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HYDROGRAPHIC INVESTIGATIONS IN THE IRMINGER SEA IN THE YEARS 1954–1964.

By

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INTRODUCTION

The first recorded oceanographic work in the Irminger Sea was carried out in 1853 under the charge of the Danish admiral C. IRMINGER. G. DIETRICH (1957) has given a summary of all investigations made in the area since that time. From this it is evident that the main hydrographic structure of the Irminger Sea was known before the turn of the century. Later, research has concentrated on different details, but most papers dealing with the area have been based on data from only one cruise.

During the years 1959–1964 research vessels from the Institute of Marine Research, Directorate of Fisheries, Bergen, have carried out 5 cruises in the Irminger Sea. All of these took place at the same time of the year. The data collected may therefore be used for studies of annual variations.

Also, at Ocean Weather Station Alpha, in latitude 62° N, longitude 33° W, hydrographic observations have been made during 5 periods. (For convenience, Ocean Weather Station Alpha will hereafter be mentioned as Station A.) The major part of these periods also cover the same season, and altogether the data from Station A and the above mentioned cruises embrace the period from 1954 to 1964. Therefore it has been found worthwhile to examine them with regard to annual variations in the area.

MATERIAL AND METHODS

On the mentioned cruises the following numbers of hydrographic stations were worked: 27 in 1959, 23 in 1961, 46 in 1962, 58 i 1963 and 58 in 1964. In 1959 some of the observations were made in the first half of July, the remainder of the programme being carried out in the middle of August. In the years 1961–1964 all sections were worked between 15th. August and 10th. September. Fig. 1 shows the station grid in 1963 and 1964. The station grids for the other years, however, differed to some extent. The section across the Denmark Strait was worked only in 1963 and 1964. In 1959 and 1961 no section was worked off Cape

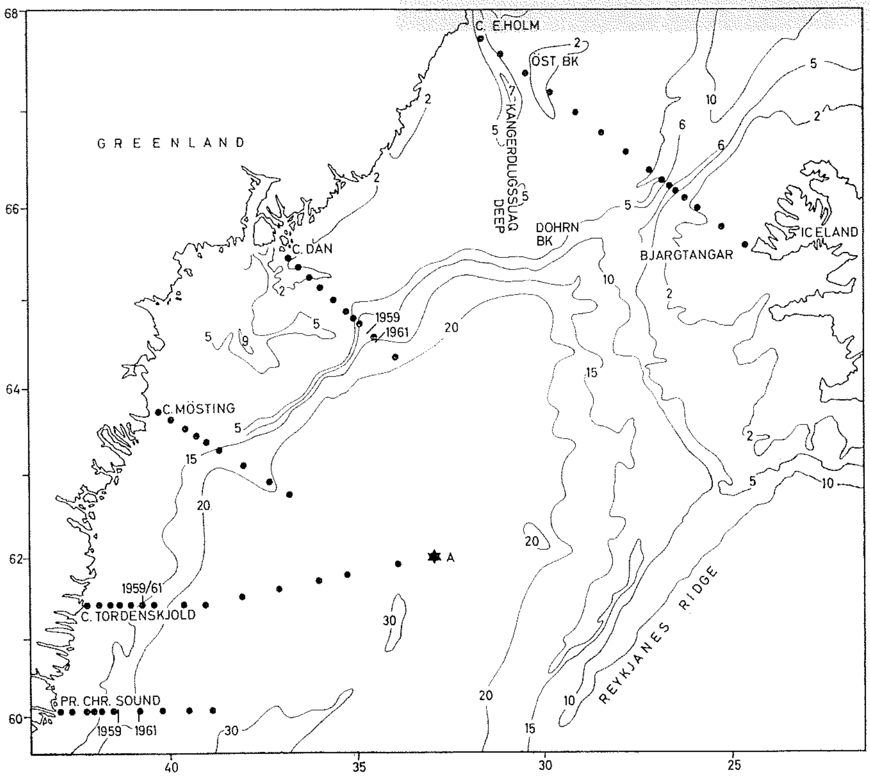

Fig. 1. Station grid for 1963 and 1964. Positions of outer stations of the sections for 1959 and 1961 are indicated. Main bathymetric features after fishery chart published by Deutsches Hydrographisches Institut, 1958. Depths in hectometres.

Møsting, and in these years the sections off Cape Dan, Cape Tordenskjold and Prince Christians Sound were shorter than in the other years. In Fig. 1 their extent is indicated by symbols in the positions of the outer stations of the sections.

On all cruises the observations were made by the usual method, Nansen reversing water bottles being used. Each water sampler was equipped with two protected reversing thermometers. No unprotected thermometers were used, but when the observations were made, the ship was always manoeuvered so that the wire was close to the vertical. At the hydrographic stations samples were usually taken at all standard depths to the bottom.

The observational work at Station A was arranged by the Institute of Geophysics, University of Bergen. The data were collected in the course of the 5 following periods when O. W. S. «Polarfront I» and O. W. S. «Polarfront II» served at the Station:

1. From 2nd July to 29 th December 1954.
2. From 3rd July 1956 to 2nd January 1957.
3. From 20th June to 16th December 1958.
4. From 21st June to 28th December 1960.
5. From 1st November 1962 to 13th April 1963.

On an average the weather ships carried out serial observations 18 times per month during these 5 periods, and altogether a total of 549 hydrographic stations were worked. At 100 of these stations samples were taken at the standard depths to 2 000 m, 346 stations were sampled at the depths 0, 50, 150, 300, 600 and 1 000 m, and at the remaining 103 stations the standard depths to 150 m were sampled.

The data from the above cruises will be available through ICES, and the data from Station A will be published by the Institute of Geophysics, University of Bergen.

THE WATER MASSES

Several different water masses enter the Irminger Sea. The more important of these are (1) Atlantic water which derives its properties in much lower latitudes, and (2) Polar water, most of which originates in polar regions.

Atlantic water is characterized by high temperature and high salinity, but in the Irminger Sea all water types with salinity above 35.00 $^0/_{00}$ are recognized as Atlantic water regardless of temperature. When entering the Irminger Sea in the region of the Reykjanes Ridge, Atlantic water exhibits salinities above 35.20 $^0/_{00}$. At Station A which is situated near the westward border of the eastern bulk of Atlantic water in the Irminger Sea, the highest salinities are about 35,18 $^0/_{00}$ with temperatures between 7° and 8° C. Off Prince Christians Sound maximum salinities usually lie between 35.05 $^0/_{00}$ and 35.10 $^0/_{00}$ and temperatures between 6° and 7° C.

Polar water is characterized by low temperature and low salinity. In the Denmark Strait values of about — 1,7° C and 33,5 $^0/_{00}$ are usually observed in its core. Further south the Polar watermass is, however, constantly eroded by mixing, and in summer the surface layer is heated by solar radiation. At this time of the year it is therefore difficult to give exact definition of Polar water in the Irminger Sea. It seems, however, practical to take 34.50 $^0/_{00}$ as the upper limit of its salinity.

Artic Bottom water is observed in the two sections across the Denmark Strait. In the deepest part of the channel through the Iceland — Greenland Ridge this shows temperatures below 0° C and salinities around 34.92 $^0/_{00}$, which are in good agreement with the accepted definition of the Artic Bottom water (HELLAND-HANSEN and NANSEN 1909).

Artic Intermediate water comes originally from a branch of the West Spitsbergen Current. According to STEFANSSON (1962 a) its temperature ranges from 0.0° to 2.0° C and its salinity from 34.8 $^0/_{00}$ to 35.0 $^0/_{00}$ in the area north of the Denmark Strait. In the Denmark Strait, however, this water has a greater admixture of Polar water, so that its temperatures are near or below 1° C and its salinities chiefly below 34.90 $^0/_{00}$. This is demonstrated by the T—S relation in Fig. 2. Artic Intermediate water, as defined by STEFANSSON, is represented by a rectangle in the Figure.

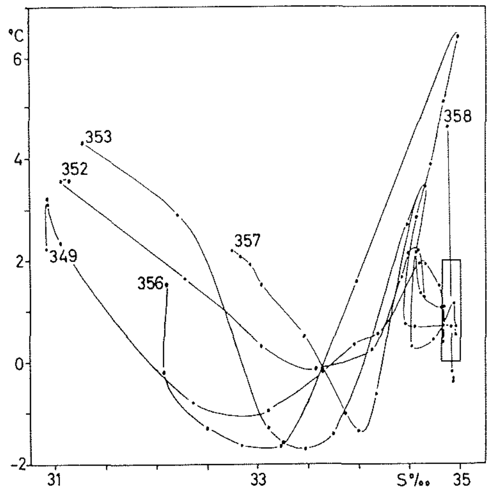

Fig. 2. T—S diagram for some stations from the section across the Denmark Strait in 1964. Arctic Intermediate Water is marked by a rectangle.

The intermediate water in the Irminger Sea forms a layer of minimum salinity at depths around 1 000 m in the central parts of the region. This water mass is characterized by a temperature of 3.5° C and a salinity of about 34.88 $^0/_{00}$ as shown by the T–S relation of observations from Station A in Fig. 3. The point of intersection of the two lines embracing the cloud of points in the Figure, indicates the characteristics of the intermediate water in 1954. Corresponding T–S diagrams for the other observational periods all give salinities slightly above 34.88 $^0/_{00}$ and temperatures between 3.45 and 3.55°C. This is in agreement with the definition given by SVERDRUP, JOHNSON and FLEMING (1946). SMITH, SOULE and MOSBY (1937), however, have studied the intermediate water in the Labrador Sea, where it is formed, and conclude that temperatures near 3.2°C and a salinity of 34.88 $^0/_{00}$ are typical characteristics.

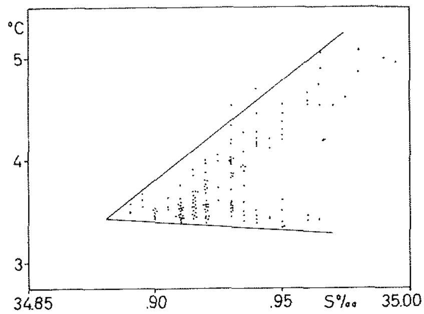

Fig. 3. T—S diagram demonstrating the characteristics of intermediate water at Station A. Observations between 400 and 2000 m depth from 1954 are plotted.

The deep water in the Irminger Sea is found at depths between approximately 1 500 and 2 500 m. It differs from the intermediate water by its higher salinity. The most saline deep water occurs at about 2 000 m depth where the salinity is significantly in excess of 34.90 $^0/_{00}$. At Station A extremely high salinities reach 34.97 $^0/_{00}$ to 34.98 $^0/_{00}$ at this depth, and the mean temperature and salinity for the 5 periods are 3.43°C and 34.943 $^0/_{00}$ respectively.

Cooper (1955), also Lee and Ellet (1965), have shown that this water mass comes from the north-eastern basin of the North Atlantic.

The bottom water of the Irminger Sea has its main source in the Arctic Intermediate water, but Arctic Bottom water is also of importance. Both these water masses overflow the Iceland–Greenland Ridge and sink to the bottom in the Irminger Sea, but Arctic Bottom water only intermittently. At the foot of the continental slope the salinities of the bottom water in the Irminger Sea are often below 34.90 $^0/_{00}$ and the associated temperatures lie between 1 and 2°C.

THE HYDROGRAPHIC SECTIONS

Between Prince Christians Sound and Cape Dan the hydrographic sections have several features in common. Polar water is always found over the shelf, while the core of the Atlantic water of the western branch of the Irminger Current is found off the edge of the shelf where it occupies the zone over the continental slope. The 34.5 $^0/_{00}$ isohaline seems to be the dividing line between Polar water and Atlantic water in this area. At the sea surface this isoline is in most cases found over the edge of the shelf.

In 1959 and 1961 the sections had only one or two stations outside the shelf, and gave little information about the Atlantic water in the western branch of the Irminger Current. In the later years, however, the sections extended farther out to sea, and off Cape Tordenskjold and Prince Christians Sound they cut through the core of Atlantic water in the western branch of the Irminger Current.

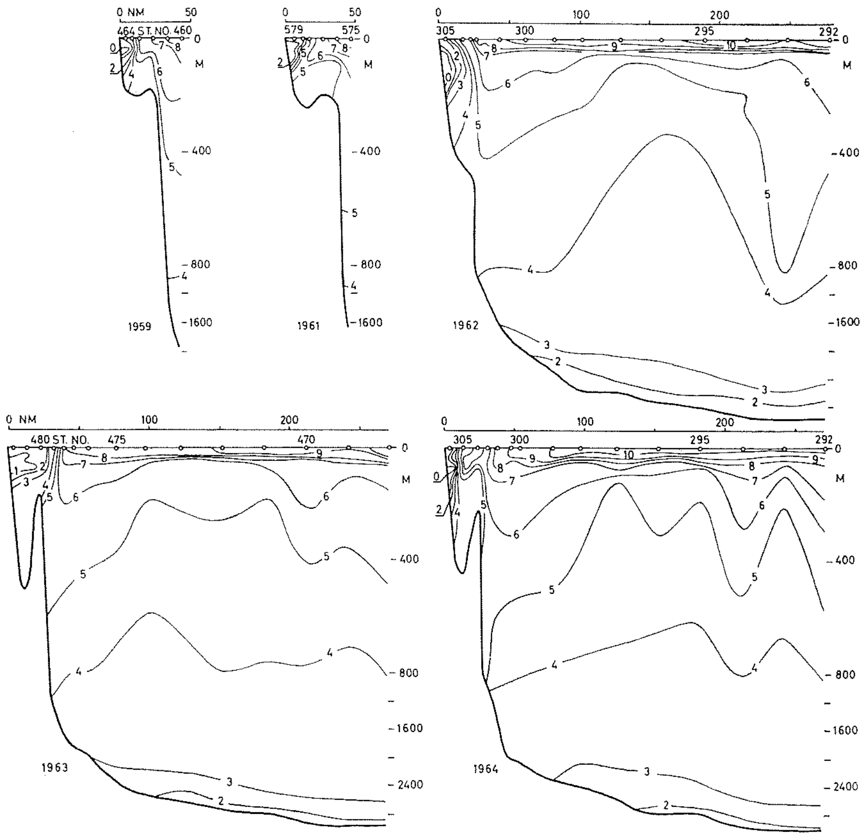

Fig. 4. Temperatures off Cape Tordenskjold in the years 1959 and 1961—1964.

The sections off Cape Tordenskjold are illustrated in Fig. 4 and 5. The lowest salinities close to the coast vary between 28.07 $^0/_{00}$ and 31.55 $^0/_{00}$ with associated temperatures between 1.65° and 3.50°C. As shown in Table 1, the lowest temperature of the Polar water is found at depths between 50 and 125 m, varying between – 0.39° and 1.58° C with salinities from 32.98$^0/_{00}$ to 33.66 $^0/_{00}$. In the different sections the width of the Polar water in the East Greenland Current is from 20 to 40 nautical miles, the 34.5 $^0/_{00}$ isohaline at the surface being found between these distances from the shore. With depth this isohaline is usually inclined to the vertical and meets the bottom on the inner part of the shelf.

Table 1. Characteristic values in the sections: minimum temperature in the Polar Water, observation depth in brackets, with associated salinity. Maximum salinity in the Atlantic water, observation depth in brackets, with associated temperature. Greatest vertical extent of the Atlantic water in the sections.

Section	Year	Polar Water: Min. temp. t°C	Polar Water: Associated sal. $^0/_{00}$	Atlantic Water: Max. sal. $^0/_{00}$	Atlantic Water: Associated temp. t°C	Atlantic Water: Vertical extent. m
Prince Chr. Sound	1959	+0.19 (30)	32.40	35.09 (150)	6.35	0 – 700
	1961	+1.22 (75)	32.36	35.11 (50)	6.46	0 – 700
	1962	– 0.76 (75)	33.35	35.07 (100)	6.46	40 – 600
	1963	– 0.59 (125)	33.37	35.07 (125)	6.29	60 – 300
	1964	+0.89 (75)	33.87	35.07 (150)	7.12	40 – 340
Cape Tordenskjold	1959	– 0.25 (50)	33.00	35.09 (250)	5.77	0 – 630
	1961	+1.58 (75)	33.08	35.10 (125)	6.46	0 – 250
	1962	– 0.39 (125)	33.34	35.06 (100)	6.51	50 – 400
	1963	+0.08 (75)	33.66	35.06 (150)	6.50	70 – 300
	1964	– 0.08 (75)	32.98	35.06 (125)	6.87	0 – 400
Cape Møsting	1962	+1.34 (75)	34.07	35.08 (125)	6.47	50 – 800
	1963	+1.54 (50)	33.82	35.06 (100)	6.61	75 – 375
	1964	+0.29 (75)	33.78	35.10 (125)	7.28	60 – 500
Cape Dan	1959	– 1.15 (20)	32.27	35.13 (75)	7.80	0 – 600
	1961	– 0.50 (0)	28.95	35.19 (150)	7.47	0 – 650
	1962	– 1.49 (50)	33.52	35.10 (150)	6.77	0 – 1000
	1963	– 0.85 (30)	33.75	35.11 (200)	6.95	30 – 650
	1964	– 1.52 (75)	33.43	35.15 (100)	7.76	0 – 600

The highest salinities in the Atlantic water have values from 35.06 $^0/_{00}$ to 35.10 $^0/_{00}$, and they are found at depths between 100 and 125 m. The corresponding temperatures vary between 5.8°C and 6.9°C. Table 2 shows that the mean salinity of the Atlantic water varies between 35.020 $^0/_{00}$ and 35.050 $^0/_{00}$. The highest salinity was observed in 1961, while 1962 and 1963 had the lowest values both in actual observations and in mean values. Fig. 5 shows that there was Atlantic water at the surface in the years 1959, 1961 and 1964. In the two remaining years Atlantic water was observed only at subsurface depths, its upper limit being at 50 to 100 m. The 1959 section was very short and did not reach far into the Atlantic water, but in spite of this it shows a vertical extent of the Atlantic water exceeding 600 m, the greatest extent found in any of the 5 years.

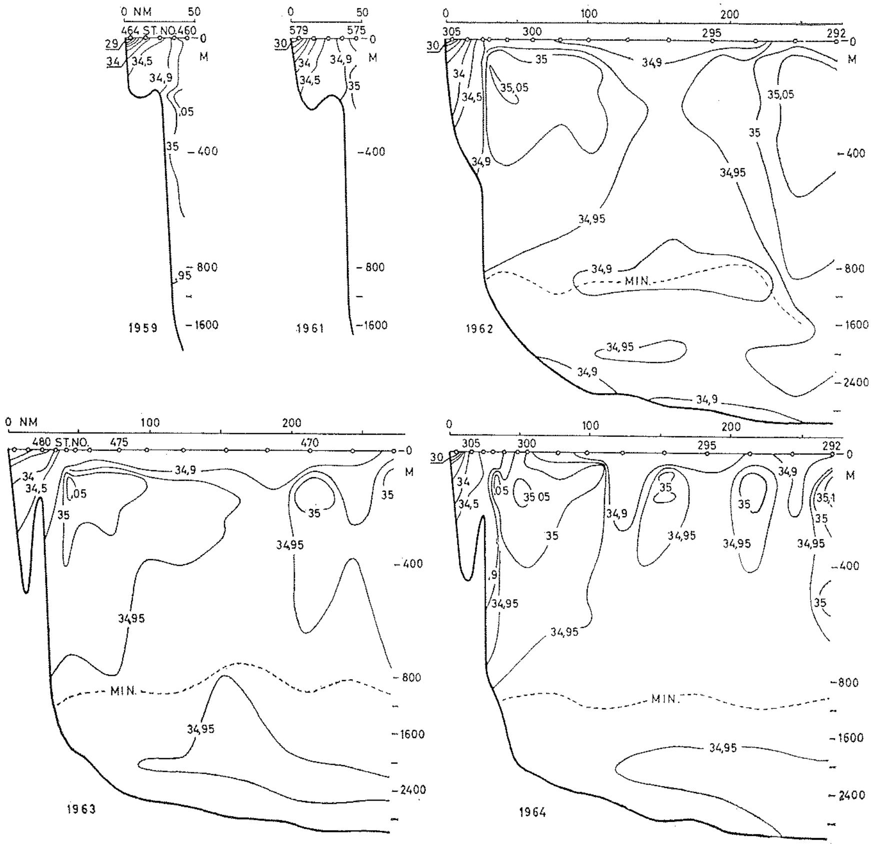

Fig. 5. Salinities off Cape Tordenskjold in the years 1959 and 1961—1964.

In the years when the sections were extended to Station A, they show that the eastward limit of the Atlantic water of the western branch of the Irminger Current is found between 100 and 115 nautical miles off Cape Tordenskjold. Farther to the east there are less saline waters

Table 2. Mean salinity of the Atlantic Water in different years and sections.

Year	Prince Chr. Sound	Cape Tordenskjold	Cape Dan
1959	35.032	35.050	35.117
1961	35.047	—	35.089
1962	35.033	35.020	35.044
1963	35.022	35.020	35.049
1964	35.032	35.032	35.051

where the salinity may decrease to values below 34.95 $^0/_{00}$, and even below 34.80 $^0/_{00}$ in the surface layer. In the eastern part of the sections Atlantic water is again observed, its extent varying much in the three sections. In 1962 when its extent was greatest, the Atlantic water was found about 60 nautical miles westwards from Station A. Vertically, its greatest extent was from 25 to 800 m depth. Salinities up to 35.07 $^0/_{00}$ were observed with temperatures around 6° C. In 1963 there was very little Atlantic water in the eastern part of the section, and it was observed only at two stations between 75 and 200 m depth, its salinities not exceeding 35.02 $^0/_{00}$. In 1964 several cores of Atlantic water were observed, and at Station A it was observed down to 500 m. At 100 m the salinity was 35.13 $^0/_{00}$.

In the sections from 1962, 1963 and 1964 the depth of minimum salinity in the intermediate water is marked out by a dashed line as shown in Fig. 5. On an average it was found at a depth of approximately 1 000 m. The salinity of the intermediate water showed only small variability, but in 1962 it was a little lower than in the two following years.

The deep water in the sections between Cape Tordenskjold and Station A is indicated by salinities in excess of 34.95 $^0/_{00}$. The sections show that its extent varies both horizontally and vertically. In 1963 and 1964 there seemed to be greater quantities than in 1962.

The lower limit of the deep water is indicated by an increase in the vertical temperature gradient. The reason for this is mixing with the colder bottom water which, from 2 500 m downwards becomes more and more dominant. As shown by Fig. 4 temperatures near the bottom were below 2°C. The influence of the bottom water was especially pronounced in the 1962 section where it exhibited salinities below 34.90 $^0/_{00}$ at several stations. In the other sections its salinity was about 34.90 $^0/_{00}$.

The sections off Prince Christians Sound and Cape Møsting show conditions which are very much the same as those in the western part of the sections off Cape Tordenskjold. A more detailed description of the distribution of temperature and salinity will therefore be omitted. The extreme values of temperature and salinity etc. in these sections are, however, given in Table 1.

The sections off Cape Dan are illustrated in Fig. 6 and 7, and minimum temperatures of the Polar water and maximum salinities of the Atlantic water are given in Table 1. From these it is seen that the lowest temperatures in the Polar water are found in the shelf area at depths between 0 and 75 m. These minimum temperatures vary between — 0.50 and — 1.25° C, and associated salinities lie between 28.95 $^0/_{00}$ and 33.75 $^0/_{00}$. Fig. 7 shows that the Polar water extends farther out to sea in this area than in the sections farther south, and there is often more

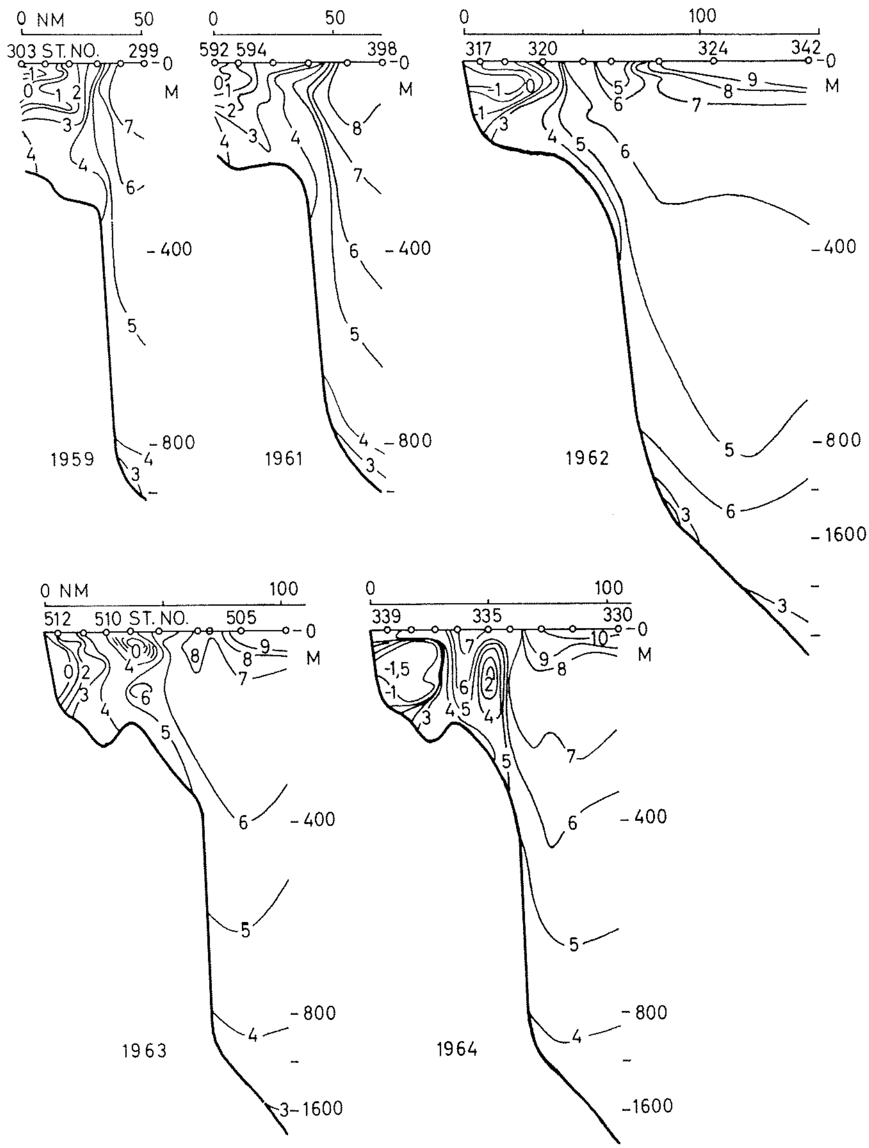

Fig. 6. Temperatures off Cape Dan in the years 1959 and 1961—1964.

than one core of cold water. In these sections the 34.5 ‰ isohaline meets the surface between 60 and 75 nautical miles off Cape Dan.

Compared with the sections farther south the Atlantic water has a great horizontal extent off Cape Dan, and in all the years except 1963, it reached to the surface. Because of the varying length of the sections in the different years, it is not possible to say in which year the Atlantic

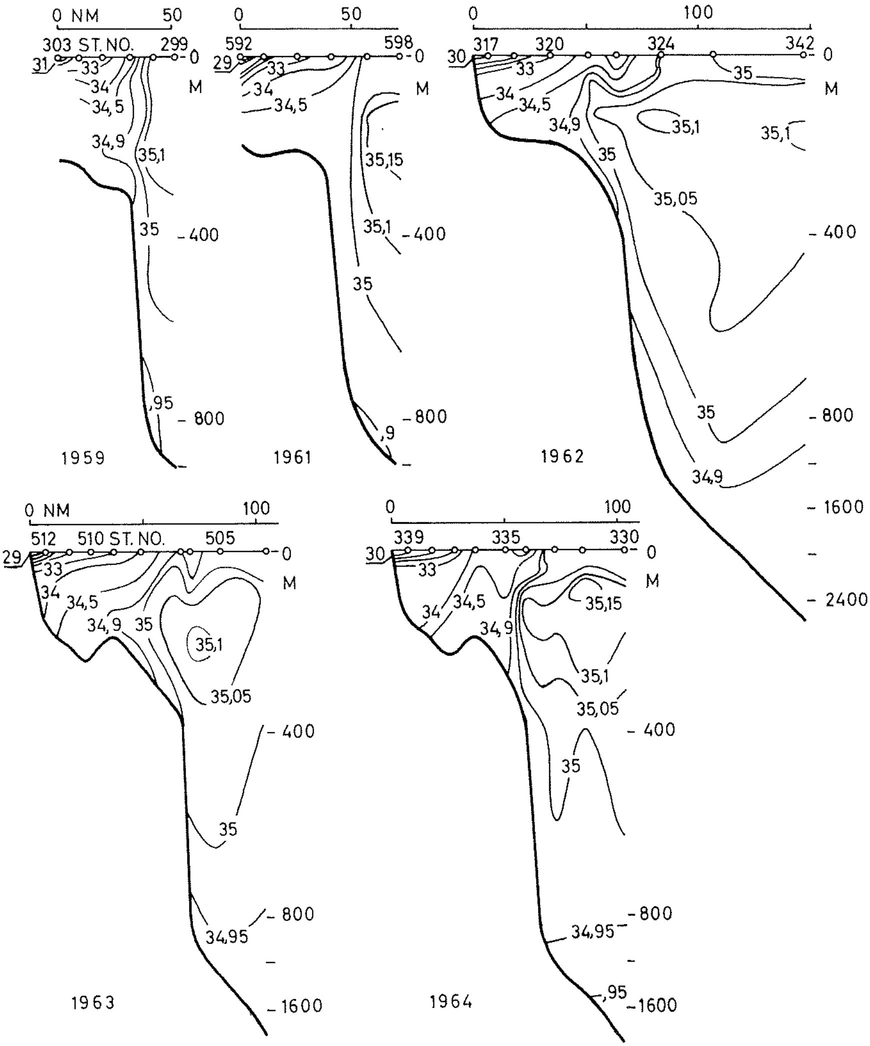

Fig. 7. Salinities off Cape Dan in the years 1959 and 1961—1964.

water had the greatest extent, but it is evident that it was smallest in 1963. As shown in Table 1, the maximum salinities of the Atlantic water vary between 35.10 $^0/_{00}$ and 35.19 $^0/_{00}$. The highest values were observed in 1961, and as shown in Table 2, the mean salinity of the Atlantic water was also high in this year.

The sections across the Denmark Strait between Cape E. Holm and Bjargtangar are illustrated in Fig. 8 which shows the section from 1964. This Figure also gives a good illustration of the conditions in 1963, which were only little different from those in 1964. In both years there were

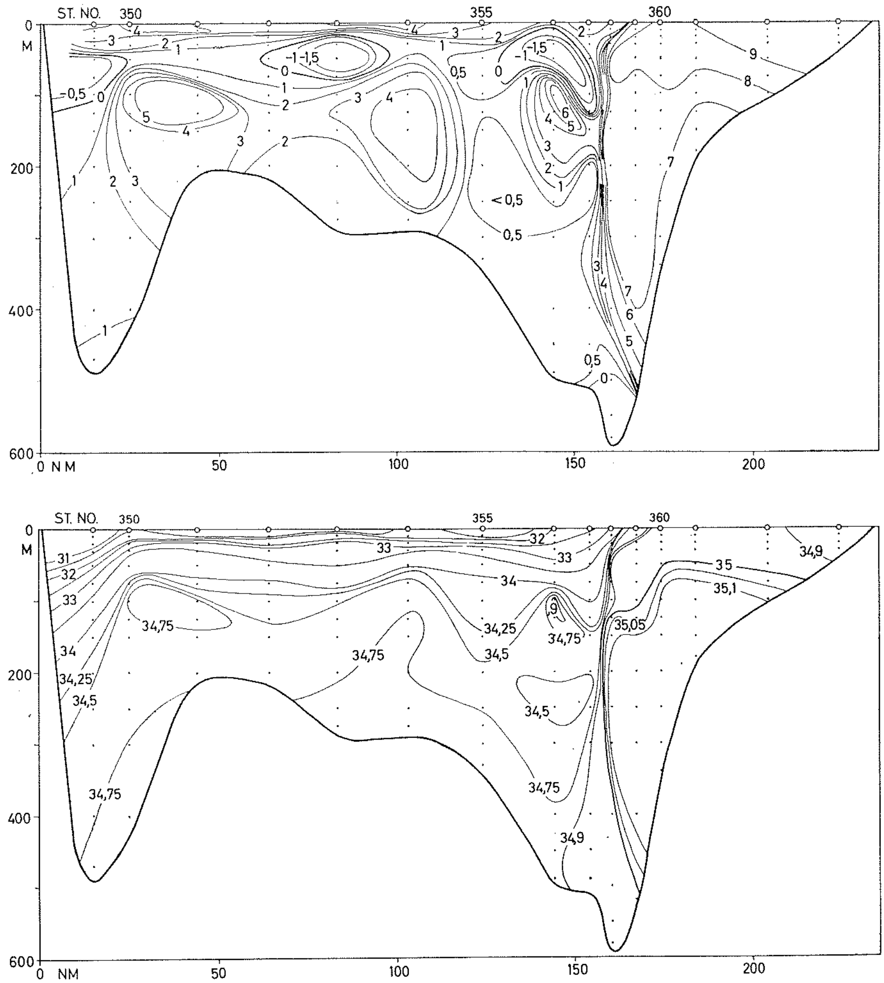

Fig. 8. Temperatures and salinities across the Denmark Strait 9.–10. September 1964.

observed three different cores of Polar water of temperature below 0° C. The most western of these was found close to the coast of Greenland. In 1963 it extended about 30 nautical miles eastwards from the coast with a minimum temperature of — 1.48° C at 75 m depth. Its vertical extent was greatest close to the coast where the temperatures were below 0° C between 30 and 150 m depth. In 1964 the corresponding core was somewhat smaller, and no temperatures below — 0.94° C were observed. In both years a second core of Polar water was observed between approximately 60 and 110 nautical miles off the Greenland coast. Temperatures near — 1.7° C were here observed at 50 m depth in both years. A third core lay over the western slope of the channel through the Iceland

–Greenland Ridge where subzero temperatures were observed down to 100 m. In 1964 the surface layer was heated to temperatures between 1° and 3° C, but in 1963 the surface temperatures were below 0° C in this area. Also here the coldest water of temperatures around – 1.7 ° C was observed at 50 m depth.

The salinity of the Polar water varied much from west to east. In the western part of the 1964 section the salinity was below 31 $^{0}/_{00}$, but the extreme Polar water in the middle of the Strait was of salinity about 33.5 $^{0}/_{00}$ in both years. West of the channel through the Iceland –Greenland Ridge the 34.5 $^{0}/_{00}$ isohaline was on the average found at 100 m depth. It had, however, a very wavy shape and reached a depth of approximately 200 m underneath the cores of Polar water. In the area over the sill in the channel it met the sea surface about 170 nautical miles off the coast of Greenland. In this area the Polar water and the Atlantic water lie very close to each other, and the horizontal gradients are very great. Fig. 9 shows a sea surface thermogram from 9th September 1963 which demonstrates how narrow the front between the two water masses can be in this area. As shown by the Figure, the temperature decreased from 7.9° to 2.2° C in the course of 10 minutes. According

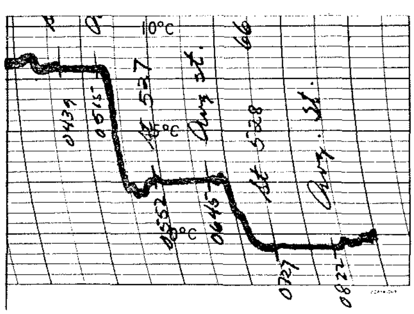

Fig. 9. Sea surface thermogram from the Denmark Strait. The sharp front between the waters of the Irminger Current and the East Greenland Current is shown.

to the speed of the ship, this corresponds to a distance of hardly 2 nautical miles. The whole front had a width of approximately 18 nautical miles, and the change in temperature amounted to 8,5° C. Fig. 8 shows that this front at the westward limit of the Atlantic water goes relatively steeply toward the bottom, and the horizontal gradients seem to be great also at subsurface depths. East of the front, Atlantic water occupies the region of the eastern slope in the channel through the Iceland–Greenland Ridge and most of the Icelandic shelf area. The extremity of the Atlantic water is found just above the edge of the shelf, its temperature and salinity being 6° to 7° C and 35.13 $^{0}/_{00}$ to 35.14 $^{0}/_{00}$ respectively.

Arctic Bottom water was in both years observed in the deepest part of the section, near the sill in the channel.

Arctic Intermediate water intruded between the Arctic Bottom water and the Polar water, and occupied the deeper water strata in the western slope area of the channel through the Icelang–Greenland Ridge.

The western part of the section crosses the Kangerdlugssuaq Deep, and in both years there was relatively warm water over the eastern slope of this deep. The salinity, which here exceeds 34.75 $^{0}/_{00}$, indicates an Atlantic origin of the water. HELLAND-HANSEN (1936) was of the opinion that this is a branch of the western branch of the Irminger Current, flowing northwards along the eastern slope of the Kangerdlugssuaq Deep. He also suggested that this water makes an anticyclonic circulation around the Øst Bank. This is in agreement with the sections from 1963 and 1964, because a core of warm water is also found east of the Øst Bank in these sections.

Annual variations in the sections are not easy to find as far as the Polar water is concerned. The most important reason for this seems to be that there occurs more occasional local variations within the East Greenland Current where the rough bottom topography contributes to a very turbulent flow. A consequence of this is an irregular mixing with waters from the Irminger Current in such a way that eddies bring water of Atlantic origin into the Polar water. Such a process of mixing probably takes place all the way between the Denmark Strait and Cape Farewell, but the ratio of mixing may have relatively great local variations along the current. Such local variations can then easily make confusion in possible phenomena of a scale great enough to have influence on the whole East Greenland Current and create annual variations.

Concerning the Atlantic water, on the other hand, the description of the sections brings into view annual variation in the western branch of the Irminger Current. In 1959 and 1961 the sections were rather short, and they did not reach far into the Atlantic water, but in spite of this, higher salinities were observed in these sections than i all later years. It is also obvious that the Atlantic water had a great vertical extent relative to the sections from 1962 and later. On the whole it looks as if there was much Atlantic water with relatively high salinity in the western branch of the Irminger Current in the years from 1959 to 1961. Later, the amount decreased so that only small quantities were observed in the sections from 1963. It may be useful to examine more closely these variations in the amount of Atlantic water in the Irminger Current. For this purpose the observations from Station A appear to fit well. In Fig. 10a, some of these observations are plotted in a T—S diagram, and in Fig. 10 b, observations are plotted from stations worked outside the shelf

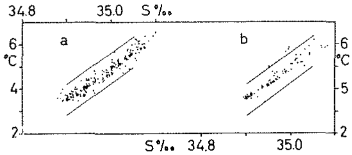

Fig. 10. T–S relation for observations off the shelf between 200 and 1200 m: a) Station A, November 1962. b) Western part of the Irminger Sea, August 1962.

area in the western part of the Irminger Sea. The Figure shows more or less the same water types at Station A as in the area of the western branch of the Irminger Current. It is therefore likely that variations in the amount of Atlantic water occuring at Station A, will also be of importance in the western part of the Irminger Sea.

VARIATIONS OF OCEANOGRAPHIC CONDITIONS AT OCEAN WEATHER STATION ALPHA

Station A lies in a border zone between two different water masses. The area between the Station and Iceland is dominated by the Atlantic waters of the Irminger Current, while the waters to the west of Station A have a more or less subarctic character. It is possible that variations in the salinity at Station A can be a consequence of the extention of the Atlantic water. If the Irminger Current carries much Atlantic water and this is extended far to the west, it might give rise to high salinity at Station A. A simple enumeration of the hydrographic stations at Station A with salinity above 35.00 $^0/_{00}$ at one or more standard depths shows great differences between some of the periods. In 1954 and 1956 Atlantic water was observed at less than 20 % of the total number of stations. In 1958 and 1960, however, salinities above 35.00 $^0/_{00}$ were observed at nearly all stations. This is suggestive of more Atlantic water in the Irminger Sea in 1958 and 1960 than in 1954 and 1956.

In order to get a better insight into the variability of temperature and salinity, isopleth diagrams have been prepared for the periods when the two weather ships served at Station A. The isopleth diagrams are based on monthly means at the standard depths. The means are produced by plotting the single observations at each particular standard depth against time, and the time axis is abscissa in the diagram. Such diagrams for 1958 are shown in Fig. 11, and the variability of temperature and salinity at the depths 0, 50, 150, 300, 600 and 1 000 m is demonstrated. For each month the means are taken from the diagrams by graphical interpolation. Such means are made for all standard depths to 2 000 m

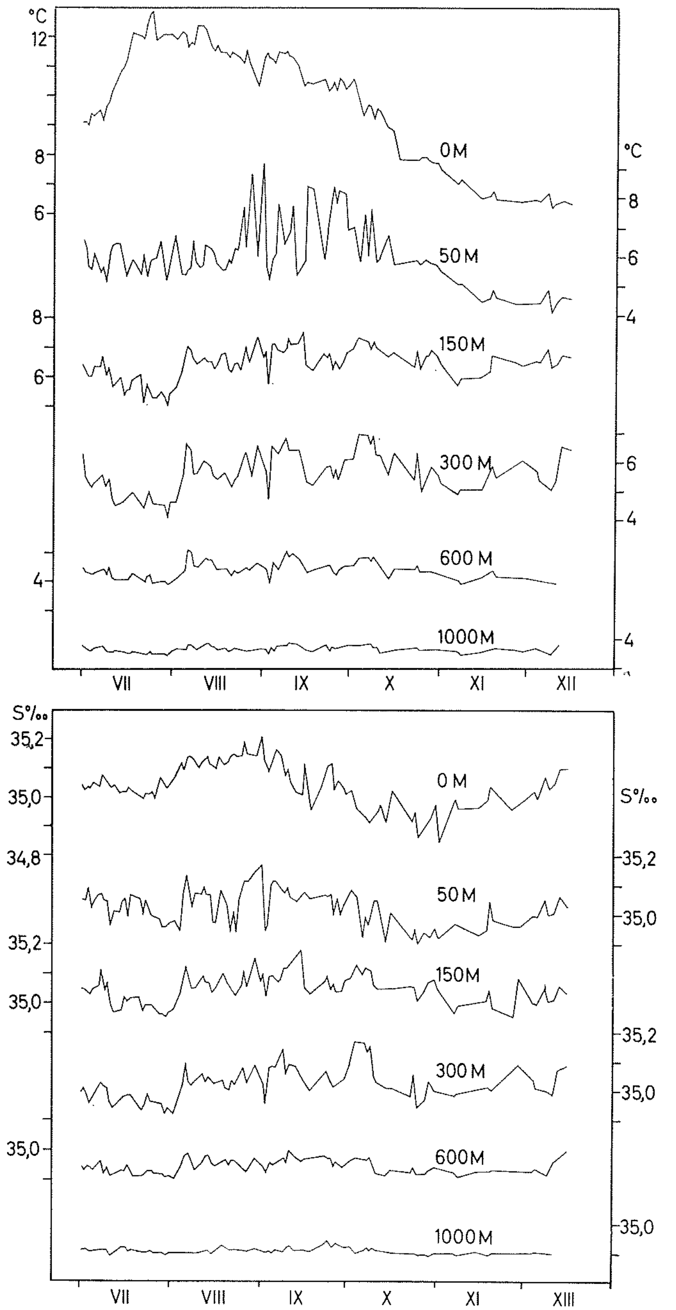

Fig. 11. Variations in temperature (upper part) and salinity at Station A during the period June-December 1958.

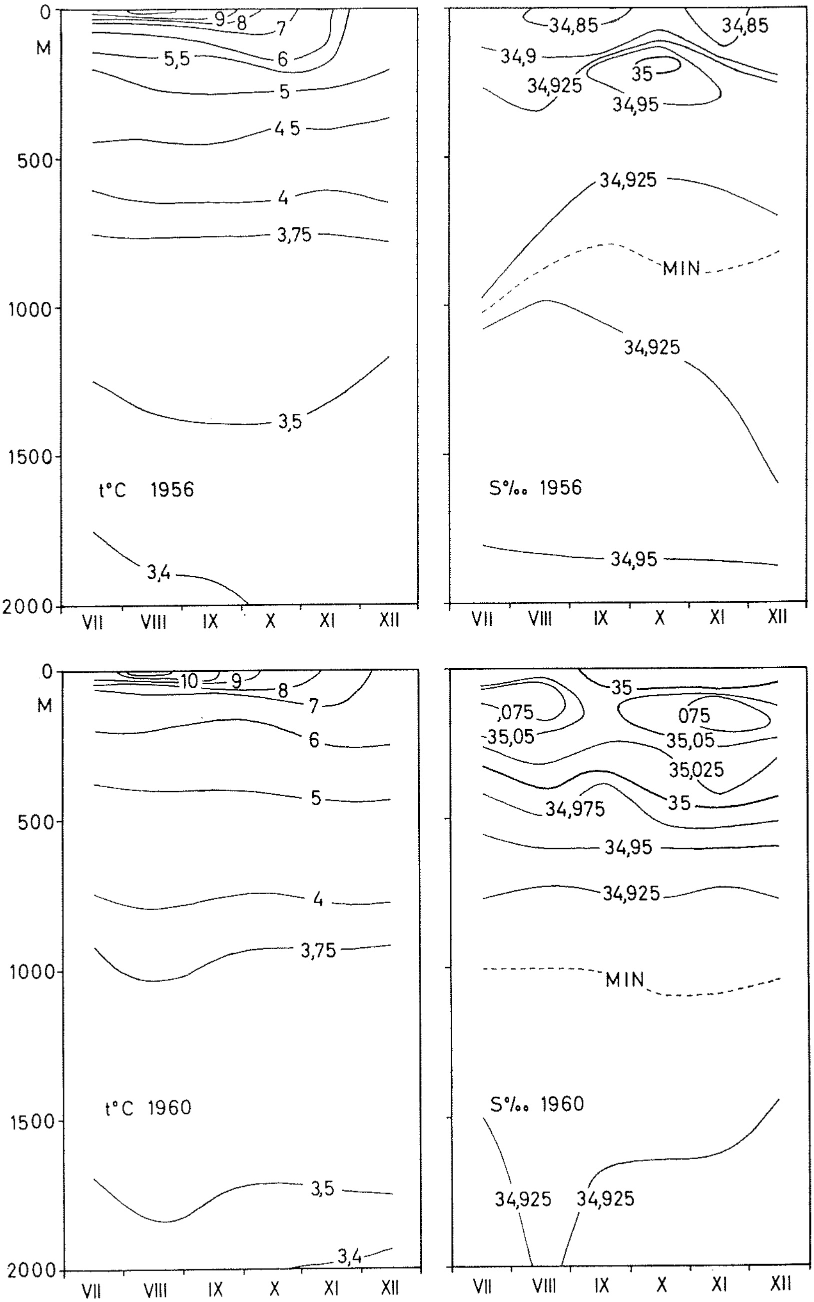

Fig. 12. Isopleth diagrams of temperature and salinity at Station A during the periods in 1956 and 1960.

for the 5 periods of observation. Isopleth diagrams for 1956 and 1960 are shown in Fig. 12. The diagrams for 1956 illustrate conditions during a period with small amounts of Atlantic water, and the diagrams for 1960 demonstrate a period when high salinities were frequently observed at Station A.

Temperature isopleths for the 5 periods show that the surface layer is warmest in August. In 1954 and 1956 the mean temperatures in the surface layer were slightly above 10° C in August, while corresponding temperatures exceeded 11° C in 1958 and 1960. A seasonal decrease is found in the upper layers so that in December the temperature was between 5° and 6° C in 1954 and 1956, and about 6.5° in 1958 and 1960. In the two former years the 6° C isotherm was found at a depth of less than 100 m during August and September, but in 1958 and 1960 the same isotherm lay between 200 and 300 m depth during these months. Even at depths as great as 2 000 m the temperature was a little lower in 1954 and 1956 than in the other years. In agreement with this the 3.5° C isotherm lay much deeper in 1958 and later periods than in 1954 and 1956.

The period in 1962/63 is not directly comparable with the other years as it does not cover the same time of year. However, at depths where the conditions are not affected by seasonal changes, the temperatures were nearly as high as in 1958 and 1960. The mean temperatures in the surface layer have their lowest values in February, near 5.5° C.

The isopleths for the salinity show that this parameter varies most in the surface layer, both from month to month and from year to year. During the periods in 1954 and 1956 the lowest salinity was observed near the surface, but in 1958 the highest salinities were found in the surface layer. Otherwise, the highest salinities are found at depths varying between 0 and 400 m. From this maximum the salinity decreases with depth to approximately 1 000 m. At this depth the intermediate water comes in, establishing an intermediate minimum of salinity as already mentioned (Fig. 3). Usually the monthly means lie a little above 34.90 $^0/_{00}$ at this depth. At greater depths the salinity increases again, and at 2 000 m the monthly means sometimes exceed 34.95 $^0/_{00}$.

At the depths where Atlantic water is found, the salinity is subject to distinct annual variations. In 1954, only the means for August at 75, 100 and 200 m were above 35.00 $^0/_{00}$, but here it is worth noting that the monthly mean at 150 m depth, which is based on a much greater number of observations, was not above 35.00 $^0/_{00}$. In 1956 the amount of Atlantic water appeared to be still smaller, as only the monthly mean for October at 200 m was above 35.00 $^0/_{00}$, but this mean is based on only 3 observations. In 1958, however, there was obviously more Atlantic water at Station A, and the mean salinity was above 35.00 $^0/_{00}$ at one or more depths in all the six months. The highest monthly mean occurred at the surface in August, and it exceeded 35.10 $^0/_{00}$. Similar conditions were found in 1960, and the isohaline for 35.00 $^0/_{00}$ lay then at depth of approximately 400 m. The highest salinities were also in this year observed in August, and the mean for this month exceeded 35.10 $^0/_{00}$ between 50 and 150 m depth.

The period in 1962/63 shows more changing conditions. The mean salinities in January exceeded 35.00 $^0/_{00}$ from the surface to 500 m depth, while February had such high values only in the surface layer. In March–April there was again Atlantic water from the surface to a depth of 300 to 400 m.

The varying conditions in the 5 periods are also easily seen in Fig. 13 which shows mean T—S relations for the periods. This Figure is based on

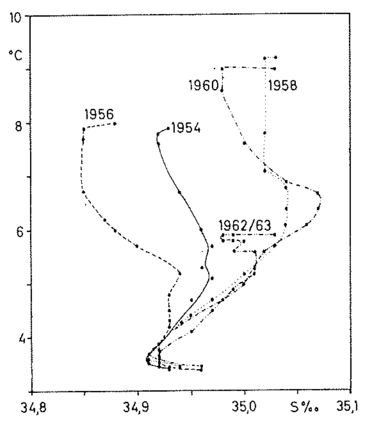

Fig. 13. Mean T–S diagram for the 5 periods of observation at Station A.

mean values of temperature and salinity, and at each particular standard depth these values are the arithmetic mean of the 6 monthly means in the period. In some cases monthly means have not been made owing to lack of observations. In these cases interpolated values have been applied when working out the mean value for the whole period. The period in 1956 had the lowest salinity between the surface and 500 m depth. The highest mean salinities were found at depths between 50 and 300 m in 1960, but also 1958 had high values between 0 and 500 m depth.

In both these years the maximum mean salinity was found at 150 m, and in 1960 it amounted to 35.07 $^0/_{00}$. In 1956 the maximum was only 34.94 $^0/_{00}$ and occurred at 200 m depth.

As a conclusion of the preceding description, it is evident that there were much greater amounts of Atlantic water at Station A in 1958–1960 than in 1954–1956. This is in agreement with the findings between the Denmark Strait and Prince Christians Sound, which also indicate much Atlantic water of relatively high salinity in the western branch of the Irminger Current 1959–1961. This is also verified by a section worked by R. V. «Dana» along latitude 62° N from the Faroes to Greenland in June-July 1959 (HERMANN 1961). This section shows Atlantic water across the whole Irminger Sea, and salinities in excess of 35.10 ‰ in the western branch of the Irminger Current. This is suggestive of an interrelation between the conditions at Station A and those in the western part of the Irminger Sea, and accordingly there should be small amounts of Atlantic water in the western part of the Irminger Sea in 1954–1956. No section from that time is involved in the data dealt with here, but good information is given by a section which was worked off Cape Tordenskjold by R. V. «Anton Dohrn» in June 1955 (DIETRICH

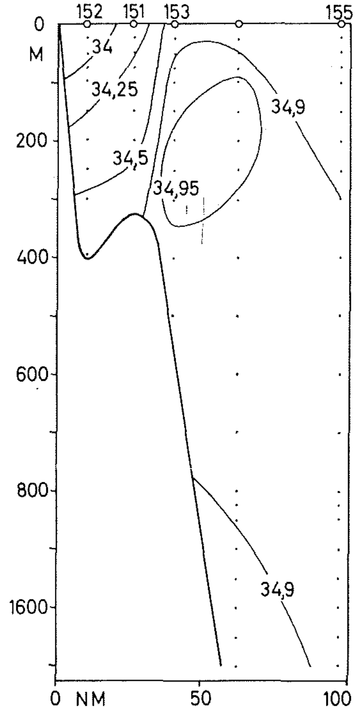

Fig. 14. Distribution of salinity off Cape Tordenskjold in June 1955. (Data from DIETRICH, 1957).

1957). The distribution of the salinity in this section is shown in Fig. 14, and it shows very low salinities in the western branch of the Irminger Current. The core of the current is indicated by salinities between 34.95

$^0/_{00}$ and 35.00 $^0/_{00}$. No values in excess of 35.00 $^0/_{00}$ were observed. The conditions in July the same year are illustrated by a section worked by «Dana» along latitude 62° N (HERMANN 1957). Also this section verifies that the western branch of the Irminger Current carried only small amounts of Atlantic water in 1955. Similar conditions are also illustrated by corresponding sections along latitude 62° N from 1954 and 1956 (HERMANN 1956 and 1958).

This comparison between the observations at Station A and the sections shows that annual variations in salinity at Station A reflect similar variations in the amount of Atlantic water in great parts of the Irminger Sea. Thus there was very little Atlantic water at Station A, as in the westers branch of the Irminger Current, during the years 1954–1956. Later, the amount increased until 1959 or 1960, and after 1961 it decreased again.

RELATION BETWEEN THE WIND CONDITIONS AT STATION A AND THE AMOUNT OF ATLANTIC WATER IN THE IRMINGER SEA

It has earlier been pointed out that the bifurcation of the Irminger Current in the Denmark Strait depends on the wind conditions. HERMANN and THOMSEN (1946) write on this matter: «The fact must be presumed to be that the water under the influence of weather conditions at times all moves into the Denmark Strait, whereas at other times a considerable proportion passes the Horn and continues along the north coast of Iceland». STEFANSSON (1962a) has examined the relationship between the wind conditions and the hydrographic conditions in Icelandic waters. He concludes that the wind conditions west of Iceland may affect the influx of Atlantic water to the North Icelandic region.

Assuming that the Irminger Current annually transports approximately the same volume of Atlantic water to the area southwest of Iceland, a result of the conclution mentioned above, must be that in years with prevailing southerly winds the Atlantic water will be found close to the west coast of Iceland, and a great proportion will find its way round the Horn and flow into the North Icelandic region. In years when northerly winds are dominant, the Atlantic water will, however, extend more westwards and the greater part of it will turn around in the Denmark Strait and continue southwest in the western branch of the Irminger Current.

In order to get a better insight into this problem, the wind conditions at Station A are examined. Observations of wind force and direction are taken from the Daily Weather Report (ANON. 1953—1962) which usually gives four observations per day at 0000, 0600, 1200 and 1800 hours G. M. T. The wind force is entered in knots, and the direction to the nearest 10 degrees. The observations are plotted into central vector diagrams for each month, and summed up for every year from 1953 to 1962 inclusive. In this way the total number of knots along one line representing a certain direction, gives a measure of the quantity of wind which has been blowing from that direction during the year. This sum of wind will here be designated as accumulated wind. Since north-easterly and south-westerly winds prevail at Station A, the accumulated wind for each year is decomposed, and the components in the directions NE–SW and NW–SE worked out. In Fig. 15 the components from NE and SW are entered (thousands of knots), and it can be seen that considerable variations occur. The NE-component was smallest in 1953 and 1956

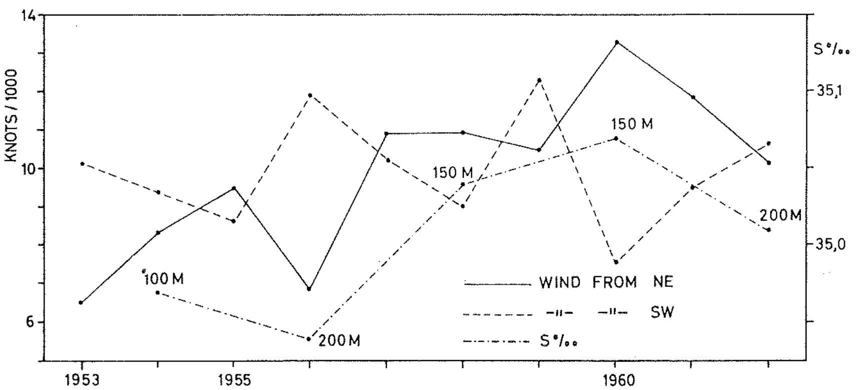

Fig. 15. Northeast and southwest components of accumulated wind (in thousands of knots) at Station A, and maximum mean salinity for each period of observation.

while 1960 presents the highest value. The SW-component had its greatest value in 1959, and was smallest in 1960 at the same time as the NE-component was greatest. The corresponding components from NW and SE are on the whole smaller than the components from NE and SW, and they show no variations of significance.

The highest mean salinity for each period of observation at Station A is also entered in Fig. 15. These are the maximum salinities which are entered in Fig. 13 for each period without regard to depth, except the surface. In all periods maximum mean is found at depths from 100 to 200 m. The Figure shows that the curve which represents the salinity follows rather closely the curve for the NE-component of accumulated wind. This is more clearly shown in Fig. 16 where the salinity and the NE-component are related. In this relation the points lie almost exactly along a straight line. Altogether this demonstrates a remarkably good

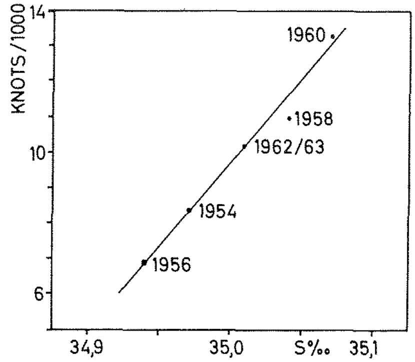

Fig. 16. Relationship between the northeast component of accumulated wind and the maximal mean salinity at Station A.

correlation between wind conditions and the salinity at Station A. It is, however, based on only 5 periods of observation and may be a matter of chance.

Following STEFANSSON (1962 a), the divergence of the Irminger Current in the Denmark Strait is influenced by the wind conditions, and there is good correlation between the salinities off Langanes in August and the wind conditions west and northwest of Iceland during the spring. The good relationship between the salinity and the wind conditions at Station A shows, however, that the wind plays a part also in this area. Further, the variations in salinity at Station A reflect related variations of salinity in the western branch of the Irminger Current. Consequently it looks as if the wind conditions as observed at Station A are of significance for the major part of the Irminger Sea.

If the amount of Atlantic water transported to the area southwest of Iceland is nearly constant from year to year, and low salinity at Station A indicates only that Atlantic water is lying close to the coast of Iceland, it might be expected that great masses of it should have been found near the coast and in the North Icelandic region in 1954 and 1956. In 1960, on the contrary, one might have expected to find only small Atlantic influx north of Iceland since there were high salinities at Station A and much Atlantic water in the western branch of the Irminger Current. STEFANSSON (1962 a) however, has shown that in 1954 and 1956 only small quantities of Atlantic water were observed in sections off Latrabjarg (Bjargtangar) compared with the years 1949, 1951, 1957, 1958 and 1959. Off Langanes the mean salinity for August between 50 and 200 m depth was in 1954 0.03 ‰ higher and in 1956 0.01 ‰ lower than the average for 15 years. For 1960 no section off Latrabjarg is available, but STEFANSSON (1962 b) found a pronounced influence of Atlantic water off northern Iceland in June. In a section off Siglunes higher salinities were found than in any previous year. Off Langanes the mean salinity for August between 50 and 200 m depth was 35.05 $^0/_{00}$, which is 0.10 $^0/_{00}$ higher than the average for 15 years. This shows that in 1960 there was a pronounced Atlantic influence in the western Irminger Sea as well as in the North Icelandic Irminger Current. In 1954–1956 the opposite was the case, because small amounts of Atlantic water were observed at Station A and in the western branch of the Irminger Current, and neither the sections off Latrabjarg nor the observations off Langanes indicated any great Atlantic influx to the North Icelandic region. A conclusion from this must be that the entire Irminger Current carried greater quantities of Atlantic water in the years around 1960 than in 1954–1956, so that the observed annual variation have their origin in related variations in the Irminger Current to the southwest of Iceland. The relationship between wind conditions and the salinity at Station A may consequently be regarded as a relationship between the wind conditions and the inflow of Atlantic water to the Irminger Sea. Here, however, it is not quite clear whether the wind is the generating force, or whether the wind conditions are influenced by oceanographic conditions.

If the wind is the generating force, it seems likely that it influences the divergence of the North Atlantic Current to the south of Iceland. In contrast to conditions at Station A, Atlantic water is here always present at the surface. It is therefore directly exposed to the wind stress, and in periods of prevailing north-easterly winds, relatively great amounts of Atlantic water may be forced so far to the west that more of it than usual flow into the Irminger Current. In this manner the Irminger Current may be fed with waters which otherwise, would flow into the area of the Faroe–Iceland Ridge, or into the Faroe–Shetland Channel. In such a case the increase of Atlantic water in the Irminger Current will take place at the expence of the transport to the Norwegian Current and give rise to variations in the latter opposite to those in the former current. TULLOCH and TAIT (1959) however, have shown that this flow from the area south of Iceland is not the main source of the North Atlantic Current in the Faroe–Shetland Channel. Variations in this flow will therefore probably be of little significance to the total Atlantic flow through the Channel.

Another possible reason for variations in the Irminger Current may lie in associated variations in the entire North Atlantic current. Such varying transport of Atlantic water will also include varying transport of heat, and in the area around Iceland and southern Greenland this may influence the atmospheric conditions. In such a case it is therefore possible that the oceanographic conditions give rise to the related wind conditions which are observed at Station A. If such great scale fluctuations really take place, it is likely that variations similar to those in the Irminger Current can be observed also in the other branches of the North Atlantic Current.

SUMMARY

1. The data examined consist of hydrographic sections in the western Irminger Sea and serial observations at Ocean Weather Station Alpha (Station A). The sections were worked in the years 1959 and 1961–1964, and at station A the data were collected during 5 periods of observation in the years 1954–1963.

2. The sections as well as the data from Station A are used to give the caracteristics and extent of different water masses. The occurence of possible annual variations is also examined.

3. South of the Denmark Strait it is difficult to characterize Polar water by means of temperature and salinity, but 34.50 $^0/_{00}$ seems to be the upper limit of its salinity.

4. The intermediate water in the Irminger Sea is found at about 1 000 m depth, and T–S relations for the data from Station A show that the minimum temperature and salinity of intermediate water are 3.5° C and 34.88 $^0/_{00}$.

5. In the Denmark Strait Arctic Intermediate water exhibits temperatures near, or below, 1°C, and salinities chiefly below 34.90 $^0/_{00}$. This water mass seems to be the main source of the bottom water in the Irminger Sea.

6. The amount of Atlantic water which is carried to the Irminger Sea by the Irminger Current, varies from year to year. These variations are studied in the western branch of the Irminger Current and at Station A. In 1954–1956 only small amounts of Atlantic water were observed, but the Atlantic inflow increased until 1959–1960. During the years after 1961 the amount decreased again.

7. At Station A the wind conditions are examined, and there is a close relationship between the accumulated wind and the mean salinity in the different periods of observation.

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