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Hydrographic Changes in the Waters Between Iceland and Jan Mayen in the Last Decade

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ABSTRACT

During the last few years a change has taken place in the proportions of the different water masses in the East-Icelandic Current northeast of Iceland (Fig. 1). It is shown that the current has changed from being an ice-free arctic current in 1948–1958 to a polar current in 1964–1968, transporting drift ice and preserving it, especially in the years 1965, 1967 and 1968. As seen in Fig. 2 the salinity of 34.7‰ is of special interest in the area these last years. As demonstrated in Fig. 11 this salinity is the critical one for the area in question, should the surface layer cool down to freezing point, −1.8° C. At salinities of 34.7‰ or lower the surface water will not reach a density high enough to start a deep vertical convection even at a temperature of −1.8° C, but at salinities of 34.8‰ or more this is possible. That means in the latter case a deep vertical convection before such a strong cooling is reached. The drift ice conditions were extremely unfavourable in North and East Icelandic waters in the spring of 1965, 1967 and 1968. Thus a close relationship between drift ice and hydrographic conditions in the East-Icelandic Current is established, throwing light on the physical causes of the situation.

A knowledge of the stratification, i. e. the salinity in the surface layer, in late winter between Iceland and Jan Mayen, may, in connection with knowledge of the atmospheric circulation and air temperature, be a tool for the prediction of ice in Icelandic waters in spring and summer.

INTRODUCTION

Between Langanes in northeast Iceland and Jan Mayen we find the cold water of the East-Icelandic Current, first described by the Danish oceanographer *Martin Knudsen* (1898). In this area the current reaches depths of ca. 200 m. According to *Stefánsson* (1962, pp. 36–37) this current consisted more or less of Arctic water composed of a mixture of Polar water (S < 34‰, t < 0° C) with water originally coming from the Norwegian Atlantic Current (*Helland-Hansen* and *Nansen,* 1909, p. 319), Atlantic water (S > 35‰) from the Irminger current north of Iceland, and North Icelandic Winter water (t = 1–2° C, S = 34.85–34.90‰).

In June 1965 it was noteworthy how much farther south and east the cold tongue northeast of Iceland reached than in previous years. This stimulated a special study of the hydrographic conditions in the area. In June 1967 the cold tongue had a similar extension as in 1965, but in June 1968 it covered a far greater area than ever observed before, even filling a long stretch of the coast.

Not only has the cold tongue expanded, but considerable changes have also taken place in temperature and salinity in the uppermost 100–200 m in this area during the last 5 years (1964–1968) compared to the period 1948–1958.

This paper deals with changes in the proportions of the different water masses in the East-Icelandic Current, the effect of these changes on the stratification and the vertical stability, and the effect of the stratification on the drift ice conditions in North and East Icelandic waters.

Preliminary results of these studies have appeared previously in the publications of the International Council for the Exploration of the Sea (*Malmberg* 1967 c, 1968 a, b, 1969) and the Fisheries Association of Iceland (*Malmberg* 1967 a, b, *Vilhjálmsson* and *Malmberg* 1968).

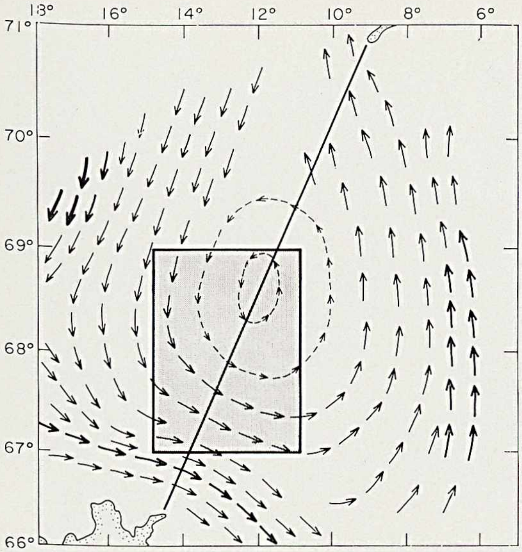

Fig. 1. The region between Iceland and Jan Mayen from where all available hydrographic observations in 1948—1968 were studied. The current system is according to *Stefánsson* (1962).

MATERIAL AND METHODS

All available hydrographic data (temperature and salinity) collected since 1948 in the area within latitudes 67° to 69° N and longitudes 11° to 15° W were studied. The area is shown in Fig. 1. It was chosen with respect to the current system in the Iceland Sea (according to *Stefánsson* 1962, p. 57) and also because a standard section has been worked annually across the area, the Langanes NE—Jan Mayen section. The material was collected from the data lists of the International Council for the Exploration of the Sea (Bull. Hydr. 1947—1956, ICES ODL 1957—1963) and the Marine Research Institute, Dept. of Oceanography, Reykjavík (1964—1968).

All the observations are from the summer months (April—September) and mostly from June. The June data were therefore studied specifically. They are available from 1950, 1952—1958 and 1964—1968. Data from July 1948 and 1949 and August 1951 were also included in the study. No hydrographic data were available from the area in question during the years 1959—1963.

This material was analysed by t-S diagrams, means of individual years and longer periods were computed as well as the deviations from means. Some typical features of the hydrography in the area in question are pointed out and a study is made of the stratification in the area in relation to vertical convection and drift ice conditions.

RESULTS

In the t-S diagrams in Fig. 2 all observations made during the years 1948—1958 are found within a relatively narrow salinity range, between 34.72‰ and 34.92‰, with no temperature below – 1° C, but during the years 1964—1968 there has obviously been an increase in the Polar water component in the Arctic water of the East-Icelandic Current. This is indicated by salinities of 34.5—34.7‰ or even lower and temperature values as low as – 1.8° C, as found in 1965, 1967 and 1968. The trend towards salinities of 34.7‰ and temperatures of – 1.8° C is of special interest and will be discussed later. The difference in the hydrographic

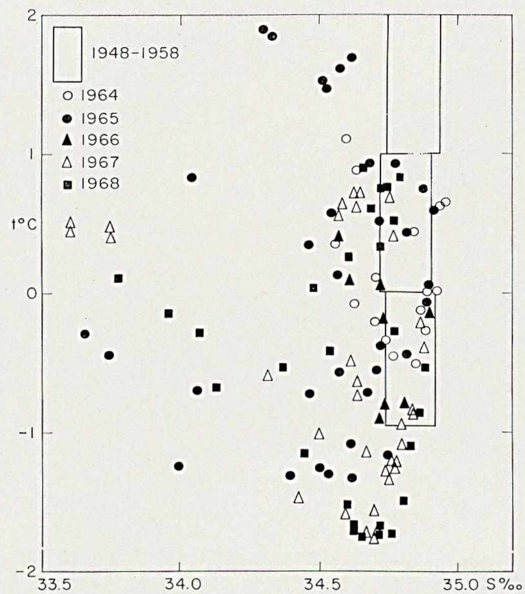

Fig. 2. t-S diagrams for all available (mostly June) hydrographic observations in the uppermost 200 m in the area shown in Fig. 1. Observed temperatures above 2° C are excluded.

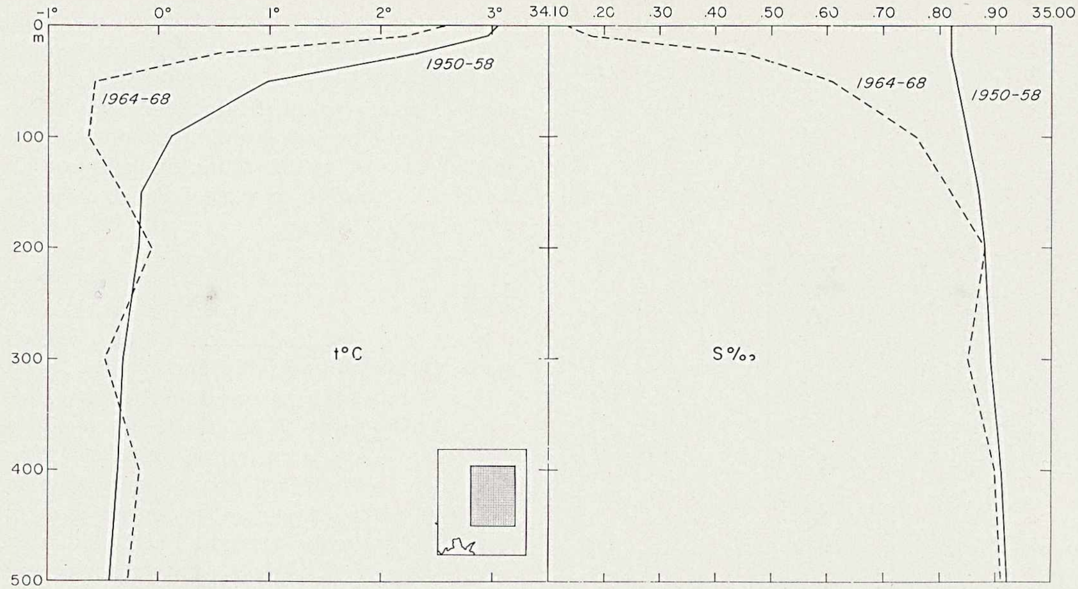

Fig. 3. The mean vertical distribution of temperature and salinity for June 1950–1958 and 1964–1968 in the area studied.

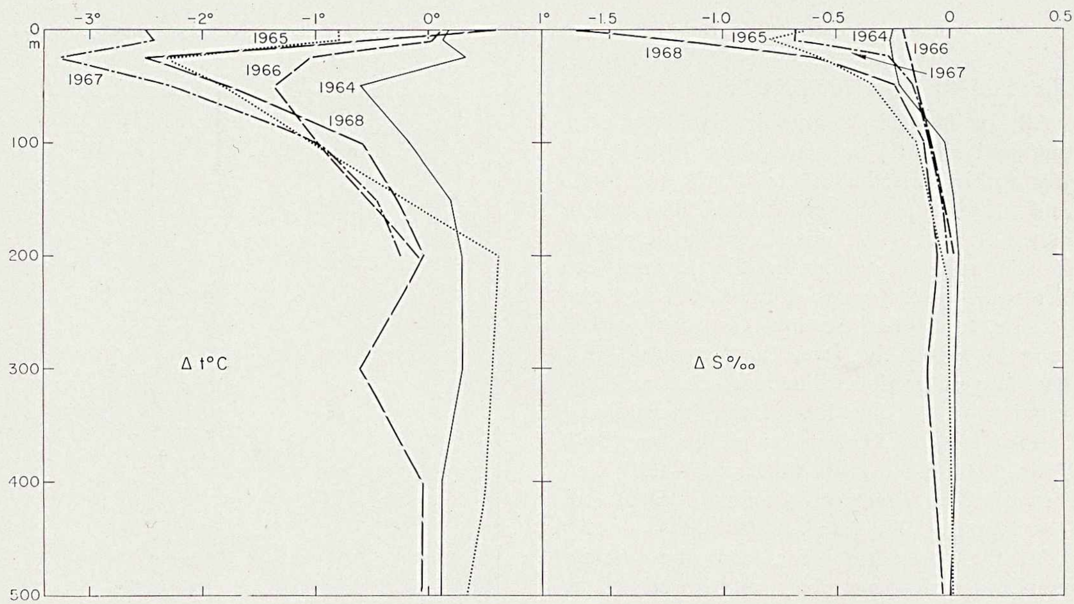

Fig. 4. The deviation of the mean vertical temperature and salinity distribution in June during the years 1964–1968 from the mean values of the period 1950–1958.

conditions in the area in the two abovementioned periods also appears in Table 1 and Fig. 3 (mean values of individual years and periods in June, 0–500 m), and in Table 2 and Fig. 4 (deviations from the mean values of the period 1950–1958, 0–500 m). The results show also that the temperature in the uppermost layers in June 1952 and 1956 was below normal, possibly due to cold winds since the salinity was at the same time about normal. In June 1953, on the other hand, the salinity was below normal northeast of Iceland, and that same year the surface salinity in the ocean south of Iceland was also the lowest of the period 1951–1960, as shown in Fig. 5. In June

TABLE 1

The temperature and salinity means within latitude 67–69° N and longitude 11–15° W in June 1950, 1952–1958, 1964–1968; the number of observations and the means for the periods 1950–1958 and 1964–1968.

1950

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	3.02	2	34.85	2
10	2.82	2	86	2
25	2.53	2	87	2
50	1.30	2	85	2
100	0.35	2	83	2
150	0.08	2	84	2
200	– 0.02	2	84	2
300	– 0.37	2	85	2
400	– 0.27	2	87	2
500	–	–	–	–
Total no. of obs.		18		18

1952

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	1.23	4	34.83	4
10	1.37	4	82	4
25	1.17	4	81	4
50	1.00	4	81	3
100	0.00	4	85	4
150	– 0.43	4	88	4
200	– 0.51	4	88	4
300	– 0.63	4	89	3
400	– 0.60	4	90	4
500	– 0.44	1	–	–
Total no. of obs.		37		34

1953

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	4.25	4	34.70	4
10	4.25	4	71	4
25	3.11	4	74	4
50	0.29	4	78	4
100	– 0.30	4	80	4
150	– 0.15	4	85	4
200	– 0.05	4	87	4
300	– 0.36	4	88	4
400	– 0.51	4	90	4
500	– 0.56	4	90	4
Total no. of obs.		40		40

1954

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	4.03	4	34.83	4
10	3.82	4	81	4
25	2.69	4	80	4
50	1.04	4	82	4
100	0.38	4	82	4
150	0.02	4	83	4
200	0.04	4	87	4
300	– 0.31	4	90	4
400	– 0.44	4	92	4
500	– 0.57	4	92	4
Total no. of obs.		40		40

1955

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	4.43	5	34.81	5
10	4.41	5	81	4
25	3.41	5	84	5
50	1.33	5	87	5
100	0.69	5	88	5
150	0.19	5	87	5
200	– 0.01	5	86	5
300	– 0.08	4	89	5
400	– 0.25	4	91	3
500	– 0.48	1		
Total no. of obs.		44		42

1956

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	1.56	2	34.85	2
10	1.39	2	84	2
25	1.16	2	84	2
50	0.72	2	86	2
100	– 0.07	2	90	2
150	– 0.40	1	91	1
200	– 0.24	2	92	2
300	– 0.27	2	92	2
400	– 0.31	2	92	2
500	– 0.36	2	93	2
Total no. of obs.		19		19

1964

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	3.24	3	34.57	3
10	3.09	3	56	3
25	2.66	3	57	3
50	0.39	3	61	3
100	– 0.05	3	83	3
150	0.05	3	89	3
200	0.13	3	92	3
300	– 0.02	3	91	3
400	– 0.24	3	92	3
500	– 0.33	3	92	3
Total no. of obs.		30		30

1957

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	2.90	2	34.80	2
10	2.64	2	80	2
25	2.54	2	80	2
50	1.40	2	81	2
100	– 0.02	2	85	2
150	– 0.26	1	87	2
200	– 0.23	2	88	2
300	– 0.16	2	90	2
400	– 0.22	2	91	2
500	– 0.32	2	91	2
Total no. of obs.		19		20

1965

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	2.26	6	34.19	6
10	2.18	6	03	6
25	– 0.01	6	25	6
50	– 0.83	6	49	6
100	– 0.92	6	70	6
150	–	–	–	–
200	0.45	6	87	6
300	–	–	–	–
400	0.15	1	93	1
500	– 0.10	2	93	2
Total no. of obs.		39		39

1958

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	2.99	3	34.88	3
10	3.01	3	88	3
25	1.98	3	87	3
50	0.80	3	87	3
100	– 0.11	3	88	3
150	– 0.28	3	89	3
200	– 0.32	2	90	2
300	– 0.38	1	90	1
400	– 0.24	2	92	2
500	– 0.32	2	93	2
Total no. of obs.		25		25

1966

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	3.16	2	34.62	2
10	2.98	2	62	2
25	1.26	2	65	2
50	– 0.37	2	68	2
100	– 0.86	2	77	2
150	–	–	–	–
200	– 0.26	1	90	2
300	–	–	–	–
400	–	–	–	–
500	–	–	–	–
Total no. of obs.		11		12

1967

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	0.56	4	34.14	4
10	0.52	4	14	4
25	– 0.94	4	56	4
50	– 1.28	4	68	4
100	– 0.85	4	76	4
150	– 0.61	4	79	4
200	– 0.42	4	87	4
300	–	–	–	–
400	–	–	–	–
500	–	–	–	–
Total no. of obs.		28		28

Mean of 1964–1968

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	2.58	19	34.13	19
10	2.21	19	18	19
25	0.55	19	45	19
50	– 0.57	19	61	19
100	– 0.63	19	76	19
150	– 0.33	11	82	11
200	– 0.06	19	88	19
300	– 0.48	4	85	4
400	– 0.18	5	90	5
500	– 0.27	6	91	6
Total no. of obs.		140		140

1968

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	3.66	4	33.11	4
10	2.26	4	57	4
25	– 0.20	4	34.22	4
50	– 0.78	4	59	4
100	– 0.47	4	74	4
150	– 0.43	4	78	4
200	– 0.20	4	83	4
300	– 0.93	1	79	1
400	– 0.41	1	84	1
500	– 0.38	1	89	1
Total no. of obs.		31		31

Mean of 1950–1958

Depth in m	t °C	No. of obs.	S ‰	No. of obs.
0	3.05	26	34.82	26
10	2.96	26	82	25
25	2.32	26	82	26
50	0.99	26	83	25
100	0.12	26	85	26
150	– 0.15	24	87	25
200	– 0.17	25	88	26
300	– 0.32	23	89	23
400	– 0.36	24	91	23
500	– 0.44	16	92	14
Total no. of obs.		242		239

TABLE 2

The temperature and salinity deviations within latitude 67–69° N and longitude 11–15° W in June 1950, 1952–1958, 1964–1968 from the mean values of the period 1950–1958.

t °C

Depth in m	1950	1952	1953	1954	1955
0	– 0.03	– 1.82	1.20	0.98	1.38
10	– 0.14	– 1.59	1.29	0.86	1.45
25	0.21	– 1.15	0.79	0.37	1.09
50	0.31	0.01	– 0.70	0.05	0.34
100	0.23	– 0.12	– 0.42	0.26	0.57
150	0.23	– 0.28	0.00	0.17	0.34
200	0.15	– 0.34	0.12	0.21	0.16
300	– 0.05	– 0.31	– 0.04	0.01	0.24
400	0.09	– 0.24	– 0.15	– 0.08	0.11
500	–	0.00	– 0.12	– 0.13	– 0.04

Depth in m	1956	1957	1958	1964
0	– 1.49	– 0.15	– 0.06	0.19
10	– 1.57	– 0.32	0.05	0.13
25	– 1.16	0.22	– 0.34	– 0.34
50	– 0.27	0.41	– 0.19	– 0.60
100	– 0.19	– 0.14	– 0.23	– 0.17
150	– 0.25	– 0.11	– 0.13	0.20
200	– 0.07	– 0.06	– 0.15	0.30
300	0.05	0.16	– 0.06	0.30
400	0.05	0.14	0.12	0.12
500	0.08	0.12	0.12	0.11

Depth in m	1965	1966	1967	1968
0	– 0.79	0.11	– 2.49	0.61
10	– 0.78	0.02	– 2.44	– 0.70
25	– 2.33	– 1.06	– 3.26	– 2.52
50	– 1.82	– 1.36	– 2.27	– 1.77
100	– 1.04	– 0.98	– 0.97	– 0.59
150	—	—	– 0.46	– 0.28
200	0.62	– 0.09	– 0.25	– 0.03
300	—	—	—	– 0.61
400	0.51	—	—	0.05
500	0.34	—	—	– 0.06

S ‰

Depth in m	1950	1952	1953	1954	1955
0	0.03	0.01	– 0.12	0.01	– 0.01
10	0.04	0.00	– 0.11	– 0.01	– 0.01
25	0.05	– 0.01	– 0.08	– 0.02	0.02
50	0.02	– 0.02	– 0.05	– 0.01	0.04
100	– 0.02	0.00	– 0.05	– 0.03	– 0.03
150	– 0.03	0.01	– 0.02	– 0.04	0.00
200	– 0.04	0.00	– 0.01	– 0.01	– 0.02
300	– 0.04	0.00	– 0.01	0.01	0.00
400	– 0.04	– 0.01	– 0.01	0.01	0.00
500	—	—	– 0.02	0.00	—

Depth in m	1956	1957	1958	1964
0	0.03	– 0.02	0.06	– 0.25
10	0.02	– 0.02	0.06	– 0.26
25	0.02	– 0.02	0.05	– 0.25
50	0.03	– 0.02	0.04	– 0.22
100	0.05	0.00	0.03	– 0.02
150	0.04	0.00	0.02	0.02
200	0.04	0.00	0.02	0.04
300	0.03	0.01	0.01	0.02
400	0.01	0.00	0.01	0.01
500	0.01	– 0.01	0.01	0.00

Depth in m	1965	1966	1967	1968
0	– 0.63	– 0.20	– 0.68	– 1.71
10	– 0.79	– 0.20	– 0.68	– 1.25
25	– 0.57	– 0.17	– 0.26	– 0.60
50	– 0.34	– 0.15	– 0.15	– 0.24
100	– 0.15	– 0.08	– 0.09	– 0.11
150	—	—	– 0.08	– 0.09
200	– 0.01	0.02	– 0.01	– 0.05
300	—	—	—	– 0.10
400	0.02	—	—	– 0.07
500	0.01	—	—	– 0.03

1958 the salinity was at the highest both northeast and south of Iceland during this same period. The results shown in Fig. 5 are based on all available sea surface data from the ocean area south of Iceland during the period 1951—1965, according to the data lists of the International Council for the Exploration of the Sea. The study was made in three areas within latitude 60° and 63° N and longitudes 10° to 15° W, 15° to 20° W and 20° to 25° W. In general the results show an increase in sea surface temperature of about 1° C from 1951 to 1960 and an increase in salinity of 0.06—0.08‰. The increase in temperature is greater in winter than in summer, at which time there may even be a decrease in temperature.

The negative salinity anomalies in June 1964—1968 northeast of Iceland are usually highest at the sea surface (see Fig. 4). They decrease with depth down to about 100—200 m, where the values become almost normal. The same is true for the temperature anomalies, except for the temperature values at the sea surface which are relatively high due to summer heating. The negative salinity and temperature anomalies in June were highest in 1965, 1967 and 1968. They were as follows:

1965 – 0.7‰ in salinity and more than – 2° C in temperature,
1967 – 0.7‰ in salinity and more than – 3° C in temperature,
1968 –1.7‰ in salinity and about – 2.5° C in temperature.

In 1964 and 1966 the negative anomalies were as follows:

1964 – 0.25‰ in salinity and about – 0.6° C in temperature,
1966 –0.2‰ in salinity and about – 1.4° C in temperature.

It should be mentioned that due to extremely unfavourable ice conditions in North Icelandic waters in the spring of 1968, the annual investigations in the area could not be carried out until late June, whereas in the other years they were mostly carried out in early June. That may be the reason why the sea temperature was higher in 1968 than in 1967.

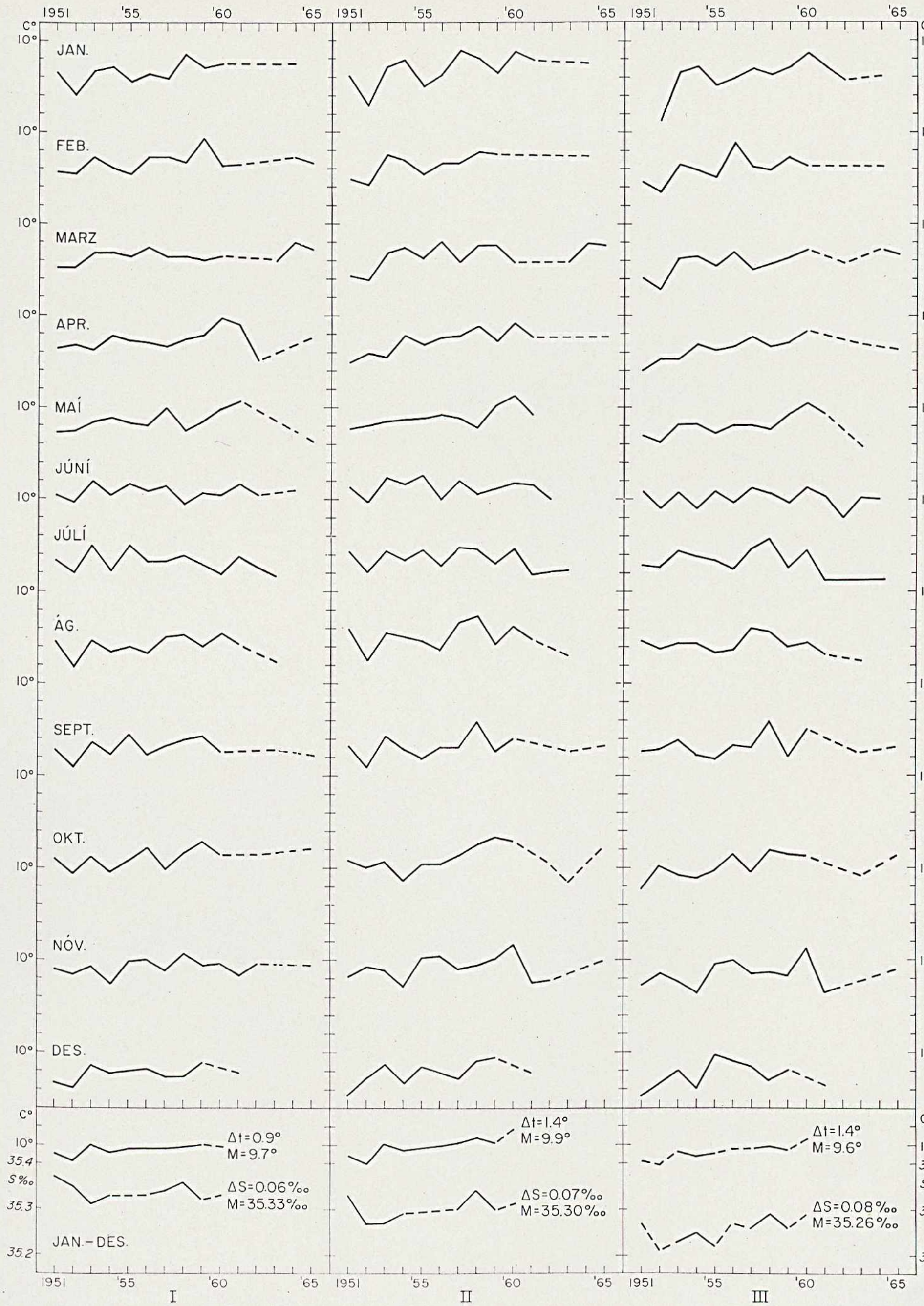

Fig. 5. Annual variations in sea surface temperature for each month of the year in the period 1951 to 1965. Annual variations in sea surface temperature and salinity from 1951 to 1960. The observations are from the regions: I (60° to 63° N, 10° to 15° W) II (60° to 63° N, 15° to 20° W), III (60° to 63° N, 20° to 25° W).

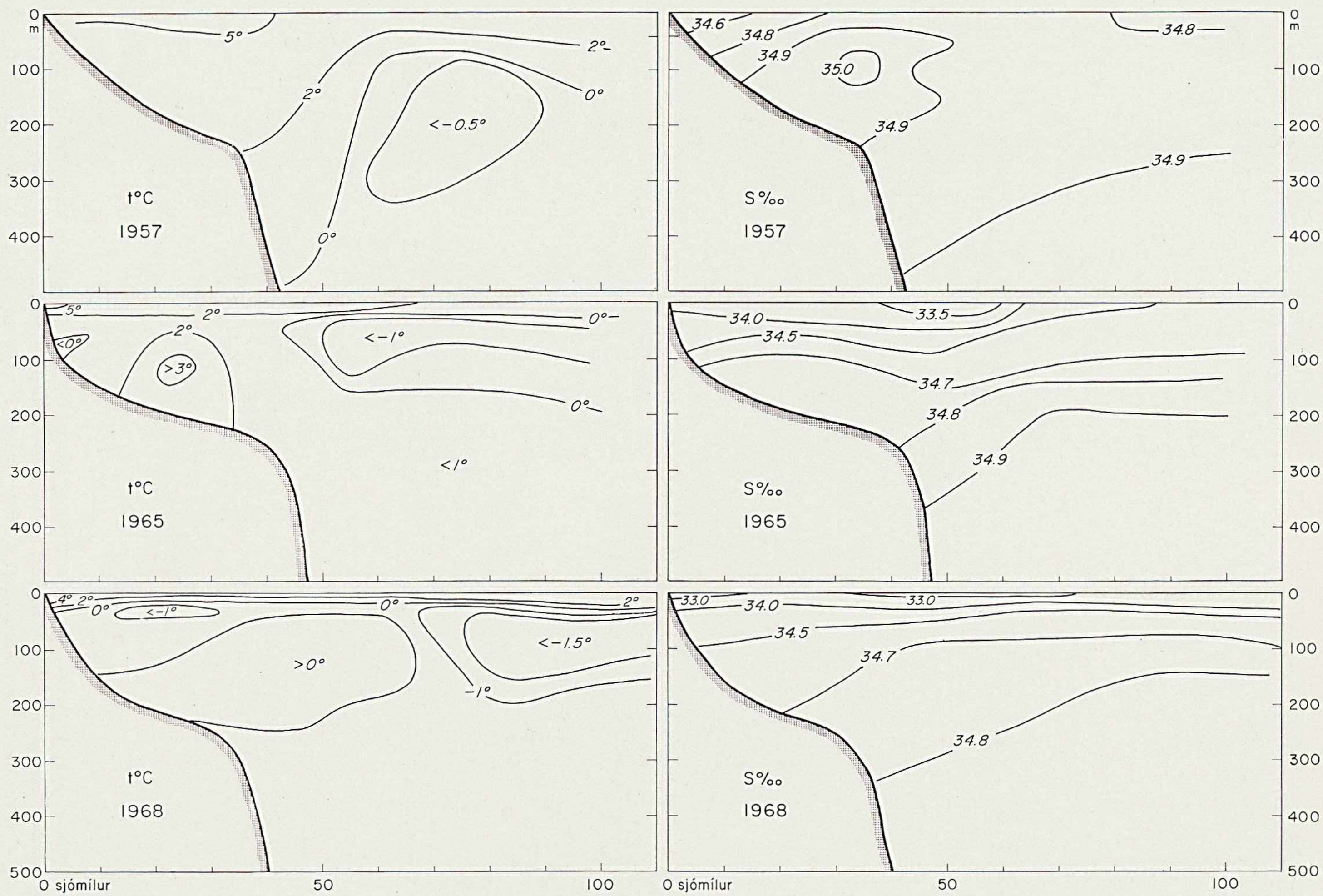

Fig. 6. Temperature and salinity profiles of the section Langanes NE–Jan Mayen in June 1957, 1965 and 1968. The horizontal scale is in nautical miles.

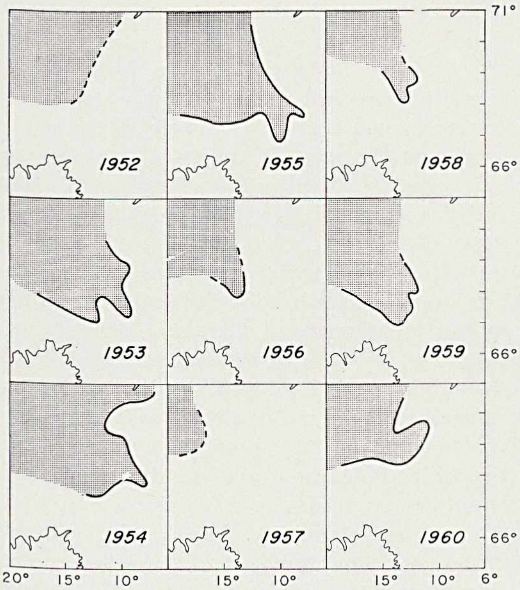

Fig. 7. The location of the 0° C isotherm at 50 m depth northeast of Iceland in June 1952–1960. (*Stefánsson* 1962, p. 206). The temperature in the shaded area is below 0° C.

Fig. 6 shows the temperature and salinity profiles of the section Langanes NE – Jan Mayen in June 1957, 1965 and 1968. The changes which have taken place in this region during the last few years are especially clear when these profiles are compared, e.g. June 1957, which represents a normal year of the 1950–1958 period, and June 1965 and 1968 which belong to the later period. The distribution of the 0° C isotherm at 50 m northeast of Iceland shown in Figs. 7 and 8 is also a clear indication of these changes. The conditions in June 1968 were quite exceptional, since the cold tongue usually found deep off the coast – even in the very cold years 1965 and 1967 – in June 1968 covered a long stretch of the coast from Skjálfandi in the north to Reyðarfjörður in the east. The polar front in the waters east of Iceland has thus advanced and in 1968 it reached the Icelandic coast and expanded farther eastwards in the Norwegian Sea than previously observed.

Furthermore, it should be noted that the temperature difference in the waters north and east of Iceland on one hand and west and south of Iceland on the other was close to 8° C in June 1968.

Fig. 9 shows the extension of the polar front east of Iceland as measured by an airborne infrared radiation thermometer in April 1968 (*Pickett and Athey* 1968). These are the most detailed measurements of the front in this region to this date since they were made continuously and in one day.

As pointed out by the author (*Malmberg* 1967 a), the extension of the polar front has thrown light on the well-known eastward shift in the herring migration in North and East Icelandic waters (*Jakobsson* and *Vilhjálmsson* 1967, *Jakobsson* 1969).

DISCUSSION

The causes of the changes in the hydrographic conditions northeast of Iceland in the last few years are more or less unknown, but here it will be attempted to point out possible explanations. In general, sea-air interaction is a well-known feature. Studies of the various conditions in the atmosphere are often used

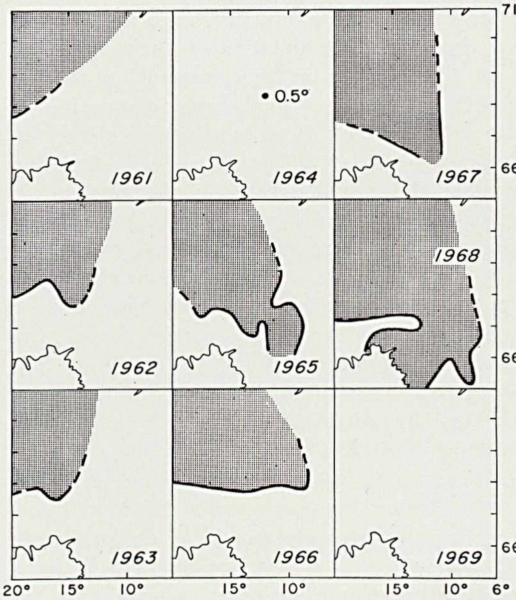

Fig. 8. The location of the 0° C isotherm at 50 m depth northeast of Iceland in June 1961–1968. The temperature in the shaded area is below 0° C.

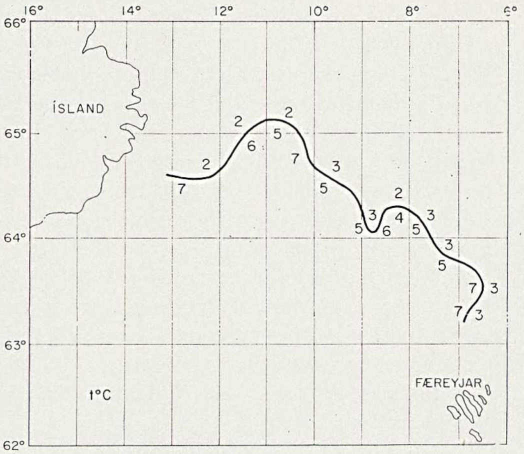

Fig. 9. The polar front in the sea east of Iceland on April 9, 1968 surveyed by means of an airborne radiation thermometer. (*Pickett* and *Athey*, 1968).

for comparison with conditions in the sea in order to understand better the acting forces involved. Various atmospheric observations are also more copious than those of the sea and thus more valuable for statistical studies. Many scientists have thus pointed out similar trends in the physical properties of the atmosphere and the sea in various regions. *Stefánsson* (1962, p. 209) has thus shown a correlation between wind conditions north of Iceland and hydrographic conditions deep off Langanes during the years 1950—1958. In this special study the effect of the atmospheric circulation may be indirect rather than direct (*Stefánsson and Gudmundsson* 1969). The recent changes in the East-Icelandic Current are probably due to more distant air and sea conditions than those of the Iceland Sea itself. Various scientists have shown a large-scale sea-air interaction in the North-Atlantic south of Iceland (a. o. *Namias* 1965, *Rodewald* 1967, 1968, *Lee, Corcrum* and *Levastu* 1967, *Dickson* and *Lee* 1969). Rodewalds results agree fairly well with the findings here presented. As shown in Fig. 10 Rodewald obtaines a low correlation coefficient between the pressure anomalies in late winter of the periods 1956—1960 and 1961—1965 in the area east of Iceland, whereas the correlation coefficient over the entire North Atlantic is high.

Björnsson (1969) discusses possible explanation of the ice drift north of Iceland. Sea ice no doubt affects the hydrographic conditions, as well as being partly dependent on these same conditions. There is also a fair agreement between the recent changes in the hydrographic conditions northeast of Iceland and the ice conditions in the area and at the coasts of Iceland. According to *Strübing* (1968) there is a close correlation between air pressure over the North Polar Sea and ice quantity in the East-Greenland Current a few months later. Part of the East-Icelandic Current is, on the other hand, a branch of the East-Greenland Current or rather the waters of its eastern boundaries (*Stefánsson* 1962, p. 57). The East-Icelandic Current and the drift ice it contains may thus also be affected by conditions in the North Polar Sea. The sea ice, responding to weather, wind conditions and ocean currents, affects the water masses by cooling them and decreasing their salinity. The decrease in salinity leads to a lowering in the density of the surface layers, which in turn increases the vertical stability. The cooling effect of cold winds the following winter, and of course sea ice, then only reaches the surface layer; the cooling cannot break down the stability and the surface layer cools down more and earlier than otherwise.

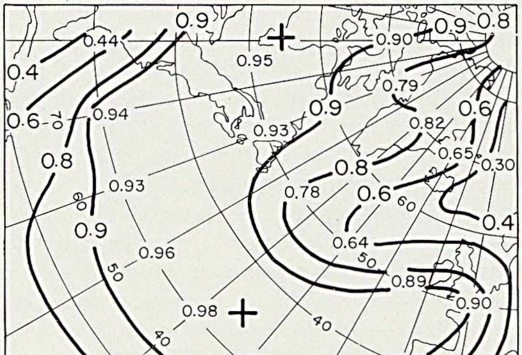

Fig. 10. Correlation between the March-pressure anomalies of the periods 1956—1960 and 1961—1965. (*Rodewald* 1967).

TABLE 3

Temperature, salinity and density of the water masses in the Iceland Sea. (Stefánsson 1962).

	North Icelandic Winter water	Arctic Int. water	Arctic Bottom water
Temperature, °C	1—2	0—2	– 0.9
Salinity, ‰	34.85—34.90	34.80—35.00	34.92
Density	27.95—27.92	27.97—28.00	28.10

Density 27.95 read 1.02795 gr cm^{-3}.

The effect of increased stability in the surface layer seems to have been in progress during the last few years northeast of Iceland. The uppermost 100—200 m have been occupied by water of relatively low density or low enough to prevent a vertical convection, although the water mass cools down to freezing point, – 1.8° C.

We will now take a look at the density of the various water masses in the region in relation to the temperature and salinity values. *Stefánsson* (1962, pp. 36—37) has defined the water masses of the Iceland Sea as shown in Table 3.

According to the temperature and salinity values given in Table 1 the temperature of 0° C and the salinity of 34.85‰ are approximately the values observed at 100—200 m depth in the area in question during the years 1964—1968. These values correspond to the density 28.01. The density of a watermass with salinity 34.7‰ or lower (as observed in June 1965, 1967 and 1968 in the uppermost 100—200 m) cannot be higher than 27.96, even though the water mass reaches freezing point, at ca. – 1.8° C. With surface salinities of 34.8‰ or higher (as observed in June 1950—1958) the density will be at least 28.05 at – 1.8° C, i.e. a deep vertical convection will start before freezing point is reached. A density of 28.01 is already reached at – 0.8° C. This temperature value fairly agrees with observations in 1950—1958, but during that period temperatures below – 1° C were not observed in the area, except in June 1953 when the temperature was about – 1° C in a limited area at 100 m depth (*Stefánsson* 1962, p. 105). It should also be mentioned that according to the scarce data from the area in the first half of this century, the observations in the years 1901, 1902 and 1903 were similar to those of the last few years, but the 1930, 1933 and 1935 observations were similar to those of 1950—1958.*

In short (see Fig. 11), when the surface layers northeast of Iceland have a salinity of 34.7‰ or lower, as observed in the extremely unfavourable ice years in Icelandic waters in 1965, 1967 and 1968, the water will not reach a high enough density to start a deep vertical convection even at a temperature of – 1.8° C, but at salinities of 34.8‰ or more this is possible. That means in the latter case a deep vertical convection before such a strong cooling is reached. This explains the trend which appears in the t-S diagrams shown in Fig. 2. The changed hydrographic conditions in the waters northeast of Iceland in the last few years have contributed to the preservation and formation of sea ice and the ice has of course intensified the changed situation, producing a decrease in salinity and an increase in stability and subsequent cooling the following winter and spring. The situation is then

*) Recently available data from June 1962 in the area in question also reveal the situation of the period 1948—1958 (*Malmberg* 1969 b).

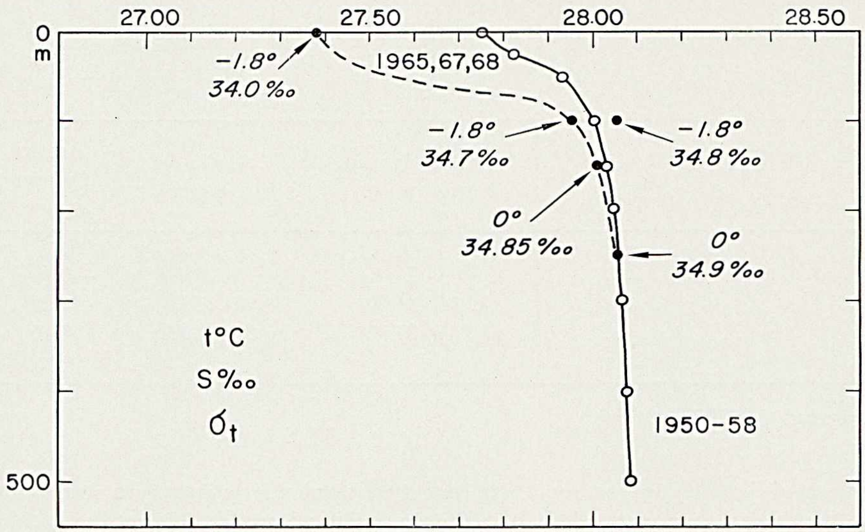

Fig. 11. The mean vertical density distribution in June 1950—1958 in the area studied. The density distribution in 1965, 1967 and 1968 is shown schematically.

a steady state unless ocean currents disturb the balance.

The origin of the cold low-salinity water is still unknown and whether an increased outflow of Polar water from the north is involved has not been confirmed. The origin of this water may be north of Jan Mayen (*Helland-Hansen* and *Nansen* 1909, p. 319), but local conditions in the Iceland Sea may also be important.

In view of what has been said above, suggested future investigations of the ice conditions in the Iceland Sea are the following: a) large-scale observations of atmospheric conditions over the Northern Seas as well as less extensive observations in the Iceland Sea, b) continuous study of the distribution of drift ice north of Iceland and c) intensive hydrographic investigations in the waters north and east of Iceland.

CONCLUSION

The main results of this paper indicate that the proportion of Polar water has increased in the Arctic water of the East-Icelandic Current northeast of Iceland during the last years compared to the period 1948—1958. That means that the East-Icelandic Current which was an Arctic current in 1948—1958 has developed into a Polar Current in 1964—1968. An Arctic current disfavours preservations and formation of sea ice because a slight vertical stratification gradient in the surface layer of such a current prevents the water masses to cool down to freezing point without starting a vertical convection. Polar currents, on the other hand, transport sea ice as far south as the Polar current maintains its characteristics: a strong vertical stratification gradient due to low salinity in the surface layer, a stratification which will prevent a deep vertical convection even at temperatures of −1.8° C. Thus the East-Greenland Current transports and even preserves the polar ice from the North Polar Sea.

The following may be concluded: There is no ice in an Arctic current but conditions in a Polar current favour sea ice. Thus a close relationship is found between the drift ice conditions in Icelandic waters, which were extremely unfavourable in the spring of 1965, 1967 and 1968, and the hydrographic conditions in the East-Icelandic Current. This relationship throws light on the physical causes of the drift ice situation. Although the drift ice situation is a complex one, depending upon climatological factors, it is considered that once the current has acquired this polar character it promotes the formation of sea ice in the deep region northeast of Iceland. This increase in the width of the ice belt in the oceanic area north of Iceland is likely to increase the frequency of drift ice in North Icelandic Waters. A knowledge of the stratification, i.e. the salinity in the surface layer, in late winter between Iceland and Jan Mayen in connection with knowledge of the atmospheric circulation and air temperature may be a tool for predicting sea ice in Icelandic waters in spring and summer.

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