RIT FISKIDEILDAR VOL. III

NORTH ICELANDIC WATERS

BY

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ATVINNUDEILD HÁSKÓLANS - FISKIDEILD
THE UNIVERSITY RESEARCH INSTITUTE - DEPARTMENT OF FISHERIES
REYKJAVÍK 1962

PRINTED IN ICELAND
LEIFTUR LTD. REYKJAVÍK

DEDICATED TO MY WIFE *Guðrún*

CONTENTS

PREFACE

The intimate relationship between the biological and the physical-chemical phenomena of the sea has long been recognized. To a fishery nation like Iceland a systematic study on the physical maritime environment must be of a paramount importance, as experience has repeatedly brought to light the close dependence of the fisheries upon the hydrographical situation. However, successful forecasting of natural conditions affecting commercial fisheries generally requires a well-founded knowledge of the physical-chemical properties of the sea and their variations in time and space.

Considerable information relating to the hydrography of North Icelandic waters may be found in various smaller papers, whilst a comprehensive account bringing together the available data has not been published so far. The present contribution is intended to give a general description of North Icelandic waters on the basis of temperature and salinity data. An attempt is made to elucidate the origin and the character of the different water masses and explain the observed variations. It is hoped that the present work, in spite of its many limitations, may stimulate further investigations in this very important area.

The temperature and salinity data discussed in this paper have already been or will be published in the Bulletin Hydrographique. The bathythermograph data collected since 1953 have been processed on punched cards and are kept on file at the Fisheries Research Institute, Reykjavík. Originally, it was planned that this work should deal with observations on dissolved oxygen, nutrients and other chemical components, besides temperature and salinity data. However, as this would have prolonged unduly the publication of the present paper, it was decided to deal with the chemical observations in a separate paper.

From a number of people valuable help and advice have been received during the preparation of this work. The author wishes to express his thanks to his former director, Dr. Árni Friðriksson, and the present director, Mr. Jón Jónsson, mag. scient., for their encouragement and kind interest in his work. Thanks are due to the director and staff of the Icelandic Meteorological Office for placing at the author's disposal various meteorological data and for valuable information. Grateful acknowledgement is made of a generous grant received from Dansk Islandsk Fond (Danish Icelandic Fund) making it possible for the author to stay for three months at the Nordisk Kollegium, Copenhagen during the winter of 1958. In this connection the author extends his warmest thanks to Professor Niels Nielsen, Dr. phil., of the University of Copenhagen. This work was also kindly aided by a grant from Vísindasjóður (Icelandic Science Fund).

Cordial thanks are due to Mr. Frede Hermann, cand. mag., of the Danish Institute for Fishery and Marine Research, for his constructive criticism and advice and to Mr. Knud Andersen, cand. mag. et scient. of the same institute, for his help with the statistical treatment. Grateful thanks are due to Professor Håkon Mosby, Dr. phil., and Mr. Odd Sælen, cand. real., of the Geophysical Institute, Bergen, for their kind interest in this work and valuable suggestions during its initial stages. Further, the author is obliged to his colleagues at the Fisheries Research Institute, Reykjavík, for fruitful discussions and their genuine interest in his work, especially Dr. Hermann Einarsson, who read part of the manuscript and made many helpful suggestions.

The author is greatly indebted to Miss Sigþrúður Jónsdóttir, B. A., for various assistance during the preparation of this paper. She has tabulated the data and made all the drawings. A great deal of the salinity determinations used in this work, were performed by Mr. Birgir Halldórsson and the opportunity is taken to thank him for his work.

Last, but not least, the author offers his thanks to Mr. Arthur J. Lee, Fisheries Laboratory, Lowestoft, for kindly reading most of the manuscript and correcting the English text.

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I.
HISTORICAL REMARKS

Systematic hydrographic investigations in Icelandic waters were not started until around the middle of the last century. Very early, however, some idea about the movement of the sea was obtained from evidence given by drifting objects and ice.

The first accounts of the currents around Iceland are found in ancient Icelandic literature of the early thirteenth century. When Ingólfur Arnarson, who is considered the first Icelandic settler, sighted the country after his voyage from Norway, he threw his *öndvegissúlur* (high-seat posts)[1] overboard and decided to settle wherever they would be recovered. He landed at Ingólfshöfði on the south coast, but sent his slaves to look for the posts westwards along the coast. Later they found the posts at Reykjavík where Ingólfur made his home in the new country (ÍSLENDINGASÖGUR I, LANDNÁMABÓK, pp. 30–32). Other Icelandic settlers who followed Ingólfur Arnarson's example always sailed to look for their high-seat posts in the same direction as he did, probably because they had heard where he found his. Thus Loðmundur hinn gamli who touched land at the east coast found his high-seat posts near Jökulsá á Sólheimasandi, a river on the south coast (loc. cit. p. 185); Þórður skeggi who landed at Lón on the southeast coast found his posts at Leirvogur in Faxaflói (Faxa Bay) (ibid. p. 189); Hrollaugur Rögnvaldsson who landed at Horn (Vestrahorn?) on the southeast coast found his posts in Hornafjörður, a little farther to the southwest (ibid. p. 192); and Hásteinn Atlason threw his *setstokkar*[2], landed himself east of Stokkseyri and recovered his posts on Stokkseyri (ibid. p. 219). Þórólfur Mostrarskegg sailed westwards along the south coast of Iceland beyond Reykjanes. He then launched his hight-seat posts in calm weather and noticed that they drifted in the direction of Breiðafjörður where he later found them on the north side of Snæfellsnes (ÍSLENDINGASÖGUR III, EYRBYGGJA, p. 5). Old Kveldúlfur, the father of Skallagrímur, who settled in Borgarfjörður, is said

1) These posts which were made of wood and decorated by carving, were raised on either side of the chief's high-seat.

2) A partition beam or post between the raised platform and the centre of the hall in the chieftain's home.

to have died when his ship was well on its way to Iceland from Norway. In accordance with his wish his coffin was thrown overboard, and Skallagrímur was brought a message that it was his father's last wish that he should settle down where his coffin would be found. Shortly after Kveldúlfur's death his crew sighted land near Southeast Iceland. As they had had the news of Ingólfur Arnarson's settlement in Faxaflói, they continued sailing westwards along the south coast beyond Reykjanes. They landed in Borgarfjörður where they came upon Kveldúlfur's coffin (ÍSLENZK FORNRIT II, EGILSSAGA, pp. 70–72). From the drift of these wooden objects, the "drift bottles" of that time, the Icelandic settlers must thus have had some knowledge of the average direction of the currents along the south and west coast of the country.

In the KONUNGS SKUGGSJÁ (*Speculum Regale*) of the thirteenth century an excellent description is given of the East Greenland ice. This description applies to Iceland as well, although Icelandic sea ice is not mentioned specifically. However, sea ice is frequently mentioned in Icelandic writings, but such accounts are usually of a limited value, especially in the older writings where the ice drift is seldom or never mentioned. But the people living on the north or east coasts of Iceland must have known the usual direction of the ice drift for centuries.

As regards the origin of the drift wood found on the shores of Iceland, opinions differed a great deal. Thus in 1576 FROBISHER held the view that the drift wood was carried to Iceland from Newfoundland, whereas others thought it came from northern Russia, Greenland or Norway. The interesting suggestion was even made that the drift wood grew on the sea floor (see THORODDSEN, 1904, pp. 119–120).

In the latter half of the sixteenth century Sir HUMPHREY GILBERT, an English explorer, pointed out the possibility that the Gulf Stream had an outlet to the northeast so that it ran towards the coasts of Iceland, Norway and Finmark (see CHAPIN and SMITH 1954, p. 105). His own theory, however, of the northwest passage led him *a priori* to believe the other alternative, viz. that the Gulf Stream had an outlet to the northwest, north of the American continent.

In ÓLAFSSON's extensive treatise on the geographical and economical history of Iceland (ÓLAFSSON 1772), the continuation of the Gulf Stream to the coasts of Iceland is clearly suggested, viz. in the discussion of the so-called *lausnarsteinar* (sea-navels) which in the old times of superstition were used for medical purposes[1] (op. cit. pp. 423–426). ÓLAFSSON pointed out that these "stones" were the nuts of tropical woods, and that the nuts had been carried to Iceland from America or the islands in the Caribbean Sea.

1) The "stones" were extracted with wine and the extract was believed to make for an easier childbirth.

II.
PREVIOUS INVESTIGATIONS

In the late eighteenth century the French sent expeditions to Icelandic waters under the leadership of Keguelen de Tremarec (1767) and Verdun de la Crenne (1771), mainly for the purpose of making navigational charts (see Thoroddsen 1902, III, pp. 93–96). Their observations were valuable in many respects and can be considered as the foundation upon which the Royal Danish Navy started to build just before the turn of the eighteenth century, when their extensive surveying of Icelandic coastal waters began.

By repeated surveys throughout the nineteenth century and during the first decades of this century the Danes continued this work. The extensive measurements of the bottom topography in Icelandic territorial waters and the general information now available to navigation in Icelandic waters must therefore largely be accredited to Danish naval officers.

During the period 1786–1824 Admiral Paul de Lövenörn was in charge of the surveying work in Icelandic waters. In his publication Lövenörn collected all the available information of that time on the currents and ice drift in Icelandic waters. He maintained that the currents along the north coast ran chiefly eastwards and pointed out that this was supported by the fact that drift wood was more frequently found on the west side of the promontories (Rifsnes, Hraunhafnartangi, Langanes) than on the east side. Lövenörn considered that the current along the north coast of Iceland was a reaction current formed when the East Greenland Current, which he believed came from the northeast, passed through the narrow strait between Iceland and Greenland. The drift wood on the north coast of Iceland he claimed to be of Siberian origin (Lövenörn 1821).

Surface temperature measurements which Schythe made on his voyage to Iceland 1839–1840, led him to believe that the warm Atlantic Current crosses the Iceland-Faroe Ridge on its way to Norway without touching the south or the southeast Icelandic coastal area which he claimed to be bathed by arctic current which he supposed surrounded the coasts of Iceland and brought the drift ice along the north and east coasts (Schythe 1843).

Schythe's views were criticized by Irminger (1843), who may be considered the pioneer in systematic hydrographical investigations in Icelandic waters. Besides criticizing SCHYTHE's estimates of the speed of the North Atlantic drift he pointed out that the east coast of Iceland is often icefree when drift ice is present along the north coast, and when the ice drifts southwards along the east coast it is very seldom found as far as Vestrahorn and never south of that point. In another paper (1853) he proved that the warm Atlantic Current continues northwards along the west coast of the country, and pointed out that this is the reason why drift ice is never observed in Faxaflói and why the climate in Iceland is so relatively mild. In a later paper (1861) where IRMINGER gave a current chart for Icelandic waters he stated that he did not think that the Atlantic Current continued eastwards along the north coast of Iceland which he believed to be bathed by a cold current of polar origin most of the time. IRMINGER was well aware of the great importance of the Gulf Stream to the climate of Northwest Europe, i.e. Ireland, Scotland, Faroes, Western Norway and Iceland. He pointed out that if the warm current west of Iceland did not exist, the bays on the west coast of Iceland would be filled with ice. Besides the sea temperature, IRMINGER mentions drifting objects as proofs for warm currents of southern origin, e.g. *mimosa scandeus*, which he states he himself found at Húsavík, North Iceland (IRMINGER 1870).

The Danish professor COLDING (1870, pp. 205–206) was of the opinion that the Atlantic Current west of Iceland gradually turned westwards and then southwards along the Greenland Polar Current. However, some ten years earlier the Icelander EINAR ÁSMUNDSSON (1861) expressed the view that the Atlantic Current turned eastwards along the north coast of Iceland. The same view was later put forward by PETERMANN (1870). He supported his arguments by the temperature data collected by IRMINGER in the years 1844–1859. From these he claimed that during the summer months the Atlantic Current must be found all along the north coast. Later observations have shown that both assumptions were correct as the Irminger Current divides off the northwest coast of Iceland.

In the summers of 1877 and 1878 investigations were made in Icelandic waters on board the Danish cruiser "Fylla". A continuation of the Irminger Current along the north coast of Iceland could be traced, whereby ÁSMUNDSSON's and PETERMANN's hypothesis was proved (HOFFMEYER 1878, BARDENFLETH 1879). HOFFMEYER (loc. cit. pp. 96–97) proposed the name Irminger Current for the current flowing north along the west coast of Iceland and eastwards along the north coast. This name has since been retained.

The *Vöringer Expedition* during the summer of 1876–78, under the leadership of MOHN and SARS, marks the beginning of detailed investigations in the waters between Norway and Greenland (MOHN 1887). During this expedition numerous stations with deep-sea soundings were made in the region north of Iceland. Although the methods of investigation were inaccurate and led MOHN to erroneous conclusions in many respects, the main bathymetrical and hydrographical features were revealed.

In the summer of 1883, Hamberg investigated the region south of the Iceland–Greenland Ridge and showed that the East Greenland Polar Current rests on warm water which he assumed to be a continuation of the Irminger Current (Hamberg 1884).

The sea between Iceland, Greenland and Jan Mayen was investigated in 1891–1892 under the command of Captain Ryder, whereby the character of the East Greenland Polar Current and its underlying waters was clearly shown (Ryder and Rördam 1895). Ryder's temperature measurements are considered to be the most reliable ones up to that time. He proved that the Polar Current near the Greenland coast rests on warm water.

The existence of a cold current of arctic origin east and northeast of Iceland, as postulated by Irminger, was discussed by Ryder (op. cit. p. 205). The main features of this current were further demonstrated by Knudsen (1899) on the basis of the material collected during the *Ingolf Expedition* 1895–1896. He gave it the name East Icelandic Current. On the basis of the same material, Knudsen also proved that the Irminger Current divides in a westerly and an easterly branch northwest of Iceland.

In 1899 and 1900 Ryder studied the surface currents between Iceland, Norway and Scotland by means of numerous drift bottle experiments. The results of these experiments and other data concerning drift bottles launched prior to 1902 were compiled by Ryder (1902, 1905).

The Norwegian oceanographic researches initiated by Dr. Johan Hjort in 1893 were gradually extended into the oceanic regions between Norway and Greenland. During the years 1900–1904, detailed investigations were carried out from the "Michael Sars" over most of this area and during 1901–1902 extensive investigations were made between Norway and Iceland from the "Heimdal". During these expeditions the measuring technique was so greatly improved by Helland-Hansen and Nansen that physical oceanographical data acquired quite a different degree of accuracy. The results of these investigations were published by Helland-Hansen and Nansen in their classical work, *The Norwegian Sea* (1909).

After the turn of the century observations were made in Icelandic waters from the Danish research vessels "Thor" and "Dana". The results of these investigations were discussed by Nielsen (1904, 1905, 1907, 1908).

During the *Danmark Expedition* 1906–1908 to the Greenland Sea, a few observations were made in the sea area north of Iceland (Trolle, 1913).

Hydrographic investigations in Icelandic waters were discontinued for the next fifteen years, partly because of the First World War and partly because the Danish research vessels, from which the major part of the investigations had been made, were investigating other areas.

In the years 1924, 1926 and 1927, investigations in Icelandic waters were resumed from "Thor" and "Dana": in 1924 by Anderson and in 1926 and 1927 by Thomsen. During these years several sections were laid off the north coast, viz. the sections off Kögur, Siglunes and Melrakkaslétta. In subsequent years these sections have generally been laid in the same manner. In this connection it may be mentioned that the North Western Area Committee of the International Council for the Exploration of the Sea recommended in 1934 that a series of continuous hydrographical sections be investigated in Icelandic waters. Those recommended for the north coast were the sections first laid in 1924 and in addition a section running eastwards from Langanes. The results of the investigations in 1924 of "Dana" and also those of "Explorer" were discussed by JACOBSEN and JENSEN (1926), and the material from 1926 was discussed by SCHMIDT (1927). In 1925 some observations were also made from the research vessels "Explorer" and "Écosse".

In the next few years extensive investigations were carried out in the Irminger Sea as well as above the Iceland–Greenland Ridge. Up to this time neither of these areas had been investigated by modern expeditions.

In 1929 the Norwegian research vessel "Öst" worked several hydrographic sections in the northern part of the Irminger Sea and on the Iceland–Greenland Ridge. On the voyage back to Norway a few hydrographic stations were worked off the north coast of Iceland. The hydrographic material was published and discussed by BRAARUD and RUUD (1932).

In the years 1931–1933 Captain IVERSEN undertook investigations in the above mentioned areas from the Norwegian research vessels "Veiding", "Polaris" and "Heimland I". The results were discussed by HELLAND-HANSEN (1936).

During the German *Meteor Expedition* in 1929, 1930, 1933 and 1935, extensive investigations were carried out in the area south of the Iceland–Greenland Ridge. The results of this expedition have been published by BÖHNECKE, HENTSCHEL and WATTENBERG (1930), BÖHNECKE (1931), BÖHNECKE, FÖYN and WATTENBERG (1932) and DEFANT (1930, 1931, 1936).

During 1931, 1932 and 1933 "Dana" also worked in these areas under the leadership of TÅNING. The hydrographic material of these expeditions was analyzed by THOMSEN (1934).

In the years after 1930 routine observations were made off the north coast of Iceland during the summer months from Danish research vessels: in 1931 by TÅNING and during 1932 and 1933 by THOMSEN. In 1930 "Rose-Mary" also worked in this area and so did "George Bligh" and "Nautilus" in 1936. Some observations were also contributed by Icelandic fishery inspection cruisers. A few of the sections investigated during these expeditions have been discussed by THOMSEN (1938).

During the summers of 1937 and 1938 investigations were carried out from the Icelandic inspection vessel "Þór". These Icelandic expeditions, which were led by Dr. ÁRNI FRIDRIKSSON, were mainly concerned with biological investigations, but some hydrographical measurements were made off the west, northwest and northeast coasts (FRIDRIKSSON 1940).

In the years 1937, 1938 and 1939, observations off the north coast were continued from "Dana" by Tåning. The influx of Atlantic water during 1939 has been compared with that of earlier years by Tåning (1943).

During the Second World War and until 1947 hydrographic investigations in Icelandic waters were unfortunately discontinued. This is the second gap in the systematic investigations started at the beginning of the century.

As the result of the increase in staff, the Icelandic Fisheries Research Institute was able to start its own hydrographic cruises in 1947. The Icelandic cruises, upon which the present paper is mainly based, will be described in the following chapter.

Observations in Icelandic waters or in the vicinity of Iceland have also been continued since 1947 by other nations. Of these may be mentioned the Danish investigations in 1948 off the north and east coasts (Hermann 1949), and in the region north of the Faroes in 1950 and subsequent years (Hermann 1951–1953, 1957, Andersen 1954, 1956, 1959). Observations were made from the Norwegian research vessel "Nordkyn" in 1947, "Uran" in 1948, "Vardholm" in 1949 (Rasmussen 1950), "G. O. Sars" 1950–1957 and "Johan Hjort" in 1958 and subsequent years. Scottish research ships made surveys in the region between the Faroes and southern Iceland in 1950 and the following years, west of Iceland in 1954 and 1955 (McIntyre and Steele 1956, 1957) and north of Iceland in 1956 and 1957 (Burns 1958, 1959). German research vessels have also greatly contributed to investigations in Icelandic waters. In 1955 observations were made from "Anton Dohrn" in the Irminger Sea, on the Iceland–Greenland Ridge and southeast of Iceland (Dietrich 1956, 1957, Krauss 1958 *a*), from "Gauss" in 1956 along the oceanic polar front between Iceland and Greenland (Dietrich 1958 *a*) and southwest of Iceland in 1957 (Dietrich 1959) and from "Anton Dohrn" in 1957 between Iceland and Greenland (Krauss 1958 *b*). During the International Geophysical Year 1958, the Germans made extensive investigations in the region southwest of Iceland (Bückmann, Dietrich and Joseph 1959, Dietrich 1960 *b*). In recent years Russian expeditions have made surveys in the waters north of Iceland. A number of publications based on these observations have appeared (e.g. Alekseev and Istosjin 1956, Alekseev, Istosjin and Ponomarenko 1961, Adrov 1959, Jaragov 1959).

Finally valuable information regarding the meteorological conditions, surface temperature and ice drift has been collected by the Danish Meteorological Institute (*Nautical Meteorological Annual*, 1892 and the following years) and the Icelandic Meteorological Office (*Íslenzk veðurfarsbók*, 1920–1923, *Veðráttan*, 1924 and subsequent years).

III.

THE ICELANDIC INVESTIGATIONS, 1947–1960

1. CRUISES

As soon as facilities permitted in 1947, hydrographical research was initiated by the University Research Institute, Department of Fisheries. The main object of the hydrographic work was to keep up the routine investigations from previous years. It was also planned to make the investigations more extensive than hitherto, so that the movement and the distribution of the water masses could be followed more closely. Throughout the investigations an attempt has been made to search for relations between hydrographical and biological phenomena that might be of practical value, leading to the ultimate goal of predicting the strength of the year classes of economically important species of fish from the study of environmental factors.

The hydrographical work at sea in 1947 and 1948 was planned by Dr. HERMANN EINARSSON and performed by him and mag. scient. JÓN JÓNSSON. The first expedition off the north coast in 1947 took place at the end of May and during June with the chartered motor vessel "Rifsnes". More extensive investigations were carried out from the patrol ship "Ægir" during July, and in late August observations on the section east of Langanes were repeated. A report on the conditions off the north coast of Iceland during the summer months has been published by EINARSSON (1949).

In early 1948 the motor vessel "Bragi" was chartered for fisheries investigations. Observations off the north coast were made during the second half of February. During the spring and summer months detailed biological and hydrographical work was carried out from "Huginn II". The investigations of 1947 and 1948 were limited to the inner part of the shelf, but the sections worked later in 1948 extended as far north as 67° 07′ N. For further particulars of the crusies in 1947–1948, see EINARSSON and JÓNSSON (1951).

In working up the material from 1948 the author felt that observations farther north in the coastal area were urgently needed. At the same time it seemed desirable that some observations should be made in the poorly investigated area north of the Icelandic submarine shelf. Therefore, in 1949 the sections were extended north to 68° N. A new section was laid from Langanes to Jan Mayen and another from Jan Mayen south along the 9° W meridian. The observations in 1949 were made during two cruises in the motor vessel "Kári" in July and August.

In 1950 two hydrographical cruises were made in the research and patrol vessel "María Júlía", the first in May and June, the second in August. During these cruises some of the sections off the north coast were extended to 68° 30′ N, but the section between Langanes and Jan Mayen was omitted. Besides temperature and salinity observations analyses of inorganic phosphates were made during both cruises. The observations in 1949 as well as 1950 were carried out by Jónsson (August 1949 and 1950) and the author (July and August 1949, May and June 1950).

During the summer of 1951 three cruises were made in the "María Júlía". The first of these cruises led by Einarsson lasted from late June till the beginning of July. Thorough investigations were then made of the distribution of zooplankton and the temperature conditions off the west and the northwest coasts. At the same time some hydrographical material was collected by stud. mag. Emilsson on board the motor vessel "Faxaborg" in the area east of Iceland and between northeast Iceland and Jan Mayen. The second cruise under the command of Jónsson lasted from the middle of July until the beginning of August. This time the North Icelandic coastal area was investigated. Finally, the third cruise, led by the author, was made during the second half of August. Hydrographic observations were then carried out off the northwest coast of Iceland, between Greenland and Jan Mayen and east of Langanes. Due to bad weather conditions at the end of August observations in the middle part of the North Icelandic coastal area could not be completed, hence the comparatively few observation stations in this area during the third cruise of 1951.

During cod investigations in May 1952 a station was worked near Kögur on the northwest coast, three stations off Siglunes and another three off Langanes. Bad weather prevented further hydrographical observations at that time. In June investigations were carried out from "María Júlía" off the north coast and the usual sections worked. Because of rough weather the section from Langanes to Jan Mayen could not be completed.

In May 1953 a few stations were worked in the area between Kögur and Langanes. In June a similar survey to that of the year before was carried out in the area north of Iceland and between Iceland and Jan Mayen. However, due to favourable weather conditions, the 1953 observations in June were somewhat more extensive than those of the previous year.

Because of the important herring fisheries on the North Icelandic grounds the main emphasis had up till now been on investigations during the spring and summer months. Hence the available material consisted mostly of summer observations, whereas the observational material from other seasons was quite scarce. Because of the lack of observations from the winter months the author found it very difficult to draw any definite conclusions regarding the annual cycle of the hydrographical conditions in the area north of Iceland. Therefore, it was decided that the author should undertake a year's study of the seasonal changes in the waters off the north coast of Iceland. These serial investigations were begun in September 1953 and carried out about once every month. For this study the section off Siglunes, the so-called Siglufjörður section, was selected. The reason for choosing this section was threefold: 1) the section runs directly north of the middle part of the coastal area where the best herring grounds used to be located, 2) it extends over the Eyjafjarðardjúp, which is definitely oceanic in character, and its depths exceed 400 meters some 10 miles offshore, and 3) few other regions in Icelandic waters have been investigated as frequently in previous years. In September 1954, after a year's run, it was decided to continue the observations for another year. The available material from the serial investigations therefore consists of monthly observations throughout the period September 1953—September 1955. Four stations on the section were worked about once a month throughout the two years period. The investigations included observations on temperature, salinity, dissolved oxygen and inorganic phosphate. A few silicate analyses were also made at one of the stations. Furthermore, when weather conditions permitted, other parts of the North Icelandic coastal area were also investigated.

As in the preceding years the Icelandic hydrographical investigations in 1954 were concentrated in the herring area north of Iceland and in the waters between northeast Iceland and Jan Mayen. These investigations were carried out from the Icelandic coast guard vessel "Ægir". The majority of the hydrographic material was collected in June; bathythermograph stations were worked during the cruises in July and early August; and in the latter half of August the observations were repeated in the region between the north coast and 69° N (Jónsson and Stefánsson 1955). During the cruises in June and late August determinations were made of dissolved oxygen and inorganic phosphate.

During the extensive herring investigations in 1955, carried out from "Ægir" under the command of Einarsson, numerous BT-data were collected (Einarsson 1956). In June hydrographic stations were worked in the sections off Kögur, Siglunes, and east of Langanes and also in a part of the section extending from Langanes to Jan Mayen. In August the sections off Kögur and Siglunes were repeated. On both cruises analyses were made of dissolved oxygen and inorganic phosphate (Stefánsson 1956).

In late May and during June 1956 an extensive survey under the leadership of Einarsson was carried out in the waters west and north of Iceland, and in the whole region between Iceland, Jan Mayen, and the Faroes. These investigations included observations on the hydrographical and chemical conditions as well as the distribution of plankton and herring shoals. In July while the research ship was guiding the herring fishing fleet off the north and east coasts a dense net of BT-stations was worked. In August these observations were repeated and additional hydrographical and chemical observations carried out.

In April 1957 a few hydrographic stations were worked in the waters northeast of Iceland and in June the usual sections were worked in the region west, north, and northeast of Iceland. Some chemical observations were made during these cruises. In July and August while the ship was engaged in herring survey on the North Icelandic grounds a great number of BT observations was made.

In late May and during June 1958 hydrographical and chemical observations were carried out west, north and northeast of Iceland under the leadership of HALLGRÍMSSON. In July and August during the usual survey of the North Icelandic herring grounds BT observations and a few hydrographic observations were carried out.

In late May and June 1959 two hydro-biological surveys were carried out in the waters west and northwest of Iceland under the leadership of EINARSSON. The investigations included observations of temperature, salinity, oxygen, phosphate, transparency, primary production, plankton, and concentration of herring shoals. In July and August a dense net of BT-stations was worked.

A routine hydro-biological survey commanded by HALLGRÍMSSON was carried out in June 1960 in the area west and north of Iceland. The temperature data consisted of BT observations except for two hydrographic sections, off Kögur and north of Siglunes. In July and August the usual BT survey was made on the North Icelandic herring grounds. In August a few hydrographic observations were made north of Siglunes and east of Langanes.

Reports on the hydrographical conditions off the north coast of Iceland during summer have been published in the *Annales Biologiques* of the I.C.E.S. for the year 1947 and subsequent years.

The frequency of observations made during different seasons is indicated in Table 1. Hydrographic stations are designated by *H*, bathythermograph stations by *BT*, and *S* indicates that only the surface temperature was measured. The numerals denote the number of stations worked north of 65° N.

As appears from Table 1 most of the observations during the period 1947 –1960 have been made during the spring and summer months, May, June, July, and August. For the other months of the year only few observations exist.

2. METHODS AND EQUIPMENT

During the summer time climate conditions off the north coast of Iceland and in other sea areas near Iceland are generally favourable to oceanographic work as calm weather prevails. Some of the measurements, however, were made in rough seas with the result that the ship was drifting fast to leeward. When possible it was attempted to eliminate the wire angle by manoeuvering the vessel. In the case of "María Júlía" and "Ægir" this was not possible because of technical difficulties. At some of the stations notes have been made in the hydrographical log book of wire angles estimated as being from 15° to 30° or even 40°. Besides, no unprotected thermometers were available for the cruises made

TABLE 1.
Frequency of observations made during different seasons.

YEAR MONTH	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1947	... ...	... ...	... ...	... ...	H 3 ...	H 42 ...	H 19 ...	H 3 ...	... ...	... ...	... ...	... ...
1948	... ...	H 22 ...	... ...	H 17 ...	H 35 ...	H 13 ...	H 61 S 69	H 57 S 12	H 24 ...	... ...	... ...	... ...
1949	... ...	... ...	... ...	... ...	... ...	... ...	H 64 ...	H 71 ...	... ...	... ...	... ...	... ...
1950	... ...	... ...	... ...	... ...	H 28 ...	H 20 ...	H 16 S 1	H 39 ...	... ...	... ...	... ...	... ...
1951	... ...	... ...	... ...	... ...	... ...	H 5 BT 2	H 137 BT 131	H 48 BT 26	... ...	... ...	... ...	... ...
1952	... ...	... ...	... ...	... ...	H 8 ...	H 37 BT 31	... ...	... ...	... ...	... ...	... ...	... ...
1953	... ...	... ...	... ...	... ...	H 9 ...	H 64 BT 42	H 5 ...	... ...	H 18 BT 12	H 7 BT 19	... ...	H 9 BT 10
1954	H 4 BT 3	H 4 BT 1	H 12 BT 9	H 13 BT 13	H 5 BT 7	H 67 BT 77	H 14 BT 149	H 31 BT 123	H 4 ...	H 4 ...	H 4 ...	... ...
1955	H 15 BT 13	H 4 BT 1	H 3 BT 7	... ...	H 8 BT 1	H 21 BT 93	H 4 BT 114	H 16 BT 98	H 3 ...	... ...	... ...	... ...
1956	... ...	... ...	... ...	... ...	H 10 BT 9	H 44 BT 124	... BT 204	H 13 BT 122	... ...	... ...	... ...	... ...
1957	... ...	... ...	... ...	H 8 BT 29	... ...	H 56 BT 124	H 10 BT 227	H 22 BT 161	... ...	... ...	H 10 BT 2	... ...
1958	... ...	... ...	... ...	... ...	H 26 BT 18	H 64 BT 130	... BT 255	H 14 BT 105	... ...	... ...	... ...	... ...
1959	... ...	... ...	... ...	... ...	H 48 ...	H 58 BT 18	... BT 196	... BT 63	... BT 28	... ...	... ...	... ...
1960	... ...	... ...	... ...	... ...	... BT 24	H 9 BT 168	H 5 BT 215	H 18 BT 166	... ...	... ...	... ...	... ...

during the years 1947—1952 and in 1955, so that the meter wheel readings may not have given the true depth even when the ship was not drifting. As the wire angles could not be determined accurately the observations have been left uncorrected. On most of the cruises in 1953, 1954, 1956, and subsequent years unprotected thermometers were used, so that the depths of reversal could be determined. Ordinarily the depth corrections were small. Therefore, it seems safe to conclude that there are relatively few instances where the wire angle has affected the results seriously.

The samples at subsurface depths were taken with frameless reversing water bottles of the type constructed by KNUDSEN (KNUDSEN 1929). Each water bottle contained two reversing thermometers protected against pressure and provided with auxiliary thermometers. When unprotected thermometers were used they were usually placed on the lowest sampling bottle and one or more intermediate bottles. Most of the thermometers were from Negretti & Zambra, a few of the thermometers used in 1947 were from the firm Schmidt and Vossberg, Berlin, and since 1956 some of the thermometers used have been from the German firm Richter und Wiese. The thermometers were provided with test certificates and the readings were corrected in the usual manner to the nearest one-hundreth of a degree using prepared correction graphs. Generally the differences between corresponding readings of the two thermometers were less than 0.02° and only rarely 0.05° or more. For sampling at depths less than 300 meters insulated water bottles were used on some of the cruises.

When taking the surface temperature, samples were collected with a dip bucket and the temperature measured with a thermometer of known calibration. Additional data on surface temperature (or rather the temperature at 2–3 meters depth) were obtained by means of sea-surface thermographs of the type manufactured by Negretti & Zambra. The thermographs were found to be quite useful in locating horizontal temperature gradients and in indicating the distance to the ice limit when sailing nearby in dark weather. Besides being used on the research vessels thermographs have been installed on board the coastal liners "Esja" and "Hekla" for studying the surface temperature along the coast. The main results from the thermographic records collected along the coasts of Iceland during the years 1949–1953 have been published (STEFÁNSSON 1950 *b*, 1954 *b*).

Since 1951 extensive temperature data have been collected with bathythermographs. These instruments have been found particularly useful for making rapid and detailed surveys of the temperature distribution of the surface layers in conjunction with searches for herring shoals and with plankton investigations. The bathythermograph is of special interest in locating the thermocline. The bathythermographs used were made by the firm Wallace & Tiernan. The instruments were calibrated in English units. The depth range was 0–450 feet. The BT slides were viewed in a reading grid and the temperature read at sufficient number of points to make it possible to redraw the BT trace on a form ruled in metric units. Such forms were printed on punch cards.

The water samples for the determination of salinity were stored in 100 ml bottles supplied with patent stoppers. The salinity was determined by titration using the conventional Mohr–Knudsen method (OXNER 1920, THOMSEN 1948) until 1956. Since 1956 a magnetic stirrer has been used when making the salinity titrations and the potassium chromate indicator replaced by a solution of sodium fluorescein and starch (MIYAKE 1939). The indicator solution used contained 0.5 g sodium fluorescein and 1 g soluble starch in 100 ml of water. Of this solution 1 ml was added to each 15 ml sample. Most of the salinity samples were run in duplicates, particularly those taken at greater depths. The salinities are considered correct within 0.02‰. All samples giving dubious values on repeated titrations were discarded.

The density, expressed as σ_t, was calculated by means of Sund's oceanographical slide rule (SUND 1929), and the anomaly of specific volume was determined either by the slide rule or by means of the anomaly tables published by SVERDRUP (1933). In calculating the dynamic heights at stations shallower than the common reference depth the method suggested by NANSEN and described by HELLAND-HANSEN (1934) was used. The construction of velocity profiles was made according to the method described by SMITH ET. AL. (1937).

IV.

BATHYMETRICAL FEATURES

1. NAMES AND DEFINITIONS

The original name for the sea area north of Iceland as well as the northern part of the Norwegian Sea was *Dumbshaf*[1] as appears in old Icelandic literature (Íslendingasögur I, Landnámabók, p. 154, Íslendingasögur III, Bárðar saga Snæfellsáss, p. 297, 301 and 302, Íslendingasögur IV, Þorskfirðingasaga, p. 344). The ocean between Norway and Iceland, however, was named *Íslandshaf* (Iceland Sea). The name was undoubtedly given on the general principle of naming the oceans after the countries to which one was sailing. Iceland was settled from Norway; hence the name Iceland Sea. This name was used by the Icelanders sailing either from Iceland to Norway (Íslendingasögur III, Víglundarsaga, p. 398 and 402, Íslendingasögur V, Fóstbræðrasaga, p. 269, ibid. Hrafns þáttur Guðrúnarsonar, p. 432, Íslendingasögur VII, Bandamannasaga, p. 375) or Norway to Iceland (Íslendingasögur I, Skáld-Helga saga, p. 427, Íslendingasögur IX, Finnboga saga ramma, p. 319).

On medieval charts there appears to be some confusion as regards the nomenclature of the northern seas. Thus the names *Mare Glaciale, Mare Septentrionalis, Mare Germanicum* or even *Mare Danicum* have been applied to the ocean waters west of Norway (Nörlund 1944). Usually, however, *Mare Germanicum* refers to the North Sea, *Mare Septentrionalis* or *Mare Glaciale* (sometimes *Congelatum*) to the area north of Iceland and *Oceanus Deacaledonius* to the Atlantic Ocean south of Iceland. On Robert Dudley's chart of 1647 (op. cit. Pl. 31 and 32) the name *Mare di Grönlandia* designates the area northwest of Iceland, *Mare d'Islandia* the area south of Iceland and *L'Oceano Settentrionale* the area east of Iceland.

On sea charts for Icelandic waters of the 18th and the 19th centuries the ocean names are rarely included. In publications from these centuries the names *the Northern Ocean* or *das nördliche Nordmeer* are commonly used for the area between Iceland and Norway. In a paper by Mohn (1878) the name *Das Norwegische Meer* is proposed for the oceanic area between Norway, the Faroe Is-

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1) Named after the king Dumbr who according to the sagas reigned in the northernmost part of Scandinavia. He was supposed to be of mythological ancestry.

lands, Iceland, Jan Mayen and Spitzbergen. MOHN writes (loc. cit. p. 11): "Das Meer, welches zwischen Norwegen, den Färöer, Island, Jan Mayen und Spitzbergen liegt, ist bis jetzt durch einen besonderen Namen nicht bezeichnet worden, was sich oft störend erwiesen hat. Da dieses Meer jetzt 1000 Jahre von Norwegern stetig besegelt worden, nämlich schon seit der Besiedelung Islands, und da die Norwegische Nation seine wissenschaftliche Untersuchung aufgenommen und angefangen hat, mache ich den Vorschlag, dass es als "Das Norwegische Meer" bezeichnet werde".

Obviously, MOHN was not familiar with the Icelandic sagas, and the name *Íslandshaf* (Iceland Sea) must have been unknown to him. HELLAND-HANSEN and NANSEN (1909) followed his proposal but go further, as they define *the Norwegian Sea* as the whole region between Norway and Greenland. However, they apply the name *Iceland Sea* to the sea area between Iceland, Greenland (south of 71° N) and Jan Mayen, but this region they consider a subdivision of the "Great Norwegian Sea Area" (loc. cit. p. 68). The Arctic explorer VILHJÁLMUR SEFÁNSSON also uses this name in his publication on Greenland (1944, p. 2). HELLAND-HANSEN and NANSEN's definition has been retained by other Norwegians. As late as 1899, however, HJORT and GRAN use the name *The Northern Ocean.* From Sweden the name *Das Skandinavische Meer* or *Skandik* has been proposed (DE GEER 1912, p. 851). The Germans, on the other hand, still retain the name *Das Europäische Nordmeer.* SCHOTT (1926, p. 42) strongly opposes the name Norwegian Sea for the whole oceanic area between Norway and Greenland, and points out that all this region can not be considered solely of Norwegian interest.

Although the original names are *Dumbshaf* for the region north of Iceland and Norway and *Íslandshaf* for the region between Norway and Iceland, it seems hardly advisable to readopt them now. However, the name Iceland Sea will be used here to designate the area between Iceland, Greenland and Jan Mayen, and it is proposed that the name Norwegian Sea be restricted to that part of the Arctic Mediterranean which lies between the Faroes, Jan Mayen, Spitzbergen and Norway, as proposed by MOHN.

The author has taken as the limits of the Iceland Sea a line from the westernmost point of Iceland, Látrabjarg, over the lowest part of the ridge between Iceland and Greenland (in the direction 305°) to Greenland; the coast of Greenland to 70° 45′ N; the 70° 45′ N parallel to the south point of Jan Mayen; the 8° W meridian from Jan Mayen to the Iceland–Faroe Ridge at 62° 30′ N; the Iceland–Faroe Ridge from 62° 30′ N, 8° 00′ W to Vestrahorn, SE-Iceland; and the Icelandic coast northwards from Vestrahorn to Látrabjarg. These limits are based partly on geographical and partly on oceanographical features. Thus in the south and the west the Iceland Sea has natural geographical boundaries, and the northern and the eastern limits nearly follow the submarine ridges west and south of Jan Mayen (see Fig. 4). Furthermore, as will be discussed in chapter VI, the eastern limit of the Iceland Sea as defined here

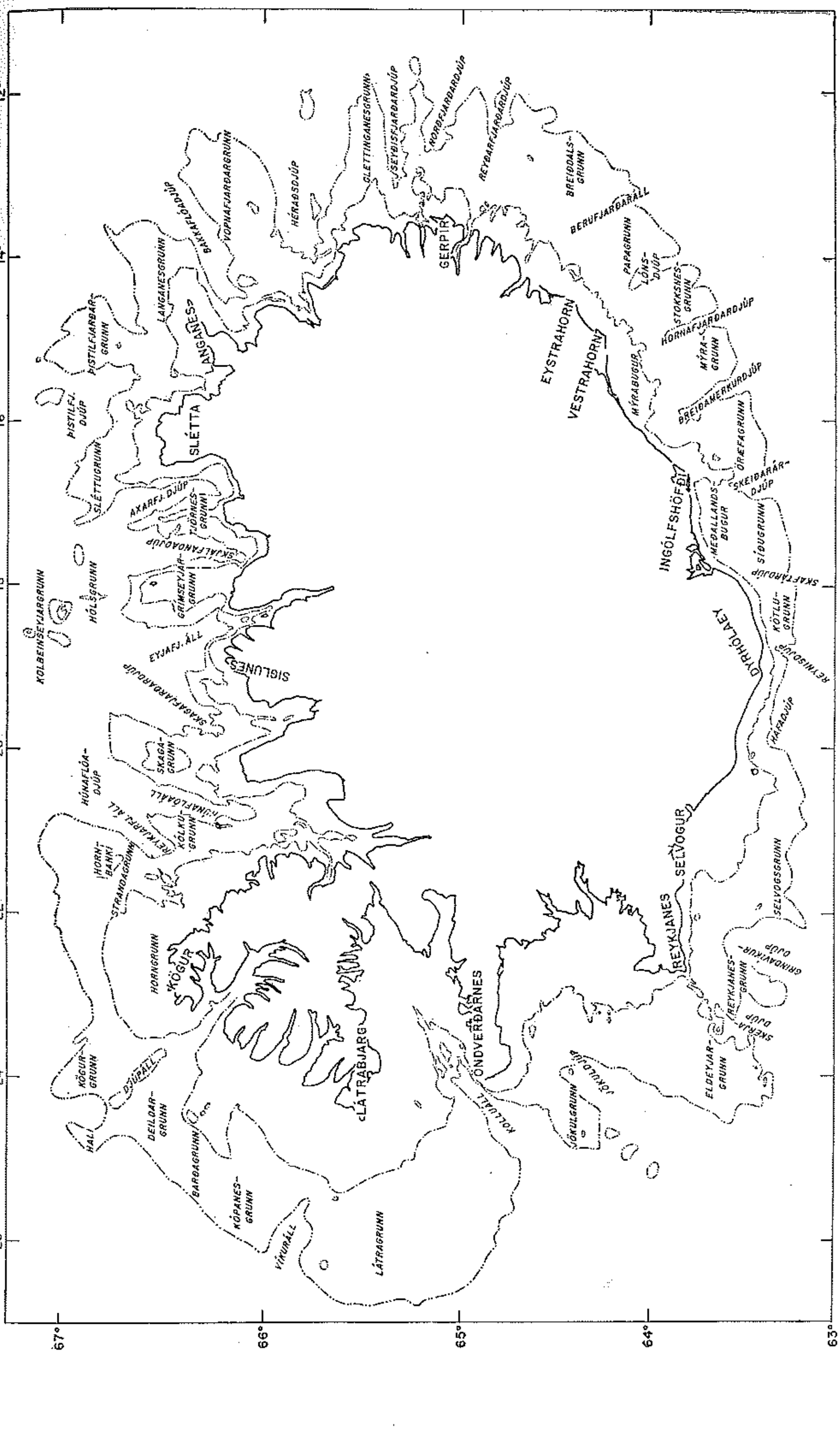


FIG. 1. *Names of the principal bathymetrical features of the Icelandic coastal region. Depth curves are shown for 100 and 200 meters.*

almost coincides with the eastern part of the cyclonic current system between Iceland and Jan Mayen, and the southeastern limit is not far from the average boundary between the Atlantic and arctic water.

2. THE BOTTOM TOPOGRAPHY

It is well known that Iceland rests on a submarine ridge extending from Scotland to Greenland. This ridge forms a barrier which separates the bottom water of the Arctic Mediterranean from that of the Atlantic. Iceland and its submarine terrace forms the broadest part of the ridge.

Recent navigational charts of the Icelandic coastal region are based on extensive soundings as regards the area inside the territorial limits. But outside these limits the available soundings are relatively few and the topographical features shown on the charts less reliable. The names of the principal bathymetrical features of the Icelandic coastal region are shown on Fig. 1. Names of localities on land frequently referred to in the text are also shown.

South of Iceland the coastal region is quite narrow, only a few nautical miles. Off the west and north coasts of Iceland, however, the shelf is relatively broad with a number of submarine valleys cutting across it. Off the northeast coast of Iceland there are steep descents, but farther south a shallow area, 500–1000 m, extends ENE some 100–200 miles offshore. This elevation must have a checking effect on the East Icelandic Current.

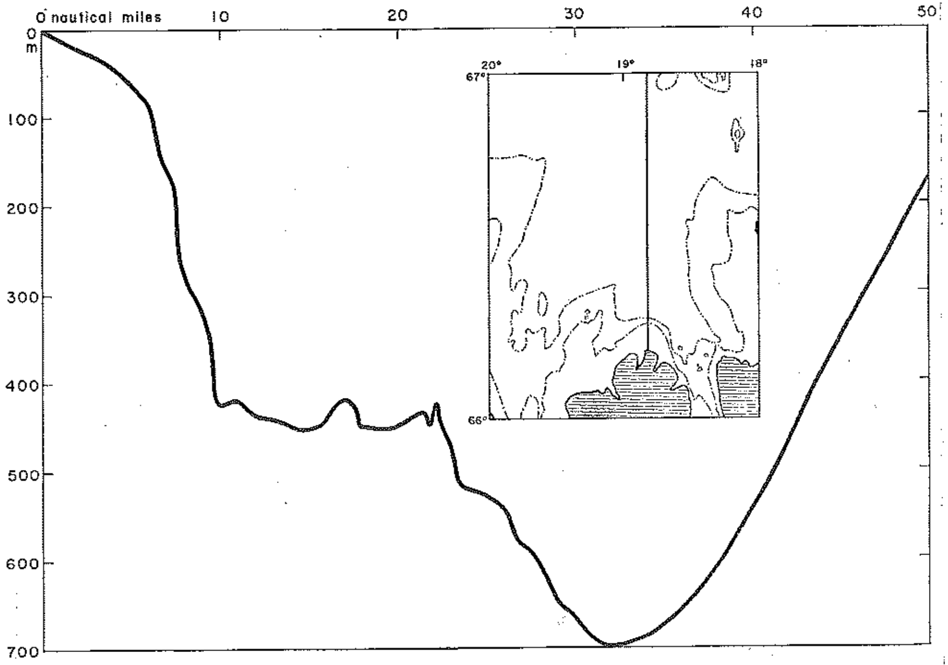


FIG. 2. *Depth profile across the Eyjafjarðardjúp.*

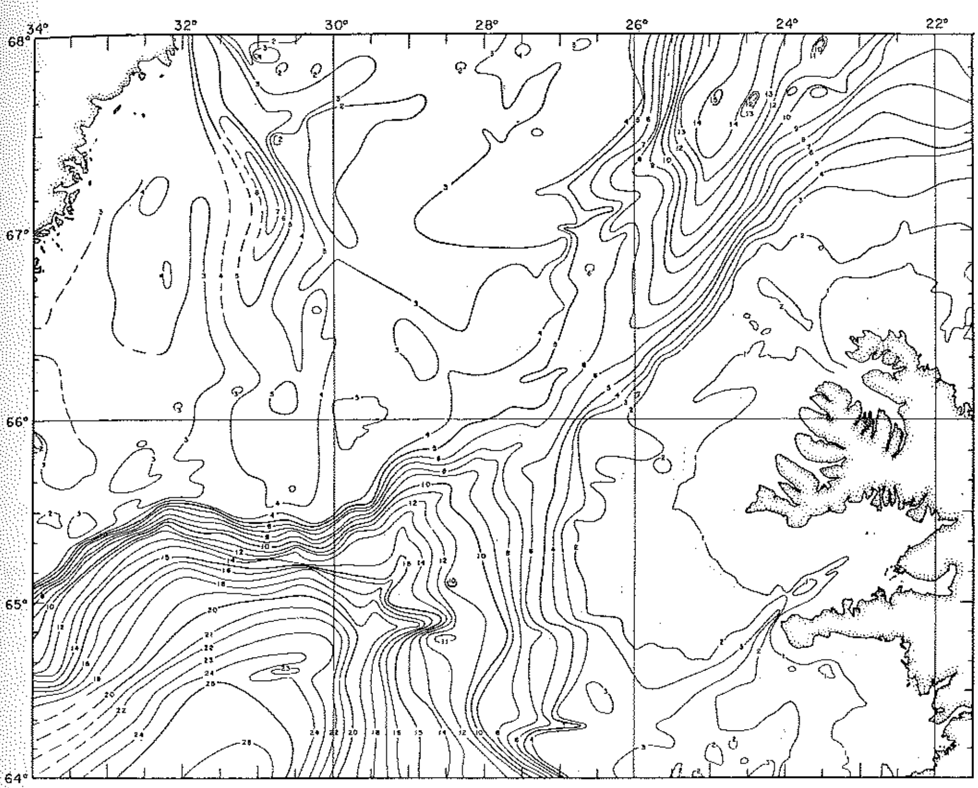


FIG. 3. *Bathymetrical features of the Iceland–Greenland Ridge. The depths are given in hectometers. (Reproduced after the chart prepared by the Deutsches Hydrographisches Institut in 1958).*

As seen from Fig. 1 the depth contours within the coastal area follow roughly the coast line, so that depressions are found off the bays and fjords and elevations off the promontories or peninsulas. There are notable exceptions however, such as the Þistilfjarðargrunn and the Vopnafjarðargrunn.

In the Eyjafjarðardjúp, west of Grímsey, a deep pit with depths about 700 meters is found. The existence of this basin has been verified by repeated sections worked north of Siglunes during the last descade. The depth profile on Fig. 2 is constructed from echograms taken in 1954 on a line due north from Siglunes towards 67° 00′ N, 18° 50′ W. The depths are uncorrected. East of this profile, between Grímsey and Kolbeinsey, shallow depths of less than 300 meters are found. On an echogram taken from the northeast corner of the Skagagrunn (see Fig. 1) to 67° 00′ N, 18° 50′ W the greatest depth found was just above 500 meters. The deepest part of the Grímseyjardjúp, Grímsey Basin, as it will be called here, is therefore isolated and not in communication with the deep water outside the shelf.

The uneven bottom configuration of the North Icelandic fishing grounds will naturally have a retarding effect on the water masses passing along the coast, and the currents will have a tendency to follow the depth contours.

The submarine ridge between Iceland and Greenland (Fig. 3) separates the Iceland Sea from the Irminger Sea. Its greatest depth of about 600 meters lies at about 26° 30′ — 26° 40′ W on a line between Látrabjarg, Iceland and Cape Edv. Hohn, Greenland (67° 50′ N, 32° 10′ W). The main part of the ridge, however, rises much higher and generally its depths are about 300–400 meters or less.

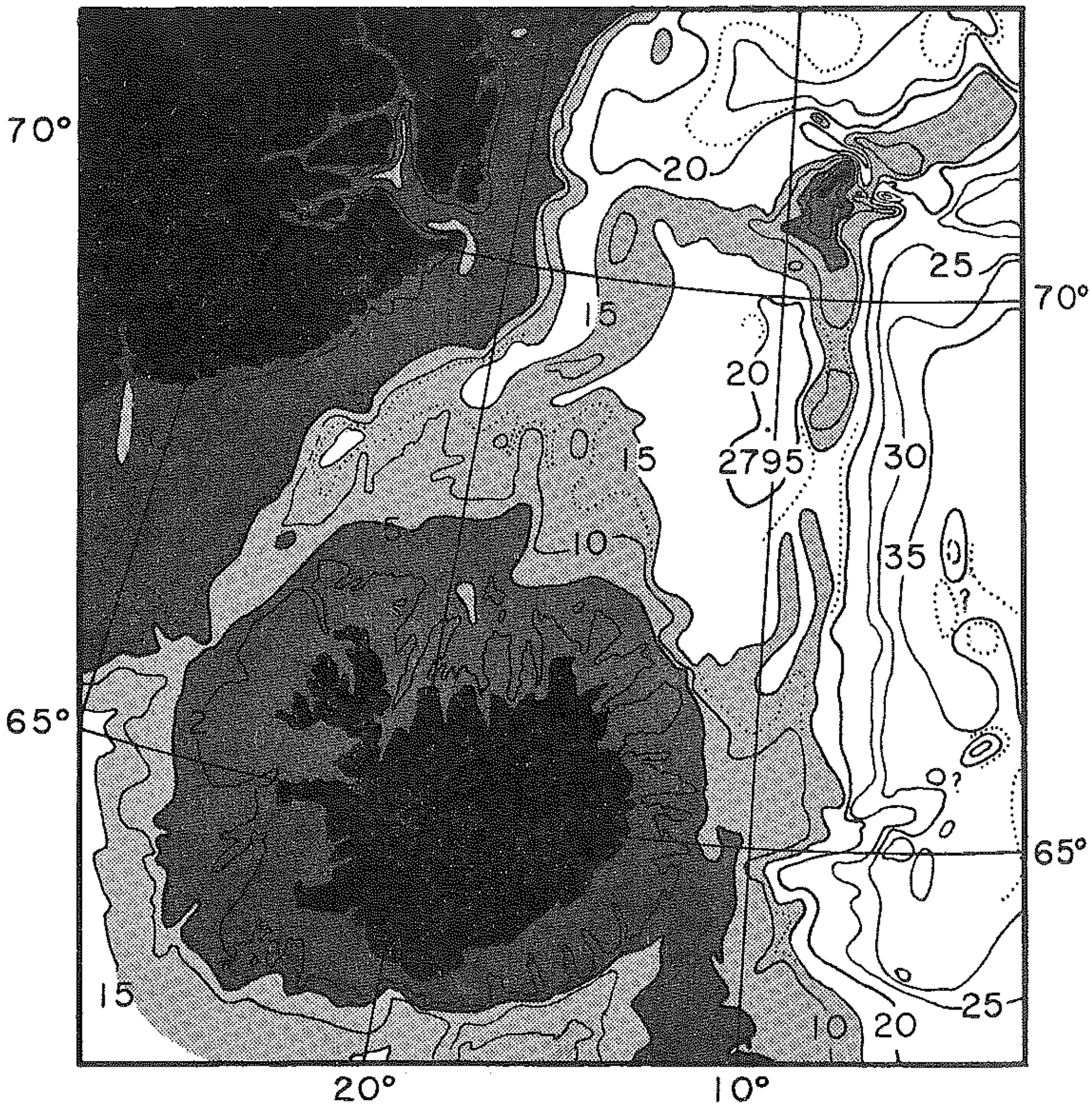


Fig. 4. *Bathymetrical features of the Iceland Sea. The depths are given in hectometers. (Reproduced after Stocks 1950).*

Relatively few soundings have been made in the deeper parts of the Iceland Sea as well as on the East Greenland continental shelf. The bathymetrical chart, Fig. 4, is reproduced after the chart presented by Stocks (1950). It is based on the Monaco Chart BI and in addition on a number of newer German and British soundings.

From the greatest depth of the Iceland–Greenland Ridge (see Fig. 3 and 4) a narrow channel, the Iceland–Greenland Channel, extends in direction SW to NE. This channel appears to be separated from the Iceland Sea Basin by the Western Jan Mayen Ridge. The slopes of the channel are rather steep, particularly on the Greeland side. Its relatively wide floor lies between 1000 and 1500 meters depth.

The Greenland continental shelf is very broad, particularly off Scoresby Sound, where the 500 meters isobath extends 70–80 nautical miles offshore. But as already mentioned only sparse soundings have been made in this area and hence the bathymetrical chart may not be altogether reliable.

The western part of the Iceland Sea Basin lies between 1000 and 1500 meters depth. The eastern half is somewhat deeper, the greatest part of it being 1500 to 2000 meters. SSW of Jan Mayen there is an isolated depression with depths exceeding 2000 meters. Its greatest depth is 2175 meters on the Monaco chart, but 2795 according to Stock's chart.

In the northeastern corner of the Iceland Sea the Jan Mayen Bank rises with slopes which are particularly steep on the western side. Three submarine ridges extend from Jan Mayen. One of these runs NE; the second ridge stretches westwards from the island to about 16° W whence it appears to have a southerly direction and separates the Iceland Sea Basin from the Iceland–Greenland Channel as previously mentioned; the third ridge with depths less than 1000 meters extends south of the Jan Mayen Bank to approximately 69° N. A continuation of the ridge can be traced all the way to the Northeast Icelandic coastal area. The Iceland Sea Basin is thus in restricted communication with the Greenland Sea on the north and the Norwegian Sea on the east.

V.
WATER MASSES

The upper layers of the sea area north of Iceland consist of waters with different characters according to their origin and mode of formation. Some of these water masses, such as the Atlantic water, have already been formed in other parts of the ocean, while other waters have been formed by various mixing processes in the Iceland Sea itself. An example of the latter is the North Icelandic Winter water.

Underlying the heterogeneous upper water strata which lie between the surface and 400–500 meters, water of a very uniform composition is found. This deep water is a part of the Arctic Bottom water filling the deeper parts of the Norwegian Sea Basin.

It is very difficult to define water masses in an exact manner in terms of temperature and salinity. Variations in the mixing processes constantly prevail and the water formed may be further changed by meteorological conditions. The different waters met with may therefore be of a very complicated nature. Here we will distinguish between three primary water masses in the region north of Iceland: 1) *Atlantic water,* 2) *Polar water* and 3) *Arctic Bottom water.*

Atlantic water is usually defined as any sea water having a salinity above 35.0‰ irrespective of the temperature. This water mainly enters the North Icelandic area from the southwest. The values of about 7°C, 35.15‰ which here will be regarded as the characteristics of "pure" Atlantic water are generally found off the west coast of Iceland.

Polar water denotes the cold upper layers with low salinity to be found in polar regions. It enters the Iceland Sea from the north. The temperature of this water is below 0°C, and the salinity ranges from less than 30‰ to about 34.5‰. During the summer time, however, the temperature of the uppermost layers may rise considerably (to more than 3°C) due to the heating by the sun. The values of about —1.80°C, 34.0‰ may be regarded as the characteristics of the extreme Polar water.

Arctic Bottom water is characterized by its uniform salinity of about 34.92‰ (varying between 34.90 and 34.94‰) and its low temperature (<0°C). In the deepest part of the Iceland Sea the extreme value of about —0.90°C is reached. This water mass fills approximately 50% of the Iceland Sea Basin.

Four secondary water masses, formed by dilution or intermixing between the primary water masses, will be considered here, viz. the *Coastal water*, the *Arctic water*, the *Arctic Intermediate water* and the *North Icelandic Winter water*.

The term *Coastal water* here indicates Icelandic coastal water only, as the Greenland coastal water is considered as belonging to the Polar water and will not be discussed here specifically. The Coastal water which naturally may be of a very variable composition consists of Atlantic water and/or Arctic water diluted by fresh water from the land.

The name *Arctic water* will here be used to designate the mixed waters occupying the surface layers in the central part of the region between Iceland, Greenland and Jan Mayen. This water is more or less formed by an intermixture of Polar water with water originally coming from the Norwegian Atlantic Current.

The *Arctic Intermediate water* is formed by cooling of the Atlantic water and mixing with Arctic Bottom water and to a lesser degree Polar water. This water appears as an intermediate layer between the Polar water and the Arctic Bottom water. Its temperature ranges between 0° and 2°C and its salinity between 34.8 and 35.0‰. It probably originates from the Spitzbergen Atlantic Current, as suggested by HELLAND-HANSEN and NANSEN (1909, pp. 279–280), but may also partly be formed in the Iceland Sea, viz. from the waters of relatively high salinity found in the region south of Jan Mayen.

The *North Icelandic Winter water* is formed in the North Icelandic coastal area during winter by vertical mixing of Atlantic water and Arctic water. The resulting homogeneous water found in the uppermost 200–300 meters may be somewhat variable in composition depending upon the degree of dilution of the Atlantic water and meteorological conditions. Usually, however, this water has a temperature of 2–3°C and a salinity of 34.85–34.90‰ (see later).

VI.

GENERAL CIRCULATION OF THE ICELAND SEA

Although a rather extensive literature is available on the circulation of the Norwegian Sea and the Greenland Sea, the knowledge of the current system in the area between northern Iceland, Greenland and Jan Mayen has been rather vague. This is because of lack of comprehensive data.

1. OLDER CURRENT CHARTS

The current chart of the Norwegian Sea most often referred to was made by HELLAND-HANSEN and NANSEN (1909, p. 9). This map is reproduced on Fig. 5. It was based on all the material available at that time. For most parts of the Norwegian Sea this map is no doubt quite reliable, and later investigations have not essentially changed their general picture of the current system. As regards the Iceland Sea their map is probably not intended to show details. Thus the East Icelandic Current is indicated on their map as branching off the East Greenland Current east of the Scoresby Sound and falling in a broad stream to the southeast between Iceland and Jan Mayen. However, in their discussion of the "Cyclonic Circulation System of the Norwegian Sea" (op. cit. p. 316–320) they state that a cyclonic movement of the surface layers is probably to be found in the Iceland Sea. Only in this way can they explain the wide distribution of the surface layers of the Polar or Arctic water in this region. In support of their statements is a chart (ibid. p. 318) showing the circulation at a depth of 100 meters in the area east and northeast of Iceland. They conclude by saying that because of limited data nothing certain can be said about this cyclonic system.

Most of later current maps including the Iceland Sea are basically drawn in accordance with HELLAND–HANSEN and NANSEN's results. Those worth mentioning because of independent features are those of MIKKELSEN (1922), NANSEN (1924), KIILERICH (1945) and ALEKSEEV and ISTOSJIN (1956).

MIKKELSEN's chart emphasizes the division of the East Greenland Current in the region west and northwest of Jan Mayen. MIKKELSEN derived his current picture mainly from observations of ice drift during the *Alabama-Expedition* to the northeast coast of Greenland in 1909—1912.

NANSEN's chart of 1924 is similar to his and HELLAND–HANSEN's chart of

1909, but a weak cyclonic eddy is indicated in the area between Iceland and Jan Mayen. Nansen ignores Mikkelsen's division of the East Greenland Current northwest of Jan Mayen (around the Belgica Bank), but in general Nansen's chart shows a distinct agreement between the currents and the distribution of ice.

Kiilerich bases his current map on the revision of earlier hydrographic data. On his chart the East Icelandic Current is indicated as extending over the whole area between Iceland and Jan Mayen, but he remarks (op. cit. p. 44)

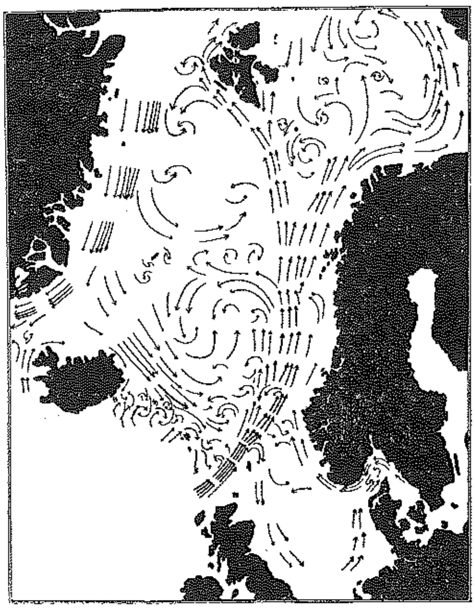


Fig. 5. *The current chart by Helland-Hansen and Nansen. (After Helland-Hansen and Nansen 1909).*

that the current velocity must be inconsiderable between Iceland and Jan Mayen, and expresses the view that the current is not continuous in this region.

The current chart of Alekseev and Istosjin is largely based on the dynamical treatment of hydrographical material collected by the Russian Polar Fishery Institute, as well as some information received from Russian herring drifters. Although the main features of Alekseev and Istosjin's current chart are the same as those of Helland–Hansen and Nansen's chart there are some distinct differences. Thus it is indicated on the Russian chart that the Norwegian Atlantic Current does not occur as a single broad stream, but is composed of discrete branches with circular eddies in between. This current picture the authors believe to be the result of the bottom configuration. Atlantic water is seen to move to the Jan Mayen area from the south as a branch of the westerly division of the Norwegian Atlantic Current. On Helland–Hansen and Nan-

SEN's current chart, however, the current flowing to the Jan Mayen area comes from the northeast. On the Russian current chart the most part of the East Icelandic Current is depicted as flowing southeastwards midway between Jan Mayen and Northeast Iceland. South of this main portion of the current a weak circular eddy is indicated which along the slope of the North Icelandic submarine terrace mixes with the east-flowing Irminger Current.

It might here be remarked that on Fuglister's temperature chart for 200 meters (FUGLISTER 1954) separate temperature gradients appear in the region of the Norwegian Atlantic Current. These discrete temperature gradients might be interpreted as reflecting separate portions of the current in agreement with the Russian current picture.

2. HYDROGRAPHIC EVIDENCE OF RECENT YEARS

The extensive hydographic data collected during the Icelandic cruises since 1949 render it possible to draw definite conclusions regarding the current system of the Iceland Sea.

From the horizontal distribution of temperature and salinity it becomes evident that in the Iceland Sea the strongest gradients are found above the slope of the North Icelandic submarine terrace (see Figs. 28–43) and along the east side of the southern Jan Mayen Ridge (see Fig. 48). In the area between Iceland and Jan Mayen, just off the Icelandic submarine terrace a tongue of cold, arctic water with salinity less than 34.8‰ in the upper layers extends to the southeast. North of this tongue, in the region south of Jan Mayen, warmer water is found with salinity approaching that of the Atlantic water. It is difficult to explain the presence of this high-salinity water unless we assume an inflow of Atlantic water either from the east or the southeast towards the Jan Mayen Bank.

The salinity and temperature distribution in the upper layers therefore suggests a cyclonic movement in the area between Iceland, Greenland and Jan Mayen, with relatively strong currents on the west side and the east side. The main branch of the East Icelandic Current appears to be located along the North Icelandic submarine terrace.

The hydrographic material from seven cruises during the years 1949–1954 was subjected to dynamic calculations for the purpose of constructing a general current map of the Iceland Sea. In calculating the dynamic heights the 800 decibar surface was selected as a reference surface and the topographies shown therefore indicate the elevation of the sea surface relative to approximately 800 meters.

Recent studies of the deep water in the southern Norwegian Sea (MOSBY 1959) seem to indicate a circulation of this water. In the summer of 1957 some bottom current measurements were made across the slope just north of the Sognefjord section (SÆLEN 1959). Within the cold water close to the bottom at

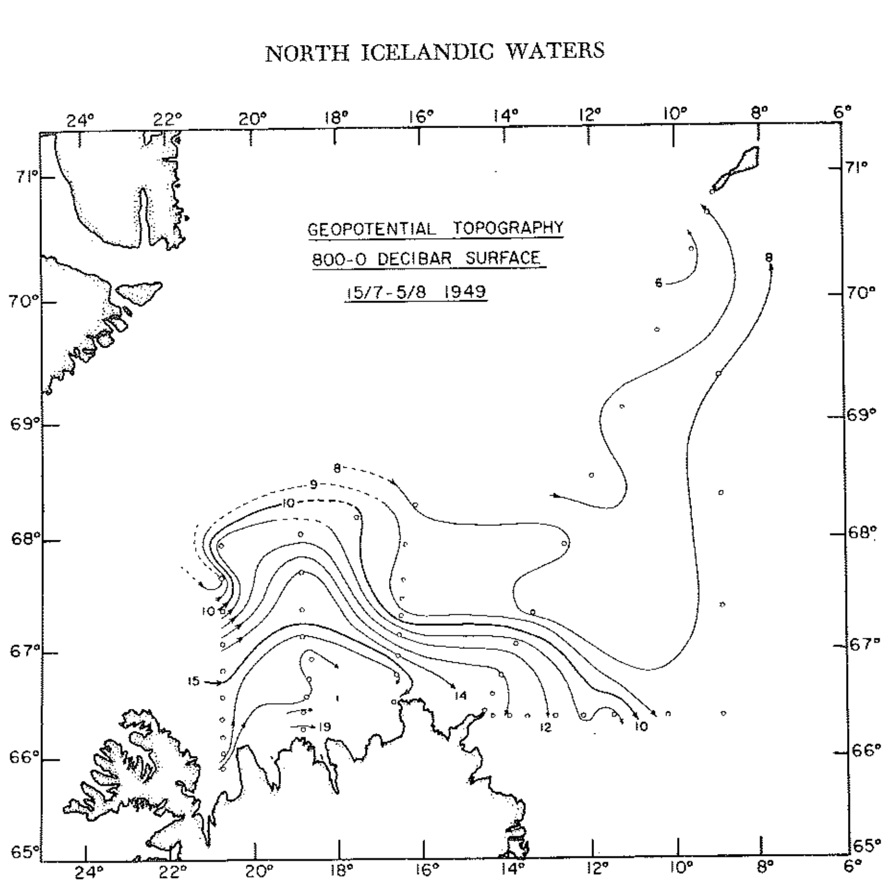


FIG. 6. *Geopotential topography 800—0 decibar surface 15/7—5/8 1949.*

800 meters the current was found to be variable and at times considerable. At 950 meters, however, the current appeared to be very weak. Velocities within the deep water north of Iceland are not known, and until direct current measurements have been made in this region, very little can be said about the motion of the deep water.

The 800 decibar surface was selected as a reference surface on the assumption that the Arctic Bottom water which is generally present at this depth and down to the bottom, is moving slowly. At this level the horizontal density gradient was generally found to be very small. As will be discussed later, the level of "no motion" probably lies higher, at about 300–400 meters depth, above the slope of the Icelandic submarine terrace. On the ridges between Iceland and Greenland and Iceland and the Faroes great current velocities may be attained near the bottom, at least intermittently (COOPER 1955, DIETRICH 1956, 1957, JOSEPH 1960). At such places a layer of no motion may not be found, but if it exists, it must be located above the depth of 400 meters. It seems likely that in the Iceland Sea Basin the Arctic Bottom water has a slow circulation in the same direction as the overlying water. At any rate it seems unlikely that the

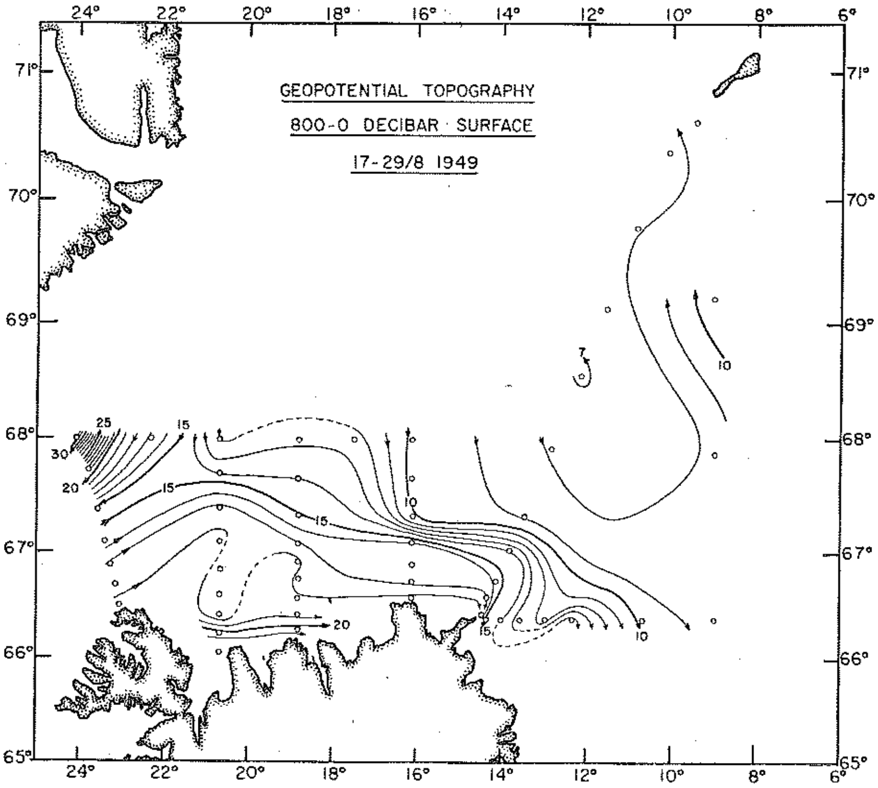


FIG. 7. *Geopotential topography 800—0 decibar surface 17/8—29/8 1949.*

Arctic Bottom water below 800 meters has a direction different from that at 800 meters. Further, the dynamic topographies obtained by using 400 dbar or 1000 dbar as the reference level instead of 800 dbar show the same main features. It therefore seems safe to conclude that the surface currents in the Iceland Sea can with a fair degree of reliability be deduced from charts of dynamic topographies with 800 dbar as reference surface.

In plotting the specific anomaly sections many interpolations and interpretations were involved. In cases where single salinity values were missing, the specific volume anomalies were estimated by interpolation or found graphically. This will not introduce any appreciable error in the computation of the dynamic height, at any rate not as regards the deep water where the salinity is found to be quite uniform. Besides this, the computations will involve the usual errors due to 1) faulty temperature and salinity determinations, 2) treating the data as if they were synoptic, 3) neglecting acceleration and frictional forces and 4) assuming that periodic changes in the distribution of mass related to internal waves are of no importance. Lastly, an additional uncertainty has been introduced when computing the dynamic height for those stations where the

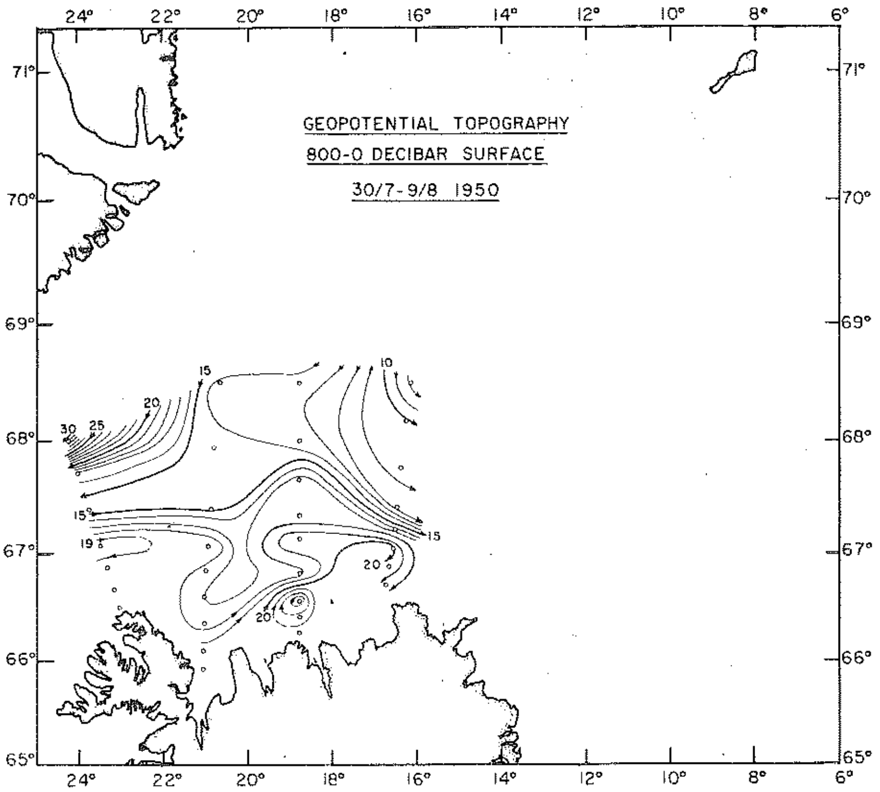


FIG. 8. *Geopotential topography 800—0 decibar surface 30/7—9/8 1950.*

depth to the bottom is less than the common reference depth. For this purpose the method previously mentioned (p. 28) was followed, i.e. δdp was integrated along the bottom from the deeper station to the shallower one.

Let us briefly consider some of these errors and their relative importance. Errors due to faulty temperature measurements will hardly be significant, as the temperature will ordinarily be correct to $\pm 0.02°$C, except in cases of appreciable wire angles where the depths of reversal have not been determined by means of unprotected thermometers. However, as mentioned elsewhere (p. 27) there are probably only few instances where the wire angles may have affected the observations seriously. The salinity determinations, on the other hand, may considerably affect the results. If the reference level selected is 800 dbar and the uncertainty in the salinity determination is 0.02‰, the standard deviation of the difference in dynamic height between two adjacent stations will be 0.65 dyn. cm.[1] Hence the difference in dynamic height can hardly be considered significant unless it exceeds 1.30 dyn. cm. On the Icelandic submarine terrace

1) See Appendix, p. 254.

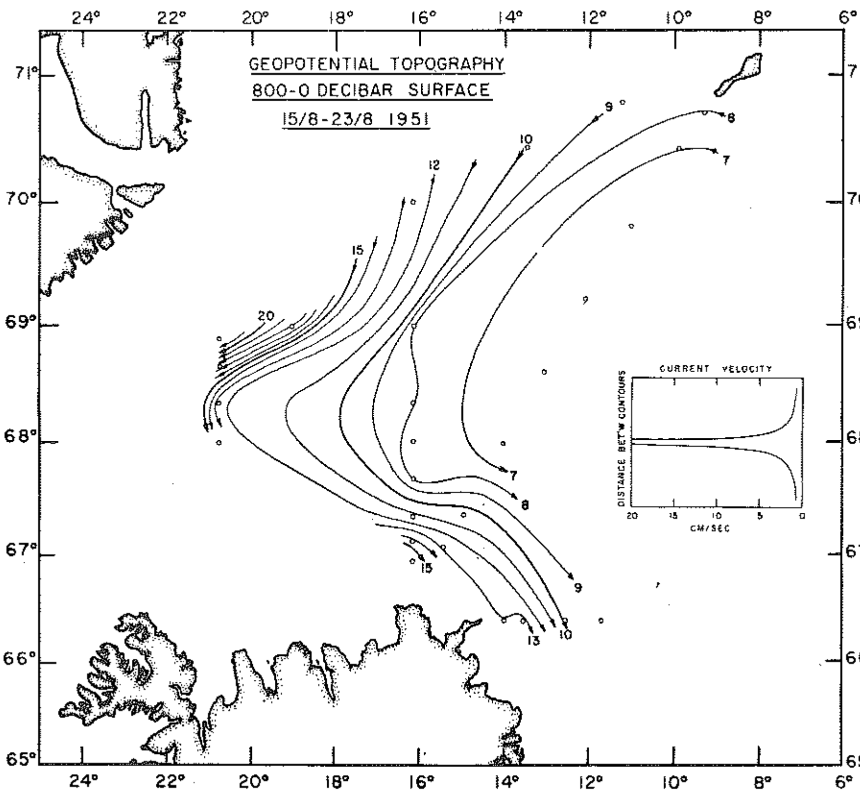


Fig. 9. *Geopotential topography 800—0 decibar surface 15/8—23/8 1951.*

where the depth is generally less than 400 meters, the standard deviation of the difference in dynamic height between two stations due to the uncertainty in the salinity determination will be less, as the dynamic height between say 800 and 400 meters is found by integrating δdp along the bottom and will be the same for all stations with observational depth less than 400 meters. Thus, if the lowest observational depth of the coastal stations is 400 meters, the standard deviation of the difference in dynamic height vill be 0.33 dyn. cm. Then a difference of at least 0.6–0.7 dyn. cm. in dynamic height is required, if the 5% level of significance is chosen.

Treating the observations as if they were simultaneous probably does not involve any serious error, particularly as a rather large area is under consideration. Plotting the dynamic topography of the 50 meter level instead of the sea surface, relative to the 800 decibar surface, gave an almost identical picture.

In those parts of the area where the greatest mixing takes place, for instance near the boundary of the Irminger Current and the East Greenland Current off

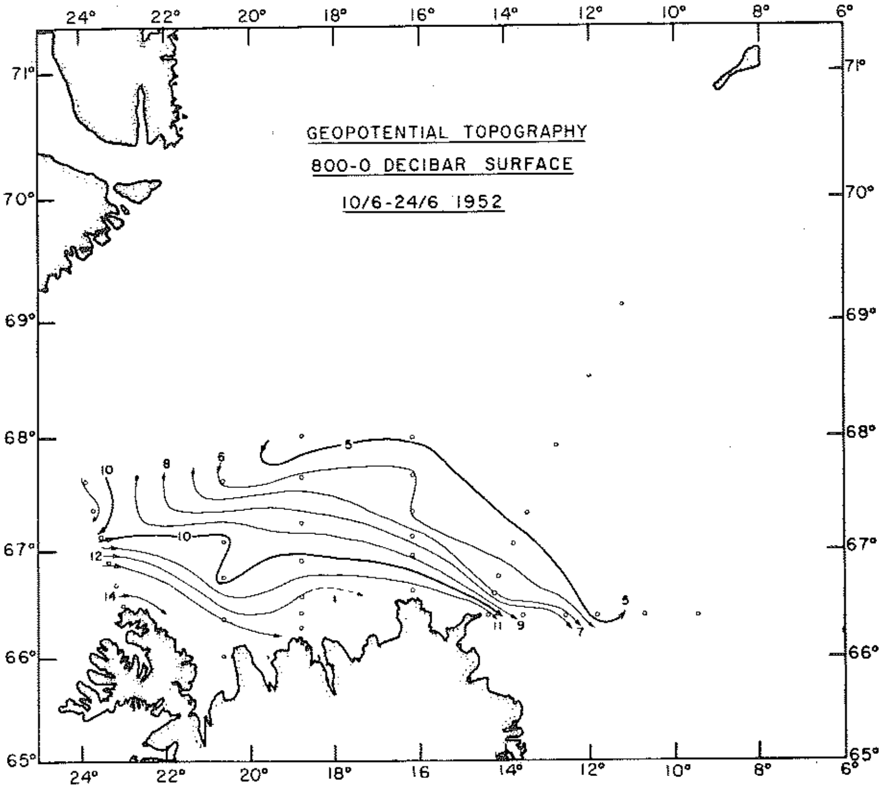


Fig. 10. *Geopotential topography 800—0 decibar surface 10/6—24/6 1952.*

the northwest coast, the currents can probably not be taken as stationary and frictionless. The calculated values of the currents must therefore be taken with reservation. In other parts of the area the effects of neglecting acceleration and friction will presumably be of minor importance.

Finally, let us consider the uncertainties introduced by the application of the method used for computing dynamic height of stations with depths less than the common reference level chosen. Even though we accept the assumptions on which the Helland–Hansen method is based as valid, i.e. that along the bottom both the horizontal velocity and the slope of the isobaric surfaces vanish, uncertainties are still inevitable when we extrapolate the anomaly curves. To minimize such errors it is important that the stations be closely spaced near the slope of the submarine terrace.

It is obvious from the foregoing considerations that great care must be exercised when interpreting the data. If the difference in dynamic height between stations is to be considered as definitely significant, it must at least exceed 0.7 dyn. cm. for depths of about 400 meters and 1.3 dyn. cm. for 800 meters.

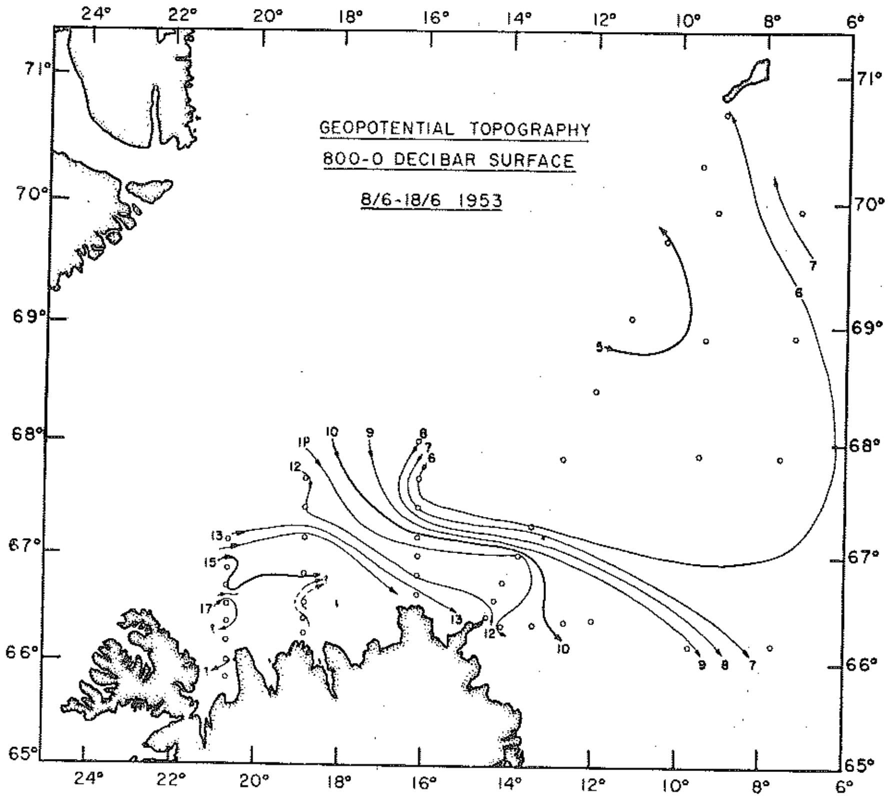


FIG. 11. *Geopotential topography 800—0 decibar surface 8/6—18/6 1953.*

The results shown in Figs. 6–20 are from the following cruises:

a) July 15th to August 5th 1949,
b) August 17th to 29th 1949,
c) July 30th to August 9th 1950,
d) August 15th to 23rd 1951,
e) June 10th to 24th 1952,
f) June 8th to 18th 1953,
g) June 9th to 22nd 1954.

It is evident from the dynamic topography charts that they illustrate quite similar features as regards the major currents. These main features are the following:

1) Whenever the observations have included the oceanic area off the northwest coast of Iceland essentially the same pattern has been revealed, viz. the East Greenland Current flowing to the southwest and attaining great velocities in the Iceland–Greenland Channel.

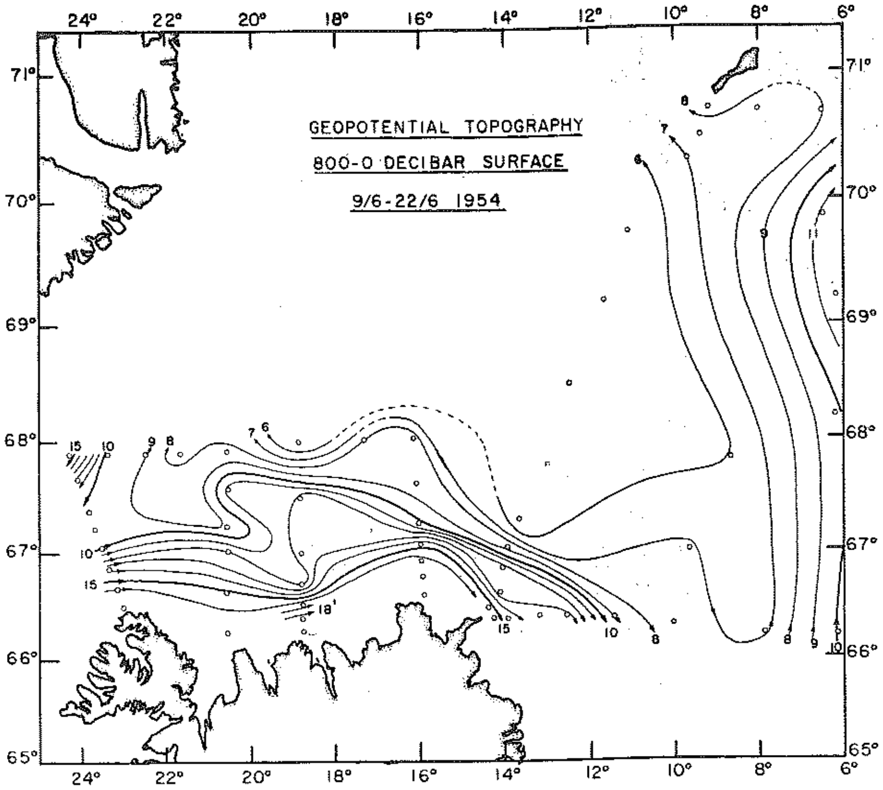


FIG. 12. *Geopotential topography 800—0 decibar surface 9/6—22/6 1954.*

2) The east-flowing Irminger Current appears as a moderately strong current with maximum velocities near the slope of the coastal shelf. At more inshore localities the current seems to be weak and irregular.

3) The East Icelandic Current is seen to be strongest over the slope of the submarine terrace off the northeast coast of Iceland. Along this slope the current makes characteristic bends which are indicated on most of the charts.

4) In the oceanic region between Iceland and Jan Mayen a weak cyclonic eddy is indicated. The southern, eastern and northeastern parts of this eddy are shown by the 1949, 1953 and 1954 observations, whereas the western part is clearly revealed by the 1951 observations.

On the other hand, certain differences are clearly seen between the various observational years, especially as regards the North Icelandic coastal area. These may be partly unreal, caused by some of the errors previously mentioned, and partly real, due to actual differences in the hydrographical situation.

In Figs. 13–20 are shown the dynamic topographies relative to 800 dbar of the 50, 100, 200 and 400 dbar levels respectively, based on observations from 1949 and 1951. Obviously these charts present features closely resembling those

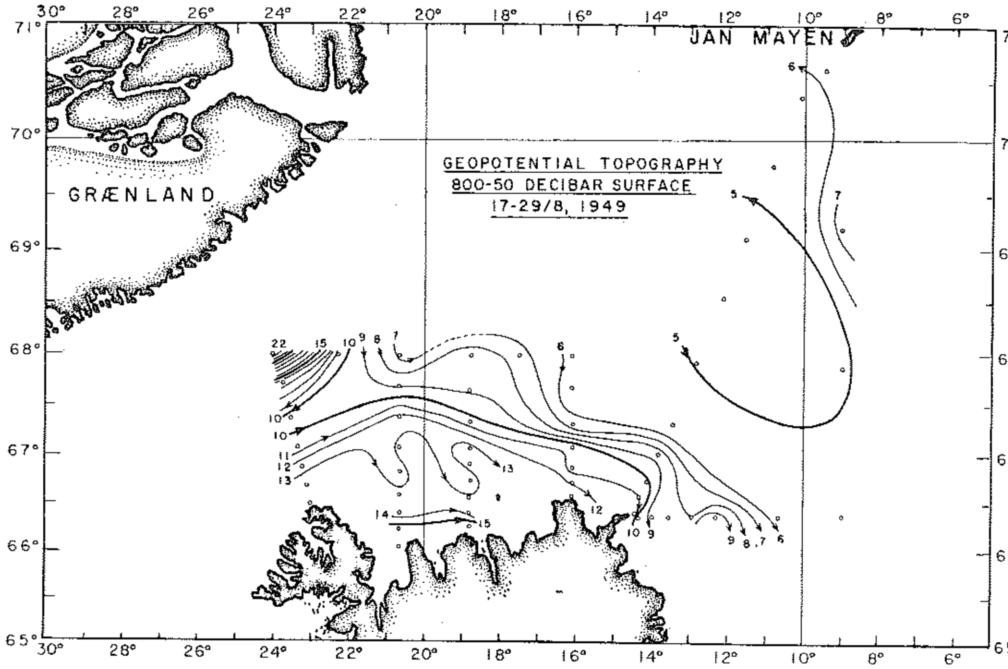


FIG. 13. *Geopotential topography 800—50 decibar surface 17/8—29/8 1949.*

of the surface layer. Thus we may conclude that in the uppermost 200–300 meters of the Iceland Sea the currents have nearly the same direction. At 50 meters the velocities are similar to those found at the surface, but at greater depths the currents gradually become weaker. The difference between the current velocity at 400 and 800 meters appears to be quite small.

3. RESULTS OF DRIFT BOTTLE EXPERIMENTS

In their extensive treatise on "Drift Bottle Experiments in the Northern North-Atlantic" HERMANN and THOMSEN (1946) have compiled all data concerning drift bottle experiments carried out prior to World War II. As will be seen from these data, an appreciable portion of recovered drift bottles from launchings in the area between Iceland and Jan Mayen and east of Iceland, were recovered in Iceland. Of 10 bottles dispatched east of Iceland (op. cit. p. 26) and stranding on the coasts of Iceland, 2 were released outside the shelf. The authors explain this drift by the wind direction, which according to wind observations from Berufjörður in Southeast Iceland and from Grímsey off the north coast, was predominantly easterly during the period after the launching of the bottles. Eight bottles from the waters between Iceland and Jan Mayen landed in Iceland, 7 stranding on East and South Iceland, and the remaining

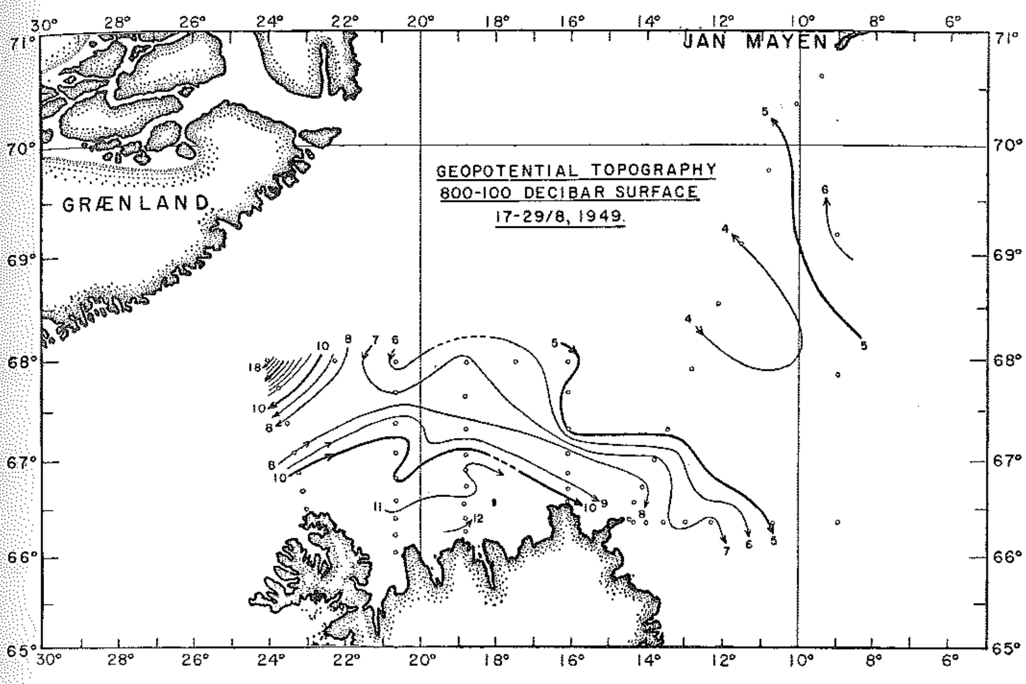


Fig. 14. *Geopotential topography 800—100 decibar surface 17/8—29/8 1949.*

one drifting to the northwest coast (op. cit. p. 26). The authors also explain this last mentioned drift by assuming that the bottle had first drifted westwards due to the easterly winds.

It seems that the drifts mentioned above could also be explained by the presence of a cyclonic eddy in the area between Iceland and Jan Mayen. With such an eddy the bottles released east of NE–Iceland would first drift to the northwest and from there to the west and south. Then depending upon the wind conditions, some of the bottles might pass into the Irminger Current which would carry them to the north coast of Iceland. Others might drift with the East Icelandic Current to the northeast or the east coast of Iceland or to the Faroes or Norway. Lastly, those bottles stranding on the south coast of Iceland having the longest drift periods, might first have drifted into the East Greenland Current and passed from there into the North Atlantic Current system.

In a previous paper by Einarsson and the present author (Einarsson and Stefánsson 1953) drift bottle experiments carried out in the Iceland Sea during 1947 and 1949 are discussed. It is pointed out (op. cit. p. 7) that of 11 bottles recovered from launchings at the end of July 1949 in the area between 68° N and Jan Mayen and 9° W and 15° W only 2 were found in Norway, but 9 in Iceland. These Iceland recoveries had a similar drift period (160 days) as those released farther south. The authors concluded that in view of hydrographic

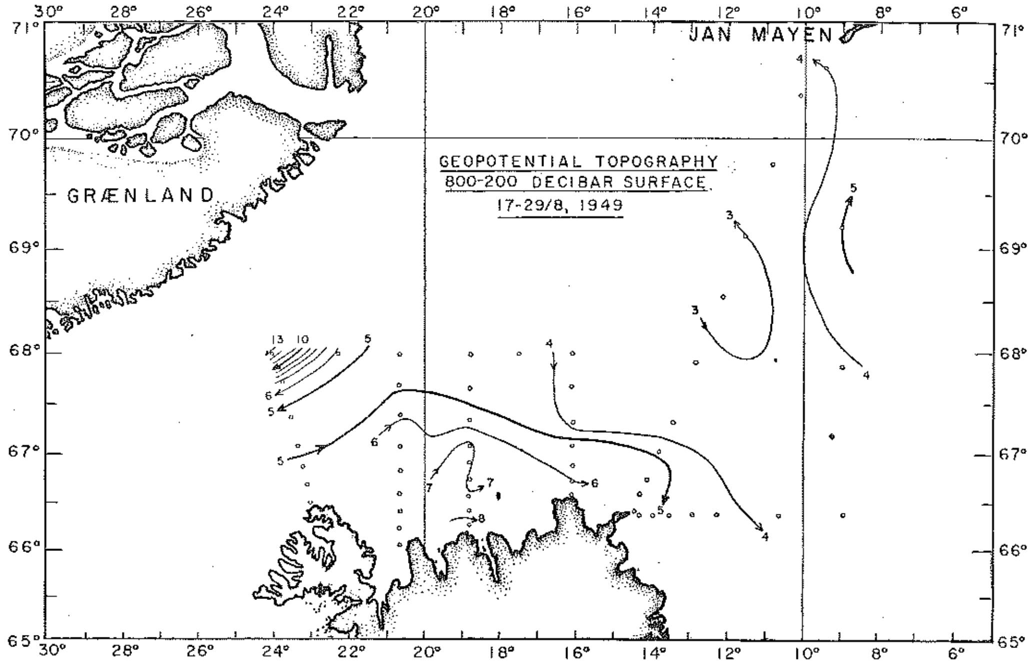


FIG. 15. *Geopotential topography 800—200 decibar surface 17/8—29/8 1949.*

evidence, not presented then but included in the present work, this drift period could only be explained by assuming a cyclonic current system in the waters between Iceland and Jan Mayen.

A similar result was obtained from drift bottle experiments in the area south of Jan Mayen in 1951 (unpublished data). Of 20 bottles released on August 19th that year at 70° 25′ N, 9° 37′ W, one was recovered in Skagafjörður in North Iceland 110 days later.

In 1952 200 drift bottles were released at 10 different stations in the area between 66° 22′ N and 69° 07′ N and 7° 25′ W and 14° 05′ W (unpublished data). Of these bottles 36 were recovered, 30 in Norway, 2 in Sweden, 1 in Jutland, 1 in the Shetland Islands, 1 in the Orkneys and 1 in the Faroes. These results were somewhat surprising as none of the bottles was recovered in Iceland.

4. EFFECT OF WIND ON THE BOTTLE DRIFT

It did not seem likely that in all the cases where bottles from the oceanic area between Iceland and Jan Mayen were recovered in Iceland, they had drifted such a long distance owing to easterly or northerly winds across the average direction of drift. To ascertain whether this was true, a study was made of the wind conditions in the area where the bottles were released. For this purpose the daily wind observations were compiled from the weather maps for the

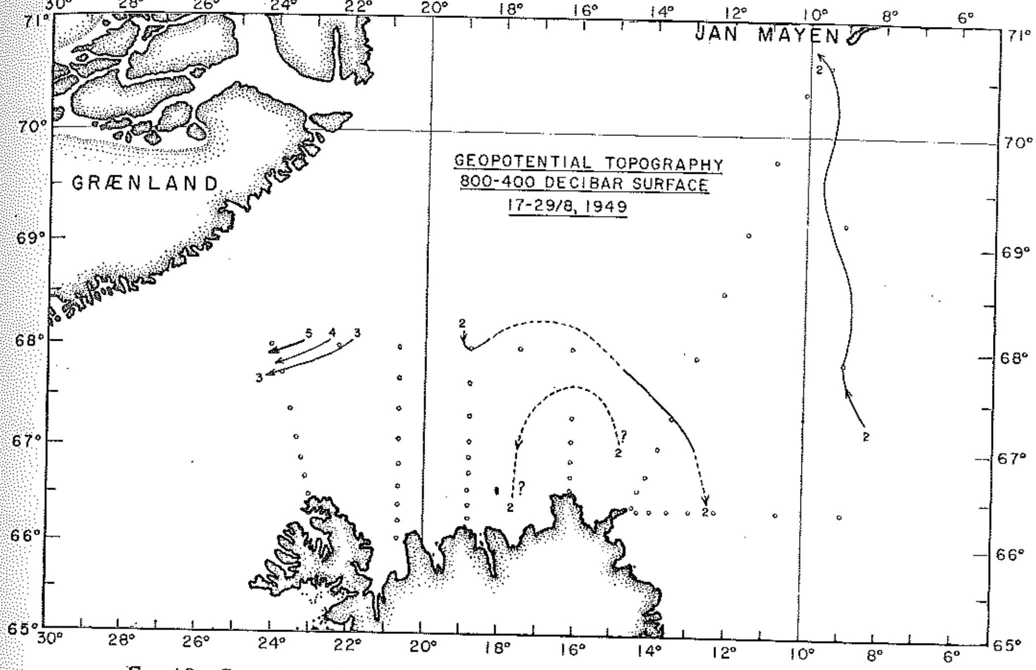


FIG. 16. *Geopotential topography 800—400 decibar surface 17/8—29/8 1949.*

periods following the release of the bottles. Three periods were analysed: August 1st to December 31st 1949, August 19th to December 6th 1951 and June 16th to September 30th 1952.

In analysing the meteorological data, the wind direction and velocity was expressed vectorically and added for the entire period. In this way the resultant wind vector was determined. A copy of the material and the calculations is kept on file at the Fisheries Research Institute in Reykjavík.

According to EKMAN (1905) the ratio between the velocity of the surface current and the wind velocity is roughly expressed by the relation

$$\frac{v}{w} = \frac{0.0127}{\sqrt{\sin \varphi}}$$

where v is the velocity of the surface current, w the wind velocity and φ denotes the latitude. For the latitude in question (about 66°–70°) this ratio, the wind factor, will be about 0.013. ROSSBY and MONTGOMERY, however, (see SVERDRUP 1946, p. 495) give higher values for the wind factor, between 0.02 and 0.03, depending upon wind velocity and latitude.

It is assumed that the water is driven in a direction 045° to the right of the surface wind (EKMAN 1902). For the area in question the northerly wind component will therefore be most effective in driving the bottles towards the north coast of Iceland, if we assume that the normal density currents are negligible

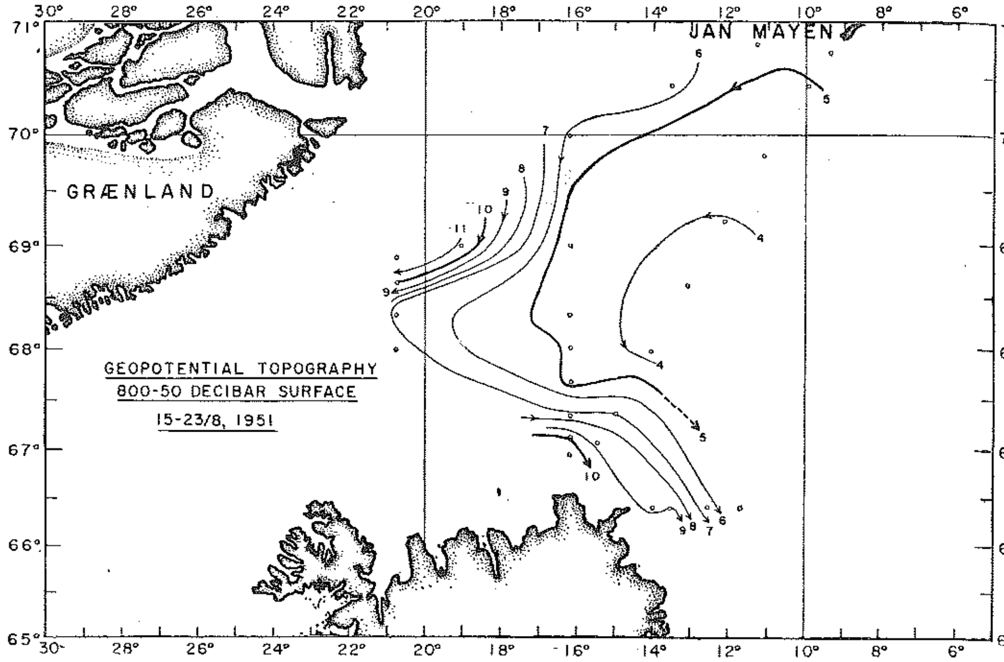


Fig. 17. *Geopotential topography 800—50 decibar surface 15/8—23/8 1951.*

as compared to the wind currents. Presumably this is not true, and we therefore have to deal with the resultant of the wind current component and the normal density current (the basic current). According to the older current picture, winds between northeast and east would seem most effective in bringing the drift bottles from the area of release to their stranding places on the northeast or east coast of Iceland. For the sake of the argument the older current picture is adopted and the normal surface current to the southeast in the region between NE-Iceland and Jan Mayen is estimated as 3 miles per day. Then the following considerations will apply.

The 1949 Experiments.

The drift bottles first considered are those launched in the area north of 68°N at the end of July. The average distance from the area of release to the places of recovery in Iceland was approximately 200 miles. The resultant wind for the 153 day period August 1st to December 31st had a mean value of 4.4 nautical miles per hour, and it was directed to the southwest, i.e. from 045°. The mean wind current component would thus have been directed to the west, i.e. from 090°.

If we use Ekman's value of 0.013, the wind current alone could have driven the bottles about 210 miles to the west, i.e. they would have passed into the East

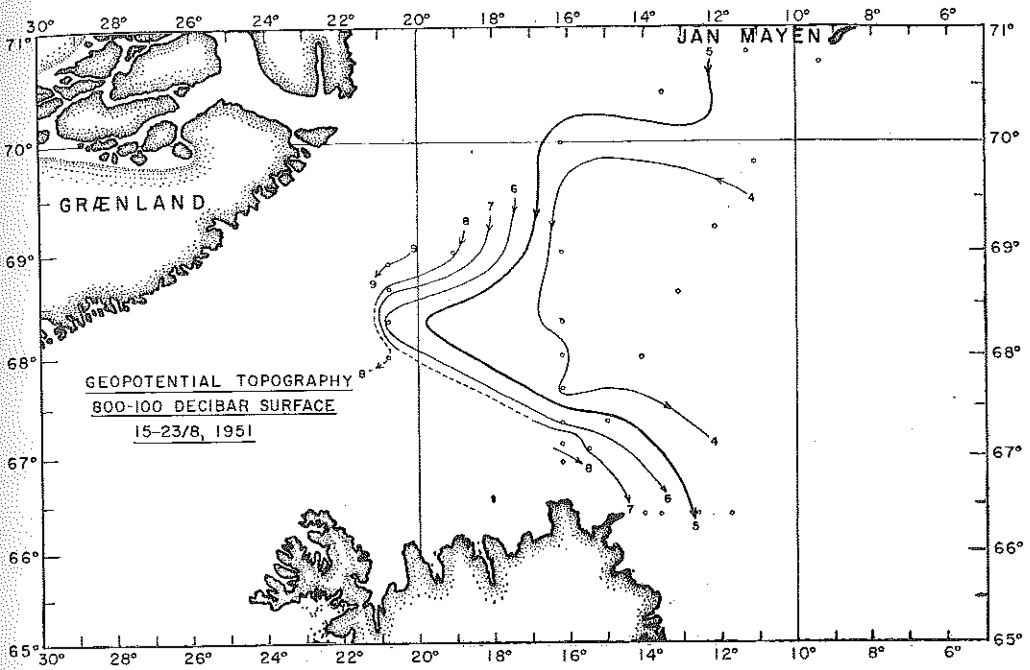


FIG. 18. *Geopotential topography 800—100 decibar surface 15/8—23/8 1951.*

Greenland Current. The basic current was estimated as 3 miles per day from 315°, so that the drift caused by that current alone during the 153 days would amount to 459 miles to the southeast. The resultant of these two components would amount to about 340 miles from 340°, i.e. the bottles would have passed by the northeast and the east coasts of Iceland and could not have stranded on these coasts. However, using the higher value of 0.025 for the wind factor, the resultant drift would have been from 015°, and then they could easily have landed on the northeast or the east coast of Iceland. Thus adopting the old current picture it appears possible to explain the results of these drift bottle experiments by the wind conditions.

On the other hand, if we consider the two drift bottle experiments carried out few days later farther southeast (at 67° 22′ N, 9° 00′ W and 66° 22′ N, 9° 00′ W) from which recoveries were also found on the northeast coast of Iceland, even as far west as Skjálfandi (see EINARSSON and STEFÁNSSON, List of Experiments, p. 20), it does not seem possible to explain those results by a direct drift due to the wind conditions, especially as during the first 3 months following the release of the bottles the wind was more northerly than easterly. Furthermore, the fact that the drift periods of most of the bottles launched in the oceanic area northeast as well as east of Langanes and stranding in Iceland were similar, suggests that they took a similar route. Lastly, it is of interest to note that of the 1949 bottles released east of Langanes, those launched close to

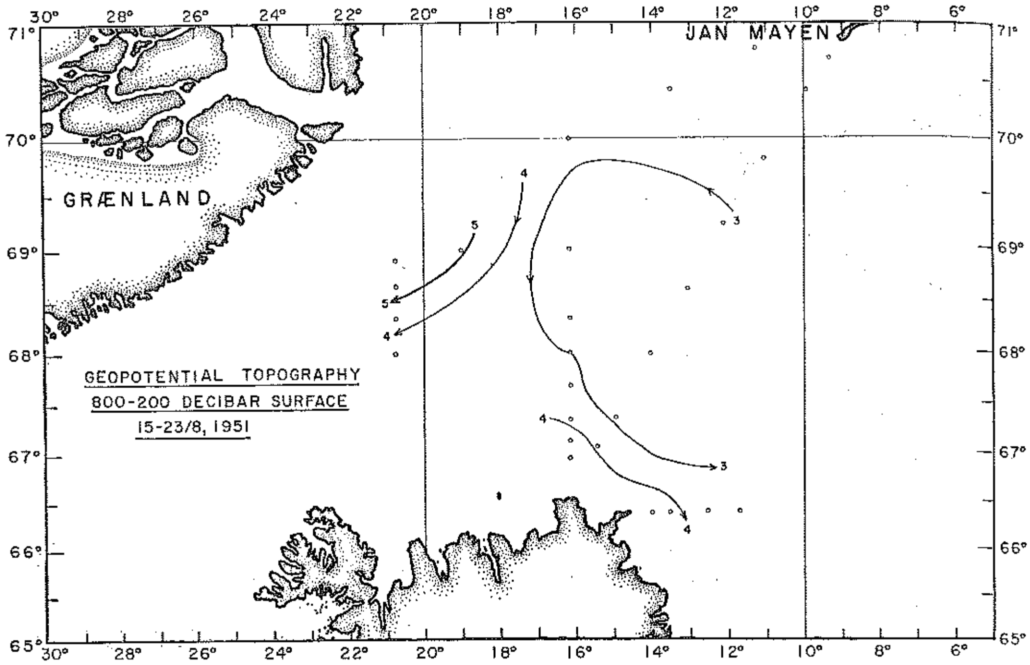


Fig. 19. *Geopotential topography 800—200 decibar surface 15/8—23/8 1951.*

shore were in general recovered in Norway, whereas those liberated at more offshore positions were recovered in Iceland (op. cit. pp. 17–20). By the older current picture these results would be difficult, if not impossible, to explain. With a circular current system as indicated by the dynamic topographies all these drifts are easily explained in the manner described on p. 47.

The 1951 Experiments.

The distance from the release point of the bottles south of Jan Mayen to the place of recovery in Skagafjörður is about 350 miles. The resultant wind for the 110 day period had a mean value of 6.9 nautical miles per hour. It was directed from 055°.

Using the smaller value for the wind factor, a surface wind current would be created from 100° having an average speed of about 2.1 nautical miles per day. The resultant current of this wind drift and the basic current (here provisionally assumed to be 3 miles per day to the southeast) would flow almost directly to the south at a speed of 1.55 miles per day. At the end of 110 days the bottle would thus be located northeast of Langanes and be over 200 miles short of its stranding place. Using the higher value of 0.025 for the wind current, the resultant drift would be from 060° and amount to 260 miles for the 110

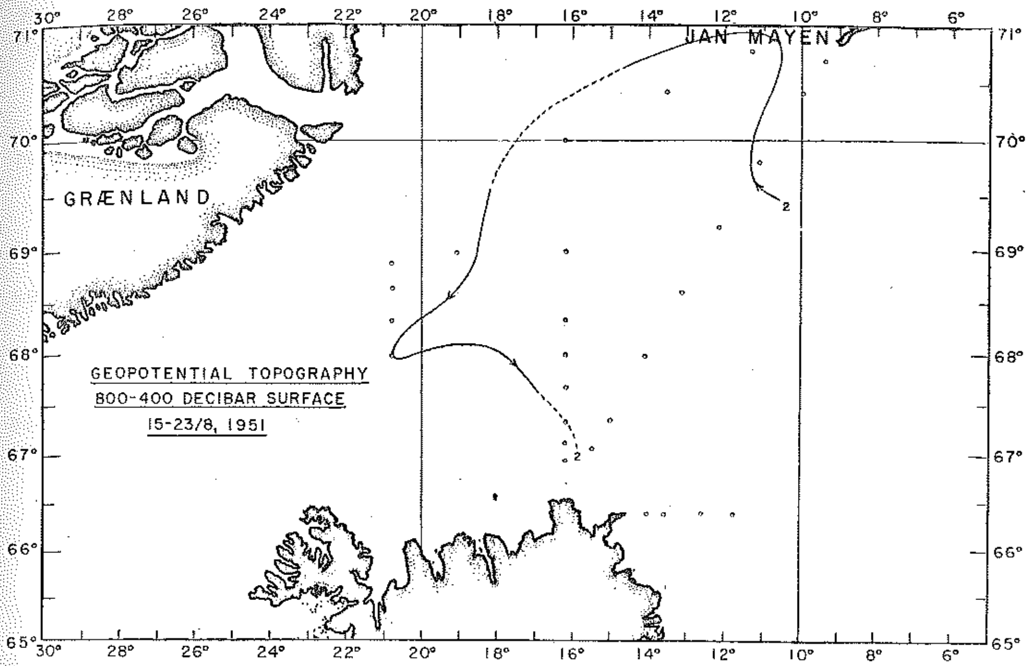


FIG. 20. *Geopotential topography 800—400 decibar surface 15/8—23/8 1951.*

day period. Thus it would still be almost 100 miles to the stranding place. It should be remarked here that using an appreciably higher mean value for the basic current would lead to more easterly direction of drift, in which case it would seem even more improbable, on the assumption made, that the bottles would be recovered in Skagafjörður.

In this experiment, therefore, it seems hardly possible to explain the bottle drift on the basis of the older current picture. Here again, the drift is easily conceivable if we assume a cyclonic current system between Iceland and Jan Mayen.

The 1952 Experiments.

The analysis of the wind data for the first 3½ months following the release of the 1952 bottles gave a resultant wind almost directly from the north and a wind current component to the southwest amounting to 140 or 270 miles depending upon which wind factor we use. Using the same value as before for the basic current, the resultant drift would be about 340 or 390 miles from 340° or 356° respectively. In either case the bottles would be unlikely to drift to East Iceland. This conclusion is thus in agreement with actual findings. The result obtained can be explained by either current picture. Provided a circular eddy exists it would seem probable that the bottles launched inside the eddy, where the motion appears to be slow, would initially have drifted to the southwest until they entered the East Icelandic Current east of Langanes, whence they would have been driven southeastwards by the density current.

Of special interest is the one bottle found adrift. It was launched at 66° 22′ N, 11° 52′ W on June 23rd and recovered at 65° 14′ N, 10° 12′ W on July 24th, i.e. 31 day later. It had thus drifted to the southeast with an average speed of 2.6 miles per day, which is in fair agreement with the value for the current velocity as indicated by dynamical calculation (cf. Figs. 6–12).

5. DISCUSSION

It must be emphasized that results obtained by drift bottle experiments must be accepted with great caution. Thus the direct effect of wind on the bottle drift may be considerable, and hence the drift route of the bottles may deviate from the direction of the actual surface current. Although the places of recovery are known, the bottle experiments yield no direct information regarding their drift route. However, from the considerations above it seems clear that the current picture indicated by the dynamic calculations is definitely supported by the results of the drift bottle experiments.

An additional support for a cyclonic current system over the Iceland Sea Basin is found by inspection of the bathymetrical features. From Stock's bathymetrical chart (see Fig. 4) it will be evident that the Iceland Sea Basin is partly isolated, viz. by the ridges extending south and west of Jan Mayen. These ridges approximately coincide with the boundaries of the circular eddy.

Easterly winds might intensify the cyclonic movement of the surface waters over the Iceland Sea Basin and thus induce more drift bottles launched east of the main East Icelandic Current to drift initially north or northwest. Later they would be carried to the north or the northeast coast of Iceland. The fact that easterly winds are normally predominant in this area (Hesselberg and Birkeland 1943, pp. 24–25) may be of importance in maintaining the eddy.

During the summer of 1952 the easterly winds were less frequent than normally observed and the weather relatively calm. For this reason the circulation was probably less intense that year. Therefore, a greater proportion of the bottles would have a tendency to drift directly southeast, towards Norway. This may explain why no recoveries were made in Iceland from that year's drift bottle experiments. On the other hand, the relatively short period of drift (110 days) of the bottle recovered from the launching south of Jan Mayen in 1951 can probably be attributed to the long spell of northeasterly and easterly winds after the release of the bottle. These strong easterly winds may have strengthened the cyclonic circulation and thus accelerated the southwestward drift.

Fig. 21 is constructed on the basis of the seven dynamical charts and by stressing schematically those features which they have in common. A preliminary sketch showing the same features was given to Dr. Einarsson in 1954

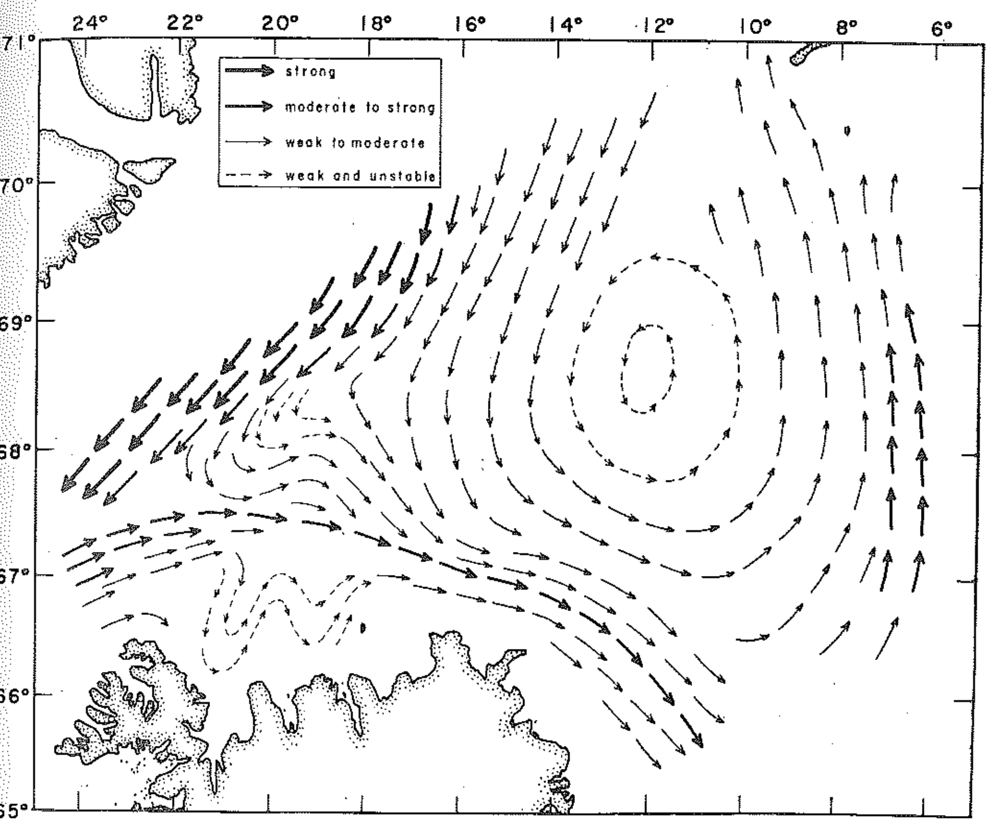


Fig. 21. *The surface currents of the Iceland Sea according to the present author's observations.*

and appeared in his paper "On the origin and dispersal of Icelandic fish populations with special regard to the herring" (Einarsson 1954). It is thought that the present map gives a fairly correct picture of the normal surface currents in the Iceland Sea during the summer season. This current chart has a distinct resemblance to that of Nansen (1924). As shown by most of the older charts the East Greenland Current is seen on Fig. 21 to flow to the southwest along the east coast of Greenland and through the Iceland–Greenland Channel. In the area south and southeast of Jan Mayen the current is directed to the north along the submarine ridge which extends south of the island, whereas southwest of Jan Mayen (near 12° W) it flows towards south or southwest. Farther south the current turns towards southeast. In the central part of the region between NE–Iceland and Jan Mayen a weak anticlockwise closed circuit is found. This circuit feeds water to the East Icelandic Current, which in addition is formed by water from the East Greenland Current and the Irminger Current, joining it in the area north of Melrakkaslétta. As shown by the current chart, the origin of the East Icelandic Current is to be found a considerable distance south of Scoresby Sound, in fact where the south-moving currents meet the North Icelandic submarine platform. First the East Icelandic Current flows in a southerly direction, but north of Melrakkaslétta it turns to the east. Then it bends again to the southeast north of Langanes. These changes in the direction of the current are probably related to the bottom configuration as suggested by the shape of the bathymetrical curves. It is of interest to note that in a recent paper JARAGOV (1959) arrives at practically the same picture of the surface currents in the Iceland Sea as here described.

The currents in the North Icelandic coastal area which seem to follow a rather complicated course, largely determined by the bottom configuration, will be dealt with in the next chapter.

VII.

THE NORTH ICELANDIC IRMINGER CURRENT

As previously mentioned it was established before the turn of the century that the Irminger Current divides west of Iceland. Most of it turns to the southwest, whereas a smaller branch continues clockwise along the coast. Later investigations have revealed that great fluctuations, both seasonal and annual, exist in this influx (Schmidt 1927, Tåning 1943, Einarsson 1949, Stefánsson 1949 and subsequent years). Until the most recent investigations however, little was known regarding the magnitude of the Atlantic influx and the limits of its extension.

The Atlantic water must have a marked influence on the general biology of the North Icelandic coastal area, as the distribution of plankton communities as well as larger animals is largely governed by the predominant water masses. Also, the Atlantic influx is of great importance for the warming up of both the surface and the deeper layers, and thus in turn creating climatic conditions which make the northern part of the country habitable.

A division of the Irminger Current west of Iceland is clearly shown on Hermann and Thomsen's current chart (Hermann and Thomsen 1946), part of which is reproduced in Fig. 22. The most conspicuous feature of this chart is the cyclonic eddy in the central Irminger Sea. They established the existence of this circuit from the results of drift bottle experiments as well as the material from the "Meteor" investigations in August 1929 and August 1930. As pointed out by the authors (op. cit. p. 65), the chart only reveals the main features of the water movements, whereas details are not reproduced.

As regards the region west of Látrabjarg two important facts emerged from Hermann and Thomsen's studies: 1) Drift bottles released west of Látrabjarg had a tendency to leave the coastal area, and the farther offshore they were released the stronger was this tendency. The majority of the recoveries took place on the southwest coast of Iceland after a drift period of more than 200 days. 2) Dynamical calculations of the "Meteor" material indicated a north-going current component in the region west of Látrabjarg as far west as approximately 26° 30′ W, but a south-going current between approximately 26° 30′ W and 31° 00′ W. The authors conclude (op. cit. p. 42) that "the fact must be pre-

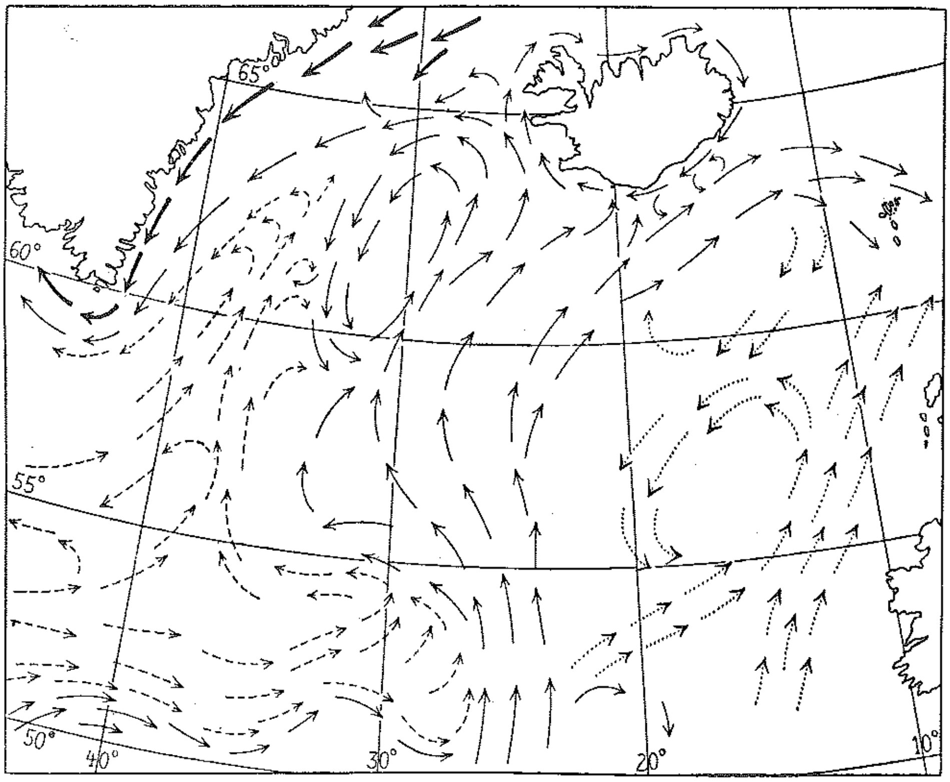


FIG. 22. *Currents in the Irminger Sea and south of Iceland. (Reproduced after Hermann and Thomsen 1946).*

sumed 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".

On the basis of the hydrographical observations made by the "Anton Dohrn" in June 1955, DIETRICH (1957) determined the dynamic topography of the sea surface. According to his chart the north-flowing Irminger Current splits about 100 miles west of Látrabjarg, one part of it turning to the southwest and the other part making a bend to the southeast and then turning north again and following the coast to the North Icelandic grounds. If this interpretation is correct, it means that most of the North Icelandic Irminger Current comes from the oceanic area some 100 miles west of Breiðafjörður and only a minor part from the West Icelandic coastal region. This would imply that the hydrographical and biological conditions north of Iceland in summer may be largely determined by the conditions in the Irminger Sea about 100 miles west of Iceland.

Only sparse material has been collected in the slope region west of Iceland and on the Iceland–Greenland Ridge during the Icelandic investigations in recent years. In this mixing area the current can certainly not be taken as stationary or frictionless, and the choice of a surface of "no motion", if possible, would be quite uncertain. Dynamical calculations of this material will therefore not be presented here. However, the density distribution, as found by the Icelandic investigations, also indicates an area with greater specific gravity than its surroundings near the slope of the West Icelandic coastal region.

By consideration of the bottom configuration it seems doubtful that the normal current pattern along the West Icelandic coastal area is in the manner indicated by Dietrich's topographical chart. It would seem more likely that in this region the current direction will be largely determined by the bottom configuration in the same manner as found for other parts of the coastal area.

Obviously, more investigations will be needed before the details of the currents in the region west of Iceland are known with certainty. This could possibly be accomplished by a close net of hydrographic stations in the area and carefully planned drift bottle experiments.

Off Kögur the general direction of the Irminger Current is to the east or southeast, but near the Polar front it is not likely to follow smooth streamlines. More likely, it will be twisting, meandering and forming eddies, and a part of it may be returned back to the southwest. Such eddies are certainly suggested on the horizontal charts as well as on some of the sections from this region (e.g. see the figures accompanying the author's reports in *Ann. Biol.* VIII (1951) and XI (1954)). Most of the north-flowing Irminger water, however, follows the slopes of the North Icelandic submarine terrace towards the east.

According to fishermen who have had experience fishing in Húnaflói, the predominant current is directed to the southeast along the west side of the bay and to the north or northeast along the east side. Thus Rev. Eyjólfsson (1861) states that fishermen claim that some 6 miles off Geirhólmur (a mountain south of Reykjafjörður) the current is always directed southwards, whereas along the Skagaströnd the current is always directed towards the north. Eyjólfsson says it is a general belief that in late August the main current is located farther offshore than in early summer. He remarks that normally the ice drifts to the Strandir (on the west side of Húnaflói) from the northwest and is carried into the inner part of the bay along its west side. The distribution of drift ice in this region also suggests a circulatory movement in Húnaflói, as appears from Koch's monthly ice charts for 1877–1939 (Koch 1945, pp. 214–225). On some of these charts a protrusion is seen to extend from the ice border towards Húnaflói while the coastal area east of Skagagrunn may be icefree.

From aerial observations of the distribution of drift ice in early May 1949 between Horn and Grímsey, T. Einarsson (1950) came to the conclusion that the current must, at least part of the year, have a cyclonic circulatory movement in that region.

Of drift bottles released prior to 1950 off the northwest coast, between 66° N and 67° N and 20° 30′ W and 23° 30′ W, the majority have been recovered on the west side of Húnaflói from Horn to Hrútafjörður (see Hermann and Thom-

SEN 1946, pp. 74–76, EINARSSON and STEFÁNSSON 1953, pp. 16–19). In August 1950 a total of 80 drift bottles were launched at 4 localities in Húnaflói as shown in Fig. 23. The arrows point towards the places of recovery, and the numbers refer to the respective drift periods in days. Also here, the result is a southerly drift along the west side of the bay.

Thus from the numerous drift bottle experiments as well as other data it seems safe to conclude that the current is directed to the south or southeast along

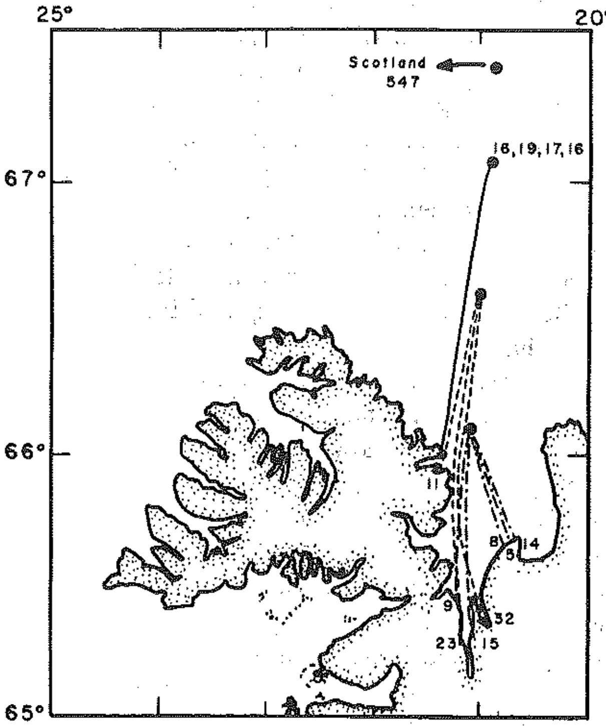


FIG. 23. *Recovered drift bottles from experiments in the Húnaflói region in 1950.*

the west side of Húnaflói. Hence, it must be directed northwards along the east side, at any rate as far as Skagi. Then the question arises whether the current flows directly across the Skagagrunn or continues northwards along the west side of this shallow bank. The latter possibility seems to be the most logical one. It is supported by the distribution of drift ice, as mentioned above, by some of the dynamical topography charts (see Figs. 6–8), and also by the temperature distribution, as for example appears clearly in Fig. 24, illustrating the temperature at 20 meters in August 1956.

From the density distribution along the section north of Siglufjörður (cf. p. 146), it is clear that over the Eyjafjarðardjúp the mean resultant current is directed eastwards. Judging by the results obtained for Húnaflói it would *a priori* be expected that the east-flowing current has a southward component along the east side of the Skagagrunn, flowing northwards over the east side of the Eyjafjarðardjúp, along the Grímseyjargrunn. This presumption is supported by the salinity distribution, as the boundary of the Atlantic water has been found to be sharply defined at the edge on the west side of the Grímseyjargrunn (HERMANN 1949 *a*), thus indicating that this water flows along the edge. It is furthermore supported by some of the temperature charts (cf. Fig. 24), which indicate that the current direction is similar for Húnaflói and Eyjafjarðardjúp.

In the Grímsey Basin the current probably flows anticlockwise and forms a weak circular eddy. Such a motion is suggested by the results of drift bottle experiments carried out in 1949, as some of the bottles released in this region were recovered on the west side of Húnaflói.

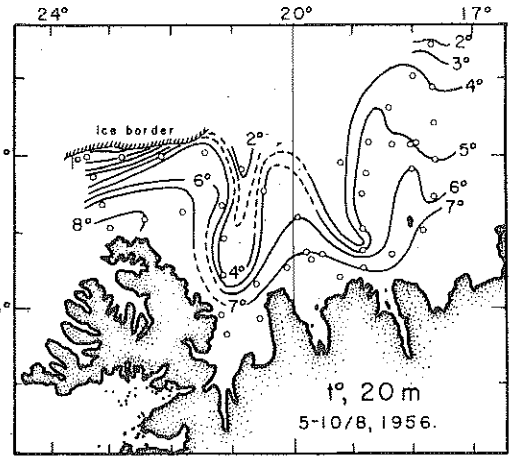


FIG. 24. *Position of the ice limit and temperature at 20 meters north of Iceland in August 1956.*

North of Kolbeinsey the Icelandic submarine terrace is broadest, but near 18° 30′ W it bends sharply to the southeast. Therefore, the northward extension of the Atlantic water, of which the greater part follows the slope of the submarine terrace, is maximal in the middle of the North Icelandic coastal area, but a trifle farther to the east the Atlantic current bends to the southeast and joins the East Icelandic Current north of Slétta.

Farther to the south, in the area between Grímsey and Slétta, practically no data exist from which the course of the coastal current can be derived. Until some such material, e.g. records from direct current measurements or drift bottle experiments, is collected from this region, our notions concerning the current direction remain purely speculative. However, considering the topographical features, a current pattern similar to that found in Húnaflói would be expected.

On the northeast coast, the mean current direction is along the coast, as found by drift bottle experiments and dynamical calculations. Regarding the details of the current system, it would seem probable that also in this region the

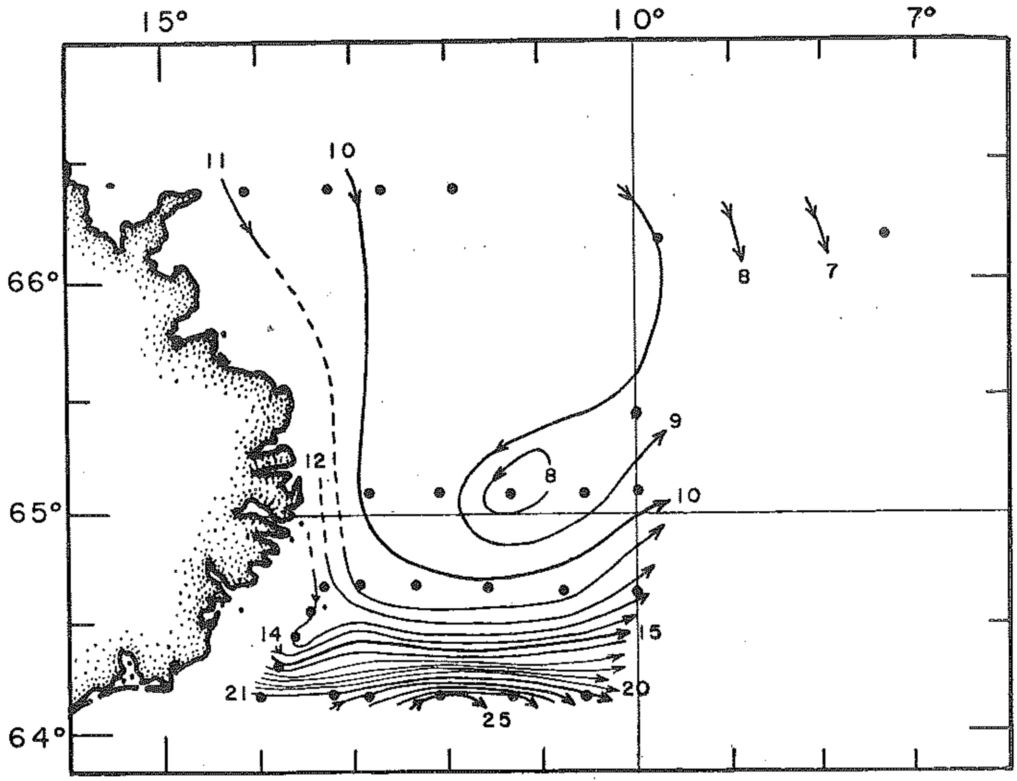


FIG. 25. *Dynamic topography of the sea surface east of Iceland (in dyn. cm.) relative to the 800 decibar surface in June 1953.*

current direction is affected by the bottom configuration in the same manner as in the western part of the North Icelandic coastal area.

It is a general experience of fishermen that along the east coast the flood current, moving southwards along the coast, is decidedly stronger than the ebb current. This is to be expected, as the residual current has a direction southwards.

In the neighbourhood of Gerpir, i.e. just north of the boundary between the Atlantic water and the Arctic water, the current leaves the coastal area as a part of the East Icelandic Current. Such a current picture is definitely indicated by drift bottle experiments, as off the southeast coast between 64° N and 65° N, about 90% of drift bottles leave the coastal area (HERMANN and THOMSEN 1946, p. 40). This current pattern is also indicated by dynamic calculations, as seen from Fig. 25. It is based on the material collected by the "María Júlía" in June 1953. The reference surface is 800 dbar. The current is seen to be strongest close to the boundary between the Atlantic and arctic water. A similar result has been obtained by other authors who have investigated this area (HERMANN 1949 *b*, DIETRICH 1957).

VIII.

DISTRIBUTION OF TEMPERATURE AND SALINITY IN SUMMER

1. HORIZONTAL DISTRIBUTION

a) Surface.

In a previous paper the author has discussed the surface temperature in the North Icelandic coastal area (Stefánsson 1954*a*). From the material published in the *Danish Nautical Meteorological Annuals* the temperature means for the period 1901–1930 were computed for each 1° square in the coastal area extending from 66° to 67° N and 14° to 24° W. From the temperature normals calculated in this way mean charts were prepared for the months June, July and August. The highest temperature values were found in the westernmost part of the coastal area (west of Cape Horn), but otherwise the difference between squares along the north coast was found to be small. The values lay between 4.7° and 6.2°C in June, 6.8° and 8.0°C in July and 7.3° and 8.9°C in August.

The temperature variations at the meteorological station on the island Grímsey off the north coast were also studied and the mean annual temperature cycle calculated for the period 1901–1930 (loc. cit. p. 6). The winter sea surface temperature at the island was found to lie between 1.5° and 2.0°C, but from the last part of March it rose until a maximum of 7–8°C was reached in August. From then on a slow decline towards the winter temperature was experienced.

On the basis of a large number of temperature and salinity data from the period 1868–1953 Krauss (1958*c*) has recently prepared charts of the mean monthly surface temperature and salinity in the northern North Atlantic. Portions of his charts for the months March, June, August and October are reproduced in Figs. 26–27.

It is noticeable that Krauss' chart for June indicates a higher mean temperature in the North Icelandic coastal area than the 1901–1930 normal. As Krauss' mean charts are based on more recent data this difference is to be expected. On his chart the mean temperature in June is 7–8°C between Látrabjarg and Horn, and 6–7°C over most of the North Icelandic coastal area west of Slétta. In the easternmost part of the area the temperature mean is somewhat lower, 5–6°C. In August the mean temperature is about 10° near Látrabjarg, decreases rapidly to less than 9° at Horn and lies between 8° and 9° over most of the North Icelandic coastal area. As was indicated by the 1901–1930 mean, a characteristic feature of the isotherms in summer is a southward bend in the Húnaflói region and a northward sweep in the area off the northeast coast. The relatively high surface temperature in the eastern part of the coastal region is undoubtedly related to the much greater stability in that part of the area.

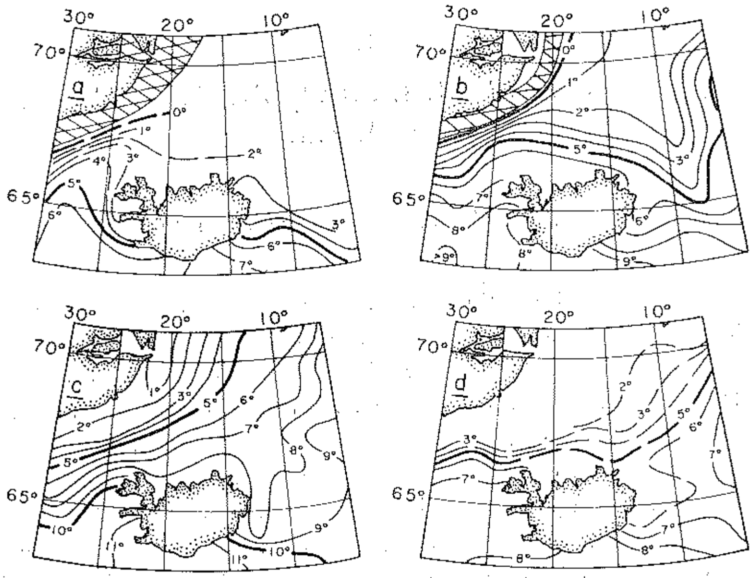


FIG. 26. *The mean surface temperature in the Iceland Sea in a) March, b) June, c) August and d) October. (After Krauss 1958).*

Near the slope of the North Icelandic shelf the surface temperature is usually found to decrease rapidly, and near the ice limit the temperature drop is very sudden indeed. On the mean charts, however, the temperature appears to decrease more gradually and really sharp current boundaries are not indicated. This must be due to the fact that the mean charts are prepared by averaging conditions which may be very variable from year to year. The oceanic fronts may shift markedly from time to time and the averaging process will tend to make the horizontal temperature gradient appear smaller. Thus mean charts such as those here discussed may, especially near the fronts, very well show features which in reality never exist. They must therefore be taken with great reservation.

As seen from Fig. 27, the surface salinity in June lies between 34.75 and 35.0 ‰ off the nortwest coast and in part of the oceanic area between Iceland, Greenland and Jan Mayen. Near the coast, however, and along the north coast south of 67° N the mean surface salinity in June is decidedly lower, below 34.5 ‰; whereas in the region between Northeast Iceland and Jan Mayen it is 34.5–34.75 ‰. In August the highest surface salinity is found off the west coast in the core of the Atlantic water. The salinity decreases rapidly in the direction of flow from Látrabjarg to Horn, being 34.00–34.25 ‰ over most of the north Icelandic shelf, but less than 34.0 ‰ in the coastal region between Horn and Slétta.

As seen from Figs. 26–27 the course of the isohalines at the surface is similar

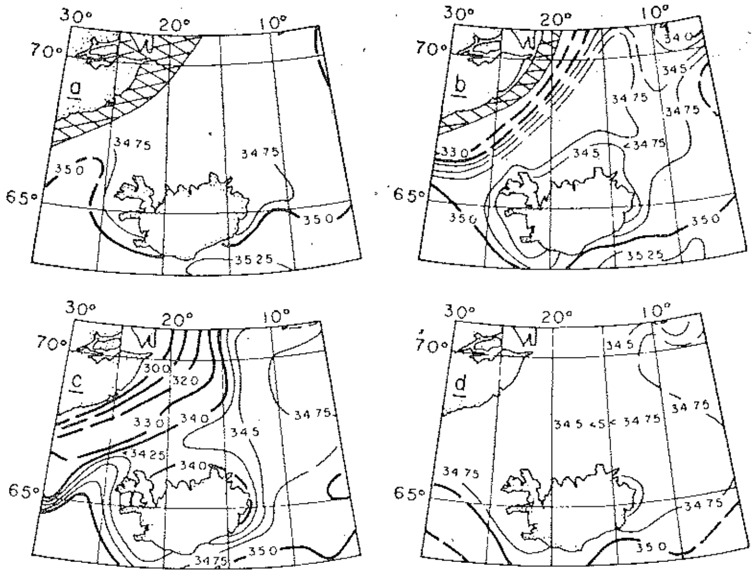


Fig. 27. The mean surface salinity in the Iceland Sea in a) March, b) June, c) August and d) October. (After Krauss 1958).

to that of the isotherms, especially near the ice limit where the salinity as well as the temperature decreases rapidly. Whenever Polar water is being carried southeast into the Icelandic coastal area, resting on top of the warm Atlantic water, it will influence the hydrographic conditions in the surface layer tremendously and markedly affect the mean values, especially in the western part of the area. In the western part of the coastal area, and even as far east as Siglufjörður, the surface salinity in early summer frequently exceeds 35.0 ‰ although such a high salinity is not indicated on the mean charts. Thus in June 1952, 1953 and 1955 a tongue of saline water in excess of 35.0 ‰ extended east to Eyjafjarðardjúp (cf. the author's reports in *Ann. Biol.* 1952, 1953 and 1955).

From the discussion above it will be evident that there are primarily two features of the surface salinity distribution on the North Icelandic shelf which may be considered characteristic, viz. 1) a higher surface salinity in the western part than in the eastern part of the region and 2) a decrease in salinity from spring to autumn.

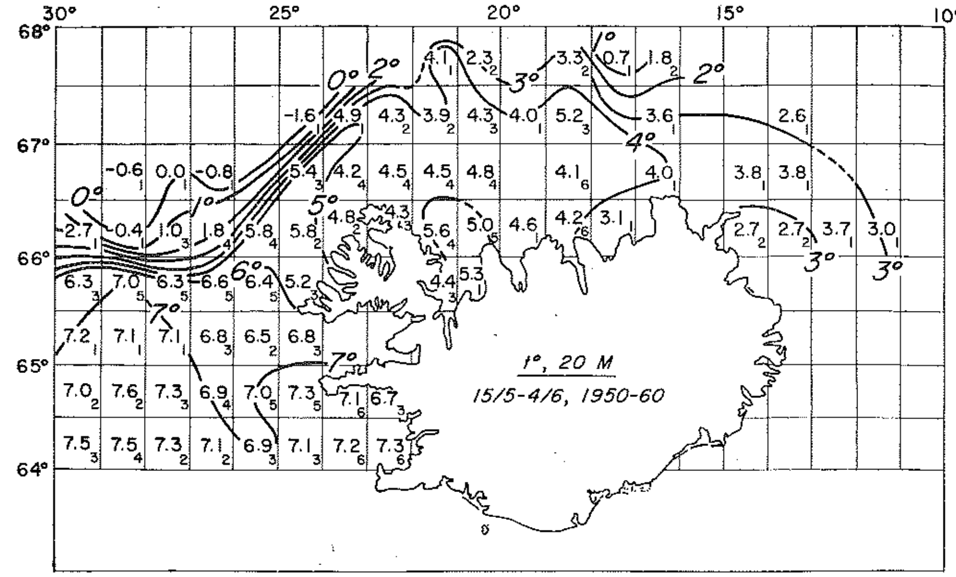


FIG. 28. *The mean temperature at 20 meters depth 15/5—4/6 1950—1960.*

b) 20 Meters.

The temperature distribution at 20 meters during the years 1954–1959 has been included in the author's reports on the hydrographic conditions in Icelandic waters, published in *Annales Biologiques* (STEFÁNSSON 1956–1961), and the normals for May 15th–June 4th and June 5th–25th, 1950–59 have been computed (STEFÁNSSON 1960).

Because of the importance of temperature distribution in connection with biological studies, it was considered advantageous to calculate the normals for the period after 1950, for which there exist in most cases simultaneous observations of herring distribution and plankton concentration. Prior to 1954 observations were made at 25 meters instead of 20 and 30 meters which have been standard depths since September 1953. The temperature values at 20 meters in the years 1950–53 were determined by interpolation between the values at 10 and 25 meters. It is unlikely that the temperature distribution derived in this manner will deviate appreciably from the true temperature distribution. After the thermocline has been established, it will in most instances be located below the 20 meter level. Therefore this level represents conditions in the surface layers. On the other hand, at 20 meters the hydrographic conditions will be less affected by sudden meteorological changes than at the sea surface.

For the present investigation the normals for May–June were recalculated to cover the period 1950–60, and the results are shown in Figs. 28–29. The normals for July and August are shown in Figs. 30–31.

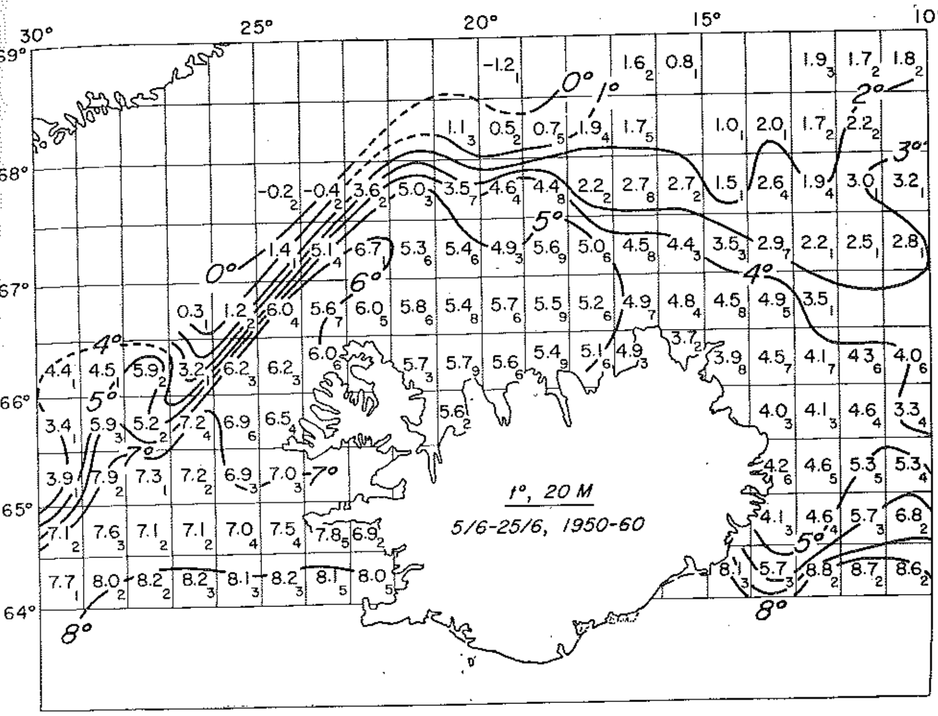


FIG. 29. *The mean temperature at 20 meters depth 5/6—25/6 1950—1960.*

As will be apparent from Table 1, by far the greatest part of the observations made during 1950–60 were BT observations, whereas the salinity observations were much less numerous. Therefore, only the temperature normals were computed.

The temperatures from each individual year were averaged for each ½° latitude and 1° longitude, and the normals for the whole period 1950–60 computed by averaging these mean values for the various years.

The calculated normals are in many instances based on one or two values only. Observations are especially scarce in the region east of Iceland in May and west of Iceland in July and August. Over the coastal region north of Iceland, however, the normals are generally based on more data.

On the basis of the inserted values, isotherms have been drawn. These follow in the main a similar course during the different observational periods.

During the period May 15th–June 4th the normal temperature is seen to vary between 6.5° and 7.5°C over the region west of Iceland, between Reykjanes and Látrabjarg. Near 66° N, 27°–30° W there is a sharp boundary between Atlantic and Polar water, and the temperature drops from 6° to less than 2°. From about 66° N, 27° W this boundary extends northeastwards to about 67° 20′ N, 24° W and then bends towards the east. Off the north coast the boundary is less sharp. Between Húnaflói and Slétta it will generally be found

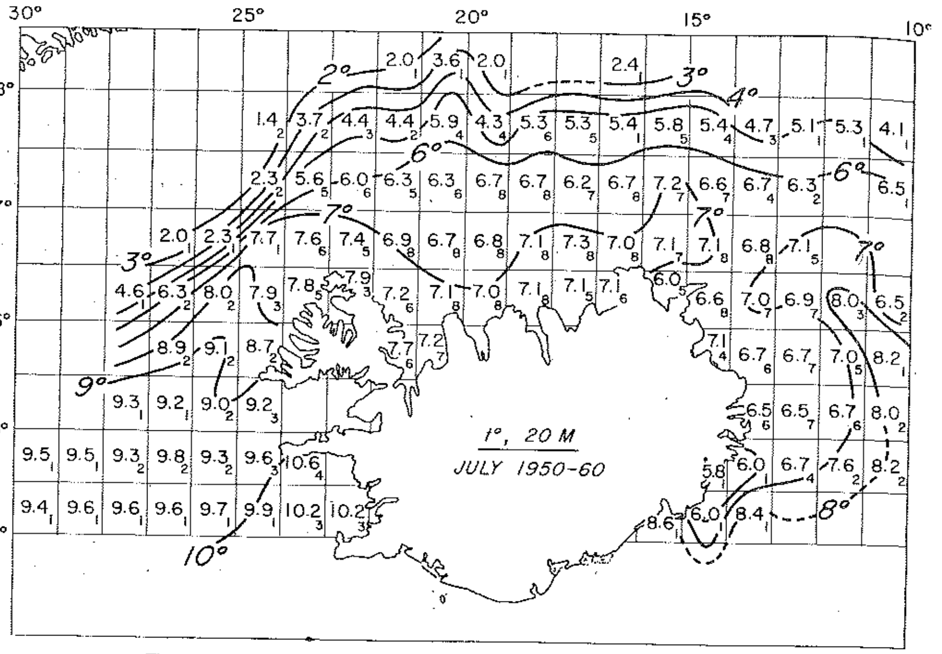


FIG. 30. *The mean temperature at 20 meters depth in July.*

between 67° 30′ and 68° N, bending southwards in the region east of Slétta. Over the coastal area between Látrabjarg and Kögur the temperature normally lies between 5° and 6°, the 5° isotherm having a tongue-like shape in the direction of flow of the Atlantic water. Off the north coast the temperature lies between 4° and 5° from Kögur to Skjálfandi, between Skjálfandi and Langanes it is 3–4° and less than 3° south of Langanes.

During June 5th–25th the temperature usually ranges betwen 7° and 8° over the region west of Iceland, between Reykjanes and Látrabjarg. From about 66° 30′ N, 26° W the boundary between the Atlantic and Polar water extends to 68° N, 22° W. From this point it bends eastwards, having a similar course as during the period May 15th–June 4th. Off the northeast coast no distinct boundary is indicated on the mean chart. Over the coastal area between Látrabjarg and Kögur the temperature normally lies between 6° and 7°, the 6° isotherm having a similar course to that of the 5° isotherm during the former period. Over the North Icelandic coastal area, between Kögur and Skjálfandi, the temperature lies between 5° and 6° and from 4–5° over the whole area from Skjálfandi along the northeast and east coast to Papey on the southeast coast.

In July (Fig. 30) the mean temperature is above 10° in Faxaflói and between 9° and 10° in the area between Reykjanes and Látrabjarg. The mean boundary between Atlantic and Polar water has a similar location in June and July. In the coastal area between Látrabjarg and Kögur the temperature varies between 7.5° and 9°, and in the North Icelandic coastal area between 7° and

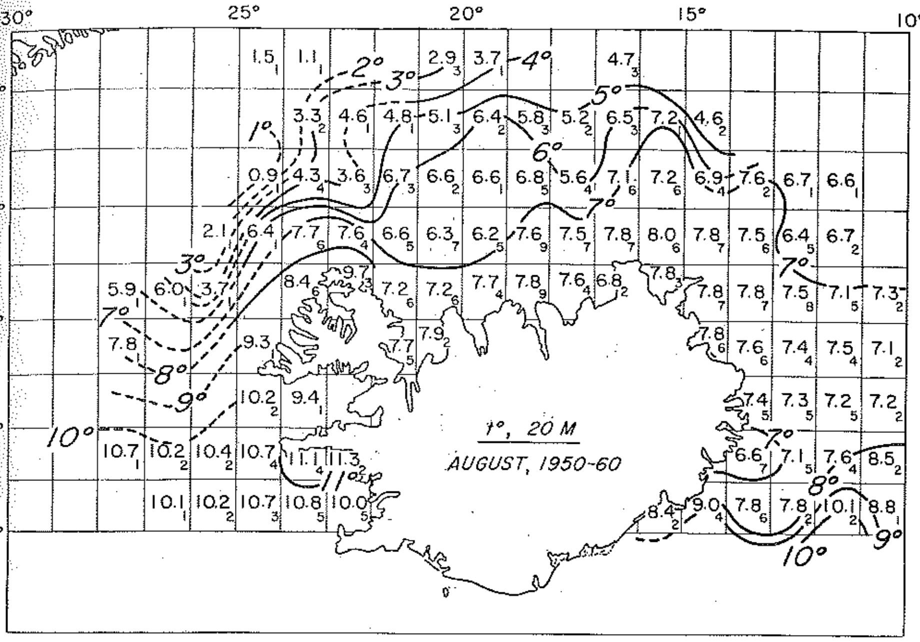


FIG. 31. *The mean temperature at 20 meters depth in August.*

7.5°. Farther north the temperature lies between 6° and 7°, dropping to less than 6° near 67° 30′ N. Along the east coast the July temperature at 20 meters lies between 6.5° and 7°.

In August (Fig. 31) the temperature is above 10° in the area west of Faxaflói and Snæfellsnes. The boundary between the Atlantic and the Arctic water off the northwest coast appears to be somewhat closer to Iceland in August than in July. This difference, however, is probably not real though appearing on the chart since the observational data are very limited from this region in August. In the coastal area all along the north and east coasts the temperature lies between 7° and 8°. As in July, the warm water has the greatest northward extension in the region north of Sléttа.

South of Papey there is a well defined boundary between the Atlantic and the Arctic water. The line of demarcation is normally located in the region between Eystrahorn and Vestrahorn on Southeast Iceland. Here the coastal water coming from the north must flow away from land. From the coastal area the boundary bends towards southeast to about 64° 10′ N, 13° 30′ W. From this point it is directed east–northeastwards to about 64° 40′ N, 11° W. Just north of the boundary minimum temperatures are usually found, as clearly seen on the 20 meters mean charts. In this region a thermocline is generally not formed during summer because of intense vertical mixing. It seems likely that this is due to turbulence maintained by the very strong tidal currents prevailing in the shallow region off the southern part of the east coast.

c) 50 Meters.

The mean temperature and salinity at 50 meters in June, July and August are illustrated in Figs. 32–37. These charts are based on material from the Hydrographic Card Index of the Service Hydrographique in Copenhagen up to 1947, material published in *Bulletin Hydrographique* 1948–1955 and Icelandic material from the years 1956–1960. The mean temperatures and salinities were computed for each ½° latitude and 1° longitude.

At the 50 meter level the isotherms are seen to run generally from south to north on the North Icelandic shelf south of 67° 20′ — 67° 30′ N. This is due to the Irminger Current being cooled on its way eastwards. Near the core of the current, especially in early summer, the isotherms often have a tongue-like shape with colder water on both sides. Farther offshore, near the slope of the North Icelandic shelf, the isotherms generally run from west to east. In this region of strong horizontal temperature gradient the northern boundary of the Irminger Current is found. This boundary roughly follows the depth contours of the slope of the shelf. Thus, off the middle part of the North Icelandic coastal area where the shelf is broadest the extension of Atlantic water is greatest. All along the slope of the North Icelandic shelf the temperature changes rapidly in a horizontal direction, but in no locality is the temperature drop as sudden as off the northwest coast near the East Greenland Polar Current. In this region boundaries between the Atlantic water and the Polar water are actually much sharper than indicated by the mean charts, for reasons mentioned previously (p. 66).

In June the mean temperature at 50 meters on the coastal shelf is 5–6°C in the region between Látrabjarg and Húnaflói, 4–5° between Húnaflói and Skjálfandi, 3–4° between Skjálfandi and Langanes but somewhat lower in Þistilfjörður. In the whole coastal region between Langanes and Gerpir the temperature is between 2° and 3°.

In July the mean temperature at 50 meters exceeds 7° off the west coast to as far as Ísafjörður, it is 6–7° between Ísafjörður and Skagagrunn, 5–6° between Skagagrunn and Slétta, 4–5° off Slétta but below 4° in the eastern area from Slétta to Gerpir.

In August the mean temperature at 50 meters is above 8° along the west coast to as far as Kögur, but some 20 miles off the northwest coast it drops to 7° or less. The mean temperature is 6–7° in the area between Húnaflói and Axarfjörður and as far north as 67° 30′ N, and 5–6° between Slétta and Langanes and all along the east coast. However, a few miles east of Glettinganes on the east coast the mean temperature falls below 5°.

In the Polar water off the northwest coast very low temperatures are found at 50 meters, generally less than —1°. In this region the temperature distribution is similar during the three summer months. Off the shelf northeast of Iceland there is a large area where the temperature is below 1°. The core of this cold water with temperatures less than 0° is found about 110–120 miles north-

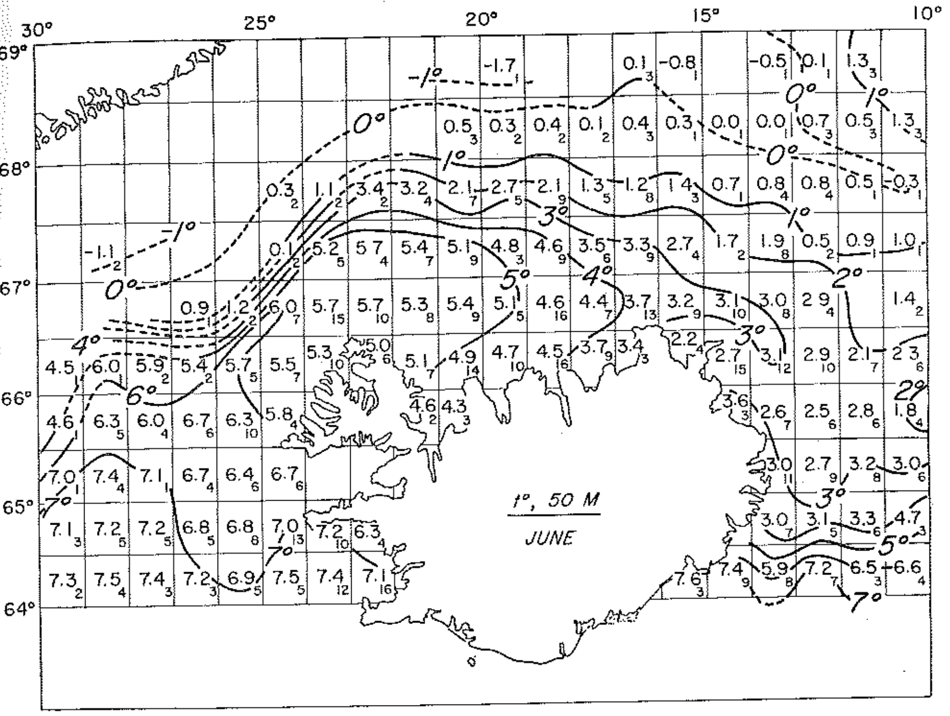


FIG. 32. *The mean temperature at 50 meters depth in June.*

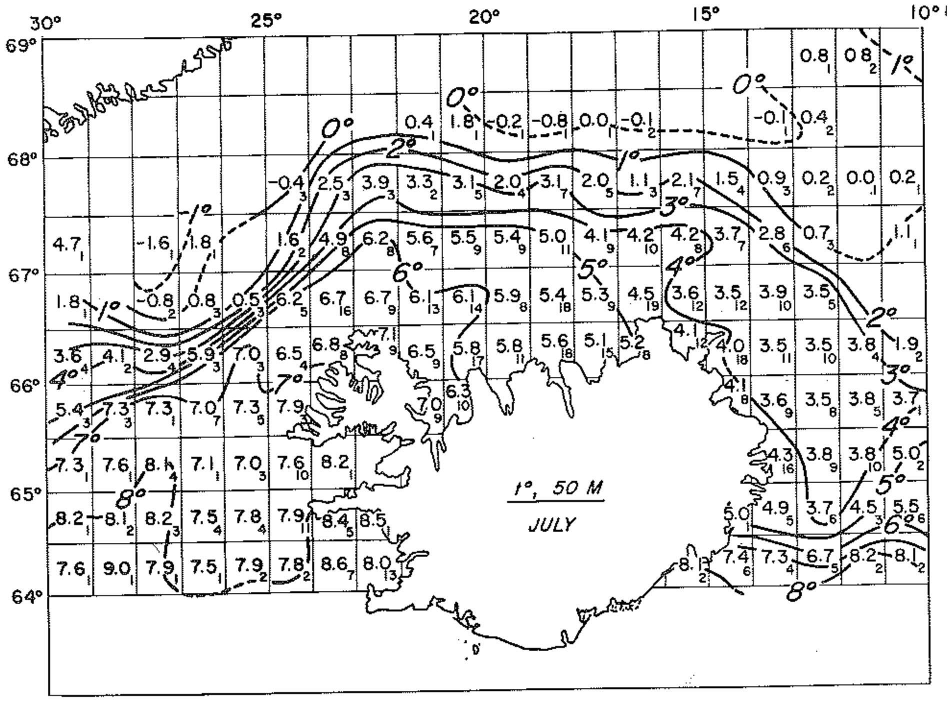


FIG. 33. *The mean temperature at 50 meters depth in July.*

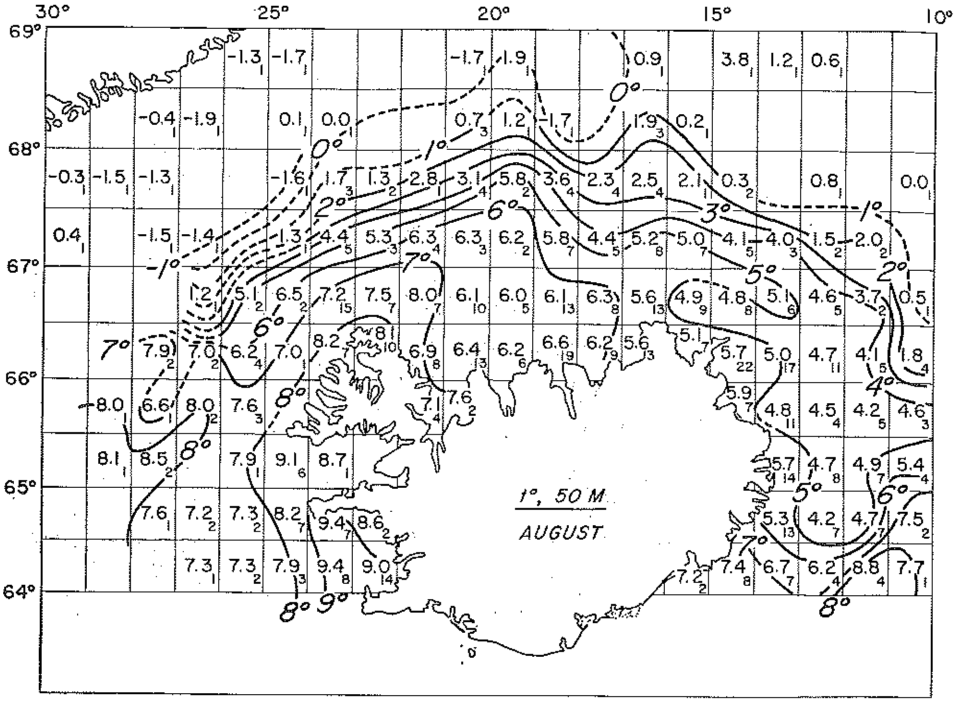


FIG. 34. *The mean temperature at 50 meters depth in August.*

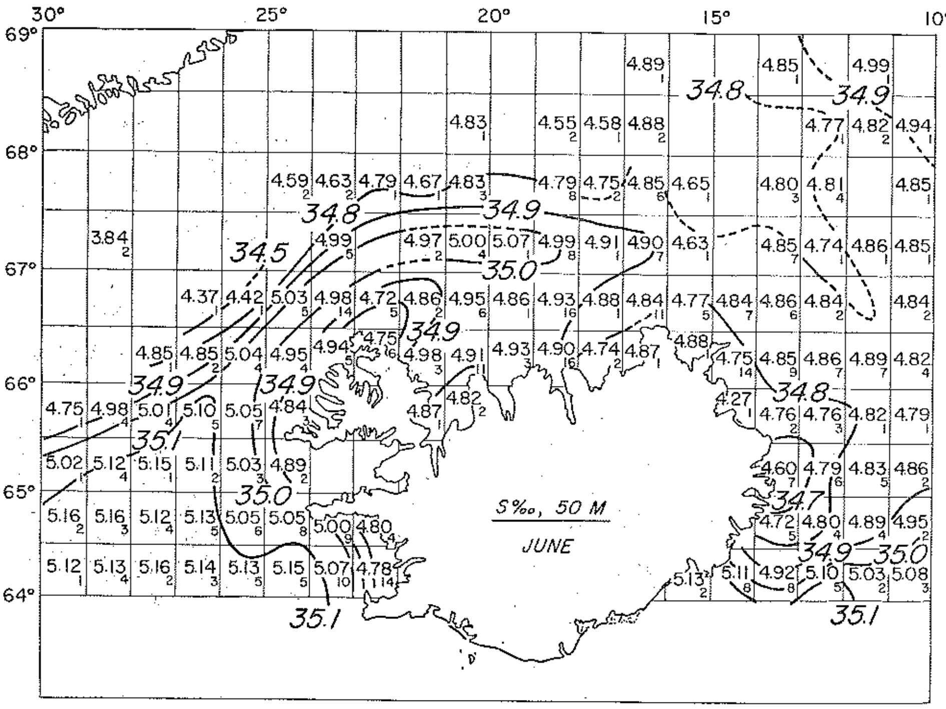


FIG. 35. *The mean salinity at 50 meters depth in June.*

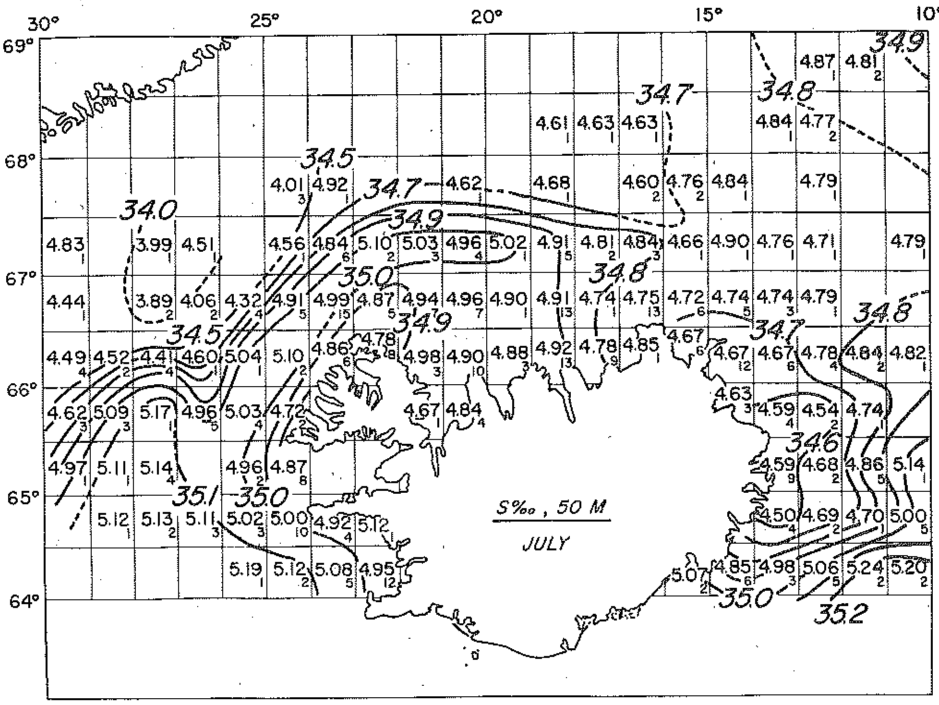


FIG. 36. *The mean salinity at 50 meters depth in July.*

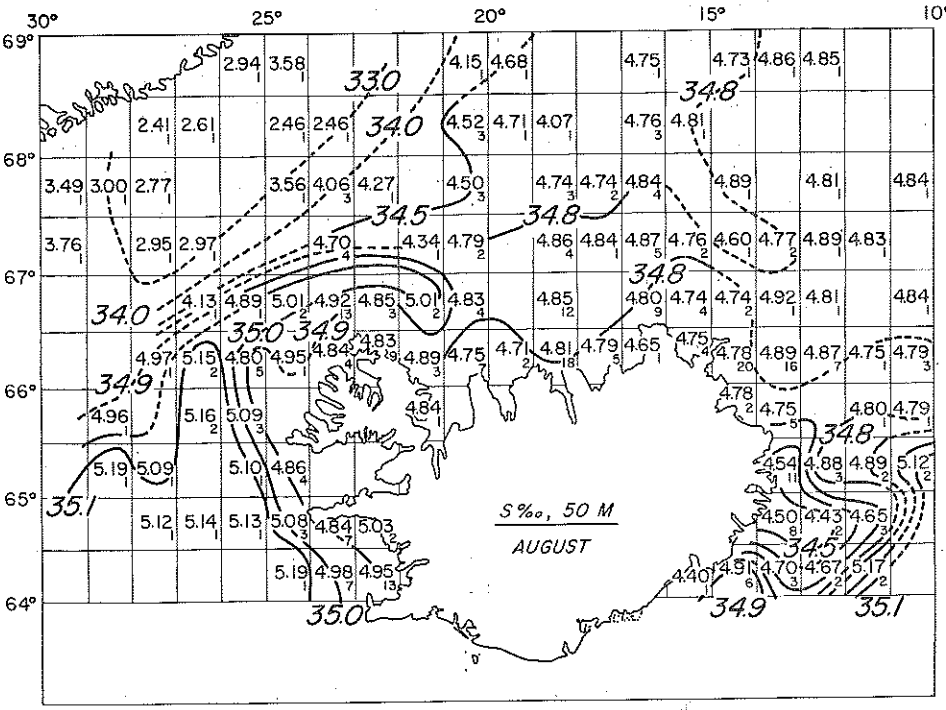


FIG. 37. *The mean salinity at 50 meters depth in August.*

east of Langanes. The distribution of water with temperature less than 0° appears to be slightly less in August than in June and July. East of 12° W and north of 68° N the temperature rises somewhat, up to 1° or more.

The isohalines at 50 meters follow the isotherms rather closely. However, the tongue-like distribution is more characteristic for the salinity, and the maximum salinities clearly coincide with the core of the east-flowing Atlantic water.

In June the mean salinity at this level is generally between 35.1 and 35.2 ‰ in the region west of Iceland, except in the shallowest part near the coast where it falls to less than 34.9 ‰. The 35.1 ‰ isohaline forms a tongue which extends to about 65° 50′ N some 70 miles WNW of Látrabjarg. The 35.0 ‰ isohaline also forms a tongue, but a much narrower one, which extends as far east as Siglunes, whilst the 34.9 ‰ curve extends east beyond Slétta.

In July the 35.0 and 35.1 ‰ isohalines have a similar course as in June. The 34.9 ‰ isohaline lies over the Grímseyjargrunn, whilst the course of the 34.8 ‰ isohaline in July corresponds to that of the 34.9 ‰ in June.

In August the 35.0 and 35.1 ‰ isohalines have a course similar to that found for July, the 34.9 ‰ curve extends to the area north of Húnaflói, and the mean salinity lies between 34.8 and 34.9 ‰ in the region east of Húnaflói, except in the shallowest part of the region where it falls to less than 34.8 ‰.

A characteristic feature of the salinity distribution at 50 meters is the low-salinity area off the east coast. As mentioned before, a thermocline is not formed in this area during summer because of the intensive vertical mixing. The relatively low salinities at 50 meters are probably formed by mixing with low-salinity surface water carried from the north by the coastal current.

Off the northwest coast at the boundary between the Atlantic and the Polar water the salinity decreases rapidly and in the East Greenland Current very low salinities are found. Here the salinity is less than 34.5 ‰ in June, less than 34.0 in July and even below 33.0 ‰ in August. However, only few observations are available from this region. In the oceanic region northeast of Iceland the salinity is relatively uniform at 50 meters, generally 34.75—34.80 ‰. The lowest salinities are found to coincide with the lowest temperature at the core of the Arctic water. In the northeasternmost part of the region covered by the charts here discussed (near 68–69° N, 10–12° W), the salinity is somewhat higher, about 34.9 ‰.

d) 100 Meters.

The mean temperature and salinity at 100 meters in June, July and August are illustrated in Figs. 38–43. These charts are based on the same material as those for 50 meters.

The course of the isotherms at 100 meters is similar to that found at 50 meters. Thus, in June the isotherms at the 100 meter level run from south to north in the shelf area and from west to east in the slope area. In July, however,

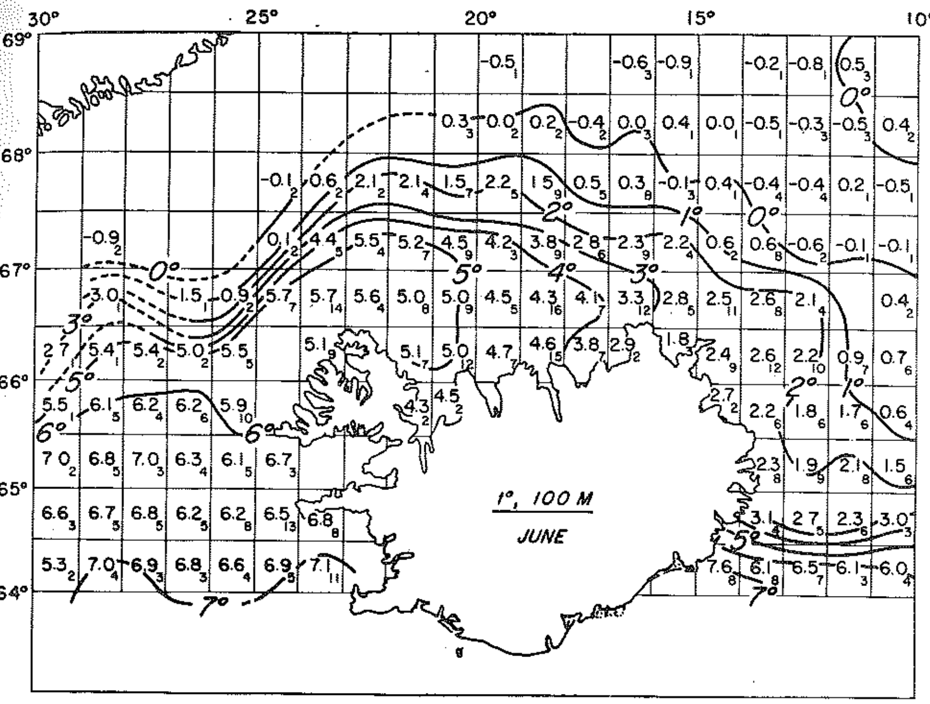


FIG. 38. *The mean temperature at 100 meters depth in June.*

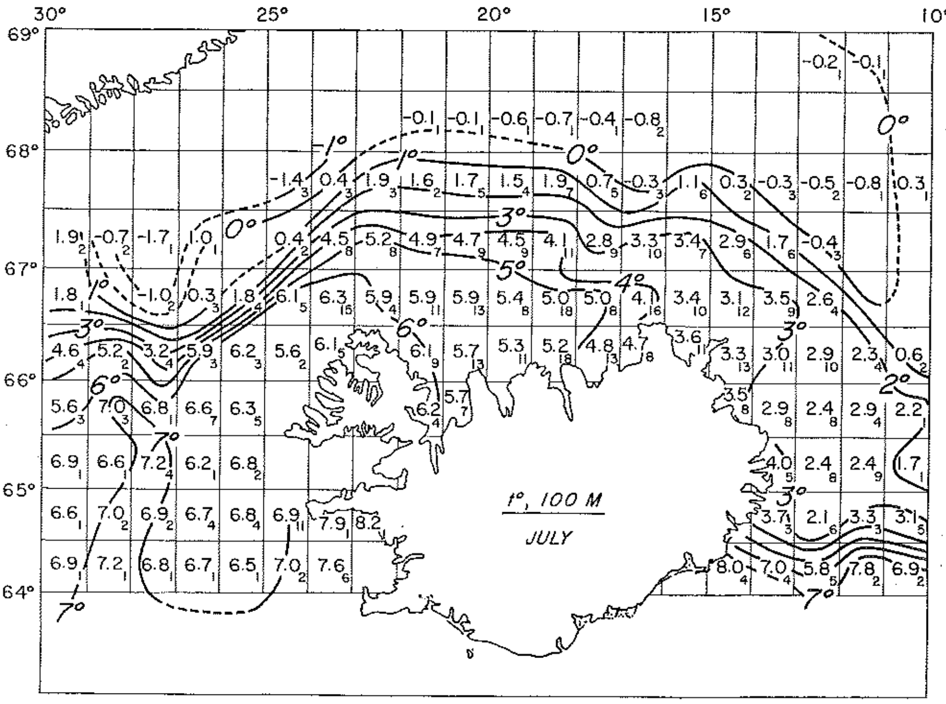


FIG. 39. *The mean temperature at 100 meters depth in July.*

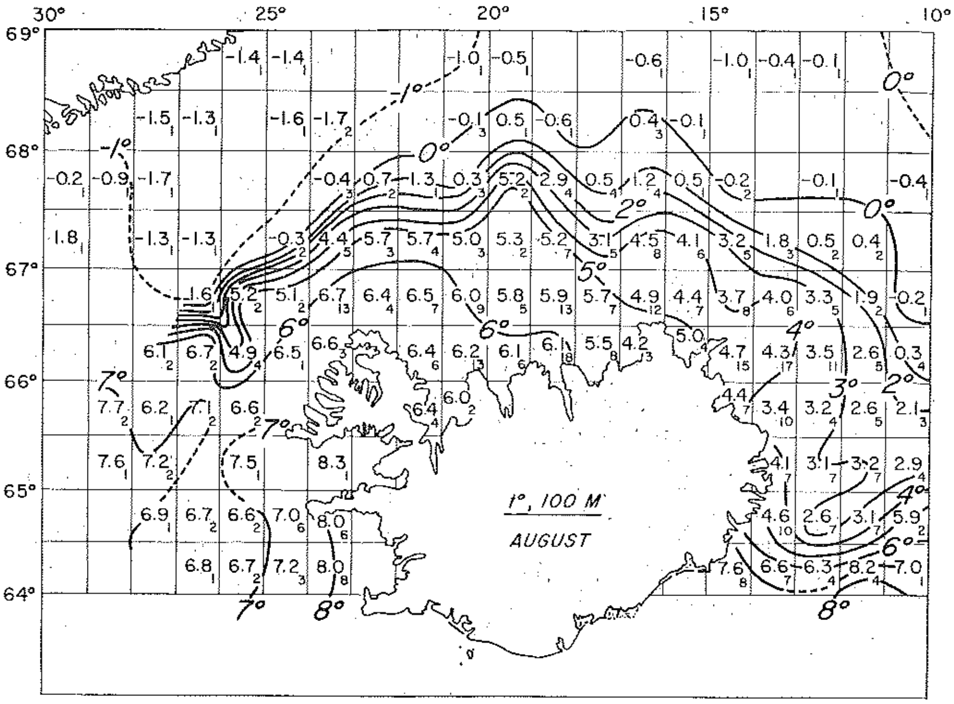


FIG. 40. *The mean temperature at 100 meters depth in August.*

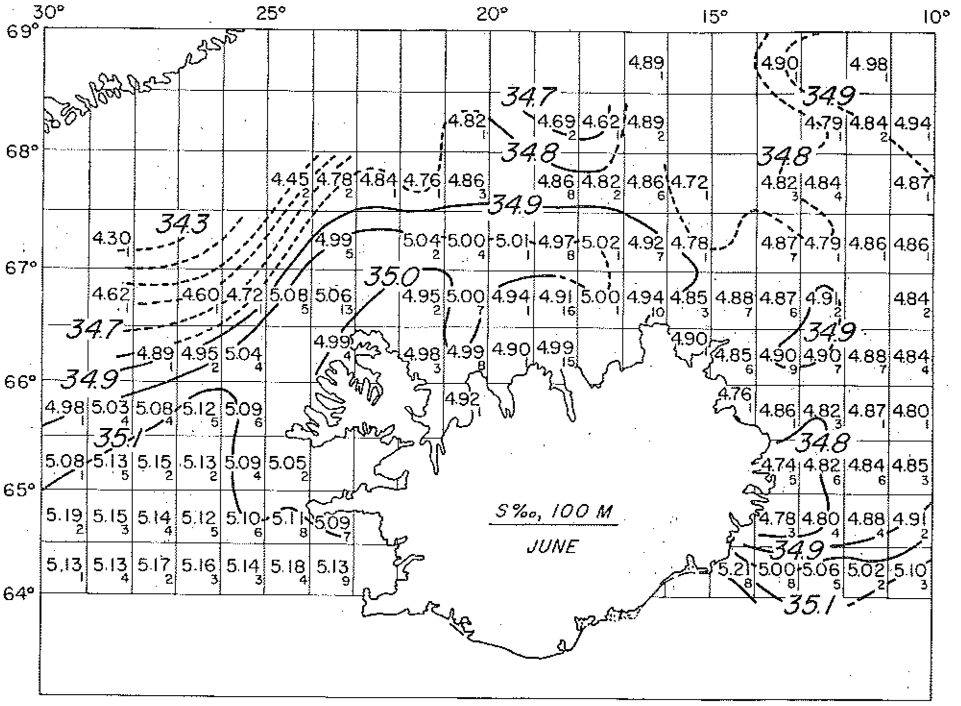
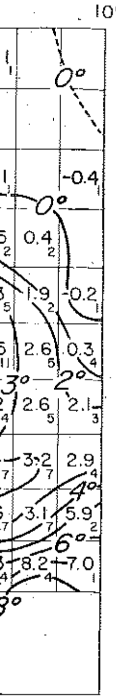
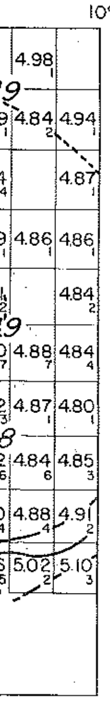


FIG. 41. *The mean salinity at 100 meters depth in June.*





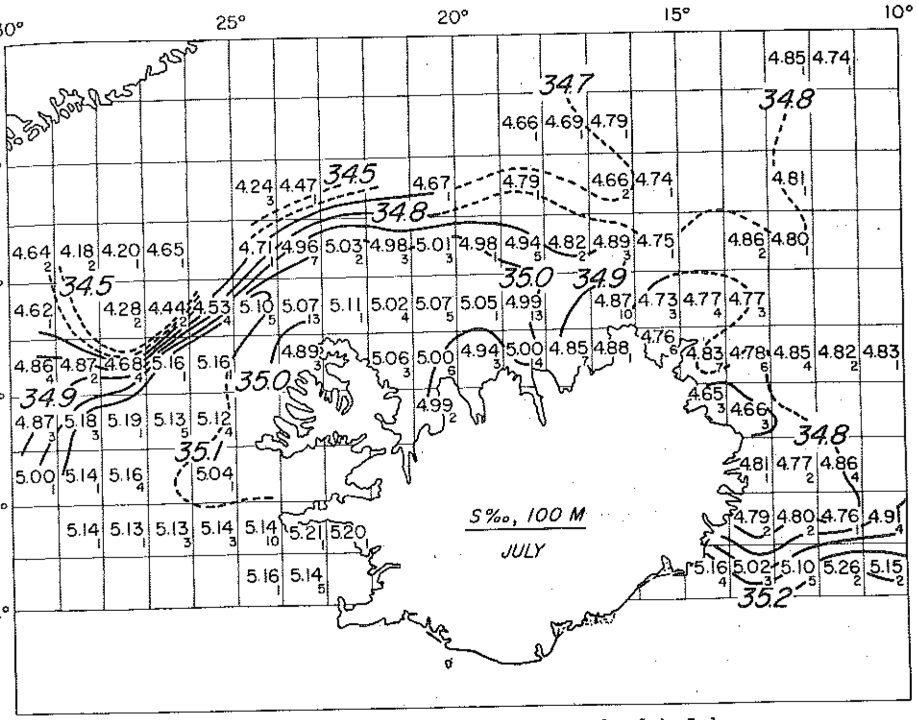


Fig. 42. *The mean salinity at 100 meters depth in July.*

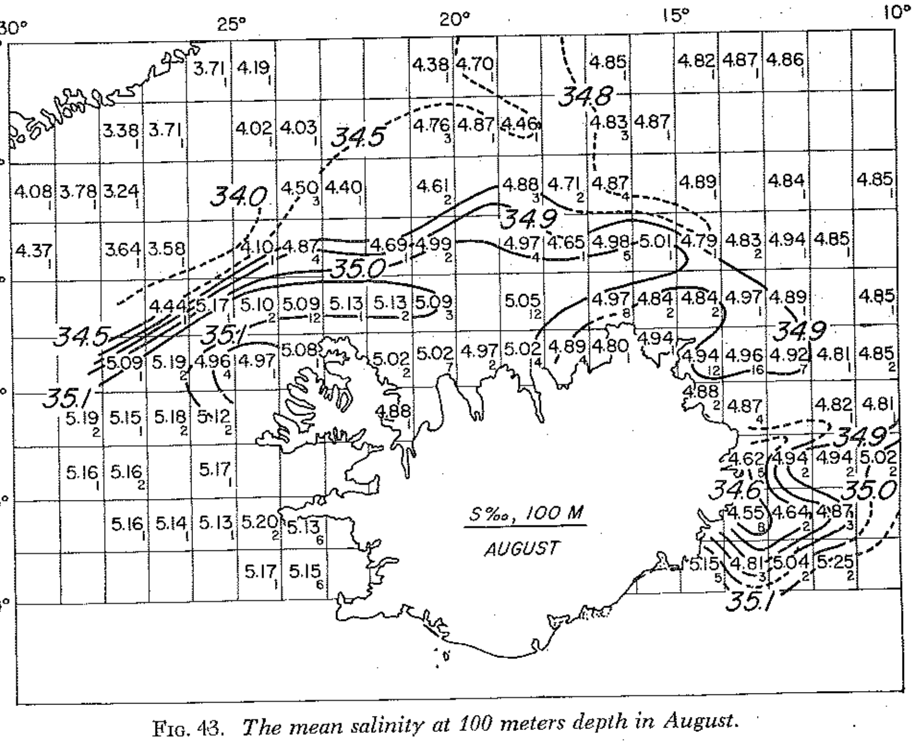


Fig. 43. *The mean salinity at 100 meters depth in August.*

and particularly in August the isotherms have a more easterly direction in the shelf area in the same manner as those near the northern boundary of the Atlantic water. This feature is probably due to the fact that after midsummer, when the Atlantic influx has reached a maximum (see later), this water will to a less extent be subjected to cooling during its course along the coast.

The mean temperature in June at the 100 meter level is 5–6°C in the northwestern part of the area from Látrabjarg to Húnaflói, 4–5° between Húnaflói and Skjálfandi, 3–4° between Skjálfandi and Slétta and 2–3° in the coastal area east of Slétta and along the east coast south beyond Gerpir.

In July the mean temperature is 6–7° in the coastal region west of Iceland, 5–6° between Kögur and Skjálfandi, drops to 3° east of Langanes and lies between 2° and 3° along the east coast.

In August the mean temperature at 100 meters is 6–7° near the coast from Látrabjarg east to Eyjafjörður, 5–6° in the middle part of the North Icelandic coastal area between Skagagrunn and Slétta, 4–5° in the region between Slétta and Héraðsflói and 3–4° south of Héraðsflói.

In the Polar water northwest of Iceland the temperature at 100 meters is less than —1° or even below —1.5°, whereas in the tongue of cold Arctic water northeast of Iceland the temperature is generally between —0.5° and 0°.

The salinity distribution at 100 meters is similar off the west coast during the three summer months. The tongue of water with mean salinities above 35.1 ‰ extends north beyond Látrabjarg in June, north of Ísafjörður in July and east to Húnaflói in August. Water with salinity above 35.0 ‰ has a somewhat greater extension at 100 meters than at 50 meters. The 35.0 ‰ curve extends beyond the Kolbeinseyjargrunn in June and July, but reaches east to 15° W in August. At this level salinities as high as 34.9 ‰ are generally not found east of Langanes in June or July, but in August water with salinity above 34.9 ‰ extends east and southeast of Langanes to the 66° N parallel.

Northwest of Iceland in the region of Polar water the salinity at 100 meters is less than 34.5 ‰ in June and July and less than 34.0 ‰ in August. Northeast of Iceland the salinity at this level is about 34.85 ‰ in most part of the oceanic area except for a narrow tongue where the salinity is below 34.8 ‰. In this narrow tongue, which in June and July has a somewhat greater extension than in August, the lowest temperatures are generally found. Off the southeast coast an area of low salinity is also found at 100 meters, corresponding to that found at 50 meters.

From the salinity distribution at the surface and at the 50 meter level during the summer months, it will be clear that the saline water lies deeper in late summer than in early summer, and that the extent of the coastal water increases. The salinity distribution at 100 meters, however, demonstrates how the Atlantic water ($S > 35.0$ ‰) at intermediate depths gradually moves farther eastwards during the course of the summer. As an example of the situation in

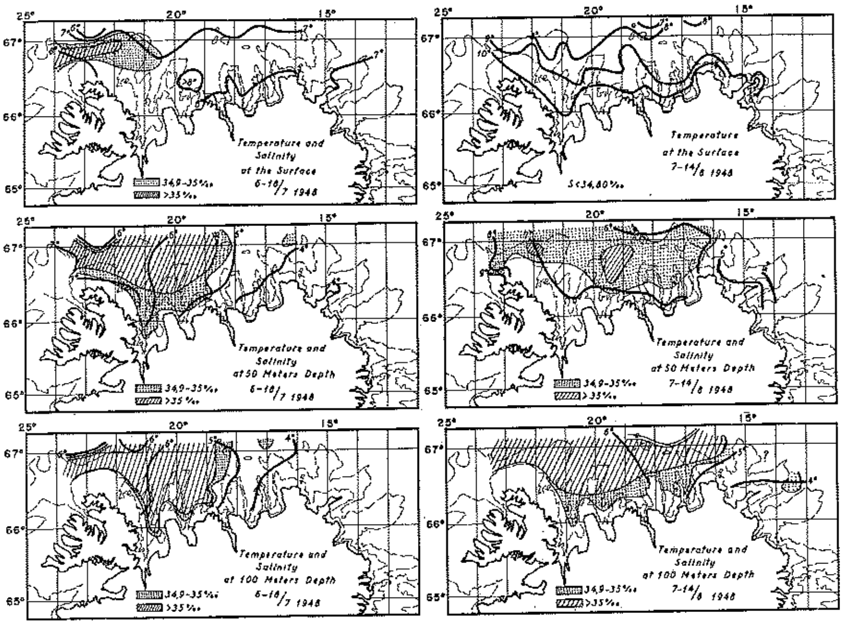


FIG. 44. *Temperature and salinity at 0, 50 and 100 meters depth 6/7–18/7 and 7/8–14/8 1948.*

individual years Fig. 44 illustrates the temperature and the salinity distribution at 0, 50 and 100 meters in early July and early August 1948. Obviously, this figure displays the same main features as shown on the mean charts.

e) 200 Meters.

On the basis of all available observations FUGLISTER (1954) has prepared a chart for the 200 meter level. In general a permanent thermocline will be found above this level. However, as will be discussed later, seasonal variations are readily detectable in the area north of Iceland at depths exceeding 200 meters. Therefore, the temperature and the salinity distribution at 200 meters in this area can hardly be represented by a mean chart for all seasons.

Figs. 46–54 show the temperature and salinity at 200 meters on 5 different occasions, i.e. 17–29/8 1949, 30/7–21/8 1950, 11–23/8 1951, 8–22/6 1954 and 28/5–13/6 1958. From these charts it will be evident that the course of the isotherms and isohalines at 200 meters resemble that found at the 100 meter level.

In June the temperature is generally above 6°C in the region south of the Iceland-Greenland Ridge, 5–6° off the northwest coast as far east as Kögur. From Kögur eastwards the temperature and salinity is gradually lowered. In Húnaflói and in the Eyjafjarðardjúp the temperature may vary between 3° and 5° and from less than 1° up to 3° off the northeast coast.

In August the temperature will be 6–7° off the west and northwest coasts. In the deep bays off the north coast, between Kögur and Slétta, the temperature

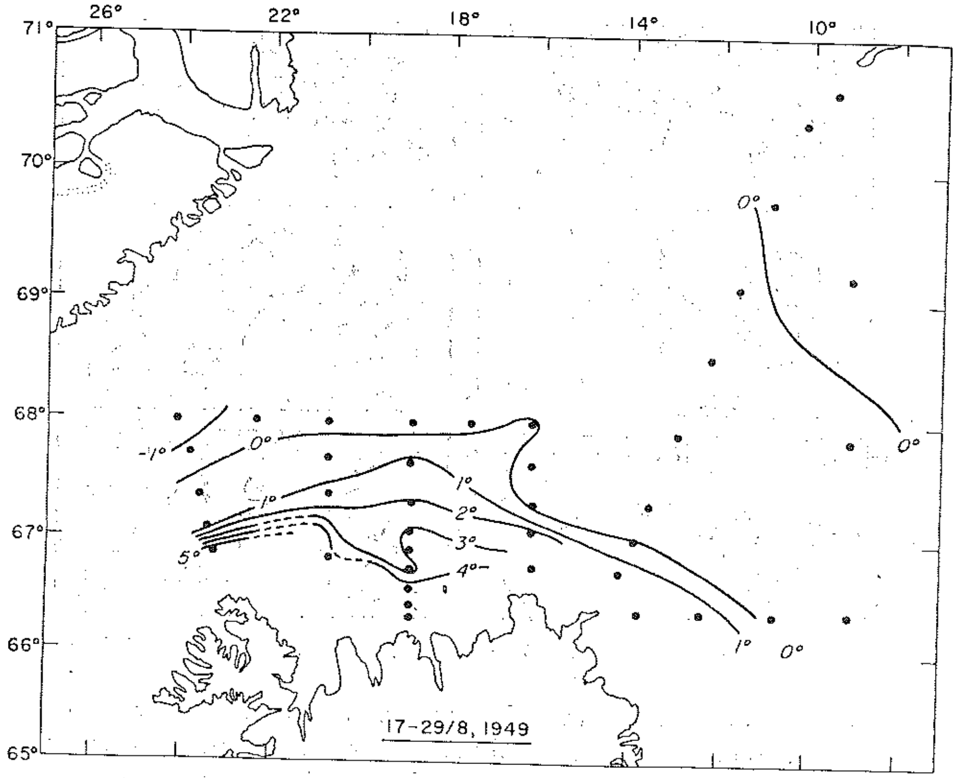


FIG. 45. *Temperature at 200 meters depth 17/8—29/8 1949.*

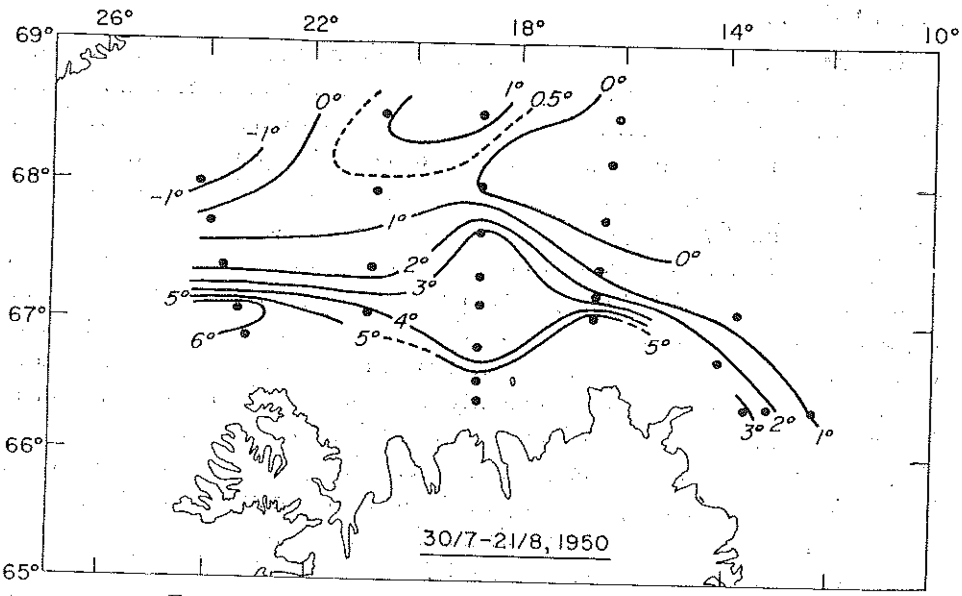


FIG. 46. *Temperature at 200 meters depth 30/7—21/8 1950.*

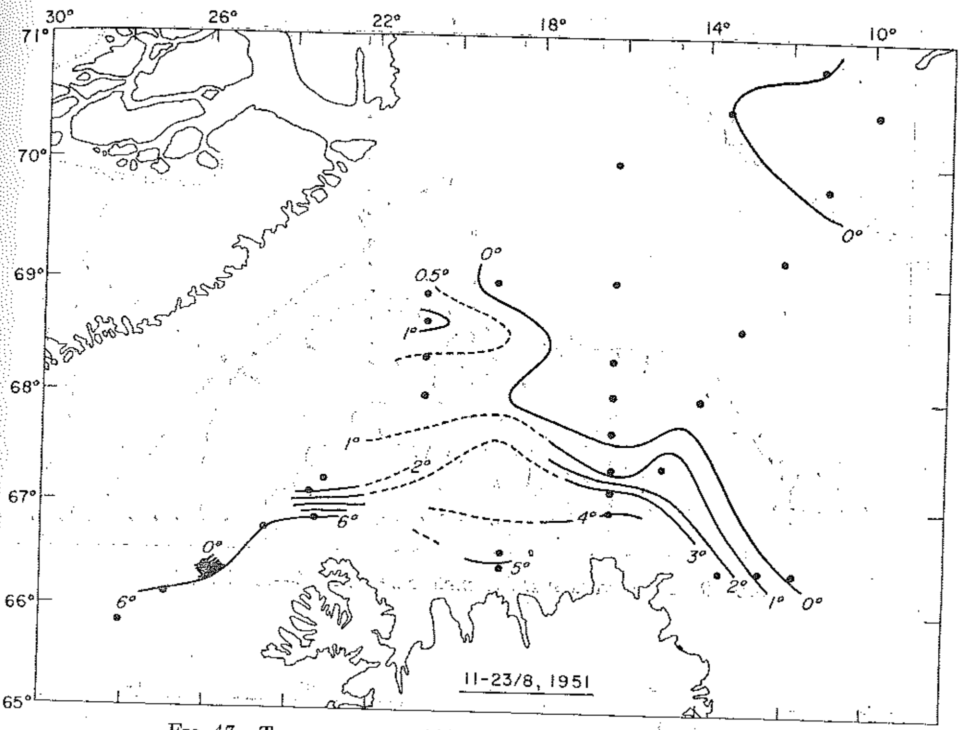


Fig. 47. *Temperature at 200 meters depth 11/8—23/8 1951.*

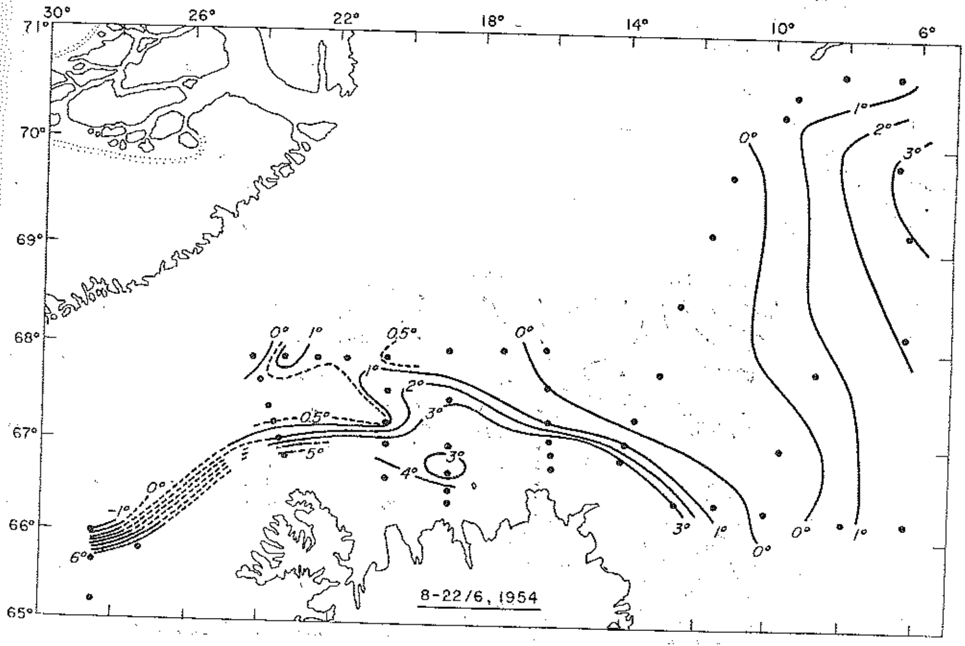
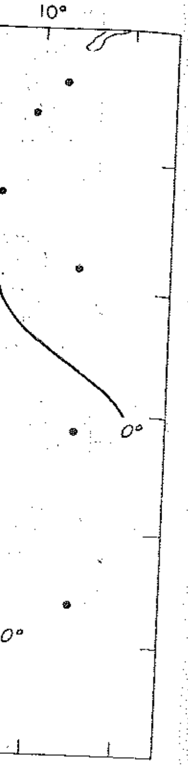


Fig. 48. *Temperature at 200 meters depth 8/6—22/6 1954.*



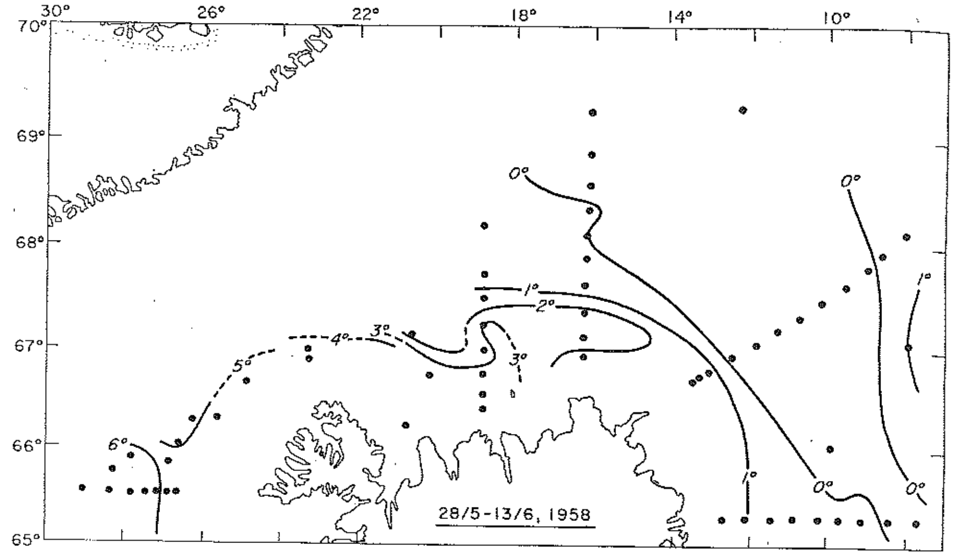


Fig. 49. *Temperature at 200 meters depth 28/5—13/6 1958.*

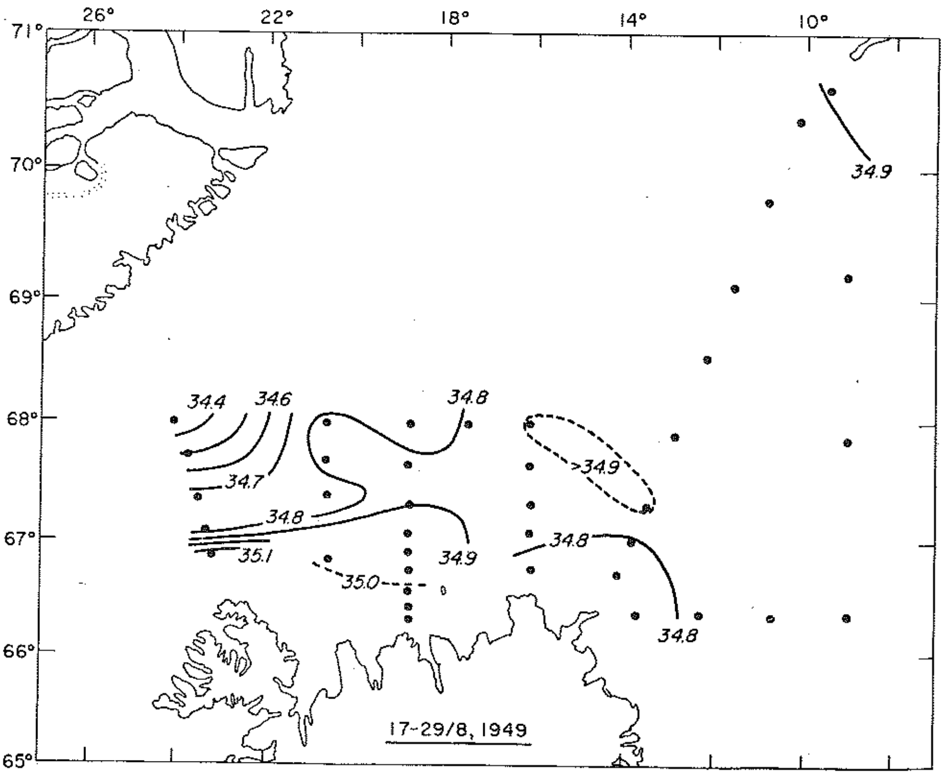
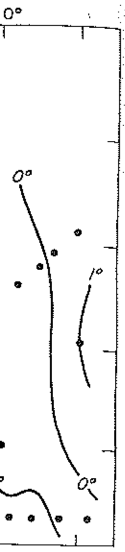
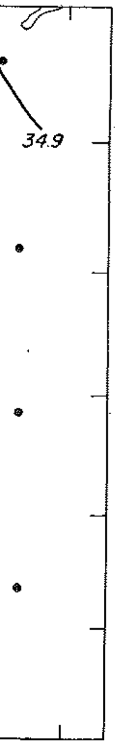


Fig. 50. *Salinity at 200 meters depth 17/8—29/8 1949.*





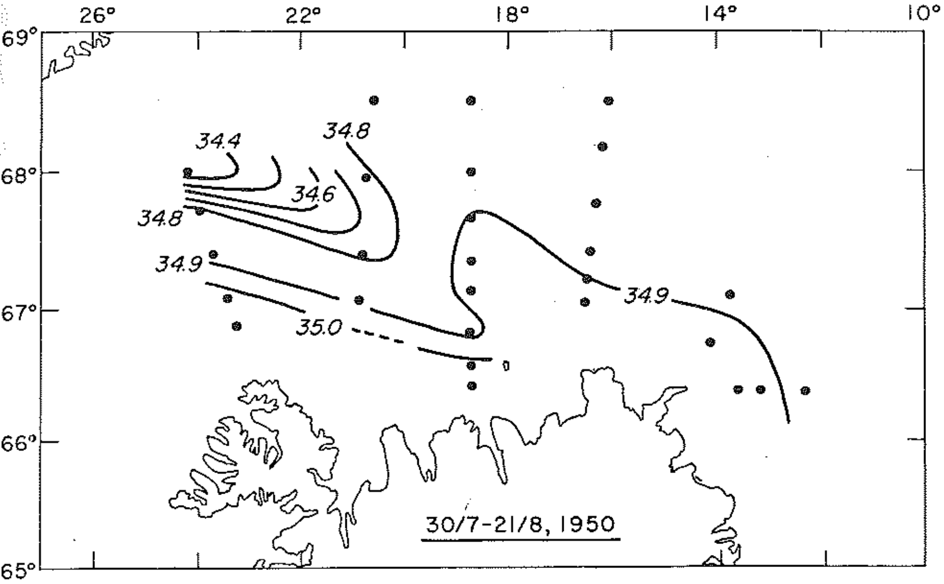


Fig. 51. *Salinity at 200 meters depth 30/7—21/8 1950.*

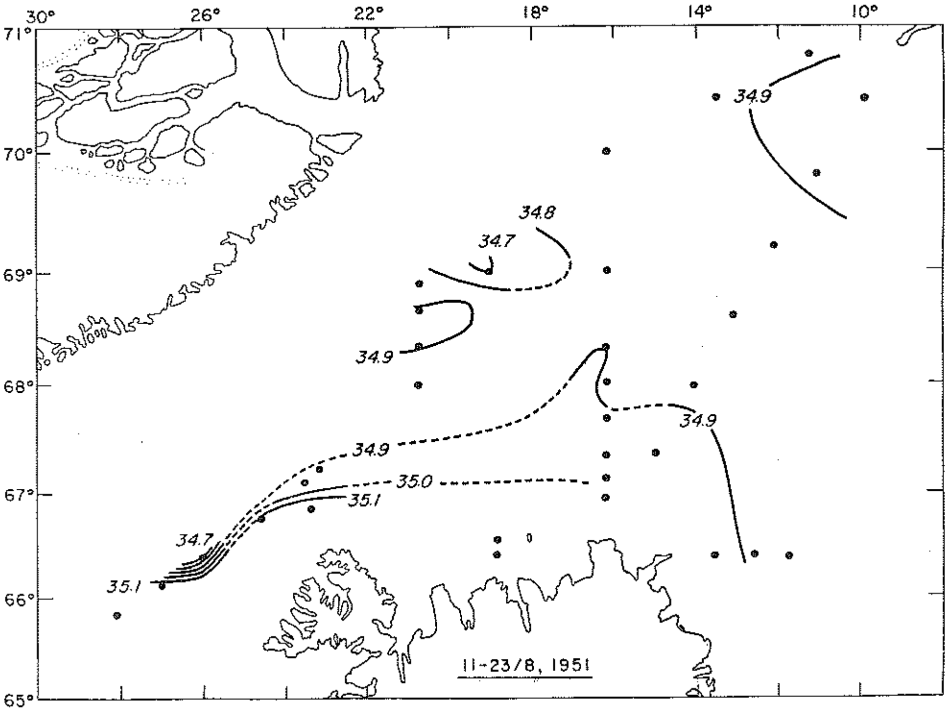


Fig. 52. *Salinity at 200 meters depth 11/8—23/8 1951.*

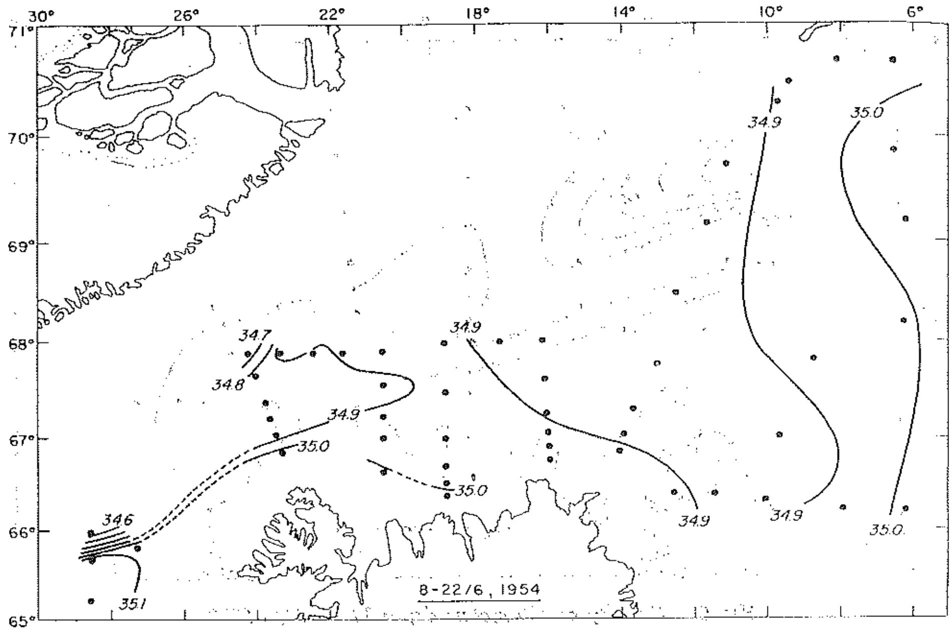


FIG. 53. *Salinity at 200 meters depth 8/6—22/6 1954.*

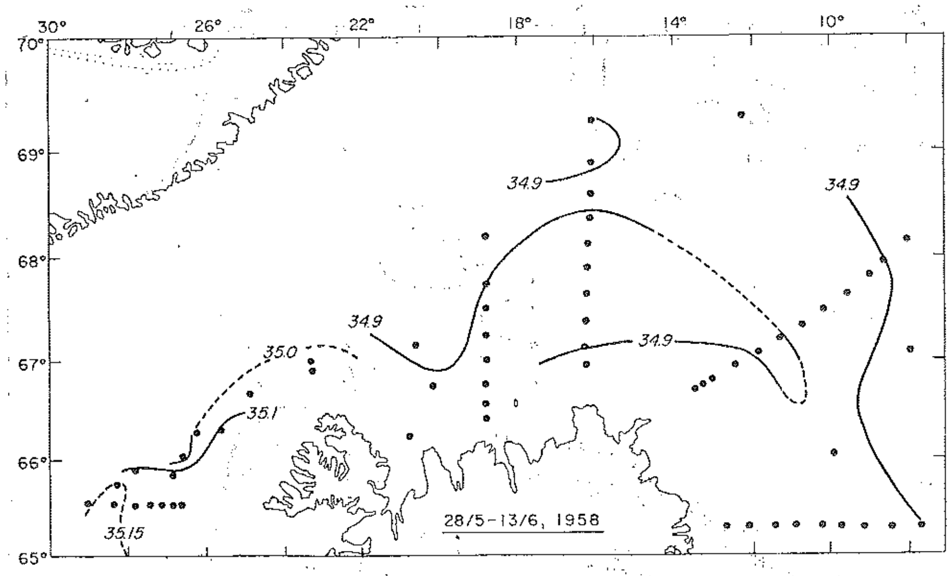


FIG. 54. *Salinity at 200 meters depth 28/5—13/6 1958.*

may vary between 4° and 6° and between 2° and 4° east of Langanes. In extremely cold years, however, such as 1949, the temperature at 200 meters may be less than 2° in August in the region east and south of Langanes.

Normally a strong horizontal temperature gradient is found at this level near the slope of the shelf off the northwest and the northeast coasts. Off the middle part of the coastal area the northward extension of Atlantic water is greatest and the boundary between the Atlantic and the Arctic water less sharp.

West of Iceland the salinity at 200 meters is generally uniform, 35.15 ‰ or more. A tongue of this saline water is found to extend northwards across the Iceland–Greenland Ridge continuing east along the North Icelandic grounds. On the way eastwards the salinity gradually decreases. In the westernmost part north of Kögur, the salinity will be 35.10–35.15 ‰ and 35.0–35.1 ‰ in the deep bays between Kögur and Grímsey. In the shelf region off the northeast coast the salinity will in very cold years be as low as 34.8 ‰ or even less, but generally it will be above 34.9 ‰ in summer. Usually the salinity at 200 meters north of Iceland will be somewhat higher in August than in June, especially in the eastern part of the area.

North of the shelf region the salinity will be lowered, especially in the western part where there is a marked influence of Polar water. In the region of the East Greenland Current the salinity at 200 meters will be 34.5 ‰ or even less.

At 200 meters a tongue of cold Arctic water with a temperature of less than 0° and salinity between 34.85 and 34.90 ‰ is found over the deep basin between Iceland and Jan Mayen. The eastern boundary of this tongue, as judged by the 0° isotherm, extends from about 67° N, 9° W to 70° N, 12° W, whilst on the western and the southern side it roughly follows the 1000 meter depth curve along the slope of the Icelandic submarine shelf.

A noticeable feature on the 200 meter charts is a region of relatively warm and saline water north of 68° N, between approximately 19° and 23° W. This must be Arctic Intermediate water which as previously mentioned forms an intermediate layer in the western part of the Iceland Sea, between the Polar or Arctic water on top and Arctic Bottom water below. This intermediate layer slopes downwards from east to west. In the region north of Slétta it can hardly be detected, but west of 19° W it is easily recognized on the t, S curves (see later). Its core is close to 200 meters in the region north of Húnaflói, but farther to the west it is found at a deeper level, and therefore appears on the 200 meter charts as an isolated region.

2. VERTICAL SECTIONS

Of the numerous vertical sections which have been worked off the coasts of Iceland in former as well as in recent years relatively few have extended outside the insular shelf. In Figs. 55–75 are shown those profiles worked in recent

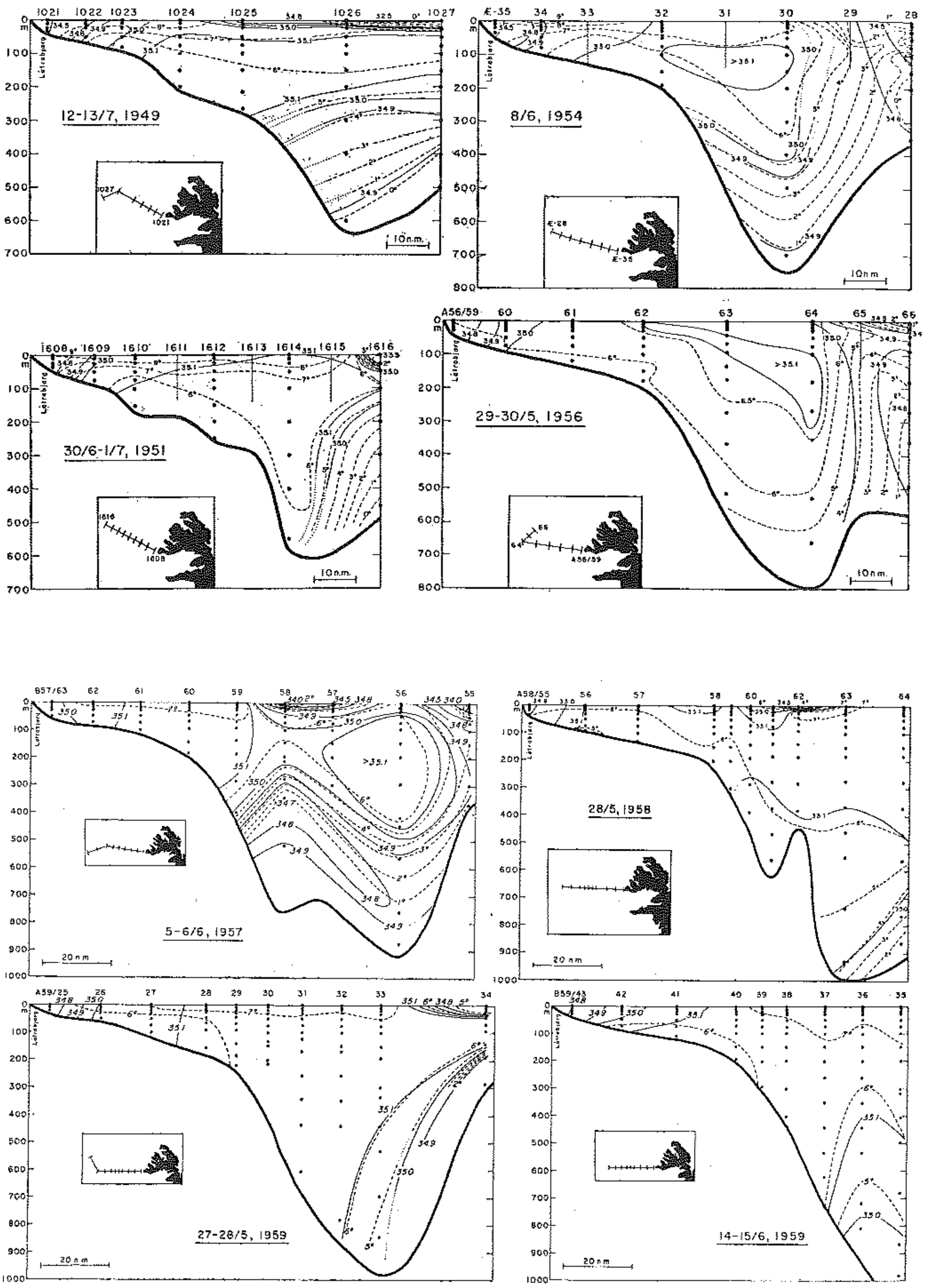


FIG. 55. *Hydrographic sections off Látrabarg 1949—1959.*

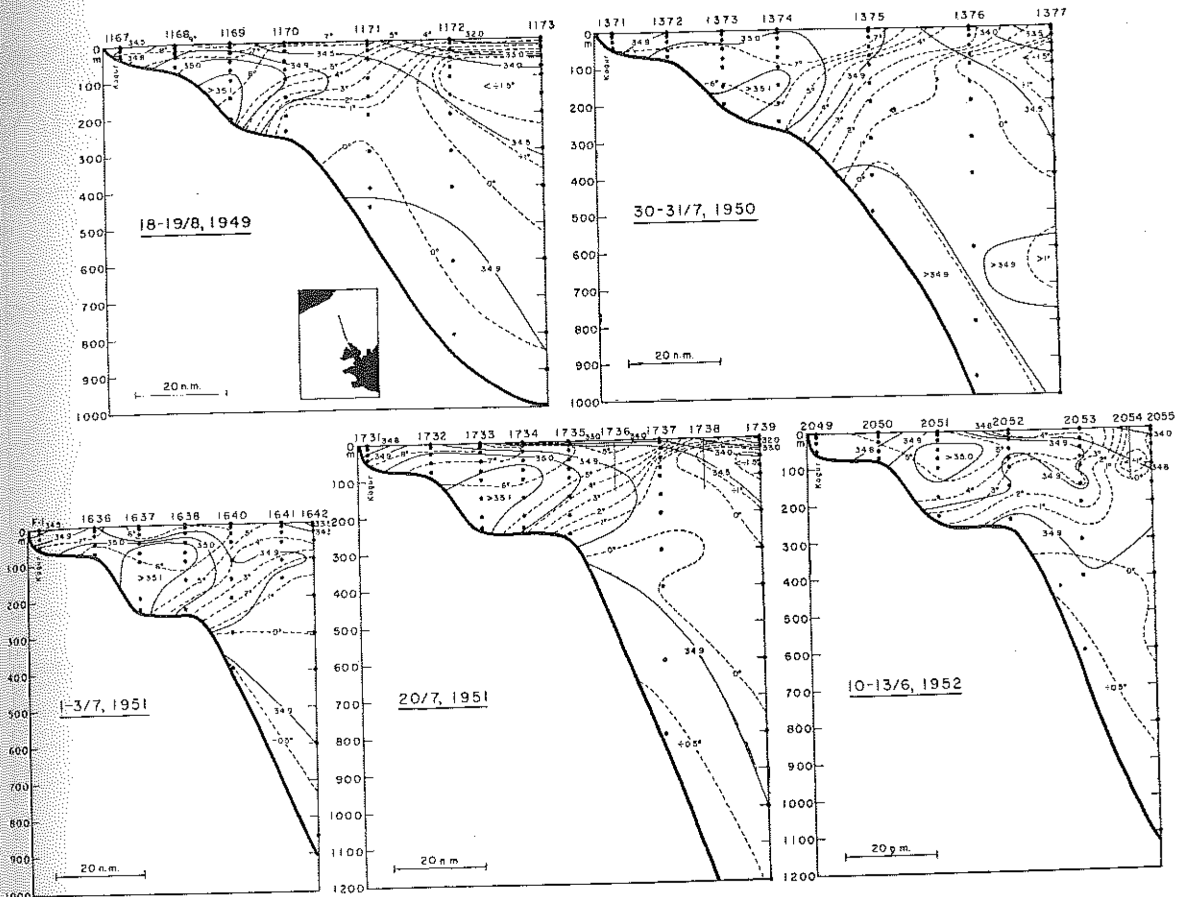


Fig. 56. *Hydrographic sections off Kögur 1949—1952.*

years which are considered the most important ones, i.e. those which cut across the North Icelandic Irminger Current.

a) *Off Látrabjarg.*

Off Látrabjarg (Fig. 55) the relatively warm and saline Atlantic water reaches close up to the coast. At 5–10 miles offshore the salinity usually exceeds 34.8 ‰ and at 10–20 miles from the coast it exceeds 35.0 ‰. The westward limit of the Atlantic water is in this section near the western side of the channel through the Iceland-Greenland Ridge 100–120 miles offshore. The width of the Atlantic water west of Látrabjarg is thus about 80–100 nautical miles. The core of the Irminger water, with salinity above 35.1 ‰, is found at the edge of the shelf and over the slope. On the shelf and in the slope area the Atlantic water extends from surface to bottom, usually all the way to the deepest part

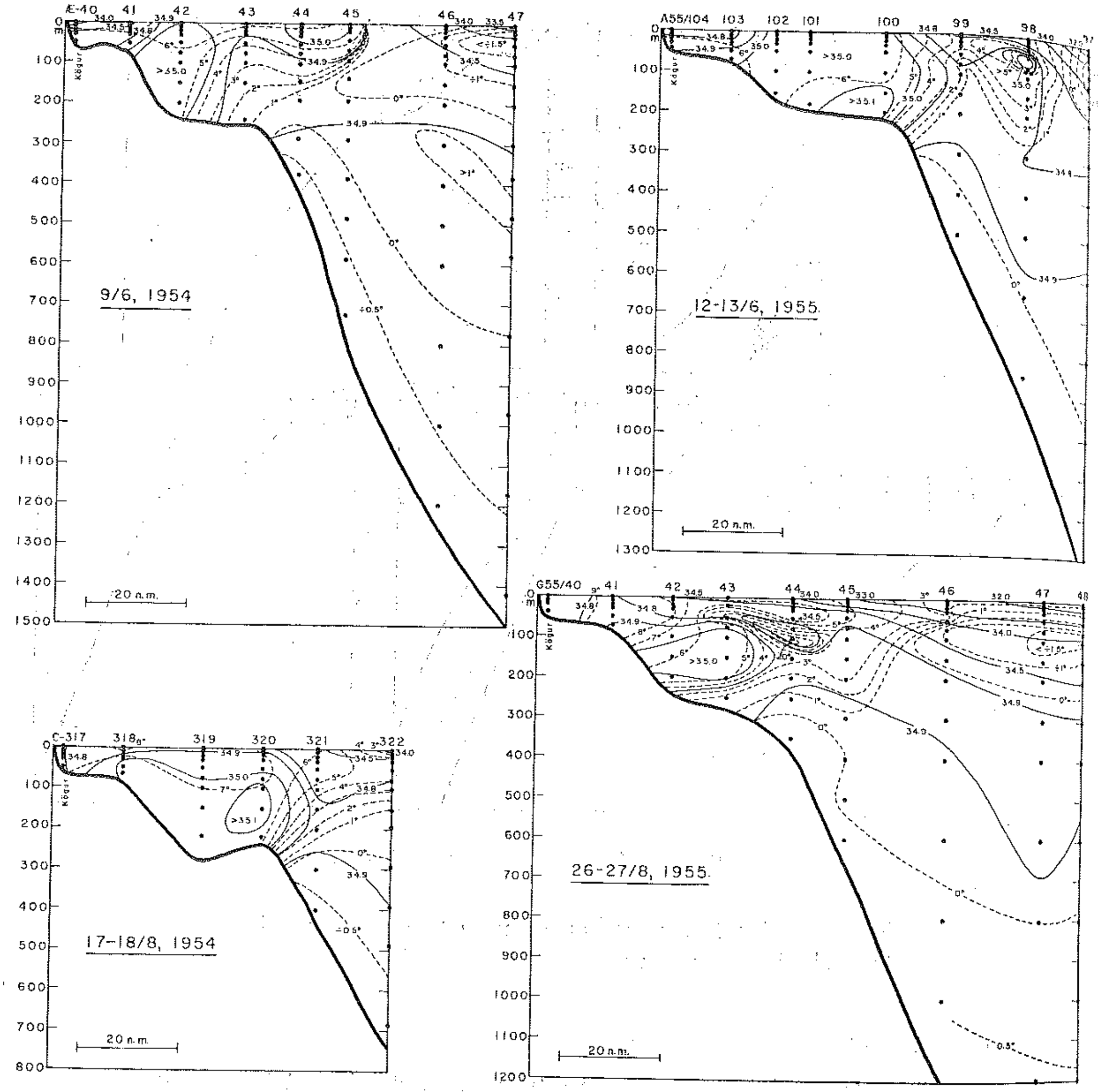


FIG. 57. *Hydrographic sections off Kögur 1954—1955.*

of the section. On approaching the sill from the south or western side of the through channel from the east, the thickness of the Atlantic water diminishes suddenly. Here the isohalines as well as the isotherms rise steeply towards the surface. The boundary between the Atlantic water and the Polar water is probably much sharper than indicated by the sections.

On the whole the different sections have similar features with the exception of the surface layer which naturally is more stratified in July than in June. The observed difference in the extension of the Atlantic water between years may at least be due partly to the fact that the sections do not have identical positions. In fact, a difference of few miles in this region may portray quite different hydrographic conditions. In the years 1949, 1951, 1957, 1958 and 1959 water with salinity above 35.1 ‰ filled most part of the section, whereas in 1954 and 1956 this water appeared as a tongue of relatively small cross-sectional area. In the core of the Irminger water the temperature lies between 6° and 7°C. This warm water slopes downwards to reach a maximum thickness at the foot of the slope. All along the bottom, however, from the 100 meter depth contour down to the edge of the shelf or even over the slope down to the 500 meter depth contour there is a layer with water of 5–6°.

In one respect there is a striking difference between the various sections off Látrabjarg. This regards the deepest part which on some of the sections is filled with Atlantic water all the way to the bottom, while in other instances there appears a thick layer of cold water at the bottom. This cold water must have been carried over the ridge from the north. It appears to be quite variable in composition and consists not only of variable mixtures of Polar water and Arctic Intermediate water, but also of Arctic Bottom water. Thus, in 1957 at a station located near the foot of the slope, water of 0.90° temperature and 34.66 ‰ salinity was found at a depth of 350 meters, but at 520 meters the temperature was 0.40° and the salinity 34.90 ‰. In 1949 and 1951 negative temperatures were found near the bottom in this section.

Cooper (1955) formulated the hypothesis that the overflow is intermittent and takes the form of a series of discrete boluses. This hypothesis is supported by recent observations made from the English Fishery Research Vessel "Ernest Holt" (Harvey 1961). These investigations revealed that rapid changes may take place in the bottom temperature in this region analogous to what was found on the Iceland–Faroe Ridge during the international survey made in June 1960.

The different hydrographic conditions near the bottom on the southern side of the ridge as revealed by the sections shown in Fig. 55 might be explained in the same manner, viz. as being due to intermittent overflow. Thus at the time when the Látrabjarg section was worked in 1957, a strong overflow was indicated, whilst during May 27th–28th and June 14th–15th 1959 only very little overflow must have been taking place.

b) *Off Kögur.*

Vertical sections worked during the years 1949–1955 north–northwest of Kögur are shown in Figs. 56–57. As indicated by these profiles a most complex hydrographic situation may be met with in this region and the conditions may be quite variable from one observation to another.

Only small amounts of coastal water are indicated in this section as the salinity exceeds 34.8 ‰ close to the shore. Generally, the Atlantic water occupies the uppermost 200 meters from the 75 meter depth contour to the edge of the shelf, i.e. between 10 and 40 miles offshore. In some cases, however, such as in June 1952, the amount of Atlantic water in this section is very small, whereas in other instances the Atlantic water may fill the whole section down to 300 meters. This may be interpreted as indicating that the Atlantic influx through the Kögur section takes place intermittently. Usually, a small tongue of water with salinity above 35.1 ‰ appears in the core of the Atlantic water. This tongue, however, is decidedly smaller than that observed in the section west of Látrabjarg.

Actually, two shelves are recognizable in this section, one from the 50 to the 75 meter depth contour and the other at depths between 220 and 280 meters. On the shelves the water is relatively homogeneous, but near the edges the isolines are more closely spaced, especially at the outer edge where they rise steeply to the surface, indicating a strong east-going current. In the mixing area farther offshore an isolated tongue of Atlantic water is sometimes observed (June 1954 and 1955). From the density distribution it seems likely that this water is moving back to the southwest.

In the northernmost part of the section, Polar water is found in the uppermost 200–300 meters. Near the surface the salinity of this water will be less than 32 ‰. Due to heating by the sun the temperature of the surface may rise to 3°C in summer, but falls rapidly below the surface and has a minimum of about —1.8° near 75 meters depth. At this level the salinity is about 34.0 ‰ which therefore may be considered as the salinity of extreme Polar water (cf. chapter V).

Below 200–300 meters increasing concentrations of Arctic Intermediate water are indicated by a rise in temperature as well as salinity. The Arctic Intermediate water slopes downwards away from the Icelandic shelf. In the northernmost part of the section (near 68° N) the core of this water is found at 500–600 meters, where the temperature may be as high as 1.5° and the salinity 34.97 ‰.

Near the 300 meter depth contour, just below the edge of the shelf, the Arctic Bottom water is found, as indicated by the low temperature ($< 0°$) and relatively high salinity (34.90–34.92 ‰). This layer of Arctic Bottom water slopes downwards along the bottom of the deep channel.

The mean temperature and salinity conditions on the first 26 miles of the Kögur section are shown in Fig. 58. These "mean" sections are constructed from mean values based on 10 years with observations in June, 13 years with observations in July and 13 years with observations in August (see Appendix). From these mean sections it will be seen that the normal temperature in June lies between 5° and 6° in the uppermost 150 meters and between 4° and 5° at 200 meters at the deepest station. In July the water is slightly more stratified and the normal temperature of the coastal water lies between 7° and 8°. The upper layers of the Atlantic water have a temperature between 6° and 7° and the lower layers (below 150 m) 5–6°. In August a marked stratification has been developed and the surface layer now has a temperature of 8–9° or even

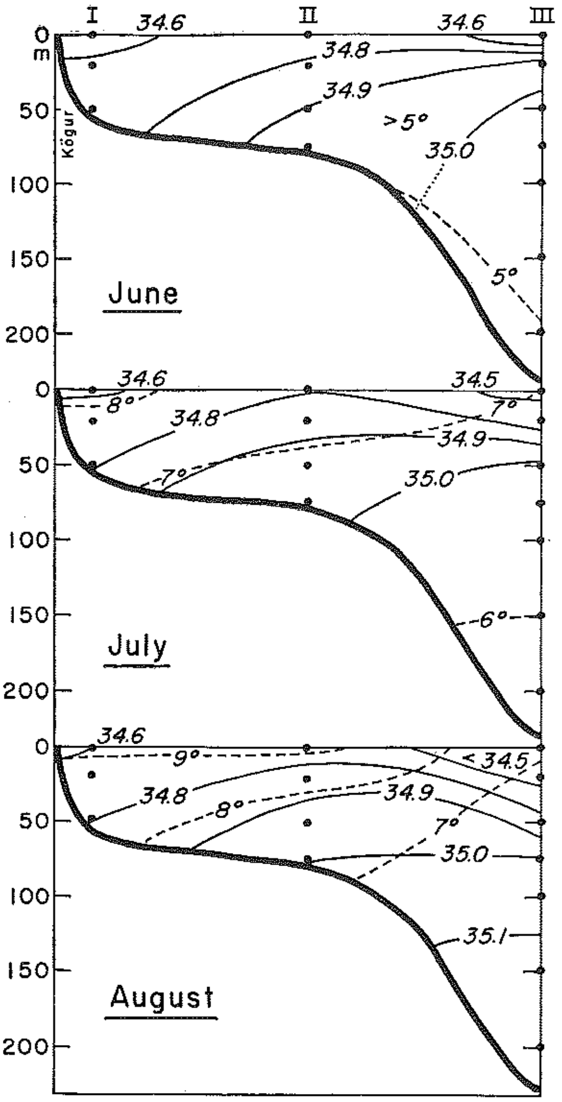


FIG. 58. *Mean temperature and salinity in the section off Kögur for June, July and August.*

above 9° in the shallower part of the section. The temperature of the deeper layers lies between 6° and 7°. The Atlantic water with salinity above 35.0‰ reaches up to the surface layers in June, but lies deeper in August. At the same time it seems to advance closer to the shore at the bottom in July and August than it does in June. As will be discussed later, the coastal water ge-

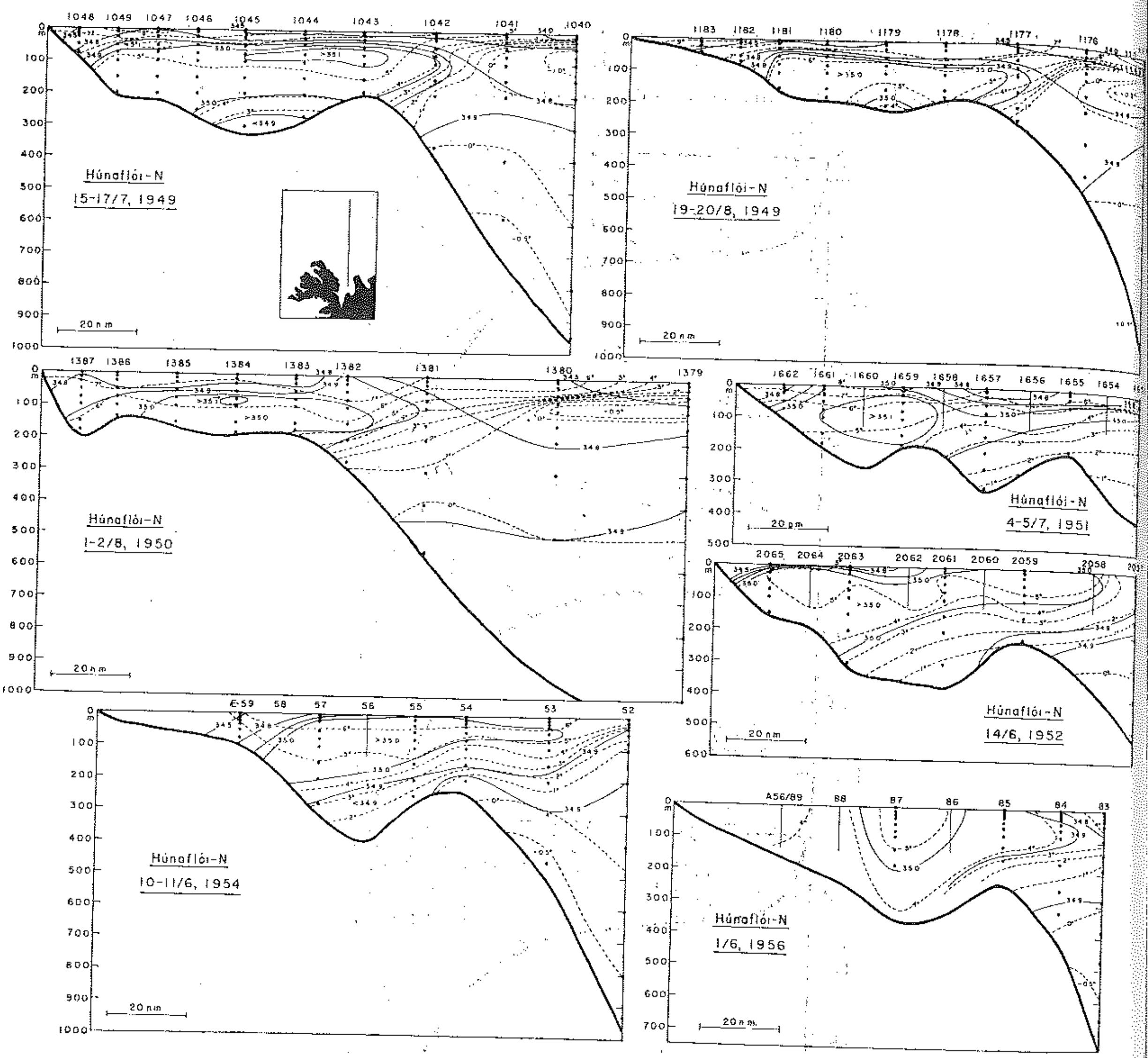
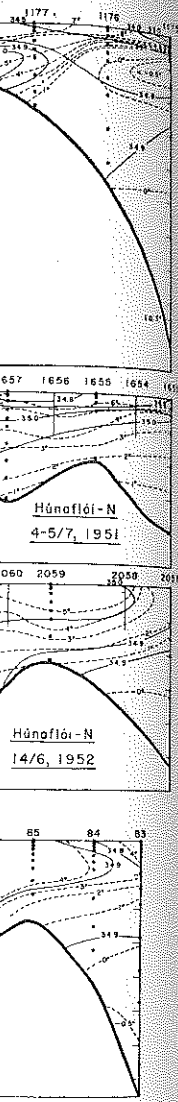


FIG. 59. *Hydrographic sections off Húnaflói 1949—1956.*

nerally has a greater tendency to spread seawards in August than in June (not so apparent on these mean sections, however), and therefore the deeper water would be expected to move closer to the shore. It should be remarked, however, that these mean sections are not based on the same years for the three months in question, and therefore the difference between months may to some extent be accidental and not be due to actual seasonal changes.



c) Off Húnaflói.

The Húnaflói section (Fig. 59) is directed due north along the 20° 40′ W meridian. The deepest part of the bay has a depth of 300–400 meters. North of this depression there is a slight elevation, about 200–250 meters in depth, near the edge of the shelf from which the sea bottom slopes down towards the Iceland Sea Basin.

In the innermost part of the Húnaflói the Atlantic water is mixed with fresh coastal water. Near the 50 meter depth contour the 34.9 ‰ isohaline is found and a few miles farther seawards the salinity usually exceeds 35.0 ‰. In this section it rarely exceeds 35.1 ‰. The northern boundary of the Atlantic water is about 100–110 miles offshore, just north of the edge of the insular shelf. The width of the tongue of Atlantic water is thus about 80 nautical miles. In June the Atlantic water extends from the surface down to about 200 meters, whereas later in the summer it lies somewhat deeper, being covered with a fresher surface layer. The thickness of Atlantic water seldom exceeds 200 meters in this region. In the shallower parts of the shelf it therefore reaches down to the bottom, but in the deepest part of the bay the Atlantic water appears as an intermediate layer with a colder and less saline bottom water. This bottom water consists of North Icelandic Winter water (see later), but at depths below 300 meters (e.g. June 1952) a mixture with Arctic Bottom water is indicated.

In June the temperature is 5–6°C in the uppermost 100 meters on the shelf, dropping to 4° or less at the lower level of the Atlantic water. In July and August similar temperatures are found at subsurface depths, but in the surface layer a thermocline is formed above which the temperature is 7–9°. North of the edge of the shelf the inclination of the isotherms indicates an east-going current. In the deepest part of the Húnaflói section Polar water is found in the uppermost 200 meters. Here, however, it is mixed with Arctic and/or Atlantic water, so that the temperature and the salinity of the surface layer are considerably higher than in the section off Kögur. Below the Polar water mixed waters (Arctic Intermediate water and/or Arctic water) are found between 200 and 500 meters. The temperature of this intermediate water ranges from 0° to 1° and the salinity from 34.8 to 34.95 ‰. As in the Kögur section, the upper boundary of the Arctic Bottom water (as indicated by the 0° isotherm) slopes downwards from the edge of the shelf, where it is found at a depth of 300–400 meters to about 500 meters in the deepest part of the section.

d) Off Siglunes.

The Siglufjörður section (Figs. 60–62) extends north of Siglunes along the 18° 50′ W meridian, over the Eyjafjarðardjúp, the Grímsey Basin (see p. 33), the shallow banks near Kolbeinsey and from there towards the Iceland Sea Basin. The sea bottom slopes very steeply a few miles offshore, and about 10 miles north of Siglunes the depth exceeds 400 meters. Most part of the Eyja-

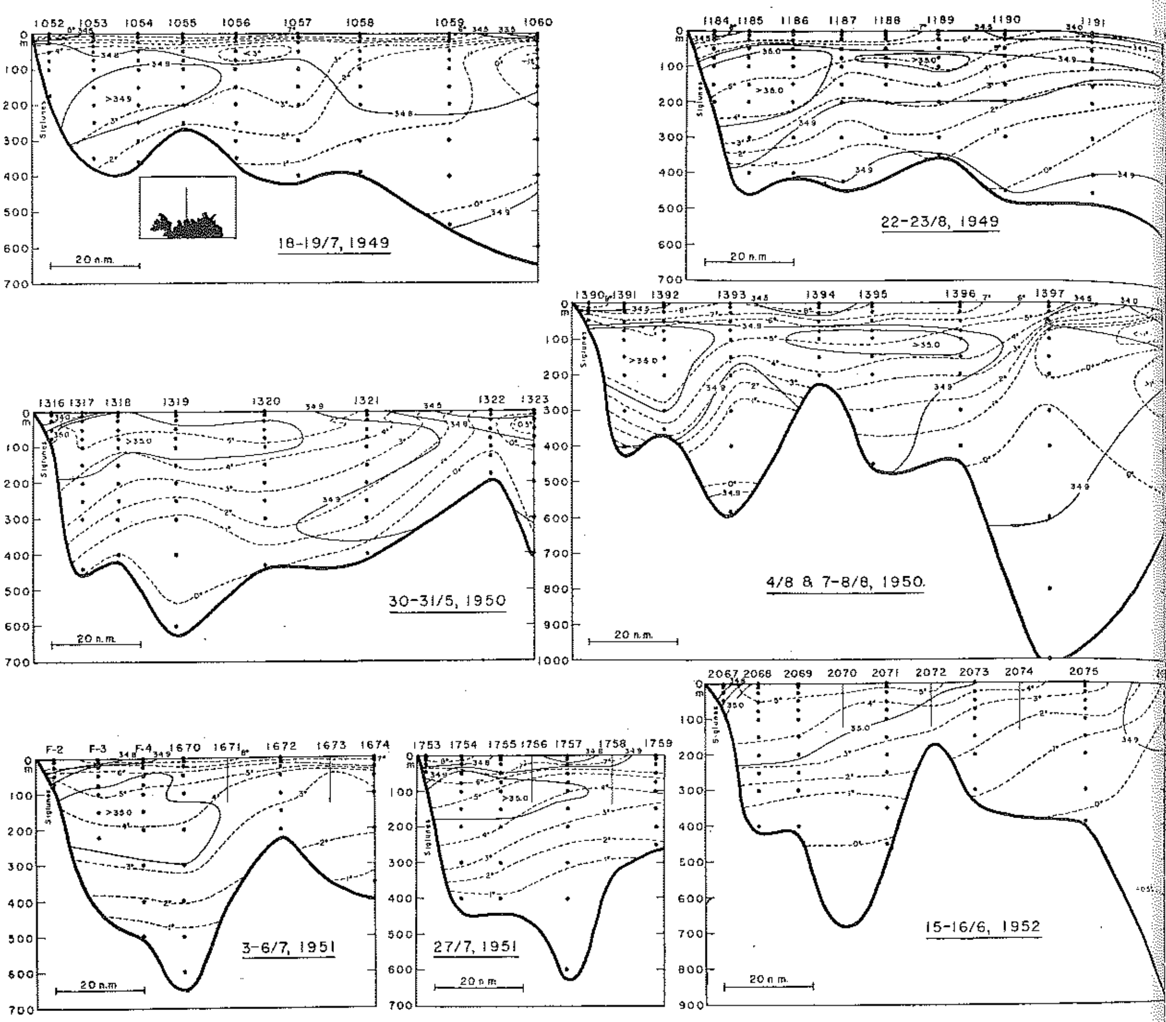


FIG. 60. *Hydrographic sections off Siglunes 1949—1952.*

fjarðardjúp is in restricted communication with the deep water north of the shelf, and as was shown in chapter IV, the Grímsey Basin is an isolated depression.

In June Atlantic water with salinity above 35.0‰ is usually observed from the surface down to 150–200 meters in the Eyjafjarðardjúp from the 100 meter depth contour northwards beyond the Kolbeinseyjargrunn. The normal width of the tongue of Atlantic water is thus about 60 miles. Farther north this tongue with salinity above 35.0‰ is usually pinched out, although the Atlantic influence can be traced all the way to the slope of the Iceland Sea Basin. In some years, however, (e.g. June 1954 and 1955), the tongue of Atlantic water may be 80–90 miles in width, or the tongue may be divided into two parts as was the case in August 1949 and 1950.

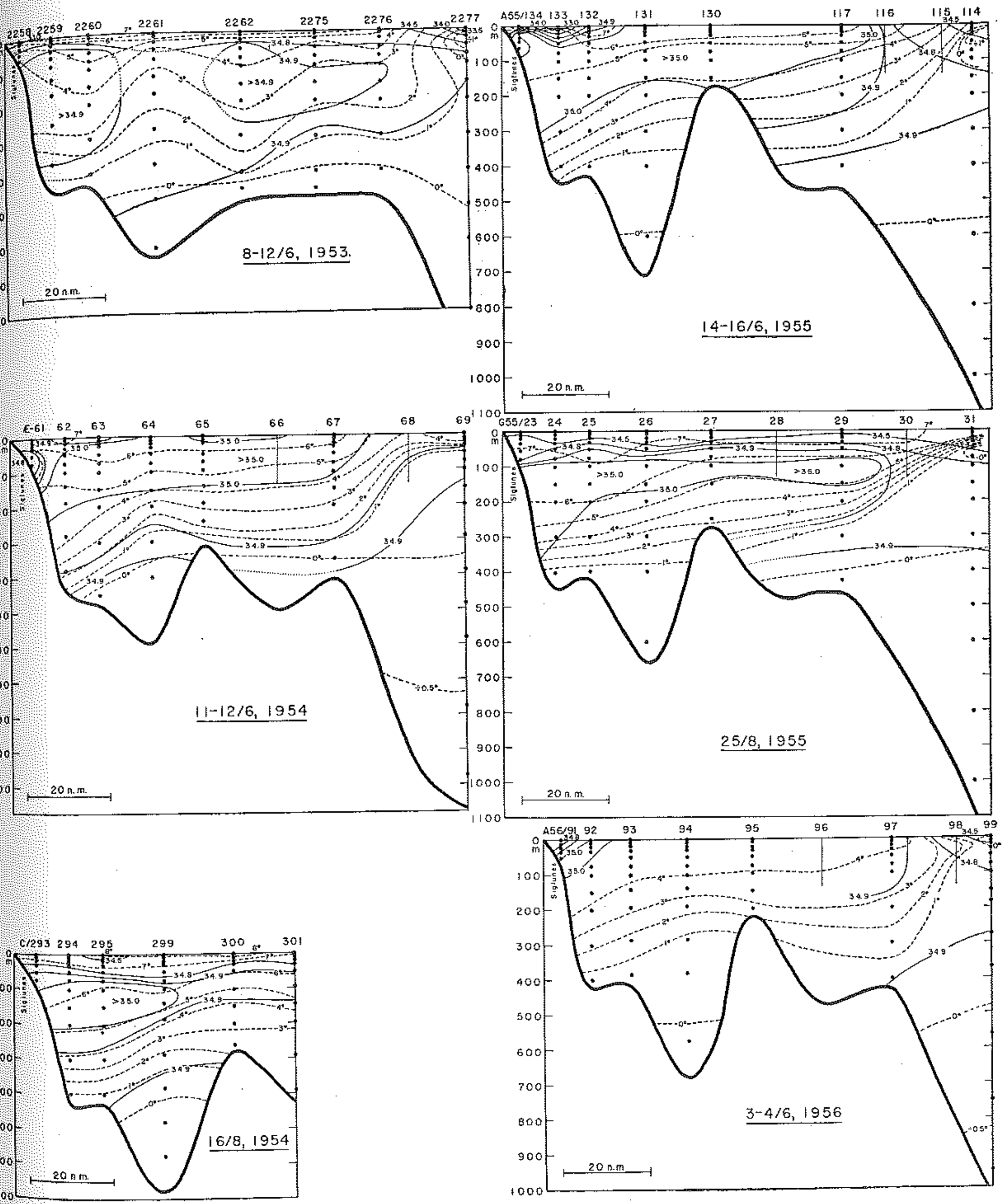


FIG. 61. *Hydrographic sections off Siglunes 1953—1956.*

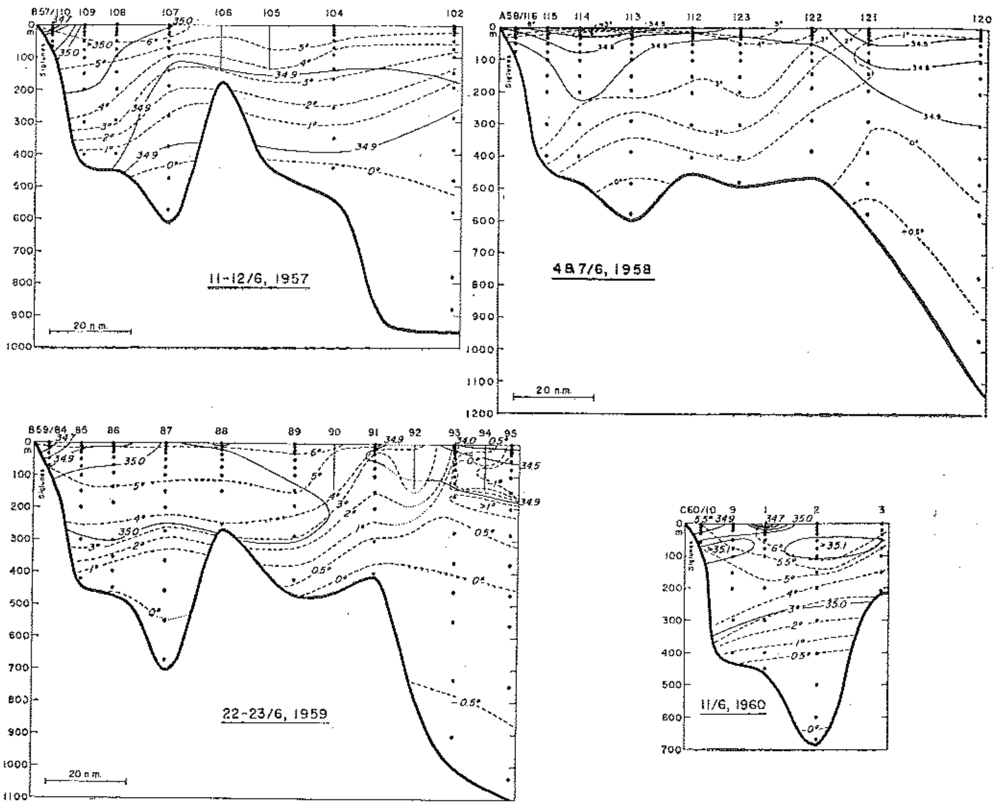


FIG. 62. *Hydrographic sections off Siglunes 1957—1960.*

Below the layer of Atlantic water North Icelandic Winter water is found, but near the bottom Arctic Bottom water is present. Above 250 or 300 meters the water is therefore essentially a mixture of Atlantic water and North Icelandic Winter water, whereas at depths exceeding 300 meters a mixture of Winter water and Arctic Bottom water is apparent. Pure Arctic Bottom water, however, usually first appears at depths greater than 400–500 meters in the Grímsey Basin, but at about 400 meters north of the Kolbeinseyjargrunn.

In late summer the width of the Atlantic water is similar or slightly less than in June, but it lies deeper and may be greater in thickness, especially in the southernmost part of the section. At this time the North Icelandic Winter water must be more or less replaced by Atlantic water and/or mixed Arctic water coming from the north.

In the deepest part of this section, viz. north of 68° N, an admixture of Polar water is usually found in the uppermost 100 meters. Below this level, between 100 and 400 meters, the presence of Arctic Intermediate water is usually indicated, and in certain years this water may be quite conspicuous, e.g. August 1950 and June 1959.

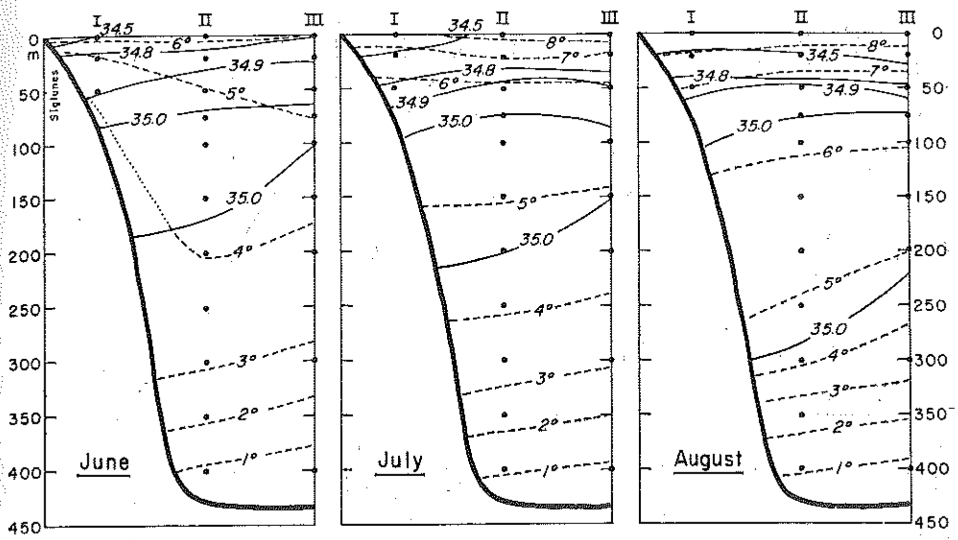


FIG. 63. *Mean temperature and salinity in the section off Siglunes for June, July and August.*

The mean conditions at the first three stations of the Siglufjörður section in June, July and August are shown in Fig. 63. The mean sections are constructed from mean values based on 14 years with observations in the case of June, 10–13 years in the case of July and 12–15 years in the case of August (see Appendix). The stratification is distinctly greater in the Siglufjörður section than farther west in the area. In June the formation of a thermocline is apparent in the surface layers, but the stratification becomes progressively greater in late summer. It is noticeable that in July the stratification of the surface layer is mainly due to the temperature gradient, whereas in August the salinity gradient becomes more important (cf. Fig. 109). In the course of summer the layer of Atlantic water increases in thickness. Between the second and the third station the mean thickness is about 100 meters in June, 125 meters in July and 175 meters in August. In June the mean temperature of the surface layer in the Eyjafjarðardjúp is about 5–6°C, between 50 and 200 meters 4–5° and 3–4° between 200 and 300 meters. At 400 meters the temperature is slightly below 1°. In July the surface layer has a mean temperature of 6–8°. The upper intermediate layer, between 50 and 150 meters, has a temperature of 5–6°, whereas the temperature is 4–5° between 150 and 250 meters, and 2–4° between 250 and 300 meters. At 400 meters the temperature is similar or slightly higher than in June. In August the temperature is 7–8° in the surface layer, about 6–7° between 50 and 100 meters, 5–6° between 100 and 200 meters and 4–5° between 200 and 300 meters. At 400 meters the mean temperature is practically identical to the July mean.

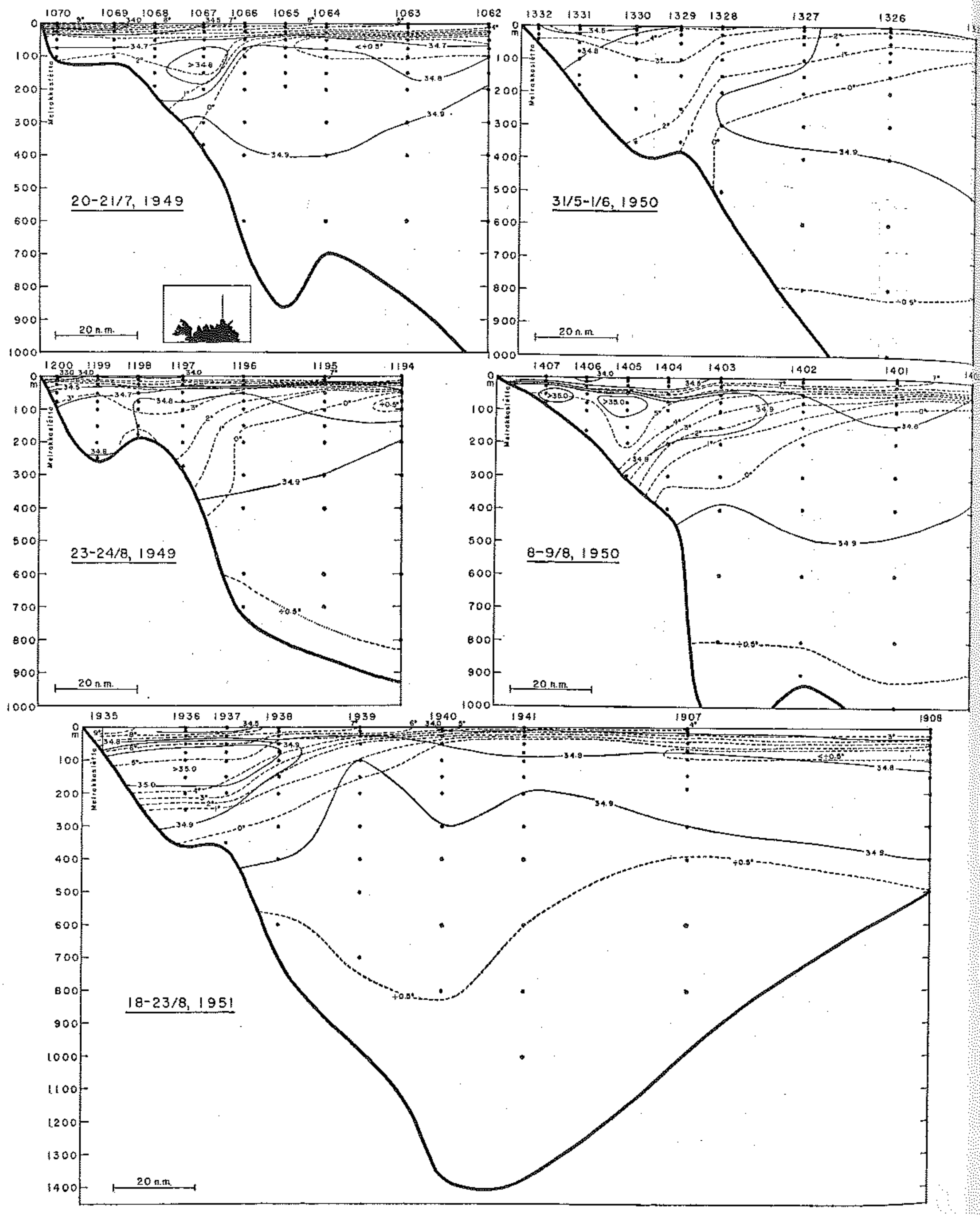
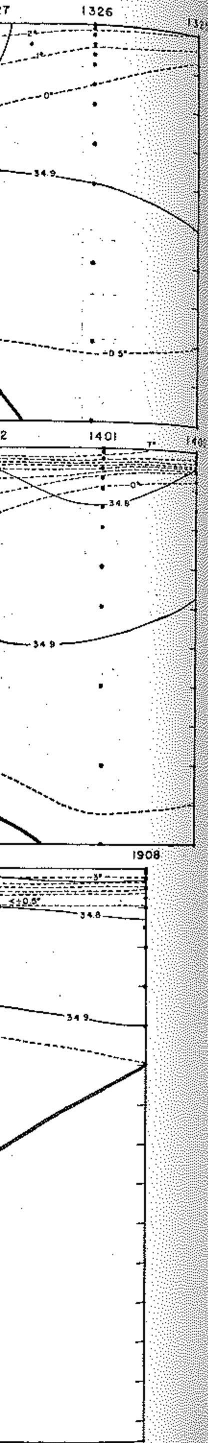


FIG. 64. *Hydrographic sections off Melrakkaslétta 1949—1951.*



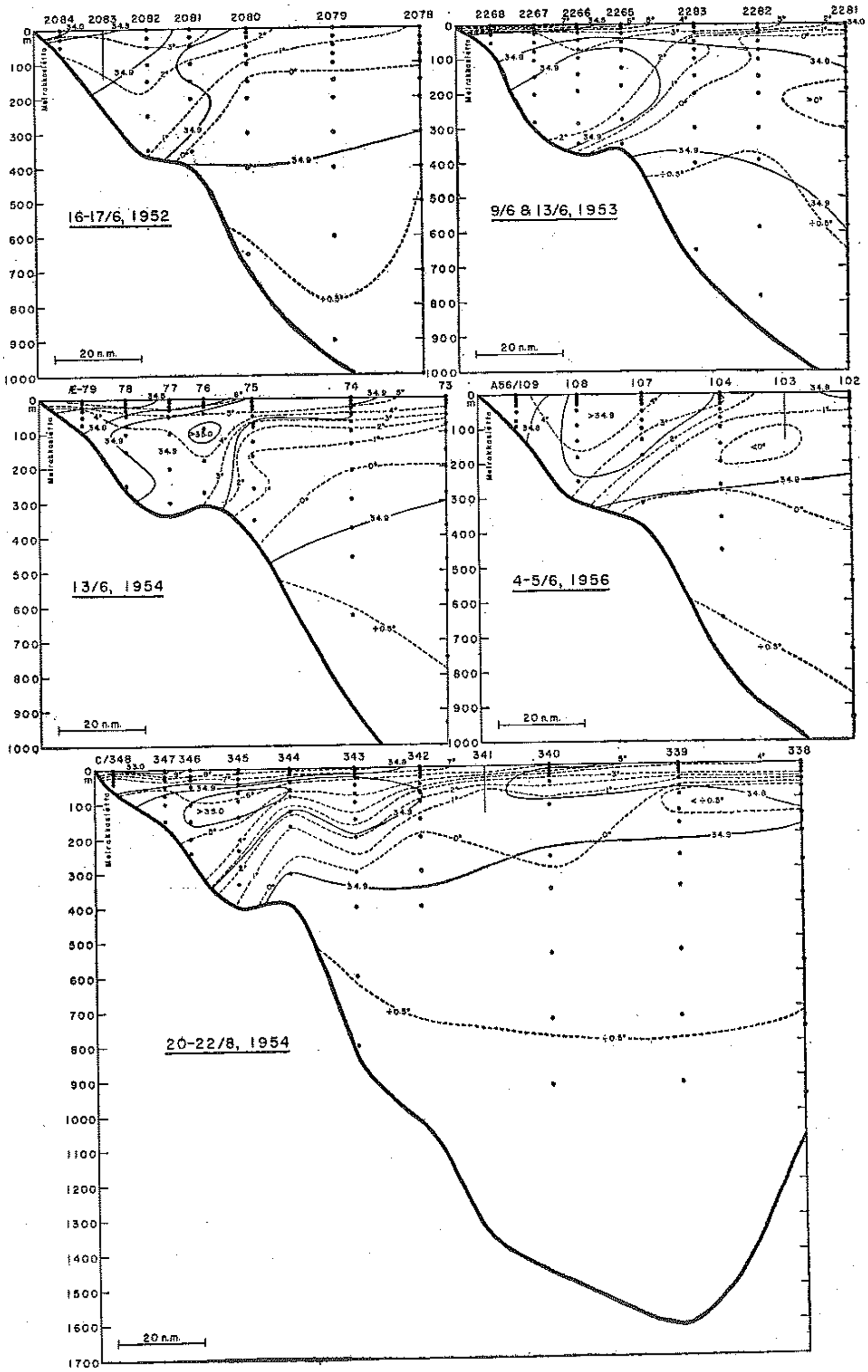


Fig. 65. *Hydrographic sections off Melrakkaslétta 1952—1956.*

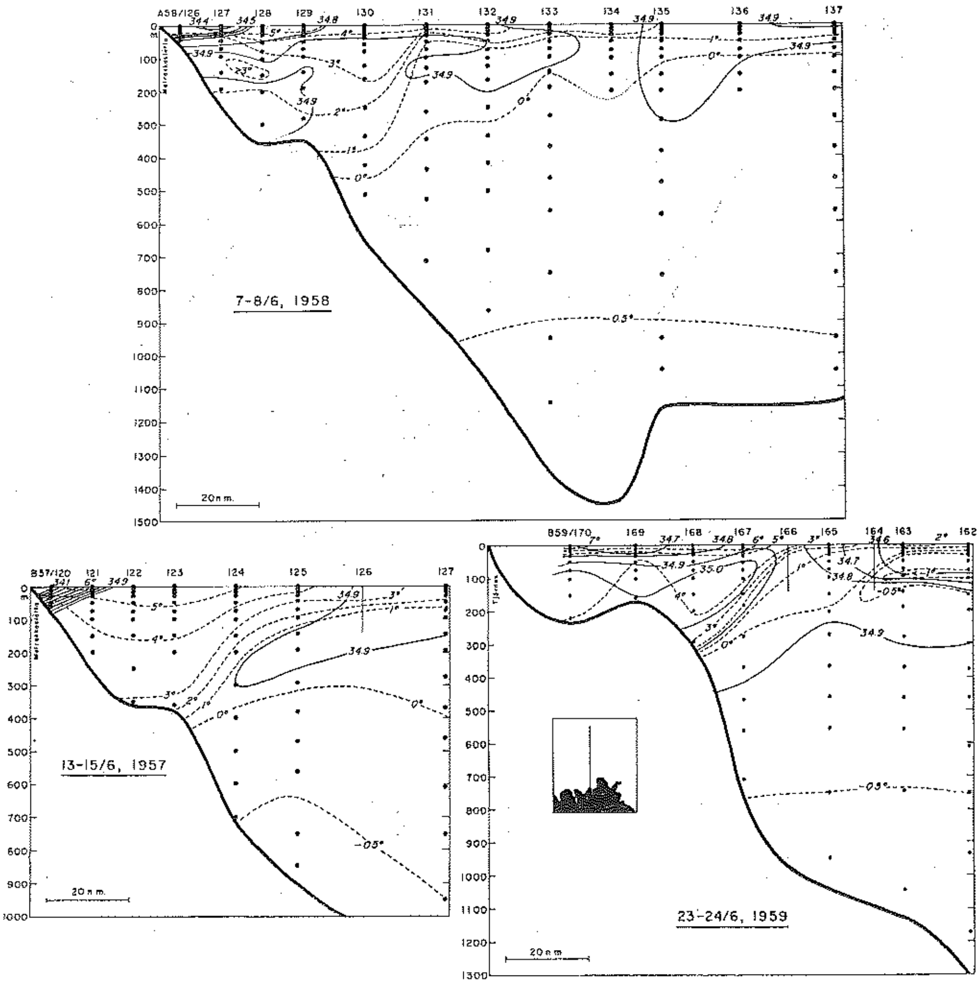


FIG. 66. *Hydrographic sections off Melrakkaslétta 1957—1958 and off Tjörnes 1959.*

e) Off Melrakkaslétta.

The section off Melrakkaslétta (Figs. 64–66) which extends over the Þistilfjarðardjúp follows the 16° 10′ W meridian. From the coast to about 25 miles offshore the sea bottom slopes evenly down to 300–400 meters. Then follows a relatively flat terrace, about 10 miles wide, north of which the bottom slopes down again towards the Iceland Sea Basin. One of the sections shown in Fig. 66 (June 1959) extends north of Tjörnes, some 30 miles west of the usual Melrakkaslétta section.

In June the salinity rarely exceeds 35.0 ‰ in this section. However, already in June the influence of Atlantic water is evident from a tongue of water with relatively high temperature and salinity between 34.9 and 35.0 ‰ in the upper layers of the Þistilfjarðardjúp. In late summer Atlantic water with salinity above 35.0 ‰ usually appears in this profile as a small tongue at intermediate depths some 30 miles in width. The Atlantic influence may, however, be traced much farther north beyond the edge of the submarine terrace. Below the Atlantic water the same water components are found as were present at corresponding depths in the Siglufjörður section, viz. North Icelandic Winter water and Arctic Bottom water.

A sharp thermocline is practically always present in summer in the surface layer of this section, with fresh water on top. This fresh water which must be coastal water spreading seawards is particularly apparent in this section. Strangely enough, the surface salinity at a distance of about 15 miles from the coast is often found to be distinctly lower than at a station located only 4 miles from the coast. This surface salinity minimum some 15 miles offshore might be explained as being due to fresh surface water being carried to this region not directly from the nearby coast, but from some other locality. Possibly this fresh water originates from the inner part of the Axafjarðardjúp whence is was carried northwards along the western side of the Sléttugrunn.

As indicated by the sections in Figs. 64–66 the temperature of the intermediate layers may be quite variable, depending upon the relative strength of the Atlantic influx. In the colder years (such as 1952 and 1953) it is 2–3° or even less at depths between 100 and 300 meters, but in the warmer years (such as 1954 and 1957) it is 3–4°. In August the temperature has increased by 1–2° at intermediate depths. The 5° isotherm is then usually found at about 150 meters and the 4° isotherm may reach down to about 300 meters in the core of the warm water. As was the case in the Siglufjörður section north of the Kolbeinseyjargrunn, the 0° isotherm is found at a depth of about 400 meters. Near the edge of the submarine terrace the isotherms rise towards the surface indicating a strong easterly current. This feature is similar to that found in the sections farther west in the area north of Iceland.

f) Off Langanes.

In Figs. 67–69 are shown temperature and salinity profiles along a line between Langanes and Jan Mayen and northeast of Langanes (Fig. 69). In August 1951 the section extended from Jan Mayen towards Melrakkaslétta. On this section the width of the shelf is only about 30 nautical miles. From the edge of the shelf the sea bottom slopes very steeply down to 1700–1800 meters. In the shelf area the temperature conditions in summer may vary greatly from year to year. In early summer the salinity rarely exceeds 35.0 ‰ in this section, as normally the eastern limit of the Atlantic water ($S > 35.0$ ‰) is at that time found a little farther west. In June 1952 and 1953 the temperature was 2–3° C in the upper intermediate layers and about 1–2° in the deeper layers on the shelf, whilst the salinity was below 34.9 ‰ at intermediate depths. The At-

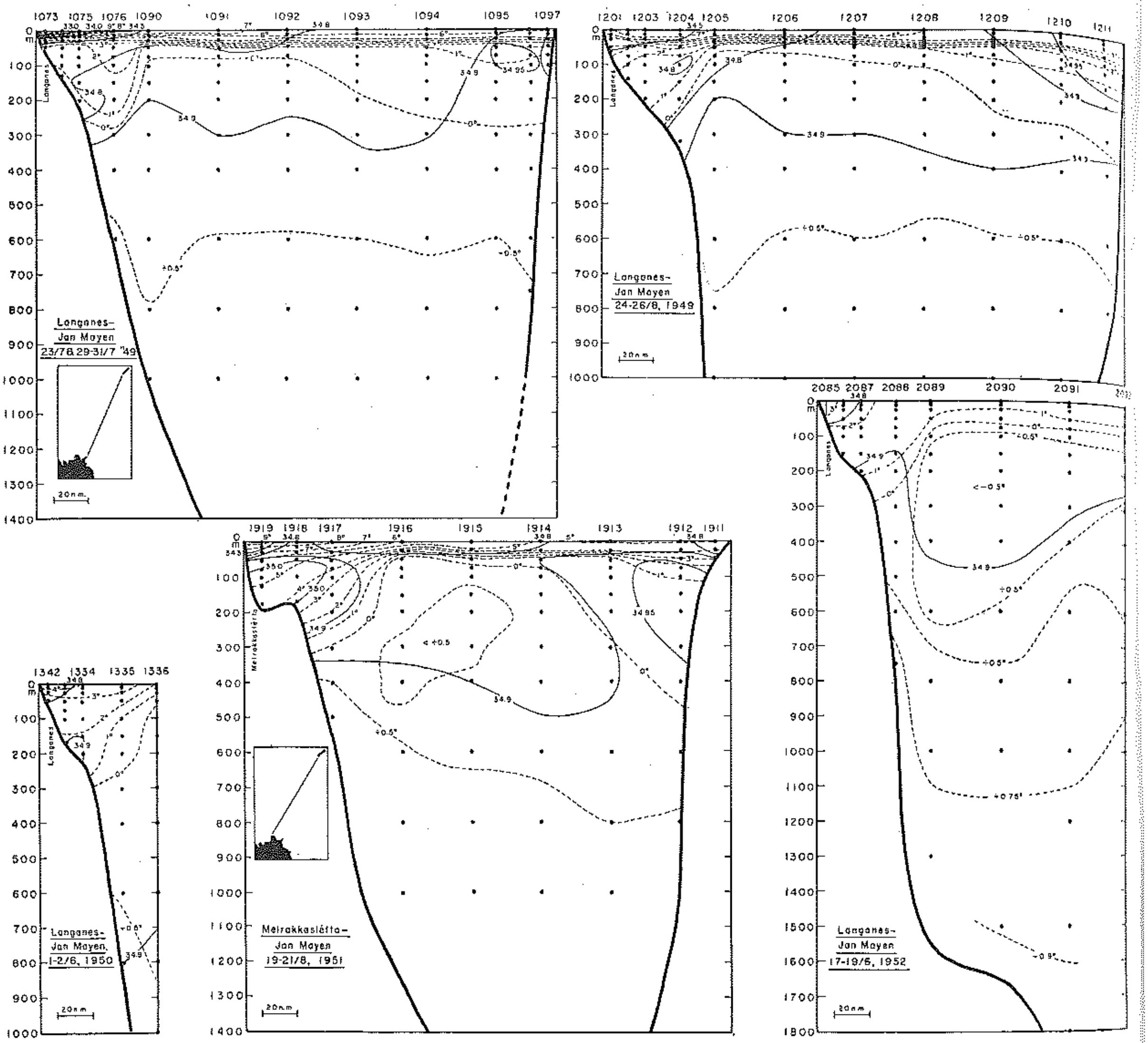


Fig. 67. *Hydrographic sections from Langanes toward Jan Mayen 1949, 1950 and 1952, and Melrakkaslétta toward Jan Mayen 1951.*

lantic influence was therefore very small. In the years 1954 and 1955, however, the Atlantic influx had obviously reached to this section, as judged by the relatively high temperature in the upper intermediate layers (3–4° in 50–150 meters) and the tongue of water with salinity above 34.9 ‰ or even above 35.0 ‰. Between 200 and 300 meters near the edge of the shelf the temperature drops to less than 1° and the 0° isotherm is found at 300–400 meters. In late summer Atlantic water is usually present in this section, although such was not the case in 1949 which was an unusually cold year.

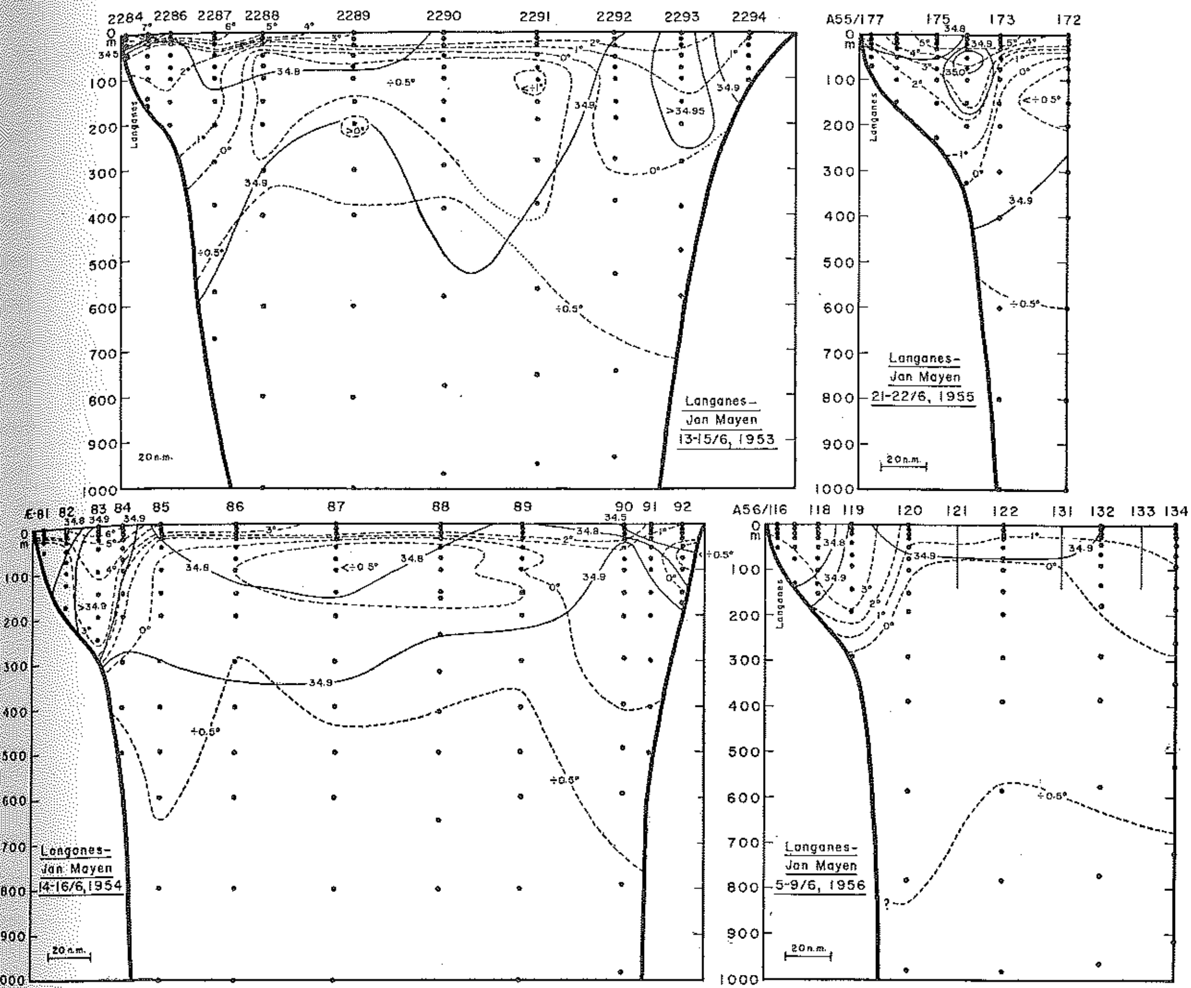


FIG. 68. *Hydrographic sections from Langanes toward Jan Mayen 1953—1956.*

In the tongue of cold Arctic water which occupies the upper layers over the deep basin northeast of Langanes the salinity is usually between 34.7‰ and 34.9‰. In summer a sharp thermocline will be developed in this region between 20 and 50 meters. At depths below 100 meters the temperature is less than 0°. On many of the sections a minimum with temperatures less than $-0.50°$ appears between 100 and 200 meters. The admixture of Polar water must, however, be slight as judged by the relatively high salinities found in this region. The core of the cold Arctic water is usually located some 100 miles northeast of Langanes. The influence of Arctic Intermediate water appears to be slight but yet recognizable in this section. Below 300 meters the presence of practically "pure" Arctic Bottom water is indicated.

Northeast of the tongue of cold water, warmer and more saline water is

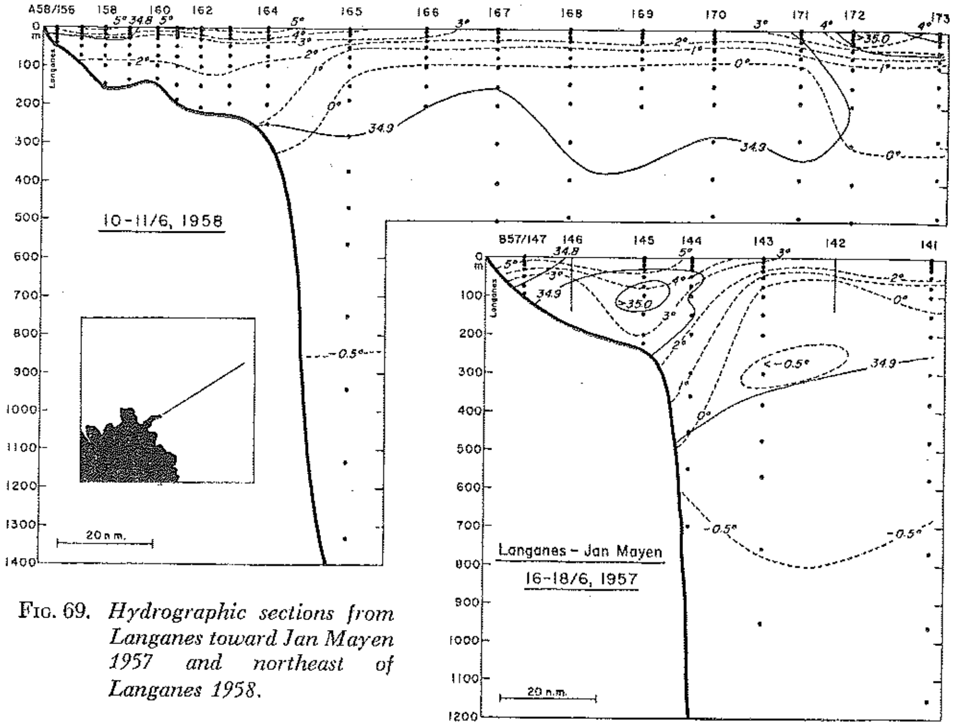


FIG. 69. *Hydrographic sections from Langanes toward Jan Mayen 1957 and northeast of Langanes 1958.*

found. As mentioned in a previous chapter this water must have come from the southeast. In this region, south of the Jan Mayen Bank, the salinity of the surface layer is so high that formation of deep water must take place during the coldest winter months. Since winter observations are lacking from this region, it is not known how deep the winter convection reaches, but it seems likely that in severe winters it reaches down to several hundred meters.

The section east of Langanes (Figs. 70–73) extends over the Bakkaflóadjúp and the northeastern flank of the shallow Vopnafjarðargrunn, from which the bottom slopes steeply to depths above 1000 meters. In this section conditions on the shelf are very similar to those found in the section Langanes–Jan Mayen. In June Atlantic water is not found in this section, but in late summer a tongue of this water usually extends from the Bakkaflóadjúp beyond the edge of the shelf. In the deep part of the section that extends beyond the slope, the cold Arctic water occupies the upper layers and extends to about 160 miles east of Langanes. From this position the upper layers become progressively warmer and more saline.

Fig. 74 shows the mean conditions in June and August at the first three stations of the section east of Langanes. The June section is based on the mean values from 8–11 years and the August section on the mean values from 15–18 years (see Appendix). The July mean section is not included as observations from only 4–5 years were available.

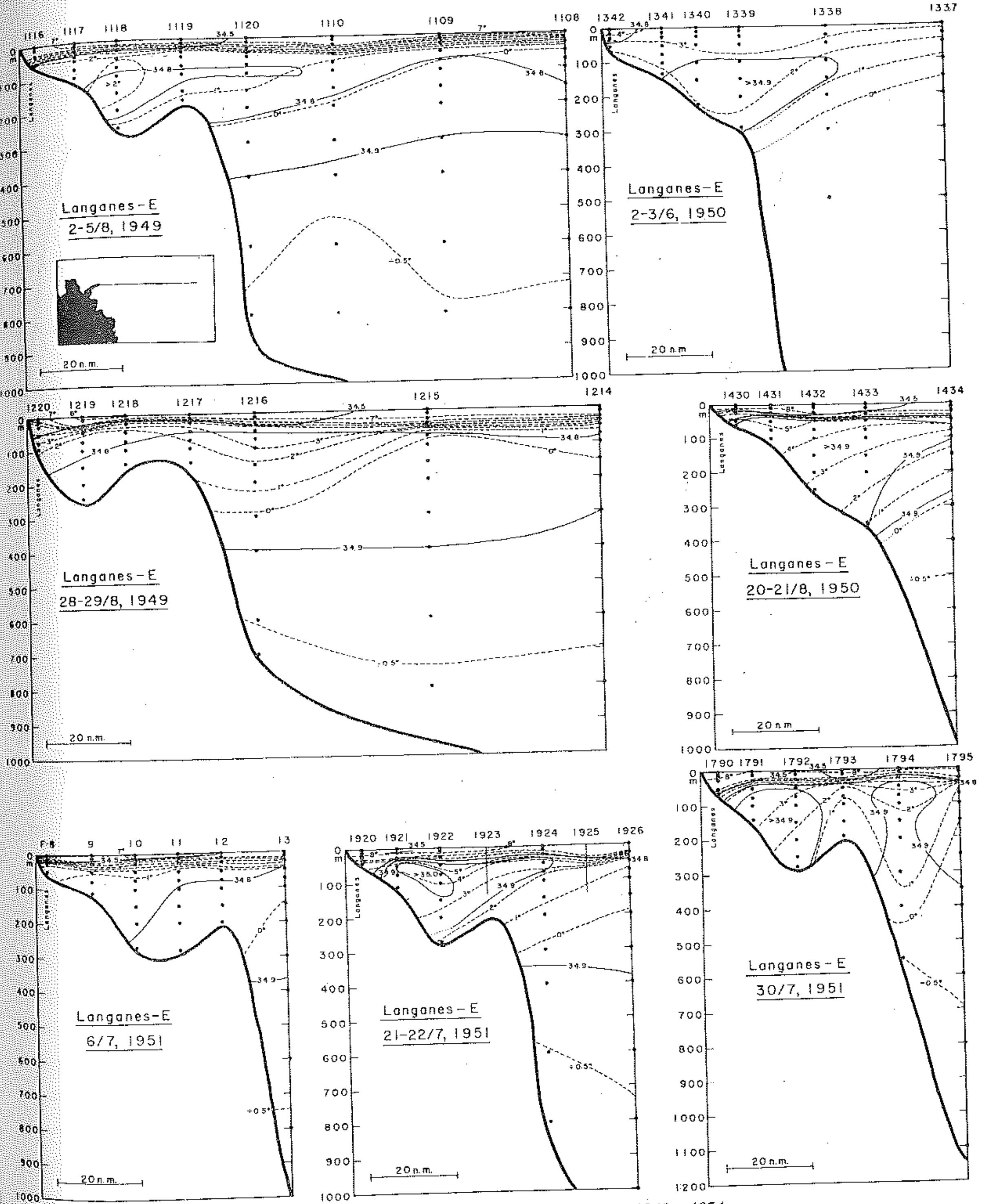


FIG. 70. *Hydrographic sections east of Langanes 1949—1951.*

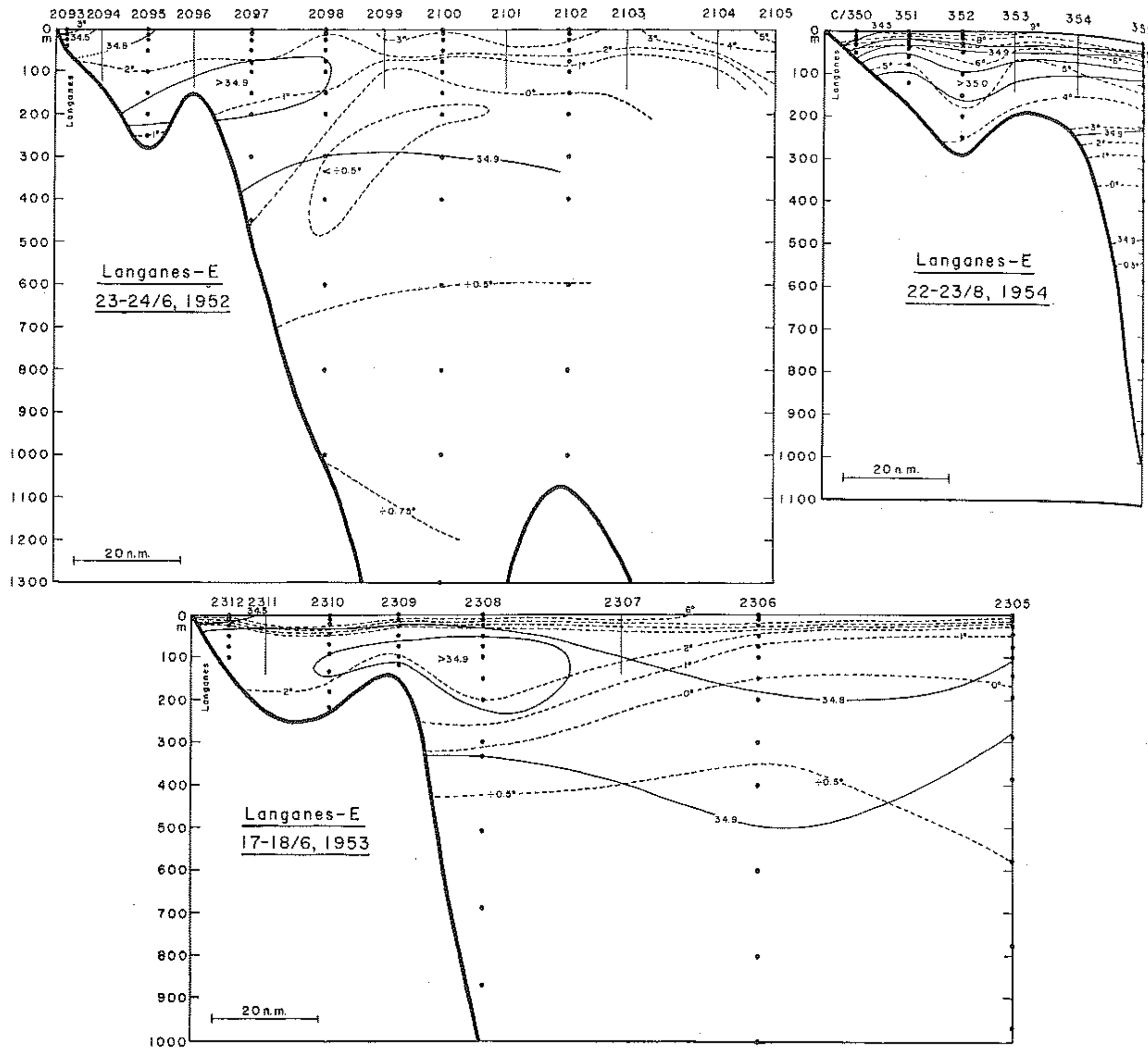
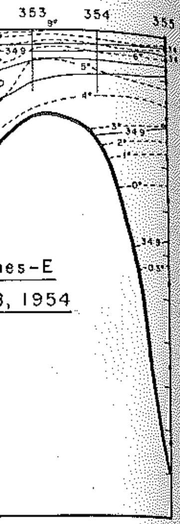


FIG. 71. *Hydrographic sections east of Langanes 1952—1954.*

In June the mean temperature is 3–5°C in the surface layers and 2–3° at depths between 50 and 200 meters. The salinity varies between 34.5 ‰ and 34.8 ‰ in the surface layers, but lies between 34.8 ‰ and 34.9 ‰ at subsurface depths. By August a marked stratification has been established in the surface layers, with a distinctly greater distribution of Coastal water than in June. Between 50 and 150 meters the mean temperature is 4–5° and at 150–200 meters 3–4°. The tongue of water with salinity 34.95–35.0 ‰ indicates a pronounced influence of Atlantic water.



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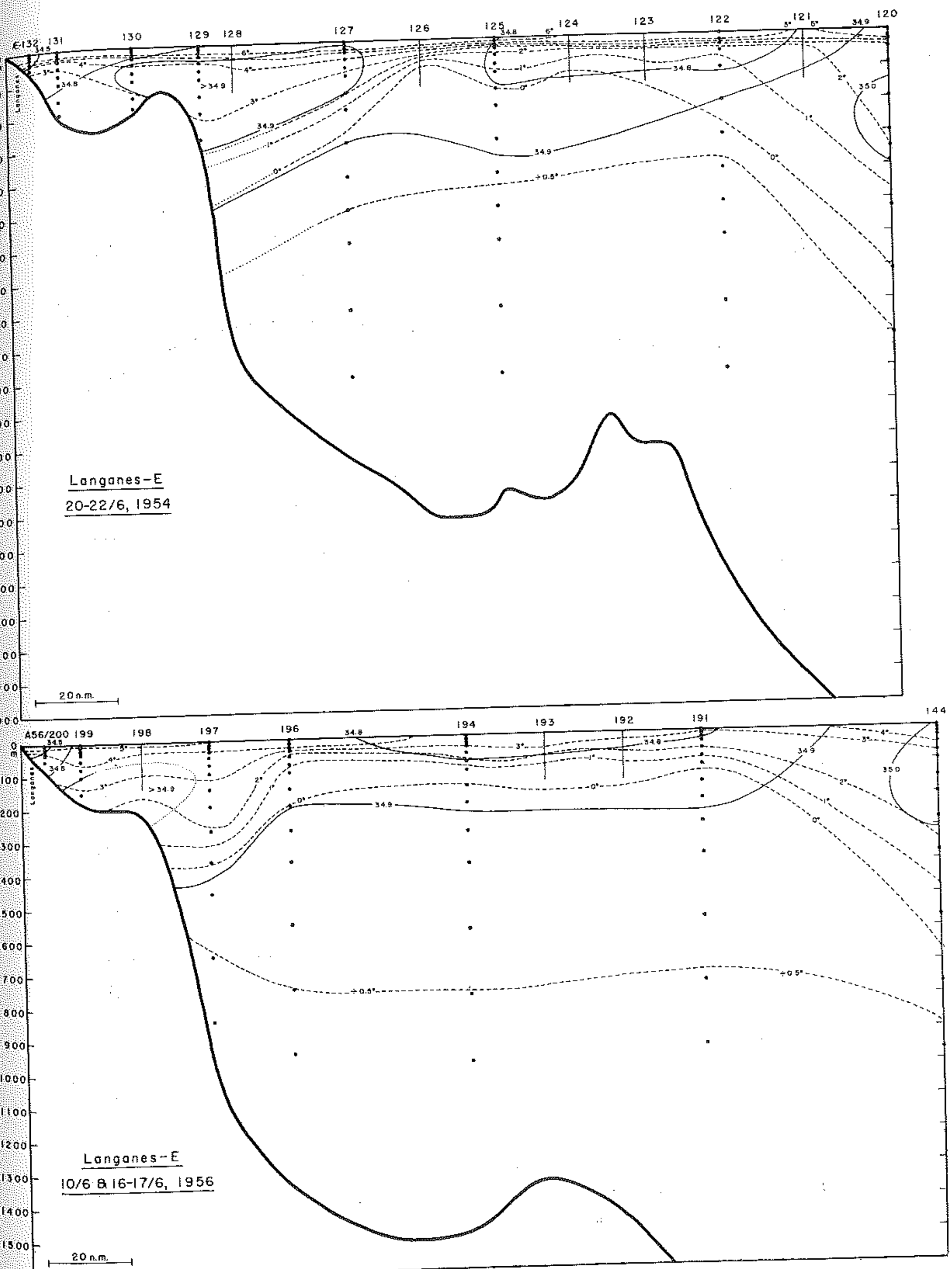

Fig. 72. *Hydrographic sections east of Langanes 1954 and 1956.*

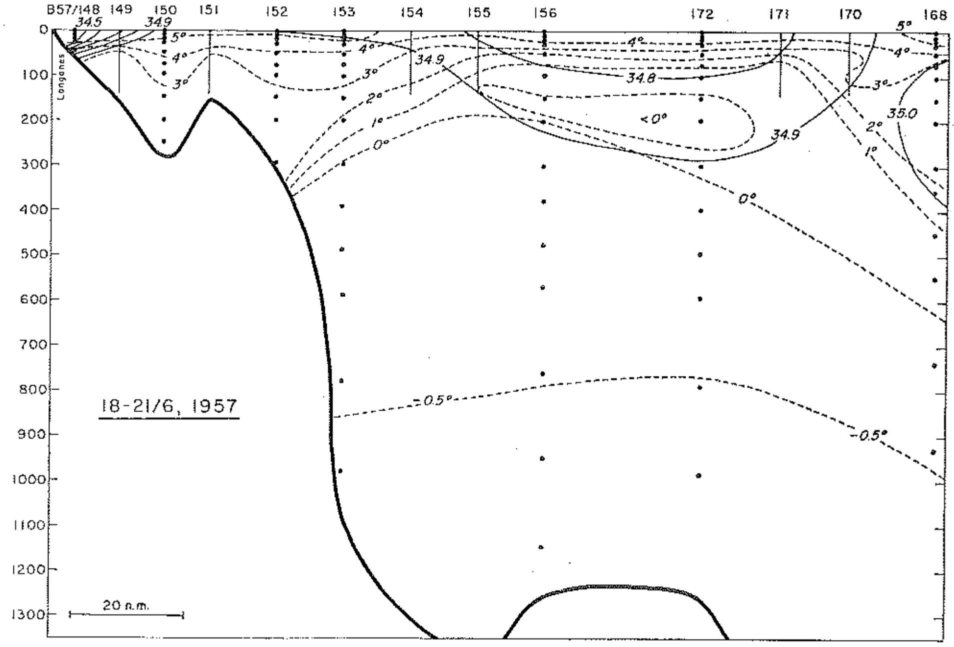

Fig. 73. *Hydrographic section east of Langanes 1957.*

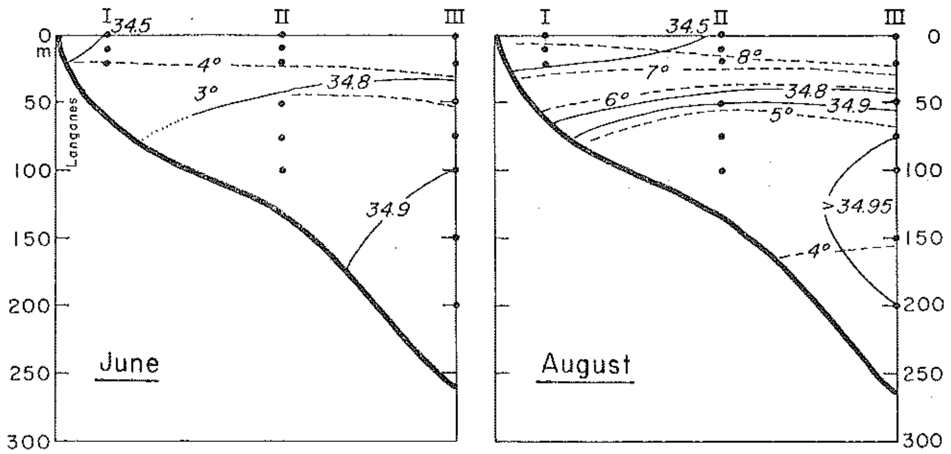

Fig. 74. *Mean temperature and salinity in the section off Langanes for June and August.*

g) The Region South of Langanes.

In the region between Langanes and Gerpir few sections have been worked across the shelf. The material at hand, however, indicates that in this area the Atlantic influence is similar or less than east of Langanes. Fig. 75 shows a section east of Seyðisfjörður (Dalatangi) in June 1958. Comparison with the section east of Langanes worked 2 days earlier (Fig. 69) shows that the hydro-

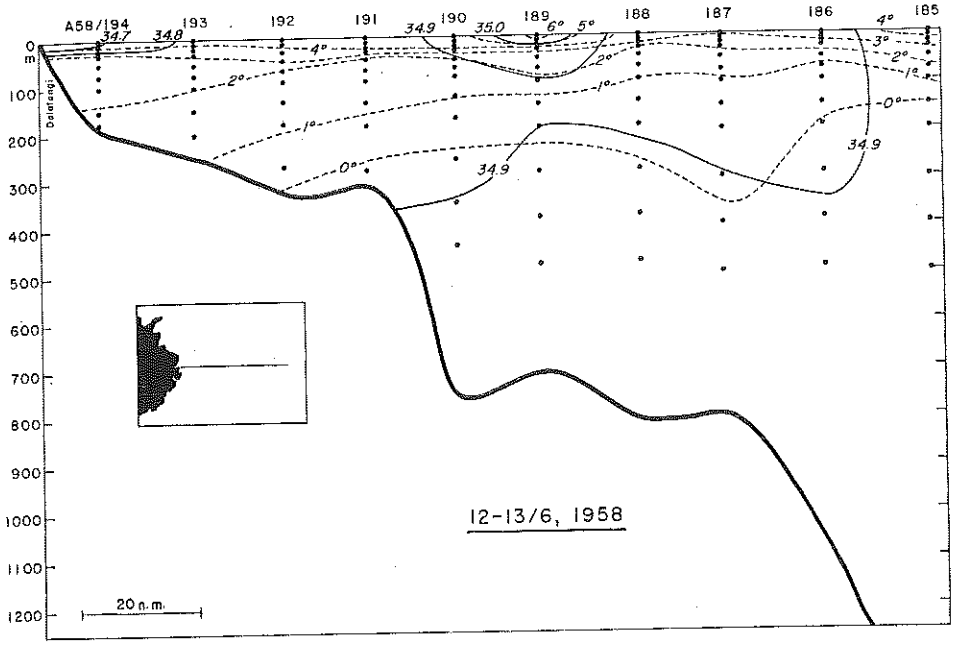

Fig. 75. *Hydrographic section east of Seyðisfjörður 1958.*

graphic conditions were quite similar in both of these sections. However, the section east of Seyðisfjörður worked by the Danish research vessel "Dana" at the end of July 1948 shows definitely lower subsurface temperatures than were found east of Langanes 2 days earlier (Hermann 1948 *b*). Still farther south, in the region east of Eystrahorn, lies the very sharp boundary of the Atlantic water. As seen on the horizontal charts this boundary bends towards northeast and may reach as far north as Seyðifjörður. This explains the tongue of warm and saline water found in the surface layers between stations 188 and 190 in Fig. 75.

In the preceding discussion it has been shown how the North Icelandic Irminger Current, which enters the Iceland Sea northwest of the country, is gradually cooled and diluted on its passage along the insular shelf. This Atlantic water which at the entrance gate is in a practically undiluted state leaves the shelf region east of Iceland after having lost most of its original character.

IX.

TEMPERATURE-SALINITY RELATIONS IN SPRING AND SUMMER[1]

Oceanographically the Iceland Sea is a unique sea area. Just like the country whose name it bears, it is a region of great contrasts where water masses of the most diverse character meet and mix. Here the warm and saline water from the vast ocean in the south meets the ice-cold polar water from the distant north. In some parts there are sharply defined boundaries, both horizontal and vertical, where the physical conditions may change radically within a short distance. In other parts where the changes are more gradual intermixing gives rise to new water masses of peculiar character which again may be modified as the result of various external factors during the different seasons of the year.

1. THE t, S CHARACTERISTICS IN DIFFERENT PARTS OF THE ICELAND SEA

The distinctive features of the water masses mentioned in chapter V are best illustrated by means of their t, S relations. Fig. 76 shows 4 typical t, S diagrams for stations worked in different parts of the region outside the Icelandic submarine shelf. The positions of the stations are indicated on the inset map. The triangle shown in the picture is formed by connecting the extreme t, S values for the three primary water masses, the Atlantic, the Polar and the Arctic Bottom water. Except for a thin surface layer which is affected by dilution from land, evaporation, precipitation, summer heating and/or ice melting, all t, S curves fall within this triangle.

The characteristics of the inflowing Atlantic water are clearly represented by curve *a* (St. 101, 14/6 1959). The surface layer had only slightly warmed up, but a thermocline had not developed. At this station which is located on the

1) Parts of this chapter were presented at the ICES meetings, Moscow, October 1960, as two papers entitled:

C.M. 1960, No. 96. "The North Icelandic Winter water".

No. 95. "A note on the overflow of North Icelandic Winter water across the Iceland-Faroe Ridge".

south side of the Iceland–Greenland Ridge, practically "pure" Atlantic water is found in the uppermost 350 meters. At greater depths an admixture of deep Arctic water is indicated whereby the salinity is lowered.

Curve *b* (St. Æ–47, 9/6 1954) illustrates the typical Polar water of the East Greenland Current. In the surface layers the salinity is lowered by the melting of ice, but it increases rapidly downwards. The uppermost 20 meters have been slightly heated by the sun, but at about 30 meters a temperature minimum of about —1.7°C is found. Farther down the temperature again increases to more than 0° between 200 and 300 meters. Taking 0° as the limit of the Polar water at subsurface depths, its thickness is found to be between 200 and 300 meters at

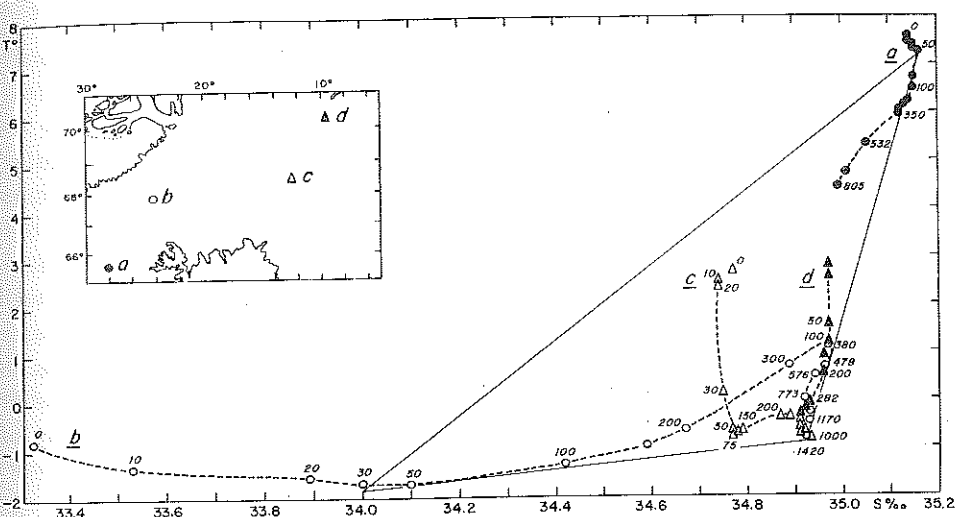

FIG. 76. *Typical t, S diagrams from the area between Iceland, Greenland and Jan Mayen and just south of the Iceland–Greenland Ridge.*

this station. At 380 meters there is another point of inflection on the curve at the core of the Arctic Intermediate water. It is noticeable that there is no direct mixing between Polar water and Arctic Bottom water at this station and the same applies to other parts of the Iceland Sea as well. Below 380 meters the temperature decreases and reaches 0° at 773 meters. The water between 380 and 773 meters is thus essentially a mixture of Arctic Intermediate water and Arctic Bottom water.

Curve *c* (St. Æ–87, 15/6 1954) represents the conditions typical for the tongue of cold water northeast of Iceland. Here the upper layers consist of Arctic water, but the concentration of "true" Polar water appears very small. This water with low temperature (below —0.5°) but relatively high salinity between 50 and 150 meters, must largely be formed outside the region of typical Polar water, probably in the area north of Jan Mayen, by intermixing of Atlantic water and Polar water from the Jan Mayen Polar Current (cf. HELLAND-HANSEN and NANSEN 1909, p. 319). It seems likely that this Arctic water has acquired its low temperature by cooling of the sea surface and vertical circulation during the previous winter. By heating at the sea surface the temperature is raised in the surface layers. Between 150 and 300 meters the t, S diagram *c* bends a trifle upwards indicating a slight influence of Arctic Intermediate water. Below 400 meters Arctic Bottom water is found. It is seen that the temperature maximum at station Æ–47 (see curve *b*, Fig. 76) occurs at 380 meters, but between 200 and 300 meters at station Æ–87. Furthermore, the water found at 1170 meters at station Æ–47 is essentially the same as that found at 400 meters at station Æ–87, and the water present at 1420 meters at Æ–47 is of the same character as found at 1000 meters at Æ–87. In the western part of the Iceland Sea the isopycnals thus slope from east to west.

Finally, consider curve *d* (St. 2293, 15/6 1953) which represents the conditions typical for the region south and southeast of Jan Mayen. Here the relatively high salinity is due to admixture of Atlantic water from the east or the southeast. The surface layers at this station could easily form the Arctic Intermediate layers observed farther west in the Iceland Sea. With sufficient winter cooling the surface layers could also contribute to the formation of Arctic Bottom water. No trace of Polar water was observed at this station at this time, but in some other years (e.g. June 1954) the presence of Polar water has been observed in the surface layers in this region. At 100 meters on curve *d* the same water is found as at 380 meters on curve *b*. At depths below 773 meters on curve *b*, below 400 meters on *c* and 282 meters on *d* practically the same water mass is found on all three curves which illustrates the great homogeneity of the deep water.

2. TEMPERATURE-SALINITY RELATIONS IN THE SHELF REGION

The Atlantic water which enters the Iceland Sea from the southwest, will in the surface layers be subjected to various influences. First of all, it will be affected by meteorolgical factors, i.e. air temperature, precipitation and evaporation, whereby the water temperature and the salinity may be changed. In spring and summer the heating effect from above will be particularly apparent, so that the water above the thermocline usually has a t, S relation entirely different from that of the water at intermediate depths. In the northern North Atlantic precipitation is in general in excess of evaporation (Wüst 1954). Hence the surface salinity will be lowered. Mixing with the coastal water will always reduce the salinity of the Atlantic water and its temperature may also be changed, provided that the temperature of the coastal water is different from that of the Atlantic water. North of the main Atlantic flow the polar influence will become apparent and progressively increase as we move farther to the north. Mixing with the Polar water will naturally lower the temperature as

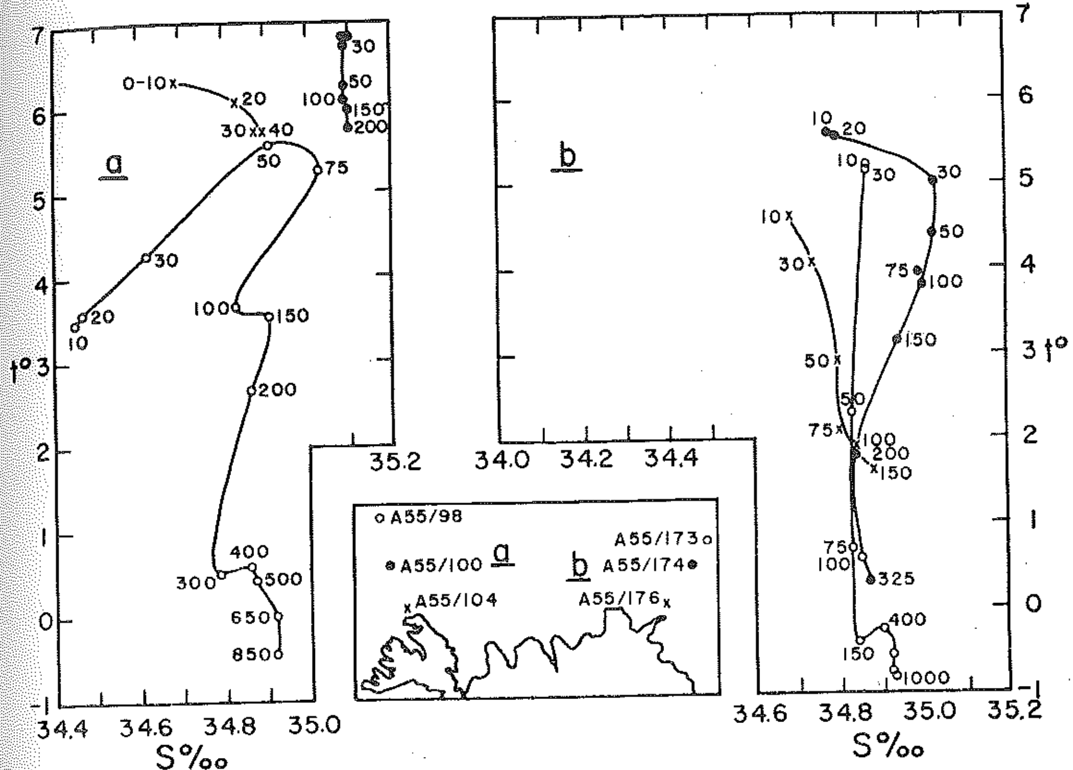

Fig. 77. *Typical t, S diagrams from two cross-sections of the North Icelandic Irminger Current.*

well as the salinity of the Atlantic water. During summer the Polar water will be heated by the sun and diluted by ice melting. The mixture between the Polar water and the Atlantic water may therefore be of a very variable composition.

Below the surface layers the mixing processes will be less complex. Here the Atlantic water will be nearly unaffected by meteorological factors, and mixing with Coastal or Polar water less extensive, although still apparent. In the central part of the Irminger water the coastal and the polar influences will be at a minimum. This is clearly seen in Fig. 77 which illustrates typical t, S diagrams from two cross-sections of the North Icelandic Irminger Current.

In Fig. 77 a the t, S diagram of the intermediate station represents almost homogeneous Atlantic water from surface to bottom. At the coastal station the salinity of the inflowing Atlantic water has been lowered by more than 0.2 ‰, and the surface temperature is also somewhat lower than farther offshore. At station A 55/98 the surface layers are composed of a mixture of Atlantic water and Polar water, the Atlantic component increasing downwards. Between 75 and 300 meters the polar influence is hardly noticeable, except at 100 meters. The water mass at 300 meters, with $t = 0.5°C$ and $S = 34.80$ ‰ is probably formed as the result of mixing of Polar water and Arctic Intermediate water.

The water between 75 and 300 meters might therefore be a mixture of Atlantic water and this afore-mentioned water mass. It is also possible that the intermediate layers down to about 200 meters consist of a mixture of Atlantic water and winter-cooled water. Below 300 meters the Arctic Intermediate water causes an upward sweep of the t, S curve which again bends downwards as the result of mixing with Arctic Bottom water.

In Fig. 77 b the maximum salinities are also found at the intermediate station. However, the water is distinctly more stratified than in the section off Kög-

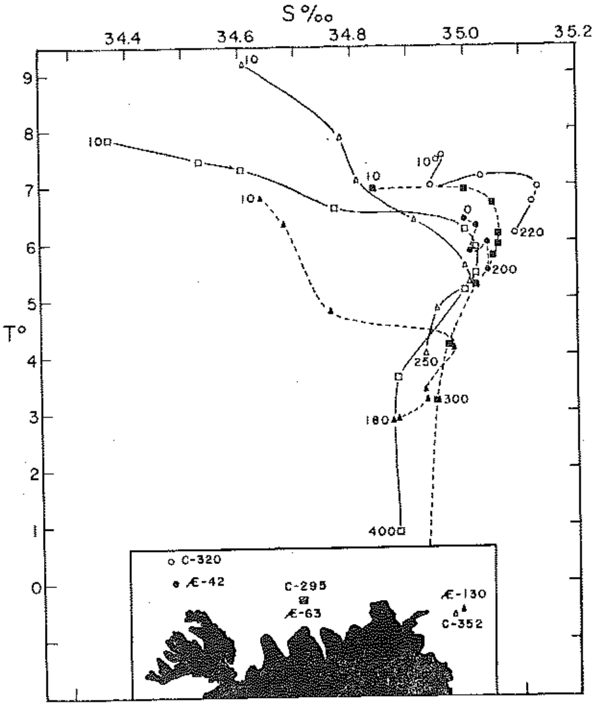

FIG. 78. *Typical t, S diagrams from a longitudinal section of the North Icelandic Irminger Current.*

ur (Fig. 77 a). The points representing the t, S values at 50, 75, 100, 150 and 200 meters roughly fall on a straight line, thus indicating a mixture of Atlantic water with a water mass having the characteristics t = 1.8°, S = 34.84 ‰. On the other hand, at depths exceeding 200 meters the t, S curve bends towards the right, indicating a mixture of the intermediate water found at 200 meters and Arctic Bottom water. At the coastal station the surface layers are decidedly fresher and colder than in the core of the east-flowing Atlantic water, in agreement with the findings off Kögur. At subsurface depths the two curves intersect. Thus the same water mass appears to be present at 100 meters at station A 55/176 and at 200 meters at station A 55/174. Station A 55/173 consists in the upper layers of Arctic water quite uniform in salinity, but the summer

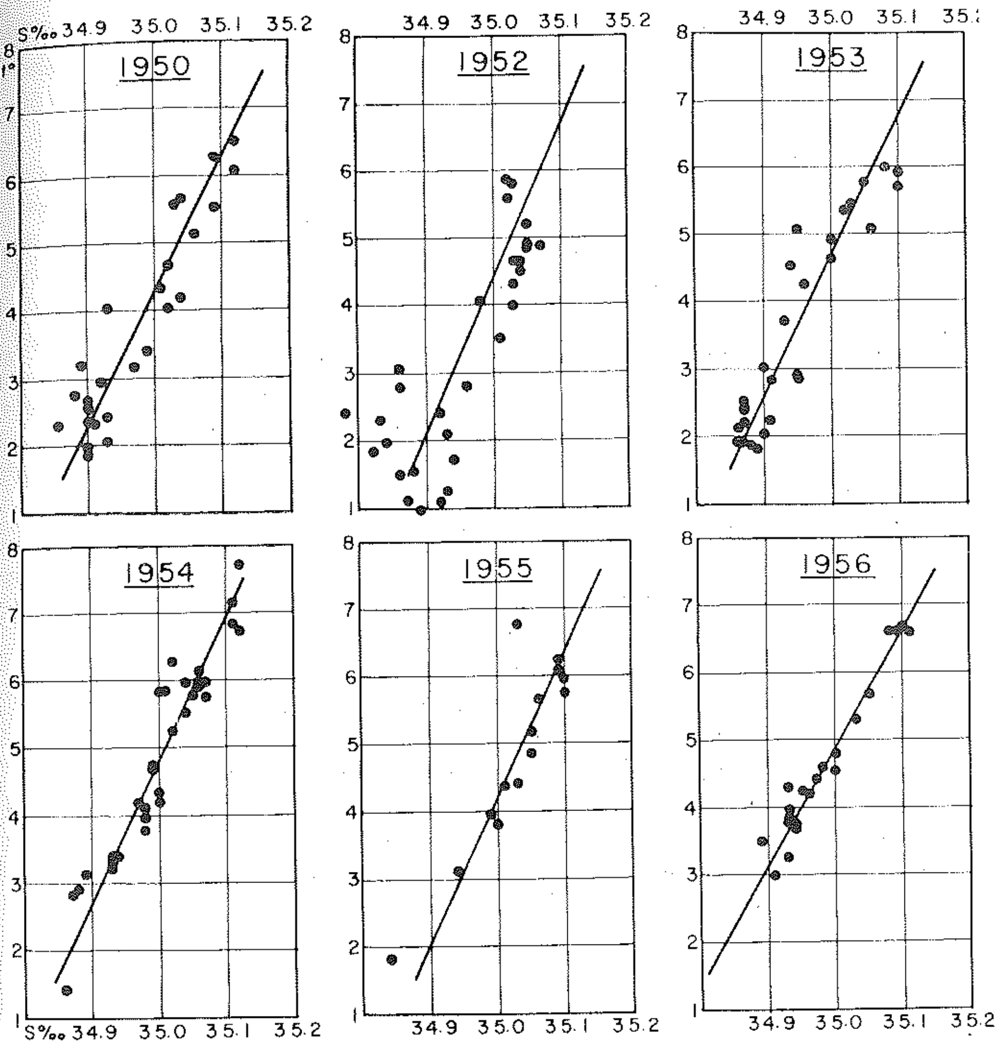

FIG. 79. *The t, S relations for 50—250 meters of stations located near the core of the North Icelandic Irminger Current in May–June 1950 and June 1952—1956.*

heating has raised the temperature near the surface. At 100 to 150 meters a temperature minimum is present. The temperature rise at 400 meters indicates the presence of Arctic Intermediate water, as was observed for station A 55/98. In the shelf region, however, Arctic Intermediate water has not been observed.

Typical t, S curves from a longitudinal section of the North Icelandic Irminger Current are shown in Fig. 78. Here the intermediate water appears to consist of two components only, as the observed temperature and salinity values roughly fall on a straight line. Such a relation holds approximately for the most part of the North Icelandic submarine terrace, with the exception of the shallowest part of the coastal area inside the 200 meter depth contour.

It was decided to investigate this relation in more detail. A preliminary study revealed that the linear relation particularly holds true in spring and early summer, when it generally applies to the depth interval between 50 and 250 meters.

Fairly extensive data exist for late May and June during 1950, 1952 and the subsequent years. The material from the years 1950 and 1952–1956 was chosen for the study of the temperature-salinity relations at the beginning of summer. To avoid as far as possible the coastal and polar influences, the study was limited to the material from stations located near the core of the North Icelandic Irminger Current. From each of the different sections off the coast, the station with the highest salinities at intermediate depths was selected. These stations were found to be inside the region shown on the inset map in Fig. 80. The location of the stations with different notations for the various years is also shown on the map. The t, S relations for 50–250 meters in the six years are shown in Fig. 79.

With the exception of the 1952–material, there exists a distinct linear relation between the temperature and the salinity. The correlation coefficient between temperature and salinity was found to be about 0.9 (see Table 2), which with this number of observations is a highly significant correlation. Regression equations in the form $S\,‰ = a + bt°$ were calculated for the different years, and the values of the constants a and b are given in Table 2. It seems remarkable indeed how similar the regression coefficients are for the different years. This similarity definitely suggests that the intermediate layers north of Iceland are at the beginning of summer composed of two water masses which only differ slightly from one year to another.

However, as the variances about the regression lines (s_i^2) differ significantly, the material can not be considered homogeneous. Therefore, it would not be strictly correct to combine all the observations from the six years and from them calculate a common regression equation. To derive an estimated normal regression line the different variations involved and their relative ef-

TABLE 2.

Regression analysis. Salinity as a function of temperature at intermediate depths north of Iceland in June.

Year	No. of Observ. N_i	a_i	b_i	Variance ($s_i^2 \times 10^2$)	Coefficient of Correlation (ϱ t, S)
1950	26	34.786	0.0502	0.0963	0.92
1952	30	34.810	0.0434	0.2686	0.81
1953	29	34.774	0.0487	0.0852	0.93
1954	33	34.771	0.0476	0.0548	0.95
1955	14	34.806	0.0457	0.0983	0.88
1956	21	34.721	0.0565	0.0242	0.97

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0.93
0.95
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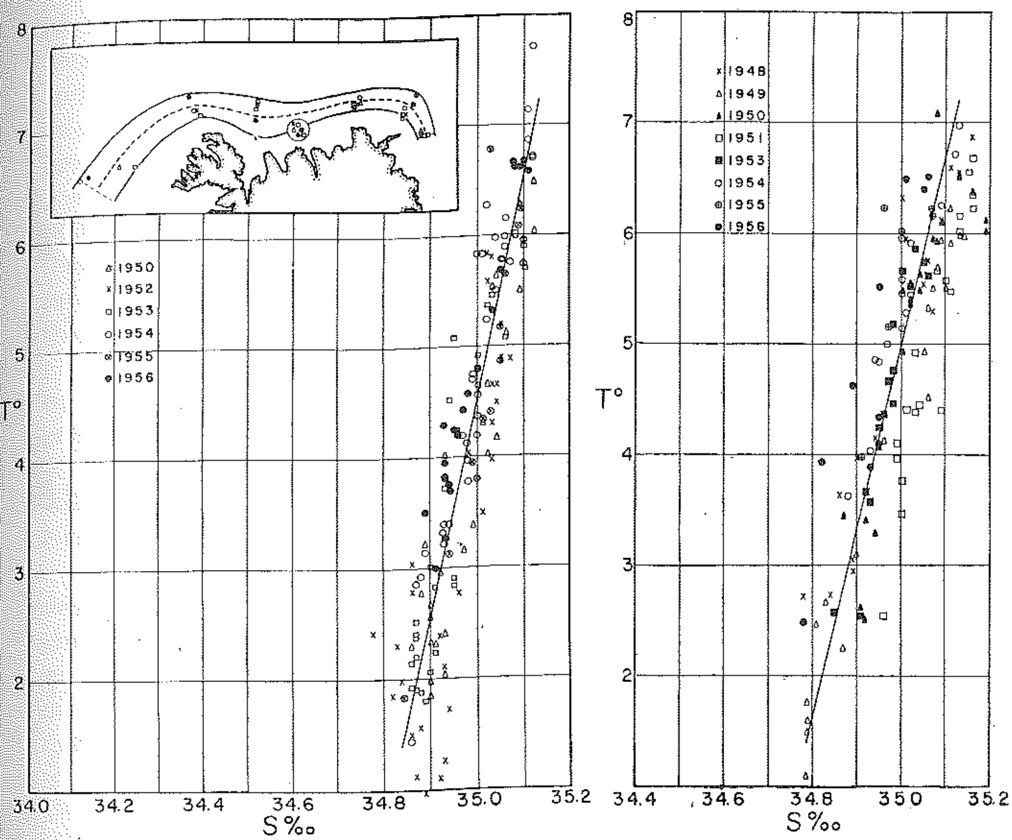

FIG. 80. *Temperature-salinity values from the longitudinal section shown on the inset map. The scatter diagram at left shows values for June from the depth interval 50—250 meters, the one at right shows values for August, from the depth interval 100—300 meters. The straight lines shown are the estimated normal regression lines.*

fects on the regression coefficients, were weighted.[1] From these considerations the following normal regression line was derived for June:

$$S‰ = 34.77 + 0.0501 \cdot t°.$$

The salinity values calculated from this equation will have an estimated standard deviation of 0.037 ‰ at 4° and 0.039 ‰ at 7°. Hence the probability of estimating the salinity within 0.10 ‰ ought to be at least 95%.

The total of 153 observations from the six years is shown in Fig. 80. The straight line is the estimated normal regression line. With the exception of only few points the t, S values fall within two times the standard deviation. The linear relationship appears to hold between about 1.4° and 7.2°C, whereas the

1) See Appendix, p. 251.

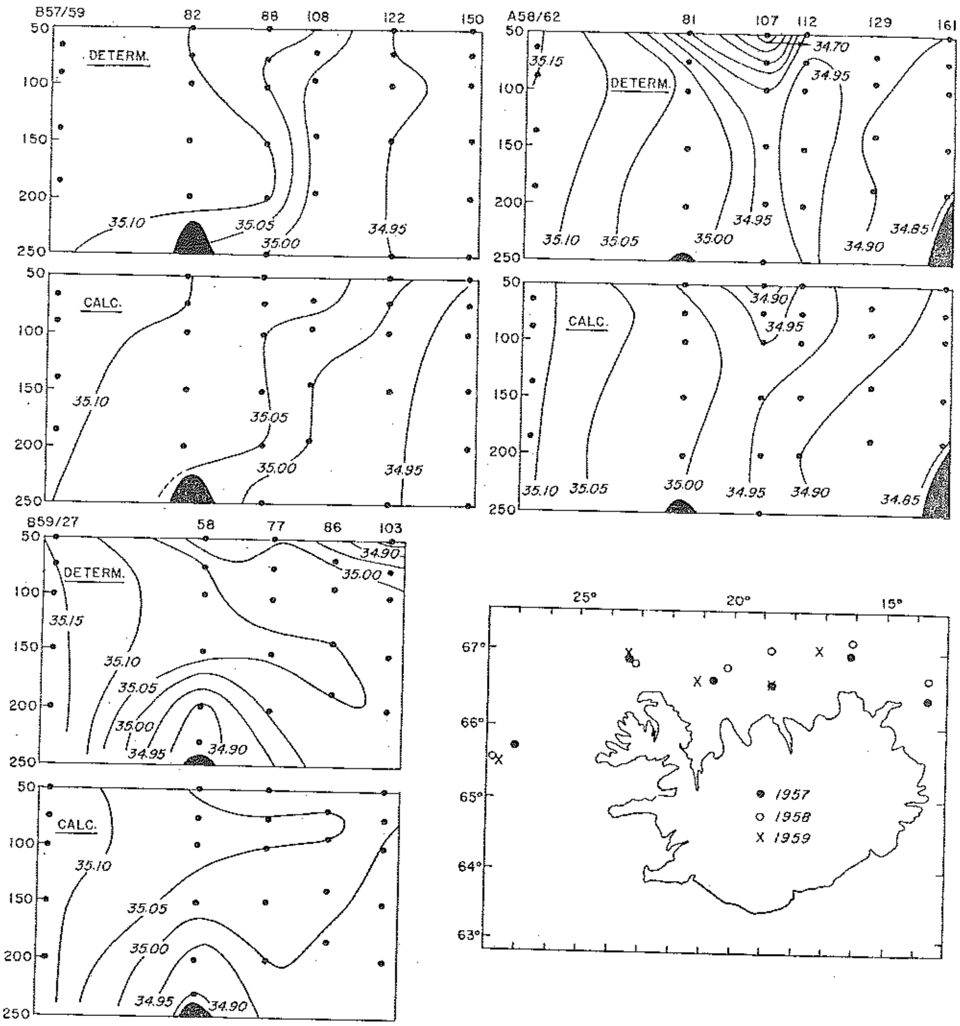

FIG. 81. *The observed and the calculated salinity distribution in a longitudinal section of the North Icelandic Irminger Current in June 1957 (top left), 1958 (top right) and 1959 (below).*

few points below 1.4° indicate an admixture with Arctic Bottom water. Below the thermocline the temperature within this region rarely exceeds 7.2°C, which thus forms the upper limit of the linear t, S curves.

3. PRACTICAL APPLICATION OF THE ESTIMATED NORMAL REGRESSION EQUATION

By means of the estimated normal regression equation it is possible with a fair degree of reliability to predict the salinity at intermediate depths from the temperature distribution. Examples of this application are shown in Fig. 81

which illustrates the observed and the calculated salinity distribution in a longitudinal section of the North Icelandic Irminger Current in June 1957, 1958 and 1959. It is seen that a reasonably good agreement was found between the calculated and the observed distributions, especially in 1957. In certain regions, however, in 1958 and 1959 the calculated values deviated appreciably from the true ones at 50–100 meters depth. In 1958 this was due to an influence of a third water mass, viz. Polar water. Thus in heavy ice years the simple t, S relationship may no longer be valid. In 1959 the deviations could be ascribed to mixing with surface water. In other regions and generally below 100 meters, the deviations do not greatly exceed the uncertainty in the salinity titrations.

This application may be of practical importance, such as during herring survey cruises in the area north of Iceland when information on the hydrographic conditions is desired as quickly as possible and a sea-going salinometer is not available. On the basis of temperature data alone, an almost immediate answer can be given in such cases as to the extension of Atlantic water on the North Icelandic herring grounds.

Another obvious application of the well-defined t, S relation at intermediate depths is the determination of density at BT stations between the regular hydrographic stations. However, it should be kept in mind that the estimated normal regression equation applies to the core of the Atlantic water; in other parts of the North Icelandic submarine terrace the linear relation holds only approximately true.

4. ORIGIN OF THE WATER COMPONENT AT INTERMEDIATE DEPTHS MIXING WITH ATLANTIC WATER

In the foregoing discussion we have seen that along the north coast of Iceland in early summer the inflowing Atlantic water gradually mixes in the intermediate layers with a water mass of 1.5°–2°C temperature and 34.82 — 34.90 ‰ salinity. Now let us consider the origin of this water mass.

A direct mixing of Atlantic water with Polar or Coastal water would certainly not result in the t, S relation observed. On the contrary, deviations from the linear relation found at the core of the east-flowing Irminger water were interpreted as being due to admixture of either of the two water masses, Polar or Coastal water. In the case of intermixing between Atlantic water and Arctic Intermediate water the t, S values would be distributed about a straight line between the points $t = 7.2°$, $S = 35.13$ ‰ and $t = 1–2°$, $S = 34.90–34.95$ ‰. Such a line would deviate significantly from the regression lines found for the various years. The water mass mixing with the Atlantic water might be generated by the intermingling of the Polar water with the Arctic Intermediate water. Such a mixture indeed exists off the western part of the North Icelandic shelf, in a thin layer at the boundary between the Polar water and the Arctic Intermediate water, usually in the depth interval 100–150 meters or 150–200 meters. The

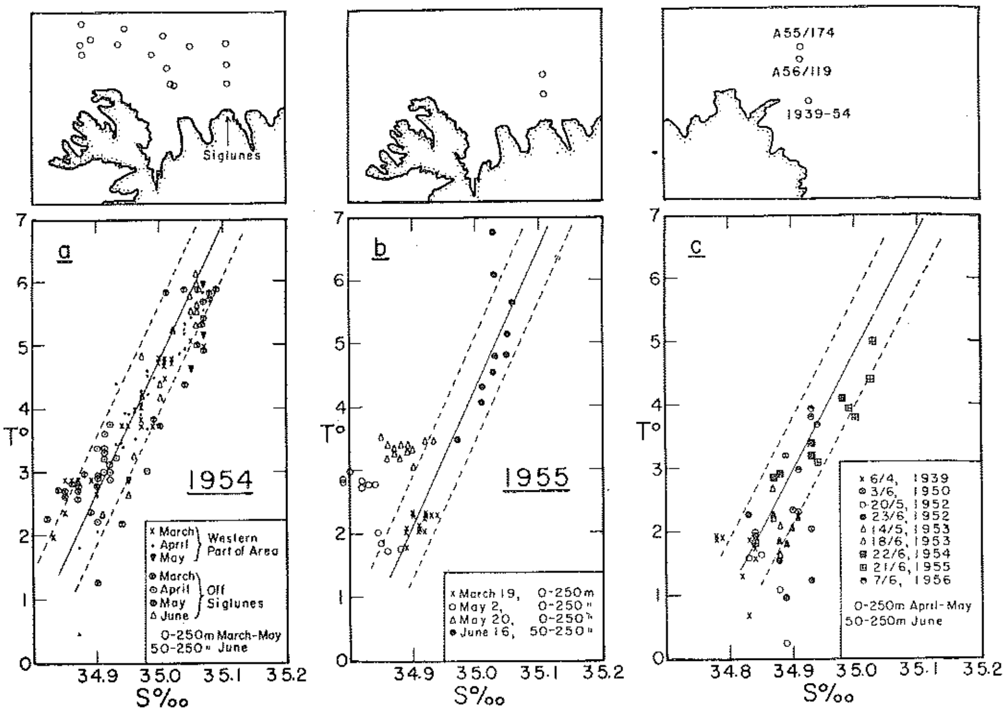

FIG. 82. *The t, S values at various localities north of Iceland during the months March to June.*

Atlantic water moving eastwards at a relatively great velocity over the slope will certainly be subjected to various mixing processes on its way and carry with it mixed Polar and Arctic water. However, if the t, S relation found along the north coast near the core of the Atlantic water resulted from a mixture of Atlantic water with Arctic Intermediate and Polar water, we would hardly expect to find an almost linear t, S relation, as indicated in Fig. 80, changing only slightly from one year to another. It would therefore seem more likely that the observed temperature-salinity characteristic of the component mixing with the Atlantic water is associated with a large-scale homogenizing process such as takes place in late winter.

A study was therefore made of the t, S relation in late winter and spring to see if it resembled that found in June. To avoid as far as possible the coastal influence, stations inside the 200 meter depth contour were not included in this study.

In Fig. 82 a are shown the t, S values at various localities off the middle and western part of the coast during the months March to June 1954. It is evident from the figure that the nearly homogeneous water mass found in late March and late April off Siglunes has the t, S value required to produce with Atlantic water the mixture represented by the t, S regression line for June 1954. In the western part of the area the t, S values also follow the regression line rather

TABLE 3.

Percentage saturation of oxygen[1]) in 100 and 200 meters at a few typical stations northwest and north of Iceland.

Station	Date	Position		Depth to Bottom	Observation Depth	t°	S‰	O_2% Saturation
		Lat.	Long.					
Æ-46	9/6 1954	67° 40′	24° 02′	1260	100 200	–1.05 0.46	34.63 34.83	95.9 94.8
A-55-97	12/6 1955	67° 48′	24° 12′	1370	100 200	–1.51 –0.72	33.92 34.59	94.0 92.9
A-56-99	4/6 1956	67° 55′	18° 51′	1015	100 200	0.24 0.16	34.80 34.88	98.5 94.0
B-59-93	23/6 1959	67° 57′	18° 52′	1000	100 200	0.20 1.04	34.84 34.96	97.2 93.0
B-59-95	23/6 1959	68° 11′	18° 53′	1110	100 200	–1.27 1.06	34.57 34.96	93.3 92.2
Æ-42	9/6 1954	66° 50′	23° 19′	236	100 200	5.84 5.50	35.01 35.04	100.7 100.8
Æ-63	11/6 1954	66° 32′	18° 50′	480	100 200	5.78 4.20	35.05 34.97	100.6 100.0
Æ-84	14/6 1954	67° 02′	14° 00′	520	100 200	2.88 1.06	34.93 34.86	99.5 (97.0)
A-55-100	13/6 1955	67° 06′	23° 42′	220	100 200	6.08 5.74	35.09 35.10	(97.4) (99.7)
A-55-132	16/6 1955	66° 32′	18° 50′	430	100 200	5.17 4.34	35.05 35.01	101.3 (103.8)
A-56-64	30/5 1956	65° 42′	28° 11′	800	100 200	6.67 6.58	35.10 35.11	100.2 100.4
A-56-93	3/6 1956	66° 32′	18° 50′	420	100 200	4.20 3.12	34.96 34.93	104.4 101.4
A-56-119	7/6 1956	66° 56′	13° 50′	298	100 200	3.79 2.70	34.93 34.91	104.1 98.9
B-59-39	14/6 1959	65° 30′	26° 55′	310	100 200	6.55 6.22	35.14 35.15	100.3 98.3
B-59-68	20/6 1959	66° 51′	20° 58′	195	100 185	5.49 4.11	34.96 34.99	105.0 98.3
B-59-86	22/6 1959	66° 32′	18° 50′	470	100 200	5.53 4.32	35.03 35.06	104.2 100.3
B-59-103	23/6 1959	67° 02′	17° 10′	300	100 200	4.41 4.11	35.02 35.04	101.5 99.7

1) The saturation values were determined according to Truesdale and Gameson (1957).

closely, the Atlantic component increasing progressively from east to west. In Fig. 82b the March values are also grouped about the regression line for June 1955, but the t, S values for May that year are displaced outside the probable range and the low salinity indicates an admixture of Coastal water. Had observations been available farther offshore in May it seems likely that a better agreement with the regression line would have been obtained. Fig. 82c shows the t, S values at a station east of Langanes during the spring months of the years 1939, 1950, 1952, 1953 and 1954 and at nearby stations northeast of Langanes in 1955 and 1956. Here also the figure gives the general impression that off Langanes the same water masses are found in April and June. It should be remarked here that in late May 1934 and late March 1938 the subsurface layers of the station east of Langanes were composed of water decidedly fresher than that found in spring during the years 1939–1956: this must be ascribed to the coastal influence.

The percentage saturation of oxygen is usually found to be quite high (close to 100%) in June in the intermediate water along the north coast, thus indicating that this water has recently been aerated. On the other hand, at the boundary of the Polar and Arctic Intermediate water off the northwest coast significantly lower oxygen values are found. This will be seen from Table 3 which shows the percentage saturation of oxygen in 100 and 200 meters at a few typical stations in the shelf region and in the oceanic area outside the shelf. Therefore, if this Arctic water was the main component mixing with the Atlantic water in the North Icelandic coastal area, a saturation value of nearly 100% would not be expected.

From the discussion above it seems evident that the water mass which in June mixes with the Atlantic water all along the north coast is formed in late winter. This winter water is probably formed all over the Icelandic shelf during the winter convection by the intermixing of Atlantic water and Arctic water coming from the northern part of the shelf region. As will be shown later the east-flowing Irminger Current must be distinctly weaker during the winter season. The fraction of the Atlantic component in late winter, which is considerable in the western part of the area, gradually becomes less, until it is hardly traceable in the eastern part. Here the winter water will have a t, S value which corresponds approximately to the lower points on the estimated normal regression line for June.

In the area between Iceland and Jan Mayen the upper layers are relatively dense. Here the winter convection is likely to bring about homogenization of water with an average salinity of about 34.82–34.86‰ in the uppermost 200 meters. BT observations made in the area northeast of Iceland between 68° and 69° N and 9° and 17° W in April 1957 showed the mean temperature of the uppermost 140 meters to be from less than 0° to 0.5°. Farther south, i.e. in the northeastern part of the Icelandic shelf region and along the slope, the winter

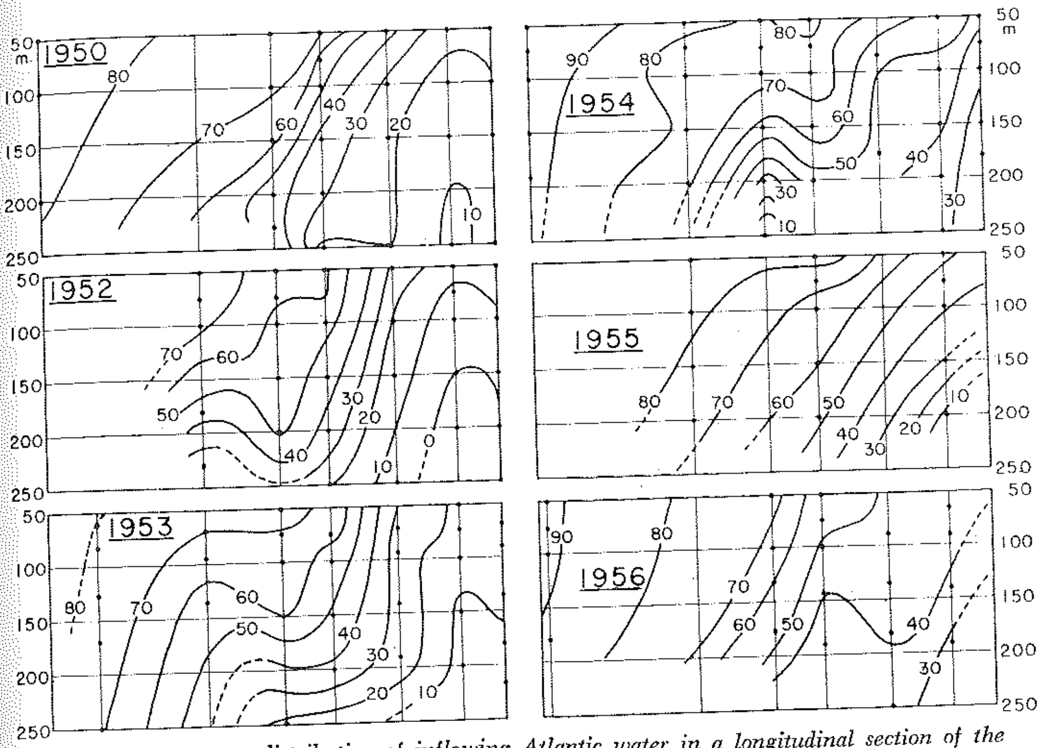

FIG. 83. *Percentage distribution of inflowing Atlantic water in a longitudinal section of the North Icelandic Irminger Current in May–June 1950 and June 1952—1956.*

temperature will be higher, probably between 1° and 2° in the uppermost 200–250 meters. The t, S values of this water will therefore be similar to the lowest points on the estimated regression line for June.

Considering the great reservoir of water, 200–300 meters in thickness, which during the winter convection is mixed vertically, it seems plausible that the water formed does not vary substantially in composition from one year to another. Near the coast, however, fresh water from land may naturally modify the winter water considerably, as was the case in May 1955 (cf. Fig. 82b).

5. THE FRACTION OF ATLANTIC WATER IN DIFFERENT PARTS OF THE REGION

From the estimated normal regression line the fraction of vernally inflowing Atlantic water at intermediate depths can be determined. In Fig. 83 the percentage distribution of inflowing Atlantic water in a longitudinal section is shown for different years. The stations are the same as those used for calculating the estimated normal regression line for June. The percentages are calculated from the regression equation, designating as 100% Atlantic water the extreme value of $t = 7.2°$, $S = 35.13‰$, and as 0% vernally inflowing Atlantic water

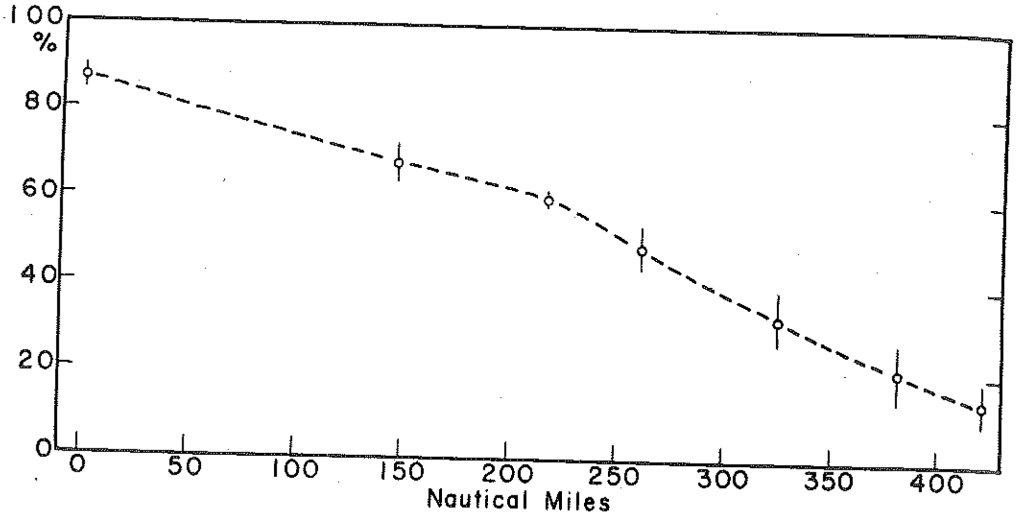

FIG. 84. *The mean percentage of vernally inflowing Atlantic water at 150 meters depth in a longitudinal section of the North Icelandic Irminger Current.*

the value $t = 1.4°$, $S = 34.84‰$. The figures illustrate clearly how the proportion of inflowing Atlantic water gradually decreases from west to east along the north coast. Generally the percentage of inflowing Atlantic water changes from 80–90% in the region west of Látrabjarg to 0–30% east of Langanes. In the westernmost part of the area the percentage of Atlantic water is similar during the six years in question whereas in the eastern part the differences between years are decidedly greater. Thus in June 1950, 1952 and 1953 the Atlantic influence was only very weak off Langanes (0–20%), whereas in 1954 and 1956 the proportion of inflowing Atlantic water was about twice as great.

Fig. 84 shows the mean percentage of vernally inflowing Atlantic water at 150 meters at the different stations on the longitudinal section (see Fig. 80). The standard deviation of the mean is also indicated. With a constant inflow of Atlantic water and the same degree of horizontal and vertical mixing all along the coast the fraction of Atlantic water would be reduced more rapidly in the western part of the region than in the eastern part, i.e. the curve would be expected to be concave in shape contrary to that indicated in Fig. 84. The convex shape of the curve suggests that the Atlantic water is more intensively diluted in the eastern part. This result could be interpreted as being due to a cycle in the Atlantic influx in such a manner that the influx is intensified in spring and summer and reduced in autumn and winter. The mean rate of change in salinity at 150 meters is about 0.4×10^{-3} ‰ per mile in the western part of the area (Látrabjarg–Húnaflói) and 0.6×10^{-3} ‰ per mile in the eastern part (Húnaflói–Langanes). The corresponding values for the mean rate of change in temperature are $0.7° \times 10^{-2} \times \text{mile}^{-1}$ and $1.3° \times 10^{-2} \times \text{mile}^{-1}$ respectively.

not a general rule and a significant difference between June and August can only be shown for 1954. But comparison between years is difficult as in some of the years (1948, 1949, 1951 and 1952) data are only available from one of the two months in question.

The line shown in Fig. 80 is the estimated "normal" regression line for August derived in the same manner as the normal regression line for June. In

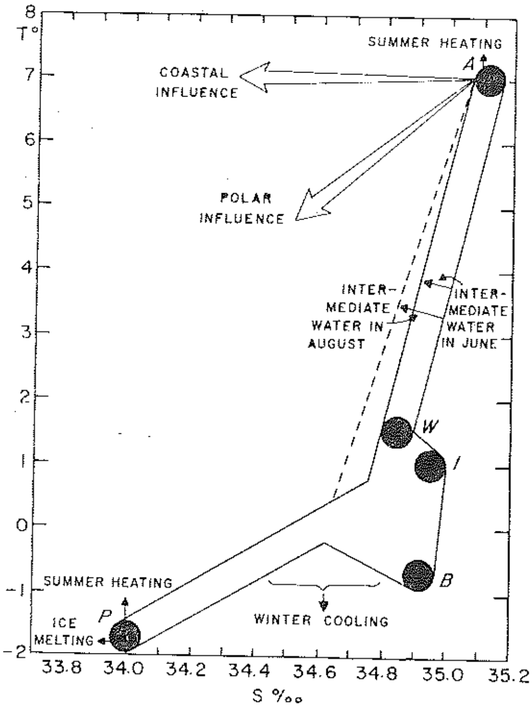

FIG. 85. *Schematic representation of the various water components in North Icelandic waters. A: Atlantic water, B: Arctic Bottom water, W: North Icelandic Winter water, I: Arctic Intermediate water, P: Polar water.*

August, however, the variations between years are so great that such a "normal" is of limited value.

To sum up the preceding discussion the various water components and the mixing processes which they undergo in spring and summer are shown schematically in Fig. 85.

7. A NOTE ON THE OVERFLOW OF NORTH ICELANDIC WINTER WATER ACROSS THE ICELAND-FAROE RIDGE

The great homogenization process which takes place north of Iceland in late winter is of great importance not only as regards the hydrography of North Icelandic waters, but also as regards the conditions in the southern Norwegian Sea and on the Iceland–Faroe Ridge. JACOBSEN (1943) in his studies of the hydrography of the Faroe–Shetland Channel recognizes the North Icelandic Winter water when he refers to "waters of 2.5° temperature and 34.90‰ salinity found north and northeast of Iceland at depths of about 300–400 meters and also largely extended in the Norwegian Sea" (loc. cit., p. 8). However, as we have seen, this water is generally not found at depths below 300 meters in the region north and northeast of Iceland.

As pointed out by Steele (1959) there is probably a more or less continuous flow over the Iceland–Faroe Ridge of water (2°–4°) which is formed by mixing on top of the ridge between "Atlantic" and "Arctic" type water masses. Dietrich (1956, 1957) has considered the Arctic Bottom water (t = −0.6°, S = 34.90‰) as the chief source of the cold overflow. This view is in agree-

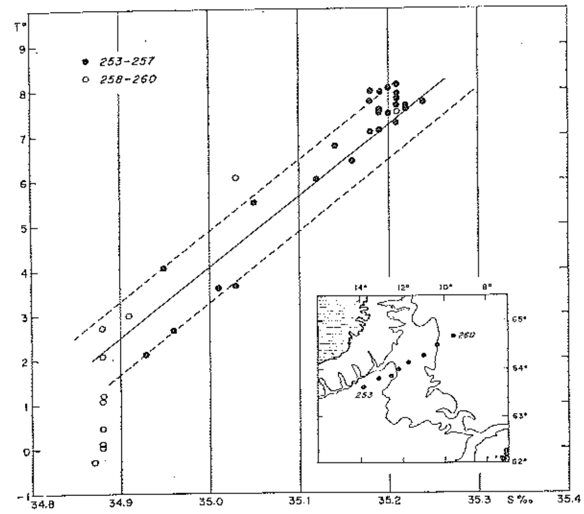

Fig. 86. *The t, S relations from a section worked from the "Anton Dohrn" across the Iceland-Faroe Ridge in June 1955.*

ment with observations made in certain areas of the ridge. Thus the relatively high salinity of the cold bottom water found in the southeastern part of the ridge (Dietrich 1956, 1960*a*) indicates an overflow of a mixture of Arctic Bottom water and Northeast Atlantic water. However, in the northwestern part of the ridge the influence of Arctic Bottom water appears to be generally only slight. This is clear from Fig. 86 which shows the t, S relation of the "Anton Dohrn" stations 253–260 (Dietrich 1957, pp. 311–312).

The t, S values shown in Fig. 86 are from 200 to 400 meters for the stations on the east side of the ridge but from 200 meters down to the bottom for stations on the west side. The distribution of the points suggests that the bottom water in this region consists mostly of a mixture of North Icelandic Winter water (t = 2.0°, S = 34.87‰) and Northeast Atlantic water. The North Icelandic Winter water is carried southwards along the insular shelf east of Iceland and probably forms the major part of the bottom water north of the "Rosengarten" area. The water found east of the shelf region in the tongue of cold water has a salinity similar to that of the North Icelandic Winter water but the temperature is much lower. Some of this water may also be carried across the Iceland-

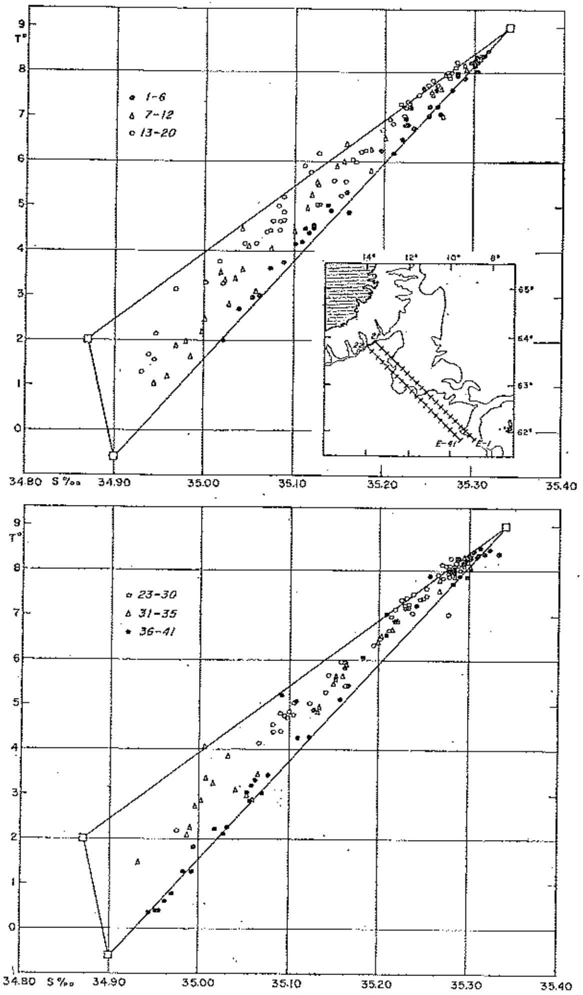

Fig. 87. *The t, S values of observations made below 200 meters along the western slope of the Iceland-Faroe Ridge in June 1960.*

Faroe Ridge but it seems likely that the overflow across the northwestern part of the ridge consists mostly of water from the outer part of the shelf or the slope region, i.e. of North Icelandic Winter water. However, the relatively low salinity values associated with the lowest temperature in Fig. 86 indicate an admixture of arctic water from the tongue of cold water. Thus the mixture of arctic waters overflowing the ridge in spring or early summer may be a complex one, although the two components, Arctic Bottom water and North Icelandic Winter water seem to be the main components. It seems likely that the conditions here are analogous to those found on the Iceland–Greenland Ridge where Arctic Intermediate water is the main component of the bottom current on the East Greenland continental slope, whereas the Arctic Bottom water probably overflows only intermittently.

The material from June 1960 collected by the "María Júlía" afforded an opportunity to make a preliminary investigation of the changes in the t, S relations along the western slope of the Iceland–Faroe Ridge. Fig. 87 shows the t, S values of observations below 200 meters during the first of the three surveys made on the ridge. It can be seen from Fig. 87 that in the southeastern part of

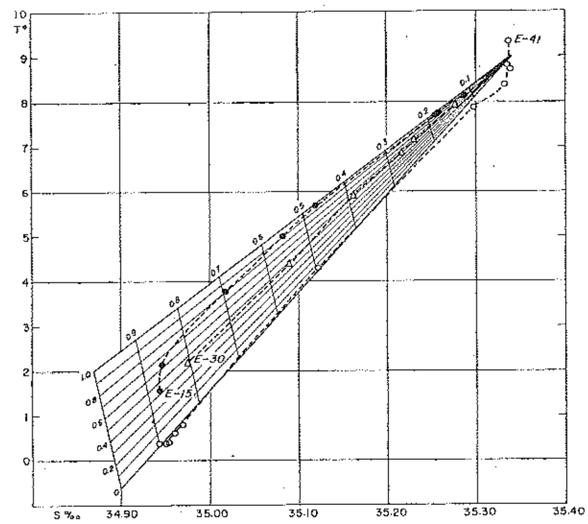

FIG. 88. *A three component diagram for determining the fraction of North Icelandic Winter water in the mixture of arctic waters and Atlantic water.*

the area (stations 1–6 and 36–41, indicated by black dots on the t, S diagram) the bottom water is essentially a mixture of Atlantic water and "pure" Arctic Bottom water, whereas in the northwestern part (stations 13–20 and 23–30, indicated by circles) the bottom water appears to be mostly a mixture of Atlantic water and North Icelandic Winter water. In the middle part of the area (stations 7–12 and 31–35, indicated by the small triangles) the arctic water intermixing with the Atlantic water seems to be a mixture of North Icelandic Winter water and Arctic Bottom water. Practically all the points are seen to fall inside the triangle formed by joining the extreme values for the three dominating water masses.

An attempt was made to determine the fraction of North Icelandic Winter water in the arctic waters mixing with the Atlantic water. This was done by means of the scaled three component diagram shown in Fig. 88. Here the t, S curves of three typical stations have been entered. Since the t, S values for station 41 practically coincide with one side of the triangle, the curve represents a mixture of two components only, viz. Atlantic water and Arctic Bottom water. The water nearest to the bottom at station 41 is seen to contain about 90% Arctic Bottom water and 10% Atlantic water. At station 15 the upper intermediate layers seem to be a mixture of Atlantic water and practically "pure" North Icelandic Winter water. At temperatures below 5.5° the influence of a third water mass, i.e. Arctic Bottom water is indicated, and this influence becomes progressively greater near the bottom. This is a general feature of most of the t, S curves and can be explained by the fact that the North Icelandic Winter water rests on the Arctic Bottom water. At station 30 all the t, S values fall within the triangle. Here the deep layers appear to consist of Atlantic water and a

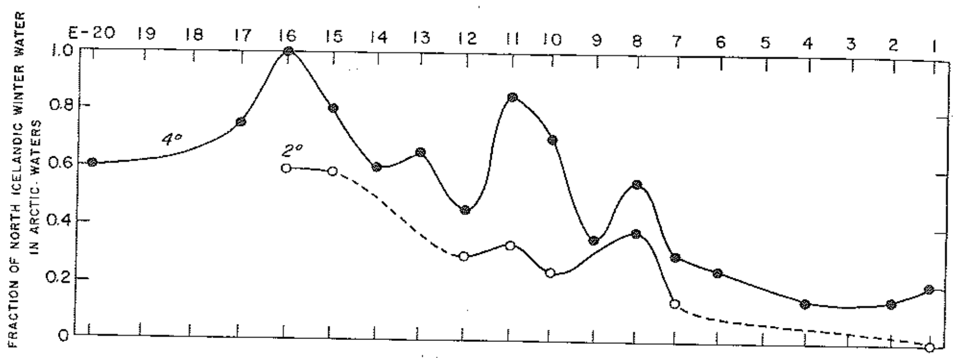

Fig. 89. *The fraction of North Icelandic Winter water at 2° and 4° along the western slope of the Iceland-Faroe Ridge.*

mixture of almost equal volumes of Arctic Bottom water and North Icelandic Winter water.

From the t, S curves for the individual stations the salinity values corresponding to a given temperature can be determined and from the scaled three component diagram the fraction of North Icelandic Winter water contained in the arctic waters mixing with Atlantic water to give the temperature in question. The results for the temperature 2° and 4° respectively at stations 1–20 are shown in Fig. 89. The fraction of North Icelandic Winter water is seen to be relatively smaller at 2° than at 4°. This is in agreement with the increased influence of Arctic Bottom water in the deepest layers. Generally the quantity of North Icelandic Winter water on the western slope of the ridge increases from southeast to northwest. Near station 16 which is located southwest of the "Rosengarten" the fraction of North Icelandic Winter water reaches a maximum. A secondary maximum is found at stations 10–11 somewhat farther south. In the southernmost part of the section where the cold bottom water probably comes from the Faroe–Shetland Channel, the influence of North Icelandic Winter water appears to be negligible. Similar results were found for the other sections (stations 23–41).

It seems possible that the method here outlined could be applied to follow the distribution of North Icelandic Winter water in the bottom layers in the different parts of the Iceland–Faroe Ridge and in the slope region west of the ridge.

X.
CURRENT VELOCITY

While the general direction of the currents in North Icelandic waters is known with certainty, the knowledge about the velocities and the transports of these currents is very fragmentary. As far as the author knows no direct current measurements are available from the region north of Iceland. Therefore, indirect methods had to be relied on. These included the conventional hydrodynamical methods, drift bottle experiments and tracking of temperature or salinity.

1. REFERENCE SURFACE FOR DYNAMIC COMPUTATIONS

The distribution of specific volume anomalies in two typical sections north of Iceland is shown in Fig. 90. The isosteres are seen to slope upward away from the coast in the shelf region and in the upper slope region. In the oceanic region well beyond the slope the inclination of the isosteres is found to be quite small, except in the outermost part of the Kögur section where the isosteres in the surface layers slope steeply downwards from left to right. Below 400 meters in both sections the specific volume anomaly curves incline downwards beyond the foot of the slope. This is a general feature observed in all the Kögur sections and usually (but not always) in the sections farther east.

The density distribution just described follows from the temperature–salinity distribution along the slope. As revealed by the hydrographic sections, especially those from the western part of the area, the deep water ascends along the bottom up to the higher levels on the slope. A similar situation is encountered in the Sognefjord section off western Norway (Sælen, 1959). As pointed out by Sælen (op. cit. p. 25) this feature might be interpreted as being due to the cold water moving in a cyclonic direction. In the author's opinion it seems likely that the deeper layers of the western and southern Iceland Sea move in this manner, viz. southwards along the East Greenland continental slope and eastwards along the slope of the North Icelandic shelf region.

From the various observations it may be safely assumed that in general the Atlantic water north of Iceland has an east-flowing movement. In view of the density distribution — the isosteres sloping upwards away from the coast in the uppermost 300 meters — this means that the reference surface for geostrophic calculations should be placed at 300 meters or below it. In a previous chapter (VI)

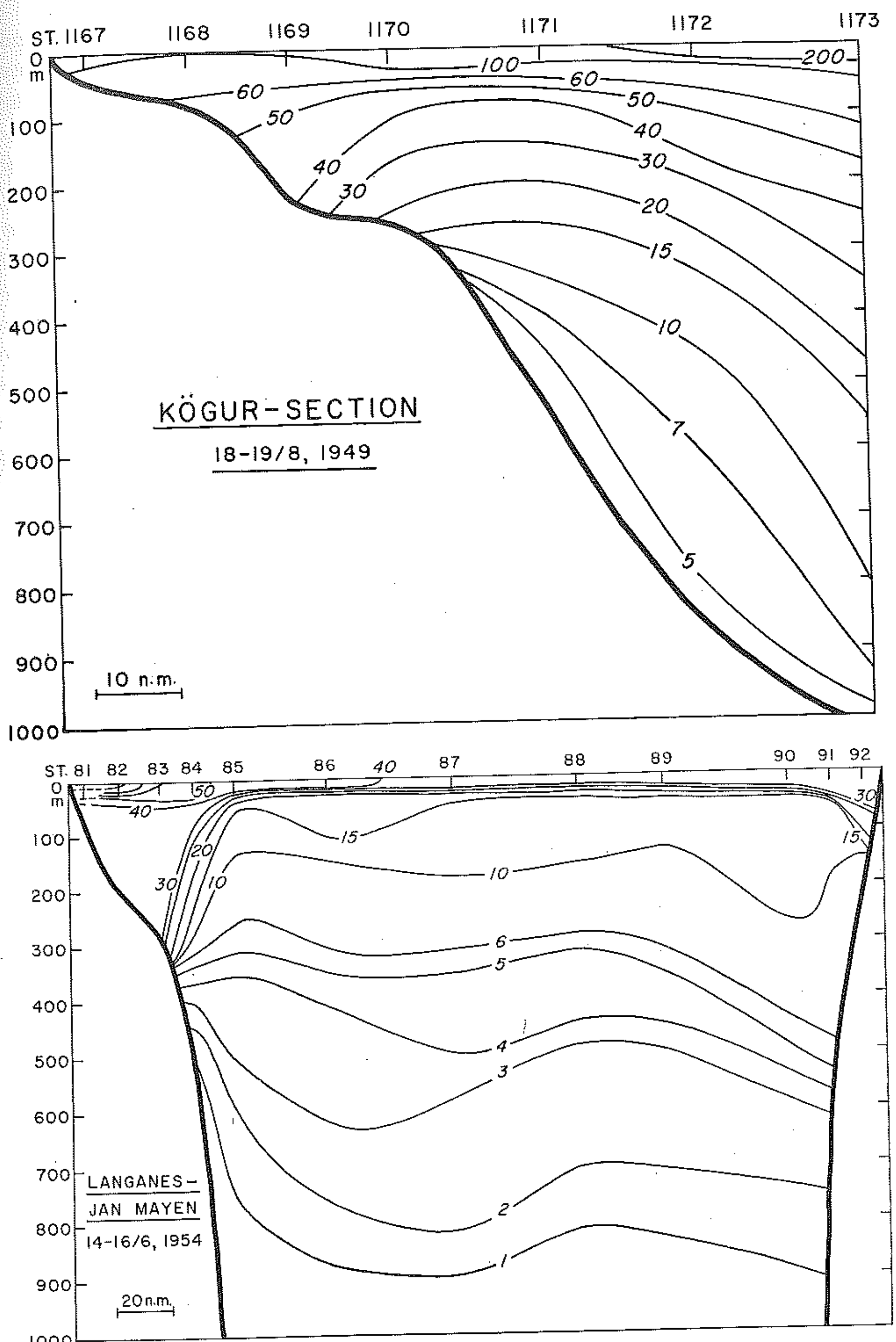

FIG. 90. *Specific volume anomalies in the section off Kögur in August 1949 and the section Langanes–Jan Mayen in June 1954.*

it was discussed that the general circulation of the surface layers in the Iceland Sea as derived from dynamic computations will be essentially the same whether the 400, the 800 or the 1000 dbar surface is used as a reference level. In the deeper layers above the slope, however, complications may arise. As just mentioned, the isosteres in the deeper layers north of the shelf have an upward bend towards the higher levels on the slope. This means that the geostrophically computed deep currents along the slope will be directed towards the west if the zero-level be placed near the bottom, but towards the east if the zero-level be placed at an intermediate depth above the deep water. In view of what was said before about the probable movement of the deep water along the slope, the zero-level, when computing velocities, was placed at the upper boundary of the Arctic Bottom water near the edge of the shelf. But referring again to what was said in chapter VI, it appears probable, although by no means certain, that in the deeper parts of the Iceland Sea beyond the slope region, the surface of no motion or perhaps more correctly the "quasi-zero-surface" is located at greater depths, near 800 meters or deeper.

With the foregoing considerations in mind the zero-level for sections extending north of the shelf was placed in such a manner that it followed the sea bottom down to the upper boundary of the Arctic Bottom water (as judged by the 0° isotherm) near the edge of the shelf. In the northwestern area (off Kögur) this will be near 300 meters but somewhat deeper (about 400 meters) in the sections farther east. North of the shelf the zero-surface slopes downwards to about 600 meters near 68° N, to 800 meters in the Iceland Sea Basin north of 68° 30′ N.

It should be emphasized that as long as the choice of the reference level for dynamic computations is arbitrary and not substantiated by actual measurements the results must be considered conjectural. In the North Icelandic coastal area, however, the current velocity as determined by the dynamic computations agrees fairly well with the results obtained by other methods (see later). Therefore, it is anticipated that errors due to a wrong choice of zero-surface will not be great for the shelf region, although they will certainly not be insignificant. In the oceanic region north of the shelf these errors may, however, become more serious.

In recent papers by KRAUSS (1958 *a* and 1958 *b*) the circulation in the region between Northwest Iceland and Greenland is discussed. In the Iceland–Greenland Channel (see p. 35) KRAUSS places the level of no motion at the sea surface. In this way he finds a very strong bottom current in the Iceland–Greenland Channel, about 25–30 cm/sec. at a depth of 1200–1400 meters. In the western part of the channel the current has according to KRAUSS a southerly movement but a northeasterly movement in the eastern part.

The correctness of KRAUSS' assumptions seems doubtful. Strong horizontal temperature and salinity gradients exist in the region north of the Iceland–Greenland Ridge. As revealed on one of the sections which he discusses (1958 *a*,

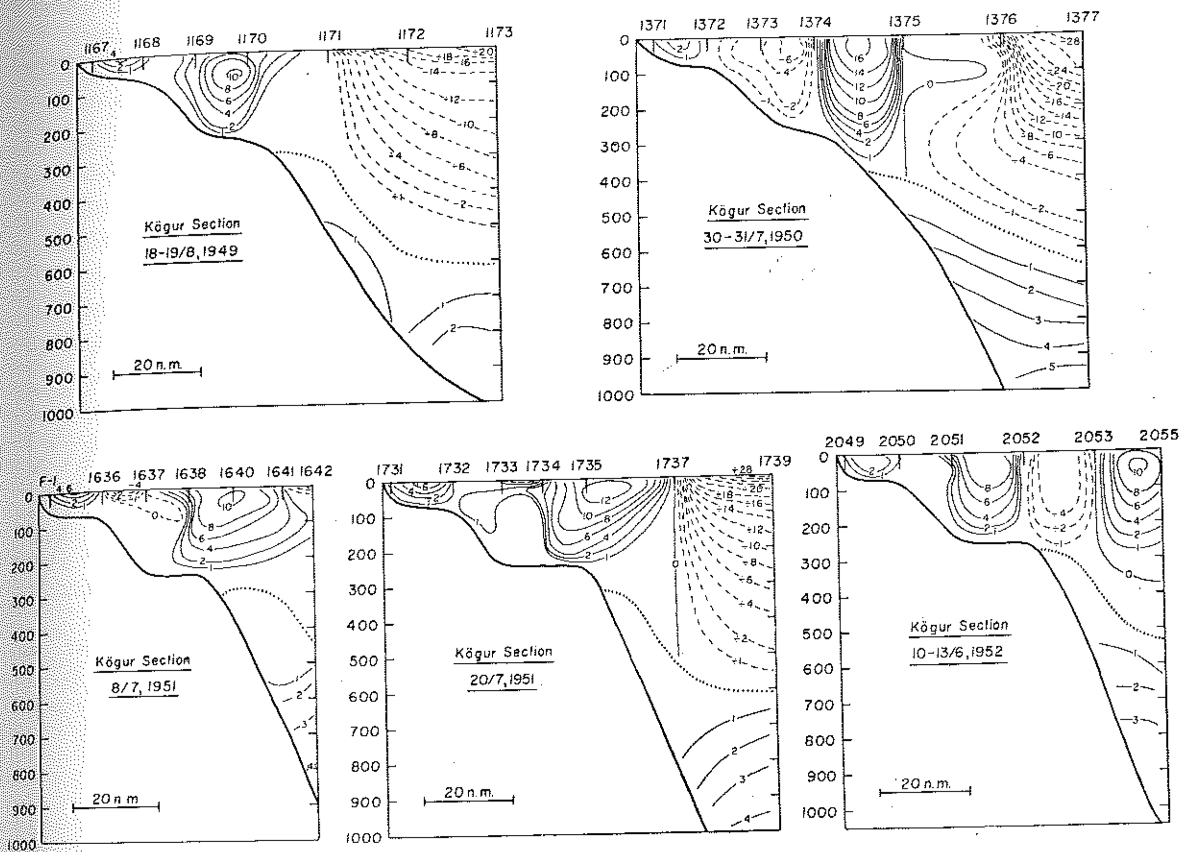

FIG. 91. *Velocities (in cm/sec.) in the section off Kögur 1949—1952. Positive values indicate currents towards east, negative values currents towards west.*

Fig. 5) the horizontal density gradient was quite strong in the surface layers between stations 1377 and 1376. In view of the fact that differences in density in a horizontal direction can only exist in the presence of currents (cf. SVERDRUP, 1946, p. 137), it does not seem likely that the surface currents were quite weak or nonexistant as assumed by KRAUSS. According to KRAUSS the Arctic Intermediate water has a strong northeasterly movement along the eastern slope of the Iceland–Greenland Channel. If this water flowed northeastwards at a velocity of 20–25 cm/sec. as indicated by KRAUSS, one would expect it to be more apparent at intermediate levels all along the slope of the North Icelandic shelf. But as we have seen this water is so much mixed in the eastern part of the region that it is just barely noticeable. This suggests that the portion of the Arctic Intermediate water which flows eastwards along the slope does not move very fast. Lastly, the great velocities of the Arctic Bottom water (25–35 cm/sec.) at depths exceeding 1000 meters in the Iceland–Greenland Channel, as proposed by KRAUSS, do not seem probable although it must be admitted once more that nothing definite can be said about the motion of this deep water.

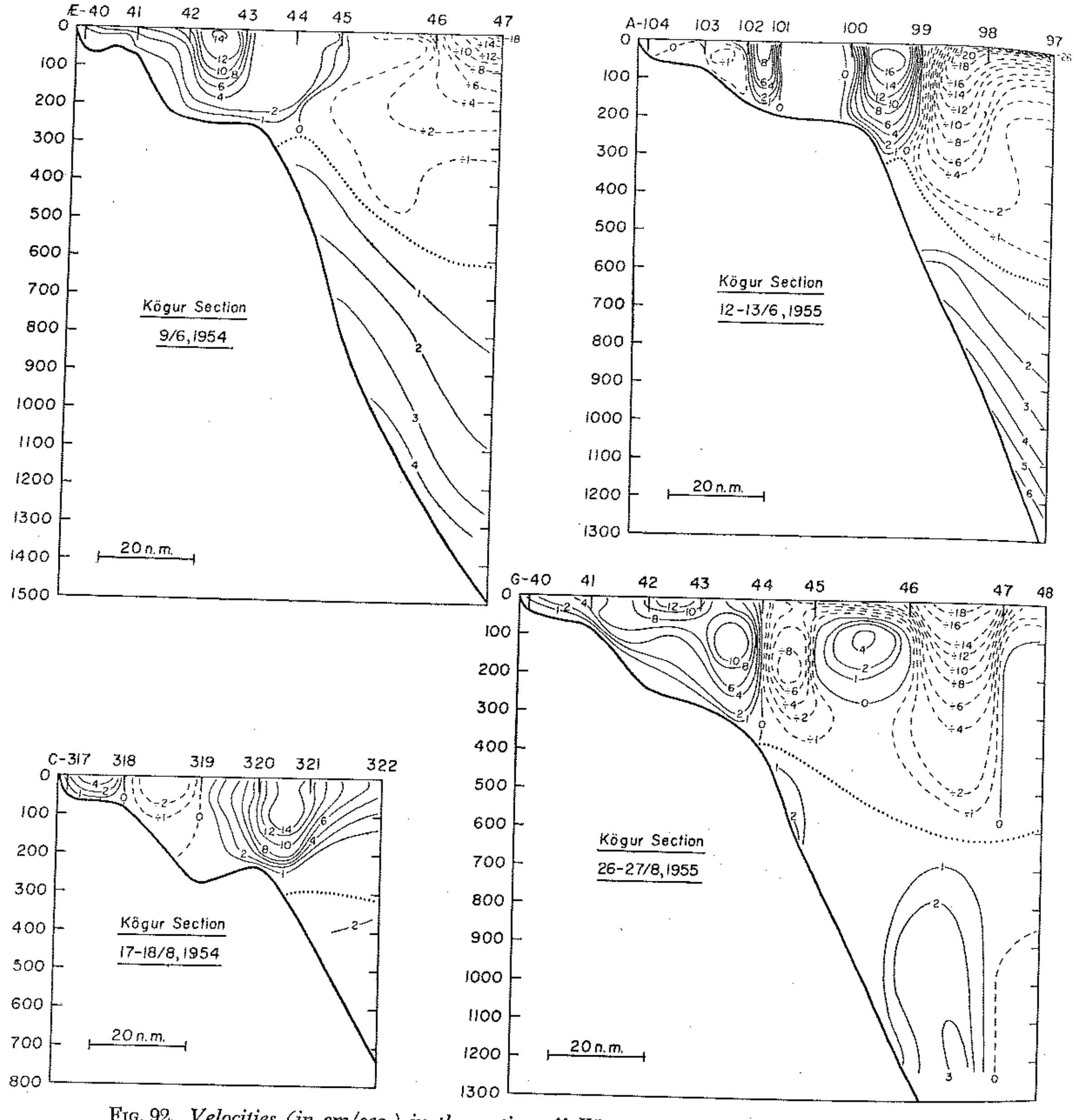

FIG. 92. *Velocities (in cm/sec.) in the section off Kögur 1954—1955. Positive values indicate currents towards east, negative values currents towards west.*

2. VELOCITY PROFILES

Figs. 91–92 illustrate velocity profiles off Kögur from various observational times. The reference level is indicated by a dotted line except in the shelf area where the movement is referred to the bottom of the sea. In all the sections except from 1950 (see Fig. 91) the upper boundary of the Arctic Bottom water as indicated by the 0° isotherm is found near the 300 meters depth contour. In 1950 this boundary was found to lie deeper, near 400 meters at the edge of the shelf. Hence in the sections from August 1949, July 1951, June 1952, June 1954, August 1954 and June 1955, the reference level was placed at 300 dbar at the edge of the shelf, but at 400 dbar in July 1950. In the section from August 1955 the reference level should also have been placed at 300 dbar near the edge of the shelf to coincide with the upper boundary of the Arctic Bottom water, but this would give a westward movement of the bottom water between stations G–55/43 and G–55/44. As it was considered more likely that the bottom water between these stations flowed eastwards, the motion was here referred to the bottom (about 380 dbar at station G–55/44). Placing the reference level at 380 dbar instead of 300 dbar makes a difference of only 0.8 cm/sec. in the mean velocity between stations G–55/43 and G–55/44.

It is pointed out by Iselin (1955) that the most pronounced coastal currents, and hence the main transport, may be expected near the 200 meter contour in the northern hemisphere, whereas a secondary current band, shallower and fresher, is characteristic near the coast. These general rules of coastal circulation apply approximately to the shelf area off the northwest coast of Iceland as indicated by the velocity profiles off Kögur. Thus the main flow of the North Icelandic Irminger Current generally takes place close to the edge of the shelf, near the 200–300 meter depth contour. A secondary shallow current band of small velocity is found close to the shore. In the Iceland–Greenland Channel the East Greenland Polar Current occupies the upper layers and flows southwards at a speed of about 20–30 cm/sec. at the surface. Probably this current is strongest at the edge of the East Greenland continental shelf. Most part of the Arctic Intermediate water below the Polar water also moves southwards but at a slower speed. Below the reference surface the lower part of the Arctic Intermediate water flows northeastwards along the North Icelandic slope, but at a slow speed. The Arctic Bottom water also flows northeastwards along the slope at a moderate or slow speed. In the deep part on the west side of the Iceland–Greenland Channel, below the threshold depth of the ridge, the Arctic Intermediate water and the Arctic Bottom water probably flow in a southerly direction following the East Greenland slope, but turn eastwards on approaching the Iceland–Greenland Ridge.

Fig. 93 shows two examples of the velocity distribution off the northeast coast. In the profile extending north of Melrakkaslétta there is a strong movement eastwards near the edge of the shelf. This easterly current appeared to be unusually strong in August 1954. Between stations C–344 and 345 the maximum velocity exceeded 30 cm/sec. in the surface layers, it was about 25 cm/sec. at 100 meters, between 15 and 20 cm/sec. at 200 meters and about 6 cm/sec. at 300 meters. In the shallowest part of the section the easterly current was found to be weak and irregular. In the upper layers of the slope region the cur-

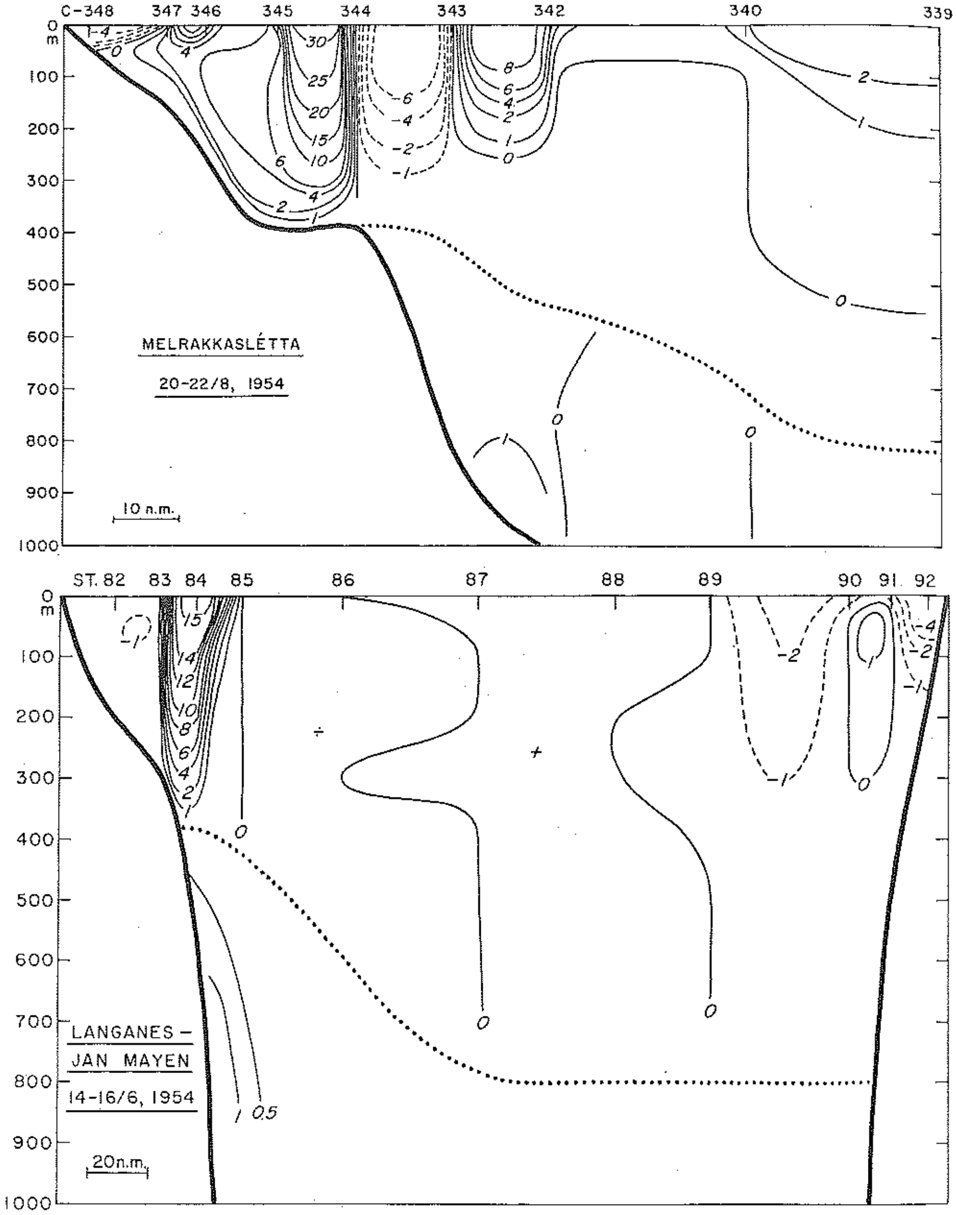

FIG. 93. *Velocities (in cm/sec.) in the section off Melrakkaslétta in August 1954 and the section Langanes-Jan Mayen in June 1954. Positive values indicate currents towards east, negative values currents towards west.*

rents were also found to be irregular, but at the foot of the slope a weak easterly movement was indicated. In the deep water north of the slope the currents appeared to be very weak. In the section from Langanes to Jan Mayen a moderate to strong easterly current was indicated along the Icelandic coastal area.

In the deep oceanic region the calculated currents were found to be very weak, whilst a weak westerly current was found in the northernmost part of the section, along the Jan Mayen Bank.

3. MEAN VELOCITY OF THE COASTAL CURRENT

On the basis of a few drift bottle experiments carried out north of Iceland RYDER (1902) estimated the surface drift along the north coast to be 6–7 nautical miles a day.

HERMANN and THOMSEN (1946, pp. 31–42) studied the records from all previous drift bottles launched in the Icelandic coastal area. As a limit of the coastal area they plotted a regular curve which roughly follows the 200 meter curve. The coastal area they divided into twelve zones. Their results were based on 258 drift bottles recovered in Iceland. They give the following values for the average rate of the coastal current from Látrabjarg to Vestrahorn:

Zone	H	(Látrabjarg to Horn)	1.8 miles per day
,,	I	(Horn to Skagatá)	3.0 ,, ,, ,,
,,	J	(Skagatá to Gjögur)	3.9 ,, ,, ,,
,,	K	(Gjögur to Rifstangi)	3.5 ,, ,, ,,
,,	L	(Rifstangi to Langanes)	7.1 ,, ,, ,,
,,	A	(Langanes to Glettinganes)	4.3 ,, ,, ,,
,,	B	(Glettinganes to Vestrahorn)	4.1 ,, ,, ,,
		Mean	4.0 miles per day.

Since these results are based on relatively abundant data, they may probably be considered fairly reliable.

As another way of estimating the average current we might attempt to follow a certain conservative property of the water on its way eastwards along the coast. For this purpose two characteristics will here be considered, viz. the temperature and the salinity. Because of excessive changes above the thermocline due to heating, cooling or dilution, neither the temperature nor the salinity can be tracked in the surface layers. At intermediate depths, however, the tracking method might be used as an approximate measure of the current, provided that 1) the net of stations is fairly complete, 2) the course of the current is horizontal and 3) that the property followed is not altered while the current is flowing. If the density at a certain depth in the inflowing Atlantic water is greater than that at a corresponding depth in the water farther east in the coastal area, the inflowing water will sink as it moves eastwards, until the proper σ_t value is reached. In this way erroneous results may be arrived at, if the displacement of a certain temperature or salinity value at a certain level is followed from one place to another. The temperature or salinity changes at intermediate depths will be due to vertical or horizontal mixing. As we have seen, the east-flowing Atlantic water will in spring and early summer be diluted and cooled because of mixing with North Icelandic Winter water. With regard to the intermediate layers, heating from above will tend to give too high values for the mean current as determined by the tracking method, whereas cooling because of horizontal mixing and mixing from below will tend to give too low values. It seems likely that after the thermocline is established the effect of heating from above is smaller than the effect of cooling due to horizontal mixing. Hence the tracking method will at best give a rough estimate of the minium rate of the coastal current.

From temperature data collected during June and July 1904 NIELSEN (1905) attempted to estimate the mean current velocity at subsurface depths by track-

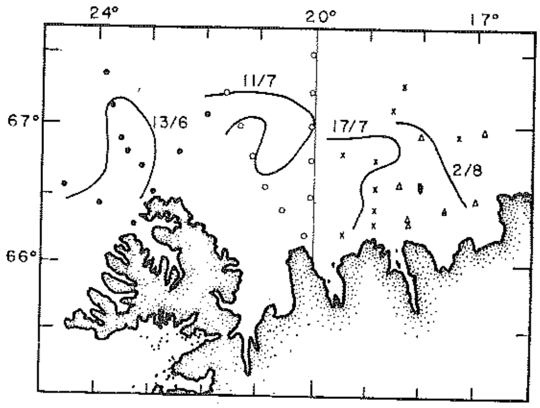

FIG. 94. *The 6° isotherm at 100 meters at different times during the summer of 1955.*

ing the temperature. In this way he arrived at the conclusion that the easterly component of the Irminger Current from Horn to Langanes was about 6 miles a day at 50 meters and about 4 miles a day at 150 meters. Because of the limited number of observations his results can hardly be accepted as reliable, even if we ignore the other errors involved.

In recent years the net of stations worked in the North Icelandic coastal area has been relatively dense, especially in the years 1948 and from 1954 on. As an example, Fig. 94 shows the course of the 6° isotherm at 100 meters at different observational dates during the summer of 1955.

The horizontal charts of temperature and salinity at 50 and 100 meters for the summer of 1948–49, 1951 and 1954–60 were analyzed. The displacements of the different isotherms were determined from one observational series to another. This gave a mean rate of about 2.9 miles a day at 50 meters and 2.3 miles a day at 100 meters. It should be noted here that these are mean values for the North Icelandic coastal area as a whole.

The maximum distribution of Atlantic water as indicated by the 35.0‰ isohaline is shown in Fig. 95 for three different periods during the summers 1948 and 1951 respectively. The chart representing the period July 26th–30th

1948 is based on observations made by the "Dana", whereas the other charts are based on Icelandic material. In 1948 the measurements near the front of the Atlantic water were made on July 10th, July 29th and August 8th. In the interval between these dates the front was displaced 46 and 29 nautical miles respectively. The rate of displacement was therefore 2.4 nautical miles per day for the first interval and 2.9 for the second. The corresponding values for the two intervals July 11th to 30th and July 30th to August 22nd 1951 were 1.8 and 1.7 nautical miles per day. As the maximum salinities are usually found near

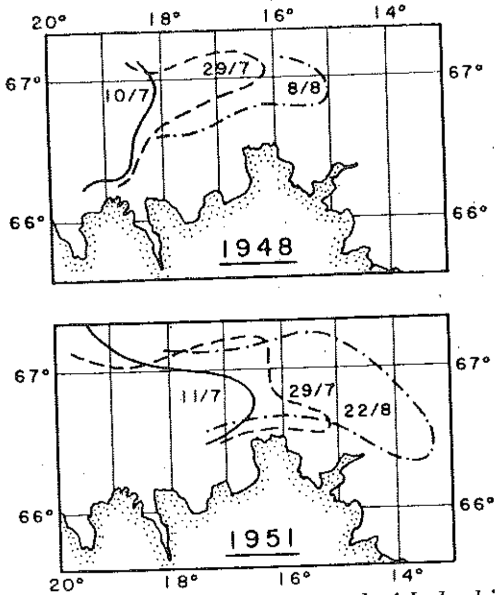

Fig. 95. *The maximum distribution of Atlantic water north of Iceland in the summers of 1948 and 1951.*

100 meters, these results represent approximately the rate of displacement of the 35.0‰ isohaline at 100 meters.

The salinity will gradually be lowered by dilution as the Atlantic water proceeds eastwards in the North Icelandic coastal area and mixes with North Icelandic Winter water or Arctic water. Therefore the method of tracking the salinity will no doubt give too low values for the velocity of the easterly current component. The mean rate of displacement of salinity is seen to be 2.2 nautical miles per day or the same as the rate of displacement of temperature at 100 meters, which also was considered to give too low values for the current velocity.

It is of interest to investigate how the results obtained by the dynamic method compare with those obtained by drift bottle experiments. Three sections will be considered, viz. off Kögur, Siglunes and Melrakkaslétta.

The mean inclination of the isobaric surfaces in dyn. cm. in the section off Kögur is shown in Table 5. The values are given in dyn. cm. for each 10 miles interval and also the standard deviations of the mean ($\bar{\sigma}$). These values are based on the following 9 summer observations:

a) August 18th to 19th 1949.
b) July 30th to 31st 1950.
c) July 1st to 3rd 1951.
d) July 20th 1951.
e) June 10th and 13th 1952.
f) June 9th 1954.
g) August 17th to 18th 1954.
h) June 12th to 13th 1955.
i) August 26th to 27th 1955.

To find the mean inclination close to the shore the curves were extrapolated to zero distance from the coast. The 300 decibar surface was chosen as reference level. The sea surface slopes downwards away from the coast. The inclination amounts to 1 dyn. cm. over the first 10 miles, to less than 0.5 dyn. cm. between 10 and 20 miles, increases again farther offshore to reach a maximum of 1.5 dyn. cm. per 10 miles distance some 50 miles north of Kögur. Then it decreases again and reaches zero 60–70 miles away from the coast. Similar features are found for the deeper levels.

Relatively smallest values for the standard deviation of the mean are found at two places, viz. close to the shore and 40–50 miles offshore where the standard deviation is 20–30%. At these two localities the current thus appears to be fairly stable. On the other hand, relatively high values are found for the standard deviation of the mean in the coastal area between 20 and 30 miles offshore and

TABLE 5.

Inclination in dyn. cm. of the isobaric surfaces relative to the 300 decibar surface off Kögur

Decibars	Distance off coast (naut. miles)						
	0—10	10—20	20—30	30—40	40—50	50—60	60—70
300—0	0.90	0.46	0.61	1.13	1.50	1.35	−0.35
$\bar{\sigma}$	0.17	0.17	0.39	0.46	0.39	0.59	0.44
300—50	0.28	0.10	0.57	1.16	1.57	1.56	0.23
$\bar{\sigma}$	0.06	0.11	0.32	0.41	0.38	0.49	0.44
300—100	.	0.08	0.42	0.91	1.54	1.03	0.11
$\bar{\sigma}$	.	0.07	0.23	0.30	0.38	0.42	0.39
300—150	.	0.03	0.23	0.72	1.21	0.61	0.03
$\bar{\sigma}$	.	0.02	0.10	0.22	0.34	0.37	0.24
300—200	.	.	0.08	0.42	0.68	0.26	−0.07
$\bar{\sigma}$	.	.	0.04	0.12	0.19	0.22	0.12
No. of observations .	9	9	9	9	9	9	8

north of the main current at 60–70 miles offshore. In both of these regions the values indicate weak and variable currents.

In Fig. 96 the mean velocity profile relative to the 300 decibar surface has been constructed. The maximum current is found near the edge of the coastal area some 50 miles offshore where it reaches 6–7 cm. per second in the surface layer. It is of interest to note that in this region the greatest mean velocities, more than 7 cm. per second, are found at 50 meters depth but not at the surface. At 100 meters the velocity is similar to that at the surface, but it decreases to 3 cm. per second or less at 200 meters. The boundary between the east-flowing Irminger Current and the southwest-flowing East Greenland Current is seen to be normally 60–70 miles north of Kögur. It should be noted, however, that the current velocities may differ considerably from year to year and the current boundary may be variable from one time to another. A secondary current

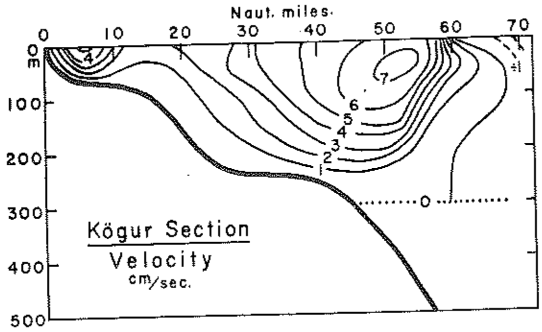

FIG. 96. *Mean velocities (in cm/sec.) relative to the 300 decibar surface in the section off Kögur. Positive values indicate currents towards east, negative values currents towards west.*

maximum is found inside the 10 miles limit where a mean current of 5 cm per second is indicated. This is in good agreement with the values found by drift bottle experiments (cf. p. 141).

The section off Siglunes extends over the deepest part of the coastal region, i.e. the Eyjafjarðardjúp. It was attempted to evaluate the mean easterly current component for this region in summer by calculating the difference in dynamic height of the sea surface relative to 400 meters (decibars) between stations S–2 (66° 24′ N, 18° 50′ W) and S–4 (66° 45′ N, 18° 50′ W) from the available summer observations. The results are shown in Table 6.

Judging from the rates of the current in different zones as found by the drift bottle experiments, the mean value of the current velocity for the whole North Icelandic coastal area is roughly the same as that for the middle part of the area. Therefore, the results obtained by the tracking method and those obtained by the dynamic calculations for the middle part of the coastal area are directly comparable.

If we assume that the motion at 400 meters is negligible and make the other usual assumptions on which the current calculations are based, the mean easter-

TABLE 6.

Difference in dyn. cm. of dynamic height relative to 400 meters (decibars) between stations S–2 (66° 24′ N, 18° 50′ W) and S–4 (66° 45′ N, 18° 50′ W) June to August in different years.

DATE	400–0 dbar	400–50 dbar	400–100 dbar	400–200 dbar	400–300 dbar
10/7 1948	2.21	2.27	2.17	2.05	1.20
27/7 1948	–0.14	0.08	0.04	0.15	0.20
10/8 1948	–0.65	0.31	0.04	–0.20	–0.20
22/8 1949	1.02	1.17	1.30	0.95	0.35
4/8 1950	4.15	3.35	3.10	2.40	0.85
27/7 1951	5.13	4.77	4.13	2.81	1.26
9/6 1953	0.68	0.97	1.13	1.10	0.55
11/6 1954	5.73	4.98	4.97	4.19	2.04
2/7 1954	5.15	4.72	4.43	3.35	1.45
20/7 1954	6.16	6.08	5.58	4.20	1.70
16/8 1954	2.78	2.60	3.07	2.70	1.45
16/6 1955	5.10	3.50	3.23	2.60	1.50
17/7 1955	0.10	–0.34	–0.38	–0.05	–0.10
25/8 1955	0.47	1.15	1.28	1.15	0.55
3/6 1956	2.58	2.45	2.36	1.83	0.73
22/6 1956	3.27	2.81	3.01	2.33	0.93
5–6/8 1956	0.57	0.97	1.10	0.85	0.45
12/6 1957	4.09	4.09	3.92	3.00	1.15
1/8 1957	2.16	2.30	2.21	2.05	0.90
26/8 1957	3.55	3.69	3.60	2.77	1.02
4/6 1958	3.20	3.14	3.01	2.43	1.43
18/6 1958	–0.60	–0.28	–0.02	0.22	–0.13
10/8 1958	1.37	1.17	1.20	0.88	0.43
22/6 1959	2.98	2.51	2.07	1.98	1.23
11/6 1960	2.17	2.07	2.33	2.10	0.95
4/8 1960	3.07	2.43	1.77	1.20	0.60
Mean	2.55	2.42	2.33	1.89	0.87
Standard Deviation of the Mean	0.39	0.33	0.31	0.24	0.11

ly current component will be 2.3 nautical miles per day at the surface. This is in fair agreement with the result of drift bottle experiments for the area between Skagatá and Gjögur (3.9 miles per day). At 50 and 100 meters the values are 2.2 and 2.1 miles per day respectively. This is in good agreement with the mean value for the whole area as found by the tracking method. Thus our assumptions seem to be at least partly justified.

From Table 6 it is clear that the values obtained for this region by dynamical calculations may vary greatly from time to time.

It has already been mentioned that the tracking method will probably give too low values for the mean current speed. Since practically the same results are obtained by the dynamic method, it seems reasonable to conclude that the movement at 400 meters cannot be neglected. However, the horizontal motion of this partly isolated bottom water is probably slow.

The results of the different methods are compared in Table 7. It should be observed that the mean current velocities, as found by dynamic calculations and the tracking method, are based on observations from the years after 1948, whereas the drift bottle rates are based on experiments from other years.

TABLE 7.

Velocity (miles pr. day) of the easterly current component in the middle part of the North Icelandic coastal area as found by different methods.

METHOD	DEPTH IN METERS					
	0	50	100	200	300	400
Drift Bottle Experiments	3.9	.	.	.	.	.
Tracking Temperature	.	2.9	2.3	.	.	.
Tracking Salinity	.	.	2.2	.	.	.
Dynamical Calculations	2.3	2.2	2.1	1.7	0.8	0.0
Mean Value	3.1	3.0	2.9	2.5	1.6	0.8

The surface velocity shown in the bottom line of the table is the mean of the two values obtained by the drift bottle experiments and the dynamical calculations. The values for the other levels are adjusted accordingly. These figures for the current speed in the middle part of the North Icelandic coastal area must be considered the best obtainable, as they are based on two sets of mean values.

As indicated by the drift bottle experiments, similar values are found for other parts of the coastal area, except in region L (between Melrakkaslétta and Langanes) where the current velocity is distinctly greater. It would seem likely that this greater current velocity is due to the strong East Icelandic Current which enters the northern part of region L on its way southeast. That such is the case is supported by dynamical calculations.

The mean inclination of the isobaric surfaces relative to the 400 decibar surface off Melrakkaslétta is shown in Table 8. The mean values are given for intervals of 10 nautical miles together with the standard deviation of the mean (σ). The values are based on the data from the following observations:

a) July 20th 1949.
b) August 23rd 1949.
c) June 1st 1950.
d) August 8th 1950.
e) August 24th 1951.
f) June 17th 1952.
g) June 13th 1953.
h) June 13th 1954.
i) August 23rd 1954.
j) June 5th 1956.
k) June 13th–15th 1957.
l) June 7th–8th 1958.

The small difference in dynamic height inside the 20 miles limit and relatively high values of the standard deviation of the mean indicate that here the easterly current component is very weak and irregular. Between 30 and 50 miles north of Melrakkaslétta the current appears to be strong and relatively stable, but farther offshore a weaker and more variable current is indicated.

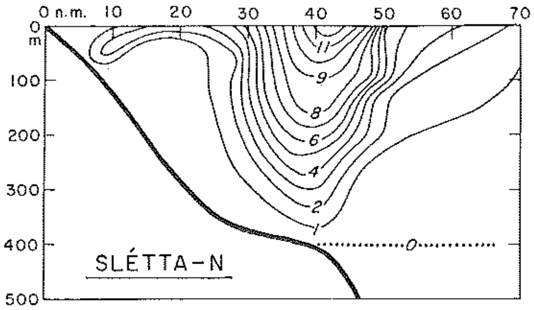

FIG. 97. *Mean velocities (in cm/sec.) relative to the 400 decibar surface in the section off Melrakkaslétta.*

Fig. 97 shows the mean velocity in the Melrakkaslétta section. Here the 400 decibar surface was selected as the reference surface. Near the coast the easterly current component is quite small. A strong easterly current is first indicated 25 to 30 miles north of Melrakkaslétta. About 10 miles farther to the north,

TABLE 8.

Inclination in dyn. cm. of the isobaric surfaces relative to the 400 decibar surface off Melrakkaslétta.

Decibars	Distance off coast (naut. miles)						
	0—10	10—20	20—30	30—40	40—50	50—60	60—70
400—0	0.08	0.44	0.88	2.18	2.75	0.99	0.63
$\bar{\sigma}$	0.40	0.23	0.33	0.37	0.38	0.37	0.19
400—50	0.19	0.16	0.32	2.01	2.23	0.80	0.47
$\bar{\sigma}$	0.09	0.15	0.23	0.36	0.31	0.34	0.18
400—100	.	0.10	0.36	1.75	1.96	0.55	0.29
$\bar{\sigma}$	.	0.11	0.23	0.29	0.28	0.28	0.12
400—150	.	0.05	0.31	1.63	1.42	0.38	0.22
$\bar{\sigma}$	.	0.09	0.19	0.32	0.26	0.22	0.08
400—200	.	0.03	0.24	1.26	1.08	0.25	0.14
$\bar{\sigma}$	.	0.05	0.13	0.23	0.23	0.14	0.05
400—300	.	.	0.10	0.50	0.35	0.08	0.02
$\bar{\sigma}$	.	.	0.04	0.10	0.11	0.05	0.02
No. of observations	9	11	12	12	12	12	12

near the edge of the coastal bank, a mean current of 10–12 cm. per second is found. In this region the maximum current is found at the surface, as was also the case in the section off Siglunes. At 50 meters the current is about 10 cm. per second, 8–9 at 100 meters, 6–7 at 200 meters and 2–3 at 300 meters. Some 50 miles offshore the mean current velocity drops suddenly to less than 3 cm. per second at the surface and less than 1 cm. per second at 100 meters.

The current maximum corresponding to 5–6 nautical miles per day in the surface layers is somewhat lower than that found by the drift bottle experiments for the mean rate of the coastal current in area L. However, it must be kept in mind that the dynamic calculations indicate marked fluctuations in the current velocities. Furthermore, the mean current velocities as found by the dynamic calculations and those found by drift bottle experiments are not directly comparable as regards time. On the whole the agreement between the dynamic method and the drift bottle experiments appears to be fairly good.

In the region north of Langanes the same essential features are revealed by the dynamical method, viz. a weak easterly current in the shallow coastal area but a current maximum of about 10 cm. per second along the slope approximately 40–50 miles off Langanes. Values of this order were obtained for the section Langanes–Jan Mayen in 1949 and in 1951 and the subsequent years.

From the area farther south, zones A and B (Langanes to Glettinganes and Glettinganes to Vestrahorn), only limited data exist on which current calculations can be based. The Danish observations in 1948 (HERMANN 1949 *b*, Fig. 21, p. 21) indicate a southeasterly current with a velocity of 2–5 cm. per second. These values are decidedly lower than those found by drift bottle experiments (cf. p. 141).

The conclusion that can be drawn from the preceding discussion is that in general there is a good agreement between the different methods used in deriving the mean rate of the coastal current. However, the tracking method and the dynamic calculations yield slightly lower values than the drift bottles. The true values probably lie between the two. As regards variations in the current velocity within the different regions, we have to depend solely on the dynamic method. The density distribution on which this method is based definitely suggests that the main current is limited to the slope, whereas on the coastal banks the current is weak and variable. The mean value of the coastal current is probably about 3 miles a day.

XI.

VOLUME TRANSPORT

1. ERRORS IN THE CALCULATION OF WATER TRANSPORT.

The uncertainties involved in the calculations of volume transport by geostrophic currents will depend on various factors. First of all are those due to the assumptions made when applying the Helland–Hansen formula for calculating the dynamic height anomalies. These assumptions were discussed in a previous chapter.

The standard deviation in volume transport as the result of the uncertainty in the salinity determinations can be derived[1] in a similar manner as the standard deviation of the difference in dynamic height between two stations. If observations have been made at 0, 10, 25, 50, 75, 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200, 1500, 2000 meters etc. and the standard deviation of the observed salinity values can be estimated as 0.02‰, the standard deviation of the volume transport ($\sigma Q_{1,n}$) for different depths of reference level (z_n) will be as follows:

z_n (m)	200	400	600	800	1000	1200	1500	2000
$\sigma Q_{1,n}$ (km^3/h)	0.04	0.16	0.32	0.57	0.89	1.22	1.90	3.86

Thus, if the salinity determinations of samples taken at great depths are not made with great accuracy, the transport calculations will be meaningless, when the zero-level is situated deep.

Another important source of error is caused by a faulty choice of the zero-level. This error will be proportional to the velocity at the reference surface and the depth of this level. Suppose the reference level was placed at 400 meters between two stations 10 miles apart. An additional velocity of only 1 cm/sec. at the reference surface would then mean an additional transport between the stations of 0.27 km^3/hour. Off the northwest coast of Iceland the width of the east-flowing Irminger Current will be approximately 60 nautical miles and the mean depth of the shelf roughly 200 meters. An additional velocity of 1 cm/sec. throughout this section will mean an additional transport of about 0.8 km^3/hour.

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1) See Appendix, p. 255.

Thus relatively great errors in the calculated transport can result from only a slight fault in the selection of reference level.

From the foregoing considerations it will be clear that the calculated transport values must be taken with great reservation. At best they may be considered as a rough estimate.

Due to the uncertainties involved it was not attempted to calculate the volume transport below the reference surface. The following discussion therefore refers to the transport above the zero-level.

A consideration was made of how the computed transport compared with the continuity of the system. For this purpose the volume transport in and out of a certain area was calculated. The area selected was bounded by the Kögur section in the west, a section directed eastwards from the northernmost station of the Kögur section, and the section north of Melrakkaslétta. Material for this calculation was available from the years 1949, 1950, 1952 and 1954. The results are shown in Table 9. Since the size of the area is not the same for the different years the transport values are not comparable. In three instances the inflow exceeded the outflow by 1.8, 4.9 and 11.0%, but in the fourth instance the outflow exceeded the inflow by about 11.1%. If we assume the difference between evaporation and precipitation to be negligible in this area, the true difference between inflow and outflow represents the run-off from land. This will be a small value compared to the volume transported by the ocean currents. Hence, if the continuity of the system is fulfilled the net inflow or outflow should be close to zero. As seen from the table the results fulfill this requirement approximately.

TABLE 9.

Volume transport (km^3/hour) to the region north of Iceland between Kögur and Melrakkaslétta.

DATE	KÖGUR SECTION		SECTION W-E		SLÉTTA SECTION		TOTAL		
	In	Out	In	Out	In	Out	In	Out	Net Inflow
18—23/8 1949	1.45	8.17	10.63	0.58	0.48	3.58	12.56	12.33	0.23
30/7–9/8 1950	3.32	8.52	11.35	0	0.40	5.81	15.07	14.33	0.74
10—17/6 1952	2.64	0.74	1.13	0.25	0	2.37	3.77	3.36	0.41
9—13/6 1954	2.14	2.11	4.69	2.08	0.67	4.27	7.50	8.46	-0.94

2. VOLUME TRANSPORT THROUGH THE KÖGUR SECTION

Unfortunately, ice conditions during the Icelandic cruises made it impossible to extend the section from Kögur all the way across the Iceland–Greenland Channel to the coast of Greenland. Therefore, an attempt could not be made to calculate the net transport between Northwest Iceland and Greenland. How-

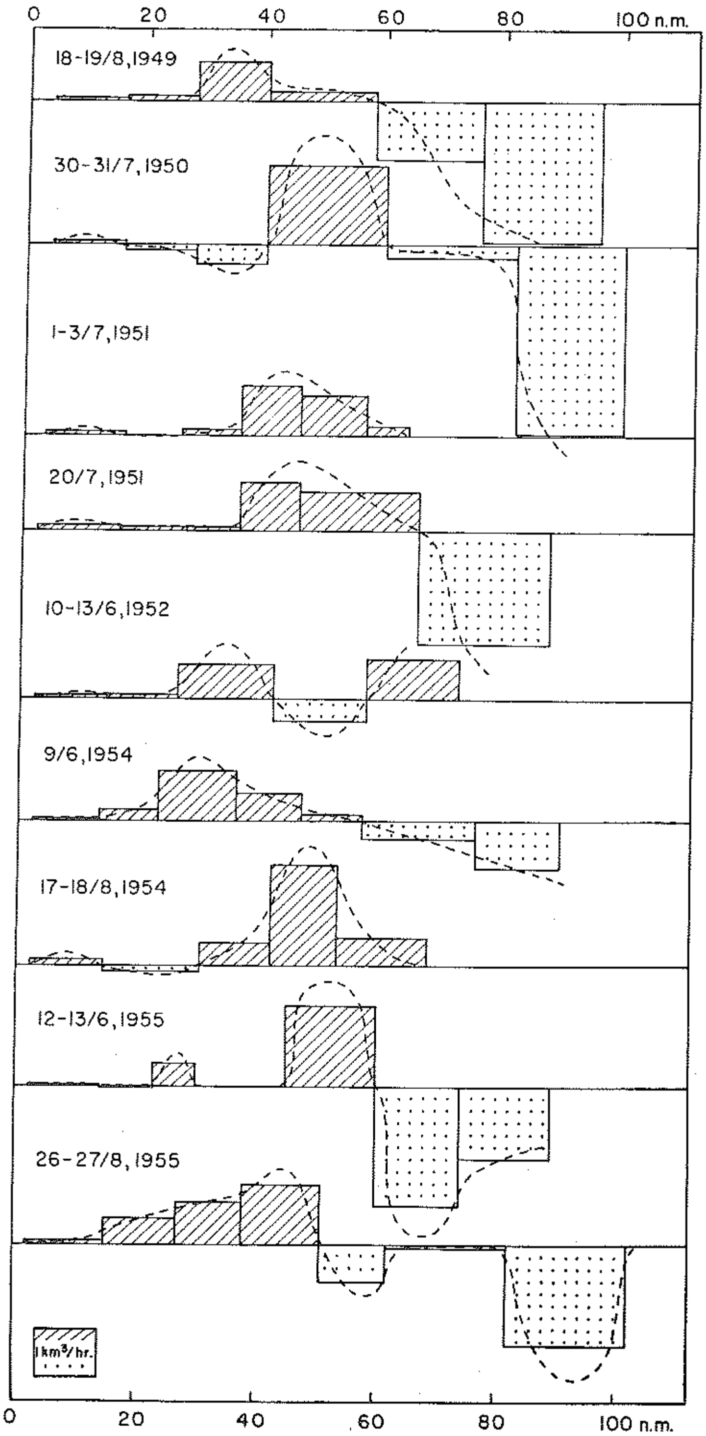

FIG. 98. *Volume transport (in km³/hr.) through the section off Kögur 1949—1955. Transports towards east are indicated by the hatched areas, transports towards west by the dotted areas.*

ever, on 9 occasions the section could be extended beyond the edge of the shelf. The results of the transport calculations are shown in Table 10 and Fig. 98. The shaded areas in Fig. 98 may be considered as the front sides of rectangular prisms of equal lengths. The size of the rectangles is therefore a measure of the volume transport. The curve shows the volume transport smoothed between the stations.

Temperature and salinity data indicate that the bulk of the Atlantic water is normally found within 60 miles off Kögur. The volume transport through this part of the section was determined from Fig. 98. The values are given in column 5 of Table 10. As these are in most instances similar to those given in column 3, it follows that the easterly transport usually takes place within 60 miles from the Icelandic coast. The greatest net east transport determined this way was found in August 1954, but the smallest in June 1952 and in August 1949. Except for these instances the values are of similar magnitude. The mean value was about 2.3 km^3/hour with a standard error of 0.28 km^3/hour.

The North Icelandic Irminger Current will in addition to Atlantic water, be composed of the following water masses: 1) North Icelandic Winter water, 2) Arctic water, 3) Arctic Intermediate water, 4) Polar water, 5) Arctic Bottom water, 6) Icelandic Coastal water.

The first of these will be apparent in spring or early summer, but in late summer it has most likely disappeared from the western part of the North Icelandic shelf. The fifth component, the Arctic Bottom water, must be almost negligible, as the reference level was placed near the upper limit of this water. Usually the amount of Polar water carried by the Irminger Current will also be small. The Coastal water will be mostly Atlantic water, diluted by a small amount of fresh water from land. Hence the main components of the North Icelandic Irminger Current in the westernmost part of the area in summer will be Atlantic water, Arctic water, Arctic Intermediate water and possibly North Icelandic Winter water. As was discussed in a previous chapter, the characteristics of these water masses will be greatly altered in the surface layers because of meteorological conditions. A determination of the relative magnitude of these components will therefore be quite difficult, if not impossible.

The inflowing Atlantic water has in early summer a maximum temperature of about 7°C at intermediate depths. In the surface layer it will be somewhat higher. The mean temperature of the other water masses can only be estimated very roughly. It will hardly be above 2° or below 0°. A value of 1° will probably be a fair estimate. At a lower temperature than 1° the admixture of Atlantic water must be very small. For estimating the Atlantic component of the east-flowing water the volume transport of water above 1° was therefore determined. Near the boundary of the 1° water the volume transport was found by tracing the 1° isotherm on the velocity profiles and determining the product of the cross-sectional area and the velocity. The heat transport of water $> 1°$ was determined in a similar manner. These calculations included all water with temperatures above 1°, except in the northernmost part of the section where

TABLE 10.

Volume and heat transport off Kögur.

Observation	Length of Section (n. miles)	Volume Transport (km^3/hour)		Net East Transport (km^3/hour) 0–60 miles off Kögur	Volume Transport > 1° (km^3/hour)			Heat Transport > 1° (kg.cal./sec. $\times 10^{-9}$)			Estimated Net East Transport of Atlantic Water (km^3/hour)
		East	West		East	West	Net East	East	West	Net East	
18—19/8 1949	96	1.40	8.17	1.39	1.44	0.35	1.09	2.17	0.20	1.97	0.9
30—31/7 1950	100	3.32	8.52	2.63	3.31	1.22	2.09	5.19	1.73	3.46	1.5
1—3/7 1951	64	2.24	0.03	2.18	2.20	0.03	2.17	2.80	0.05	2.75	1.2
20/7 1951	88	2.94	5.19	2.84	2.85	0.01	2.84	3.78	0.01	3.77	1.6
10—13/6 1952	72	2.64	0.74	0.64	1.73	0.68	1.05	1.89	0.63	1.26	0.6
9/6 1954	90	2.14	2.11	2.12	2.31	0	2.31	3.05	0	3.05	1.4
17—18/8 1954	68	3.83	0.18	3.53	3.66	0.18	3.48	5.39	0.33	5.06	2.1
12—13/6 1955	88	2.79	5.77	2.72	2.72	3.22	–0.50	3.29	2.79	0.50	0.4
26—27/8 1955	112	3.37	5.18	2.62	3.22	0.86	2.36	5.03	0.75	4.28	1.9
Mean	.	.	.	2.30	.	.	1.88	.	.	.	1.3
St. dev. of mean	.	.	.	0.28	.	.	0.39	.	.	.	0.2

the Polar water may reach this temperature in summer. Therefore, where the water with temperature above 1° was found only above 50 meters, it was not included. The results are shown in columns 6–11 in Table 10. The net transport found this way is in most cases similar to that found by considering the net transport through the first 60 miles of the section. A notable exception was found for June 1955, when there appears to have been a backflow of the Atlantic water to the west, some 60–70 miles off Kögur. The mean net transport of water with temperature above 1° is about 1.9 km^3/hour, which is about 0.4 km^3/hour less than the mean net transport through the first 60 miles of the section. However, if the abnormal value of June 1955 is excluded the mean will be about 2.2 km^3/hour. It seems reasonable to conclude from this that the net east transport within 60 miles from Kögur consists almost entirely of water with temperature above 1°C.

The transport values appear to be somewhat higher for August than for June. Furthermore, since the temperature of the surface layers increases from June to August, the heat transport values for August will be markedly higher than those for June.

If the mean temperature of the Atlantic water, as well as the water masses mixing with it, can be estimated with a fair degree of accuracy, the net east transport of Atlantic water through the Kögur section can be computed from the following equations:

$$H = q_A \cdot \overline{t_A} + q_R \cdot \overline{t_R} \quad (1)$$

$$q_T = q_A + q_R \quad (2)$$

Here q_T denotes the total volume transport of water with temperature above 1°, H its heat transport, q_A and q_R the volume transport of Atlantic water and other water masses respectively, $\overline{t_A}$ the mean temperature of the Atlantic water and $\overline{t_R}$ the mean temperature of the other water masses. A fair estimate of the mean temperature of the Atlantic water will probably be 7° for June, 7.5° for July and 8° for August. As mentioned before, the mean temperature of other water masses than Atlantic water can probably be estimated roughly to be about 1°. Using these values for the mean temperatures the results shown in column 12 were obtained. Similar equations could be set up for the salt transport, but there the estimation of mean values would be even more uncertain.

As seen from column 12 in Table 10, the mean net transport of Atlantic water is 1.3 km^3/hour. Omitting the year 1955 the value will be 1.4 km^3/hour which is 64% of the mean net transport of water with temperature above 1°. Thus it can be roughly estimated that the North Icelandic Irminger Current as it crosses the Kögur section consists of 60–70% Atlantic water and 30–40% of other water masses. The heat transport during the summer season to the region east of the Kögur section due to Atlantic water alone will be roughly 2.7×10^9 kg. cal./sec.

3. VOLUME TRANSPORT THROUGH THE MELRAKKASLÉTTA SECTION

The results of the calculations of volume transport through the Melrakka-slétta section are shown in Table 11 and in Fig. 99.

The main easterly transport usually takes place within 50 miles from the coast. Exceptions from this were found in the years 1951, 1957 and especially 1958. North of 68° N (88 miles from the coast) the easterly transport component is in most cases quite small. The August values appear to be somewhat higher than the June values, but the years with observations from both months are only two, viz. 1950 and 1954 so that the observed difference can hardly be considered significant. The highest transport value was found for August 1954.

TABLE 11.

Volume transport (km³/hour) through the Melrakkaslétta section.

Date	Length of section (naut. miles)	Transport		Net East Transport 0–50 n.m.	Net East Transport 50–88 n.m.	Net East Transport > 88 n.m.
		East	West			
20—21/7 1949	110	2.43	0.29	1.87	0.13	0.14
22—23/8 1949	89	3.58	0.48	3.00	0.11	–0.01
31/5—5/6 1950	114	3.42	0.43	2.93	0.33	–0.27
8—9/8 1950	119	5.81	0.40	3.63	0.51	1.29
18—24/8 1951	208	3.19	1.14	1.46	1.05	–0.46
16—17/6 1952	87	2.37	0	1.71	(0.66)	.
9—13/6 1953	86	2.91	0.75	2.66	(–0.50)	.
13/6 1954	89	4.27	0.67	3.33	0.28	–0.01
22—23/8 1954	135	7.42	1.31	5.40	–0.06	0.75
4—5/6 1956	84	4.03	0	3.89	(0.14)	.
13—15/6 1957	100	4.85	0.27	3.62	0.98	–0.02
7—8/6 1958	94	4.57	0.27	0.72	3.21	0.37
Mean	.	.	.	**2.85**	**0.57**	.

It is of interest to compare the transport values for the Kögur section with those of the Melrakkaslétta section, when observations were made at both sections (quasi–) simultaneously. The results are shown in Table 12, where the net east transport values 0–60 miles off Kögur are compared with the net east transport south of 68° N (0–88 nautical miles) in the section off Melrakkaslétta.

As can be seen from this table there is almost a constant difference between the volume transport through the two sections. The correlation is indeed very close ($\varrho=0.99$), and even though the observations are only 5, this correlation

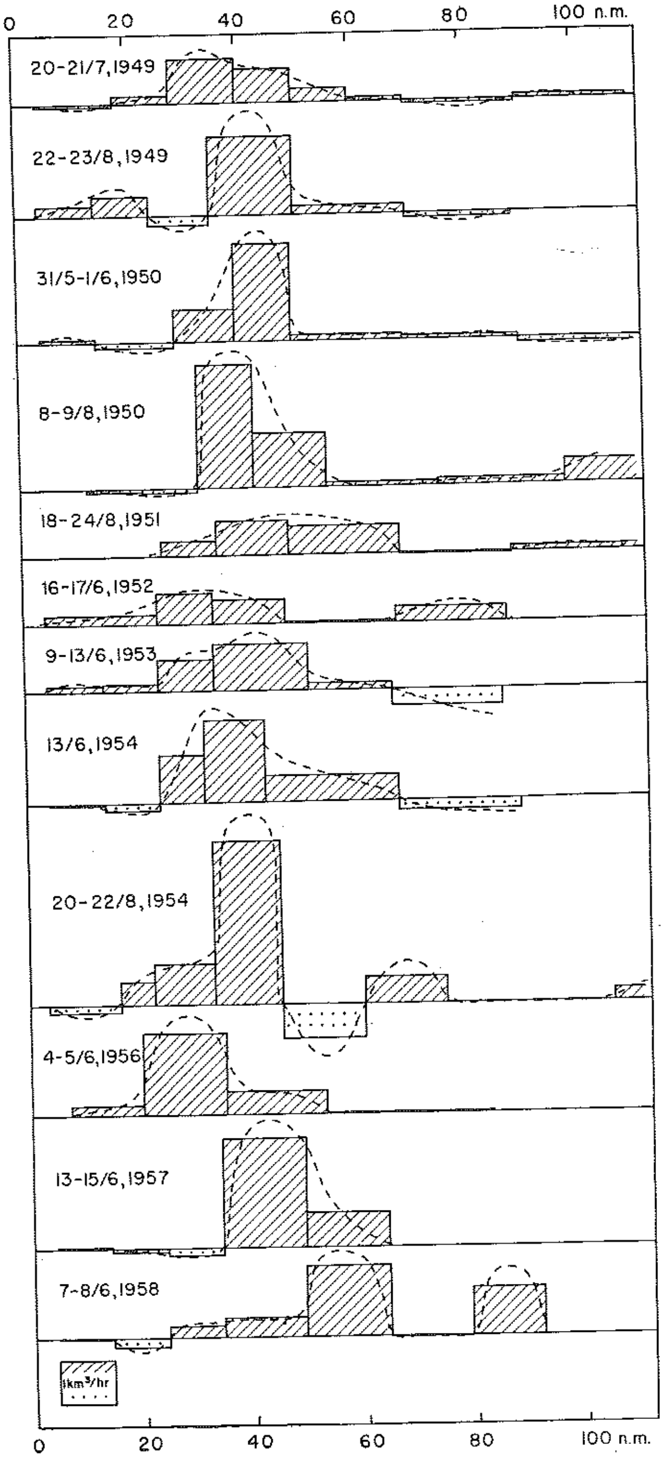

FIG. 99. *Volume transport (in km³/hr.) through the section off Melrakkaslétta 1949—1958. Transports towards east are indicated by the hatched areas, transports towards west by the dotted areas.*

TABLE 12.

Comparison between the net east volume transport off Kögur and Melrakkaslétta.

Off Kögur 0—60 miles: Date	Transport (km^3/hour)	Off Melrakkaslétta 0—88 miles: Date	Transport (km^3/hour)	Difference in Transport (km^3/hour)
18—19/8 1949	1.43	22—23/8 1949	3.11	1.68
30—31/7 1950	2.63	8—9/8 1950	4.14	1.51
10 & 13/6 1952	0.64	16—17/6 1952	2.37	1.73
9/6 1954	2.12	13/6 1954	3.61	1.49
17—18/8 1954	3.53	22—23/8 1954	5.34	1.81
			Mean	1.64

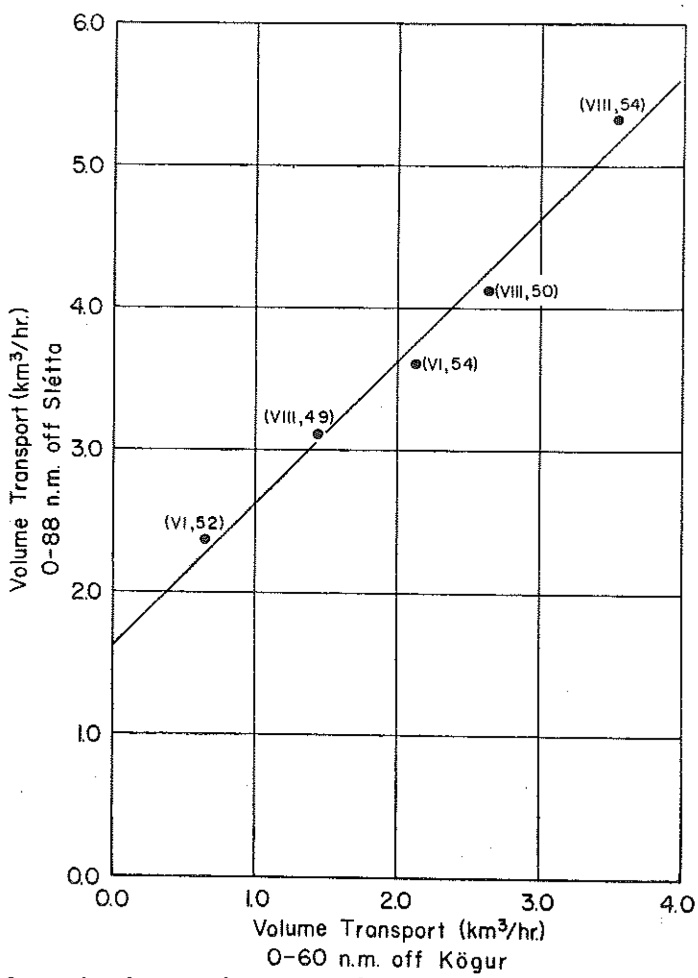

FIG. 100. *Comparison between the net east volume transport off Kögur and Melrakkaslétta.*

exceeds the 0.2% level of significance. The calculated regression line is shown in Fig. 100. The equation of this line is:

$$V_M = 1.64 + V_K$$

where V_M denotes the net east volume transport north of Melrakkaslétta (0–88 miles) and V_K the net east volume transport north of Kögur (0–60 miles). This relation definitely indicates that in the 5 instances here considered, variations in the transport of the East Icelandic Current have almost entirely been caused by variations in the North Icelandic Irminger Current, whereas the transport of the residual current component appears to be almost constant.

According to Table 11 the mean value for the net east transport through the section from Melrakkaslétta to 68° N is 3.42 km³/hour. The dynamic topography charts of the region north of Iceland (Figs. 6–12) indicate that most of the East Icelandic Current flows through this part of the section. Therefore, on the average, the East Icelandic Current consists of about 50% Irminger water. The amount of undiluted Atlantic water carried by the East Icelandic Current will then on the average be 30–35%, and 65–70% other water components, mainly Arctic water, but also North Icelandic Winter water and probably small amounts of Polar water and Arctic Intermediate water.

XII.

SEASONAL VARIATIONS

1. GENERAL CONSIDERATIONS

All along the north coast of Iceland the hydrographic conditions will change markedly with the seasons. These variations are naturally most conspicuous in the surface layers, but they are also observed at intermediate depths down to at least 300 meters. The most rapid seasonal changes will as a rule be observed in spring and autumn, whereas in the middle of winter the conditions change relatively slowly.

In North Icelandic waters we may distinguish between two kinds of seasonal variations, viz. 1) hydrographic variations directly associated with changes in the sun's altitude and 2) variations in the relative magnitude of Atlantic water. The first of these variations, which especially affects the conditions in the surface layers, will at all places along the coast be nearly in phase with the corresponding air temperature. On the other hand, the relative magnitude of the Atlantic water has a decisive influence on the conditions at intermediate depths. As the time of maximum Atlantic influence varies with the region, it may not be in phase with the time of maximum surface temperature. Generally, the maximum Atlantic influence is observed in early summer in the western and middle part of the area, but one or two months later in the eastern part.

The variations during the summer season, June to August, were discussed in chapter VIII, the most conspicuous features being 1) the increased stratification from June to August and 2) the increased eastward extension of Atlantic water at intermediate depths during the same period.

As seen from KRAUSS' charts (Fig. 26) the mean surface temperature in October all along the north coast from Látrabjarg to Gerpir lies between 5° and 6°C. Farther north near the 67° parallel it drops to less than 4°. In March it is 3–4° off the northwest coast, 2–3° in the area south of 67° N between Ísafjörður and Langanes and 3–4° along the east coast. The surface salinity (Fig. 27) appears to be quite uniform during the winter months, as in October as well as March it lies between 34.50 and 34.75 ‰ over the whole region along the north coast. It should be kept in mind, however, that the temperature and especially the salinity data for the region north of Iceland in winter are very sparse. The mean charts for October and March are therefore based on relatively few observations as regards this region.

2. SEASONAL VARIATIONS IN THE EXTENSION OF DRIFT ICE

The distribution of polar ice northwest of Iceland varies markedly both annually and seasonally. At Northeast Greenland the maximum quantities of ice are normally found in late winter. From this region great masses of ice are

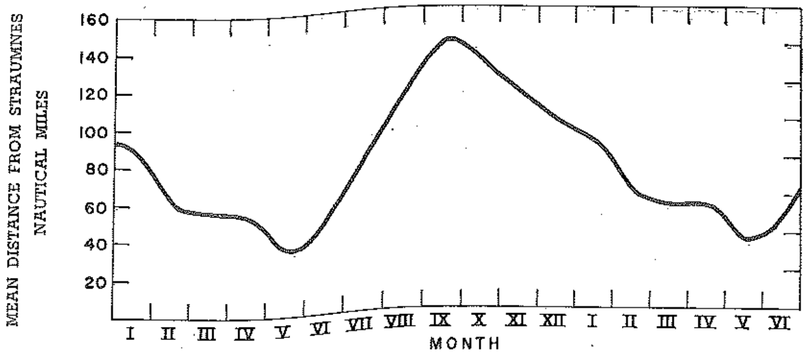

FIG. 101. *The distance (in naut. miles) from Straumnes on Northwest Iceland to the mean ice border.*

carried swiftly southwards by the East Greenland Current. It will take some time, however, before the ice masses have drifted south to the Iceland–Greenland Ridge. Spring will therefore be the heaviest ice season in the area north-

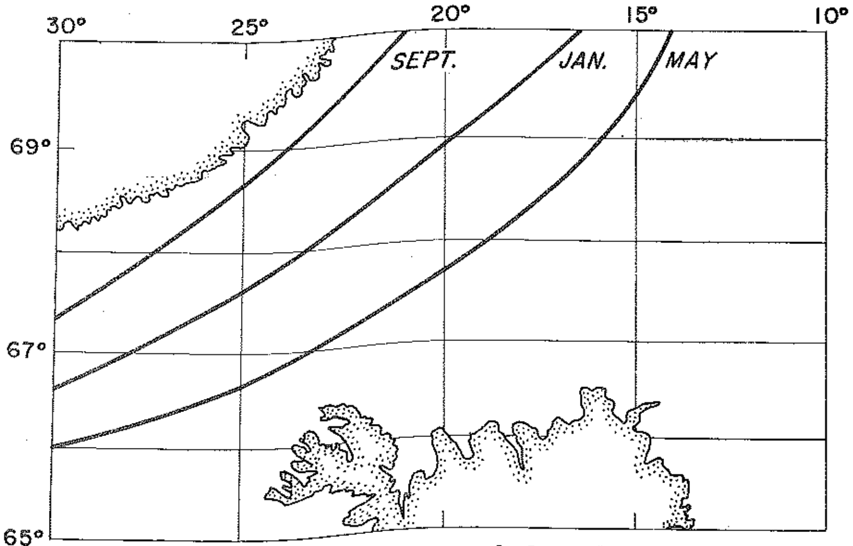

FIG. 102. *The mean ice limit during the months September, January and May.*

west of Iceland. During summer the ice border gradually retreats farther and farther away from the Icelandic coastal area, and in autumn ice occurs very rarely at the northwest coast of Iceland. In winter the ice belt again becomes broader, and in January it is found at about the same distance away from the

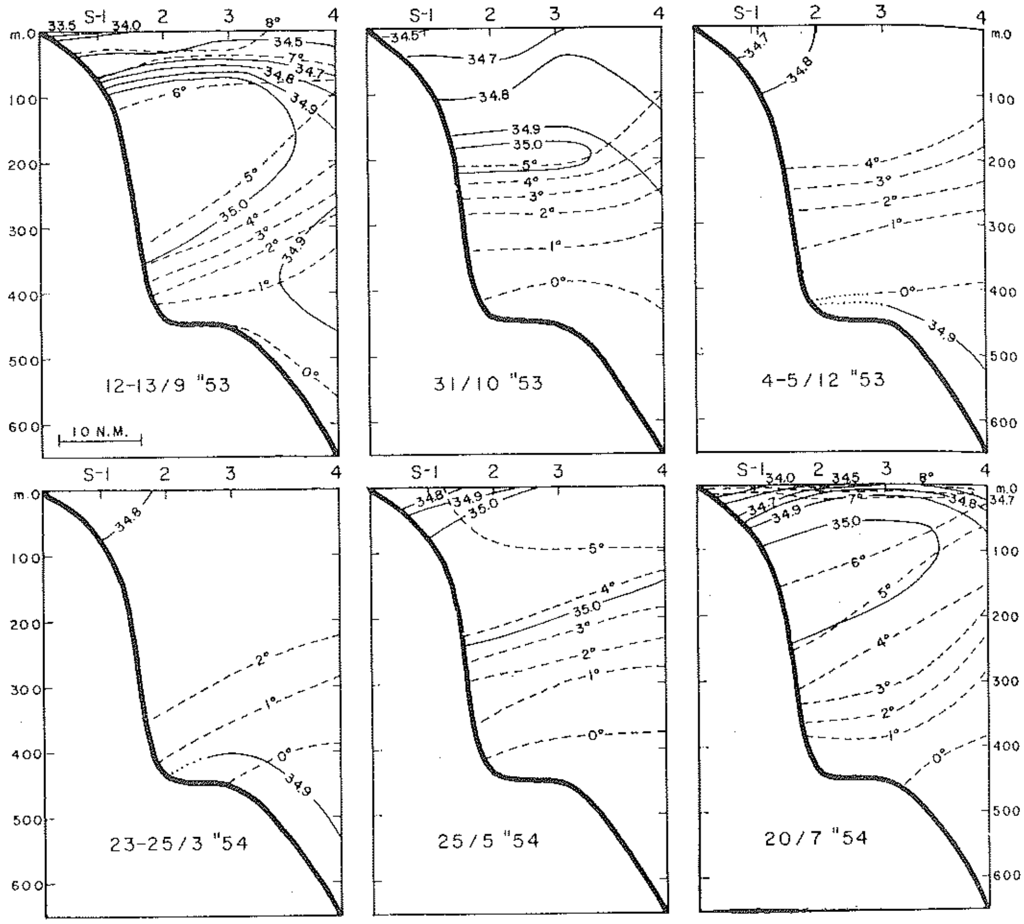

FIG. 103. *The Siglufjörður section on 6 occasions from September 1953 to July 1954.*

Icelandic coast as in July. The chances of drift ice extending into the Icelandic coastal area are therefore greatest in spring and early summer, especially after a spell of strong southwest winds.

The distance from Straumnes on Northwest Iceland to the mean ice border in different seasons is shown in Fig. 101. It is based on the 50% frequency curves for the period 1919–1943 given by the Deutsches Hydrographisches Institut in Hamburg (BÜDEL 1950). The mean ice limit during the months September, January and May is shown in Fig. 102.

3. TEMPERATURE, SALINITY AND DENSITY VARIATIONS NORTH OF SIGLUFJÖRÐUR DURING THE YEARS 1953–1955

The best available observational material for studying seasonal variations in North Icelandic waters is that collected during the period September 1953 to September 1955. The main results from this material will now be considered.

Investigations in previous years had indicated that the Atlantic influx must be quite weak during winter but greately intensified in spring and summer as a gradual eastward movement of the Atlantic water could be followed. Fig. 103 shows the Siglufjörður section at 6 different dates from September 1953 to July 1954. In September the surface layers are stratified down to 100 meters and the Atlantic water ($S > 35.0$ ‰) is found as an intermediate layer between 100 and 300 meters at stations S–2 and S–3. At the end of October this intermediate layer has become much thinner and in December it has disappeared. In March the water is practically homogeneous down to 300 meters. In late May the saline Atlantic water appears again and now occupies the surface as well as the intermediate layers down to 200 meters. And in July the Atlantic water is limited to the intermediate layers with the surface layers stratified down to 30–50 meters. Below 400 meters the conditions appear to be similar at all seacons.

Temperature and salinity variations in the region north of Siglunes are shown in Fig. 104. The curves on top illustrate the seasonal variations in the mean salinity between the surface and 400 meters. These will be discussed later.

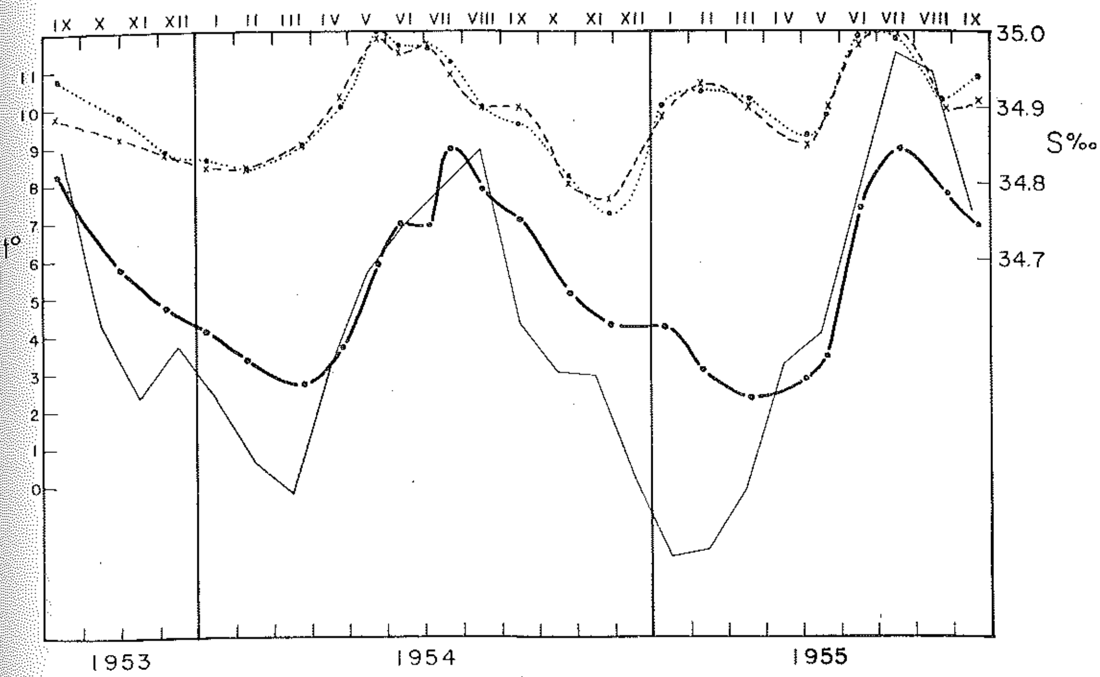

FIG. 104. *Temperature and salinity variations north of Siglunes, September 1953 to September 1955. The curves at top show the seasonal variations in the mean salinity 0—400 meters at station S–3 (66° 32′ N, 18° 50′ W) (dotted line) and the average of the mean salinities 0—400 meters at stations S–2 (66° 24′ N, 18° 50′ W), S–3 and S–4 (66° 45′ N, 18° 50′ W) (broken line). The curves below show the mean monthly air temperature (average for Siglunes and Grímsey) (thin solid line), and the sea temperature at 10 meters at station S–3 (thick line).*

The curves below indicate the monthly variations in air temperature (mean for the meteorological stations Grímsey and Siglunes) and the temperature at 10 meters at station S–3 (66° 32′ N, 18° 50′ W). Whereas the sea temperature is generally in excess of the air temperature in autumn and winter, the two follow each other rather closely in spring and early summer. In one of the years (1955) the air temperature in July and August was about 2°C higher than the sea tem-

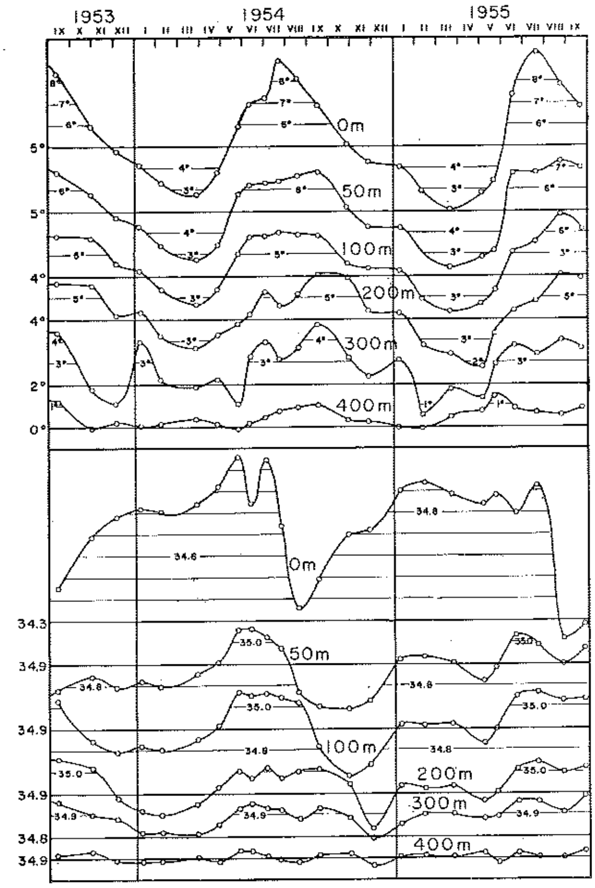

Fig. 105. *Temperature and salinity variations at different levels at station S–3.*

perature. The annual amplitude of the air temperature in 1954 was about 3° in excess of that of the sea temperature, and it was as much as 6° in excess in 1955. At the meteorological station Grímsey the mean value for this excess was found to be 3.5° for the period 1901–1930 (Stefánsson 1954*a*, p. 6).

As an example of the temperature and the salinity variations at different levels the results from station S–3 have been chosen (Fig. 105). The results from the other stations on this section gave a very similar picture. In the surface layer the temperature varies between a minimum of 2–3° in winter and a maximum of about 9° in summer. With increasing depth the annual amplitude becomes progressively smaller and at 400 meters it is hardly noticeable. At the surface the temperature minimum occurs in March and the maximum in July. At the lower levels the temperature minima are usually in phase with that of the surface, but the temperature maxima at subsurface depths occur later in the summer, as late as September at 200 meters. The surface salinity changes relatively little during the first half of the year. In midsummer it drops suddenly, by as much as 0.7‰, to reach a minimum of less than 34.4‰ in August–September. Then it rises again to reach a value of 34.8–34.9‰ in late winter. At the lower levels the annual salinity range becomes much smaller. At 50 meters it is less than 0.4‰, at 200 meters 0.2–0.3‰ and at 300 meters 0.1–0.2‰. At 400 meters no seasonal salinity variations can be established as the difference between observations is of the same order as the uncertainty in the salinity titrations. A conspicuous feature in the salinity variations is the much later occurence of a salinity minimum in the deeper layers than at the surface. At 200 meters this occurs as late as December–January. The salinity maximum is also delayed at subsurface depths, but the phase difference is here less distinct.

The temperature distribution at different times of the year is further illustrated (Fig. 106) by the temperature isopleths at stations S–2 (66° 24′ N, 18° 50′ W) and S–4 (66° 45′ N, 18° 50′ W). At station S–3 the conditions resembled closely those found at S–2. At station S–4 the temperature is somewhat lower than at S–2, especially in the upper layers, but otherwise the variations are very similar at all three stations. As was shown in Fig. 105, the surface temperature reaches a maximum of 8–9° in July but at subsurface depths the maximum is reached later, in August or September. The waters are subject to seasonal variations even below 300 meters, but at 400 meters or deeper the temperature variations are small and irregular. It is noticeable, however, that the temperature variations in the bottom layers show a distinct similarity at all three stations. Since the stations were not worked simultaneously but with a time difference of several hours, the observed correlation between the temperature variations of the deep water indicate that the variations concerned are not due to short-period changes in the distribution of mass. In both years the minimum temperature occurs in March at all levels down to 300 meters. At that time the water is isothermal down to 300 meters. The temperature variations are qute similar in both years, but in 1955 the vernal warming up was somewhat more abrupt. A peculiar feature of the temperature variations at 200–300 meters appears in both years. When the winter convection starts the water is cooled from above, becoming isothermal down to about 200 meters in early winter. But the intermediate water also appears to be cooled from below, possibly because of a cold and dense water having moved in, presumably from the north, and replaced or mixed with the lower levels of the intermediate water. By midwinter, however, the convection has reached deeper, and thus the lower levels of the intermediate water are again warmed because of mixing from above.

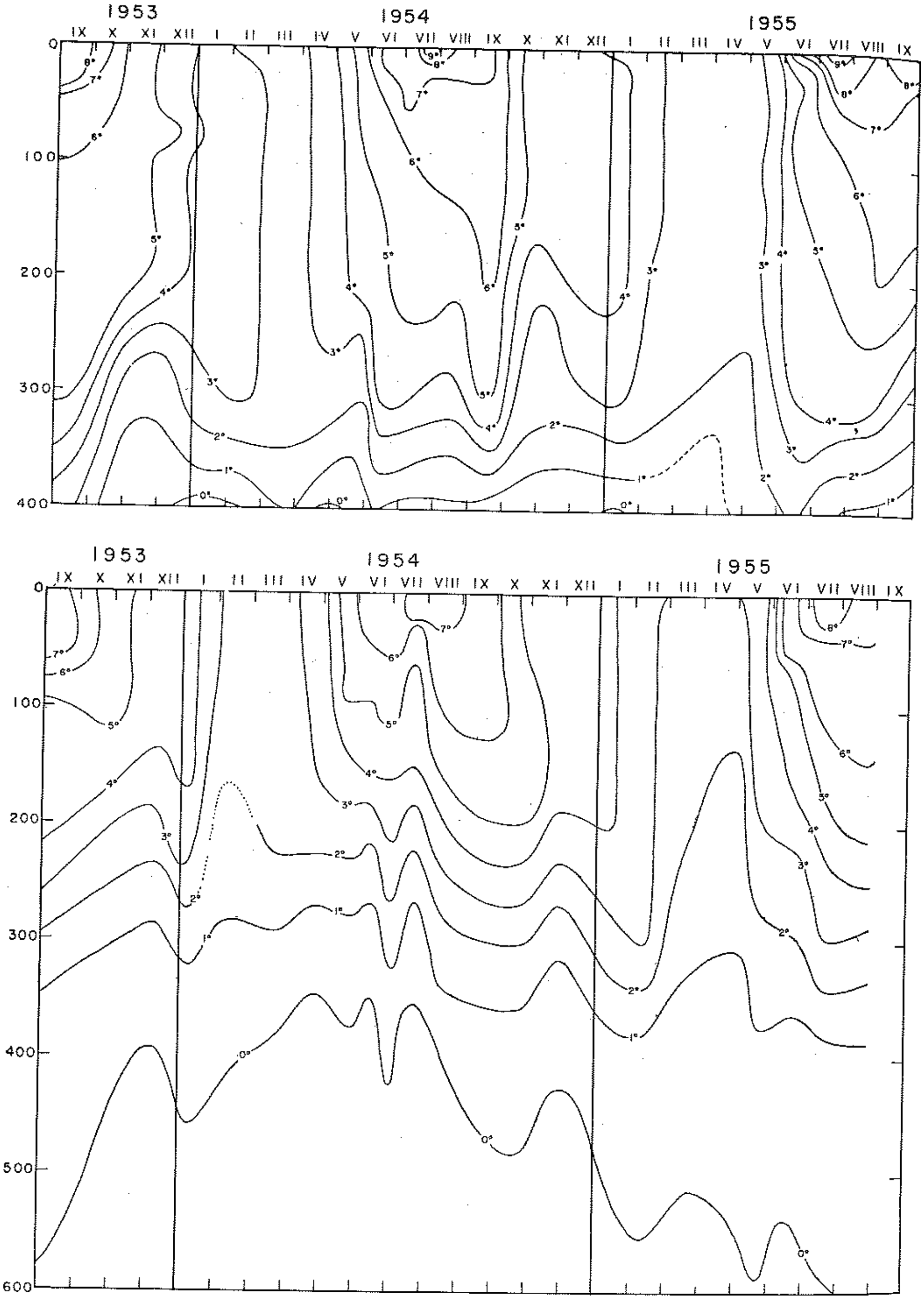

FIG. 106. *Temperature isopleths at station S–2 (on top) and S–4 (below) September 1953 to September 1955.*

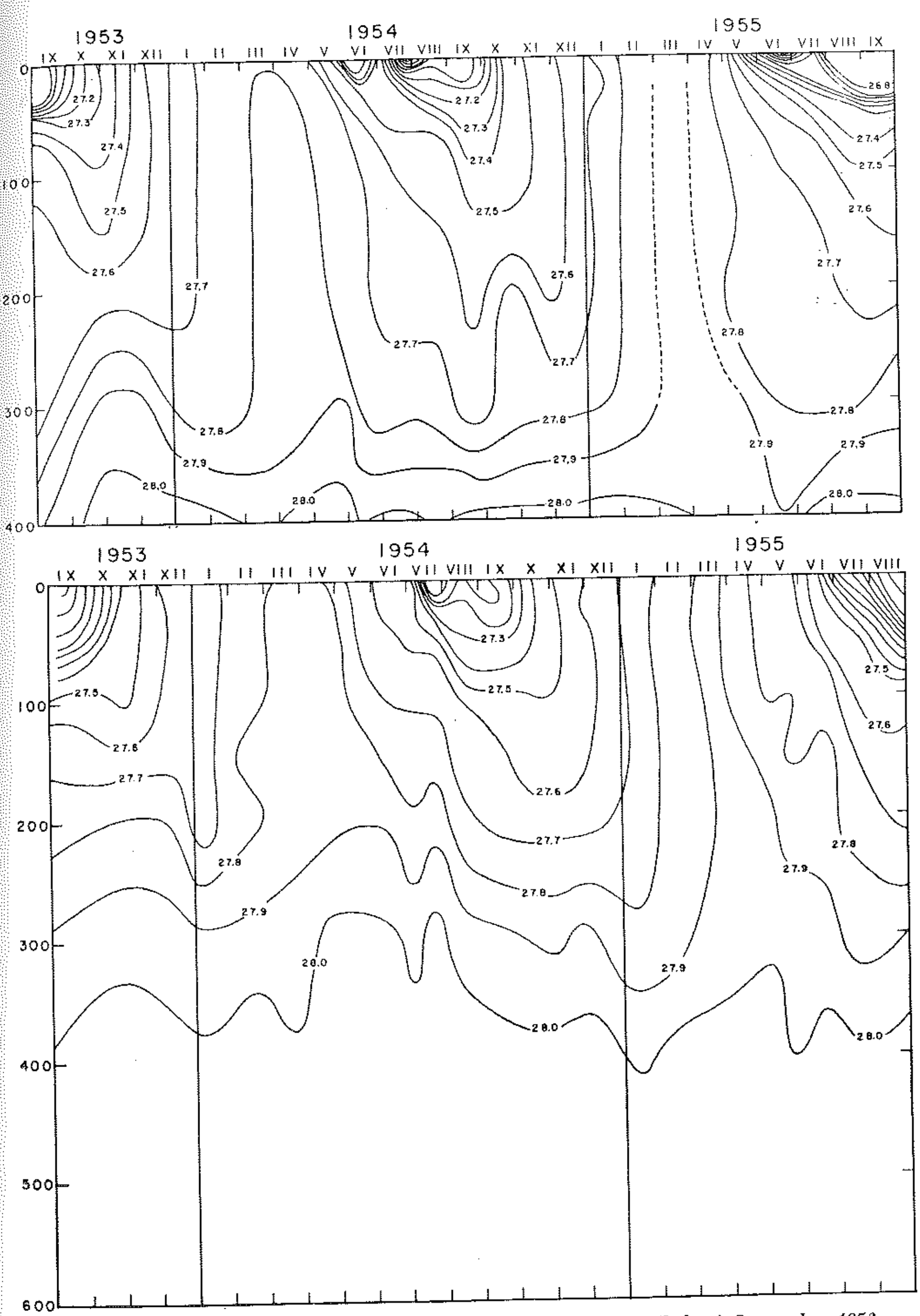

Fig. 107. *Density isopleths at station S–2 (on top) and S–4 (below) September 1953 to September 1955.*

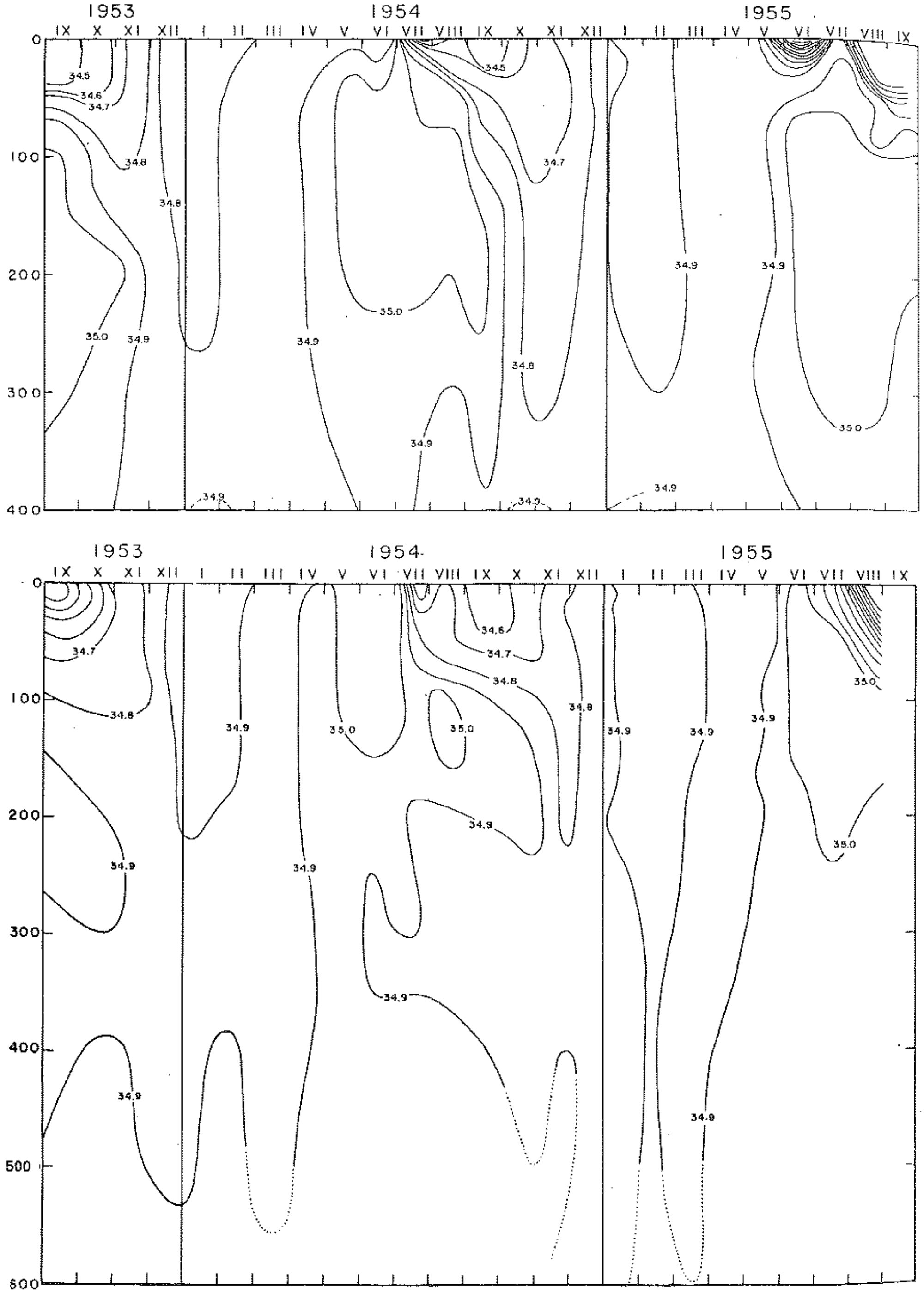

FIG. 108. *Salinity isopleths at station S–2 (on top) and S–4 (below) September 1953 to September 1955.*

A noticeable feature of the temperature distribution of the deep water at station S–4 is the difference in the position of the 0° isotherm. In 1954 it fluctuates between 350 and about 450 meters but in 1955 it lies below 500 meters. This seems to indicate that the quantity of Arctic Bottom water at this station was greater in 1954 than in 1955.

The variations in density (σ_t) at the two stations are shown in Fig. 107. Obviously the course of the σ_t curves resembles that of the isotherms. Stratification starts in early May and gradually the light surface water reaches deeper and deeper. The vertical density gradient and hence the stability was decidedly greater during the summer of 1955 than during 1954. The winter convection started in October both in 1953 and 1954, and in February and March the density was practically constant down to 300 meters.

Fig. 108 illustrates the salinity isopleths at stations S–2 and S–4. In the surface layers the highest salinity is usually found in spring or early summer (cf. Fig. 105), and the lowest in late summer or autumn. In 1955, however, two salinity minima are found in the surface layer at station S–2, one in June and the other in August–September. At intermediate depths there is a layer of Atlantic water characteristic of the summer season. Whereas this water may reach up to the surface at the beginning of summer it is found to lie deeper towards the end of that season. The maximum depth of the 35.0‰ isohaline is about 300 meters. In the bottom layer, which usually consists of almost pure Arctic Bottom water, practically a constant salinity is found. Its mean value is 34.90‰.

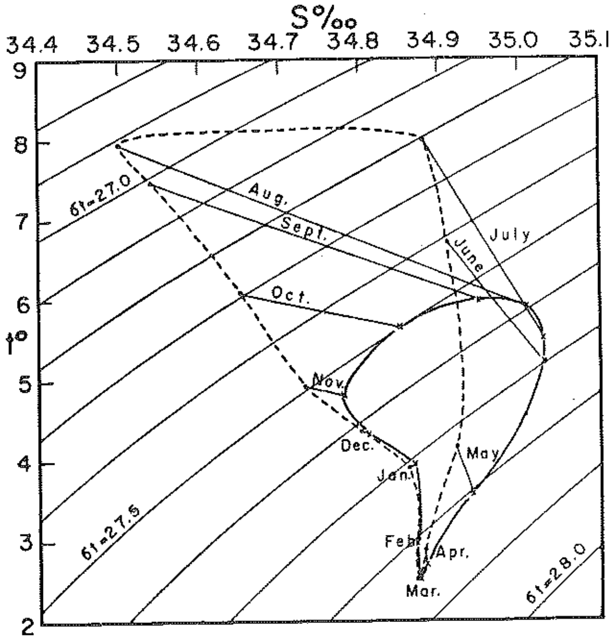

FIG. 109. *The t, S cycle for station S–3.*

The t, S cycle for station S–3 is illustrated in Fig. 109. It is based on the mean values for the two-year period September 1953 to August 1955. The points lying on the dotted curve represent the t, S values of the surface layer, 0–30 meters, and the points on the solid line the corresponding mean values for the intermediate water, 50–200 meters. The annual cycle in the hydrographic features is clearly demonstrated. In February and March the water column is homogeneous. In April the surface layers begin to warm and the intermediate layers to less extent. At the same time the salinity increases. From May to July the stratification increases progressively, but during this period the density difference between the surface layers and the intermediate layers is mainly due to temperature difference. In August the decrease in the surface salinity causes a noticeable change in the t, S cycle and during the autumn months the density gradient is mainly due to salinity difference. The greatest density gradient is found in August and September. From September the temperature and the salinity decrease steadily until the water becomes practically homogeneous again in winter.

4. REGIONAL DIFFERENCES IN THE SEASONAL VARIATIONS

The main features described for the stations of the Siglufjörður section will undoubtedly apply to most of the region between Skagagrunn and Sléttugrunn (see Fig. 1). In other parts of the North Icelandic area observations from different seasons are very limited. However, from November in the years 1934–1937 there exist almost simultaneous observations in the sections off Kögur and Langanes. These sections are shown in Fig. 110.

In November 1934 no Atlantic water appears to be present north of Kögur as judged by the temperatures and the salinities which indicate Coastal water at the first two stations of the section and mostly Polar water at the third station. In 1935 and 1936 Atlantic water is present but in less quantity than is usually observed in this section in summer, and in 1937 the Atlantic influence is even less. East of Langanes, however, the relatively high salinity found at subsurface depths in November indicates an admixture of Atlantic water in no less quantity than north of Kögur. The temperature is also relatively high, being 4–5° or even above 5° in the uppermost 200 meters. These sections thus reveal the interesting fact that in late autumn the quantity of Atlantic water north of Kögur is quite small as compared to the summer season, whereas east of Langanes the Atlantic influence is just as apparent in November as in August.

Three stations worked at the beginning of December 1953 off Húnaflói (Fig. 111) also indicate a reduced Atlantic influence in that region in late autumn.

In midwinter, however, February to March, the situation is entirely different (Fig. 112). Off Kögur the Coastal water seems to be limited to the region inside the 100 meter depth contour, as farther offshore the temperature increases by as much as 3° and the salinity exceeds 35.0 or even 35.1 ‰. Thus the boundary between the Atlantic and the Coastal water in this region seems to be sharper in midwinter than in late autumn. Off Langanes, on the other hand, low temperatures prevail beyond the coastal area. Here the temperature is 1–2° in the uppermost 200 meters and the salinity below 34.8‰. The admixture of Atlantic water at this time must therefore be very small in the region east of Langanes.

In late winter the Atlantic water exerts a marked influence on the hydrographic conditions in the western part of the area north of Iceland. In late

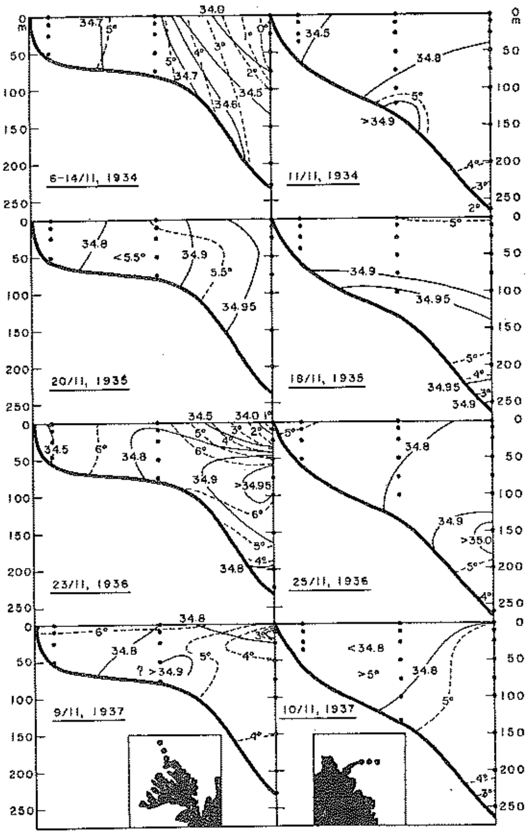

Fig. 110. *Hydrographic sections off Kögur and Langanes November 1934—1937.*

March 1954 (Fig. 113) the tongue of water with salinity above 35.0‰ extended almost east to the Húnaflóadjúp at the surface but in the deeper layers the Atlantic water did not reach as far east. In the region east of Skagagrunn the influence of Atlantic water seemed at this time to be very small. In late April the saline water had moved considerably farther east and at the same time the temperature in the surface layers had increased. East of the Eyjafjarðardjúp, however, the influence of Atlantic water seems to have been quite small.

Observations east of Langanes in April 1939 and May 1934 and 1935 indi-

TABLE 13.

Comparison of the mean temperature and salinity, 50—200 meters off Kögur and Langanes.

MONTH	YEAR	KÖGUR		LANGANES		DIFFERENCE	
		t_1° (mean)	S_1‰ (mean)	t_2° (mean)	S_2‰ (mean)	t_1–t_2	S_1–S_2
February—March . . .	1935	5.31	35.09	0.97	34.77	4.34	0.32
	1938	6.00	35.13	1.71	34.78	4.29	0.35
	1948	(5.75) [1]	.	1.82 [1]	.	(3.93) [1]	.
June	1936	6.15 [2]	35.00 [2]	2.65 [2]	34.93 [2]	3.50	0.07
	1952	5.03	35.00	1.77	34.86	3.26	0.14
	1953	5.35 [2]	35.04 [2]	2.21 [2]	34.88 [2]	3.14	0.16
	1954	5.87	35.02	3.17	34.91	2.70	0.11
	1957	6.36	35.11	3.08	34.93	3.28	0.18
	1958	4.82	34.97	1.90	34.85	2.92	0.12
July	1938	5.13	35.01	3.18	34.86	1.95	0.15
	1947	6.79	35.07	2.88	34.64	3.91	0.43
	1948	6.56	35.12	3.30	34.87	3.26	0.25
	1951	5.92	35.11	1.57	34.85	4.35	0.26
August	1934	6.83	35.05	3.50	34.86	3.33	0.19
	1935	6.88	35.07	4.75	35.00	2.13	0.07
	1936	6.76	35.14	5.83	35.01	0.93	0.13
	1939	6.10	34.93	4.95	35.07	1.15	-0.14
	1948	7.00	35.11	3.65	34.86	3.35	0.25
	1949	6.20	35.11	1.92	34.79	4.28	0.32
	1951	6.47	35.13	3.86	34.98	2.61	0.15
	1954	6.81	35.03	5.50	34.98	1.31	0.05
	1956	6.36	34.99	4.28	34.94	2.08	0.05
	1957	6.98	35.13	5.79	35.00	1.19	0.13
	1958	6.94	35.11	3.10	34.90	3.84	0.21
	1960	7.01	35.12	4.97	35.05	2.04	0.07
November	1934	1.69	34.35	4.66	34.83	–2.97	–0.48
	1935	5.70	34.97	5.32	34.92	0.38	0.05
	1936	5.62	34.92	5.42	34.90	0.22	0.02
	1937	3.98	34.80	4.72	34.80	–0.74	0

1) 0—150 m. 2) 50—100 m.

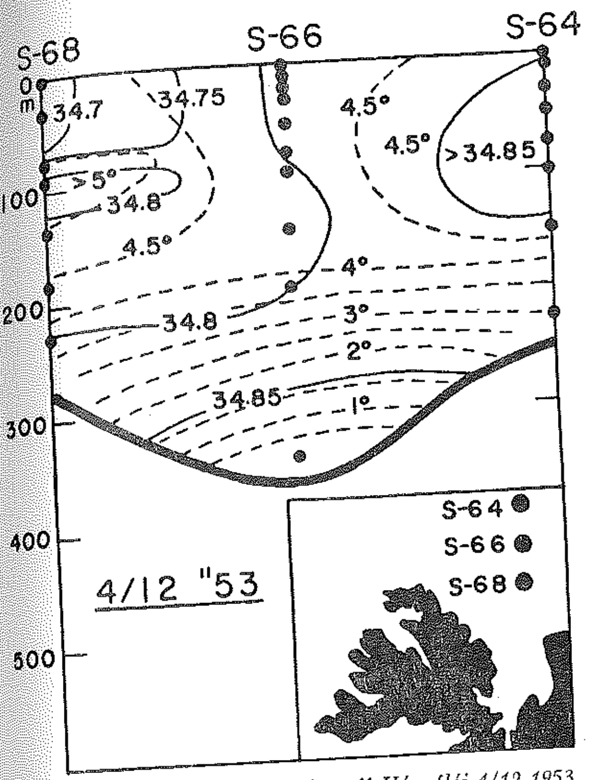

FIG. 111. *Hydrographic section off Húnaflói 4/12 1953.*

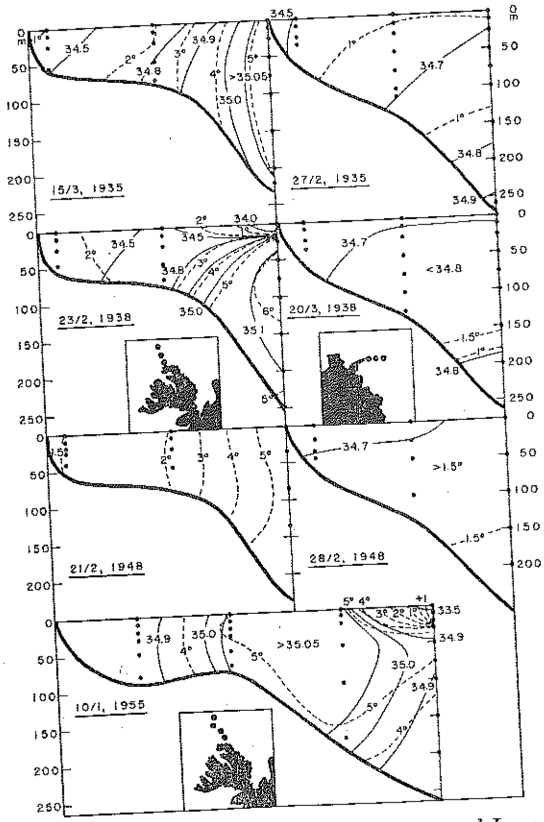

FIG. 112. *Hydrographic sections off Kögur and Langanes in midwinter 1935, 1938, 1948 and 1955.*

cate conditions very similar to those found for midwinter except for a slight temperature rise in the surface layers (Fig. 114). Thus no increase in the quantity of Atlantic water appears to take place from February to at least May. However, the sections worked off Kögur in May 1937 and 1939 indicate an Atlantic influence as strong as that found during summer.

In Table 13 a comparison is made of the mean temperature and the mean salinity of 50–200 meters at station K–3 (66° 53′ N, 23° 19′ W) and station L–3 (66° 22′ N, 13° 35′ W) at different times of the year. As will be evident from the table, the difference between the mean temperature of the intermediate layers off Kögur and off Langanes is greatest in winter and spring but least in late summer and autumn. The salinity differences show the same tendency. In November the mean temperature as well as the mean salinity appears to be similar off the northwest and the northeast coast, but in late winter the temperature at intermediate depths is about 4° higher in the western part than in the eastern part. It should be remarked, however, that this comparison refers to the deeper part of the shelf area; in the shallow coastal area the temperature will be more equal all along the coast.

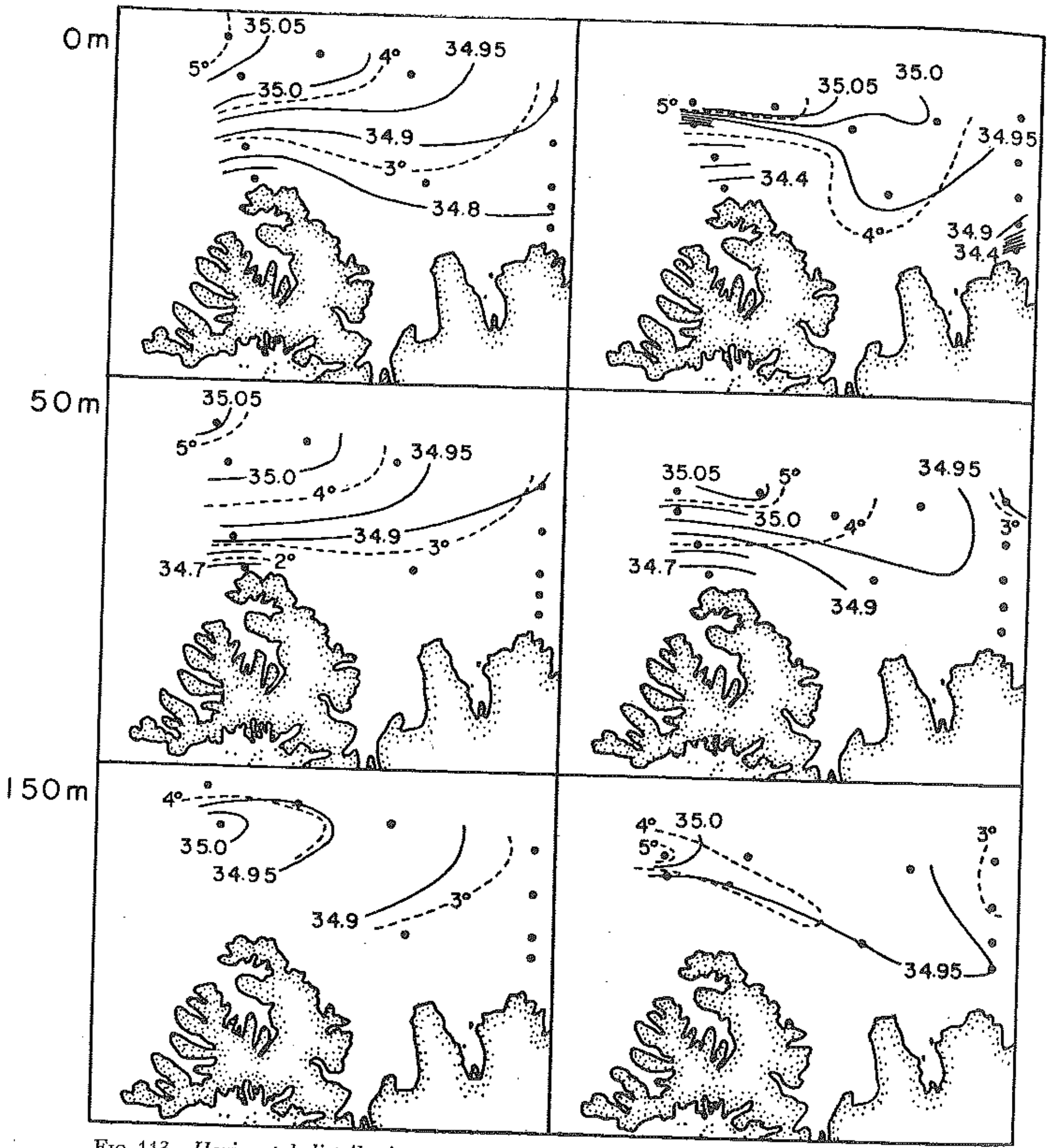

FIG. 113. *Horizontal distribution of temperature and salinity in the western part of the area north of Iceland 23/3—25/3 (at left) and 23/4—25/4 1954 (at right).*

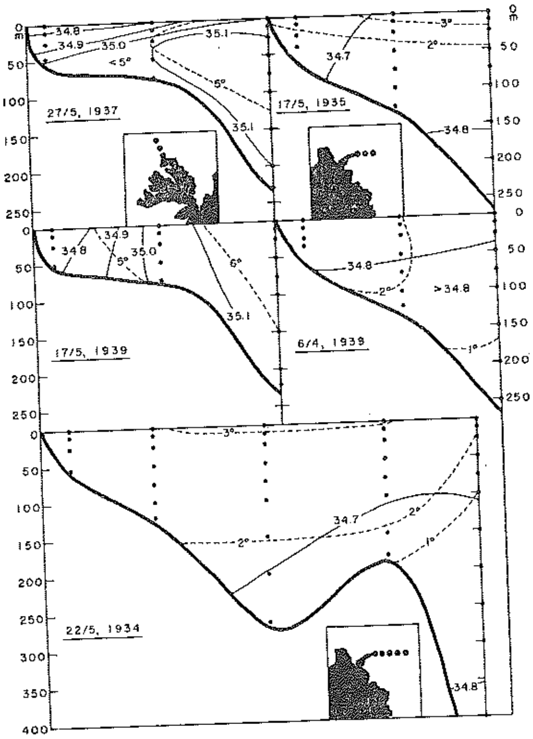

FIG. 114. *Hydrographic sections off Kögur and Langanes April–May 1934, 1935, 1937 and 1939.*

5. SEASONAL VARIATIONS IN THE COASTAL WATER

In summer when the water is stratified the light Coastal water will be limited to the thin surface layer above the thermocline, and it will spread away from the coast. In winter when vertical mixing is favoured the Coastal water will not be confined to the surface layer but may reach as far down as the winter convection allows. Hence the Coastal water will occupy a thicker layer of water in winter and then its horizontal extension must be less. This difference in the distribution of Coastal water between summer and winter is shown schematically in Fig. 115.

In connection with the seasonal changes in the distribution of the Coastal water it is of interest to compare the conditions off Kögur in late autumn to those in midwinter. In October to November the winter convection has started and the water is turned over. In November (Fig. 110) the homogenized water column must contain Coastal water from the summer which reduces its salinity. In February to March this water has been carried away from the area and the Coastal water now does not extend as far from the coast as in summer. Besides, the run-off from land may be reduced because of freezing. It is therefore not surprising to find in midwinter higher salinities and temperatures in the deeper part of the coastal area than were found in November, and they do not have to be connected with increased inflow of Atlantic water.

Due to this seasonal difference in "lateral oscillation" of the Coastal water (cf. HELLAND-HANSEN and NANSEN 1909, p. 258) one would expect an inverse relation between the surface salinity and the bottom salinity at inshore stations. This is roughly indicated in Fig. 116 which shows the seasonal variations in salinity at surface and near bottom at station S–1 (66° 16′ N, 18° 50′ W). Here the surface salinity is generally highest in winter, the reverse being true for the salinity at 50 meters.

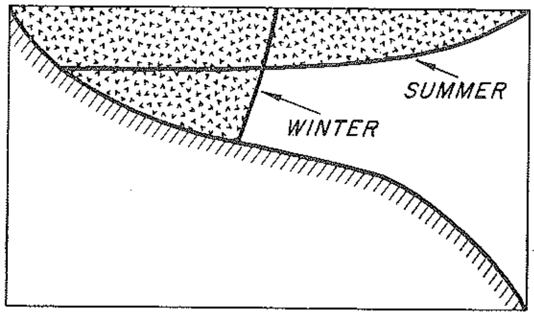

FIG. 115. *The difference in location of the boundary between coastal water and oceanic water in summer and in winter.*

The mean monthly run-off from the river Kolka in Skagafjörður during the period September 1953 to August 1955 is shown graphically in Fig. 116 (top). The annual cycle in the run-off of this river may be considered as characteristic for the region Skagafjörður–Eyjafjörður.[1] The monthly precipitation is also shown graphically in Fig. 116, calculated as the mean value for the two meteorological stations Siglunes and Grímsey.

The precipitation is greatest in summer and autumn but smallest in winter and spring.[2] To a certain extent the seasonal fluctuations in the drainage from land show similarity to those of the precipitation. However, all direct run-off rivers have rich water flood in spring when the snow thaws. At this time (see Fig. 116) the precipitation may be at a minimum. In late summer the run-off decreases considerably, but may increase again in autumn due to increased precipitation. When winter sets in direct run-off from rivers begins to decrease and diminishes steadily during the frost period (RIST 1956, p. 74).

As indicated by Fig. 116 (bottom) there is a distinct negative correlation between the surface salinity at the coastal station and the river discharge, whereas the negative correlation between the surface salinity and the precipitation is decidedly less. Thus the run-off from the land has a greater effect on the sali-

1) Information from the State Electricity Authority, Hydrological Survey.

2) According to verbal information from Mr. F. SIGURÐSSON of the Meteorological Office, Reykjavík, the precipitation measurements may not be reliable in winter. He believes the published values to be in general somewhat too low for that season.

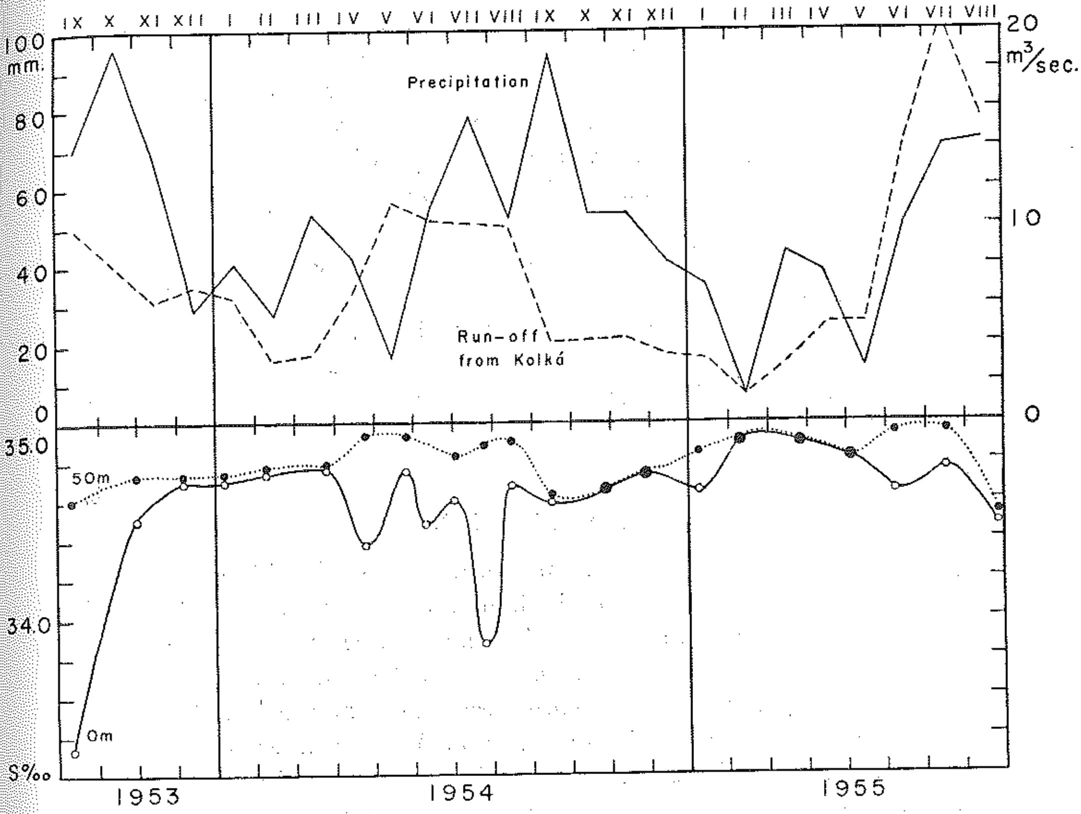

Fig. 116. *Variations in precipitation, run-off from the river Kolka, and salinity at the coastal station S–1 from September 1953 to August 1955.*

nity of the Coastal water than the amount of precipitation. A consideration of the relative magnitude of the precipitation in the coastal region as compared with the river discharge will also lead to this result. The mean annual precipitation in the North Icelandic coastal area for the period 1931–1955 amounts to about 500–600 mm.[1] The drainage area for the region between Kögur and Langanes amounts to 39.000 km^2 (Rist 1956, p. 38). If the mean run-off to the north coast of Iceland is estimated to be 50 liters sec.$^{-1}$ km^{-2} (op. cit., p. 124), the mean flow for the north coast area will be approximately $6.2 \cdot 10^{10}$ m$^3 \cdot$ year^{-1}. If the run-off from the land does not extend farther offshore than, say 100 naut. miles, which does not seem likely, the run-off from the north coast would be contained in a sea area of approximately 60.000–80.000 km^2. This would correspond to roughly 900 mm precipitation if the run-off water were equally mixed over the whole area. This, however, will certainly not be the case as the concentration of fresh water will decrease in an offshore direction. So the conclusion must be that at the inshore station, which is located only some 7 naut.

1) Information from the Meteorological Office, Reykjavík.

miles off Siglunes, the surface salinity must depend much more on fluctuations in the direct run-off than on fluctuations in the precipitation.

In the foregoing considerations only precipitation and run-off have been considered. Data on evaporation from this region are very limited. According to SVERDRUP (1946, p. 119) the amount of evaporation in higher latitudes is largely determined by the difference between the sea and the air temperature. Off the north coast of Iceland the sea temperature is several degrees higher than the air temperature in winter, the reverse being true for the summer season (STEFÁNSSON 1954*a*, p. 6, and 1954*b*, Fig. 12). In agreement with this the frequency of fog during the summer months is much greater than in winter in the North Icelandic coastal area (*Veðráttan* 1949, p. 56). Hence the evaporation in Noth Icelandic waters is probably less in summer than in winter in spite of higher water temperature.

6. DISCUSSION

From the results described in the preceding sections it will be evident that there exists an annual cycle in the distribution of Atlantic water. The relative quantity of this water, at any rate at intermediate depths, seems to increase during spring and reach a maximum eastward extension in autumn when its influence in the western part of the area seems to be markedly reduced. Thus it appears that the relatively great quantities of Atlantic water off Langanes in November are the remains of an influx having a maximum in summer but becoming reduced in autumn. The changes in the distribution of Atlantic water at the end of summer might therefore be explained as being due to a reduced inflow of Atlantic water or increased admixture with other water components.

It might seem possible to explain the results found as being due to increased vertical mixing at the end of summer whereby the presence of Atlantic water is masked. However, the distinctly greater difference between the mean temperature of the western part and the eastern part of the area in winter and spring than in summer and autumn, indicate a seasonal change in the Atlantic influence. Another argument that may be advanced is the fact that the mean salinity changes seasonally. Let us return to this feature which was illustrated in Fig. 104. The curves at the top illustrate the mean salinity of the whole water column from surface to 400 meters at station S–3 (dotted line) and the average for S–2, S–3 and S–4 (broken line). The general trend is obviously an increase in the salinity during spring with a maximum in summer, and a decrease at the end of summer. These salinity variations cannot be explained by differences in evaporation and precipitation (see above), so it must be concluded that there exists an annual cycle in the relative quantity of Atlantic water, the Atlantic component being greatest in late spring and summer, but smallest in early winter.

However, this conclusion alone does not necessarily imply a seasonal variation in the inflow of Atlantic water. Thus it should be noted that, whereas the salinity variations at the near-shore stations off Siglunes indicate a maximum Atlantic influence in early summer, June–July, the volume transport calculations for the sections off Kögur and Slétta generally yield higher values for August than June. The reason for this apparent discrepancy could be the greater precipitation in late summer than in spring. The increased stratification during summer might also be of importance (see later).

Let the composition of the water masses along the north coast of Iceland be represented by the following equation:

$$q_A \cdot S_A + q_C \cdot S_C + q_R \cdot S_R = q_t \cdot \overline{S},$$

where q_i denotes the quantity of the respective water masses and S_i their salinity. The subscripts A and C refer to Atlantic water and Coastal water respectively, R refers to water masses other than these two and t stands for the total. Let us consider how the different terms of the equation affect the magnitude of $\overline{S}$, the mean salinity.

Coastal water usually denotes Atlantic water or any other water mass diluted by fresh water from the land. For the sake of simplicity, however, q_C in the equation above denotes fresh water and hence $S_C = 0$. As was shown in the last section the precipitation is greatest in late summer and autumn and smallest in winter and spring, whereas the direct run-off from land has a maximum in summer and a minimum in winter. Therefore, neither the seasonal changes in the precipitation nor in the run-off can explain the higher mean salinity in summer than in winter.

On the contrary, the decreased quantity of Coastal water in winter when a great deal of the precipitation will be bound on land in the form of ice or snow will tend to increase the mean salinity. In this way the secondary maximum in the mean salinity in the winter of 1954–1955 (Fig. 104) may probably be explained. During that winter the frost was more severe than in the year before as seen from the air temperature. Therefore more fresh water was bound upon land and the run-off was indeed very small (Fig. 116). That this weak salinity maximum is the result of reduced run-off from land and hence an increased proportion of Atlantic water is supported by the temperature curve for 10 meters at station S–3 (Fig. 104). The temperature in January 1955 was practically the same as it was in December although the air temperature dropped suddenly during this period, and in February 1955 the temperature was only slightly lower than the year before in spite of much lower air temperature. The wind observations at the nearby meteorological stations Grímsey and Siglunes do not indicate more westerly winds during December and January 1954/55 than 1953/54. The density distribution in the Siglufjörður section in January and February 1955 certainly does not indicate an increased easterly current component (Fig. 118). On the contrary, during the whole observation period these two months are those with the smallest difference in dynamic height (400–0 meters) between stations S–2 and S–4. The explanation offered here therefore appears the most plausible one.

From the afore-mentioned considerations it will be clear that the annual cycle in the relative quantity of Atlantic water cannot be explained on the basis of seasonal variations in the volume of the Coastal water. However, it might seem possible to seek the clue to the lower mean salinity in winter in the difference between the distribution of the Coastal water in winter and summer. Conversely the higher mean salinity in summer might conceivably be explained on the assumption that only a part of the Coastal water is contained inside station S–4, the rest of it being carried farther north.

It seems doubtful if the seasonal variations in the relative quantity of Atlantic water can be explained in this manner. In the first place, it was shown on p. 176 that the total amount of Coastal water is probably considerably greater in spring than in winter. Therefore, the increased offshore extension of Coastal water in spring and summer would have to affect the mean salinity more than does the actual amount of fresh water. Secondly, this lateral oscillation of the Coastal water can hardly explain why the layer of Atlantic water first appears in the western part of the coastal area, where the stratification is always less, and then gradually moves farther east reaching the easternmost part in late summer. Thirdly, if the seasonal difference in the distribution of Coastal water did explain the apparently less Atlantic influence in winter, one would expect to find a markedly greater increase in the mean salinity away from the coast in winter than in summer. However, except for the months September 1953 and October and November 1954, the mean salinity at stations S–2 and S–4 was almost identical during the two years period. At the time of maximum salinity in the early summer of 1954 and 1955 the Atlantic water occupied the surface layers at stations S–3 and S–4 and the same was true of stations situated near the core of the North Icelandic Irminger Current in the sections off Húnaflói and Kögur. At this time, therefore, all the Coastal water must have been confined to the shore-side of the Atlantic water, and hence a part of it could not have escaped north of stations S–3 and S–4. Later in the summer, however, when the mean salinity was found to be less, the Coastal water appears to have reached its maximum offshore extension. The conclusion from these arguments must be that, although the distribution of Coastal water undoubtedly undergoes seasonal variations in the manner described, such variations cannot be responsible for the marked seasonal changes in the relative quantity of Atlantic water.

Let us next consider the oceanic water masses other than Atlantic water. These have a lower salinity than the Atlantic water, and therefore either a seasonal change in their salinity or their magnitude will affect the mean salinity. The salinity of these water masses will not change appreciably with the season, except for the Polar water whose salinity will decrease in summer. Such a change will certainly not increase the mean salinity. However, the admixture of Polar water at stations S–2 to S–4 appears at all seasons to be almost insignificant.

On the basis of the available data it is not possible to prove whether the influx of Arctic water from the north changes seasonally. It was pointed out previously that as the autumn overturn cools and dilutes the Atlantic water layer in the Siglufjörður section from above, it also appears to be reduced from below by Arctic water having moved in. A similar process takes place in other parts of the area as indicated in Fig. 117 which shows the vertical variations in temperature and salinity at a locality north of Slétta on the 14th of September and the 31st of October 1953. This process could be explained either by a decreased Atlantic influx or an increased influx of Arctic water or the combined effect of both. But if the Atlantic influx to the area north of Iceland were constant the observed changes in the mean salinity would imply a greater influx of Arctic water and hence an increased easterly current in winter. The density distribution indicates that such cannot be the case.

Seasonal variations in the salinity of the Atlantic water entering the area north of Iceland are not known to exist. The final conclusion must therefore be that the seasonal variations in the relative quantity of Atlantic water are due to variations in the Atlantic current component.

The density distribution indicates that the east-going current component is strengthened in summer, not only in the region near the coast but also along the slope.

The difference in dynamic height of the surface relative to 400 decibars between stations S–2 and S–4 at various observational dates is shown in Fig. 118. The seasonal changes in the difference of the dynamic height indicate a stronger east-going current component between stations S–2 and S–4 in summer and weaker in winter.

From Fig. 107 it is evident that the density is reduced during summer at all depths between the surface and 200–300 meters at stations S–2 and S–4. Similar seasonal changes must be presumed to take place in other parts of the insular shelf. North of the Icelandic submarine terrace, however, the seasonal changes in density will be mostly limited to the surface layer above the thermocline, whereas at depths below 50–75 meters the density will probably be similar in summer and winter. Thus observations made in April 1957 in the area between Slétta and Siglunes north of 68° N showed temperatures at 50–140 meters similar to those usually found in June or August in that region. From this it follows that the mean density of the water column in the shelf area will be reduced to a greater extent during the summer season than that of the water column in the area north of the slope. This indicates a stronger east-going current across the region in summer than in winter.

Now the question arises as to which are the causes of the seasonal variations in the North Icelandic Irminger Current. It will not be attempted to give

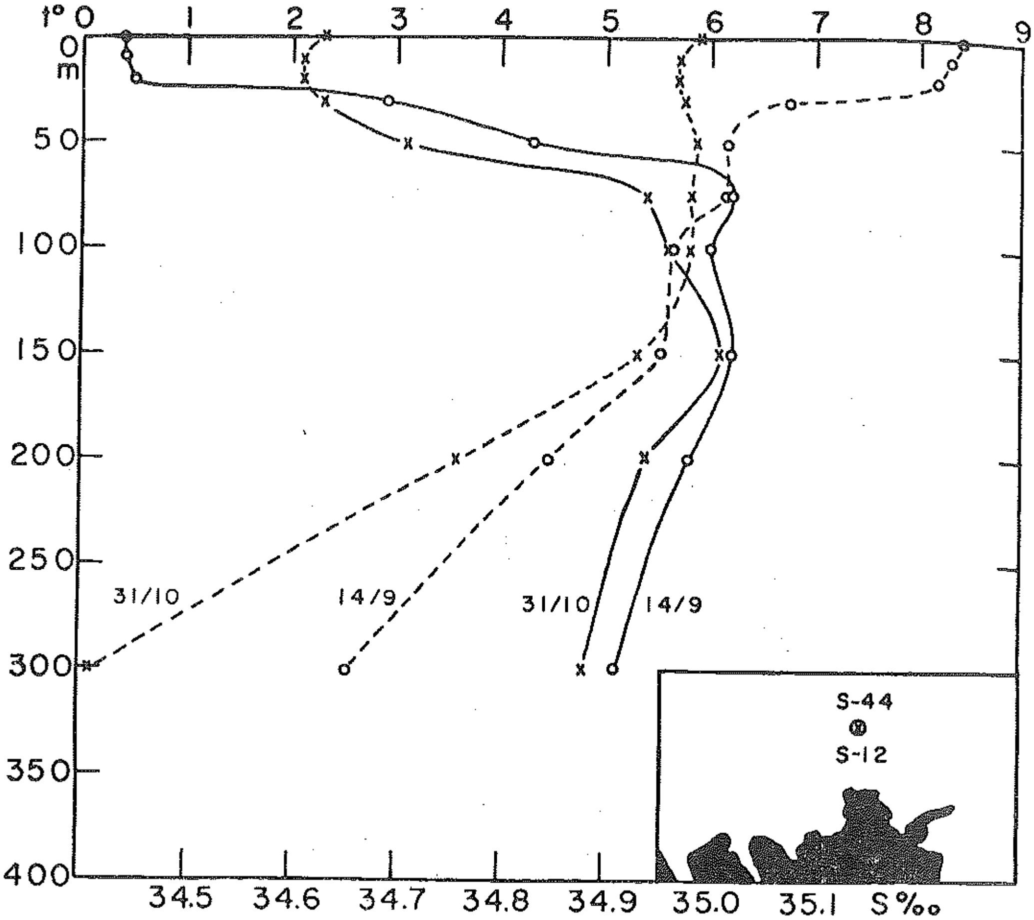

FIG. 117. *Vertical variations in temperature (broken lines) and salinity (solid lines) at a station north of Melrakkaslétta 14/9 and 31/10 1953.*

a complete answer to that question here. However, let us briefly consider some of the possible causes.

It is well known that the winds are very variable in the vicinity of Iceland. Yet the mean pressure distribution (e.g. the 1931–1960 mean) indicates a definite seasonal variation, viz. increased SE-winds in winter but less frequent SE-winds in summer. These changes, however, are very small, whereas the differences from one month to another may be great and irregular. Therefore, it seems hardly possible that the relatively regular seasonal change in the Atlantic influx to the region north of Iceland results from seasonal variations in the prevailing wind system.

It must be presumed that the warming up in summer will have a greater effect on the coastal water than on the Atlantic water. The density of the coastal water will therefore be lowered to a greater extent in summer than that of the

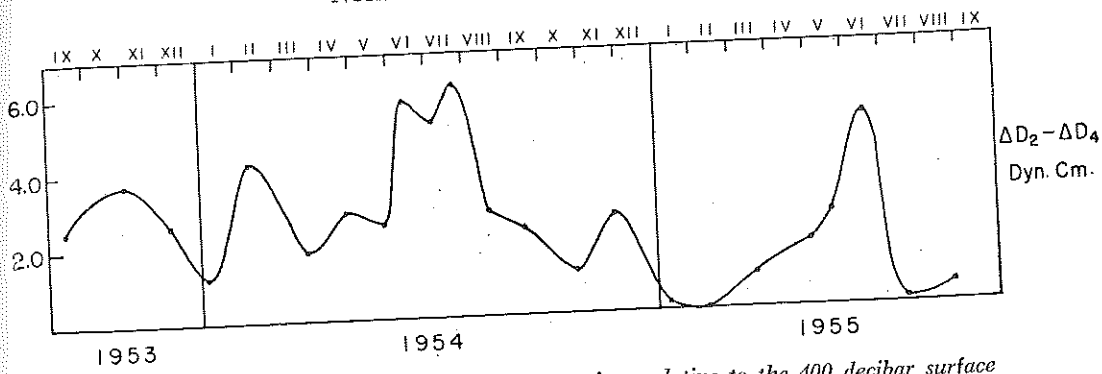

FIG. 118. *Difference in dynamic height of the sea surface relative to the 400 decibar surface between stations S-2 and S-4 at various observational dates during the period September 1953 to September 1955.*

Atlantic water. This change in the density distribution will cause a stronger east-going current in the shallower part of the coastal area during the summer season.

Here should also be mentioned the theory advocated by KRAUSS (1955) that the source of energy for oceanic currents in high latitudes is the field of mass maintained by the run-off of fresh water along the coast. Although it may be doubtful that the fresh water afflux can account for the quasi-permanent oceanic circulation, such as the Norwegian Atlantic Current (cf. SÆLEN 1959, p. 9) it seems likely that coastal currents such as around Iceland are largely maintained by the fresh water afflux along the coast. As this afflux is increased in spring and summer, it must be presumed that the coastal current is strengthened during these seasons. This increased coastal circulation may in turn accelerate the movement of the Atlantic water farther offshore.

With the increased stratification in summer the frictional forces will become less. Conversely, in winter the stability becomes smaller and friction is increased, whereby the current will be weakened. The variations in stability may thus play an important role in creating seasonal variations in the strength of the current, but a further study of this phenomenon is beyond the scope of this paper.

XIII.

ANNUAL VARIATIONS

In the region north of Iceland where the conditions are governed by complex hydrographical factors, great year to year variations have been observed in the surface layers as well as at intermediate depths.

Numerous investigations have revealed a general increase in the sea surface temperature of northern waters in recent decades. In the North Icelandic coastal area the surface temperature fluctuated somewhat irregularly until 1920. In the twenties a marked increase was observed in the sea surface temperature culminating between 1930 and 1940 (Fig. 119). The rise in temperature was especially conspicuous in the eastern part of the North Icelandic coastal area (SMED 1949, p. 11; STEFÁNSSON 1954 *a*, p. 25). Similar changes have undoubtedly also occurred at subsurface depths, but the material at hand is in general too sparse to prove them.

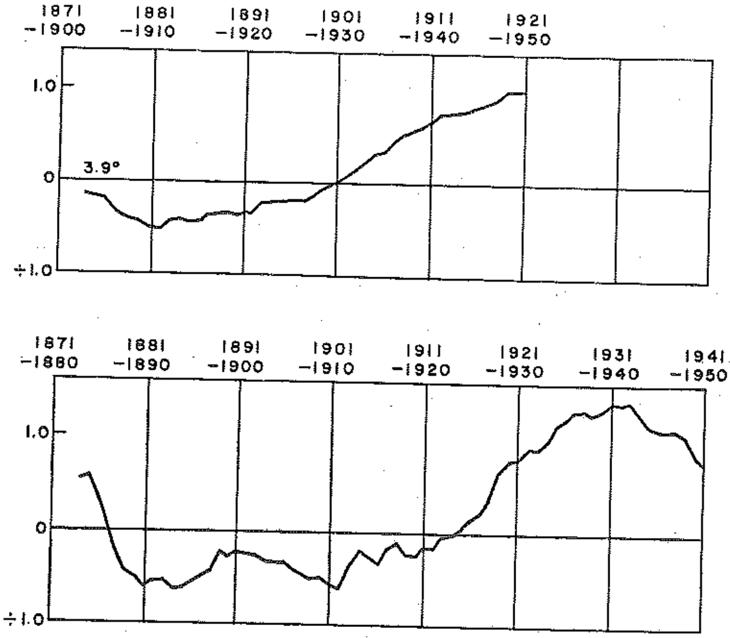

FIG. 119. *Variations in the annual mean sea surface temperature at Grímsey in consecutive 30 years periods (at top) and in consecutive 10 years periods (below). (After Stefánsson 1954).*

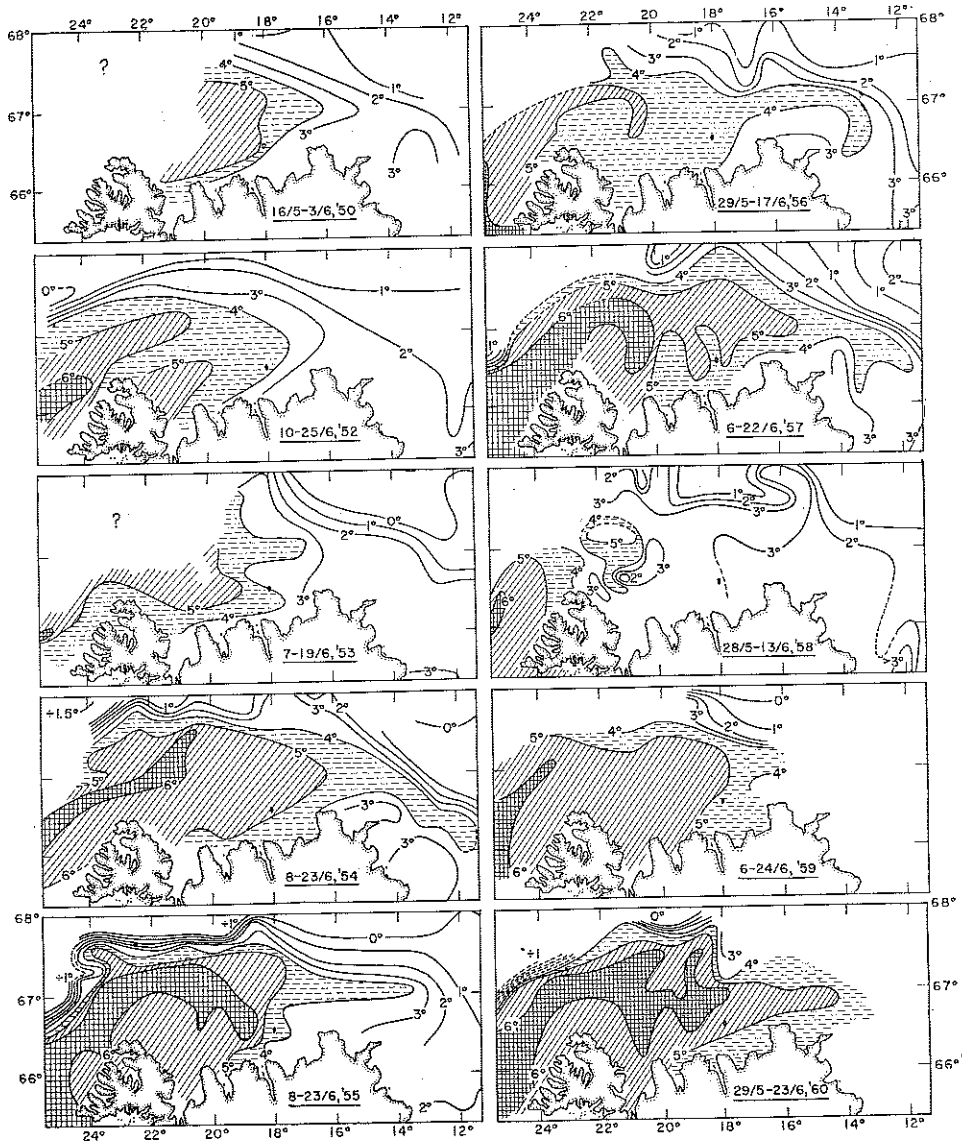

FIG. 120. *Distribution of temperature at 50 meters depth in May–June 1950 and 1952—1960.*

Numerous examples of the differences between years in the horizontal distribution of temperature and salinity in North Icelandic waters may be seen by consulting the author's reports in Annales Biologiques for the years 1951–1960.

As an example of horizontal variations Fig. 120 shows the year to year variations in the distribution of temperature at 50 meters. The observations are from May–June 1950 and 1952–1960. Of the 10 years under consideration 1960 was the warmest, but 1954, 1955 and 1957 were also warm years.

1959 was moderately warm, especially in the western part of the shelf. The years 1950, 1952 and 1953 were moderate or rather cold in June; 1956 was rather cool in the western part of the area, but relatively warm in the eastern part, whereas 1958 was an abnormally cold year. In the Húnaflói region the temperature conditions were quite complex in early June 1958 in the surface layers as well as at subsurface depths.

1. ANNUAL VARIATIONS IN THE EXTENSION OF DRIFT ICE

The occurrence of drift ice at the coast of Iceland has a pronounced influence on the climate in the country. During the last century heavy ice years were frequent, with the result that all navigation along the north coast was blocked and farming suffered greatly.

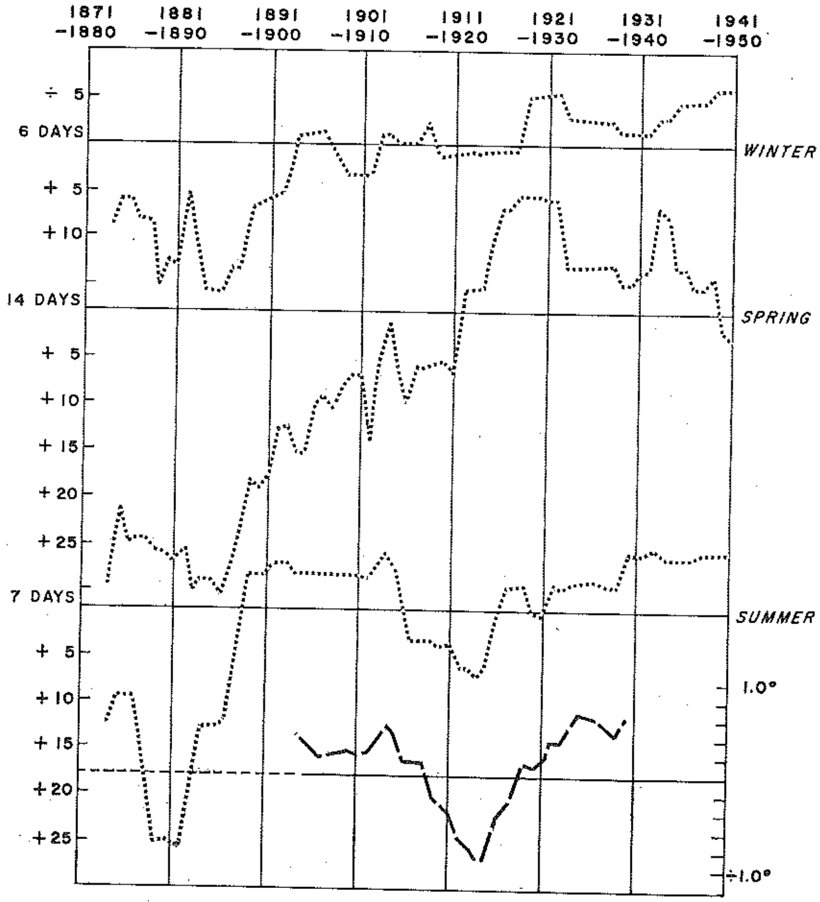

FIG. 121. *Variations in the frequency of drift ice in winter, spring and summer. Broken line shows temperature variations in the western area (21°—24° W) in summer (After Stefánsson 1954).*

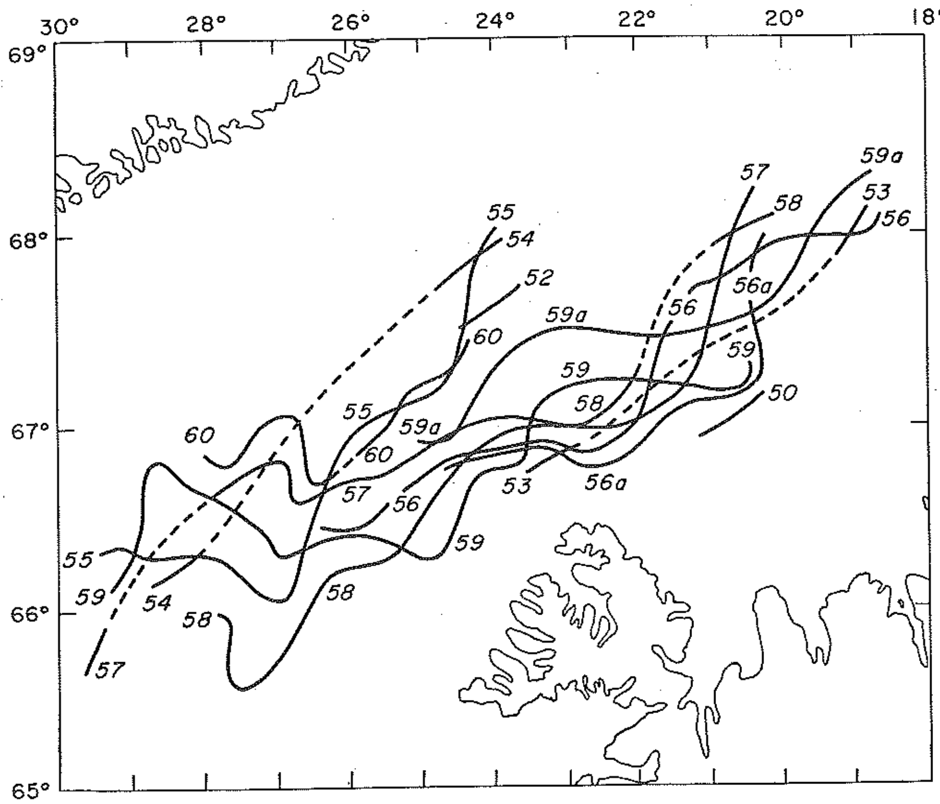

Fig. 122. *The position of the ice limit in June 1950—1960.*

Since the beginning of this century the ice conditions at Iceland have been improving, and in recent decades drift ice has rarely been observed in the coastal area except for occasional scattered floes. Studies on the annual and seasonal variations of drift ice (Stefánsson 1954 *a*, pp. 21–23) reveal a distinct decrease in ice frequency shortly before the turn of the century and again in the twenties. The mean values of the frequency of drift ice at the northwest coast of Iceland for the period 1901–1930 are as follows: winter 6 days, spring 14 days, summer 7 days and the entire year 27 days (see Fig. 121). During the last three decades the mean frequency for the whole year has been less than 2 weeks.

In spite of the general improvement of the ice conditions the extension of ice on the Iceland–Greenland Ridge and north of Húnaflói may be quite variable. In some years the drift ice limit is in May–June located midway between Northwest Iceland and Greenland, whereas in other years it may be only few miles off the coast of Iceland. This is apparent from Fig. 122 which shows the ice limit in June in the years 1950–1960. Of these the years 1952, 1954, 1955 and 1960 were favourable ice years whereas in June 1953, 1956 1957 and 1958 the ice limit was only some 30 miles off the coast.

As was mentioned previously, the drift ice has normally much less extension in summer than in spring. Very often, however, the ice conditions may be quite different from what is indicated on the mean charts. Thus in July 1949 the ice limit was only 30–40 miles off Kögur, but in August that year no drift ice was observed at a distance of 80–90 miles off the coast. In early July 1951 the ice was located farther off the coast than was found about the middle of August. In 1956 the ice conditions were also abnormal, drift ice being observed in the western part of the coastal area throughout the summer. Usually, however, the shelf area north of Iceland is icefree during July and August as was the case in 1954, 1955, 1957 and 1958. In September, the whole area between Northwest Iceland and Greenland is normally practically icefree.

Low surface temperatures and salinities, especially in the western part of the area, are usually associated with the nearness of the ice limit. The cooling effect will be particularly marked in spring and summer, as will be apparent from Fig. 121 (bottom).

The northward extension of Atlantic water will naturally be less in heavy ice years. In Fig. 125 the course of the 35.0 ‰ isohaline is shown for June in different years in a vertical section north of Siglunes. In the favourable ice years 1952, 1954 and 1955 the 35.0 ‰ curve is seen to extend farther to the north than in the years when the drift ice was observed farther east. However, the influx of Atlantic water to the North Icelandic grounds does not appear to have a relation to the position of the ice limit. Thus in June 1956 and 1957 the Atlantic influence was unusually pronounced in the eastern part of the North Icelandic coastal area.

2. ANNUAL VARIATIONS IN DIFFERENT REGIONS OF THE SHELF

Since 1924 observations have occasionally been carried out at a few fixed stations in the North Icelandic coastal area. The most intensively investigated of these are 3 stations on the section northnorthwest of Kögur, 3 stations north of Siglunes and 3 stations east of Langanes (cf. chapter VIII). The temperature and salinity deviations in different years at these stations are shown in Tables I–XXIV in the Appendix. The deviations were calculated from the mean of the observations made up to 1960. Only variations from the summer season are here considered, as the observational data from other seasons are very limited.

Another way of studying year to year variations is to compare sections from different years. For assessing variations in the Atlantic influx this method is more reliable as the horizontal as well as the vertical distribution of temperature can be measured. However, only recent years' observations are extensive enough to make such a comparison possible.

Western area.

Temperature and salinity variations in the section off Kögur (Tables I–IX) may be considered as representative of the year to year fluctuations in the western part of the area.

At the coastal stations, K–1 and K–2, the lowest June temperatures were found in the years 1924 and 1953, and the highest temperatures were observed in 1936 and 1957. The June temperature was rather low in 1952, moderately high in 1954 and 1955, whilst 1926, 1959 and 1960 were average years. The lowest July temperatures were observed in 1924 and 1938 and the highest in

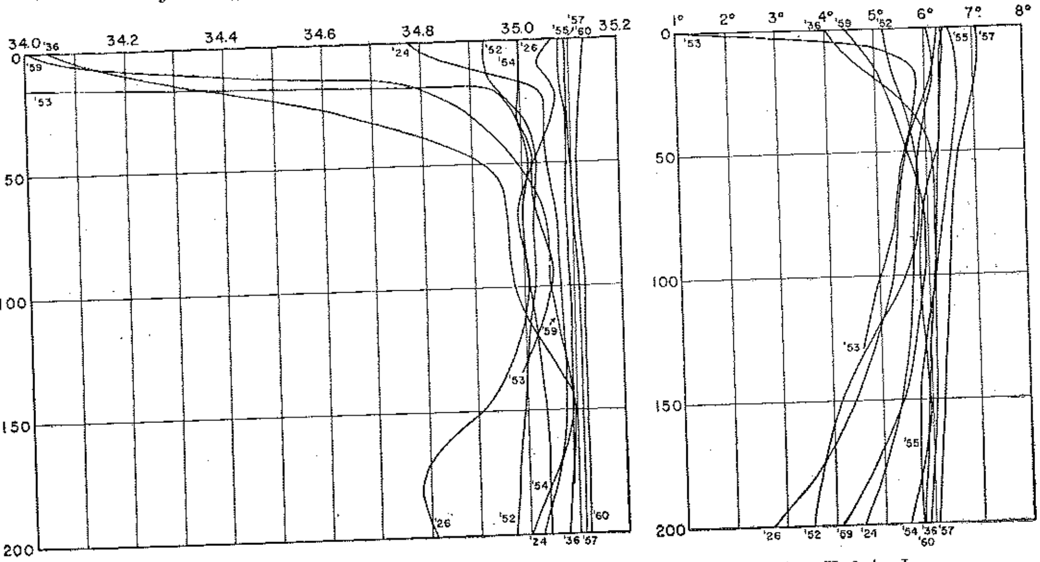

Fig. 123. *Variations in temperature and salinity with depth at station K–3 in June.*

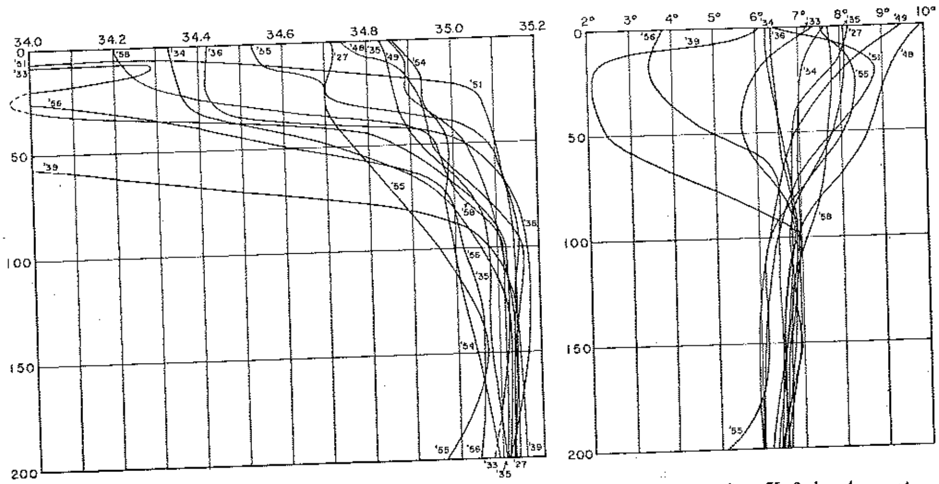

Fig. 124. *Variations in temperature and salinity with depth at station K–3 in August.*

1927, 1947 and 1957. Otherwise deviations in July were small. In August negative deviations predominated at K–1 and K–2 in the years 1934, 1949, 1954 and 1958 but positive deviations in 1933, 1939, 1948 and 1955. The salinity is seen to fluctuate in a similar manner as the temperature, especially at subsurface depths. This was to be expected, considering the close correlation between temperature and salinity previously mentioned.

Figs. 123–124 show the variations of temperature and salinity with depth at station K–3. At this station the conditions may be quite variable in the surface layer depending upon the nearness of the drift ice. Thus very low surface salinities and low surface temperatures were found in June 1936 and 1953 and in August 1933, 1939 and 1956. In the deeper layers considerable variations may be found in June, especially near the bottom, where the difference between observations from individual years may exceed 3° in temperature and 0.30‰ in salinity. The lowest June temperatures were found in 1926, 1952 and 1953, the years 1924 and 1959 were also cold at depths greater than 100 meters, whilst in the years 1954, 1955, 1957 and 1960 the deeper layers were found to consist of nearly undiluted Atlantic water. In August the conditions are found to be generally very uniform at depths greater than 100 meters. The year 1955 is here an exception, the bottom temperature being about 1° lower than in the other 12 years.

Middle area.

The variations in temperature and salinity at the three stations north of Siglunes (S–1, S–2 and S–3, see Tables X–XVIII) may be considered as representative of year to year fluctuations in the middle part of the coastal area.

The lowest June temperatures at all three stations were observed in 1924, but other cold years were 1952 and 1958. The highest June temperatures were found in 1936, 1954, 1955 and 1960.

The course of the 4° isotherm in late May 1950 and June 1952–1959 in the section north of Siglunes is shown in Fig. 126. The cross-sectional area of water with temperatures above 4° in the different years was measured with a planimeter, and the results are shown in Table 14, where the size of the areas is expressed as the fraction of the area determined for 1959. The table also contains the corresponding ratios between the areas confined by the 35.0‰ isohaline in different years, shown in Fig. 125. The observations in 1950 were carried out on May 30th–31st, whereas those of 1952–1959 were made during the period June 3rd to 16th.

According to Table 14, 1959 was the warmest of the 8 years compared, 1955 rates as the second and 1954 as the third; 1958 was by far the coldest. Usually, high salinities correspond to high temperatures. Thus the extension of water with salinity above 35.0‰ was greatest in 1954, 1955 and 1959, which were the warmest years in June in this region. However, there are notable exceptions such as in 1952 when low temperature coincided with relatively high salinity and vice versa, as was the case in 1957, but the difference in salinity between these two years may probably be ascribed to the ice conditions. Only slight influence of Polar water in the surface layers will lower the salinity to less than 35.0‰, although the Atlantic influx is not thereby reduced. Therefore, the course of the 35.0 % isohaline may not give a true picture of the actual Atlantic influx, whereas the temperature distribution at intermediate depths,

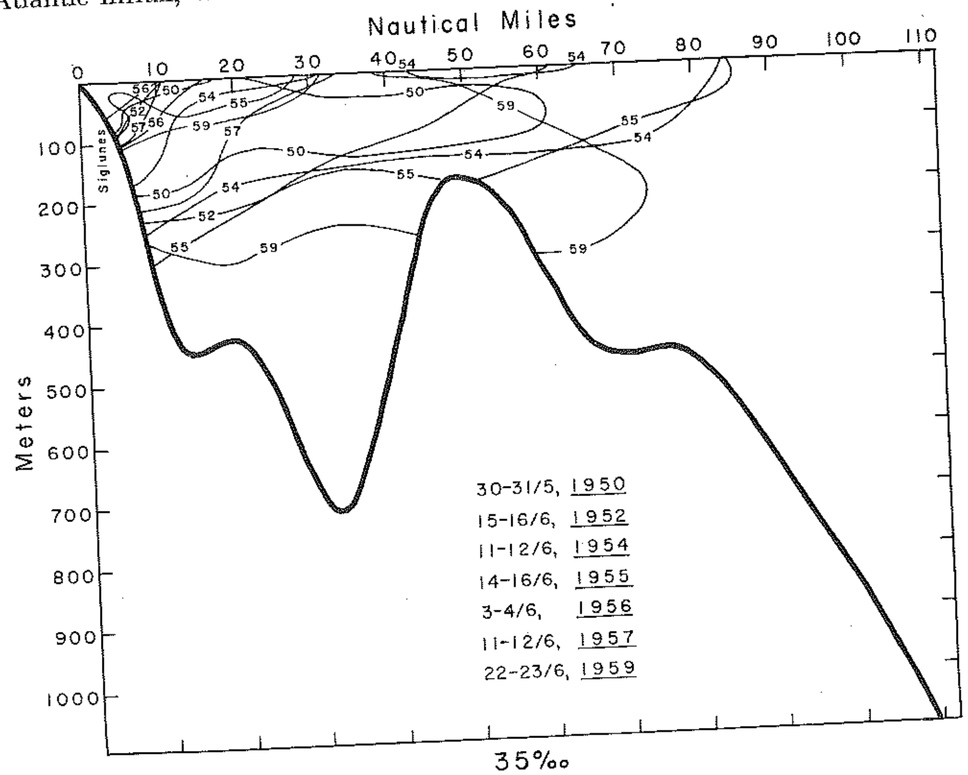

FIG. 125. *The course of the 35.0‰ isohaline for June in different years in the section off Siglunes.*

e.g. as judged by the size of the cross-sectional area confined by the 4° isotherm, will probably afford a better measure.

Of the 10–13 years with observations in July (Tables XIII–XV) 1932 and 1938 were the coldest, and 1926 and 1955 the warmest at the coastal staton S–1. At the deeper stations, S–2 and S–3, 1949 was definitely the coldest year, but other notably cold years were 1924, 1932 and 1938. July 1951 was about normal, but the other years showed positive anomalies. The highest temperature in the surface layers was observed in July 1926 and 1955.

In August 1925, 1931, 1954, 1956 and 1958 negative temperature deviations were predominant at the coastal station S–1, but in the years 1933, 1939, 1948, 1955 and 1960 positive deviations predominated. At the deeper stations, S–2

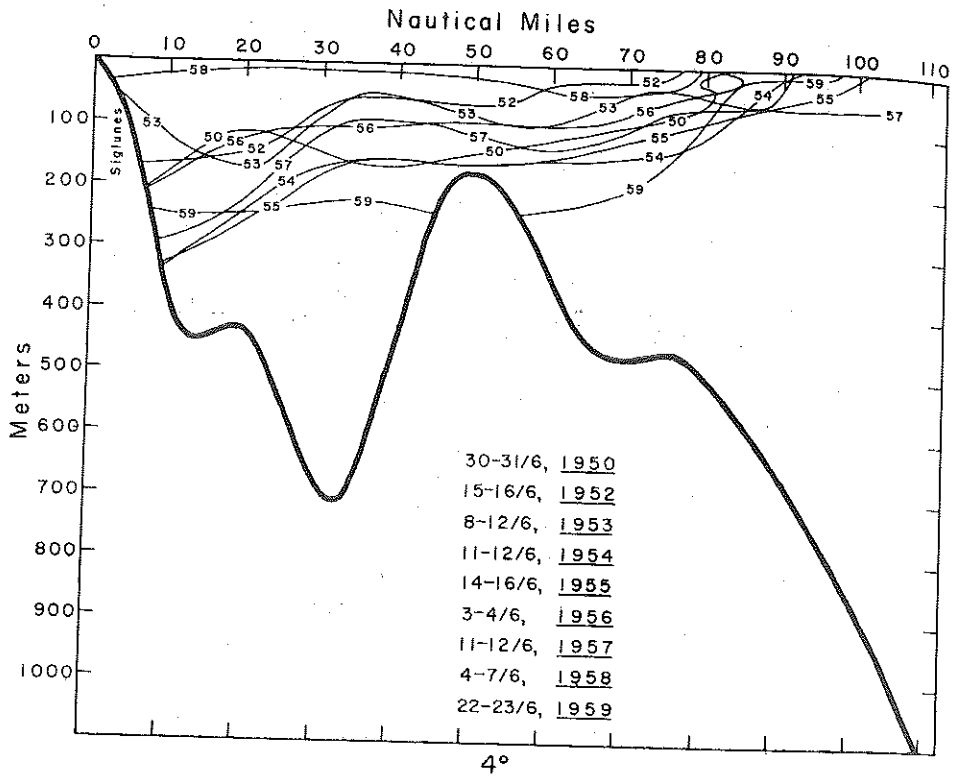

FIG. 126. *The course of the 4° isotherm in May 1950 and June 1952—1959.*

and S–3, the year 1956 was by far the coldest year in August, but other years with notably low August temperatures were 1927 (at S–2) and 1949. Exceptionally high temperatures at all depths were found in 1939 and 1960, whilst 1948 and 1955 were moderately warm years.

TABLE 14.

The areas confined by the 4° isotherm and the 35.0‰ isohaline in the section off Siglunes in June in different years. Expressed as the fraction of the area determined for 1959.

YEAR	AREA WITH TEMPERATURE > 4°	AREA WITH SALINITY > 35.0‰
1950	0.59	0.42
1952	0.35	0.50
1953	0.41	0
1954	0.80	0.68
1955	0.85	0.84
1956	0.48	0.04
1957	0.73	0.19
1958	0.11	0
1959	1.00	1.00
Mean	0.59	0.41

Eastern area.

For studying the influence of Atlantic water in the vertical section Langanes–Jan Mayen, the areas enclosed by the various isotherms and isohalines in the different years were measured with a planimeter. As the Atlantic water does not at any time extend appreciably beyond the slope, only the first 70 miles of the section were considered. The results are expressed in Table 15 as the percentages of the total cross-sectional area between the surface and 300 meters from Langanes to a distance of 70 miles offshore.

From Table 15 it is evident that of the 9 years considered, Atlantic influence in the eastern area in June was greatest in 1954, 1956 and 1957; in June 1953 the Atlantic influence was almost insignificant, and also quite small in 1952, as judged by the temperature distribution. In July 1949 the influence of Atlantic water must have been abnormally small in this region, as the temperature and the salinity were even lower than normally found in June.

TABLE 15.

Percentages of the cross-section through the region northeast of Langanes enclosed by the various isotherms and isohalines in July 1949 and June 1950—1958.

YEAR	S ‰			t°		
	< 34.8	34.8—34.9	> 34.9	< 2°	2°—3°	> 3°
1949	47.5	44.7	7.8	69.6	10.3	20.1
1950	3.7	93.8	2.5	65.1	22.6	12.3
1952	6.3	72.7	21.0	88.4	10.0	1.6
1953	30.1	69.0	0.9	75.2	13.3	11.5
1954	13.3	52.5	34.2	45.1	18.7	36.2
1955	13.7	71.6	14.7	52.7	14.5	32.8
1956	19.3	16.2	64.5	40.6	25.6	33.8
1957	4.8	63.2	32.0	44.1	26.1	29.8
1958	3.7	90.8	5.5	62.0	24.0	14.0
Mean	15.8	63.8	20.4	60.3	18.3	21.4

At the fixed station L–1 east of Langanes (Table XIX) positive temperature anomalies predominated in June 1936, 1953, 1954, 1956 and 1957, but negative anomalies in 1924, 1926, 1952, 1955 and 1958. At L–2 and L–3 (Tables XX–XXI) the year 1952 was by far the coldest, but negative temperature anomalies were also found in 1937, 1947 and 1950. The highest temperatures were found in 1954, but positive anomalies also predominated in 1936, 1956 and 1957. In 1953 the temperature was above normal in the surface layers, but below normal at subsurface depths.

In July only a few observations have been carried out in the section east of Langanes except at the coastal station, L–1. Here the temperature was found to be low in July 1932 and 1933, but high in 1947. At L–2 and L–3 1947 was definitely warm in the surface layer, but 1951 was a cold year in the deeper layers.

In August (Table XXII) the highest temperatures at L–1 were found in 1947, whereas 1931, 1948 and 1949 were abnormally cold. At the deeper stations, L–2 and L–3 (Tables XXIII–XXIV), 1949 was definitely the coldest

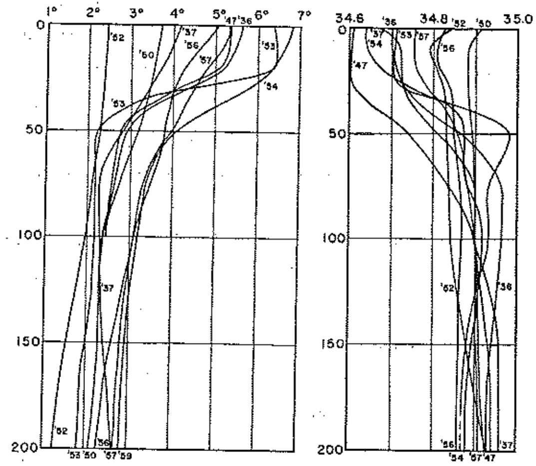

FIG. 127. *Variations in temperature and salinity with depth at station L–3 in June.*

year. Other cold years were 1934, 1948, 1956 (in the surface layers) and 1958. The years 1936 and 1947 were exceptionally warm, but relatively high temperatures were also found in 1939 and 1954.

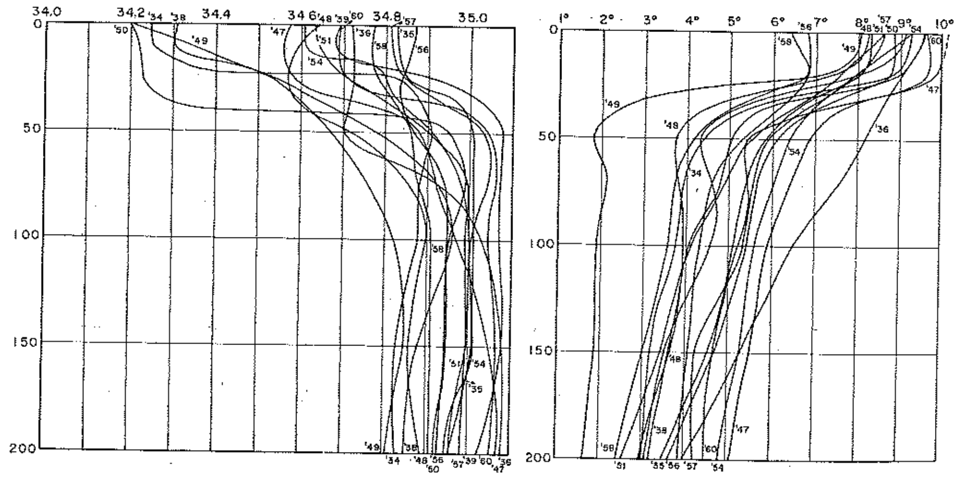

FIG. 128. *Variations in temperature and salinity with depth at station L–3 in August.*

Variations in temperature and salinity in June and August at station L–3 are shown in Figs. 127–128. Here also the salinity is seen to fluctuate in a similar manner as the temperature. Thus the salinity was found to be abnormally low between 50 and 200 meters in the cold years 1934 and 1949, but high in the warm years 1936, 1939 and 1947.

It is of interest to compare the magnitude of the variations in different months and in different regions. Table 16 shows the standard deviations of the mean temperature at various depths in June and August at 3 different localities, viz. K–3 (66° 53′ N, 23° 19′ W), S–2 (66° 24′ N, 18° 50′ W) and L–3 (66° 22′ N, 13° 35′ W). The results are taken from Tables III, IX, XI, XVII, XXI and XXIV.

TABLE 16.

Standard deviation of the mean temperature at different localities north of Iceland.

LOCALITY	JUNE				AUGUST			
	0 m	50	100	200	0 m	50	100	200
K–3 ……	0.56	0.12	0.14	0.40	0.44	0.45	0.08	0.11
S–2 ……	0.24	0.26	0.23	0.19	0.34	0.18	0.16	0.17
L–3 ……	0.46	0.24	0.15	0.21	0.27	0.39	0.29	0.24

It will be seen that near the surface the year to year variations are greatest at K–3. This is due to the influence of the drift ice as previously mentioned. The variations at K–3 and S–2 are found to be similar in the deeper layers but somewhat smaller in August than in June. In the eastern area (L–3), however, the temperature (and salinity) variations are decidedly greater in August than in June. Furthermore, in late summer the difference between years is greater off Langanes than off Kögur on the northwest coast. Considering the seasonal changes in the Atlantic influx previously mentioned these differences are not surprising. As early as June the Atlantic component in the region off Langanes has generally not increased appreciably from what it is in late winter. Therefore the differences between years will be small at this time of year. In late summer, however, after the maximum influx is reached, the quantity of Atlantic water at intermediate depths in the easternmost part of the region may be quite variable from one year to another, depending upon the strength of the influx. Once more, we have an example of the important part played by the Atlantic water in maintaining the relatively high temperature of North Icelandic waters.

Corollary.

The main results discussed in this section are summarized in Table XXV in the Appendix. It covers the periods 1924–1939 and 1947–1960. The table contains information on the ice conditions May–August, the air temperature May–August, and the sea temperature June–August. The region north of Iceland is here divided into three areas: the western area west of 21° W, the middle area between 17° and 21° W, and the eastern area east of 17° W. The different years have been given characters to indicate the ice conditions and the temperature of the air as well as the sea. The frequency and extension of drift ice in North Icelandic waters is indicated by the numbers 0–4. These denote:

0. No drift ice or ice bergs reported in North Icelandic waters. The mean ice limit probably more than 60 miles off the northwest coast.
1. A few growlers or ice bergs reported in the coastal area.
2. Frequent occurrence of small floes, growlers or ice bergs in the coastal area.
3. Ice floes extending over large parts of the coastal area, at times impeding navigation.
4. Compact ice close to shore over most part of the North Icelandic coastal area during the whole month.

During the period covered by the table the occurrence and compactness of drift ice has never been greater than that indicated by number 3, whereas the heavy ice years before 1920 would have been denoted by number 4. The ice conditions were judged according to the ice reports published in the *Danish Meteorological Annual* and *Veðráttan* and recent reports by Eyþórsson (1953–1958).

As a measure of the air temperature the monthly means at the three meteorological stations Kjörvogur (65° 59′ N, 21° 23′ W), Grímsey (66° 32′ N, 18° 00′ W) and Raufarhöfn (66° 28′ N, 15° 57′ W) were used.[1] In the few instances where observations were missing calculated values were used. These were determined by comparison with the results from neighbouring localities.

The means for each month were compared with the 1931–1960 normal (*Veðráttan* 1931–1960). The air temperature was considered normal if the monthly mean deviated less than 0.5°C from the normal; high if the temperature was 0.5° to 1.5° above normal; and exceptionally high if it was more than 1.5° above normal. Conversely, it was considered low if it was 0.5° to 1.5° below normal; and exceptionally low if it was lower than 1.5° below normal. The signs used to characterize the temperature are as follows:

++ denotes exceptionally high temperature.
\+ denotes high temperature.
0 denotes normal temperature.
– denotes low temperature.
–– denotes exceptionally low temperature.

The sea temperature was judged from the available hydrographical data. In many instances, however, the data were either very limited or missing altogether. Therefore, sea temperature normals could not be calculated for the period 1931–1960. The differences between years were judged on the basis of

1) Observations at Kjörvogur were begun in 1934 but prior to that time they were carried out at the nearby locality Grænhóll (65° 59′ N, 21° 22′ W).

the mean values for the fixed stations off Kögur, Siglunes and Langanes (Tables I–XXIV) and/or the mean temperature charts for 50 and 100 meters. The different signs denote roughly the same temperature intervals as used for the air temperature. The surface layers here refer to 0–50 meters and the intermediate layers to 50–200 meters.

Owing to the limitations mentioned, the estimation of the sea temperature variations will be less satisfactory than that of the air temperature. It is thought, however, that the table gives a trustworthy picture of the main year to year variations.

In the 30 years here considered the ice conditions have generally been favourable during spring and summer. In the years 1928, 1932, 1937, 1938, 1949 and 1956 frequent occurrence of drift ice floes in the coastal area were reported in May and June. In July and August drift ice was rarely observed. However, in July 1937 and both July and August 1929 and 1956 small ice floes, growlers or ice bergs were noted. Only in three instances, i.e. July 1929, May 1938 and May 1949 the extension of ice was so great in Icelandic waters as to be designated by number 3.

Abnormally low air temperatures persisted throughout most of the summer in 1924, 1938, 1952 and 1958. The lowest May temperatures were observed in 1949, but other abnormally cold years in May were 1924, 1938, 1948, 1952 and 1958. The lowest June temperatures were found in 1924, 1931, 1938 and 1952, the lowest July temperatures in 1924, 1932, 1938 and 1958, and the lowest August temperatures in 1924, 1929, 1956 and 1958. High air temperature prevailed during the summers of 1933, 1936 and 1939. The highest May temperatures were in 1935, 1936 and 1939, the highest June temperatures in 1933, 1936, 1939 and 1953, the highest July temperatures in 1926, 1927, 1933, 1947 and 1955, and the highest August temperatures in 1939, 1947 and 1955.

If we divide the 30 years into four periods, viz. 1924–1931, 1932–1939, 1947–1953 and 1954–1960, the first period will be the coldest as regards the air temperature, with 3 of the years definitely cold and no exceptionally warm year. The second period will be the warmest with only 1 definitely cold year but 3 exceptionally warm years. In the third period there is a trend towards lower temperatures again, with 3 of the years definitely cold but only 2 warm years, whilst in the fourth period only 1 year was exceptionally cold but 3 years were definitely warm.

The sea surface temperature is seen to fluctuate in a similar manner to the air temperature (cf. Stefánsson 1954 *a*, pp. 11–12) and a similar trend is also indicated for the deeper layers. Considering the summer season as a whole the years 1924, 1930, 1932, 1938 and 1949 may be characterized as exceptionally cold, and 1936, 1939, 1947 and 1960 as exceptionally warm. The years 1952 and 1958 may be considered as definitely cold, the years 1933, 1935, 1955 and 1957 as definitely warm, whereas the other 15 years may probably be considered as normal years.

3. RELATIONSHIP BETWEEN THE INFLUX OF ATLANTIC WATER AND METEOROLOGICAL FACTORS

Considering the complexity of the water masses found in the sea area north of Iceland, an analysis of the possible causes of the year to year variations may be very difficult.

The factors most likely to affect the conditions in the North Icelandic shelf region are 1) variations in the extension of drift ice, 2) variability in the strength of the North Icelandic Irminger Current and 3) variations in air temperature and/or other meteorological factors.

As we have already discussed (p. 188) the temperature and salinity of the surface layers north of Iceland, especially in the western part of the shelf region, will largely depend on the nearness of the drift ice. A distinct correlation was therefore found to exist between the surface temperature in the western part of the area and the frequency of drift ice at the northwest coast. Also the surface salinity was found to be closely associated with the ice conditions. However, the warming up of the surface layers north of Iceland will not only depend on the location of the ice limit, but also on the influx of Atlantic water from the southwest. As regards the conditions in the deeper layers the influx of Atlantic water appears to be the dominating factor.

A priori it would be expected that southerly winds would intensify the flow of Atlantic water northwards along the west coast of Iceland. Conversely, northerly winds in the region west of Iceland would be expected to reduce the northward flow of Atlantic water. No direct measurement exists of the intensity of the Atlantic inflow in spring but it could be estimated indirectly. In the western part of the coastal area where the concentration of Atlantic water is generally great at all times during spring and summer the variations in the influx do not manifest themselves clearly in the temperature or the salinity distribution. In the eastern part of the coastal area, however, the salinity as well as the temperature at intermediate depths is quite variable, especially in late summer (cf. Table 16), depending upon the strength of the influx.

It was therefore decided to establish whether there was a positive relationship between the mean salinity and temperature at intermediate levels in the region east of Langanes in August and the wind conditions in the preceding period. The distance from the region northwest of Iceland to the Bakkaflóadjúp east of Langanes is about 300 miles. If we assume the average rate of the coastal current to be about 3 miles a day (cf. chapter X), it will take a water particle approximately 3 months to travel from the northwest coast to the region east of Langanes. Therefore, if our hypothesis is true, the effects of variable wind conditions west of Iceland on the inflow of Atlantic water to the North Icelandic shelf region, should be reflected in the hydrographic conditions east of Langanes three months later. This supposition is indeed corroborated by the existing data.

TABLE 17.

The relationship between wind conditions and air temperature in May and hydrographic conditions of the intermediate layers at L–3 in August.

Year	Mean t° L–3 August 50–200 m t°	Mean S‰ L–3 August 50–200 m S ‰	Frequency of N, NE and NW winds in May Stykkishólmur %	Mean pressure difference in May (Stykk.-Angm.) Mb.	Mean pressure difference in May (Djúpav.-Stykk.) Mb.	Air temperature May t°
1934	3.51	34.86	35	–1.6	0.9	3.5
1935	4.75	35.00	30	1.2	1.1	6.2
1936	5.98	35.01	21	2.9	2.4	6.3
1938	3.95	34.89	40	–2.0	–0.1	2.2
1939	4.95	35.07	12	0.8	1.6	6.4
1947	5.79	34.99	13	–1.6	2.9	5.1
1948	3.56	34.85	32	–1.9	0.1	2.5
1949	1.88	34.79	48	–4.2	–3.9	0.4
1950	3.97	34.95	29	1.0	0.6	4.7
1951	3.86	34.98	17	1.7	1.2	4.5
1954	5.49	34.98	26	–2.2	1.2	4.6
1956	4.28	34.94	30	–3.6	–0.9	3.8
1957	4.86	35.00	36	2.4	2.4	4.0
1958	3.27	34.90	52	–3.1	–2.2	1.9
1960	4.97	35.05	17	–2.8	3.0	5.1
Mean	4.34	34.95	29	–0.9	0.7	4.1

The relationship between the wind conditions in May and the hydrographic conditions of the intermediate layers at L–3 (66° 22′ N, 13° 35′ W) in August is revealed by Table 17. It is evident that in those years when low salinities and low temperatures were observed in August, northerly winds predominated west of Iceland in May, whereas pronounced Atlantic influence was found in years with infrequent northerly winds in spring. In a similar manner the mean pressure difference in May between Djúpivogur and Stykkishólmur was found to be positive in years with relatively high August sea temperature, but negative in years with relatively low August sea temperature. Although the pressure difference between the east and the west coast of Iceland is not an accurate measure of the southerly wind component along the west coast of Iceland, it will probably be a satisfactory estimate. However, as the wind direction in the vicinity of Iceland may very often be different from that found farther west in the Irminger Sea, the pressure difference between Stykkishólmur and Angmagssalik will probably give a less reliable picture of the wind conditions along the west coast of Iceland. In agreement with this only a weak correlation was indicated between the hydrographic conditions east of Langanes and the pressure difference across the Irminger Sea.

A closer examination was made of the relationship found between the hydrographic conditions and the pressure distribution. To this end the mean temperature and the mean salinity in August at station L–3 were correlated with the mean monthly pressure difference between Djúpivogur and Stykkishólmur in various months during spring and summer. The difference was taken as positive if the air pressure was greater at Djúpivogur, but negative if it was greater at Stykkishólmur. A positive difference was therefore indicative of a net southerly wind component, but a negative difference indicated a net northerly component. The results are shown in Table 18. They are based on the 15 years with observations in August (cf. Table XXIV). It can be seen that there is a significant correlation between the hydrographical conditions in August east of Langanes and the wind conditions in May, the correlation coefficient exceeding the 0.1% level of significance. On the other hand the correlation coefficient is not significant for the pressure difference in April, June, July or August.

TABLE 18.

Values of the correlation coefficient between the pressure difference (Δp) *(Djúpivogur minus Stykkishólmur) in various months and the mean salinity and temperature 50—200 meters in August at station L–3.*

	APRIL	MAY	JUNE	JULY	AUGUST
$\varrho_{\Delta p,t}$	0.49	**0.85**	0.02	0.28	0.35
$\varrho_{\Delta p,S}$	0.39	**0.79**	0.04	0.20	0.20

Having established a relationship between the southerly wind component in May and the sea temperature and salinity at intermediate depths in August, an investigation was made of the depth at which the southerly wind component influenced the sea temperature or salinity to the greatest extent. However, in the various depth bands the temperature and the salinity will usually be dependent upon the conditions in the levels above or below. It can be seen (Table 19) that the association is similar for the surface layers as for the intermediate layers as regards the temperature but not as regards the salinity. This result is not surprising considering the complexity of factors affecting the surface salinity.

TABLE 19.

Values of the correlation coefficient between the pressure difference (Δp) *(Djúpivogur minus Stykkishólmur) in May and the temperature and salinity in August at L–3 at various depths.*

	0–50 m	50–100 m	75–150 m	100–200 m	50–200 m
$\varrho_{\Delta p,t}$	0.89	0.87	0.88	0.84	0.85
$\varrho_{\Delta p,S}$	0.37	0.72	0.78	0.77	0.79

A study was also made of the relationship between the wind conditions and the hydrographic conditions in the middle part of the coastal area. The sea temperature (the mean for 50–100 meters) in June, July and August at station S–3

(66° 32′ N, 18° 50′ W) was correlated with the air pressure difference between Djúpivogur and Stykkishólmur in various months.

The distance from the westernmost part of the North Icelandic shelf region to station S–3 is roughly 120–140 nautical miles. If we assume the mean rate of the coastal current to be 3 miles a day, the effects of variable winds west of Iceland on the influx of Atlantic water to the region north of Iceland should be manifested by the hydrographic conditions at S–3 approximately 1½ month later.

TABLE 20.

Values of the correlation coefficient between the mean monthly pressure difference (Δp) *(Djúpivogur minus Stykkishólmur) and the sea temperature (50—100 meters) at S–3.*

Sea Temperature in	MEAN PRESSURE DIFFERENCE IN							No. of observations
	April	April–May	May	May–June	June	June–July	July	
June	0.54	**0.74**	0.56	0.47	0.19	.	.	14
July	0.36	0.74	0.72	**0.76**	0.18	.	.	10
August . .	.	.	0.31	0.36	0.15	**0.44**	0.42	12

From the results in Table 20 it will be seen that a significant correlation was found between the sea temperature in June and the pressure difference in April–May and also for the sea temperature in July and the pressure difference in May–June. Thus the best association was found for a time difference of about 1½ month. The results obtained are consequently in agreement with the supposition that the wind conditions west of Iceland may affect the influx of Atlantic water to the North Icelandic region.

It should be noted that the correlation found between the sea temperature at S–3 in August and the pressure difference was hardly significant. The fact that the correlation coefficient was positive and greatest for June–July, might, however, indicate a tendency in the sense of the relationship mentioned. In this region pronounced Atlantic influence has always been observed in August and year to year variations are relatively small. In this case the effect of the wind might be obscured by other factors.

A number of trial correlations were made to investigate at which depth the association was greatest between the sea temperature at S–3 and the pressure difference. The best agreement was found for the depth band 50–100 meters.

The relationship found between the hydrographic conditions and the wind appears surprisingly close considering the roughness involved in the correlation analysis. Thus the tacit assumption is made that the hydrographic conditions in August east of Langanes in the various years, as determined by observations made at different dates during the whole month, are governed by the mean value of the pressure difference in May. It seems likely that a more distinct relationship would have been revealed by comparing the hydrographic conditions and the pressure difference for various time intervals of shorter duration. Also, a better result might have been obtained by studying the weather maps for the region west of Iceland.

A study was made on the relation between the westerly or the easterly wind component and the temperature at intermediate depths at station S–3 (66° 32′ N, 18° 50′ W) in July in different years. From the records of the Icelandic Meteorological Office[1] the air pressure was obtained for 3 times a day at the meteorological station Vestmannaeyjar and Akureyri. The mean differences in air pressure between these two meteorological stations were computed for 10 days interval over the 60 days period prior to the working of the hydrographical section. The result was that no significant correlation could be found between the hydrographical conditions north of Siglunes in July and the pressure difference in the 60 days period prior to the working of the station. This result does not, however, necessarily imply that there extists no relation between the hydrographical conditions and the wind. The effects of the east-west wind component might be obscured by other more important factors, especially the south-north wind component off the west coast which seems to be the most influential factor as regards the influx of Atlantic water.

In North Icelandic waters the sea temperature exceeds that of the air except during the months June and July when the air temperature is slightly in excess (see e.g. STEFÁNSSON 1961 *b,* p. 239). When the sea surface is warmer than the air an appreciable convective transport of heat will take place. The heat transport will be limited, however, when the air is warmer than the water, because the cooled air causes a high stability close to the sea surface.

Generally, a correlation is found between the sea surface temperature and the concurrent air temperature. This relation is not very close, however, since the sea temperature will depend upon other factors as well, e.g. winds, vertical and horizontal mixing, etc.

A comparison of the air temperature in spring and the hydrographic conditions at intermediate depths in late summer in the eastern part of the North Icelandic coastal area, reveals an association between the two phenomena. This will be evident if we compare columns 2, 3 and 7 of Table 17. Calculations of the correlation coefficients show that a significant positive correlation exists between the air temperature in May and the salinity or the temperature at intermediate depths east of Langanes in August. No significant correlation was found between the sea temperature in August and the air temperature in June or July, and only a weak correlation was found between the sea temperature in August and the air temperature in August.

It should be remarked that the correlation coefficient, although highly significant, does not indicate anything about the causal association between the series of numbers representing variations in the air temperature, sea temperature or

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1) The material for this study is kept on file at the Icelandic Fisheries Research Institute and will not be presented here.

salinity. The explanation could simply be the fact that high air temperatures are usually associated with southerly winds but low air temperatures with northerly winds. The relation between the pressure difference (Djúpivogur minus Stykkishólmur) and the air temperature was tested and a significant correlation was found. However, an independent effect of the air temperature on the inflow of Atlantic water seems also possible.

In the discussion of seasonal variations it was pointed out that the warming up in spring will probably affect the Coastal water more than the water farther offshore, with the result that the density of the Coastal water will be lowered to a greater extent than that of the Atlantic water. This increased horizontal density gradient was presumed to cause a stronger east-going current in summer than in winter in the shallower part of the coastal area. In years with unusually high air temperature in spring, the warming up will be more intensive and then, if our explanation is true, it follows that in such years the east-flowing current will be stronger.

4. PRACTICAL APPLICATIONS

The relationship between the pressure difference (Djúpivogur minus Stykkishólmur) in May and the mean sea temperature 75–150 meters is described by the regression equation

$$t_{75-150} = 4.14 + 0.5 \cdot \Delta p_{\text{May}}.$$

It is of interest to investigate whether this equation can with fair success be used to predict the mean temperature conditions in August from the air pressure in May. The variance of a calculated value of the mean temperature will depend on the uncertainty in the estimate of the regression line plus the variance about the regression line (cf. Hald 1957, chapter 18).

For values of the mean pressure difference between —4 mb and +4 mb, the standard error of the estimate of the mean sea temperature will be $\pm 0.61° - 0.71°$. The 95% confidence limits determined with the aid of the t-distribution (Hald 1952, Table IV) will be $\pm 1.31° - 1.53°$. It follows that the sea temperature east of Langanes in August can be predicted with fair degree of accuracy from the mean air pressure in May. Fig. 129 shows the regression line and the 95% confidence limits as determined from the t-distribution.

A prediction was made of the temperature conditions east of Langanes in August 1961 using the calculated regression equation. According to information from the Icelandic Meteorological Office[1] the mean pressure difference in May 1961 between Djúpivogur and Stykkishólmur may be estimated to be about −0.1 mb. This gives a calculated mean temperature of 4.1° at 75–150

1) Observations from Djúpivogur were lacking, but an estimated value was found from the observations at the two nearby stations Dalatangi (Seyðisfjörður) and Hólar (Hornafjörður).

meters. This is in reasonably good agreement with the observed value of about 4.5°.

For station S–3, located north of Siglunes, the relation between the mean pressure difference April–May and the mean sea temperature 50–100 meters in June based on 14 observations is given by

$$t_{50-100} = 4.80 + 0.39 \cdot \Delta p_{\text{April–May}}.$$

The standard error of the estimate of the mean temperature from this equation will be $\pm$ 0.61°—0.76° for values of the mean air pressure difference

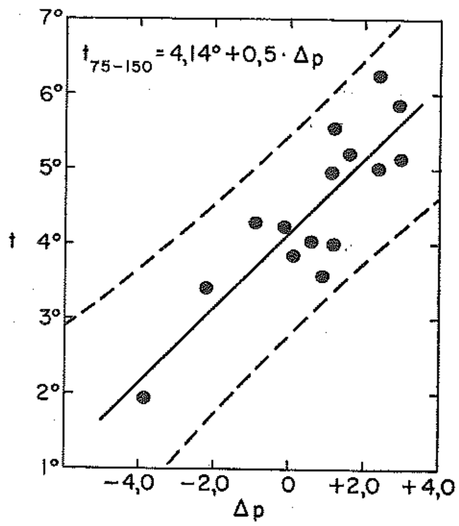

Fig. 129. *Correlation between the difference in air pressure (Djúpivogur–Stykkishólmur) in May and the sea temperature (75—150 meters) in August at station L–3.*

between — 4 mb and + 4 mb. The 95% confidence limits are $\pm$ 1.33° — 1.66°. A similar equation based on 10 observations for calculating the sea temperature at S–3 in July from the mean air pressure in May–June is given by

$$t_{50-100} = 5.41 + 0.62 \cdot \Delta p_{\text{May–June}}.$$

Here the uncertainty in estimating the sea temperature will be considerably greater, so that predictions for this area in July cannot be made with any great degree of accuracy.

In his studies on the distribution and availability of the North Icelandic herring, Jakobsson (1961) shows that there have been great variations from year to year in the percentage catch during the second half of the herring season, viz. in August. According to his results especially high proportion of the total yield was taken after 31st of July in the years 1932, 1938, 1943, 1944, 1948 and 1949, whereas the August catch was relatively less for the years 1933, 1935, 1936, 1939, 1942, 1945, 1946 and 1947. For the years 1940–1946 hydrographic data are lacking. As regards the other years a consultation of Table XXV in the Appendix indicates that the years giving good August catches were cold years off the north and east coasts, whereas in the years giving poor catches the temperatures were relatively high. Jakobsson remarks (loc. cit. p. 8) that during the last decade, when the herring catches have generally been poor, the relationship between the August catch and the temperature is obscured by increased catches coming from outside the north coast area proper. But it has also become evident that in the warm years 1957, 1959, 1960 and 1961, practically no fishing took place on the north coast herring grounds proper after the middle of July. As Jakobsson points out, the sea temperature as such is probably not a preventing factor. But as we have seen, high sea temperatures north of Iceland in summer are generally associated with strong influx of Atlantic water in spring, and Jakobsson points out that the experience of recent years has often shown the Atlantic water to be poor with regard to food for favourable shoaling behaviour.

With the preceding remarks in mind it is of interest to investigate whether a relation can be found between the pressure distribution in spring and the August herring fishery. The mean pressure difference in May between Djúpivogur and Stykkishólmur in the years 1931–1950 was correlated with the August herring yield (as percentage of total yield) during these years according to Jakobsson's data (loc. cit. p. 2). While there is generally a negative correlation between the pressure difference (Djúpivogur minus Stykkishólmur) and the percentage yield after 31st of July, there are notable exceptions, such as 1944 when the yield was very high but the pressure difference relatively great. The correlation coefficient was found to be small ($\varrho = -0.55$), but still almost significant at the 1% level of significance. Thus the wind conditions in spring may give some indication as regards the food conditions for herring north and east of Iceland in summer and even give a hint as to the probable catch during the second half of the herring season.

5. VARIATIONS IN THE TONGUE OF COLD WATER NORTHEAST OF ICELAND

In the oceanic area between northeast Iceland and Jan Mayen year to year variations have also been observed. This will be apparent from Fig. 130 which shows the position of the 0° isotherm at 50 meters in June in the years 1952–1960. In 1953, 1954 and 1955 the extension of cold water was decidedly greater than in 1956, 1957 and 1958. Especially in 1957 was the temperature relatively high in the upper layers of the area between Iceland and Jan Mayen.

For a closer examination of the conditions in the tongue of cold water Table 21 was constructed. It shows the mean temperature and salinity at different levels in that part of the section from Langanes to Jan Mayen that extends over the tongue of cold water between about 50 and 200 miles off Langanes. The southern limit of the tongue of cold water will be roughly near the 1000

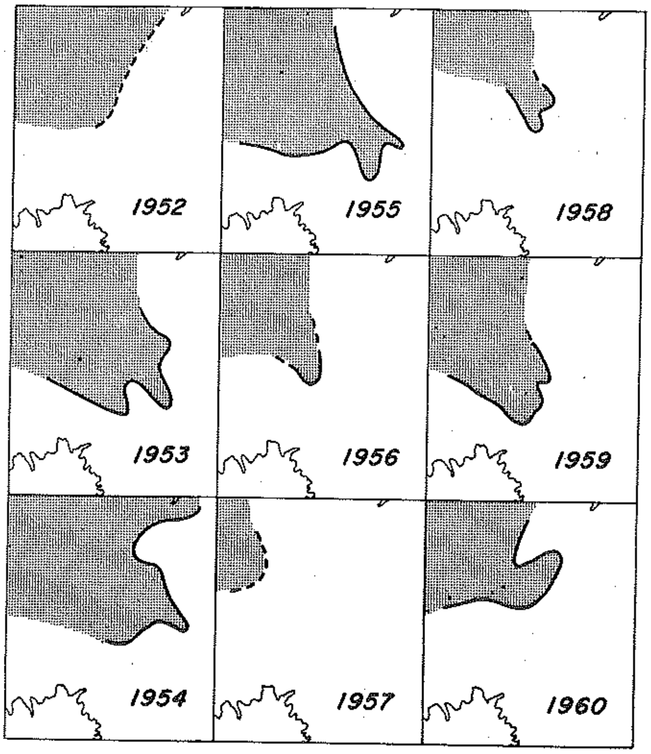

Fig. 130. *The position of the 0° isotherm at 50 meters in June 1952—1960. Within the shaded areas the temperature was below 0°.*

meter depth contour which is found at about 50 miles NNE of Langanes, and the width of the "tongue" in this direction as judged by the 0° isotherm at 200 meters will be approximately 150 miles. The temperature and salinity values at the end points (i.e. at 50 miles and about 200 miles NNE of Langanes) were determined by linear interpolation from the values at adjacent stations. In 1951 the section extended from Jan Mayen to Sléttugrunn. In this instance the southern limit of the tongue was also placed at the 1000 meter depth contour and the width considered to be 140 miles. In 1952 the section only extended 185 miles and in 1956 180 miles off Langanes. In these years the means could not be calculated for the whole distance of 150 miles. But as variations are not great within the tongue of cold water, the means calculated in this way will probably not deviate notably from the true ones. In the year 1955 hydrographic observations were only available within 80 miles and in 1957 within 100 miles off Langanes. The means for these years were therefore based on BT observations. Since the observations in 1949 and 1951 were made in late July or August, but in June during the remaining years, the mean values are not comparable as regards the surface layer. At depths below 50 meters, however, the temperature and salinity conditions probably do not change appreciably from June to August in this region (cf. Figs. 38–43).

TABLE 21.

Mean temperature and salinity in the tongue of cold water NE of Iceland.

DATE	YEAR	50 m		100 m		200 m		300 m		400 m		600 m		800 m		1000 m	
		t°	S‰	t°	S‰	t°	S‰	t°	S‰	t°	S‰	t°	S‰	t°	S‰	t°	S‰
23–29/7	1949 . . .	0.45	34.85	0.03	34.84	–0.24	34.87	–0.22	34.90	–0.18	34.92	–0.49	34.91	–0.67	34.92	–0.77	34.92
24–26/8	1949 . . .	1.18	34.83	–0.08	34.84	–0.27	34.87	–0.20	34.90	–0.23	34.91	–0.52	34.91	–0.68	34.91	–0.77	34.91
19–21/8	1951 . . .	0.63	34.89	–0.04	34.89	–0.32	34.89	–0.39	34.89	–0.44	34.90	–0.44	34.91	–0.61	34.92	–0.73	34.92
19–20/6	1952 . . .	0.96	34.81	–0.38	34.84	–0.80	34.87	–0.66	34.90	–0.62	34.90	–0.53	34.92	–0.60	34.93	–0.73	34.93
13–14/6	1953 . . .	–0.18	34.81	–0.78	34.82	–0.43	34.87	–0.46	34.89	–0.52	34.91	–0.53	34.91	–0.66	34.91	–0.77	34.91
14–15/6	1954 . . .	–0.24	34.79	–0.53	34.80	–0.33	34.87	–0.40	34.90	–0.47	34.91	–0.57	34.92	–0.66	34.92	–0.75	34.93
20–21/6	1955 . . .	0.10	.	–0.20	.	.	.	.	.	.	.	.	.	.	.	.	.
7–9/6	1956 . . .	0.93	34.89	0.18	34.91	–0.05	34.93	–0.23	34.93	–0.32	34.92	–0.45	34.93	–0.60	34.93	–0.74	34.93
16–18/6	1957 . . .	1.64	.	0.05	.	.	.	.	.	.	.	.	.	.	.	.	.
Mean		0.61	34.84	–0.19	34.85	–0.35	34.88	–0.37	34.90	–0.40	34.91	–0.50	34.92	–0.64	34.92	–0.75	34.92
Standard deviation		0.64	0.04	0.31	0.04	0.23	0.02	0.17	0.01	0.16	0.01	0.05	0.01	0.04	0.01	0.02	0.01
St. dv. of mean . . .		0.21	0.015	0.10	0.015	0.09	0.009	0.06	0.005	0.06	0.003	0.02	0.003	0.01	0.003	0.01	0.003

It is seen that 1952, 1953 and 1954 are the coldest of the years here considered, whereas 1956 is by far the warmest between 100 and 400 meters. Judging by the standard deviation of the mean given at the bottom line of Table 21, it is seen that the year to year variations are relatively small as compared with those found in the North Icelandic shelf region, especially the eastern part of the shelf. In this connection it may be recalled that calculations of volume transport through the Melrakkaslétta section (see p. 159) indicated that the transport variations of the East Icelandic Current are almost entirely due to variations in the North Icelandic Irminger Current, whereas variations in the transport of the residual component which consists mostly of Arctic water, appeared to be small. The deep water below 400 meters is seen to be virtually homohaline. The mean salinity at 800 and 1000 meters is found to be 34.92 ‰ which is in perfect agreement with the mean value given by Mosby (1959) for the southern part of the Norwegian Sea. Within the upper part of this homohaline water only slight temperature variations are indicated. The maximum difference between the mean values of individual years amounts to 0.13° at 600 meters, 0.08° at 800 meters and 0.04° at 1000 meters. Thus in the deepest layers the year to year fluctuations, if they exist, must be very small.

In 1957 the temperature was found to be relatively high, both on the North Icelandic grounds and in the tongue of cold water northeast of Iceland. In June 1956 and especially in June 1958 the temperature was found to be low in the shelf region but relatively high in the oceanic area northeast of the shelf, the reverse being true for 1954. Thus the temperature conditions in the tongue of cold water do not seem to be related to the position of the ice limit northwest of Iceland or the influx of Atlantic water to the North Icelandic shelf region. However, a number of other factors may be involved, such as the intensity of cooling during the previous winter, the wind conditions in nearby or distant regions and other meteorological phenomena.

An investigation was made to test if the variations between years could be explained by the wind conditions. Fig. 131 shows the mean temperature and the mean salinity at 50–200 meters for the three stations indicated on the inset chart. These stations are located near the core of the cold water. The intermediate layers were selected for this study, rather than the surface layer, on the assumption that the conditions at the surface will largely depend upon the warming up due to radiation from above and the formation of thermocline. The values shown on the histogram are all from June. The means are based on the values for the three stations except the mean for 1950 which is based on observations from one station only, and the means for 1955 and 1957 which are based on observations from two stations. The hydrographic conditions in this region will not only depend upon the mixing processes and cooling in previous winter (cf. p. 114), but must also be greatly influenced by the influx of relatively warm and saline water coming from the area south or southeast of Jan Mayen. An admixture of Polar water from the west will naturally greatly reduce the temperature as well as the salinity of the Arctic water. It is therefore to be expected to find a correlation between the temperature and the salinity of this water, as indicated by Fig. 131.

The hypothesis was formulated that easterly winds would strengthen the movement of relatively warm and saline water from the east towards the tongue

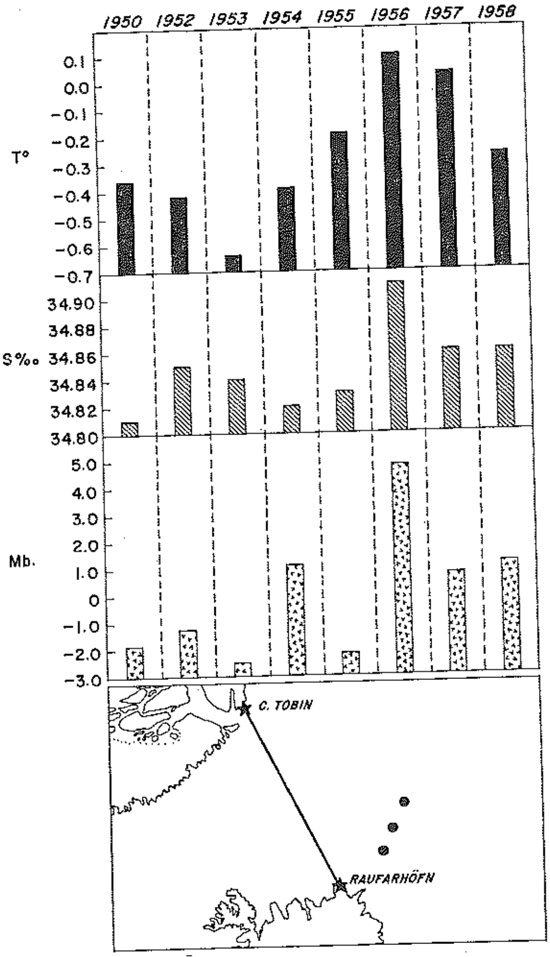

FIG. 131. *The correlation between sea temperature, salinity and air pressure in the oceanic area northeast of Iceland. The columns at top and in the middle indicate the mean temperature and salinity at 50—200 meters at the stations shown below, but the columns at the bottom indicate the difference in air pressure (in millibars) between C. Tobin and Raufarhöfn 20—40 days prior to making the hydrographic observations.*

of cold water and thereby raise the temperature and the salinity of the Arctic water. Conversely, westerly winds were expected to weaken this influx but increase the admixture of Polar water from the west. To test this hypothesis the difference in air pressure between Cape Tobin, Greenland and Raufarhöfn, Northeast Iceland (see Fig. 131), was computed for various time intervals prior to the working of the hydrographic stations. Table 22 gives the results of a number of trial correlations made between the air pressure difference [1] and the temperature and the salinity at 50–200 meters at the three stations shown in Fig. 131.

TABLE 22.

Correlation between the mean pressure difference (Δp) (C. Tobin minus Raufarhöfn) and temperature and salinity in the tongue of cold water.

Correlation Coefficient	Time interval in days prior to the working of the stations					
	0–10	0–20	20–30	20–40	30–50	40–60
$\varrho_{\Delta p, t}$	0.36	0.21	0.58	0.73	−0.03	−0.02
$\varrho_{\Delta p, S}$	0.10	0.18	0.83	0.72	0.08	0.25

As demonstrated by Table 22 no correlation was found between the hydrographic conditions and the mean air pressure in the preceding 20 day period. A significant correlation was found between the salinity and the mean air pressure 20–30 days before working the stations. This correlation coefficient exceeds the 1% level of significance, but the correlation between the temperature and the mean air pressure for this time interval cannot be considered significant. For the time interval 20–40 days before making the hydrographic observations the correlation was found to be significant, both as regards temperature and salinity. These coefficients exceed the 5% level of significance. When the time difference exceeded 40 days no association was indicated between the hydrographic conditions and the mean easterly wind component. Our conclusion must be that there probably exists a relation between the hydrographic conditions at intermediate depths in the tongue of cold water and the easterly wind component some 20–40 days earlier. According to the Ekman model (Ekman 1902), the wind drift should be shallow in this area. It therefore seems that the effect of the wind must in this case be an indirect one. However, the correlation is not very close, which indicates that other factors besides the wind may affect the hydrographic conditions in the tongue of cold water.

1) Reckoned as positive if the pressure was greater at C. Tobin than at Raufarhöfn.

SUMMARY AND CONCLUDING REMARKS

1. The present work is based on temperature and salinity data sampled in North Icelandic waters. The bulk of this material has been collected during the last 15 years.

2. Attention is drawn to the fact that the first accounts of the ocean currents around Iceland are found in ancient Icelandic literature of the early thirteenth century. From the evidence given by the sagas regarding the drift of wooden objects and ice, it is clear that very early the Icelanders must have known the approximate direction of the coastal current.

3. A historical survey is given of the main expeditions to the sea area near Iceland and the various contributions to the hydrography of Icelandic waters. Systematic hydrographic investigations in this area began around the middle of the last century with the pioneering work of Irminger. During the years 1875–1908 a number of expeditions were sent to Icelandic waters and adjacent sea areas. As the result of these observations the main features of the current system around Iceland were known in the beginning of this century. In the period between the two world wars, investigations in North Icelandic waters were continued and a series of fixed stations were laid where observations have since been repeated. In 1947 hydrographic research was initiated by the Icelandic Fisheries Research Institute. In the following years observations were carried out in the poorly investigated area north of the Icelandic submarine shelf. These investigations have mostly been made in connexion with biological observations and herring survey during spring and summer. The material collected in other seasons has been limited, except for observations collected in the so-called Siglufjörður section during the period September 1953 to September 1955. A brief mention is made of the numerous investigations made in Icelandic waters by other nations in recent years.

4. A historical review is given of the nomenclature of the sea area north and east of Iceland. It is pointed out that the original name for the area north of Iceland is *Dumbshaf*, but *Íslandshaf* (Iceland Sea) for the sea between Iceland and Norway. In later centuries there has been some confusion regarding the nomenclature of northern seas. It is proposed that the name Iceland Sea be used to designate the area between Iceland, Greenland and Jan Mayen, but the name Norwegian Sea be restricted to that part of the Arctic Mediterranean which lies between the Faroes, Jan Mayen, Spitzbergen and Norway. A survey of the main bathymetrical features is given.

5. Descriptions are given of three primary water masses in the region north of Iceland. These are a) Atlantic water, b) Polar water and c) Arctic Bottom water. Four secondary water masses, formed by dilution or intermixing between the primary water masses, are considered, viz. Coastal water, Arctic water, Arctic Intermediate water and North Icelandic Winter water.

6. Older current charts of the sea area north of Iceland are discussed. On the basis of the hydrographical data collected during the Icelandic cruises since 1949, a new current chart is constructed. According to this chart the surface current in the region south and southeast of Jan Mayen is directed to the north along the submarine ridge which extends south of the island, whereas southwest of Jan Mayen it flows towards south or southwest. Farther south the current turns towards southeast. In the central part of the region between NE-Iceland and Jan Mayen a weak anticlockwise circuit is found. This circuit feeds water to the East Icelandic Current which in addition is formed by water from the East Greenland Current and the east-flowing Irminger Current. This current picture, derived from dynamic computations, is supported by the results of drift bottle experiments. An additional support is found by consideration of the bathymetrical features.

7. The course of the North Icelandic Irminger Current in different regions is discussed. While the general direction is eastward along the north coast, the mean current appears to follow the depth contours rather closely. This is demonstrated as regards the Húnaflói and the Eyjafjarðardjúp. Off the southeast coast the current appears to leave the coastal area as a part of the East Icelandic Current.

8. The distribution of temperature and salinity in summer is discussed. Mean charts of temperature at 20 meters and temperature and salinity at 50 and 100 meters were prepared for the months June, July and August. The mean vertical distribution in the sections off Kögur, Siglufjörður and Langanes is also shown for the three summer months.

9. The t, S relations of North Icelandic waters are analyzed. It is found that in the deeper part of the coastal area the intermediate layers consist of two components, Atlantic water and North Icelandic Winter water. From the combined observations of six years an estimated normal regression equation is derived. It is shown that this equation may with fair success be used to calculate the salinity distribution at intermediate depths. Also the percentage of vernally inflowing Atlantic water may be estimated. This is found to change from 80–90% in the region west of Látrabjarg to 0–30% east of Langanes. The relation found, however, only holds true in the deeper part of the coastal area near the core of the east-flowing Atlantic water. The origin and formation of the North Icelandic Winter water are discussed. From studies of the t, S relations on the Iceland–Faroe Ridge it is concluded that the overflow across the ridge consists partly of North Icelandic Winter water. A method is suggested for estimating the fraction of North Icelandic Winter water in the bottom layers of different regions along the western slope of the ridge.

10. By means of dynamic calculations the velocity distribution is derived for the section off Kögur in different years and for the sections off the northeast coast, assuming zero current at the bottom in the shelf region and at 300–400 meters near the edge of the shelf. In the oceanic region the zero-surface is assumed to slope downwards to 800 meters at 68° 30′ N. The mean rate of the coastal current is estimated to be about 3 miles a day. This estimate is based on drift bottle experiments, dynamic computations and tracking of temperature and salinity. The mean velocity profiles indicate that the maximum east-flowing current is found near the edge of the shelf, whilst the current appears to be weak and variable in the shallower part of the coastal area. In general, a good agreement is found between the different methods used.

11. It is attempted to calculate the volume transport through the sections off Kögur and Melrakkaslétta. The uncertainties involved in these calculations are emphasized. The results obtained indicate that the average net east transport in summer within 60 miles off Kögur amounts to about 2.2 km^3/hr. This transport appears to consist almost entirely of water with temperature above 1 °C. It is estimated that the heat transport during summer to the region east of Kögur due to Atlantic water alone amounts to roughly 2.7×10^9 kg. cal./sec. A comparison of the calculated transports through the Kögur section and the Melrakkaslétta section indicates that the variations in the volume transport of the East Icelandic Current depend mostly on variations in the North Icelandic Irminger Current, whereas variations in the transport of the residual current appear to be small.

12. The extension of drift ice northwest of Iceland is found to be greatest in spring. During summer the ice border gradually retreats farther and farther away from the Icelandic coastal area, and in autumn ice occurs very rarely at the northwest coast of Iceland. The seasonal variations at 3–4 stations off Siglunes during the years 1953–1955 are described. Seasonal changes are detected down to a depth of at least 300 meters. It is shown that two kinds of seasonal changes can be distinguished, viz. a) hydrographic variations directly associated with changes in the sun's altitude and b) variations in the relative magnitude of Atlantic water. The Atlantic influence is found to increase in spring and reach a maximum in summer. In autumn and winter it is greatly reduced. These variations are considered to be due to variations in the Atlantic current component. Some of the possible causes of such seasonal variations are discussed.

13. Year to year variations in the North Icelandic shelf region are studied by means of a) observations at fixed stations, b) comparison of vertical sections from different years and c) comparison of horizontal charts. The year to year variations are found to be greatest in the eastern area in late summer. These differences are attributed to variable influx of Atlantic water. In the period 1924–1960 the years 1924, 1930, 1932, 1938 and 1949 were found to be exceptionally cold and 1936, 1939, 1947 and 1960 exceptionally warm. The causes of the observed year to year variations are investigated. It is shown that a distinct relation exists between the air pressure distribution in spring and the hydrographic conditions in summer. It is concluded that the wind condition in the area west of Iceland is the dominating factor as regards influx of Atlantic water to the region north of Iceland. It is shown that it is possible with a fair degree of accuracy to predict the temperature conditions east of Langanes in August using calculated regression equation expressing the sea temperature as a function of air pressure difference in May. Similar equations can be used to predict the conditions farther west in the area. The practical value of this application is briefly discussed. Variations in the tongue of cold water NE of Iceland are analyzed and investigations made to test if the variations between years can be explained by the wind conditions. The result is that there probably exists a relation between the hydrographic conditions at intermediate depths in the tongue of cold water and the east-west wind component in the preceding 20–40 days.

From the results described in this paper it will be evident that investigations in Icelandic waters are in great need of expansion and improvement. In the coming years emphasis should be placed on seasonal studies, not only in the North Icelandic coastal area, but also in the oceanic region north of the shelf. The mechanism of mixing between different water masses should be investigated in more detail. It seems likely that isotopic studies might here be applied with success.

As regards the current velocity, great uncertainties are involved. Direct current measurements are badly needed from this region, especially continuous measurements which might reveal short-periodic variations. These measurements would probably be best accomplished by means of recording buoys.

The relation between the wind conditions west of Iceland in spring and the hydrographic conditions north of Iceland in summer should be studied in more detail. It seems likely that a better correlation would be obtained by studying the actual weather maps rather than dealing with mean monthly values. The possibility of using air pressure data or other meteorological material for predicting oceanographic conditions should be a matter of thorough investigation.

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LIST OF ILLUSTRATIONS

APPENDIX

TABLE I

Deviations in temperature and salinity in June at K–1 (66° 30′ N, 23° 00′ W).

YEAR	0 m		20 m		50 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	—1.75	+0.28	—1.57	+0.14	—1.38	+0.05
1926	—0.05	+0.09	—0.07	—0.01	—0.04	—0.07
1936	+1.48	—0.06	+1.67	—0.07	+1.73	+0.17
1952	—1.18	+0.09	—0.84	—0.05	—0.63	—0.11
1953	—0.66	—0.12	—0.80	—0.19	—0.89	—0.21
1954	+0.92	—0.62	+0.33	—0.14	+0.35	—0.05
1955	+0.41	+0.18	+0.43	+0.18	+0.35	+0.15
1957	+0.92	—0.29	+0.97	—0.08	.	.
1959	+0.17	+0.17	+0.01	+0.01	+0.26	—0.06
1960	—0.28	+0.30	—0.10	+0.19	+0.24	+0.11
Mean	5.88	34.51	5.63	34.65	5.37	34.74
St. dev. of mean	0.32	0.09	0.30	0.04	0.30	0.04

TABLE II

Deviations in temperature and salinity in June at K–2 (66° 41′ N, 23° 09′ W).

YEAR	0 m		20 m		50 m		75 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	—0.17	+0.14	—1.12	+0.11	—1.19	+0.12	—1.08	+0.06
1926	—0.29	+0.03	—0.08	—0.02	+0.01	—0.06	+0.07	—0.07
1936	+0.97	+0.26	+1.08	+0.23	+1.09	+0.16	+1.15	+0.12
1952	—0.73	—0.05	—0.34	—0.05	—0.64	—0.05	—0.56	—0.07
1953	—1.36	—0.41	—1.56	—0.23	—1.17	—0.23	—0.86	—0.21
1954	+0.27	—0.29	+0.60	—0.28	+0.25	—0.07	.	.
1955	+0.07	—0.02	+0.60	—0.02	+0.33	+0.01	+0.38	+0.01
1957	+1.05	+0.23	+0.53	+0.19	+0.76	+0.13	+0.72	+0.08
1959	+0.57	+0.18	+0.40	+0.12	+0.41	+0.02	.	.
1960	—0.43	—0.04	—0.13	—0.05	+0.18	—0.04	+0.20	+0.06
Mean	5.92	34.78	5.62	34.81	5.31	34.91	5.20	34.95
St. dev. of mean	0.24	0.07	0.26	0.05	0.24	0.04	0.28	0.04

TABLE III

Deviations in temperature and salinity in June at K–3 (66° 53′ N, 23° 19′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	+0.76	+0.24	+0.19	+0.03	−0.18	+0.01	−0.19	+0.02	−0.13	+0.02	−0.17	+0.02	−0.30	0
1926	+0.96	+0.53	+0.14	+0.08	−0.43	−0.01	−0.54	−0.06	−0.51	−0.04	−1.12	−0.15	−2.13	−0.22
1936	−1.33	−0.32	−0.99	−0.41	+0.08	−0.07	+0.22	−0.05	+0.33	−0.04	+0.57	+0.02	+1.02	+0.05
1952	−0.14	+0.39	−0.61	0	−0.24	−0.01	−0.09	−0.03	−0.24	−0.03	−0.80	−0.06	−1.34	−0.08
1953	−4.26	−2.45	−0.17	−0.01	−0.43	−0.02	−0.55	−0.01	−0.80	0	.	.	.	.
1954	+1.06	+0.46	+0.28	+0.04	+0.24	−0.02	−0.09	−0.05	+0.01	−0.04	+0.42	−0.02	+0.61	+0.01
1955	+1.16	+0.54	+0.68	+0.12	+0.48	+0.05	+0.41	+0.04	+0.33	+0.04	+0.18	+0.03	+0.85	+0.07
1957	+1.74	+0.55	+1.06	+0.13	+0.65	+0.06	+0.57	+0.05	+0.63	+0.06	+0.70	+0.05	+1.19	+0.08
1959	−0.92	−0.54	−0.88	−0.15	−0.39	−0.05	0	0	+0.10	0	−0.11	+0.03	−0.76	−0.03
1960	+0.96	+0.59	+0.33	+0.16	+0.21	+0.07	+0.26	+0.06	+0.31	+0.07	+0.37	+0.06	+0.90	+0.09
Mean	5.34	34.54	6.01	34.96	6.04	35.04	5.93	35.05	5.83	35.05	5.56	35.06	4.89	35.03
St. dev. of mean	0.56	0.30	0.21	0.05	0.12	0.01	0.12	0.01	0.14	0.01	0.21	0.02	0.40	0.03

TABLE IV

Deviations in temperature and salinity in July at K–1 (66° 30′ N, 23° 00′ W).

YEAR	0 m Δt°	0 m ΔS‰	20 m Δt°	20 m ΔS‰	50 m Δt°	50 m ΔS‰
1924	−2.23	+0.21	−2.11	+0.11	−1.83	+0.03
1926	+0.63	−0.44	+0.46	−0.17	+0.18	−0.09
1927	+1.31	−0.21	+1.30	−0.21	+1.62	−0.23
1931	+0.41	+0.19	−0.25	+0.16	−0.18	+0.16
1932	−0.06	+0.04	−0.74	+0.10	−0.85	+0.05
1938	−1.91	+0.03	−1.60	−0.07	−1.48	−0.20
1947	+0.79	−0.19	+1.03	+0.09	+0.59	+0.13
1948	−0.40	−0.44	−0.05	−0.41	−0.21	−0.02
1949	−0.02	+0.25	−0.13	+0.07	+0.07	−0.03
1950	−0.43	+0.23	−0.47	+0.14	−0.09	+0.03
1951	+0.15	−0.04	+0.28	+0.02	−0.13	+0.16
1957	+1.23	+0.11	+1.60	0	+1.65	−0.09
1960	+0.58	+0.28	+0.69	+0.13	+0.72	+0.11
Mean	8.02	34.57	7.70	34.71	7.35	34.81
St. dev. of mean	0.30	0.07	0.30	0.05	0.28	0.03

TABLE V

Deviations in temperature and salinity in July at K–2 (66° 41′ N, 23° 09′ W).

YEAR	0 m Δt°	0 m ΔS‰	20 m Δt°	20 m ΔS‰	50 m Δt°	50 m ΔS‰	75 m Δt°	75 m ΔS‰
1924	−1.88	+0.05	−1.66	+0.02	−1.31	−0.01	−1.24	+0.01
1926	+0.01	+0.14	−0.05	+0.08	−0.05	−0.03	+0.15	−0.02
1927	+0.98	+0.07	+0.80	+0.06	+0.51	−0.07	+0.48	−0.04
1931	−0.39	+0.09	−0.14	+0.05	−0.33	+0.11	−0.27	+0.11
1932	−0.09	−0.10	−0.51	−0.08	−0.67	+0.02	−0.55	+0.03
1938	−2.05	−0.08	−1.78	−0.06	−1.19	−0.04	−0.78	−0.18
1947	+1.89	−0.02	+0.82	+0.12	+0.93	+0.04	+1.06	−0.04
1948	+0.06	−0.38	−0.49	−0.15	−0.71	−0.08	−0.68	−0.02
1949	−0.53	+0.16	−0.15	+0.10	+0.23	−0.03	−0.08	−0.02
1950	−0.44	+0.12	−0.20	+0.03	+0.21	+0.11	−0.32	+0.10
1951	+0.08	+0.16	−0.17	+0.14	−0.19	+0.05	−0.26	+0.08
1957	+1.90	−0.25	+2.49	−0.30	+1.61	−0.06	+1.60	−0.07
1960	+0.45	+0.08	+1.08	+0.01	+0.93	+0.04	+0.94	+0.05
Mean	8.15	34.78	7.54	34.84	6.67	34.97	6.52	34.98
St. dev. of mean	0.33	0.05	0.31	0.04	0.24	0.02	0.23	0.02

TABLE VI

Deviations in temperature and salinity in July at K-3 (66° 53′ N, 23° 19′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	—0.56	+0.56	—0.51	+0.28	—0.37	+0.03	—0.27	+0.03	—0.33	+0.03	—0.53	—0.05	—0.45	+0.02
1926	+0.64	+0.02	+0.32	+0.05	—0.05	+0.02	+0.05	—0.02	+0.13	—0.01	+0.25	—0.02	+0.63	+0.02
1927	+0.19	—0.74	+0.67	+0.25	+0.04	+0.06	—0.08	+0.03	—0.22	+0.05	—0.01	0	+0.40	+0.02
1932	+0.84	+0.24	—0.41	—0.05	—0.23	—0.14	—0.05	—0.11	+0.11	—0.06	+0.09	—0.01	+0.48	+0.04
1938	—3.51	—0.54	—3.06	—0.47	—1.44	—0.24	—1.30	—0.11	—1.25	—0.06	—1.06	—0.02	—0.18	—0.02
1947	+1.95	+0.43	+1.02	+0.22	+0.40	+0.03	+0.59	—0.02	+0.66	—0.02	+0.45	—0.01	+0.93	+0.03
1948	+0.81	+0.61	+0.96	+0.32	+0.35	+0.10	+0.36	+0.02	+0.37	+0.04	+0.35	+0.04	+0.61	+0.06
1949	—3.70	—1.73	—2.58	—0.83	—0.91	+0.10	—0.64	+0.09	—0.81	0	—0.50	+0.01	—2.95	—0.21
1950	+0.32	+0.48	+0.41	+0.19	+0.08	0	—0.05	—0.02	—0.03	—0.04	—0.09	—0.02	+0.37	+0.06
1951	+0.35	+0.14	+0.10	—0.04	—0.18	+0.04	—0.30	+0.02	—0.30	+0.02	—0.45	0	—0.11	+0.07
1957	+2.50	+0.51	+2.64	+0.23	+1.55	+0.04	+0.71	+0.07	+0.66	+0.07	+0.62	+0.04	+1.05	+0.09
1960	+0.20	+0.05	+0.44	—0.16	+0.81	—0.03	+0.99	.	+0.98	.	+0.90	+0.10	—0.80	—0.22
Mean	7.00	34.47	6.87	34.74	6.67	35.02	6.49	35.07	6.33	35.07	6.05	35.10	5.57	35.06
St. dev. of mean	0.54	0.20	0.44	0.10	0.22	0.03	0.18	0.02	0.18	0.01	0.16	0.01	0.31	0.03

TABLE VII

Deviations in temperature and salinity in August at K–1 (66° 30′ N, 23° 00′ W).

YEAR	0 m		20 m		50 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1927	+0.52	—0.01	+0.47	+0.04	—0.04	+0.10
1933	+2.11	—0.29	+1.85	—0.13	+1.89	—0.12
1934	—0.81	—0.01	—1.07	+0.02	—1.07	+0.03
1935	+0.23	—0.20	+0.52	—0.08	+0.58	—0.07
1936	—0.40	+0.16	—0.97	+0.16	—1.05	+0.08
1939	+0.74	+0.01	+0.32	—0.01	+0.29	—0.04
1948	+1.52	—0.20	+1.35	—0.20	+1.25	—0.15
1949	—0.41	—0.13	—0.64	—0.08	—0.73	—0.04
1951	—0.01	+0.09	+0.04	+0.10	—0.47	+0.16
1954	—1.67	+0.18	—1.39	+0.07	—1.05	—0.01
1955	+0.34	+0.08	+0.85	—0.02	+1.14	—0.10
1956	—0.96	+0.11	—0.46	+0.03	·	·
1958	—1.26	+0.22	—0.87	+0.16	—0.76	+0.12
Mean	9.06	34.62	8.63	34.72	8.31	34.80
St. dev. of mean	0.30	0.05	0.28	0.03	0.30	0.03

TABLE VIII

Deviations in temperature and salinity in August at K–2 (66° 41′ N, 23° 09′ W).

YEAR	0 m		20 m		50 m		75 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1927	+0.34	+0.13	+0.54	+0.08	—0.66	+0.07	—0.53	+0.07
1933	+1.87	—0.21	+1.50	+0.02	+0.78	+0.03	+0.60	+0.03
1934	—1.03	—0.10	—0.80	—0.09	—0.68	+0.03	—0.38	+0.03
1935	—0.20	—0.10	+0.64	—0.15	+0.51	—0.03	+0.56	—0.03
1936	—0.47	+0.20	—0.75	+0.13	—0.50	+0.01	—0.44	+0.02
1939	+1.02	—0.30	+0.82	—0.21	+0.45	—0.04	+0.61	—0.05
1948	+1.85	—0.01	—0.04	0	+0.40	—0.05	+0.39	—0.04
1949	—0.20	+0.10	—0.09	+0.04	—0.69	—0.04	—0.68	—0.02
1951	—0.03	+0.08	+0.34	+0.08	+0.53	+0.02	—0.45	+0.07
1954	—0.93	+0.10	—1.50	+0.10	—0.71	+0.04	—0.56	+0.01
1955	—0.37	+0.07	+0.58	—0.01	+1.51	—0.09	+1.72	—0.10
1956	—0.43	—0.03	—0.63	+0.02	—0.34	—0.02	—0.21	—0.01
1958	—1.43	+0.13	—0.55	+0.04	—0.61	+0.06	—0.65	+0.08
Mean	9.13	34.77	8.27	34.85	7.35	34.98	7.13	34.99
St. dev. of mean ...	0.29	0.04	0.23	0.03	0.20	0.01	0.20	0.01

TABLE IX

Deviations in temperature and salinity in August at K-3 (66° 53′ N, 23° 19′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1927	+0.90	+0.66	+0.94	+0.32	+0.16	+0.25	+0.05	+0.11	+0.04	+0.05	+0.06	+0.03	+0.03	+0.04
1933	+0.05	—0.25	—0.90	—0.32	—1.00	+0.04	—0.35	+0.03	+0.11	+0.03	—0.03	+0.01	+0.31	0
1934	—1.05	+0.27	—0.57	—0.03	—0.12	—0.11	0	—0.03	+0.20	—0.03	+0.40	+0.02	+0.24	+0.02
1935	+0.79	+0.77	+1.23	+0.48	+1.13	+0.09	+0.37	+0.04	0	—0.01	+0.41	—0.03	+0.12	+0.01
1936	—0.92	+0.36	—0.48	+0.04	—0.16	+0.20	—0.04	+0.10	+0.17	+0.08	+0.29	+0.06	+0.18	+0.02
1939	—1.23	—2.61	—4.78	—2.00	—4.25	—1.03	—1.95	—0.37	+0.25	—0.01	+0.14	+0.04	+0.36	+0.06
1948	+2.66	+0.68	+2.31	+0.52	+2.00	+0.12	+1.01	+0.05	+0.13	+0.07	—0.04	+0.02	+0.24	+0.03
1949	+2.17	+0.79	+1.18	+0.51	+0.17	+0.20	—0.26	+0.08	—0.51	+0.02	—0.59	+0.03	—0.33	+0.03
1951	—0.81	—0.40	+1.96	+0.48	+1.15	+0.27	+0.09	+0.13	—0.29	+0.06	—0.40	+0.02	—0.30	+0.03
1954	+0.30	+0.80	+0.18	+0.55	+0.30	+0.16	+0.21	—0.02	+0.26	—0.09	+0.11	—0.06	+0.27	—0.02
1955	+0.25	+0.47	+1.40	+0.32	+1.40	—0.07	+0.40	—0.14	—0.51	—0.13	—0.38	—0.04	—1.16	—0.13
1956	—3.50	—1.71	—3.44	—0.77	—1.70	—0.29	—0.26	—0.03	—0.29	—0.08	—0.04	—0.05	+0.08	—0.05
1958	+0.40	+0.14	+0.92	—0.08	+0.97	+0.13	+0.79	+0.01	+0.39	+0.02	+0.11	0	—0.07	+0.01
Mean	7.30	34.06	6.88	34.38	6.68	34.83	6.76	35.00	6.74	35.09	6.56	35.11	6.32	35.10
St. dev. of mean	0.44	0.29	0.58	0.20	0.45	0.10	0.20	0.04	0.08	0.02	0.09	0.01	0.11	0.01

TABLE X

Deviations in temperature and salinity in June at S-1 (66° 16′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	—0.39	—0.21	—2.51	—0.24	—2.79	—0.28
1926	—1.18	+0.26	—0.33	+0.01	+0.35	+0.03
1936	+1.59	+0.56	+2.00	+0.21	+1.95	+0.12
1937	—0.89	+0.09	—1.01	+0.06	—0.50	+0.07
1947	+0.36	+0.08	—0.38	+0.07	—0.20	+0.03
1952	—1.52	+0.07	—1.18	—0.09	—0.74	0
1953	+1.45	—1.65	+0.28	—0.13	—0.24	—0.03
1954	—0.22	—0.04	+1.15	+0.13	—0.04	—0.10
1955	+2.38	+0.11	+1.16	+0.16	+0.06	+0.05
1956	—0.16	+0.09	+0.26	+0.02	+0.45	+0.03
1957	—0.45	—0.02	—0.23	—0.09	+0.46	—0.06
1958	—0.05	+0.10	+0.24	—0.10	—0.54	—0.02
1959	—0.27	+0.19	+0.20	—0.10	+0.67	+0.05
1960	—0.62	+0.36	+0.35	+0.04	+1.13	+0.10
Mean	6.12	34.52	5.09	34.84	4.20	34.89
St. dev. of mean	0.30	0.14	0.30	0.03	0.29	0.03

TABLE XI

Deviations in temperature and salinity in June at S–2 (66° 24′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m		300 m		400 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	−1.69	−0.06	−2.35	−0.24	−2.46	−0.18	−2.59	−0.20	−2.39	−0.18	−2.06	−0.12	−1.82	−0.08	−0.90	−0.05	−0.41	.
1926	−0.60	+0.04	−0.04	−0.14	+0.14	−0.03	+0.25	−0.01	+0.38	0	+0.22	−0.01	+0.05	−0.02	−0.32	−0.05	.	−0.01
1936	+0.55	+0.26	+1.02	+0.14	+1.00	+0.11	+0.80	+0.07	+0.62	+0.04	+0.41	+0.02	+0.19	0	.	.	.	.
1937	−1.09	+0.26	−0.78	+0.07	−0.61	−0.09	−0.54	−0.05	−0.45	−0.02	.	.	.	.	.	.	.	.
1947	+0.70	+0.23	+0.19	+0.09	+0.04	+0.09	+0.15	+0.05	−0.02	+0.01	+0.06	0	+0.03	0	+0.09	.	.	.
1952	−0.40	+0.37	−0.28	+0.19	.	+0.11	−0.02	+0.09	−0.14	+0.02	−0.13	+0.06	−0.50	+0.03	−1.62	−0.03	−0.67	+0.01
1953	+0.98	+0.12	+0.51	−0.01	−0.20	−0.06	−0.22	−0.05	−0.31	−0.07	−0.44	−0.07	−0.45	−0.07	−0.68	−0.03	−0.33	−0.01
1954	+0.80	−0.04	+1.22	+0.07	+0.80	+0.05	+0.62	+0.06	+0.63	+0.04	+0.57	+0.02	+0.73	+0.01	+0.83	+0.02	+0.17	−0.01
1955	+1.50	−1.79	−0.33	−0.26	+0.40	−0.05	+0.89	+0.09	+0.88	+0.06	+0.56	+0.05	+0.44	+0.04	+0.90	+0.04	+1.23	−0.01
1956	−0.94	−0.01	−0.10	−0.20	−0.12	−0.05	−0.06	−0.03	−0.01	−0.04	+0.19	−0.02	+0.28	−0.04	−0.31	−0.02	−0.31	0
1957	+0.40	+0.37	+1.01	+0.20	+0.96	+0.09	+0.74	+0.05	+0.58	+0.05	+0.47	+0.01	+0.60	+0.01	+0.68	+0.01	−0.56	+0.01
1958	+0.02	−0.34	−1.13	−0.21	−1.35	−0.17	−1.18	−0.14	−1.00	−0.11	−0.73	−0.07	−0.53	−0.05	+0.21	0	+0.92	+0.02
1959	+0.13	+0.27	+0.71	+0.12	+0.73	+0.01	+0.46	+0.01	+0.41	+0.05	+0.34	+0.06	+0.28	+0.07	+0.37	+0.05	+0.14	+0.03
1960	−0.30	+0.26	+0.41	+0.12	+0.65	+0.13	+0.70	+0.12	+0.87	+0.09	+0.50	+0.07	+0.65	+0.06	+0.70	+0.07	0	+0.01
Mean	6.20	34.66	5.43	34.84	5.00	34.97	4.82	34.99	4.62	35.01	4.34	35.00	4.08	34.99	3.20	34.95	0.93	34.91
St. dev. of mean	0.24	0.15	0.26	0.04	0.26	0.03	0.25	0.03	0.23	0.02	0.20	0.02	0.19	0.01	0.23	0.01	0.19	0.00

TABLE XII

Deviations in temperature and salinity in June at S–3 (66° 32′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m		300 m		400 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	−2.45	−0.08	−2.65	−0.08	−2.81	−0.16	−1.79	−0.08	−1.97	−0.06	−1.91	−0.07	−1.78	−0.05	−1.60	−0.05	−0.58	+0.01
1926	−0.48	+0.13	−0.06	+0.08	+0.29	+0.04	+0.32	+0.03	+0.42	+0.03	−0.20	−0.07	−0.12	−0.07	−0.36	−0.03	−0.08	−0.02
1936	+0.45	−0.16	+0.76	−0.05	+0.70	+0.11	+0.61	+0.09	+0.58	+0.07	.	.	.	.	.	.	.	.
1937	−0.02	+0.20	−1.05	+0.10	−0.86	−0.02	−0.72	−0.04	−0.51	−0.01	.	.	.	.	.	.	.	.
1947	+0.53	+0.13	+0.53	+0.07	−0.09	−0.03	−0.05	−0.04	−0.06	−0.04	+0.06	−0.03	+0.08	−0.01	−0.01	+0.02	+0.90	−0.01
1952	−0.58	+0.19	−0.19	+0.17	−0.36	+0.06	−0.14	+0.07	−0.26	+0.04	−0.30	+0.04	−0.32	+0.04	−1.32	−0.04	−0.48	0
1953	+1.03	−0.06	+0.23	−0.09	−0.08	−0.06	+0.06	−0.05	−0.24	−0.06	−0.03	−0.03	−0.10	−0.04	+0.34	−0.02	+0.22	−0.02
1954	+0.72	+0.05	+1.37	+0.13	+0.94	+0.07	+0.96	+0.06	+1.02	+0.05	+0.96	+0.03	+0.38	0	+0.60	+0.02	+0.16	+0.02
1955	+1.20	+0.01	+1.59	+0.04	+1.56	+0.04	+0.62	+0.06	+0.41	+0.05	+0.56	+0.06	+0.52	+0.04	+1.14	+0.03	+0.17	+0.01
1956	−0.46	−0.12	+0.12	−0.16	−0.46	−0.09	−0.26	−0.06	−0.20	−0.05	−0.05	−0.04	−0.10	−0.04	−0.12	−0.03	−0.53	0
1957	+0.24	+0.26	+0.87	+0.16	+1.20	+0.94	+0.50	+0.03	+0.29	−0.01	+0.28	+0.01	+0.65	+0.01	+0.46	+0.02	−0.08	0
1958	−0.09	−0.62	−1.62	−0.25	−1.20	−0.16	−1.04	−0.13	−0.71	−0.09	−0.68	−0.07	−0.72	−0.07	−0.17	−0.04	+0.47	+0.01
1959	+0.09	+0.16	−0.22	+0.11	+0.16	+0.03	+0.39	+0.04	+0.49	+0.04	+0.45	+0.08	+0.56	+0.10	+0.85	+0.07	−0.18	+0.03
1960	−0.18	−0.14	+0.35	−0.21	+1.03	+0.06	+0.58	+0.08	+0.73	+0.07	+0.84	+0.08	+0.94	+0.10	+0.20	+0.05	+0.07	+0.02
Mean	6.18	34.79	5.59	34.87	5.22	34.99	5.02	35.00	4.76	35.00	4.28	34.99	3.82	34.97	2.62	34.93	0.68	34.91
St. dev. of mean	0.24	0.06	0.31	0.04	0.30	0.02	0.20	0.02	0.20	0.01	0.22	0.02	0.21	0.02	0.24	0.01	0.12	0.00

TABLE XIII

Deviations in temperature and salinity in July at S-1 (66° 16′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	—1.18	+0.16	—0.72	+0.18	—0.08	+0.15
1926	+1.58	—0.39	+0.78	+0.03	+0.67	—0.02
1927	+1.36	+0.35	+0.78	+0.07	+0.59	+0.04
1932	—2.46	—0.14	—1.38	—0.31	—1.19	—0.23
1938	—1.41	—0.93	—1.49	—0.28	—0.94	—0.18
1947	—0.02	+0.53	+0.39	+0.23	+0.55	+0.10
1948	+0.12	+0.12	—0.13	—0.02	—0.48	+0.04
1949	+0.63	—0.25	—0.18	—0.08	—1.08	+0.01
1951	+0.62	+0.03	+0.49	0	+0.51	+0.02
1954	—0.11	—0.03	+0.02	—0.01	+0.55	—0.01
1955	+0.91	+0.50	+1.43	+0.23	+0.87	+0.12
Mean	7.89	34.26	6.51	34.66	5.27	34.84
St. dev. of mean	0.38	0.13	0.28	0.05	0.24	0.04

TABLE XIV

Deviations in temperature and salinity in July at S–2 (66° 24′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m		300 m		400 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	−0.95	−0.08	−0.30	+0.01	+0.06	+0.03	−0.10	+0.02	−0.24	−0.01	−0.50	−0.03	−0.61	−0.02	−0.76	−0.02	−0.57	−0.02
1926	+1.64	+0.20	+0.53	+0.19	+0.72	+0.06	+0.68	+0.02	+0.60	+0.02	+0.61	+0.01	+0.61	+0.01	+0.54	−0.01	+1.54	+0.02
1927	+1.94	−0.04	+1.56	−0.10	+0.72	+0.01	+0.86	+0.01	+0.94	+0.06	+0.76	+0.03	+0.59	+0.02	+0.05	−0.04	.	.
1930	+0.76	−0.06	−0.27	+0.20	+0.25	+0.09	+0.19	+0.03	+0.08	+0.01	−0.03	0	−0.14	0	−0.44	0	−0.19	−0.02
1931	−0.83	+0.11	−0.87	+0.18	+0.27	+0.12	0	+0.06	−0.10	+0.05	−0.12	+0.06	−0.05	+0.07	+0.01	+0.08	.	.
1932	−1.13	−0.51	−1.16	−0.48	−1.01	−0.08	−1.10	−0.10	−1.24	−0.14	−1.14	−0.14	−1.08	−0.13	.	.	.	.
1938	−1.79	−0.27	−1.49	−0.34	−1.07	−0.13	−0.43	−0.02	−0.13	0	−0.05	+0.02	−0.46	−0.05	−0.59	−0.06	−0.82	0
1947	−0.14	+0.21	+0.26	+0.12	+0.57	+0.05	+0.56	+0.03	+0.51	+0.05	+0.63	+0.04	+0.76	+0.04	.	.	.	.
1948	−0.42	+0.12	−0.18	+0.01	−0.19	−0.02	+0.11	−0.01	+0.33	+0.03	+0.33	+0.03	+0.59	+0.06	+0.28	−0.01	+0.56	−0.03
1949	−0.46	−0.04	−0.66	−0.16	−2.79	−0.25	−1.98	−0.17	−1.87	−0.13	−1.19	−0.09	−1.10	−0.08	−0.50	−0.06	.	.
1951	+0.38	+0.06	+0.46	0	+0.22	+0.07	−0.08	+0.04	−0.20	+0.07	−0.14	−0.01	−0.31	−0.02	−0.11	+0.02	−0.10	+0.01
1954	−0.07	+0.03	+0.21	+0.19	+1.04	+0.04	+0.77	+0.03	+0.77	+0.03	+0.70	+0.03	+0.74	+0.01	+0.63	+0.01	−0.41	+0.01
1955	+1.08	+0.27	+1.93	+0.16	+1.19	+0.01	+0.54	+0.06	+0.54	+0.06	+0.22	+0.03	+0.41	+0.06	+0.93	+0.08	−0.02	+0.05
Mean	8.22	34.62	6.97	34.75	5.75	34.96	5.30	35.01	5.30	35.02	5.02	35.02	4.73	35.01	3.49	34.94	1.04	34.90
St. dev. of mean	0.31	0.06	0.24	0.06	0.29	0.03	0.22	0.02	0.22	0.02	0.18	0.01	0.19	0.02	0.17	0.01	0.26	0.01

TABLE XV

Deviations in temperature and salinity in July at S-3 (66° 32′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m		300 m		400 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1926	+1.64	+0.15	+0.56	+0.13	+0.46	+0.13	+0.46	+0.05	+0.55	+0.03	+0.64	+0.02	+0.64	+0.02	+0.72	+0.04	−0.62	−0.01
1927	+1.34	−0.07	+0.75	−0.01	+0.72	+0.10	+0.70	+0.05	+0.77	+0.06	+0.62	+0.04	+0.48	+0.04	+0.20	−0.03	+0.19	−0.01
1932	−1.17	−0.68	−1.35	−0.51	−0.85	+0.02	−0.71	−0.06	−1.36	−0.13	−1.23	−0.13	−0.92	−0.11	−0.60	−0.04	−0.58	−0.01
1938	−1.94	−0.32	−1.64	−0.31	−1.47	−0.40	−0.70	−0.05	−0.16	+0.04	−0.18	+0.03	−0.44	−0.02	−0.66	−0.06	−0.17	−0.03
1947	+0.43	+0.20	+0.27	+0.21	+0.86	+0.06	+0.87	+0.02	+0.97	+0.04	+0.78	+0.01	+0.68	+0.04	+0.87	+0.01	+0.98	+0.06
1948	−0.34	+0.04	+0.17	+0.01	+0.05	+0.03	+0.28	−0.03	+0.48	−0.02	+0.61	−0.02	+0.68	+0.02	+0.84	+0.04	+0.95	0
1949	−0.65	−0.09	−0.45	−0.06	−2.11	−0.10	−1.84	−0.15	−1.62	−0.09	−1.25	−0.03	−1.28	−0.07	−1.06	−0.05	.	.
1951	−0.12	+0.19	−0.04	+0.12	+0.75	−0.05	+0.20	+0.04	−0.34	−0.01	−0.37	+0.01	−0.38	+0.01	−0.89	+0.02	−0.25	+0.01
1954	−0.20	+0.27	−0.02	+0.22	+0.56	+0.09	+0.52	+0.05	+0.54	+0.04	+0.35	+0.02	+0.27	+0.02	+0.36	+0.01	−0.26	−0.01
1955	+1.05	+0.30	+1.71	+0.22	+0.98	+0.08	+0.25	+0.08	+0.21	+0.06	+0.05	+0.03	+0.29	+0.07	+0.22	+0.05	−0.23	−0.01
Mean	8.25	34.63	6.91	34.71	5.73	34.91	5.59	34.99	5.36	35.01	4.95	35.00	4.52	34.97	3.16	34.91	0.85	34.91
St. dev. of mean	0.36	0.10	0.31	0.08	0.35	0.05	0.27	0.02	0.28	0.02	0.24	0.02	0.22	0.02	0.23	0.01	0.20	0.01

TABLE XVI

Deviations in temperature and salinity in August at S-1 (66° 16′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1925	—1.08	+0.31	—1.09	+0.22	—0.24	+0.12
1927	+0.59	+0.11	—0.06	+0.15	+0.25	—0.02
1931	—0.14	+0.24	—1.75	+0.35	—1.06	+0.17
1933	+1.97	—0.77	+0.39	—0.07	+0.20	+0.01
1939	+1.76	—0.12	+0.89	0	+0.97	—0.05
1948	+1.02	—0.04	+1.52	—0.21	+0.42	—0.04
1949	—0.45	+0.08	+0.09	—0.06	—0.25	0
1950	+0.26	—0.05	—0.15	—0.05	—1.17	—0.02
1951	—0.12	+0.17	+0.21	+0.10	+0.40	—0.07
1954	—1.25	+0.35	—1.51	+0.24	—0.56	—0.10
1955	+0.15	+0.16	+0.76	—0.03	+1.74	—0.28
1956	—2.50	—0.64	—0.78	—0.38	—0.42	—0.08
1957	+0.07	+0.22	+0.69	+0.07	+0.72	+0.07
1958	—0.70	—0.29	—0.35	—0.45	—1.23	+0.06
1960	+0.45	+0.26	+1.03	+0.19	+0.27	+0.07
Mean	8.90	34.32	8.11	34.55	6.86	34.80
St. dev. of mean	0.30	0.09	0.25	0.06	0.22	0.03

TABLE XVII

Deviations in temperature and salinity in August at S–2 (66° 24′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m		300 m		400 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1925	−1.17	.	−1.17	.	−1.17	.	+0.26	.	+0.13	.	+0.21	.	+0.41	.	+0.28	.	−0.82	.
1927	+1.00	+0.04	+1.46	−0.05	+0.57	−0.02	−0.37	−0.01	−0.92	+0.04	−0.75	+0.02	−1.00	+0.06	−1.76	+0.07	−0.74	+0.03
1931	+0.39	−0.77	−0.68	+0.27	−0.10	+0.18	−0.37	+0.06	−0.55	−0.01	−0.43	+0.04	−0.21	+0.06	−1.30	−0.02	−0.54	+0.05
1933	+1.70	−0.24	+0.65	+0.11	−0.06	+0.06	−0.06	+0.06	+0.13	+0.04	+0.16	+0.02	+0.21	+0.02	+0.73	+0.03	−0.12	−0.02
1939	+2.01	+0.31	+1.80	+0.15	+0.71	0	+0.42	−0.03	+0.51	−0.01	+0.52	0	+1.09	−0.03	+2.05	+0.10	+4.18	+0.11
1948	+1.08	+0.41	−0.32	+0.32	−0.43	+0.02	−0.14	−0.04	+0.24	−0.07	+0.26	+0.02	+0.38	+0.05	+0.54	+0.04	.	.
1949	−0.82	+0.25	−0.10	+0.06	−0.78	0	−0.83	+0.02	−0.70	+0.02	−0.98	−0.02	−0.95	0	−1.03	−0.02	−0.74	−0.05
1950	−0.04	+0.11	+0.30	−0.01	+0.57	−0.09	−0.34	+0.02	−0.23	−0.02	−0.23	+0.01	−0.15	−0.01	−0.43	−0.03	−0.56	−0.03
1951	+0.14	+0.32	+0.56	+0.11	+0.05	0	−0.12	−0.05	−0.06	−0.05	−0.21	−0.01	−0.09	+0.03	+0.52	+0.05	+0.56	+0.03
1954	−0.86	+0.29	−0.63	+0.17	+0.05	+0.03	−0.02	0	+0.17	−0.01	+0.03	−0.06	−0.25	−0.06	−0.45	−0.10	−0.36	−0.05
1955	−0.86	−0.01	−0.12	−0.21	+0.88	−0.03	+0.32	−0.14	+0.57	−0.03	+0.41	+0.01	+0.49	+0.01	+0.27	+0.04	−0.46	+0.01
1956	−3.16	−0.93	−3.99	−0.60	−1.24	−0.21	−0.17	+0.01	−0.33	−0.05	−0.53	−0.02	−0.99	−0.13	−1.36	−0.20	−0.92	−0.04
1957	+0.47	+0.06	+1.30	−0.13	+0.15	0	+0.32	+0.05	+0.45	+0.05	+0.58	+0.01	+0.51	0	+0.24	−0.04	−0.55	0
1958	−0.66	−0.11	+0.04	−0.35	−0.12	−0.02	−0.14	+0.04	+0.23	+0.02	+0.35	−0.01	−0.37	−0.02	−0.13	+0.01	+0.15	.
1960	+0.84	+0.26	+0.96	+0.12	+0.90	+0.12	+1.22	+0.07	+0.40	+0.07	+0.59	+0.03	+0.88	+0.05	+1.77	+0.13	+0.88	.
Mean	8.66	34.27	7.87	34.49	6.39	34.92	6.26	35.00	6.03	35.04	5.83	35.08	5.51	35.06	4.13	34.98	1.12	34.93
St. dev. of mean	0.34	0.11	0.36	0.07	0.18	0.02	0.12	0.01	0.16	0.01	0.13	0.01	0.17	0.01	0.28	0.02	0.35	0.01

TABLE XVIII

Deviations in temperature and salinity in August at S–3 (66° 32′ N, 18° 50′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m		300 m		400 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1927	+1.44	−0.03	+2.02	−0.21	−0.12	+0.10	+0.14	+0.13	+0.17	+0.09	−0.12	+0.03	−0.36	0	−0.87	+0.02	−0.51	+0.04
1933	+0.66	−1.22	−1.79	−0.13	−0.63	−0.01	−0.13	−0.03	−0.20	−0.03	−0.23	−0.01	−0.13	0	−1.05	−0.04	−0.60	−0.01
1948	+0.70	+0.35	−0.57	+0.26	+0.02	+0.07	+0.04	−0.08	+0.24	−0.05	+0.16	+0.02	+0.25	.	+2.19	+0.14	.	.
1949	−0.46	+0.38	−0.14	+0.16	−0.50	+0.11	+0.66	+0.07	−0.75	+0.01	−0.67	+0.01	−0.54	+0.05	−1.25	−0.05	−0.30	−0.04
1950	+0.08	+0.35	+0.33	+0.19	+0.51	−0.13	−0.44	−0.02	−0.15	+0.03	−0.05	−0.02	+0.29	+0.01	+1.43	+0.08	.	.
1951	+0.44	+0.39	+0.09	+0.31	+0.22	+0.13	−0.25	+0.02	−0.41	+0.03	−0.02	+0.06	−0.67	+0.08	+0.89	+0.11	+1.00	+0.04
1954	−0.28	+0.19	−0.33	+0.14	+0.47	−0.09	+0.02	−0.04	−0.17	−0.03	−0.16	−0.02	+0.07	−0.01	+0.13	−0.04	+0.04	−0.04
1955	−0.50	+0.05	−0.02	−0.17	+1.17	+0.04	+0.95	−0.07	+0.72	−0.02	+0.62	+0.03	+0.95	−0.01	+0.49	−0.01	−0.30	−0.02
1956	−3.76	−1.07	−2.51	−0.52	−1.69	−0.40	−0.32	−0.11	−0.56	−0.10	−0.80	−0.17	−1.38	−0.20	−1.30	−0.12	−0.04	−0.03
1957	+0.19	+0.21	+0.69	+0.01	+0.44	+0.09	+0.39	+0.02	+0.61	+0.06	+0.36	+0.03	+0.35	0	−0.17	−0.02	−0.36	+0.01
1958	−0.26	−0.02	+0.22	−0.23	−0.31	−0.04	+0.10	+0.03	+0.16	+0.01	+0.34	+0.01	+0.09	+0.04	+0.51	−0.03	−0.04	+0.01
1960	+1.74	+0.41	+2.06	+0.21	+0.44	+0.19	+0.16	+0.06	+0.30	+0.05	+0.56	+0.07	+1.03	+0.10	−1.05	+0.01	+1.11	.
Mean	8.36	34.17	7.78	34.39	6.13	34.86	6.20	35.04	6.08	35.05	5.60	35.04	5.07	35.01	3.49	34.92	0.84	34.92
St. dev. of mean	0.40	0.16	0.38	0.07	0.21	0.05	0.12	0.02	0.13	0.02	0.13	0.02	0.20	0.02	0.33	0.02	0.19	0.01

TABLE XIX

Deviations in temperature and salinity in June at L–1 (66° 22′ N, 14° 22′ W).

YEAR	0 m		10 m		20 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1924	—2.06	+0.11	.	.	.	.
1926	—1.23	+0.26	—1.37	+0.25	—0.87	+0.18
1936	+1.18	—0.32	+0.67	—0.21	+0.72	—0.18
1937	+0.14	—0.16	—0.19	—0.03	+0.20	—0.05
1947	+0.15	+0.02	—0.57	+0.12	—0.24	+0.07
1950	—0.25	+0.20	—0.13	+0.19	—0.21	+0.17
1952	—1.35	—0.22	—1.29	—0.19	—0.83	—0.15
1953	+1.03	—0.35	+0.72	—0.34	+0.49	—0.19
1954	+1.45	.	+1.41	.	+0.99	.
1955	—1.25	+0.24	—0.66	+0.19	—1.40	+0.16
1956	+1.15	—0.05	+0.87	—0.13	+0.28	—0.01
1957	+1.27	—0.10	+1.37	—0.14	+1.72	—0.19
1958	—0.26	+0.36	—0.84	+0.24	—0.81	+0.18
Mean	4.45	34.50	4.33	34.53	3.78	34.60
St. dev. of mean	0.33	0.07	0.28	0.06	0.26	0.05

TABLE XX

Deviations in temperature and salinity in June at L–2 (66° 22′ N, 14° 01′ W).

YEAR	0 m		10 m		20 m		50 m		75 m		100 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1936	+0.81	+0.04	+0.63	+0.03	+0.84	+0.02	+0.64	+0.06	+0.09	+0.06	+0.63	+0.05
1937	—1.02	+0.05	—1.14	0	—0.55	—0.06	—0.44	—0.05	—0.24	—0.04	—0.14	—0.02
1947	—0.03	+0.03	+0.02	+0.19	—0.97	+0.05	—0.71	—0.07	—0.37	—0.05	—0.35	—0.04
1950	—1.11	+0.19	—1.08	+0.13	—0.29	+0.10	—0.33	+0.05	—0.32	+0.06	—0.43	+0.03
1952	—2.21	.	—2.11	.	—1.29	.	—0.18	.	—0.25	.	—0.83	.
1953	+1.51	—0.29	+1.75	—0.31	—1.19	+0.02	—0.56	+0.01	—0.23	0	—0.28	—0.01
1954	+1.59	—0.15	+1.63	—0.17	+1.90	—0.19	+0.22	—0.08	—0.03	—0.07	+0.19	—0.06
1956	+0.14	+0.13	—0.02	+0.12	+0.53	+0.09	+1.34	+0.06	+1.23	+0.05	+1.00	+0.05
1957	+0.36	.	+0.29	.	+1.01	.	+0.02	.	+0.15	.	+0.17	.
Mean	5.01	34.69	4.91	34.71	4.09	34.76	2.88	34.83	2.55	34.84	2.52	34.85
St. dev. of mean ..	0.42	0.06	0.43	0.07	0.37	0.04	0.22	0.02	0.16	0.02	0.19	0.18

TABLE XXI

Deviations in temperature and salinity in June at L–3 (66° 22′ N, 13° 35′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1936	+0.66	—0.06	+0.54	+0.04	—0.22	+0.01	—0.13	+0.08	—0.20	+0.06	.	.	.	.
1937	—0.82	—0.06	—0.91	—0.02	—0.31	—0.06	—0.51	—0.02	—0.23	—0.03	+0.02	+0.06	+0.41	+0.05
1947	+0.37	—0.15	+0.54	—0.16	—0.38	—0.12	—0.15	—0.06	—0.11	0	.	+0.02	.	+0.03
1950	—1.27	+0.15	—1.07	+0.12	+0.07	+0.03	+0.01	+0.01	—0.23	0	—0.07	+0.01	+0.11	+0.01
1952	—2.57	+0.08	—2.26	+0.05	—0.85	—0.03	—0.63	—0.05	—0.59	—0.06	—0.83	—0.02	—0.98	+0.02
1953	+1.40	—0.05	+1.72	—0.06	—0.90	+0.01	—0.55	0	—0.37	+0.01	—0.39	—0.01	—0.41	—0.03
1954	+1.83	—0.12	+1.70	—0.08	+0.98	+0.12	+0.63	+0.05	+0.65	+0.03	+0.54	—0.02	+0.59	—0.04
1956	+0.05	+0.07	—0.39	+0.05	+0.66	—0.02	+0.75	—0.02	+0.59	—0.03	+0.25	—0.04	+0.05	—0.05
1957	+0.38	+0.18	+0.14	+0.16	+0.91	+0.07	+0.59	+0.05	+0.53	+0.03	+0.49	+0.03	+0.42	+0.02
Mean	4.97	34.76	4.66	34.76	3.14	34.86	2.77	34.88	2.57	34.90	2.39	34.90	2.24	34.91
St. dev. of mean	0.46	0.04	0.44	0.03	0.24	0.02	0.18	0.02	0.15	0.01	0.18	0.01	0.21	0.01

TABLE XXII

Deviations in temperature and salinity in August at L–1 (66° 22′ N, 14° 22′ W).

YEAR	0 m		10 m		20 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1925	—0.99	+0.34	—0.64	+0.28	—0.62	+0.21
1927	+0.26	+0.05	+0.82	—0.08	+1.18	—0.13
1931	—1.09	+0.37	—1.99	+0.37	—1.94	+0.35
1934	+0.58	—0.36	—0.19	—0.11	—0.37	—0.03
1935	—0.09	—0.06	+0.43	—0.04	+0.45	+0.02
1936	+0.58	+0.18	+0.66	+0.16	+0.95	+0.18
1938	+0.38	—0.93	—1.15	—0.55	—1.25	—0.51
1939	+0.26	+0.33	+0.38	+0.25	+0.50	+0.19
1947	+2.07	0	+1.70	+0.08	+1.81	+0.13
1948	—1.75	+0.05	—2.20	+0.06	—2.17	+0.03
1949	—1.35	—0.25	—1.50	—0.25	—1.50	—0.30
1950	+0.54	—0.10	+0.66	—0.17	—0.16	+0.02
1951	+0.67	.	+0.75	.	+0.56	.
1954	+0.66	+0.02	+1.02	—0.04	+0.85	—0.12
1956	—0.83	—0.02	—0.21	—0.14	+0.11	—0.18
1957	—0.16	+0.36	+0.27	+0.26	+0.32	+0.18
1958	—0.73	—0.16	—0.23	—0.02	+0.06	+0.01
1960	+1.07	+0.11	+1.38	+0.02	+1.19	—0.02
Mean	8.23	34.33	7.75	34.44	7.34	34.51
St. dev. of mean	0.22	0.08	0.26	0.06	0.26	0.05

TABLE XXIII

Deviations in temperature and salinity in August at L–2 (66° 22′ N, 13° 35′ W).

YEAR	0 m		10 m		20 m		50 m		75 m		100 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1904	—0.81	—0.05	—1.70	+0.03	—2.24	+0.06	—0.22	—0.05	+0.17	—0.07	.	.
1934	+0.35	—0.28	+0.68	—0.30	+0.45	—0.30	—1.67	—0.16	—1.41	—0.19	—1.19	—0.16
1935	+0.07	+0.19	+0.11	+0.20	+0.46	+0.18	+1.27	+0.05	+0.95	+0.04	+0.67	+0.05
1936	+0.28	+0.26	+0.13	+0.18	+0.51	+0.17	+2.30	+0.17	+1.90	+0.14	+2.32	+0.14
1938	+0.13	—0.23	+0.38	—0.28	+0.45	—0.28	—0.91	—0.21	—0.09	—0.01	+0.22	+0.04
1939	+1.24	+0.02	+1.48	0	+1.65	—0.02	+1.24	+0.12	+0.66	+0.10	+0.30	+0.09
1947	+1.27	+0.26	+1.40	+0.36	+0.95	+0.30	+1.88	+0.14	+1.89	+0.09	+1.84	+0.03
1948	+0.07	—0.06	—0.62	—0.06	—1.38	—0.11	—1.28	—0.18	—0.97	—0.20	—0.81	—0.20
1949	—0.78	—0.47	—0.73	—0.46	—0.58	—0.33	—2.82	—0.20	—3.18	—0.20	—2.72	—0.18
1950	+0.18	—0.38	+0.38	—0.41	+0.25	—0.30	+0.20	+0.03	+0.31	+0.04	0	0
1951	+0.22	—0.05	—0.08	—0.07	—0.10	—0.10	—0.21	+0.09	—0.64	+0.04	—0.50	+0.05
1954	+0.57	+0.14	—0.13	+0.24	—0.96	+0.27	+0.70	+0.09	+0.47	+0.06	+0.24	+0.05
1956	—2.15	+0.09	—1.82	+0.05	—1.21	0	+0.30	+0.04	+0.38	+0.01	+0.38	+0.02
1957	—0.23	+0.27	+0.15	+0.26	—0.01	+0.23	—0.08	+0.03	+0.18	+0.01	+0.40	+0.02
1958	—1.53	+0.16	—1.01	+0.14	—0.57	+0.08	—1.54	—0.06	—1.47	+0.01	—2.07	—0.02
1960	+1.07	+0.17	+1.33	+0.14	+1.35	+0.13	+0.91	+0.14	+0.84	+0.12	+0.95	+0.11
Mean	8.73	34.52	8.40	34.54	7.85	34.60	5.02	34.91	4.61	34.94	4.36	34.94
St. dev. of mean	0.23	0.06	0.25	0.06	0.28	0.05	0.35	0.03	0.32	0.03	0.34	0.03

Mean	8.73	34.52	8.40	34.54	7.85	34.60	5.02	34.91	4.61	34.94	4.36	34.94
St. dev. of mean	0.23	0.06	0.25	0.06	0.28	0.05	0.35	0.03	0.32	0.03	0.34	0.03

TABLE XXIV

Deviations in temperature and salinity in August at L–3 (66° 22′ N, 13° 35′ W).

YEAR	0 m		20 m		50 m		75 m		100 m		150 m		200 m	
	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰	Δt°	ΔS‰
1934	+0.57	—0.34	+0.63	—0.29	—0.87	+0.02	—1.05	—0.07	—0.86	—0.08	—0.88	—0.13	—0.49	—0.12
1935	—0.38	+0.24	—0.13	+0.21	+0.60	+0.12	+0.41	+0.06	+0.48	+0.05	+0.51	+0.05	—0.02	+0.01
1936	+0.92	+0.13	+0.85	+0.09	+2.92	—0.19	+2.50	+0.01	+1.87	+0.07	+1.27	+0.14	+0.50	+0.13
1938	+0.42	—0.28	—0.17	—0.29	—0.96	—0.11	—0.29	—0.02	—0.06	0	—0.53	—0.08	—0.42	—0.10
1939	+0.89	+0.10	+0.83	+0.12	+0.87	+0.19	+0.68	+0.12	+0.80	+0.11	+0.61	+0.12	+0.12	+0.08
1947	+1.46	—0.01	+1.70	—0.06	+1.60	—0.01	+1.45	—0.02	+1.28	+0.01	+1.46	+0.06	+1.60	+0.12
1948	—0.44	+0.06	—0.84	—0.05	—1.53	—0.18	—1.08	—0.14	—0.65	—0.06	—0.41	—0.10	—0.55	—0.06
1949	—0.64	—0.37	—1.07	—0.25	—3.45	—0.22	—2.83	—0.17	—2.71	—0.16	+2.15	—0.14	—1.84	—0.14
1950	+0.13	—0.39	+0.59	—0.40	—0.23	+0.06	—0.19	+0.04	—0.56	—0.01	—0.41	—0.01	—0.30	—0.03
1951	—0.09	+0.05	—0.64	+0.08	+0.27	+0.01	—0.15	+0.05	—0.52	+0.03	—0.58	+0.04	—0.96	+0.01
1954	+0.51	+0.02	—0.30	+0.15	+1.15	+0.02	+1.06	+0.01	+0.96	+0.04	+1.24	+0.05	+1.34	0
1956	—1.89	+0.28	—1.35	+0.22	+0.04	—0.02	—0.42	—0.01	—0.29	—0.01	+0.04	—0.01	+0.39	—0.02
1957	—0.09	+0.22	—0.23	+0.20	+0.63	+0.14	+0.60	+0.09	+0.74	+0.04	+0.18	+0.03	+0.73	+0.03
1958	—2.29	+0.18	—1.37	+0.14	—1.09	—0.03	—1.27	—0.07	—1.02	—0.05	—1.03	—0.05	—1.06	—0.04
1960	+0.91	+0.10	+1.48	+0.06	+0.12	+0.15	+0.57	+0.11	+0.60	+0.08	+0.62	+0.10	+0.98	+0.10
Mean	8.69	34.59	8.17	34.63	5.25	34.89	4.93	34.95	4.62	34.96	4.04	34.96	3.50	34.95
St. dev. of mean	0.27	0.06	0.25	0.05	0.39	0.03	0.33	0.02	0.29	0.02	0.26	0.02	0.24	0.02

TABLE XXV

Ice conditions, air temperature, and sea temperature in North Icelandic waters during the summer season in the years 1924—1960.
For explanation see text chapter XIII, pp. 195—196.

YEAR	ICE CONDITIONS MAY	ICE CONDITIONS JUNE	ICE CONDITIONS JULY	ICE CONDITIONS AUG.	TEMPERATURE AIR MAY W	TEMPERATURE AIR MAY M	TEMPERATURE AIR MAY E	TEMPERATURE AIR JUNE W	TEMPERATURE AIR JUNE M	TEMPERATURE AIR JUNE E	TEMPERATURE AIR JULY W	TEMPERATURE AIR JULY M	TEMPERATURE AIR JULY E	TEMPERATURE AIR AUGUST W	TEMPERATURE AIR AUGUST M	TEMPERATURE AIR AUGUST E	TEMPERATURE SURFACE LAYERS JUNE W	TEMPERATURE SURFACE LAYERS JUNE M	TEMPERATURE SURFACE LAYERS JUNE E	TEMPERATURE SURFACE LAYERS JULY W	TEMPERATURE SURFACE LAYERS JULY M	TEMPERATURE SURFACE LAYERS JULY E	TEMPERATURE SURFACE LAYERS AUGUST W	TEMPERATURE SURFACE LAYERS AUGUST M	TEMPERATURE SURFACE LAYERS AUGUST E	TEMPERATURE INTERMEDIATE LAYERS JUNE W	TEMPERATURE INTERMEDIATE LAYERS JUNE M	TEMPERATURE INTERMEDIATE LAYERS JUNE E	TEMPERATURE INTERMEDIATE LAYERS JULY W	TEMPERATURE INTERMEDIATE LAYERS JULY M	TEMPERATURE INTERMEDIATE LAYERS JULY E	TEMPERATURE INTERMEDIATE LAYERS AUGUST W	TEMPERATURE INTERMEDIATE LAYERS AUGUST M	TEMPERATURE INTERMEDIATE LAYERS AUGUST E
1924	0	0	0	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.	.	.	0	—	(—)	—	—	—	.	.	.
1925	0	2	0	0	—	—	—	+	++	++	+	+	+	0	0	—	0	0	—	.	.	.	0	0	—	0	0	(0)	.	.	.	—	+	.
1926	0	0	1	0	—	—	—	0	0	0	+	++	++	—	0	0	0	0	—	+	+	.	.	.	++	—	0	(0)	0	+	.	.	.	.
1927	1	1	0	0	0	0	0	0	—	—	++	++	++	—	0	0	.	.	.	+	++	+	+	0	+	.	.	.	0	+	.	0	—	.
1928	2	1	1	0	++	+	+	—	—	—	—	—	0	0	—	—	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1929	1	0	3	2	—	—	—	—	—	—	+	+	+	—	—	—	.	.	.	.	.	.	.	0	(+)	.	.	.	.	.	.	.	+	(0)
1930	1	0	0	0	0	0	0	0	+	+	—	0	—	—	—	—	0	—	0	0	—	0	.	.	.	—	—	0	0	—	—	.	.	.
1931	0	0	0	0	—	—	—	—	—	—	—	—	—	++	+	+	.	.	.	0	0	.	.	—	—	.	.	.	0	0	.	.	—	.
1932	2	1	1	0	—	0	0	+	+	+	—	—	—	+	+	+	.	.	.	0	—	—	.	0	.	.	.	.	0	—	.	.	.	.
1933	1	1	0	0	+	+	+	++	++	++	++	++	++	+	+	+	.	.	.	++	.	++	+	0	.	.	.	.	+	.	.	+	0	.
1934	1	1	0	0	0	—	0	+	++	++	0	+	+	0	0	+	.	.	.	.	.	.	—	.	0	.	.	.	.	.	.	0	.	—
1935	1	0	0	0	++	++	++	0	0	—	0	+	+	—	—	0	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	+	.	+
1936	1	2	0	0	++	++	++	++	++	++	+	+	+	+	+	+	++	+	+	.	.	.	—	.	+	+	+	+	.	.	.	0	.	++
1937	1	2	2	0	—	0	+	0	+	+	—	0	0	0	+	+	.	—	—	.	.	.	.	.	.	.	—	0	.	.	.	.	.	.
1938	3	1	1	0	—	—	—	—	—	—	—	—	—	0	0	+	.	.	.	—	—	—	.	.	—	.	.	.	—	—	+	.	.	—
1939	0	1	1	1	++	++	++	++	++	++	0	+	0	++	++	++	.	.	.	.	.	.	+	++	+	.	.	.	.	.	.	0	++	+
1947	0	0	0	0	+	+	++	0	0	0	+	++	++	++	++	++	.	0	0	++	+	++	.	.	++	.	0	0	+	+	0	.	.	++
1948	1	0	1	1	—	—	—	—	—	—	0	—	—	+	+	0	.	.	.	0	0	0	++	+	—	.	.	.	+	+	+	+	+	—
1949	3	1	1	0	—	—	—	0	+	+	0	0	+	—	—	—	.	.	.	0	—	.	0	—	—	.	.	.	—	—	.	—	—	—
1950	1	0	0	0	+	0	0	0	0	—	0	0	—	0	0	—	.	.	—	0	.	.	.	+	+	.	.	0	0	.	.	.	0	0
1951	1	0	0	1	+	0	0	0	—	—	0	—	—	—	—	—	.	.	.	0	0	0	0	+	0	.	.	.	0	0	—	0	+	—
1952	0	1	0	0	—	—	—	—	—	—	+	—	—	—	—	—	—	0	—	.	.	.	.	.	.	—	0	—	.	.	.	.	.	.
1953	1	1	0	1	0	0	—	++	++	++	0	+	0	+	+	+	—	+	++	.	.	.	.	.	.	—	0	0	.	.	.	.	.	.
1954	0	0	0	0	+	+	0	0	0	—	—	—	—	—	0	—	+	+	++	0	+	+	—	—	0	+	+	+	+	+	+	0	0	+
1955	0	0	0	0	0	—	—	+	0	0	++	++	++	+	++	++	+	+	0	0	++	++	+	+	++	+	+	—	+	+	0	0	+	+
1956	1	2	2	2	0	0	—	0	—	—	0	—	—	—	—	—	—	0	0	—	—	—	—	—	—	0	0	+	0	0	+	0	—	0
1957	0	2	0	0	0	0	0	+	0	—	+	0	—	+	+	0	+	+	+	+	+	++	+	+	0	+	+	+	+	0	+	0	+	+
1958	1	1	0	0	—	—	—	—	0	—	—	—	—	—	—	—	—	—	0	0	—	—	—	0	—	—	—	—	—	—	—	0	0	—
1959	1	0	0	0	+	+	+	—	0	—	0	0	0	—	—	—	+	+	.	+	0	0	0	0	+	0	+	.	0	0	0	0	0	0
1960	0	0	0	1	+	+	+	+	+	+	0	0	0	—	—	—	+	+	+	+	+	+	+	++	+	+	+	++	+	++	++	+	++	+

Derivation of an Estimated Normal Regression Equation Expressing Salinity as a Function of Temperature at Intermediate Depths North of Iceland in June.

The author is indebted to Mr. Knud Andersen, cand. mag. et scient., Danish Institute for Fishery and Marine Research, Charlottenlund, for having derived an estimated normal regression equation expressing salinity as a function of temperature at intermediate depths north of Iceland. It is based on observations from the years 1950 and 1952–1956. The derivation is as follows:

Let the estimated normal regression equation be represented by $y = y_{N_{4^\circ}} + b_N(x - 4^\circ)$, where $y_{N_{4^\circ}}$ denotes the normal mean value of y at 4°C. The value at 4° was chosen as this temperature corresponds roughly to the "centre of gravity" of the total number of observations, where the estimation of the regression line will be best.

For each individual year the slope,

$$b_i = B + \varepsilon_i + \delta_i,$$

where B is the "true" normal slope, ε_i the annual deviation from the normal, and δ_i the deviation of the individual measurements from the true annual value.

The variance of b_i, $v\{b_i\} = v\{\varepsilon_i\} + v\{\delta_i\} = \sigma^2_{\varepsilon_i} + \sigma^2_{\delta_i}$.

If $\bar{b} = \frac{1}{6}\sum_{i=1}^{6} b_i$, $v\{\bar{b}\} = \frac{1}{6^2}\sum_{i=1}^{6}\sigma^2_{\varepsilon_i} + \frac{1}{6}\sum_{i=1}^{6}\sigma^2_{\delta_i} = \frac{\sigma^2_{\varepsilon_i}}{6} + \frac{1}{36}\sum_{i=1}^{6}\sigma^2_{\delta_i}$;

$v\{\bar{b}\}$ will be estimated by $\frac{1}{5\cdot 6}\sum_{i=1}^{6}(b_i - \bar{b})^2 = 0.33\cdot 10^{-5}$; hence

$\frac{\sigma^2_{\varepsilon_i}}{6} + \frac{1}{36}\sum_{i=1}^{6}\sigma^2_{\delta_i} = 0.33\cdot 10^{-5}$; an estimate for $\sigma^2_{\delta_i}$ will be $\frac{s_i^2}{SSD_{x_i}}$

where s_i^2 is the variance about the regression line for each individual year and

$SSD_{x_i} = \sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2$; $\quad \frac{1}{36}\sum_{i=1}^{6}\sigma^2_{\delta_i} \approx \frac{1}{36}\sum_{i=1}^{6}\frac{s_i^2}{SSD_{x_i}} = 0.34\cdot 10^{-5}$;

hence $\frac{\sigma_{\varepsilon_i}}{6} \approx 0$. Therefore, b_N should be calculated as the weighted mean of the slopes $b_1, b_2, \dots b_6$, using the reciprocal values of the variances as weights:

$$b_N = \frac{\sum_{i=1}^{6} b_i \frac{SSD_{x_i}}{s_i^2}}{\sum_{i=1}^{6} \frac{SSD_{x_i}}{s_i^2}} = 0.0501$$

In a similar manner: $y_{i_{4^\circ}} = A + \varrho_i + \tau_i$ where A is the "true" normal, ϱ_i the annual deviation from the normal, and τ_i is the deviation of the individual measurements from the true annual value.

$$v\{y_{i_{4^\circ}}\} = v\{\varrho_i\} + v\{\tau_i\} = \sigma^2_{\varrho_i} + \sigma^2_{\tau_i}. \text{ If } y_{4^\circ} = \frac{1}{6}\sum_{i=1}^{6} y_{i_{4^\circ}},$$

$$v\{\bar{y}_{4^\circ}\} = \frac{1}{6^2}\sum_{i=1}^{6} \sigma^2_{\varrho_i} + \frac{1}{6^2}\sum_{i=1}^{6} \sigma^2_{\tau_i} = \frac{\sigma^2_{\varrho_i}}{6} + \frac{1}{36}\sum_{i=1}^{6} \sigma^2_{\tau_i};$$

$$v\{\bar{y}_{4^\circ}\} \approx \frac{1}{5\cdot 6}\sum_{i=1}^{6} (y_{i_{4^\circ}} - \bar{y}_{4^\circ})^2 = 0.46\cdot 10^{-4}; \ \frac{1}{36}\sum_{i=1}^{6} \sigma^2_{\tau_i} \approx \frac{1}{36}\sum_{i=1}^{6} s_y^2,$$

where $s_y^2 = s_i^2 \cdot \left[\frac{1}{N_i} + \frac{(4^\circ - \bar{x}_i)^2}{SSD_{x_i}}\right]$. Since $\frac{1}{36}\sum_{i=1}^{6} s_y^2 = 0.09\cdot 10^{-4}$

it follows that $\frac{1}{36}\sum_{i=1}^{6} \sigma^2_{\tau_i} \approx 0.09\cdot 10^{-4}$. This means that σ_{τ_i} is negligible as compared to σ_{ϱ_i}. From this follows that we can calculate an estimated mean value of $y_{N_{4^\circ}}$ as $y_{N_{4^\circ}} = \frac{1}{6}\sum_{i=1}^{6} y_{i_{4^\circ}} = 0.9727$

The variance of $y_{N_{4^\circ}}$ will be $\frac{1}{5\cdot 6}\sum_{i=1}^{6} (y_{i_{4^\circ}} - y_{N_{4^\circ}})^2 = 0.46\cdot 10^{-4}$

The estimated normal equation will then be

$$y = 0.9727 + 0.0501\,(x-4) = 0.772 + 0.0501x$$

An estimate of the standard deviation of the salinity values as determined from the estimated normal equation will be

$$\sigma_S\,{}^0/_{00} = \sqrt{\bar{s}^2 + 6v\{y\}}, \text{ where } \bar{s}^2 = \frac{\sum_{i=1}^{6}(N_i-2)s_i^2}{\sum_{i=1}^{6}(N_i-2)} = \frac{0.1547}{141} = 0.001097,$$

and $v\{y\} = v\{y_{N_{4^\circ}}\} + (t-4)^2 \cdot v\{b\} - 2\varrho_{y_{N_{4^\circ}}\, b_N} \cdot \sigma_{y_{N_{4^\circ}}} \cdot \sigma_{b_N} \cdot (\bar{x}-4)$.

If $\varrho_{y_{N_{4^\circ}}\, b_N}$ which is the correlation coefficient between $y_{N_{4^\circ}}$ and b_N, is assumed to be positive or at least zero,

$v\{y\} \leq v\{y_{N_{4^\circ}}\} + (t-4)^2 \cdot v\{b\} = 0.46 \cdot 10^{-4} + (t-4)^2 \cdot 0.34 \cdot 10^{-5}$

For $t=4^\circ$ $v\{y\} = 0.46 \cdot 10^{-4}$ and $\sigma_S\,{}^0/_{00} = \sqrt{(10.97 + 2.76)\,10^{-4}} = \underline{0.037}$ and for $t=7^\circ$, which is about the maximum temperature in the intermediate layers, $v\{y\} = 0.76 \cdot 10^{-4}$ and $\sigma_S\,{}^0/_{00} = \sqrt{(10.97 + 4.58)\,10^{-4}} = \underline{0.039}$.

Standard Deviation of the Anomaly of Dynamic Height and Calculated Volume Transport Due to Uncertainty in Salinity.

The author is indebted to Mr. Frede Hermann, cand. mag., Danish Institute for Fishery and Marine Research, Charlottenlund, for having derived formulas for calculating the standard deviation of dynamic height and calculated volume transport due to uncertainty in salinity. The derivations are as follows:

1. *Dynamic Height Anomalies.*

Let $z_1, z_2, z_3, \ldots . z_n$ denote observational depths in meters
$\delta_1, \delta_2, \delta_3, \ldots . \delta_n$ anomaly of specific volume in ml/g

$y = \int_{z_1}^{z_n} \delta dz$, the anomaly of dynamic height

σ_S the standard deviation of $S\,^0/_{00}$

σ_y the standard deviation in the anomaly of dynamic height because of uncertainty in $S\,^0/_{00}$

$$y = (z_n - z_{n-1})\,(\delta_n + \delta_{n-1})/2 + (z_{n-1} - z_{n-2})\,(\delta_{n-1} + \delta_{n-2})/2 + \ldots . (z_2 - z_1)\,(\delta_2 + \delta_1)/2;$$

$$= {}^1/_2\,((z_n - z_{n-1})\delta_n + (z_n - z_{n-2})\delta_{n-1} + (z_{n-1} - z_{n-3})\delta_{n-2} + \ldots . \;(z_2 - z_1)\delta_1);$$

$$\sigma_y^2 = (\partial y/\partial S_1 \cdot \sigma_{S_1})^2 + (\partial y/\partial S_2 \cdot \sigma_{S_2})^2 + \ldots . \;(\partial y/\partial S_n \cdot \sigma_{S_n})^2; \text{ as}$$

$$\partial y/\partial S_x = \partial y/\partial \delta_x \cdot \partial \delta_x/\partial S_x, \text{ there results:}$$

$$\sigma_y^2 = {}^1/_4\,(((z_n - z_{n-1})\,\partial\delta_n/\partial S_n \cdot \sigma_{S_n})^2 + ((z_n - z_{n-2})\,\partial\delta_{n-1}/\partial S_{n-1} \cdot \sigma_{S_{n-1}})^2 + ((z_{n-1} - z_{n-3})\,\partial\delta_{n-2}/\partial S_{n-2} \cdot \sigma_{S_{n-2}})^2 + \ldots((z_2 - z_1)\partial\delta_1/\partial S_1 \cdot \sigma_{S_1})^2).$$

If we put $\sigma_{S_1} = \sigma_{S_2} = \ldots \sigma_{S_n} = 0.02$ and $\partial\delta_n/\partial S_n = \partial\delta_{n-1}/\partial S_{n-1} \ldots . = \partial\delta_1/\partial S_1 = 0.75 \cdot 10^{-3}$ we get

$$\sigma_y^2 = {}^1/_4\,(0.75 \cdot 0.02 \cdot 10^{-3})^2\,((z_n - z_{n-1})^2 + (z_n - z_{n-2})^2 + (z_{n-1} - z_{n-3})^2 + \ldots . \;(z_3 - z_1)^2 + (z_2 - z_1)^2).$$

For 800 meters we thus get: $\sigma_y = 0.46$ dyn. cm. The standard deviation of the difference in dynamic height between two stations will then be

$\sigma_{(y_a - y_b)} = \sqrt{2} \cdot \sigma_y = 0.65$ dyn. cm.

2. *Standard Deviation in Volume Transport.*

Let $z_1, z_2, \ldots z_n$	denote observation depths. z_1 denotes the surface of the sea, z_n denotes the depth of the reference surface.
$l_{1,2}, l_{2,3} \ldots l_{n-1,n}$	denote the distances between observation depths.
$\delta_{A,1}, \delta_{A,2} \ldots \delta_{A,n}$	denote anomalies of specific volume at station A.
$\delta_{B,1}, \delta_{B,2} \ldots \delta_{B,n}$	denote anomalies of specific volume at station B.
$S_{A,1}, S_{A,2} \ldots S_{A,n}$	denote observed salinities in $^0/_{00}$ at station A.
$S_{B,1}, S_{B,2} \ldots S_{B,n}$	denote observed salinities in $^0/_{00}$ at station B.
$q_{i,i+1}$	denote volume transport between z_i and z_{i+1} and between A and B.
$Q_{1,n}$	denote volume transport between the sea surface and the reference level and between A and B.
σ_S	denote the standard deviation in $S\,^0/_{00}$; σ_S is assumed to be constant for all observations.

$Q_{1,n} = f(\delta_{A,1}, \delta_{A,2}, \ldots \delta_{A,n}, \delta_{B,1}, \delta_{B,2}, \ldots \delta_{B,n})$, where $\delta_{A,i} = \delta(S_{A,i}, t_{A,i})$.

$$v\left\{Q_{1,n}\right\} = \sigma^2_{Q_{1,n}} = \left(\frac{\partial f}{\partial S_{A,1}}\right)^2 \sigma_S^2 + \left(\frac{\partial f}{\partial S_{A,2}}\right)^2 \sigma_S^2 + \ldots \left(\frac{\partial f}{\partial S_{A,n}}\right)^2 \sigma_S^2 +$$

$$\left(\frac{\partial f}{\partial S_{B,1}}\right)^2 \sigma_S^2 + \left(\frac{\partial f}{\partial S_{B,2}}\right)^2 \sigma_S^2 + \ldots \left(\frac{\partial f}{\partial S_{B,n}}\right)^2 \sigma_S^2.$$

$$\sigma^2_{Q_{1,n}} = \sigma_S^2 \left[\left(\frac{\partial f}{\partial \delta_{A,1}} \cdot \frac{\partial \delta_{A,1}}{\partial S_{A,1}}\right)^2 + \ldots \left(\frac{\partial f}{\partial \delta_{A,n}} \cdot \frac{\partial \delta_{A,n}}{\partial S_{A,n}}\right)^2 + \left(\frac{\partial f}{\partial \delta_{B,1}} \cdot \frac{\partial \delta_{B,1}}{\partial S_{B,1}}\right)^2\right.$$

$$\left. + \ldots \left(\frac{\partial f}{\partial \delta_{B,n}} \cdot \frac{\partial \delta_{B,n}}{\partial S_{B,n}}\right)^2\right].$$

As $\left(\frac{\partial \delta}{\partial S}\right)^2$ can with sufficient accuracy be taken as constant within the range of t and S values in question

$$\sigma^2_{Q_{1,n}} = \left(\frac{\partial \delta}{\partial S}\right)^2 \cdot \sigma_S^2 \left[\left(\frac{\partial f}{\partial \delta_{A,1}}\right)^2 + \left(\frac{\partial f}{\partial \delta_{A,2}}\right)^2 + \ldots \left(\frac{\partial f}{\partial \delta_{A,n}}\right)^2 + \left(\frac{\partial f}{\partial \delta_{B,1}}\right)^2 + \left(\frac{\partial f}{\partial \delta_{B,2}}\right)^2\right.$$

$$\left. + \ldots \left(\frac{\partial f}{\partial \delta_{B,n}}\right)^2\right] \quad \text{(I)}$$

$$Q_{1,n} = \sum_{i=1}^{n-1} q_{i,i+1}; \quad \frac{\partial Q_{1,n}}{\partial \delta_{A,r}} = \sum_{i=1}^{n-1} \frac{\partial q_{i,i+1}}{\partial \delta_{A,r}}; \quad \frac{\partial Q_{1,n}}{\partial \delta_{B,r}} = \sum_{i=1}^{n-1} \frac{\partial q_{i,i+1}}{\partial \delta_{B,r}}$$

$$q_{i,i+1} = K\left[\frac{1}{2}(\Delta D_{A,i+1} - \Delta D_{B,i+1}) + \frac{1}{2}(\Delta D_{A,i} - \Delta D_{B,i})\right] \cdot l_{i,i+1}$$

$$\frac{\partial q_{i,i+1}}{\partial \delta_{A,r}} = \frac{1}{2}K\left[\frac{\partial \Delta D_{A,i+1}}{\partial \delta_{A,r}} + \frac{\partial \Delta D_{A,i}}{\partial \delta_{A,r}}\right] \cdot l_{i,i+1}; \frac{\partial q_{i,i+1}}{\partial \delta_{B,r}} = -\frac{1}{2}K\left[\frac{\partial \Delta D_{B,i+1}}{\partial \delta_{B,r}} + \frac{\partial \Delta D_{B,i}}{\partial \delta_{B,r}}\right]$$

$$\Delta D_{A,i} = \sum_{j=i}^{n-1} \frac{1}{2}(\delta_{A,j+1} + \delta_{A,j}) \cdot l_{j,j+1}; \ \Delta D_{A,n} = 0.$$

$$\frac{\partial \Delta D_{A,i}}{\partial \delta_{A,r}} = \sum_{j=i}^{n-1} \frac{1}{2}\left(\frac{\partial \delta_{A,j+1}}{\partial \delta_{A,r}} + \frac{\partial \delta_{A,j}}{\partial \delta_{A,r}}\right) \cdot l_{j,j+1}; \text{ where } \frac{\partial \delta_{A,j}}{\partial \delta_{A,r}} = \begin{cases} 1 \text{ for } j = r \\ 0 \text{ for } j \neq r \end{cases}$$

$$\frac{\partial \Delta D_{A,i}}{\partial \delta_{A,r}} = \left\{\begin{array}{l} \frac{1}{2} l_{n-1,n} \text{ for } r=n \\ \frac{1}{2}(l_{r-1,r} + l_{r,r+1}) \text{ for } n>r>i \\ \frac{1}{2} l_{i,i+1} \text{ for } r=i \\ 0 \text{ for } r<i \end{array}\right\} = \frac{\partial \Delta D_{B,i}}{\partial \delta_{B,r}}$$

$$\frac{\partial \Delta D_{A,i+1}}{\partial \delta_{A,r}} = \left\{\begin{array}{l} \frac{1}{2} l_{n-1,n} \text{ for } r=n \\ \frac{1}{2}(l_{r-1,r} + l_{r,r+1}) \text{ for } n>r>i+1 \\ \frac{1}{2} l_{i+1,i+2} \text{ for } r=i+1 \\ 0 \text{ for } r<i+1 \end{array}\right\} = \frac{\partial \Delta D_{B,i+1}}{\partial \delta_{B,r}}$$

For $r=n$ we get for $i=n-1$:

$$\frac{\partial q_{n-i,n}}{\partial \delta_{A,n}} = K\left[\frac{1}{2}\frac{\partial \Delta D_{A,n-1}}{\partial \delta_{A,n}}\right] \cdot l_{n-1,n} = K \cdot \frac{1}{2} \cdot \frac{1}{2} \cdot l^2_{n-1,n} = \frac{1}{4} \cdot K \cdot l^2_{n-1,n};$$

and for $i<n-i$

$$\frac{\partial q_{i,i+1}}{\partial \delta_{A,n}} = K \cdot \frac{1}{2}\left[\frac{1}{2} l_{n-1,n} + \frac{1}{2} l_{n-1,n}\right] \cdot l_{i,i+1} = \frac{1}{2} K \cdot l_{n-1,n} \cdot l_{i,i+1}.$$

Hence $$\frac{\partial Q_{1,n}}{\partial \delta_{A,n}} = \sum_{i=1}^{n-1} \frac{\partial q_{i,i+1}}{\partial \delta_{A,n}} = \frac{1}{4} K \cdot l^2_{n-1,n} + \sum_{i=1}^{n-2} \frac{1}{2} K \cdot l_{n-1,n} \cdot l_{i,i+1} =$$

$$\frac{1}{2}K\left(\frac{1}{2} l^2_{n-1,n} + l_{n-1,n} \cdot l_{1,n-1}\right)$$

for $n>r>i+1$ we get

$$\frac{\partial q_{i,i+1}}{\partial \delta_{A,r}} = \frac{1}{2}K\left[\frac{1}{2}(l_{r-1,r} + l_{r,r+1}) \cdot 2\right] l_{i,i+1} = \frac{1}{2}K(l_{r-1,r} + l_{r,r+1}) l_{i,i+1}.$$

for $r=i+1$ we get

$$\frac{\partial q_{r-1,r}}{\partial \delta_{A,r}} = \frac{1}{2} K \left[\frac{1}{2} l_{r,r+1} + \frac{1}{2}(l_{r-1,r} + l_{r,r+1})\right] \cdot l_{r-1,r}$$

$$= \frac{1}{2} K \left[(l_{r-1,r} + l_{r,r+1})\, l_{r-1,r} - \frac{1}{2}\, l^2_{r-1,r}\right]$$

for $r=i$ we get

$$\frac{\partial q_{r,r+1}}{\partial \delta_{A,r}} = \frac{1}{2} K \left[0 + \frac{1}{2} l_{r,r+1}\right] \cdot l_{r,r+1} = \frac{1}{2} K \left(\frac{1}{2} \cdot l^2_{r,r+1}\right).$$

$$\frac{\partial Q_{1,n}}{\partial \delta_{A,r}} = \frac{1}{2} K \left[\frac{1}{2}\, l^2_{r,r+1} - \frac{1}{2}\, l^2_{r-1,r} + (l_{r-1,r} + l_{r,r+1})\left(l_{r-1,r} + \sum_{i=1}^{r-2} l_{i,i+1}\right)\right]$$

$$\frac{\partial Q_{1,n}}{\partial \delta_{A,r}} = \frac{1}{2} K \left[\frac{1}{2}\, l^2_{r,r+1} - \frac{1}{2}\, l^2_{r-1,r} + (l_{r-1,r} + l_{r,r+1})\, l_{1,r}\right]$$

$$\frac{\partial Q_{1,n}}{\partial \delta_{A,r}} = \frac{1}{2} K \left[(l_{r-1,r} + l_{r,r+1})\left(l_{1,r} + \frac{1}{2} l_{r,r+1} - \frac{1}{2} l_{r-1,r}\right)\right]$$

By substitution in equation (I) we get:

$$\sigma^2_{Q_{1,n}} = \left(\frac{\partial \delta}{\partial S}\right)^2 \cdot \sigma^2_S \left(\frac{1}{2} K\right)^2 \left[\left(\frac{1}{2}\, l^2_{n-1,n} + l_{n-1,n} \cdot l_{1,n}\right)^2 + \sum_{r=1}^{n-1} \left((l_{r-1,r} + l_{r,r+1})\left(l_{1,r} + \frac{1}{2} l_{r,r+1} - \frac{1}{2} l_{r-1,r}\right)\right)^2\right]$$

Here $\frac{\partial S}{\partial \delta} \approx 0.75 \cdot 10^{-3}$, and if Q is expressed in km^3/h and l in meters

$$K = \frac{10}{2\omega \cdot \sin \varphi} \cdot 3.6 \cdot 10^{-6} = 0.268 \text{ for } \varphi = 67^\circ$$

Hence $\sigma_{Q_{1,n}} =$

$$2.01 \cdot 10^{-6} \sqrt{\left(\frac{1}{2}\, l^2_{n-1,n} + l_{n-1,n} \cdot l_{1,n}\right)^2 + \sum_{r=1}^{n-1} \left((l_{r-1,r} + l_{r,r+1})\left(l_{1,r} + \frac{1}{2} l_{r,r+1} - \frac{1}{2} l_{r-1,r}\right)\right)^2}.$$

DANSK RESUMÉ

Det foreliggende arbejde er baseret på hydrografisk materiale fra havområdet nord for Island. Den største del af dette materiale er blevet indsamlet i de sidste 15 år af islandske ekspeditioner. Indsamlingen af materialet har hovedsagelig fundet sted i sommermånederne juni–august i forbindelse med sildeundersøgelser på det nordislandske sildefelt, hvorimod observationer fra andre årstider er meget spredte.

Det bemærkes, at de første oplysninger om strømforhold ved Island findes i de islandske sagaer fra det 13. århundrede. Af sagaernes beskrivelse af forskellige genstandes drift samt drivisens forløb nordvest og nord for Island, må man antage, at allerede i sagatiden har islændinge i hovedtrækkene kendt den omtrentlige strømretning i havet omkring Island.

I en historisk oversigt skildres de forskellige ekspeditioner til havområdet omkring eller i nærheden af Island samt de væsentlige bidrag til de islandske farvandes hydrografi. Systematiske hydrografiske undersøgelser i dette område begyndte i midten af sidste århundrede med det grundlæggende arbejde af den danske admiral Irminger. I årene 1875–1908 blev forskellige ekspeditioner sendt til de islandske farvande og nærliggende havområder. På grundlag af disse undersøgelser kunne man i begyndelsen af dette århundrede danne sig et afrundet billede af strømforholdene ved Island. I perioden mellem de to verdenskrige blev de hydrografiske undersøgelser fortsat, og en serie faste stationer blev etableret, hvor observationer er blevet gentaget i årenes løb. I årene efter den sidste verdenskrig blev hydrografiske undersøgelser sat i gang hos det islandske fiskeri- og havforskningsinstitut, *Fiskideild*. I 1949 og de følgende år blev forskellige togter foretaget til det hidtil dårligt undersøgte område nord for den islandske fastlandssokkel. En kort oversigt er også udarbejdet om andre nationers undersøgelser i islandske farvande i de sidste 15 år.

Den tidligere nomenklatur af havområdet nord og øst for Island bliver diskuteret. Det bemærkes at det ældste kendte navn for havet nord for Island er *Dumbshaf*, mens havet mellem Island og Norge kaldtes for *Íslandshaf* i sagatiden. I de senere år har der hersket en mere eller mindre forvirring med hensyn til nomenklatur af de nordlige havområder. Det foreslås, at havet mellem Island, Grønland og Jan Mayen kaldes for *Islandshavet* (Iceland Sea), mens navnet *Norske havet* (Norwegian Sea) begrænses til den del af Nordhavet som ligger mellem Færøerne, Jan Mayen, Spitsbergen og Norge.

En beskrivelse gives af bundforholdene. Det vises, at i det islandske kystområde nordvest for Grímsey findes et isoleret bassin hvor dybden er mellem 600 og 700 meter. Denne dybde findes ikke på tilgængelige søkort fra kystområdet nord for Island.

Tre primære vandmasser i området nord for Island beskrives. Disse er a) atlantisk vand, b) polarvand og c) arktisk bundvand. Desuden beskrives 4 sekundære vandmasser, nemlig kystvand, arktisk vand, arktisk mellemlagsvand og nordislandsk vinterafkølet vand. Disse sidsnævnte vandmasser er dannede ved blanding mellem de primære vandmasser og forskellige meteorologiske forhold. Det vises, at i den såkaldte „kolde tunge" i området mellem Island og Jan Mayen findes almindeligt polarvand kun i ubetydelige mængder. Den forholdsvis høje saltholdighed men lave temperatur i kærnen af den „kolde tunge" tyder på, at dennes vand er dannet ved blanding og vinterafkøling af atlantisk vand og polarvand i området nord for Jan Mayen uden for den egentlige polarstrøm.

Ældre strømkort fra havområdet nord for Island diskuteres. På grundlag af det hydrografiske materiale, som er blevet indsamlet under de islandske togter til dette område, er der tegnet et nyt strømkort. Til støtte for de hydrodynamiske beregninger foretages en analyse af strømflaskeforsøg i området, og en bedømmelse af vindens indflydelse på flaskedriften forsøges. Ifølge det nye strømkort er overfladestrømmen syd og sydøst for Jan Mayen rettet mod nord langs den undersøiske ryg, som strækker sig syd fra Jan Mayen-banken. Sydvest for Jan Mayen er strømmen rettet mod syd eller sydvest. Længere mod syd er strømmens retning mod sydøst. I den centrale del af området mellem NØ-Island og Jan Mayen findes der en svag anticyclonisk strømkreds, der fører arktisk vand til den Østislandske Strøm, som desuden er dannet af den Nordislandske Irmingerstrøm samt en ringe mængde polarvand fra den Østgrønlandske Strøm.

Strømretningen af den Nordislandske Irmingerstrøm i de forskellige strøg af fastlandssoklen bliver diskuteret. Idet strømretningen i almindelighed er mod øst langs den nordislandske kyst, synes strømmen at følge dybdekurvernes forløb meget nøje. Dette vises for Húnaflói og Eyjafjörður. Ved det sydøstlige hjørne af Island ser det ud til, at strømmen forlader kystområdet som en del af den Østislandske Strøm.

I et særligt kapitel behandles vertikale snit og horisontal fordeling af temperatur og saltholdighed. Gennemsnitskort, som viser temperaturfordelingen i 20 meter og temperatur og saltholdighed i 50 og 100 meter, er udarbejdet for månederne juni, juli og august. Den gennemsnitlige vertikale fordeling er også vist for tre snit i kystområdet.

De hydrografiske forhold behandles yderligere ved hjælp af t, S diagrammer. Det viser sig, at i den dybere del af kystområdet består de mellemliggende vandlag (50–200 meter) af en blanding af to komponenter, atlantisk vand og vinterafkølet vand (North Icelandic Winter water). Juni-observationer fra årene 1950 og 1952–1956 kombineres, og på grundlag af dette materiale udledes en normal regressionsligning, som kan bruges til udregning af saltholdigheder i de mellemliggende dyb. De udregnede værdier stemmer forholdsvis godt med dem, som blev fundet med analyse for årene 1957, 1958 og 1959. Under den forudsætning, at de mellemliggende vandlag kun består af to komponenter, kan den procentvise sammensætning vurderes. På denne måde finder man, at vægtprocenten af atlantisk vand ændres fra ca. 80–90% i den vestlige del til 0–30% i den østlige del af kystområdet. Dette forhold gælder imidlertid kun tilnærmelsesvis eller slet ikke i området, som ligger uden for kærnen af den østgående strømning. Vintervandets dannelse og dets indflydelse på de hydrografiske forhold i andre områder diskuteres. På grundlag af undersøgelser på den undersøiske ryg mellem Island og Færøerne sluttes, at dybstrømninger over ryggen til dels består af vinterafkølet vand fra området nord for Island. Det antages, at dette vand bliver ført med den Østislandske Strøm sydover langs den østislandske fastlandssokkel.

Hastigheden af den østgående strømkomponent i et snit nord for Kap Kögur bestemmes ved hjælp af dynamiske beregninger. Lignende beregninger udføres for andre snit i den østlige del af kystområdet. I kystområdet antages nulfladens beliggenhed at være bunden; ved ydersiden af fastlandssoklen antages den at være i 300–400 meter dybde, men i det oceaniske område nord for fastlandssoklen antages nulfladen at have en hældning til 800 meter nær 68° 30′ N. Kyststrømmens gennemsnitlige hastighed beregnes at være omtrent 3 sømil pr. dag. Denne størrelse er fundet på grundlag af strømflaskeforsøg, dynamiske beregninger og ved at følge udbredelsen af det atlantiske vand. Gennemsnitlige hastighedsprofiler tyder på, at den maksimale strømning mod øst finder sted nær yderkanten af fastlandssoklen, hvorimod strømmen ser ud til at være svag og labil i den lavere del af kystområdet. I almindelighed er der en forholdsvis god overensstemmelse mellem de forskellige methoder.

Der gøres forsøg på ved hjælp af dynamiske beregninger at vurdere volumentransporten gennem snittene nord for Kap Kögur og Melrakkaslétta. Der lægges vægt på usikkerheden i disse beregninger. De fundne resultater tyder på, at inden for 60 sømil fra Kap Kögur er der gennemsnitligt en østgående netto transport på 2.2 km^3 pr. time. Denne transport synes at bestå næsten udelukkende af vand med temperatur over 1°C. Det anslås, at den varmetransport øst for Kap Kögur, som alene skyldes det atlantiske vand, om sommeren vil være omtrent $2.7 \cdot 10^9$ kg. kal. pr. sek. En sammenligning af den beregnede volumentransport gennem snittene nord for Kap Kögur og Melrakkaslétta tyder på, at variationer i volumentransporten af den Østislandske Strøm først og fremmest skyldes vekslinger i Irmingerstrømmen, hvorimod det ser ud, som om vekslinger i den tilbageværende arktiske komponent er forholdsvis små.

Drivisens udbredelse nordvest for Island er størst om foråret. I løbet af sommeren trækker isgrænsen sig længere og længere væk fra den islandske kyst, og om efteråret, september–oktober, træffes drivis som regel ikke i det islandske kystområde. Undersøgelser af årstidssvingninger i de hydrografiske forhold i årene 1953–1955 på 3–4 stationer nord for Siglunes beskrives. Årstidssvingningerne kan mærkes ned til en dybde på i det mindste 300 meter. Der kan skelnes mellem to slags årstidsvariationer, nemlig a) variationer, som direkte skyldes forandringer i solens højde og b) variationer i den atlantiske indstrømning. Det vises, at den atlantiske indflydelse forøges om foråret og når sit maksimum om sommeren. Om efteråret og vinteren tager den meget betydeligt af. Disse variationer i indflydelse af atlantisk vand formodes at stå i sammenhæng med styrken af den atlantiske strømkomponent. De mest sandsynlige årsager til disse variationer diskuteres.

Variationer fra år til år i de hydrografiske forhold nord for Island sammenlignes og diskuteres ved hjælp af a) observationer fra faste stationer, b) sammenligning af vertikale snit og c) sammenligning af horisontale kort. Variationerne viser sig at være størst i den østlige del af området sent om sommeren. Dette antages at skyldes svingninger i den atlantiske indstrømning. I perioden 1924–1960 var årene 1924, 1930, 1932, 1938 og 1949 meget kolde, men årene 1936, 1939, 1947 og 1960 var særdeles varme. Årsagerne til disse variationer undersøges. Det bevises, at der eksisterer en tydelig sammenhæng mellem den atmosfæriske trykfordeling om foråret og de hydrografiske forhold om sommeren. Der drages den slutning, at vindforholdene i havet vest for Island om foråret må være en dominerende faktor, hvad angår indstrømning af atlantisk vand til området nord for Island. Det vises, at det er muligt med en grov tilnærmelse at forudsige temperaturen øst for Langanes i august ud fra lufttrykfordelingen i maj. Til dette formål bruges en lineær regressionsligning, hvor havtemperaturen udtrykkes som en funktion af den gennemsnitlige forskel i lufttryk i maj mellem Djúpivogur og Stykkishólmur. Analoge ligninger kan bruges til forudsigelse af sommertemperaturen længere mod vest i området. Den praktiske værdi af denne anvendelse diskuteres. Variationer i forholdene i den kolde tunge nordøst for Island analyseres, og det undersøges, om de nævnte variationer kan forklares på grundlag af vindforholdene. Resultatet tyder på, at der sandsynligvis er en sammenhæng mellem de hydrografiske forhold i 50–200 meter dybde i den kolde tunge og øst–vest vindkomponenten i de foregående 20–40 dage.

Det er indlysende, at mange af de resultater, som her er fremlagt, trænger til nærmere belysning, og nye og forbedrede undersøgelser mangler fra forskellige årstider. Det er forfatterens håb, at hovedresultaterne må kunne blive af værdi for den fremtidlige forskning på dette område.

I fremtiden bør der lægges større vægt på årstidsundersøgelser — ikke alene i det nordislandske kystområde, men også i de dybere strøg nord for fastlandssoklen. Blandingsmekanismen mellem de forskellige vandmasser bør nøje undersøges. Det er sandsynligt, at isotopiske undersøgelser i denne henseende kunne være til stor hjælp.

Med hensyn til strømhastigheden er der stor usikkerhed. Det er nødvendigt, at der foretages direkte strømmålinger i dette område, især kontinuerlige målinger, som kunne give kort-periodiske variationer til kende. Den slags målinger kunne sikkert bedst foretages ved hjælp af registrerende bøjer.

Korrelationen mellem vindforholdene i havet vest for Island om foråret og de hydrografiske forhold nord for Island om sommeren bør undersøges i detaljer. Det er sandsynligt, at man ville finde en bedre korrelation, hvis selve vejrkortene blev undersøgt i stedet for de månedlige gennemsnitstal. Den mulighed at kunne bruge den atmosfæriske trykfordeling eller andre meteorologiske data til at forudsige oceanografiske forhold bør nøje undersøges.

ÁGRIP Á ÍSLENZKU

Rit þetta fjallar um hafsvæðið norðan Íslands og byggist að mestu leyti á gögnum um sjávarhita og seltu, sem safnað hefur verið í íslenzkum leiðöngrum síðustu 15 árin.

Fyrstu heimildir um hafstrauma við Ísland er að finna í íslenzkum fornritum. Af frásögnum Landnámu og fleiri rita um rek öndvegissúlna má ljóst vera, að Íslendingar hafa þegar frá öndverðu þekkt í aðalatriðum hafstraumana við Suður- og Vesturland. Þeir sem bjuggu við norður- og austurströnd landsins hljóta að hafa vitað af reynslu, hvernig ísrekinu var venjulega háttað. Einnig í þessum landshlutum hafa menn því snemma öðlazt þekkingu á gangi hafstrauma.

Í sögulegu yfirliti er skýrt frá helztu leiðöngrum til hafsvæðanna umhverfis Ísland og nefnd helztu rit, er fjalla um niðurstöður þeirra rannsókna. Telja má, að kerfisbundnar sjórannsóknir á íslenzkum hafsvæðum hefjist um miðja síðustu öld með grundvallarrannsóknum danska flotaforingjans IRMINGER. Á árunum 1875–1908 voru farnir allmargir leiðangrar um hafsvæðin umhverfis Ísland og nálæg svæði, þar sem safnað var upplýsingum um hafdýpi og hitastig í djúplögum sjávar. Á árunum milli fyrri og síðari heimsstyrjaldarinnar var rannsóknum haldið áfram á svæðinu norðan Íslands. Voru það einkum Danir, sem að þeim rannsóknum stóðu. Á þessum árum voru athuganir hafnar á nokkrum föstum stöðvum, þar sem mælingar hafa síðan verið endurteknar á undanförnum áratugum.

Á árunum eftir síðari heimsstyrjöldina hófust Íslendingar handa um eigin sjórannsóknir. Sumarið 1949 og árin þar á eftir voru leiðangrar farnir út í mitt Grænlandssund og norður til Jan Mayen. Áherzla var þó aðallega lögð á almennar umhverfisrannsóknir á landgrunnssvæðunum, einkum seint á vorin og í sumarbyrjun um það leyti, sem síldarvertíð hefst að jafnaði við Norðurland. Litlar athuganir eru til um ástand sjávar á svæðinu norðan Íslands á öðrum árstíðum, ef frá eru taldar mánaðarlegar rannsóknir á svæðinu vestan Grímseyjar á árunum 1953–1955. Gerð er stutt grein fyrir helztu erlendum leiðöngrum, sem farnir hafa verið til hafsvæðanna í grennd við Ísland síðasta áratuginn. Hafa Rússar einkum kannað svæðið norðan Íslands, Danir og Norðmenn austan Íslands, en Skotar og Þjóðverjar sunnan Íslands og vestan.

Rætt er um nafngiftir hafsvæðanna norðan Íslands og austan í fortíð og nútíð. Bent er á, að elzta nafn á hafinu norðan Íslands sé *Dumbshaf*. Hafsvæðið milli Íslands og Noregs var aftur á móti nefnt *Íslandshaf* að fornu. Á sjókortum síðari alda gætir nokkurs ruglings í nafngiftum norðurhafa. Lagt er til, að heitið

Íslandshaf sé látið ná yfir svæðið milli Íslands, Grænlands og Jan Mayen, en heitið *Noregshaf* nái aðeins til þess hluta Norðurhafsins, sem liggur milli Færeyja, Jan Mayen, Svalbarða og Noregs. Lýst er botnlögun og dýpi umhverfis Ísland og í Íslandshafi. Athygli er vakin á, að Íslandshaf takmarkast að norðan og austan af neðansjávarhryggjum, er ganga til suðurs og vesturs frá Jan Mayen. Sýnt er fram á, að á landgrunnssvæðinu norðvestan Grímseyjar er mun meira dýpi (600–700 m) en sýnt er á sjókortum frá þessu svæði.

Lýst er einkennum þriggja aðalsjógerða á svæðinu norðan Íslands, en þær eru: a) Atlantssjór, b) pólsjór og c) botnsjór Norðurhafsins. Auk þeirra má greina milli fjögurra annarra sjógerða, sem myndaðar eru við kælingu eða blöndun aðalsjógerðanna. Þessar sjógerðir eru: svalsjór, sem aðallega er myndaður við blöndun á Atlantssjó og pólsjó, vetrarsjór Íslandshafsins, sem myndast síðari hluta vetrar við blöndun og kælingu í hafinu norðan Íslands, strandsjór, sem aðallega er myndaður við blöndun á Atlantssjó eða vetrarsjó við ferskt vatn frá landi, og loks millisjór pólstraumsins. Síðast nefnda sjógerðin er einkum til orðin við kælingu og blöndun á Atlantssjó á svæðinu vestan Svalbarða.

Getið er eldri straumkorta af hafinu milli Íslands, Jan Mayen og Grænlands. Birt er nýtt straumkort af þessu svæði. Er það aðallega byggt á gögnum, sem aflað hefur verið í íslenzkum leiðöngrum á árunum 1949–1954. Það sem sérstaklega einkennir straumkerfi Íslandshafsins samkvæmt þessu nýja korti, er hringstraumur rangsælis í hafinu milli Íslands og Jan Mayen. Er þessi straumhvirfill sterkastur við útjaðrana. Austurhluti straumhvirfilsins flytur sjó úr suðaustri, sem gerir það að verkum, að sunnan við Jan Mayen-grunnið er hlýrri og saltari sjór en á svæði hinnar svokölluðu köldu tungu norðan við íslenzka landgrunnið. Vestur- og suðurhluti hvirfilsins er Austur-Íslandsstraumurinn. Samkvæmt eldri straumkortum fellur hann sem samfelld straumkvísl til suðausturs á öllu svæðinu milli Íslands og Jan Mayen. Íslenzku rannsóknirnar hafa hins vegar leitt í ljós, að straumurinn er sterkastur í útjaðri íslenzka landgrunnsins, en hans gætir lítt, þegar lengra dregur norðaustur í hafið. Straumhvirfillinn flytur Austur-Íslandsstraumnum sjó úr norðri austan við hinn eiginlega Austur-Grænlandsstraum, og því gætir pólsjávar ekki í Austur-Íslandsstraumnum nema að litlu leyti. Meginhluti straumsins myndast aftur á móti við blöndun og kólnun á Atlantssjó, sem berst með Irmingerstraumnum austur með jaðri landgrunnsins út af Norðurlandi. Straumflösku-tilraunir, sem gerðar hafa verið á svæðinu, staðfesta þá straummynd, sem hér er lýst.

Á íslenzka landgrunnssvæðinu er meginstraumstefnan réttsælis umhverfis landið. Straumurinn fylgir þó að mestu útlínum landgrunnsins. Þannig leggur hann inn með Húnaflóa vestanverðum, út með flóanum austanverðum, inn með Skagagrunni austanverðu og út með Grímseyjargrunni vestanverðu. Í námunda við Vestrahorn eru mjög skörp skil milli Atlantssjávarins og svalsjávarins að norðan. Hér leitar strandsjórinn sennilega að mestu út frá landinu til suðausturs sem hluti af Austur-Íslandsstraumnum.

Sérstakur kafli fjallar um sjávarhita og seltu mánuðina maí–ágúst á mismunandi dýptum og í lóðréttum sniðum. Birt eru meðallagskort, er sýna sjávarhita í 20 metrum og hitastig og seltu í 50 og 100 metrum. Einnig er sýnt meðallagsástand í lóðréttum sniðum út frá Kögri, Siglunesi og Langanesi.

Rannsökuð eru t, S-línurit frá ýmsum stöðum á svæðinu norðan Íslands. Í ljós kemur, að miðdýpis í kjarna Irmingerstraumsins, sem liggur austur með Norðurlandi, er í byrjun sumars tiltölulega einföld blanda af tveim sjógerðum, Atlantssjó og vetrarsjó, og fer magn þess fyrrnefnda minnkandi, er austar dregur. Í þessari blöndu er mjög náið samræmi milli hitastigs og seltu. Á grundvelli júní-athugana frá árunum 1950–1956 er reiknað línulegt samband milli sjávarhita og seltu, og sú líking síðan notuð til þess að reikna út hlutfallslegt magn Atlantssjávar á mismunandi árum. Í júnímánuði reyndist magn hans vera 80–90% á svæðinu vestan Látrabjargs, en aðeins 0–30% austan Langaness. Líkinguna má einnig nota með sæmilegum árangri til þess að reikna seltuútbreiðsluna miðdýpis út frá hitastiginu. Þetta var gert fyrir árin 1957, 1958 og 1959. Niðurstaðan varð sú, að hin útreiknuðu gildi reyndust koma vel heim við þau, sem fundin voru með efnagreiningu. Hið einfalda samband milli hitastigs og seltu gildir þó aðeins um dýpri hluta landgrunnssvæðisins nálægt kjarna Irmingerstraumsins. En neðan 250–300 metra tekur áhrifa botnsjávarins að gæta í ríkum mæli um mest allt svæðið norðan Íslands, og á 400–500 metra dýpi má heita, að víðast sé komið þar í hreinan botnssjó. Rætt er um uppruna og myndun vetrarsjávar Íslandshafsins. Er líður á sumarið, berst vetrarsjórinn smám saman burt af Norðurlandssvæðinu, og Austur-Íslandsstraumurinn flytur hann suður með Austfjörðum. Með hliðsjón af t, S-línuritum frá svæðinu milli Íslands og Færeyja er ályktað, að botnrennslið yfir Íslands–Færeyjahrygginn sé að nokkru leyti vetrarsjór frá svæðinu norðan Íslands.

Til ákvörðunar á straumhraða er stuðzt við útreikninga, sem byggðir eru á eðlisþyngdardreifingunni. Forsenda þessara útreikninga er sú, að gera megi ráð fyrir, að straumlaust sé nálægt botni á grynnsta hluta svæðsins, nálægt 300–400 metra dýpi við landgrunnsbrúnina, en á 800 metra dýpi, þegar komið er norður á 68° 30′ n. br. Útreikningarnir benda til þess, að straumhraðinn sé mestur í tiltölulega mjóu belti nálægt brúnum landgrunnsins, en mun minni uppi á grunnunum. Ályktað er, að meðalstraumhraði strandsjávarins norðan Íslands sé um 3 sjómílur á sólarhring. Kemur sú tala allvel heim við niðurstöður rekflösku-tilrauna, og svipuð niðurstaða fæst með því að fylgja eftir tilteknum eiginleikum sjávarins, t. d. kortleggja útbreiðslu Atlantssjávarins með stuttu millibili.

Reynt er að áætla sjávarrennslið gegnum snið, er liggja norður frá Kögri og Melrakkasléttu. Lögð er áherzla á ýmis atriði, er valdið geti ónákvæmni í slíkum útreikningum. Niðurstöðurnar benda til þess, að meðal nettórennsli austur fyrir Horn innan 60 sjómílna frá landi, nemi að sumarlagi nálægt 2.2 km^3 á klukkustund. Virðist hér nær eingöngu um að ræða sjó með hitastigi yfir 1°. Áætlað er, að varmarennsli til Norðurlandssvæðisins sé að sumarlagi um það bil $2.7 \cdot 10^9$ kg. kaloríur á sekúndu. Samanburður á útreiknuðu rennsli gegnum Kögursnið og Melrakkasléttusnið bendir til þess, að sveiflur í rennsli Austur-

Íslandsstraumsins á svæðinu út af Melrakkasléttu stafi aðallega af sveiflum í rennsli Irmingerstraumsins, en hins vegar muni litlar sveiflur eiga sér stað í þeim hluta Austur-Íslandsstraumsins, sem að norðan kemur.

Rætt er um árstíðabreytingar norðan Íslands í sérstökum kafla. Útbreiðsla hafíssins er mjög breytileg eftir árstíðum. Við Norðvesturland er breidd hafísbeltisins mest að vori, á tímabilinu marz–júní. Ísbráðnunin er aftur á móti mest seinni hluta sumars. Er líður á sumarið, færist ísröndin nær og nær Grænlandi, og er fjærst frá Íslandi mánuðina ágúst–október. Eftir því sem dregur fram á veturinn, smábreikkar ísbeltið á nýjan leik. Lýst er árstíðabreytingum í ástandi sjávar á svæðinu norðan Sigluness á árunum 1953–1955. Greina má árstíðabreytingar niður á 300 metra dýpi. Ástand sjávar norðanlands er einkum komið undir tvennu: upphitun af völdum sólar og innstreymi Atlantssjávar austur fyrir Horn. Fyrra atriðið, upphitun af völdum sólar, hefur einkum áhrif á yfirborðssjóinn og veldur lagskiptingu hans. Innstreymi Atlantssjávar ræður hins vegar mestu um sjávarhitann í djúplögum á svæðinu norðan Íslands. Sýnt er fram á, að áhrif Atlantssjávarins norðanlands séu minnst á veturna, færist í aukana á vorin og nái hámarki nálægt miðju sumri. Á haustin dregur mjög úr áhrifunum á vesturhluta svæðisins, en þeirra gætir verulega austan Langaness fram eftir hausti. Magn Atlantssjávarins nær þannig hámarki á ólíkum tímum á mismunandi svæðum, og kemur þessi afstöðumunur skýrt fram, ef bornar eru saman árstíðabreytingar á austur- og vestursvæði. Leidd eru að því rök, að þessar breytingar stafi af sveiflum í rennsli Atlantssjávarins. Hugsanlegar orsakir slíkra árstíðabreytinga eru ræddar.

Á grundvelli margvíslegra gagna, sem safnað hefur verið sumarmánuðina árin 1924–1939 og 1947–1960, er gerður samanburður á útbreiðslu hafíss, lofthita, yfirborðshita sjávar og sjávarhita í djúplögum á landgrunnssvæðinu norðan Íslands. Síðustu áratugina hefur hafís sjaldan sézt uppi við strendur landsins. Ísskilyrði fyrir Norðvesturlandi hafa þó enn sem fyrr verið breytileg ár frá ári. Almennt má segja, að sjávarhiti neðan yfirborðslagsins hafi farið hækkandi árin 1924–1939, lækkað lítils háttar á tímabilinu 1947–1953, en hækkað aftur síðustu árin. Sé litið á einstök ár, má telja, að sumurin 1924, 1930, 1932, 1938 og 1949 hafi verið óvenju köld, en sumurin 1936, 1939, 1947 og 1960 sérstaklega hlý. Breytingar ár frá ári reynast mestar á austasta hluta svæðisins síðari hluta sumars, og virðist mega ætla, að þær muni aðallega standa í sambandi við breytilegt rennsli Atlantssjávar. Kannaðar eru helztu orsakir slíkra sveiflna. Sýnt er fram á, að greinilegt samræmi er milli loftþrýstingsins á vorin og sjávarhita og seltu í djúplögum síðla sumars. Ályktað er, að vindátt í hafinu vestan Íslands ráði mestu um innstreymi Atlantssjávar norður fyrir land. Sýnt er fram á á grundvelli staðtölulegra útreikninga, að mögulegt er að spá með sæmilegri nákvæmni um sjávarhitann austan Langaness í ágústmánuði út frá loftþrýstingnum í maí. Er þá sjávarhitinn reiknaður út frá mismuni loftþrýstingsins milli Djúpavogs og Stykkishólms. Hliðstæða útreikninga er hægt að nota til þess að spá fyrir um ástand sjávar vestar á svæðinu. Rætt er um hagnýtt gildi slíkra spádóma. Athugun er gerð á sveiflum í ástandi sjávar á úthafssvæðinu milli Íslands og Jan Mayen. Koma þar einnig fram nokkrar breytingar á sjávarhita ár frá ári. Kannað er, hvort rekja megi slíkar breytingar til mismunandi vindáttar. Niðurstaðan er sú, að sennilegt megi telja, að tiltölulega hátt hitastig og há selta miðdýpis í köldu tungunni norðaustan Íslands sé afleiðing mikillar austanáttar 20–40 dögum áður, en hins vegar megi búast við lægri sjávarhita og lægri seltu eftir vestanátt. Í djúplögum þessa svæðis er ástandið mjög stöðugt.