field as previously described occur frequently.

It is well known that these variations have an evident effect on local fishing activities, either by significant changes in the physical environment or by changes in food supply. However, a permanent influence is to be sought in the fate of eggs and larvae from species which spawn in Skagerrak in this season. Sprat must be the first to be considered. Bakken (5) observed that in calm weather or with winds from the south the sprat fry drift into the fjords of Rogaland (just north of Jæren). By a northerly wind the fry pass this fjord system and drift into the fjords further to the north. Statistically, he stated a positive correlation during the spawning season between the frequency of northerly winds outside western Norway and the northward shifting of the most productive fishing area of sprat the year after. The correlation also suggests that such abiotic factors play a relatively significant part in determining the recruitment strength compared to presumtive important biotic factors such as success in spawning, feeding etc.

An outstanding feature of the main movement of the surface waters in the Skagerrak basin is a large anti-clockwise eddy which is belived to be able to keep fish-eggs and larvae in the area for a longer time (6). This property together with the short-term varitation which has been described, and the fact that the area is an important spawning and nursery ground for fish stocks, should be born in mind when considering Skagerrak a recipient for various types of pollutants.

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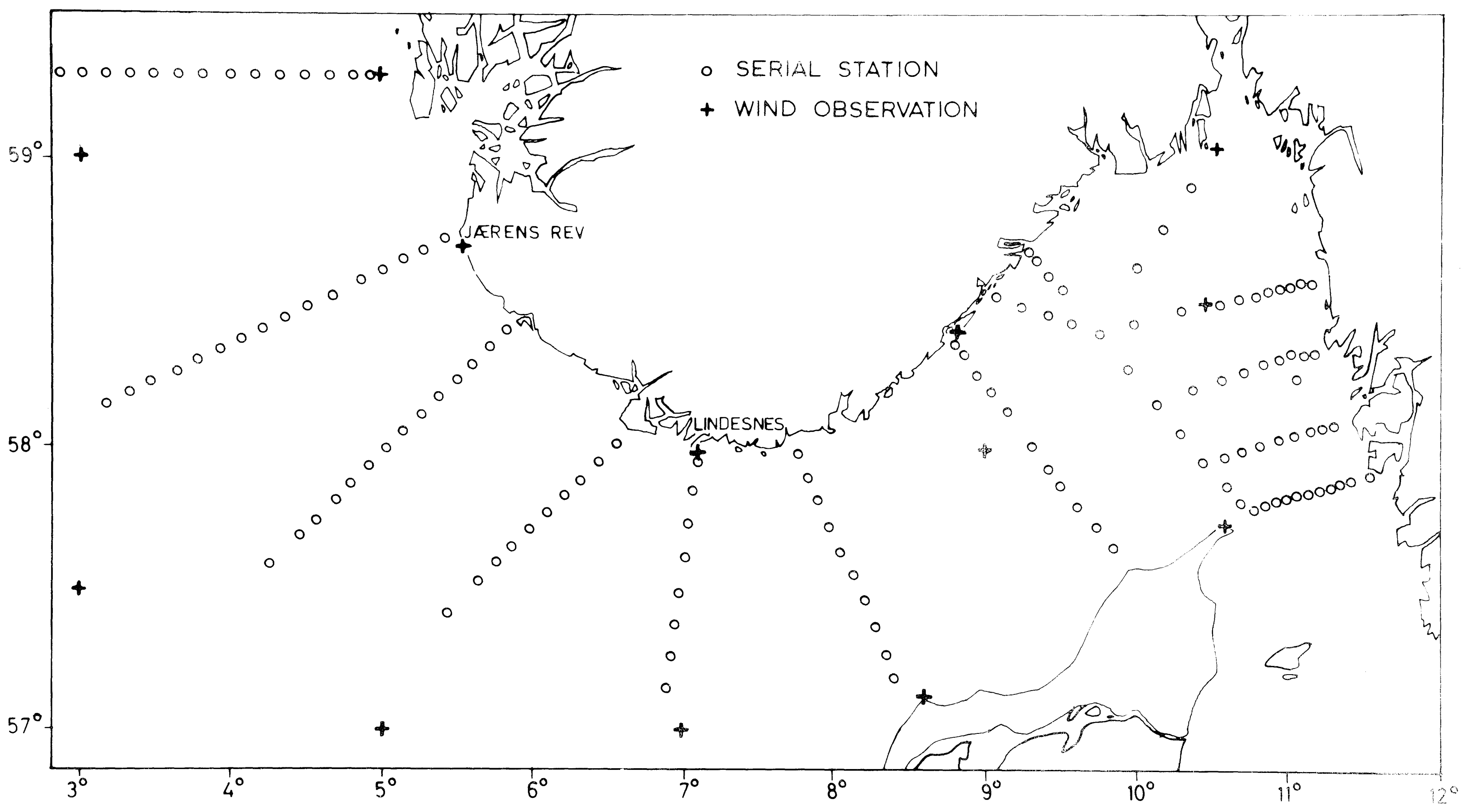
o SERIAL STATION
+ WIND OBSERVATION
JÆRENS REV
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59°
58°
57°
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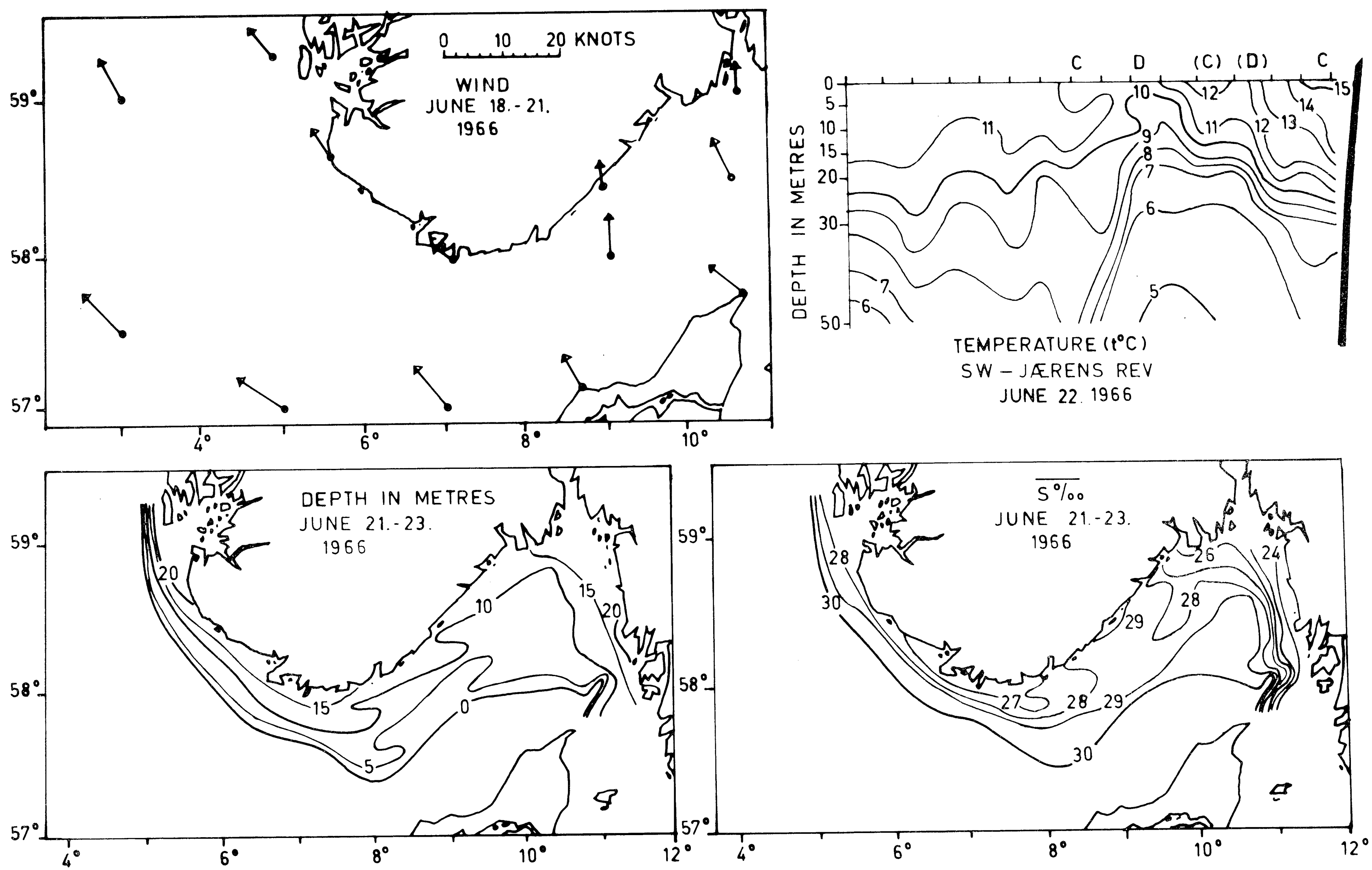
FIGURE 1.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WIND
JUNE 18.-21.
1966
DEPTH IN METRES
TEMPERATURE (t°C)
SW – JÆRENS REV
JUNE 22. 1966
DEPTH IN METRES
JUNE 21.-23.
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57°
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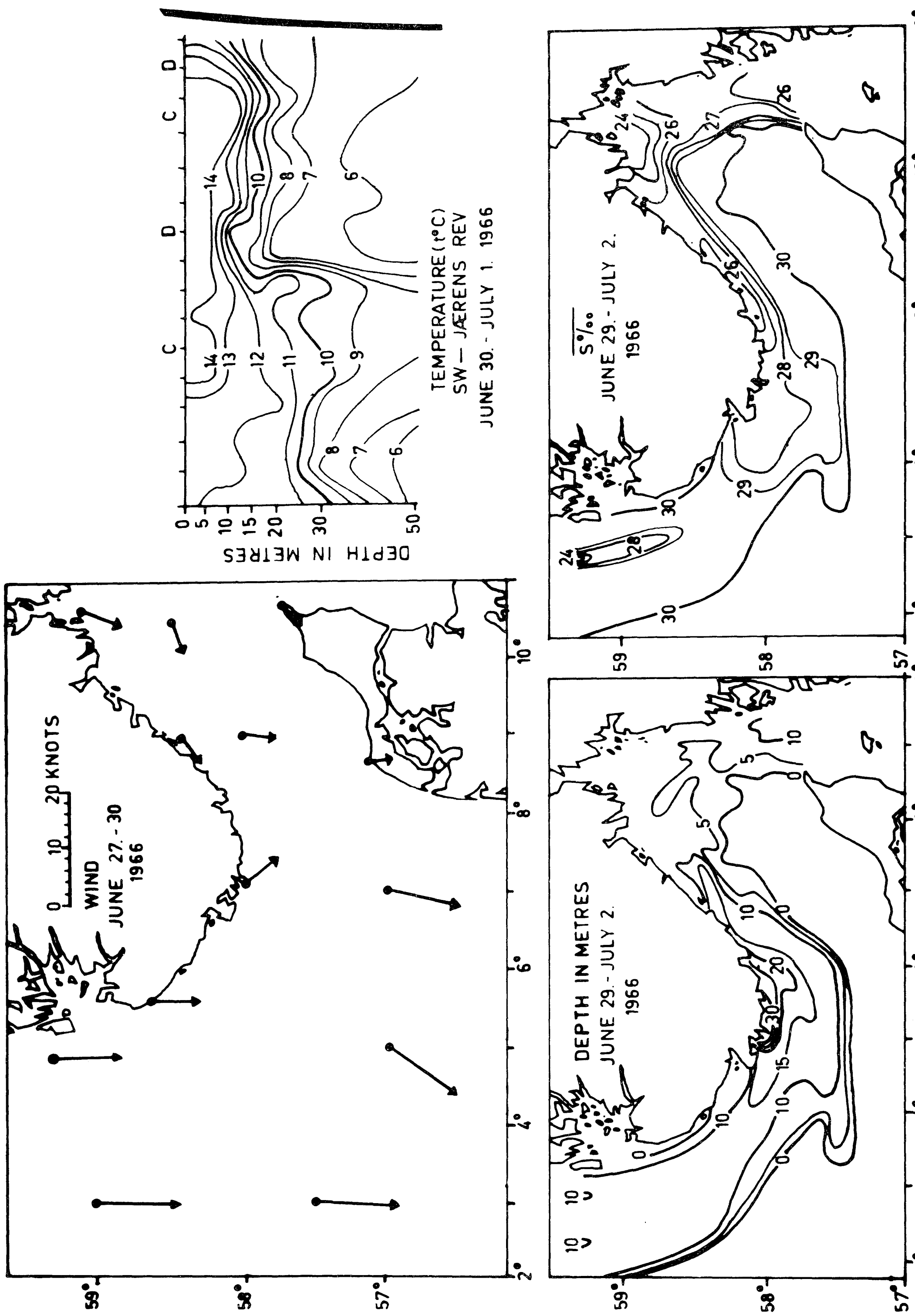
FIGURE 2.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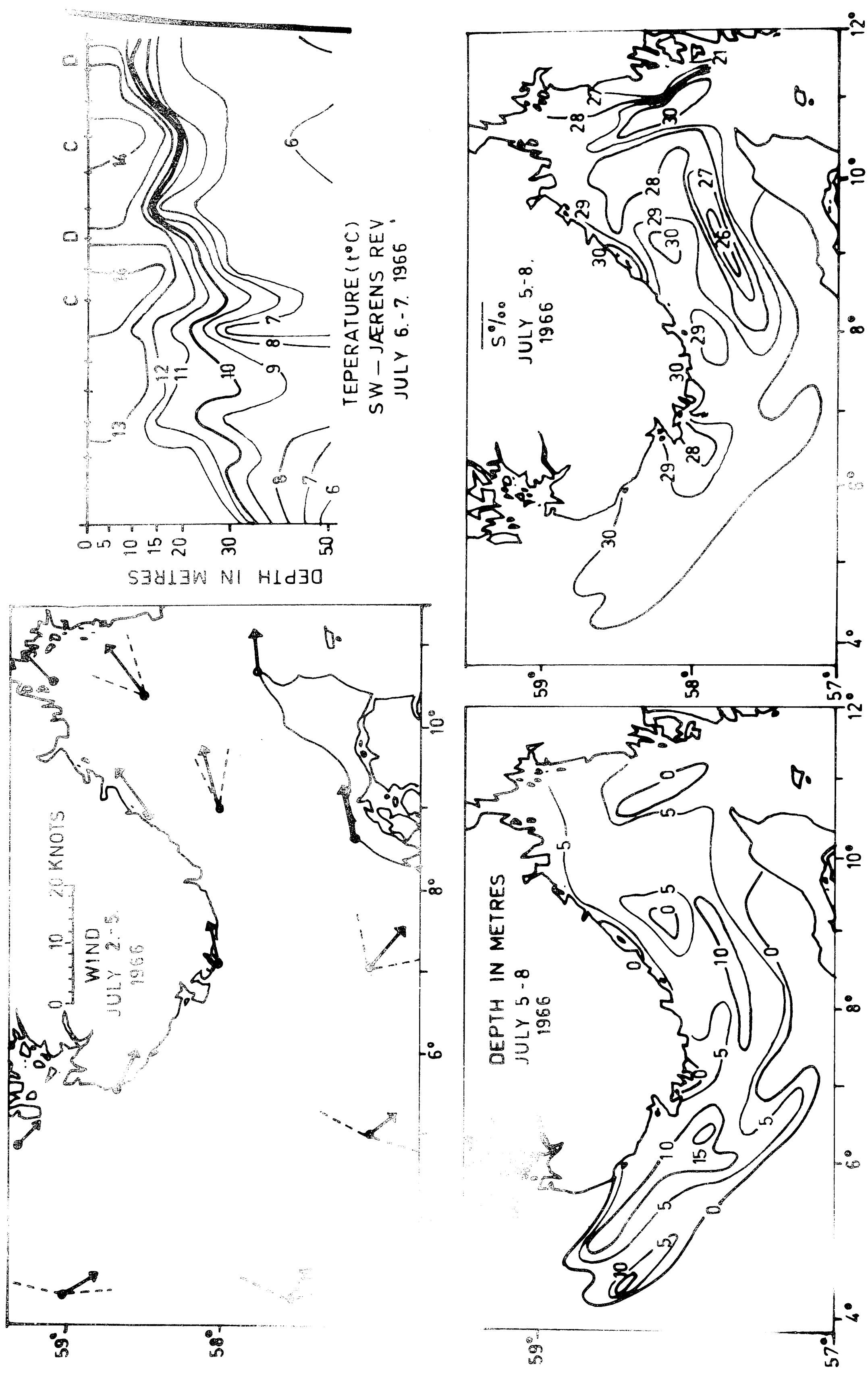
JUNE 27.-30
1966
0 10 20 KNOTS
TEMPERATURE (t°C)
SW — JÆRENS REV
JUNE 30. - JULY 1. 1966
DEPTH IN METRES
DEPTH IN METRES
JUNE 29.- JULY 2.
1966
S‰
JUNE 29.- JULY 2.
1966

FIGURE 3.


WIND
JULY 2-5
1966
0 10 20 KNOTS
TEPERATURE (t°C)
SW – JÆRENS REV
JULY 6.-7. 1966
DEPTH IN METRES
S‰
JULY 5-8.
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DEPTH IN METRES
JULY 5-8
1966
59°
58°
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4°
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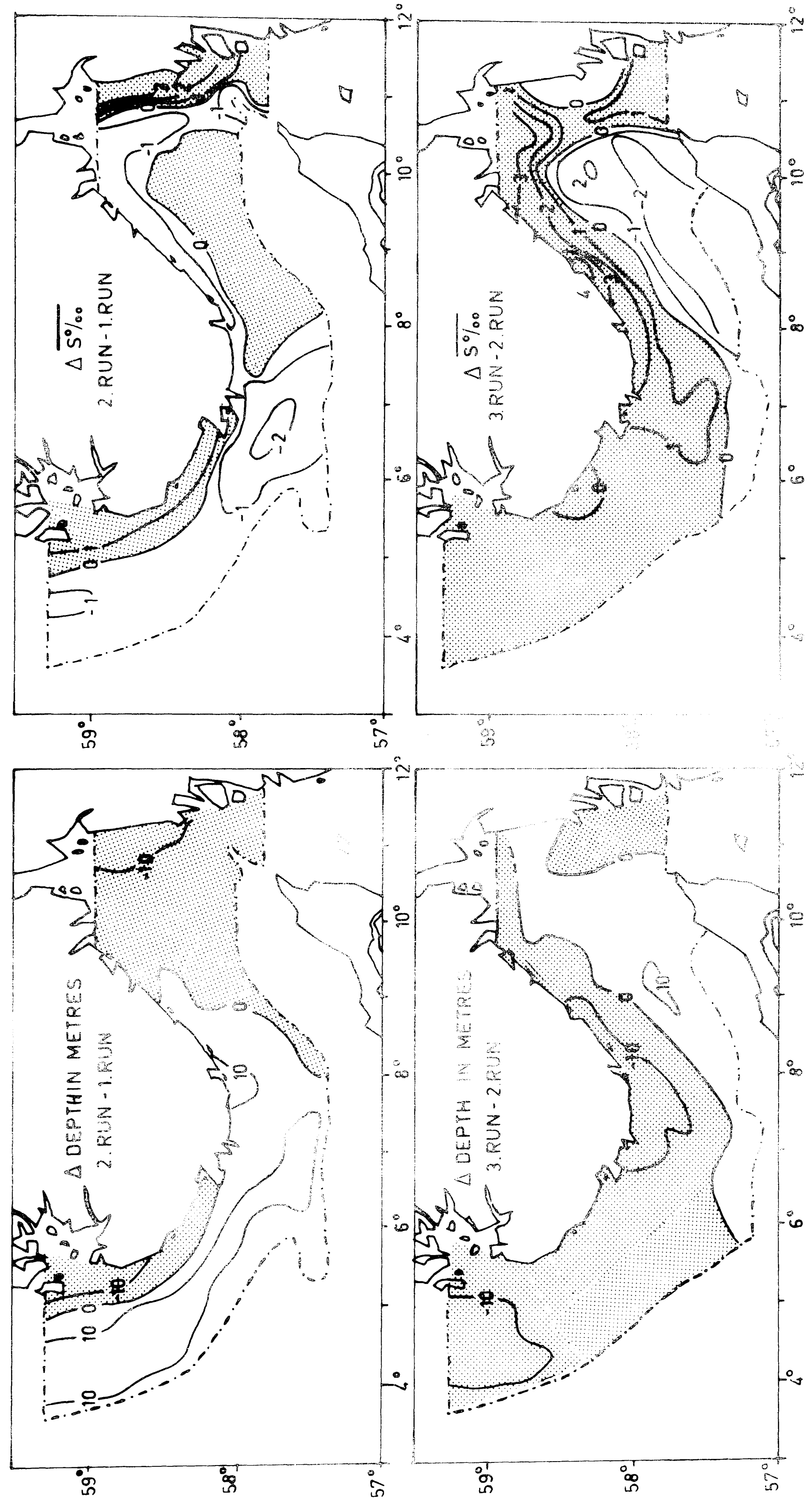
FIGURE 4.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Δ DEPTH IN METRES
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59°
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FIGURE 5