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International Council for the Exploration of the Sea

CM 1968/C:26
Hydrographic Committee

An analysis of the current measurements made during Operation RHENO

by

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During the period 14 August-4 September 1965 an ICES diffusion experiment (Operation RHENO) was carried out in the east central North Sea based on the use of Rhodamine B dye as a tracer; ships from the Federal Republic of Germany, the Netherlands and the United Kingdom participated. As part of the Lowestoft Laboratory's contribution to the ICES report on this exercise we have been analysing the current measurements made as a complement to the diffusion studies. This analysis is almost completed and we have recently made a first draft of our report available to our colleagues who are working on other aspects of the RHENO experiment. However, we consider that some of our findings have an interest sufficient to warrant our making them available to the Hydrography Committee as a whole, particularly in view of the discussions which took place during the Committee's 1967 meeting as to the desirability of carrying out at an early date an international experiment on the variability of the current system in the central North Sea.

Current measurements at three levels in the water column were recorded by means of moored current meters at each of three positions that formed a triangle enclosing the area of the dye patch (Figure 1). The mooring systems were of the type described in Lee and Ramster (1968), while the instruments used were those designed by Hydrowërkstatten of Kiel for use in the 0-50 metre layer. Stations A and B were laid from R.V. "Gauss" by the Deutsches Hydrographisches Institut, Hamburg, and station C from R.V. "Clione" by the Fisheries Laboratory, Lowestoft. At station B the mid-depth instrument did not work and the compass of the near-bottom meter failed after 12 days, but the other seven meters provided 5-minute values of current speed and direction over a common 10-day period. Details of the positions, depths and operating periods of the instruments are given in Table 1.

Table 1 Positions, depths and operating periods of the recording current meters used during Operation RHENO

Station	Depth (metres)	Depth of instrument (metres)	Position of instrument		Time when useful data begins (GMT)	Time when useful data ends (GMT)
A	64	11	56°13' 7"N	4°29' 2"E	1532 14 Aug	1531 4 Sep
		36	56°13' 6"	4°29' 6"	2358 14 Aug	1432 4 Sep
		50	56°13' 4"	4°29' 8"	1429 14 Aug	1631 4 Sep
B	62	11	56°46' 5"	3°35' 8"	0927 14 Aug	0858 4 Sep
		36	NO RECORD			
		52	56°46'	3°35' 3"	0702 14 Aug	1527 26 Aug (compass failure)
C	66	10	56°56'	04°47'02"	0840 18 Aug	1020 31 Aug
		25	56°56'	04°47'12"	0935 18 Aug	0945 31 Aug
		50	56°56'15"	04°47'30"	1010 18 Aug	0845 31 Aug

A cursory examination of the hourly means computed from the data showed that the measurements at station C were very different in character from those at the other stations (Figure 2). In particular, for long periods of time during the first half of the record peak velocity values of the near-surface tidal streams did not exceed 15 cm/second compared with overall levels of 20 cm/second at station A and 35 cm/second at station B. Furthermore, the northerly component of flow at all depths was small at station C, yet dominant at station B and as well developed as the southerly component at station A. At first it was suspected that the instruments at station C might have been malfunctioning, but more detailed consideration of the records showed that the differences from station to station became much less marked with increasing depth and that an uncharacteristic short-term peak velocity of 40 cm/second found in the near-surface record at station C was measured at the same time at the other stations.

The wind-water relationship at the time of gale-force winds

The occurrence of this phenomena simultaneously in all the near-surface records pointed to close links between near-surface water movements and the wind regime. In fact this major event in the near-surface velocity records occurred during the second of the two occasions when wind velocities exceeded 20 knots. The first gale began some 60 hours after all the stations had been laid when gale-force southerly winds blew for the 30 hours preceding neap tides; the second, north-westerly, gale began after 152 hours and blew at a time of rising tides. On both occasions maximal wind velocities of 30-34 knots were measured. The southerly gale overwhelmed the tidal forces in the near-surface layer at stations A and B and sustained north-going drift occurred; at station C the pronounced south-going component of flow was temporarily halted (Figure 3). At the time of the north-westerly gale there was no sustained southeast-going drift; the energy imparted to the water from the gale force winds simply stemmed a northeast-going stream and increased the velocity of the following southwest-going tide. This differing response of the near-surface layer to the two gales would seem to be a consequence of the change from neap to half tides. In the mid-depth and near-bottom records there is no indication of either the sustained north-going flow resulting from the first gale or the short-term increase in peak velocity associated with the second. In the latter case, in fact, the reverse occurs in that at these levels peak stream values fall significantly during the north-westerly gale (Figures 4 and 5).

The residual drift

Daily mean current components at all depths have been calculated from the hourly means by Dr Rossiter of the Liverpool Tidal Institute using Doodson's Xo stencil which filters out oscillations of frequency 1 cpd and higher. The progressive vector diagrams that can be drawn from these mean components are best appreciated when broken up into sections situated in time about the periods of gale force winds and then plotted in their true spatial relationship (Figure 6). From this diagram it can be seen that before and after the southerly gale the area between stations B and C is a region of north-south shear as far as the near-surface layer is concerned. At mid-depth and near-bottom levels, easterly movements prevail at all stations. After the north-westerly gale, however, northerly movements occur in the near-surface layer at both stations B and C, while the south-easterly trends found hitherto at station A are re-established. At mid-depth and near-bottom levels in this period northerly trends occur at station C and north-easterly movements at station A.

It is clear from the progressive vector diagrams that, of all the records obtained from the near-surface layer, that at station C is the most variable in character. Serial temperature and salinity data taken in the vicinity of this station at the beginning and end of the measurements provide an indication of the cause of this variability (Figure 7). At the beginning of the record they show Baltic Outflow water (salinity < $34^{o}/oo$) lying on top of North Atlantic water with the pycnocline extending from 7 to 30 metres. At the end of the exercise central North Sea water fills the surface layer to a depth of 21 metres and the pycnocline occupies the zone 21-30 metres.

The Baltic Outflow water would appear to be the cause of the dominant southerly component of drift through station C. Salinity samples taken in this area by commercial vessels for the Lowestoft Laboratory verify, first, the presence of Baltic Outflow water at the beginning of the exercise in the region of station C and, second, the fact that station B lies on the eastern border of the lobe of North Atlantic water where north-going residuals are to be expected (Figure 8). Furthermore, these samples show that after the north-westerly gale the Baltic Outflow has been stemmed and suggest that the region of station C is now part of the general North Sea circulation (Figure 9). Previous papers on the nature of the Baltic Outflow (Lisitzin 1962 and, in particular, Dietrich 1951) have all shown it to be stemmed by westerly winds.

It appears therefore that the distinct differences in the pattern of near-surface residual drift between the three stations are best explained with reference to the general circulation of this part of the North Sea. Station B always lies in or close to the lobe of North Atlantic water and so north-going residuals are found there all the time. South-going Baltic Outflow water moves through the near-surface layers at station C during most of Operation RHENO, but north-going residuals appear after this outflow has been brought to an end. At station A the general east-going drift is conceivably a vestige of the main Atlantic inflow from the north combined with part of the south-going trend through station C and north-easterly movements through the German Bight. The east-going drift below 20 metres is thought to be part of the inflow of Atlantic water to the Baltic.

Discussion

The surface salinity data at our disposal as yet are limited, but, as we have seen, have been sufficient to indicate large-scale phenomena, such as the presence or absence of Baltic Outflow water in an area. We do not think, however, that we have enough data to be able to infer from our isohaline charts the probable current systems. Such systems were inferred by Böhnecke (1922) for the whole of the North Sea from his examination of monthly surface salinity values over the period 1902-14. His chart for August (see Figure 10) suggests that the RHENO area is filled by a counter-clockwise swirl as Baltic Outflow water interacts with the main North Sea circulation. The RHENO data show no trace of this gyre and indeed examination of salinity data for this area since 1914 suggests that only rarely is Baltic Outflow water found here in August. Of the six August salinity values available to Böhnecke, two were of less than $34^{o}/oo$ and three in the range 34.2-$34.4^{o}/oo$, but in the period 1920-54 there are only two years (1921 and 1926) when Baltic Outflow water was found in the ICES Atlas field containing stations C and A during this month. In the period 1932-35 the August monthly means lie in the range 34.1-$34.3^{o}/oo$, but at all other times surface salinity values are quite clearly those associated with central North Sea water. In Figure 10 the relevant section of Böhnecke's chart is compared with the trends suggested by the RHENO data. It is appreciated that this is not a fair comparison because of the fundamentally different sources of the residual patterns. However, it serves to underline the fact that as more detailed current measurements are made we shall have to adopt a more flexible approach to the charting of residual current systems that takes account of the relationship between wind and surface water movements from week-to-week rather than month-to-month.

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OPERATION RHENO

MOORED CURRENT METER STATION
AND DYE RELEASE POINT

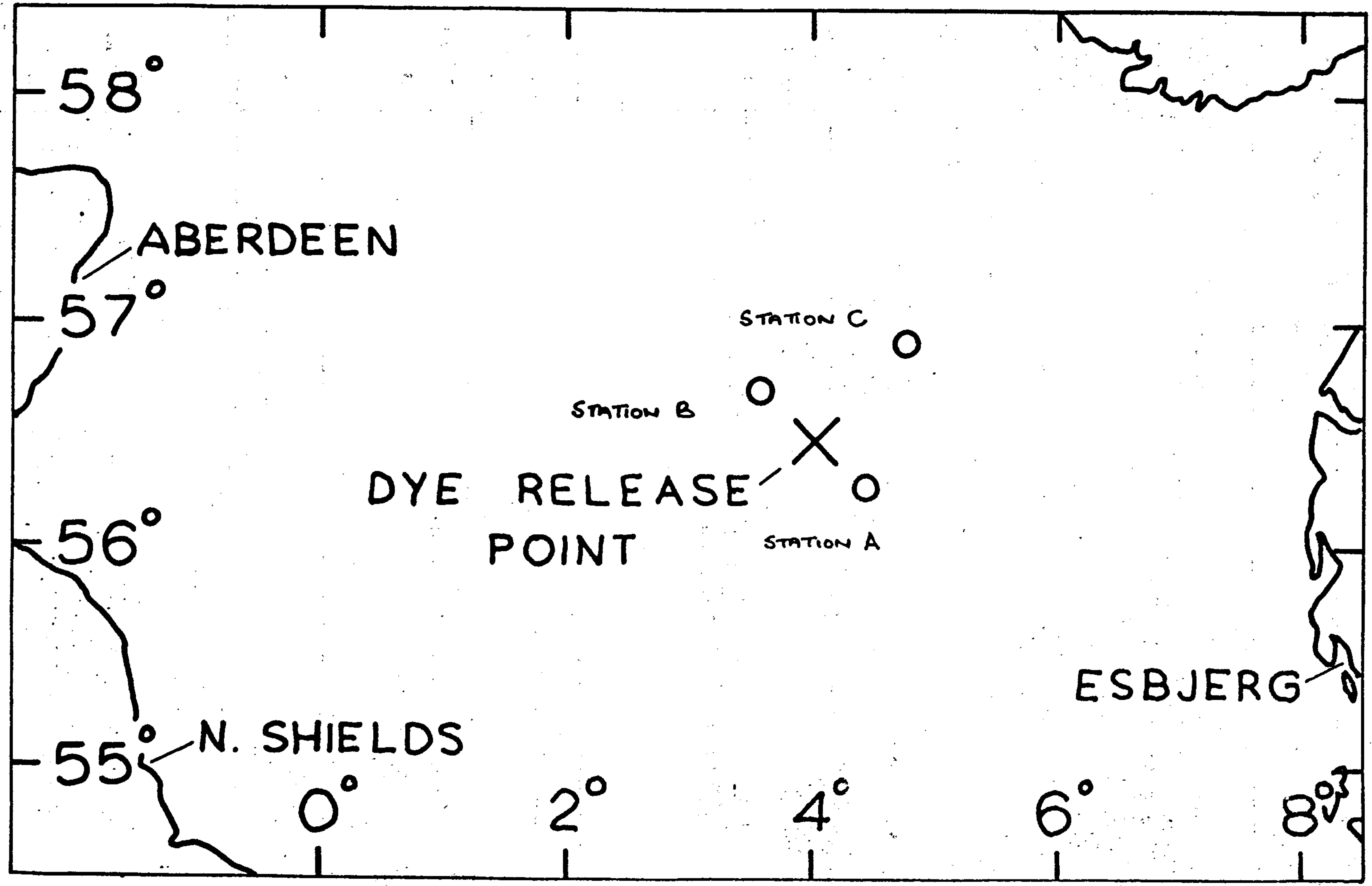
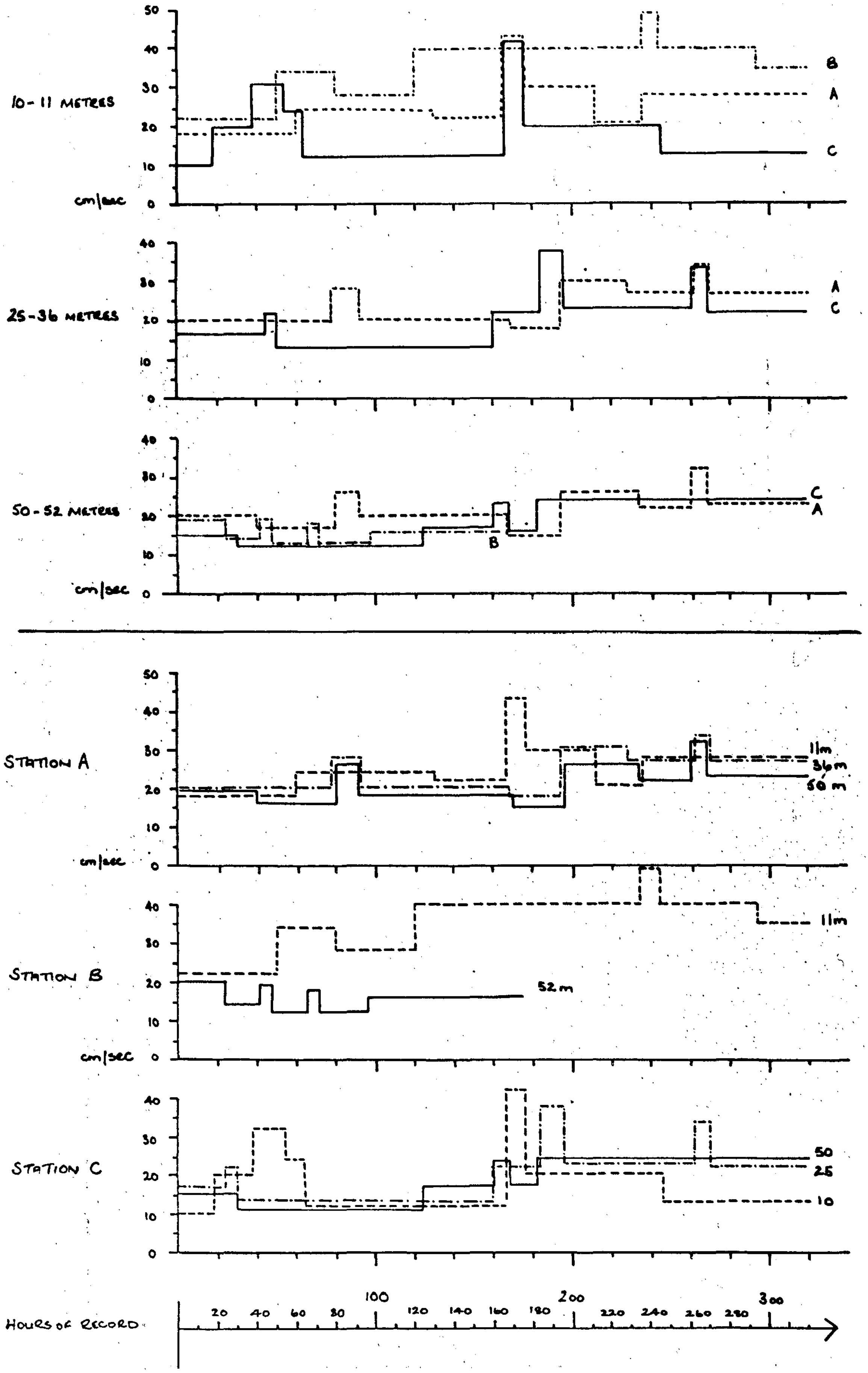


FIG. 1.

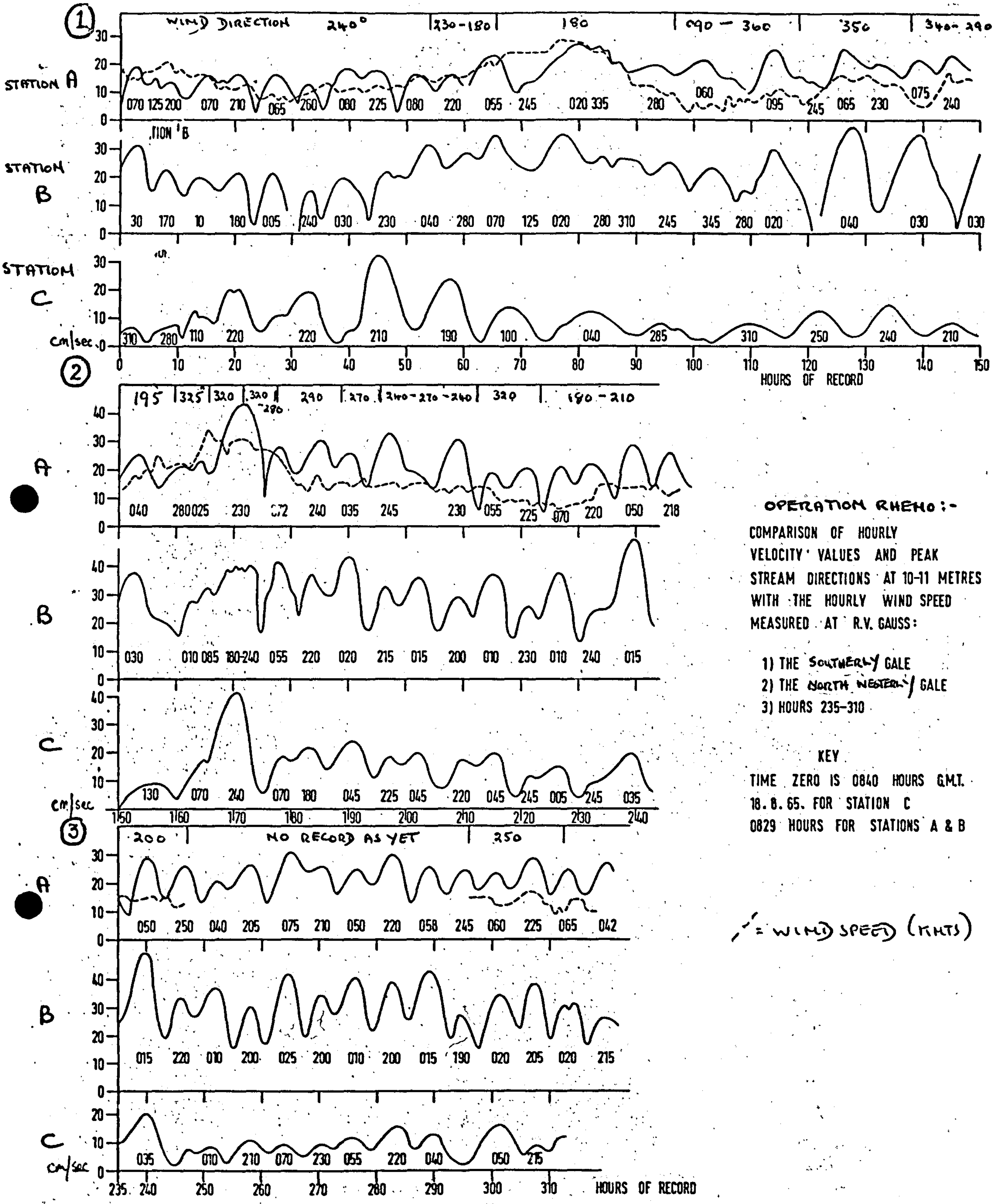
683557



COMPARISON OF THE GENERAL LEVELS OF THE DOMINANT PEAK VELOCITY LEVELS AT EACH RECORDING LEVEL AND EACH STATION

FIG. 2.

683557



OPERATION RHENO :-

COMPARISON OF HOURLY VELOCITY VALUES AND PEAK STREAM DIRECTIONS AT 10-11 METRES WITH THE HOURLY WIND SPEED MEASURED AT R.V. GAUSS:

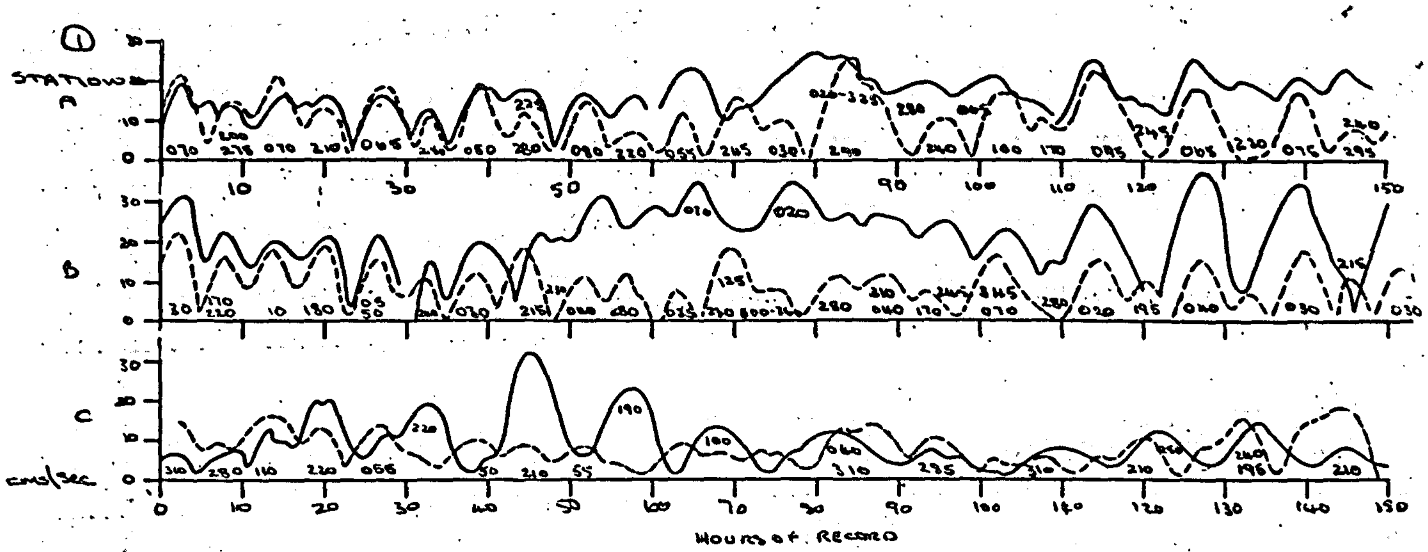
1) THE SOUTHERLY GALE
2) THE NORTH WESTERLY GALE
3) HOURS 235-310

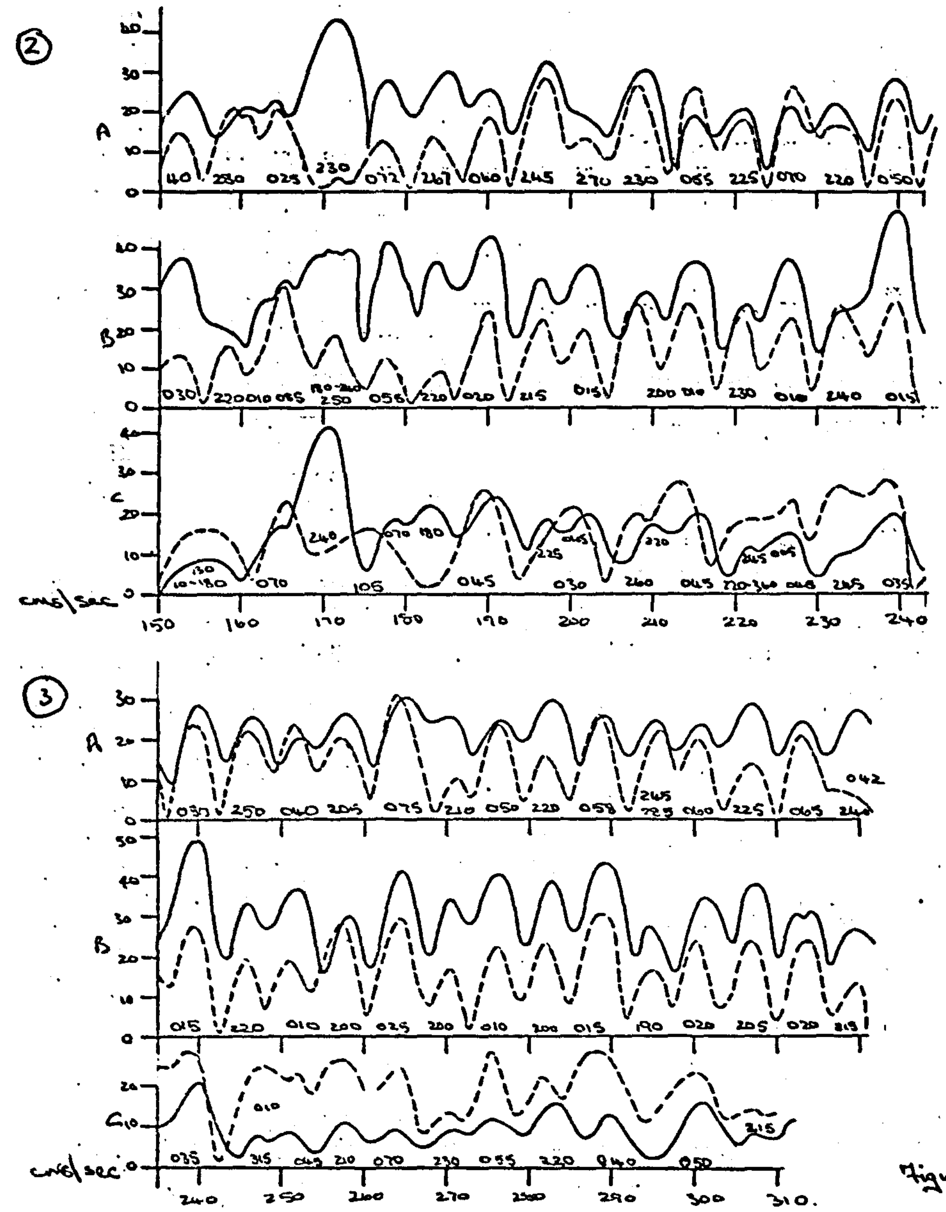
KEY

TIME ZERO IS 0840 HOURS G.M.T. 18. 8. 65. FOR STATION C
0829 HOURS FOR STATIONS A & B

- - = WIND SPEED (KNTS)

FIG. 3





OPERATION RHENO

NEAR-SURFACE AND NEAR BOTTOM HOURLY VELOCITY VALUES AND PEAK STREAM DIRECTIONS AT STATIONS A, B AND C.

①. THE SOUTHERLY GALE

②. THE NORTH WESTERLY GALE

③. HOURS 235-310.

KEY.

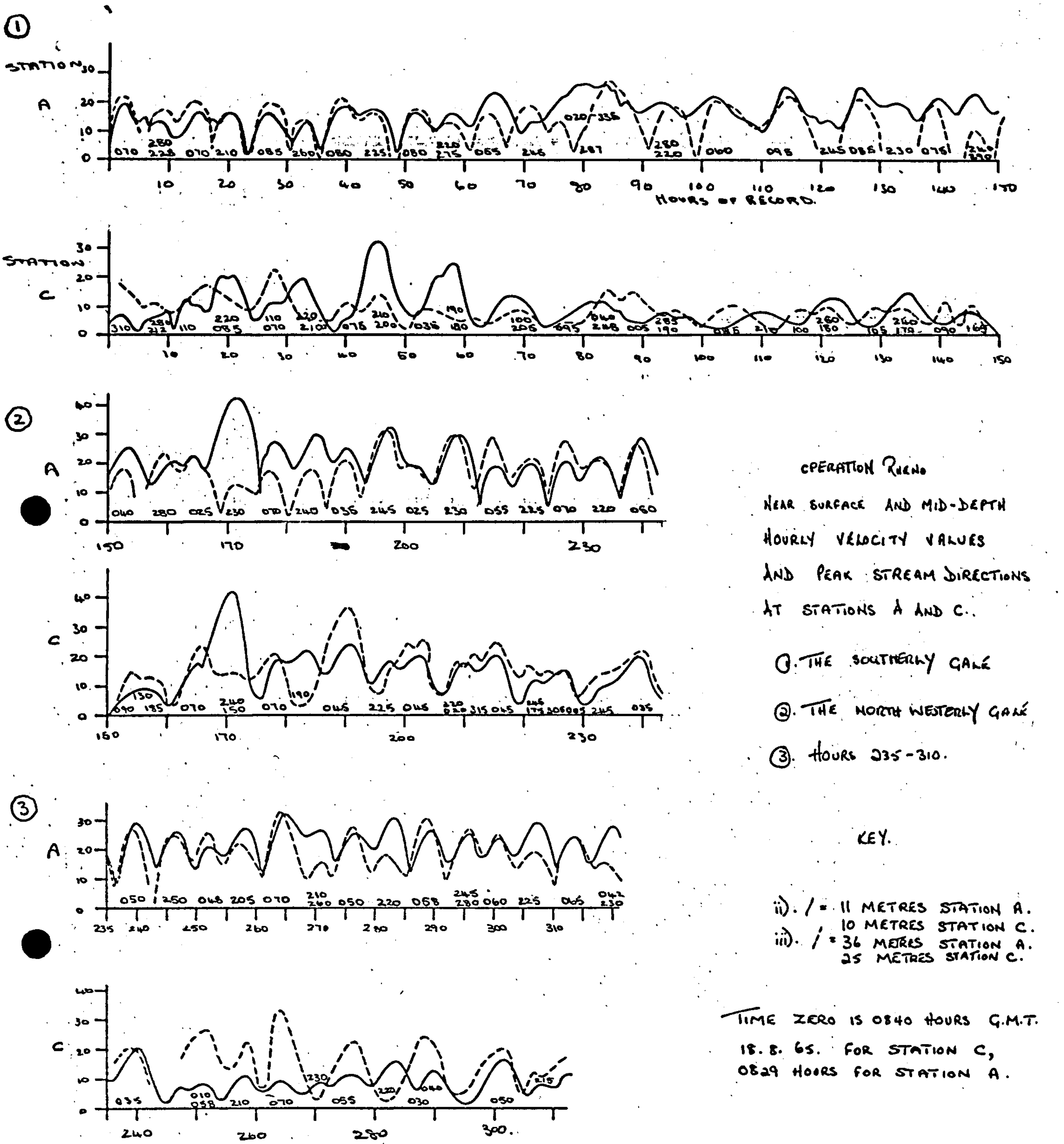
i). /= 11 METRES STATIONS A AND B.
10 METRES STATION C.

ii). / = 52 METRES STATIONS A AND B.
50 METRES STATION C.

TIME ZERO IS 0840 HOURS G.M.T. 18.8.65. FOR STATION C, 0829 HOURS FOR STATIONS A AND B.

Figures are peak direction values at 10 metres and are ± 30° those at near bottom EXCEPT where a lower figure is shown. This value is the peak direction at near bottom.

FIG. 4.



Figures are peak direction values at 10 metres and are ± 30° those at mid-depth EXCEPT where a lower figure is shown. This value is the peak direction at mid-depth.

FIG. 5

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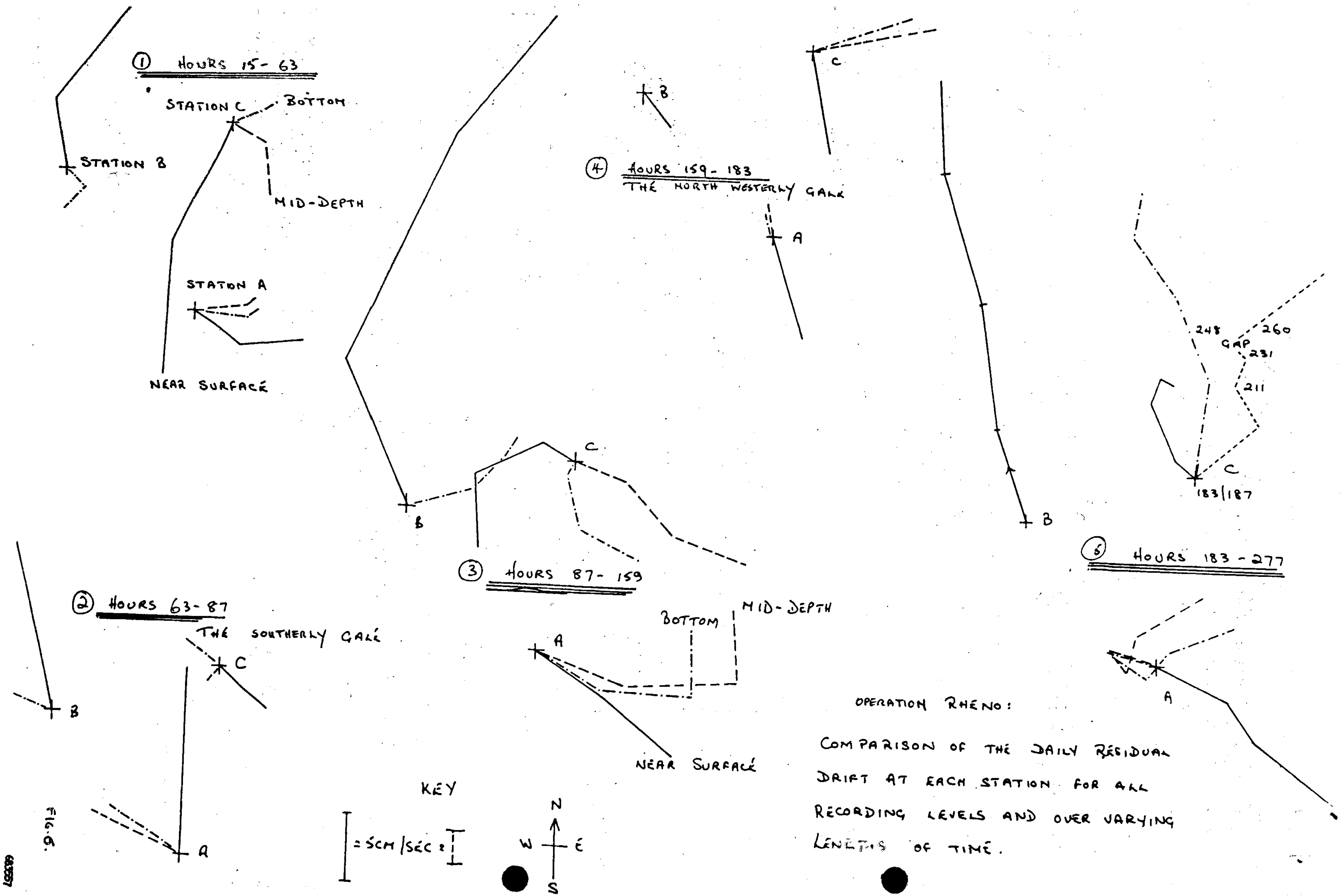

OPERATION RHENO:

COMPARISON OF THE DAILY RESIDUAL DRIFT AT EACH STATION FOR ALL RECORDING LEVELS AND OVER VARYING LENGTHS OF TIME.

FIG. 6.

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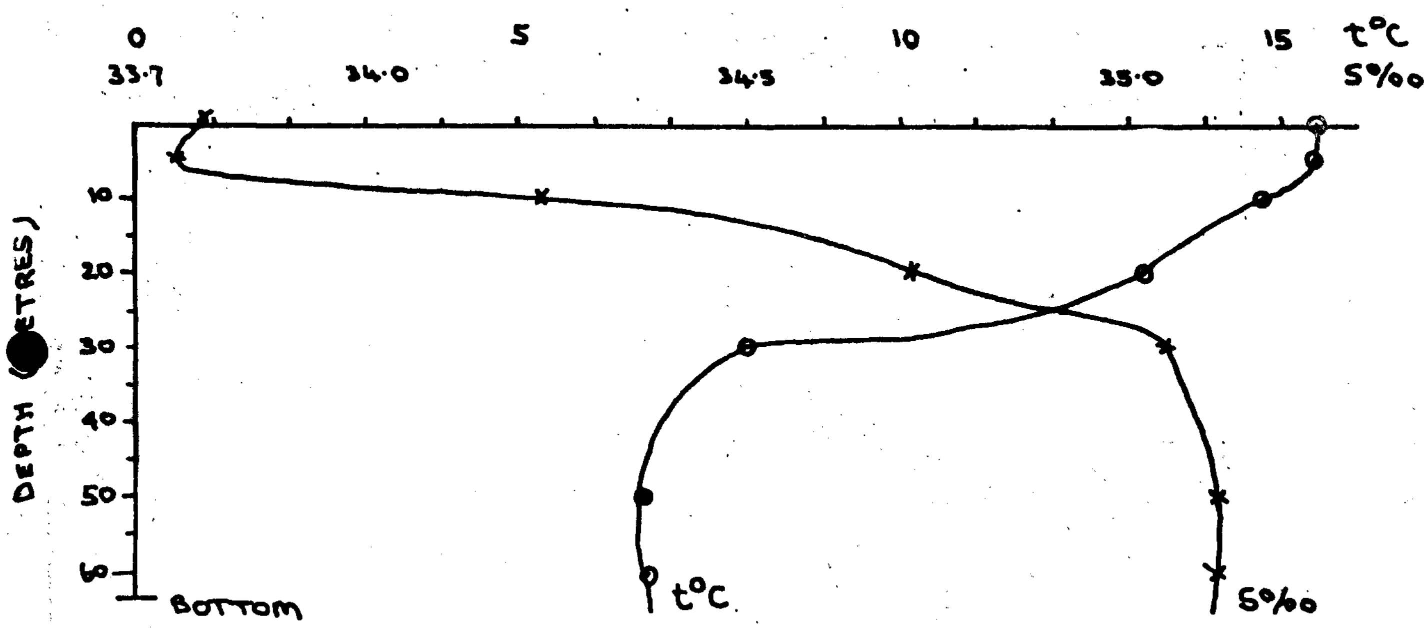
OPERATION RHENO

VERTICAL DISTRIBUTION OF TEMPERATURE AND SALINITY AT STATION C.

a) 18.8.65.



b) 31.8.65

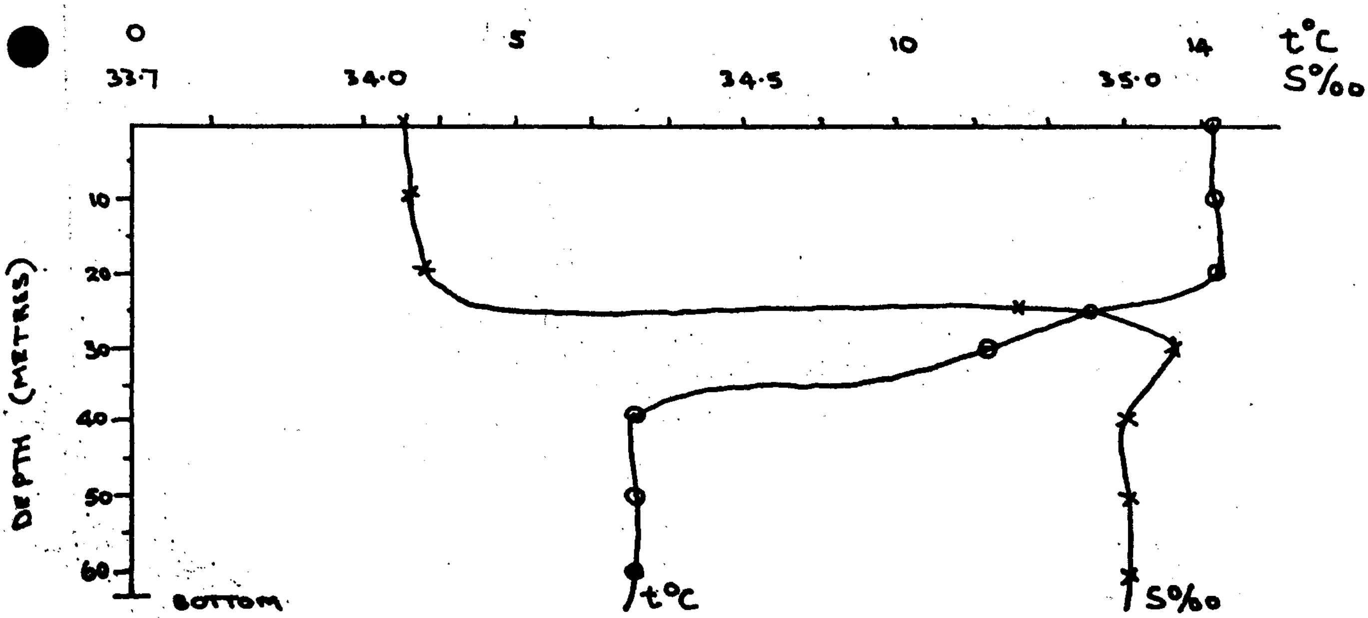


FIG. 7

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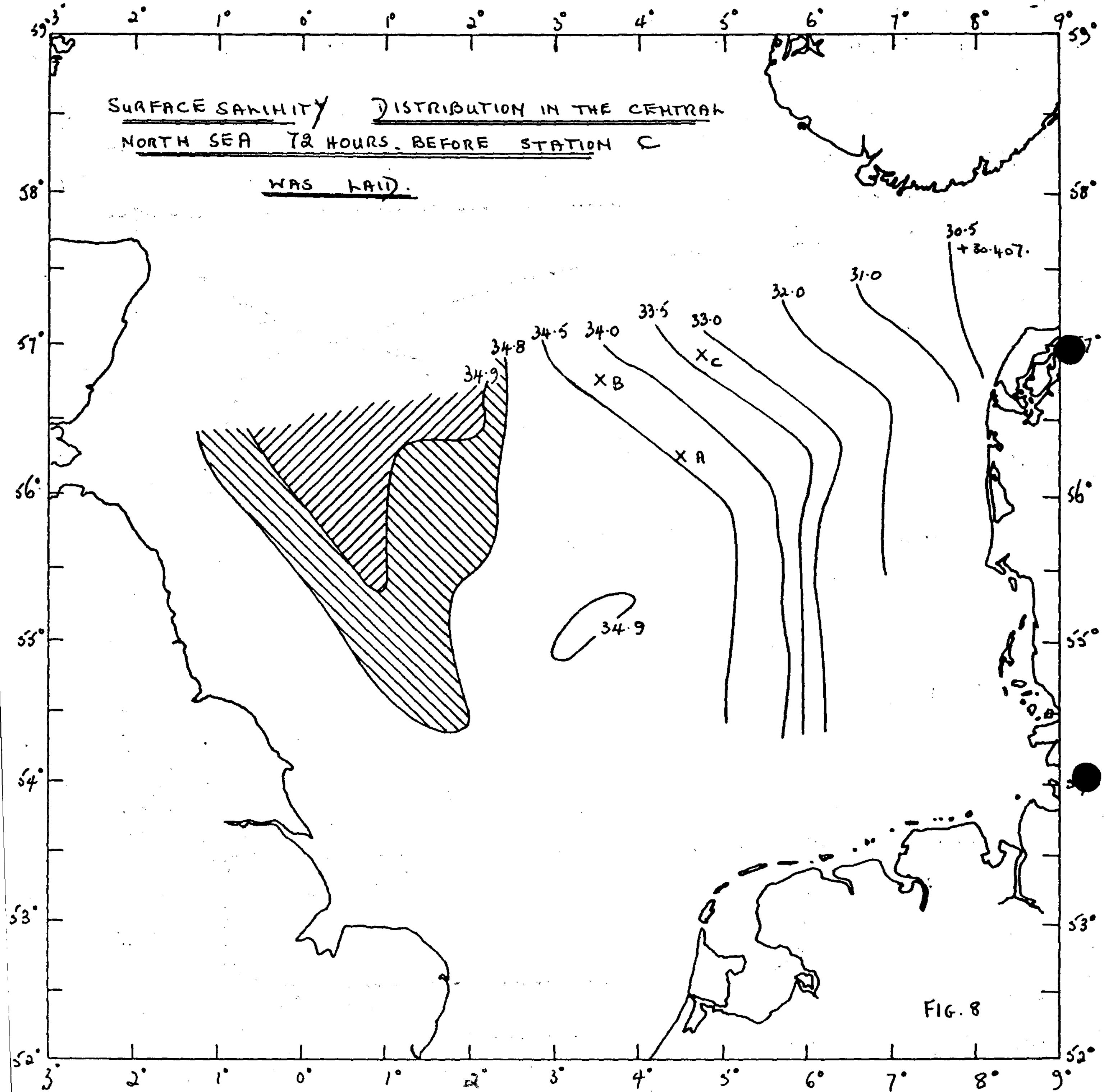
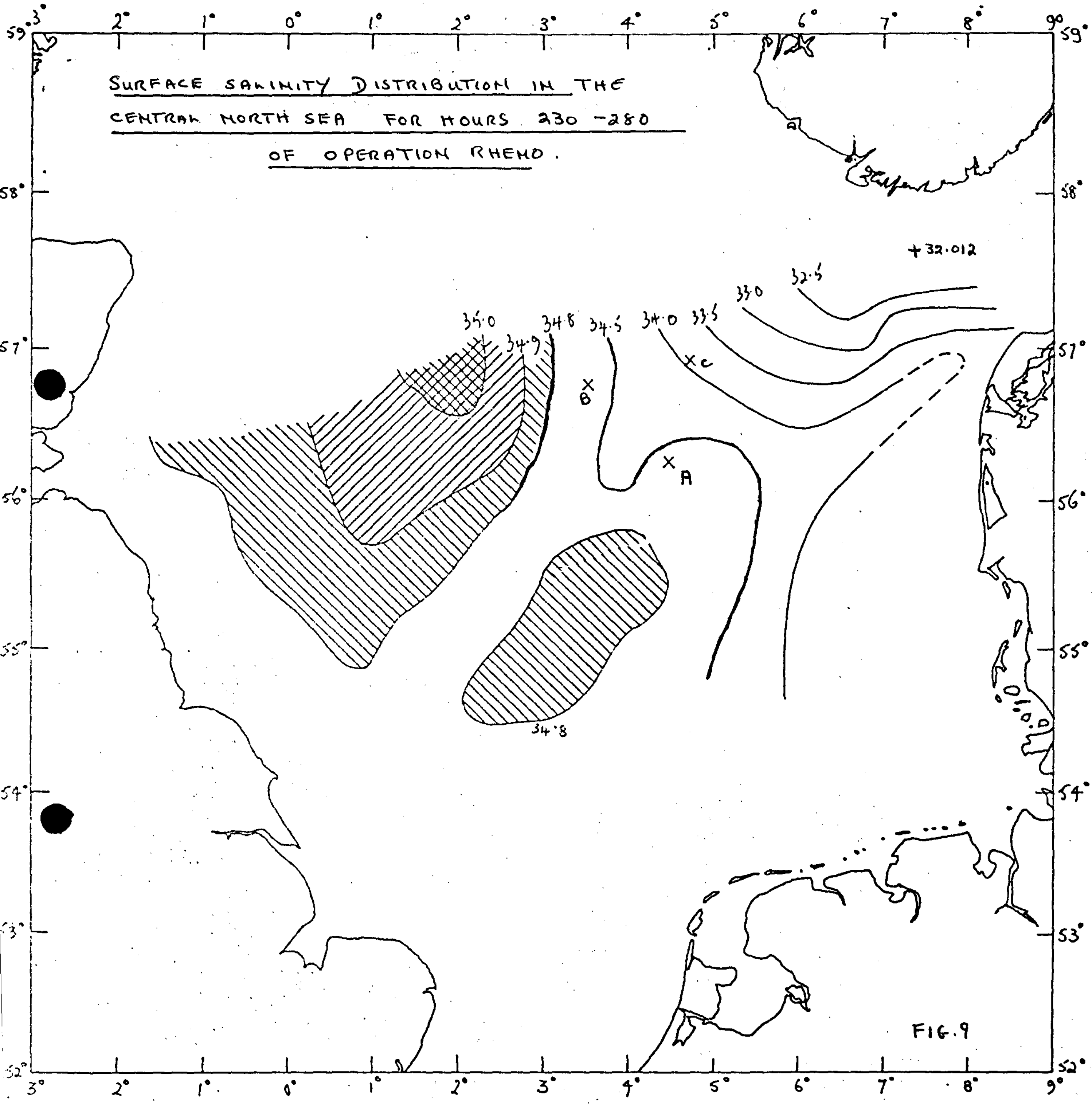


SURFACE SALINITY DISTRIBUTION IN THE CENTRAL NORTH SEA 72 HOURS BEFORE STATION C WAS LAID.
30.5
+ 30.407.
31.0
32.0
33.5
33.0
34.5
34.0
34.8
34.9
x B
x C
x A
34.9
59°
58°
57°
56°
55°
54°
53°
52°
3°
2°
1°
0°
1°
2°
3°
4°
5°
6°
7°
8°
9°

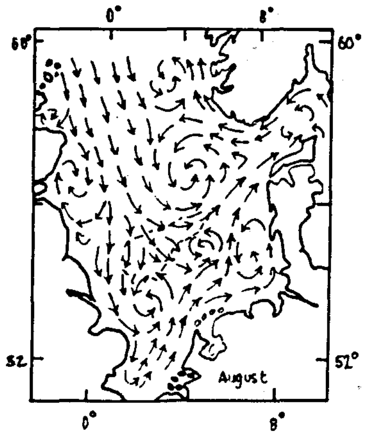
FIG. 8

683557


SURFACE SALINITY DISTRIBUTION IN THE CENTRAL NORTH SEA FOR HOURS 230 -280 OF OPERATION RHENO.
34.0
34.9
34.8
34.5
34.0
33.5
33.0
32.5
+32.012
A
B
C
34.8
FIG. 9

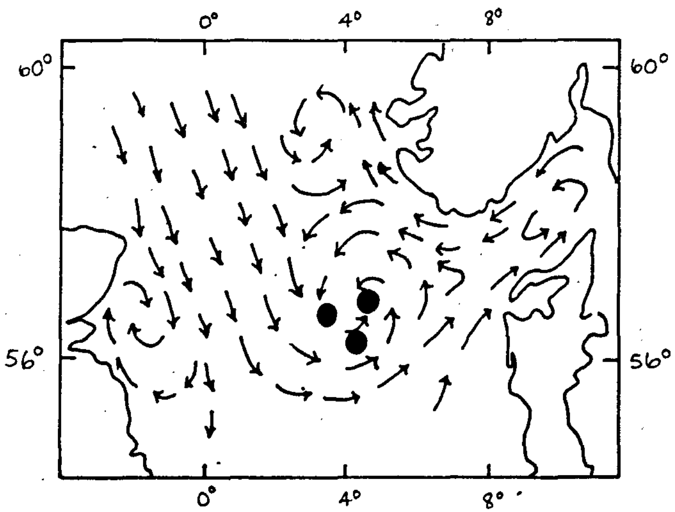
683557

RESIDUAL SURFACE DRIFT PATTERNS SOUTH OF NORWAY
IN AUGUST AS PROPOSED BY BÖHNECKE AND AS
INFERRED FROM THE RHENO CURRENT MEASUREMENTS

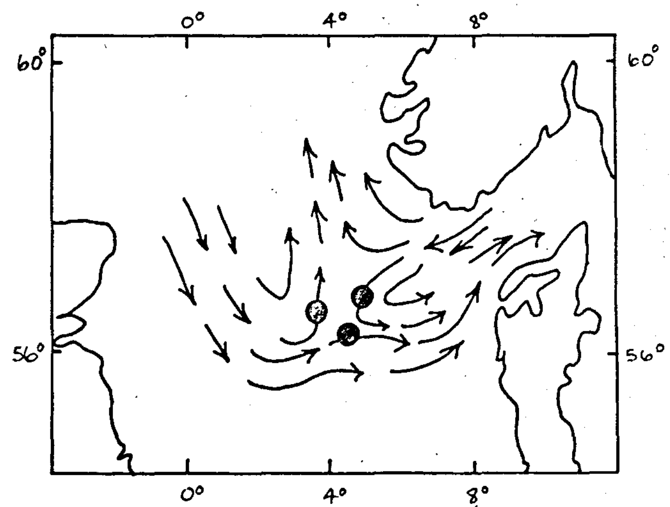


KEY ● MOORED CURRENT METER STATIONS

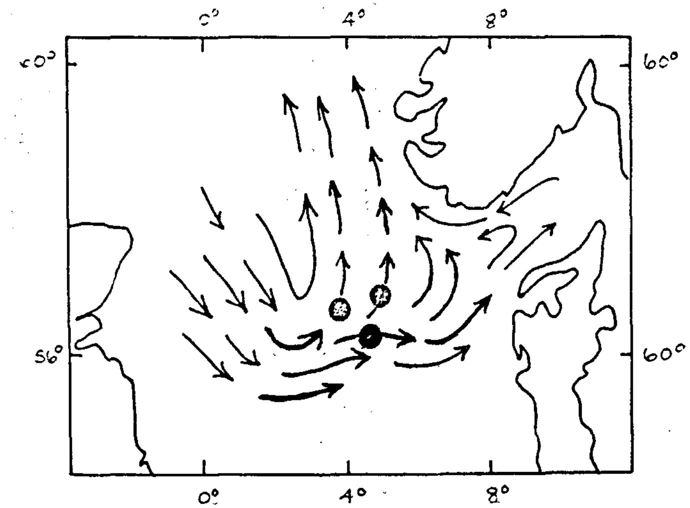
BÖHNECKES PATTERN FOR THE WHOLE OF THE NORTH SEA IN AUGUST



AUGUST 1902 – 1914



AUGUST 1965
BEFORE THE NORTH WESTERLY GALE



AUGUST 1965
AFTER THE NORTH WESTERLY GALE.

FIG. 10.

RESIDUAL PATTERNS FOR THE RHENO AREA

683557