INTERNATIONAL COMMISSION
FOR THE
NORTHWEST ATLANTIC FISHERIES

REDBOOK 1967 PART IV

Selected Papers from a Special Meeting of the
Environmental Subcommittee, May 1967, on
Fluctuations in Sea and Air Temperature
in the ICNAF Area Since 1950

Issued from the Headquarters of the Commission
Dartmouth, N.S., Canada
NOVEMBER 1967

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ON FLUCTUATIONS IN SEA AND AIR TEMPERATURE IN THE ICNAF AREA SINCE 1950

(from Serial Numbers 1804, 1814, 1820, 1849, 1854,
1857, 1859, 1861, 1867)

Note

REDBOOK 1967 appears in 4 books. The first book contains Part I, Proceedings of the Standing Committee on Research and Statistics. The second book contains Part II, Reports on Researches in the ICNAF Area in 1966. The third book contains Part III, Selected Papers from the 1967 Annual Meeting. The fourth book contains Part IV, Selected Papers from a Special Meeting of the Environmental Subcommittee, May 1967.

Prepared by Vivian C. Kerr and Jean S. Maclellan

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1967

PART IV. SELECTED PAPERS FROM A SPECIAL MEETING OF THE ENVIRONMENTAL SUBCOMMITTEE, MAY 1967, ON FLUCTUATIONS IN SEA AND AIR TEMPERATURE IN THE ICNAF AREA SINCE 1950.

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Fluctuations in sea and air temperature in the ICNAF Area since 1950

Chairman's Report

by Arthur Lee
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At the 1966 meeting of the Research and Statistics Committee, it was recommended that the Chairman of the Environmental Subcommittee take steps to obtain from appropriate experts a synthesis of hydrographic and meteorological fluctuations in the ICNAF Area in recent years and to report back to the 1967 meeting. I accordingly invited papers from physical oceanographers and meteorologists working in the ICNAF Area and a total of nine were presented at the 1967 meeting in Boston, Massachusetts. They are all published here.

That by Martin Rodewald (p.6) surveys the North Atlantic as a whole and relates sea surface temperature (SST) anomalies to the mean surface pressure anomalies. Taken as a whole the North Atlantic shows a cooling trend over the period 1951-65. When examined on a regional basis it shows a warming trend in the areas to the west, south and east of Iceland, *i.e.*, northwards from about latitude 60°N, and a strong cooling trend in the area between latitudes 60° and 40°N from North America to Europe. Seasonally, there is more of a cooling trend during the six months June-November than during the period December-May. During the decade 1956-65, cyclonic activity was above normal in middle latitudes to the south of the Icelandic low. The Greenland high, on the other hand, intensified and there was an anomalous northeasterly wind over the Northwest Atlantic. This meteorological situation brought about the recent trends in SST and it has been remarkable in its persistence. In most months of the year there was a high degree of type tendency during the period 1956-65, and it is thought that feedback from the ocean is responsible.

The cooling trend in the Northwest Atlantic over the last 15 years along the coasts of New England and Maritime Provinces (Subareas 4 and 5) is shown in the papers by Lauzier (p.24), Chase (p.37) and Welch (p.33). Louis Lauzier demonstrates this trend in SST at St. Andrews, New Brunswick and in the southwestern Gulf of St. Lawrence, in the air temperature over Nova Scotia, and in the bottom temperatures of the Bay of Fundy, Gulf of Maine and the Scotian Shelf. It amounts to about 0.2°-0.25°C per year, as far as sea temperatures are concerned. The core of the warm deep layer in Cabot Strait also shows a cooling since the late 1950's. Walter Welch reports a downward trend in SST at Boothbay Harbour, Maine since 1953 with a temporary check between 1959 and 1963. Both winter and summer temperatures have this decline, but the cooling has been noticeably greater in the cold season. Again, it amounts to about 0.25°C per year. Joseph Chase also considers the Boothbay Harbour SST data and shows that the August temperatures in the last year or two are at a level equal to those in 1941, which were the lowest for that month since records were started at the beginning of the century. The February and annual means have not yet reached the levels of previous minima. He examines too air temperatures along the New England coast. The winter minimum at Boston and New Haven during the last one or two years has been comparable to the previous minima in 1946 and 1918.

John Colton in his paper (p.42) demonstrates that the trends at Boothbay Harbour are paralleled offshore in the Shelf waters between Nova Scotia and Long Island as far as the period December 1964-September 1966 is concerned. He compares offshore conditions at 0, 20, 50 and 100 m depth during this time with the 1940-59 mean values and shows that they were appreciably colder, with the greatest negative anomalies, up to 8°C, at the edge of the Continental Shelf, and the smallest, up to 2°C, inshore. By contrast, he shows that March 1953 was a month with positive temperature anomalies, up to 1°C, over the Shelf as well as in the coastal waters: the year 1953 was at the peak of the warming period prior to the cooling of recent years. He suggests that the fact that the greatest negative anomalies are at the Shelf edge indicates that the cause of the cooling lies in changes in the relative position and degree of mixing of the coastal and oceanic water masses: these may be due to the type of change in the atmospheric circulation that is postulated by Martin Rodewald.

With Taivo Laevastu and LCDR Corkrum, I (p. 48) examine the SST anomalies off the American coast in the months February-July in each of the years 1963-66. We have chosen a different baseline to that of John Colton and our anomalies are from the mean of the 20-year period 1946-65, but our work supports his findings. Firstly, we show that, whereas 1963 was a year of positive anomaly over the Grand Banks and Georges Bank, the other years were ones of negative anomaly. Secondly, by comparing the charts of SST anomaly with those giving the mean atmospheric pressure distribution, we show that the anomalies are largely due to the thermal and dynamic effects of the wind on the ocean. We also show that there is considerable degree in the persistence through late winter and spring of anomaly patterns established in fall and early winter. However, our anomalies for the Grand Banks as a whole for January-May in the years 1963-66 do not show the same trend as the SST data presented by Wilfred Templeman (p. 69) for a fixed station 2 nautical miles from the coast in the vicinity of St. John's, Newfoundland. Moreover, although the sets of 5- and 11-year running means of air temperature for the months December-April and May-November in this area show a rise from about 1920 to a peak in the early 1950's and then a decline, in agreement with the findings for New England and the Maritime Provinces, the sea temperatures at this fixed station do not show any clear trend either upwards or downwards.

Events in West and South Greenland waters during the last 15 years have been quite different from those further south. Frede Hermann (p. 76) shows that air and sea surface temperatures there, up to 1963 at least, have had an upward trend since 1950, when the decline from the peak value of the early 1930's was halted: this new rise amounts to 0.5°C in the case of SST. More striking still is an increase in July temperatures at 200-300 m depth along the edge of the West Greenland Banks. Since the early 1950's it has amounted to 2°-3°C. Its cause is not entirely clear. Frede Hermann thinks that it may be due to less severe winter cooling in the area south and east of Greenland, and Johan Blindheim (p.86) throws light on this process. He examines Norwegian data for the months March-April collected off West Greenland since 1959 and shows that, as far as the surface layers are concerned, the years 1959-61 were warm compared with the subsequent years, but that the Irminger component at depth was well developed in 1960 and 1965 and particularly well developed in 1964 and 1966. There is, therefore, no relationship between the trends at the surface and those at depth. Neither is there one between winter air temperature and sea surface temperature as the coldest winters occurred around 1960 when sea surface temperatures were highest. However, the salinity of the surface layer was higher during the years of high surface temperature than during the years 1964-65 when the surface temperature was low and the Irminger component was well developed. Lower salinity in the upper layers of the water column increases its stability, and so concentrates the cooling effect of the cold winter winds in these upper layers and prevents deep convection from reaching the Irminger component and reducing its temperature. The low salinity water in the upper layers is contributed by the East Greenland component of the West Greenland Current. It is possible that the anomalous northeasterly wind over the Irminger Sea found by Martin Rodewald has led to a greater transport into the West Greenland area of both this and the Irminger component of the West Greenland Current; a possibility not mentioned in any of the papers published here, but raised during the discussion following their presentation at the Boston meeting.

The fluctuations in sea temperature in the ICNAF Area are so marked that the meeting gave consideration to the possibility of forecasting them, particularly as the value of oceanographic forecasts in relation to the prediction of the availability of fish had been demonstrated in a paper concerning the albacore tuna of the eastern Pacific Ocean presented to the meeting by Glenn Flittner. The paper by myself, Laevastu and Corkrum shows that there is persistence in SST anomaly patterns and that this can help in forecasting. A paper submitted to the meeting by Paul Wolff, Taivo Laevastu and LCDR Tatro reviewed the methods used for forecasting at the US Fleet Numerical Weather Facility, Monterey and examined their accuracy and future prospects. Another by the US Coast Guard Oceanographic Unit, Washington, D.C. gave examples of the oceanographic analyses and forecasts for the Northwest Atlantic provided for that unit by the Monterey facility. USSR methods of forecasting fluctuations in water mass limits on the Scotian Shelf and Georges Bank were described in a paper by V. A. Bryantsev and V. N. Yakovlev.

Recent variations of North Atlantic sea surface temperatures (SST) and the "Type-Tendencies" of the atmospheric circulation[1]

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The thermal state of the northern part of the North Atlantic sea surface may be taken as fairly well represented by the results of the observational system of the 9 Ocean Weather Stations (OWS). Their distribution is shown in Fig. 1.

Results of analysis of a·grand total of about 380,000 SST measurements made by the OWS's during the last 15 years (1951-65) show that this recent period is characterized by a distinct cooling trend. Running 5-year means for the whole of the 9 OWS's clearly show this cooling phenomenon (Fig. 2, after Rodewald, 1966).

The development of SST depends on many factors (Laevastu, 1960), but one of the primary questions may be that of the special pattern of the atmospheric circulation, because the air circulation includes other factors influencing SST, such as air temperatures, cloudiness, storm frequency, wind effect on ocean currents, *etc*. The general pattern of the atmospheric circulation during the cooling 10-year period 1956-65 may be represented in the form of mean pressure anomalies over the North Atlantic (Fig. 3). These are to be read like high and low pressure systems superposed to the normal pressure distribution, and with the vector "anomaly winds" going around them. Fig. 3 shows that the cyclonic activity was above normal in middle latitudes of the ocean, to the south of the normal Icelandic low. On the other hand, there was a strengthening of the Greenland high, accompanied by northeasterly anomaly winds over the Northwest Atlantic.

The year of coldest surface waters during the period 1956-65 was that of 1963, if we consider the whole of the 9 OWS's. The air circulation of this year is represented by Fig. 4. The type of pressure anomalies during 1963 comes out to be similar but more pronounced than that of the whole 10-year period. A southerly belt of cyclonic activity extends between the sea off the USA east coast and Spain, while there is a high pressure tendency in sub-polar regions.

These pictures underline what the author said some years before concerning the North Atlantic decade 1951-60 (Rodewald, 1963): "The decadal development seems to support the idea that an expanding polar vortex over the

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[1] Submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/64

ocean is accompanied by a cooling of the sea surface on a spatial average, especially so in middle latitudes."

The recent SST development, however, was neither uniform in the different sea areas nor in the different months of the year. Table 1 gives for the various OWS's (A, B, C, *etc.*) and for the 12 months the amount of warming (+) or cooling (-) which occurred from the 5-year period 1951-55 to the 5-year period 1961-65, expressed in hundredths of degree C. In each column the arrangement is from the highest positive value to the highest negative one.

Table 1. Change of mean monthly sea surface temperatures (hundredth °C) at the Ocean Weather Stations (OWS) from the 5-year period 1951-55 to the 5-year period 1961-65.

DEC		JAN		FEB		MAR		APR		MAY	
A	+102	A	+ 80	A	+ 76	A	+116	A	+136	A	+102
M	+ 28	M	+ 40	M	+ 60	M	+ 44	M	+ 54	I	+ 38
I	+ 2	B	+ 36	B	+ 50	I	+ 40	I	+ 46	M	+ 30
C	- 26	I	+ 32	I	+ 22	B	- 12	B	+ 6	K	- 6
B	- 34	J	- 6	J	- 6	J	- 12	J	- 6	C	- 54
J	- 44	C	- 10	K	- 30	E	- 14	C	- 14	E	- 58
K	- 48	K	- 30	C	- 44	K	- 42	K	- 38	J	- 70
D	- 82	E	- 70	E	- 84	C	- 88	E	- 88	B	- 82
E	- 86	D	-136	D	-188	D	-230	D	-168	D	-172
Mean	-21		- 7		- 16		- 22		- 8		- 30

JUN		JUL		AUG		SEP		OCT		NOV	
E	+ 68	A	- 8	A	+ 32	D	+ 2	A	+ 52	M	+ 36
M	+ 26	M	- 14	E	- 14	M	± 0	M	+ 36	A	+ 18
A	+ 18	I	- 36	M	- 16	A	- 16	I	+ 12	I	- 20
B	- 20	J	- 50	I	- 44	I	- 38	C	- 24	B	- 42
I	- 20	B	- 50	J	- 58	K	- 38	K	- 36	J	- 56
J	- 66	E	- 52	K	- 58	J	- 44	J	- 42	C	- 60
C	- 88	C	- 74	B	- 68	B	- 72	E	- 50	K	- 70
K	- 88	K	-108	D	-140	C	- 92	B	- 88	E	- 82
D	-226	D	-210	C	-142	E	-100	D	- 94	D	-116
Mean	-44		- 67		- 56		- 44		- 26		- 44

The great majority of months show OWS A at the top position in Table 1 and OWS D at the bottom position. This means that, in general, the Irminger Sea is the region of maximum warming during the last 10 years, while the region about halfway between Newfoundland and the Azores is that of maximum cooling, this cooling being generally much more pronounced than the sub-polar warming.

The warming - or least cooling - is mostly confined to the OWS's A, M, I which represent the areas to the west, south and east of Iceland. The more extensive area of stronger cooling is around OWS D, including Stations C, E and even K near Southwest Europe. Seasonally, there is more cooling and less warming during the 6-month period June-November than during the period December-May. Fig. 5 illustrates the seasonal SST development for the Northeast Atlantic area of predominant warming (OWS's A, M, I), for the remaining larger area of cooling (OWS's B, C, D, E, K, J), and for the whole area represented by the OWS's. In general, the cooling tendency was more pronounced during the warmer half of the year than during winter and early spring.

An even more regular annual variation results, when the monthly SST means for the 5-year period 1961-65 are compared with the SST normals of the OWS's compiled 15 years ago (Rodewald, 1952). This is shown in Fig. 6 for the same areas as in Fig. 5. In the Northeast (OWS's A, M, I), the positive SST anomaly has its maximum (+1.1°) in March (scattering February-March) and its minimum (+0.2°) in September (scattering August-October). This annual variation of the SST anomalies is almost contrary to the annual variation of the SST itself, so that the annual range of SST is decreased by this type of seasonal anomaly distribution.

For the remaining North Atlantic region, the annual variation of SST anomalies shows the minimum in May (-0.5°) and the maximum in December (+0.3°), but there exists a greater scattering at the time of extremes between the various OWS's. The fact that the greatest cooling and negative anomaly occurred in the warmer season of main radiation input could indicate an effect of increased cloudiness but it could also be due to increased windiness and other factors.

It is worth mentioning that the recent SST cooling trend took place also along the Canadian and USA east coast, as may be seen from the papers in ICNAF Spec. Publ. No. 6, Section H (1965). At St. Andrews, New Brunswick, the cooling from the period 1951-55 to the period 1961-65 was of the same amount (-1.4°) as at OWS D, the seasonal distribution showing the maximum decrease in July (-2.1°) and the minimum decrease in December (-1.0°).

For the rest, it may be taken from the trend curves of the OWS's B, C, D adjoining the ICNAF Area (Fig. 7-9) that the cooling trend has stopped or reversed recently - raising uncertainty about the future development. The rewarming is greatest at OWS B from what appears to have been spreading from the warmed Irminger Sea, in consequence of the intensified circulation (Fig. 2 and 3).

With regard to the fact that the SST variations and anomalies were far from uniform seasonally, it is interesting to note that the atmospheric circulation also showed great seasonal differences in its anomalies. In the

5-year period 1961-65, for instance, strong positive pressure anomalies prevailed in the northern regions between Baffinland and Norway during the 5-month period November-March, whereas, pressure was below normal in middle and subtropical latitudes of the North Atlantic. Contrary to this "type-tendency" of the winter months, negative pressure anomalies prevailed in the northern regions during the 7-month period April-October. Tables 2 and 3 demonstrate the effect on the pressure difference between the Azores high and the Icelandic low along a central meridian of the North Atlantic.

Table 2. Mean pressure difference (in mbar) along 30°W between 35°N and 65°N.

	Normal difference	Mean difference 1961-65	Percentage of Normal
Annual mean	15.5	14.5	93.6
Mean (November-March)	20.4	13.2	64.7
Mean (April-October)	12.0	15.4	128.3

Table 3. Departure (mbar) from the normal mean pressure difference along 30°W between 35°N and 65°N during the 5-year period 1961-65.

APR	MAY	JUN	JUL	AUG	SEP	OCT
+3.5	+3.4	+4.6	-1.3	+1.1	+4.9	+7.3
	NOV	DEC	JAN	FEB	MAR	
	-6.6	-9.3	-6.6	-8.3	-5.1	
Mean (April-October)		+3.4		Mean (November-March)		-7.2

The meridianal pressure difference is an indicator for the vector mean speed of west winds between sub-tropical and sub-polar latitudes. This westerly component was sharply below normal during the cold season (November-March) 1961-65, and it was well above normal during the warmer season of this 5-year period. Due to this, the normal annual variation of the vector mean speed of westerlies was smoothed in the period 1961-65. The seasonal distribution of SST anomalies, on the whole, corresponds to such a differential "type-tendency" of the atmospheric circulation.

A special phenomenon - and problem too - was the outstanding persistence of the type of atmospheric circulation during several months of the 10-year period 1956-65. The high degree of "type-tendency" may be shown for the months of March and October.

Fig. 10 and 11 illustrate the mean circulation during *March* for the 5-year periods 1956-60 and 1961-65. During both periods the Icelandic low shows a pronounced displacement and extension to the south, with a belt of strong "southern westerlies" in sub-tropical latitudes.

In order to express numerically the similarity of the two periods, field correlation has been computed for the gridpoints of the overlapping areas:

15° - 40°N, 0° - 20°W, 10° - 30°W, *etc.*
40° - 60°N, 0° - 30°W, 15° - 45°W, *etc.*
60° - 85°N, 0° - 40°W, 20° - 60°W, *etc.*

The results are shown in Fig. 12 in which correlation coefficients have been entered near the centre of the respective fields, *underlined* values being statistically significant. It comes out that the persistence of the March anomaly type from 1956-60 to 1961-65 is much more than by pure chance.

The month of *October* is an example of another type of atmospheric circulation: the Icelandic low is greatly intensified almost in its normal position, with strong "northern westerlies" blowing around its southern semicircle (Fig. 13 and 14). Also, in this case, the persistence is well developed (Fig. 15).

Over extended areas the sign (+ or -) frequency of the monthly pressure anomalies was 80-90% for the 10 months of March and October, 1956-65.

Table 4 shows the computed "anomaly winds" for the northern part of the North Atlantic for the two months March and October during the 10-year period 1956-65. The grid point data for the latitudes 65° - 45°N, longitudes 10° - 60°W clearly demonstrate the different mean wind systems of March and October which are superposed to the normal wind systems of the respective months.

Actual anomaly winds will have about 0.65 of the geostrophic wind speed (and an angle of inclination of about 13° with regard to isallobars). Even with such a reduction, they appear to be sufficiently strong to exert their influence which, in the Northwest Atlantic, would consist in a strengthening of both the warm Irminger Current and the cold Polar Current during the 10-year period 1956-65.

The SST anomalies in their space-time distribution certainly are correlated more or less to the atmospheric circulation anomalies, and the SST trend phenomena seem to be due no little to circulation "type-tendencies"

Table 4. Geostrophic windfield of the pressure anomalies for the 10-year period 1956-65; months of March (M) and October (O).
D = Direction of the "anomaly wind" in degrees
F = Speed of the "anomaly wind" in knots

		65°N		60°N		55°N		50°N		45°N	
		D	F	D	F	D	F	D	F	D	F
10°W	M	163	2.0	150	9.2	147	10.2	160	7.9	201	6.7
	O	212	6.0	237	7.9	243	4.2	237	1.5	73	3.1
20°W	M	130	6.8	122	10.0	139	7.9	171	6.0	219	6.9
	O	177	3.7	227	9.9	235	7.4	238	4.3	141	2.1
30°W	M	102	6.8	74	7.4	93	7.0	102	2.4	235	4.7
	O	67	5.3	222	8.1	238	9.6	235	5.3	184	2.8
40°W	M	47	7.6	63	8.8	55	9.6	37	6.6	352	4.0
	O	54	10.1	356	3.2	267	8.8	259	6.2	239	3.5
50°W	M	47	6.4	53	7.1	35	8.8	41	6.2	31	6.1
	O	31	4.6	3	7.1	323	5.6	295	2.9	216	1.0
60°W	M	50	3.6	38	6.0	50	9.0	53	7.5	26	5.6
	O	6	2.5	338	3.9	327	5.1	19	1.4	77	2.8

which are predominant for a longer time. But what are these tendencies and their quasi-persistence from if not the sea? There should exist some sort of feedback, since the atmosphere may be assumed to have no memory in itself for more than half a month. This is an unsolved but important problem, and any attempt to predict future SST developments will depend to a large extent on its solution.

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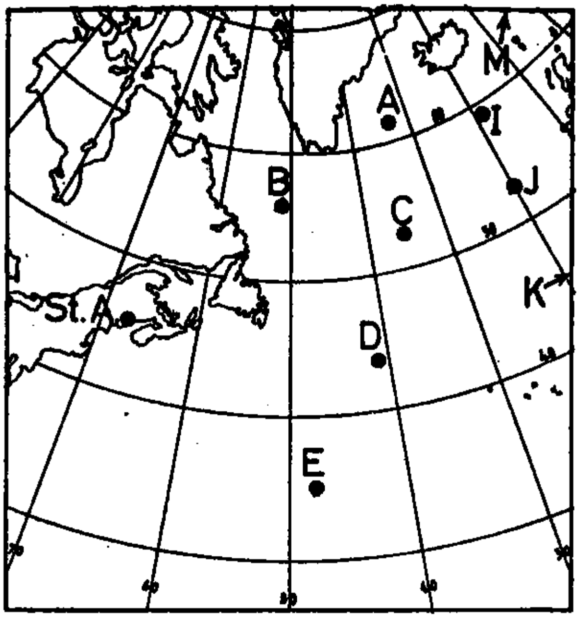

Fig. 1. Distribution of the Ocean Weather Stations. Positions M = 66°N, 2°E; K = 45°N, 16°W; St.A = St. Andrews, N.B.

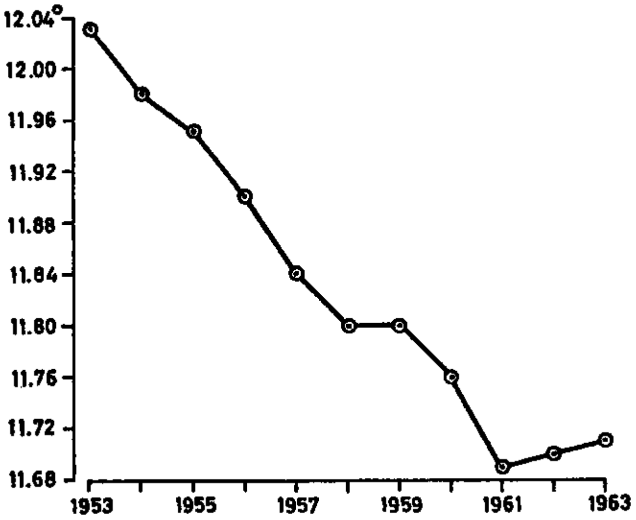

Fig. 2. Running 5-year means of SST for the whole of the 9 OWS's. Year numbers indicate the central year of the 5-year period (1953 = 1951-55).

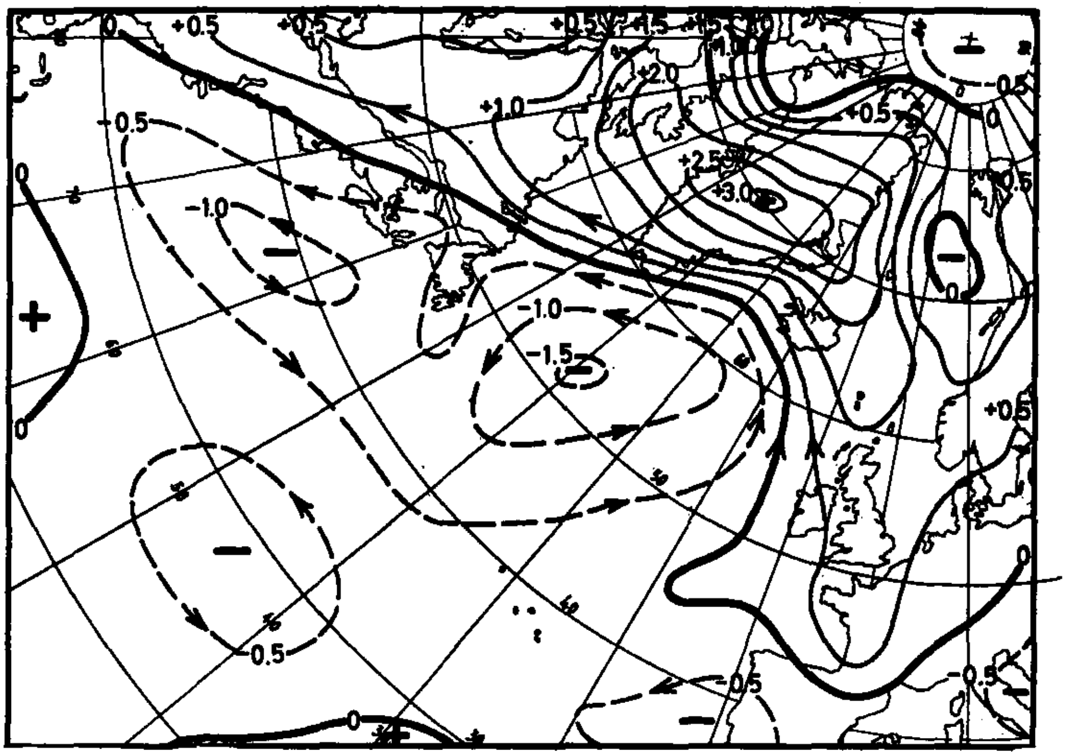

Fig. 3. Mean pressure deviation (mbar) from normal for the 10-year period 1956-65. Normal period 1900-1939. Arrows indicate the sense of anomaly circulation.

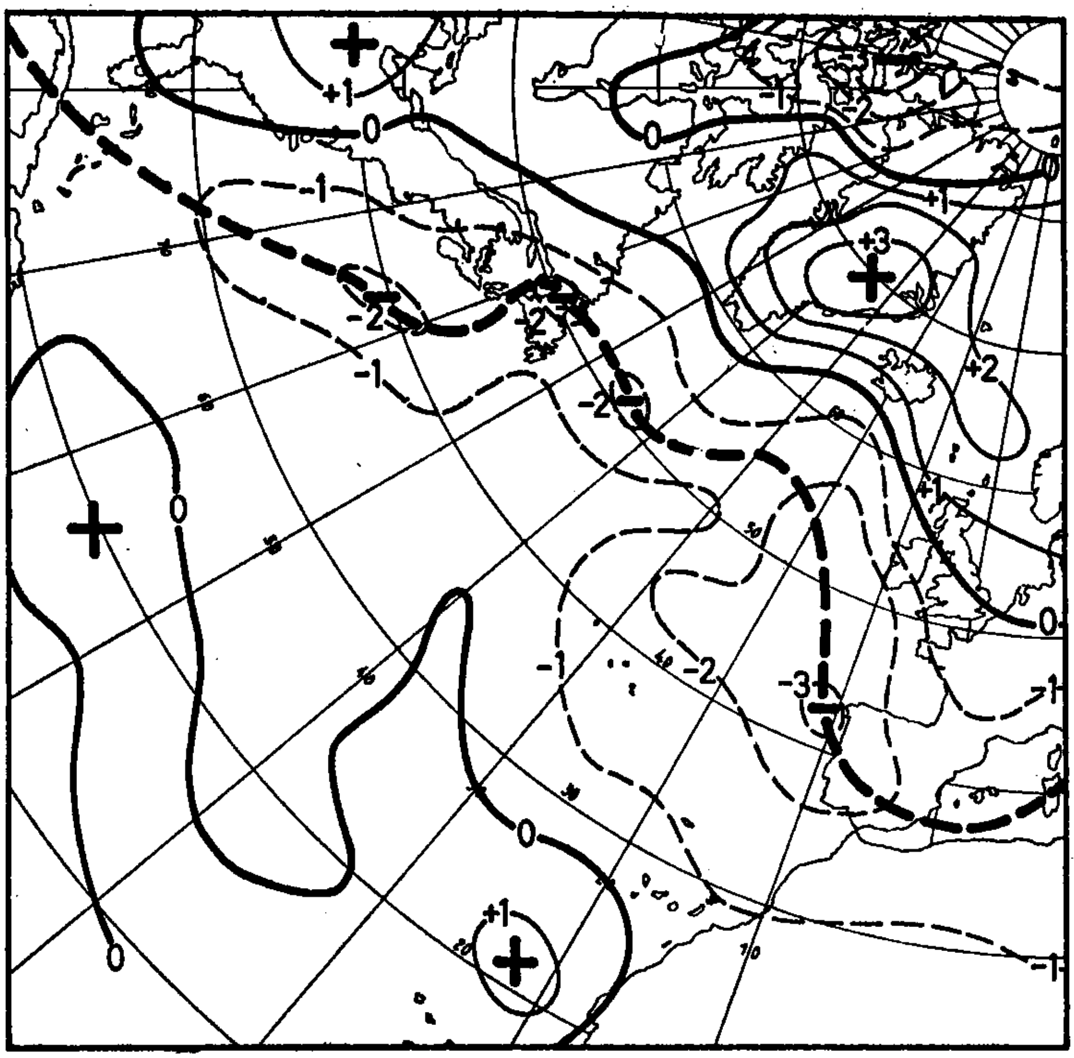

Fig. 4. Mean pressure deviation (mbar) from normal for the year 1963. The thick dashed line marks the axis of above-normal cyclonic activity.

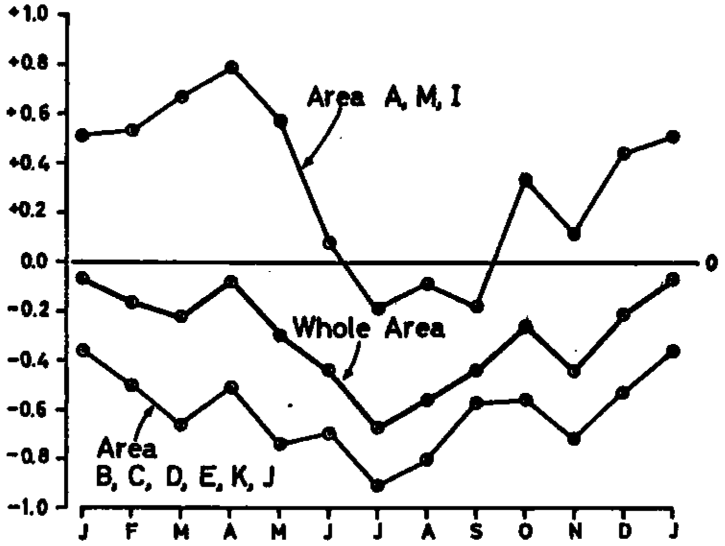

Fig. 5. Change of mean SST from the period 1951-55 to the period 1961-65 for the area of OWS's and for two subareas.

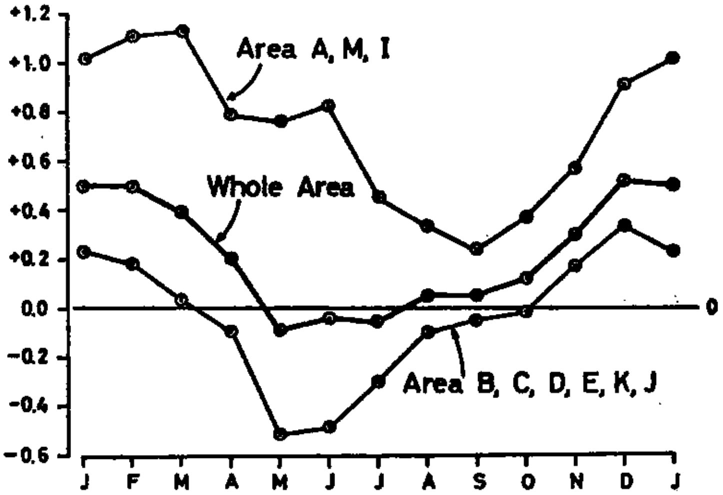

Fig. 6. Departure from normal SST during the period 1961-65 for the area of OWS's and for two subareas.

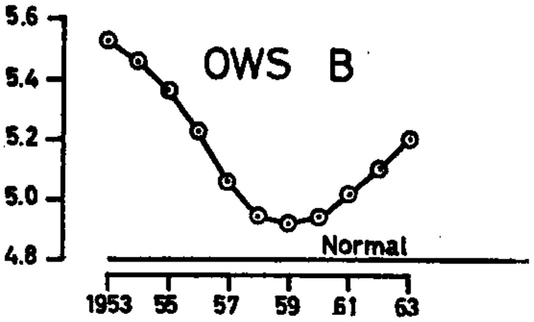

Fig. 7. SST running 5-year means for OWS B (1953 = period 1951-55).

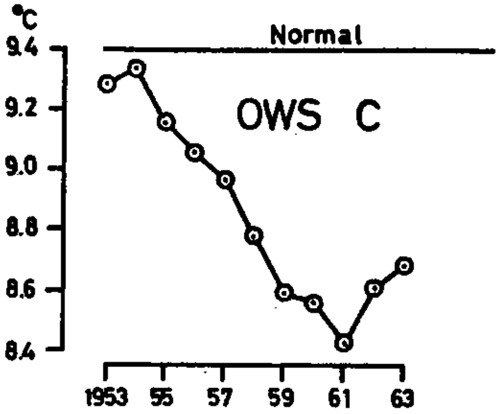

Fig. 8. SST running 5-year means for OWS C (1953 = period 1951-55).

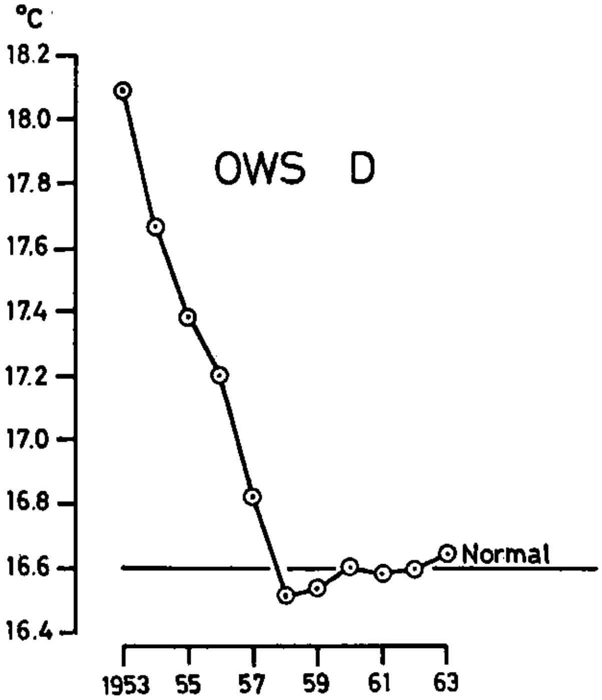

Fig. 9. SST running 5-year means for OWS D (1953 = period 1951-55).

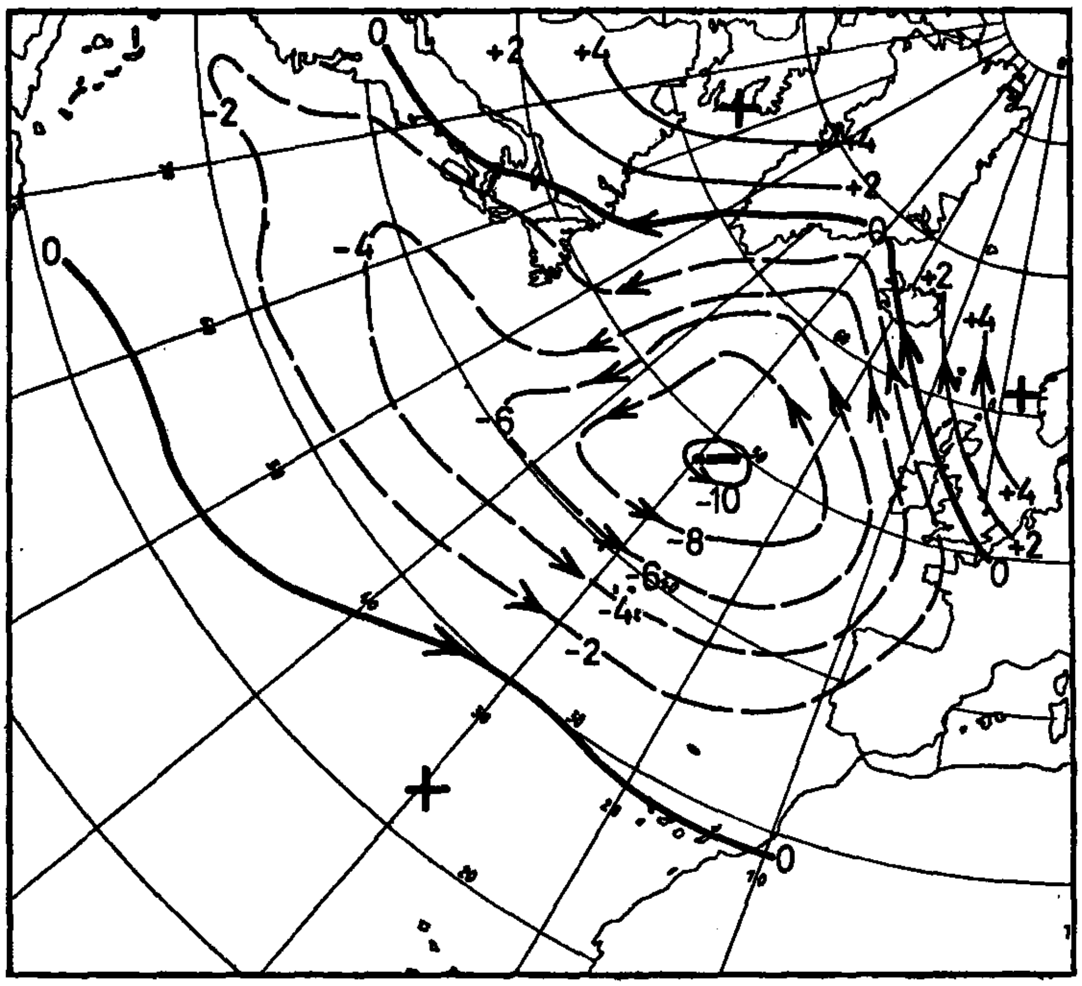

Fig. 10. Mean pressure deviation (mbar) from normal for the month of March during the period 1956-60.

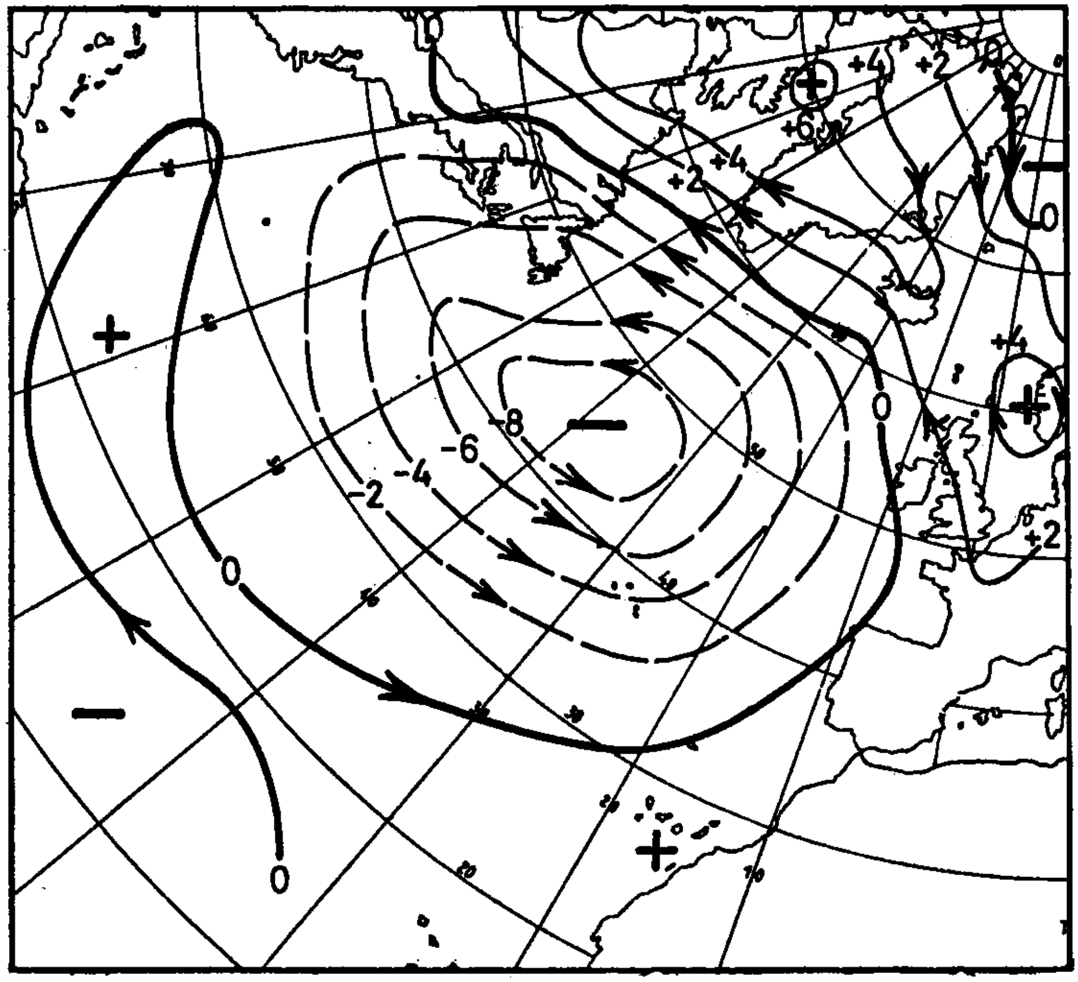

Fig. 11. Mean pressure deviation (mbar) from normal for the month of March during the period 1961-65.

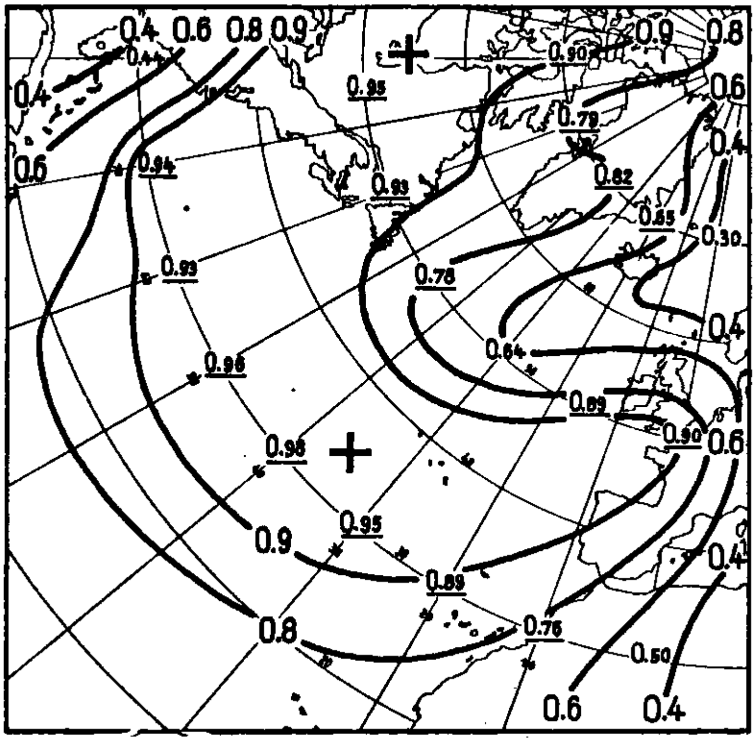

Fig. 12. Correlation between the March pressure anomalies of the periods (1956-60) and (1961-65).

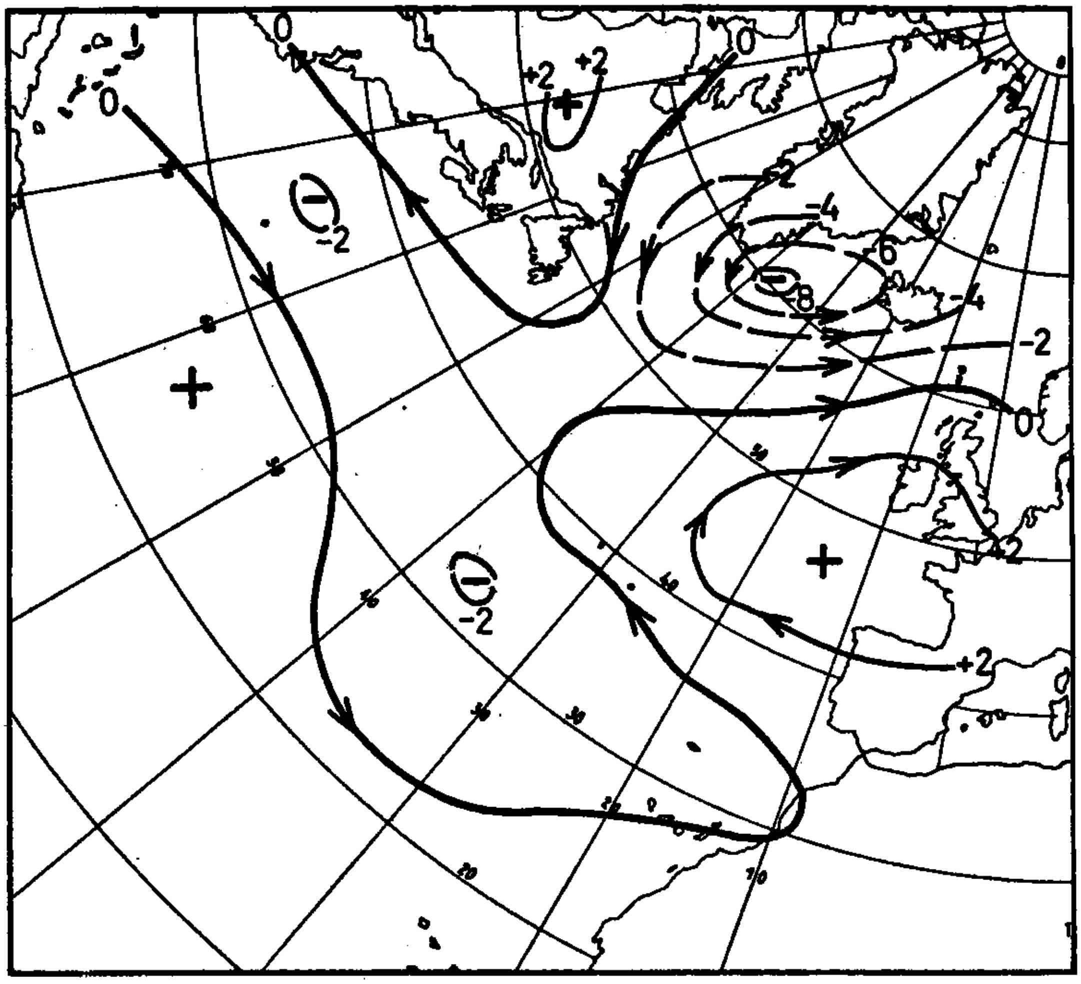

Fig. 13. Mean pressure deviation (mbar) from normal for the month of October during the period 1956-60.

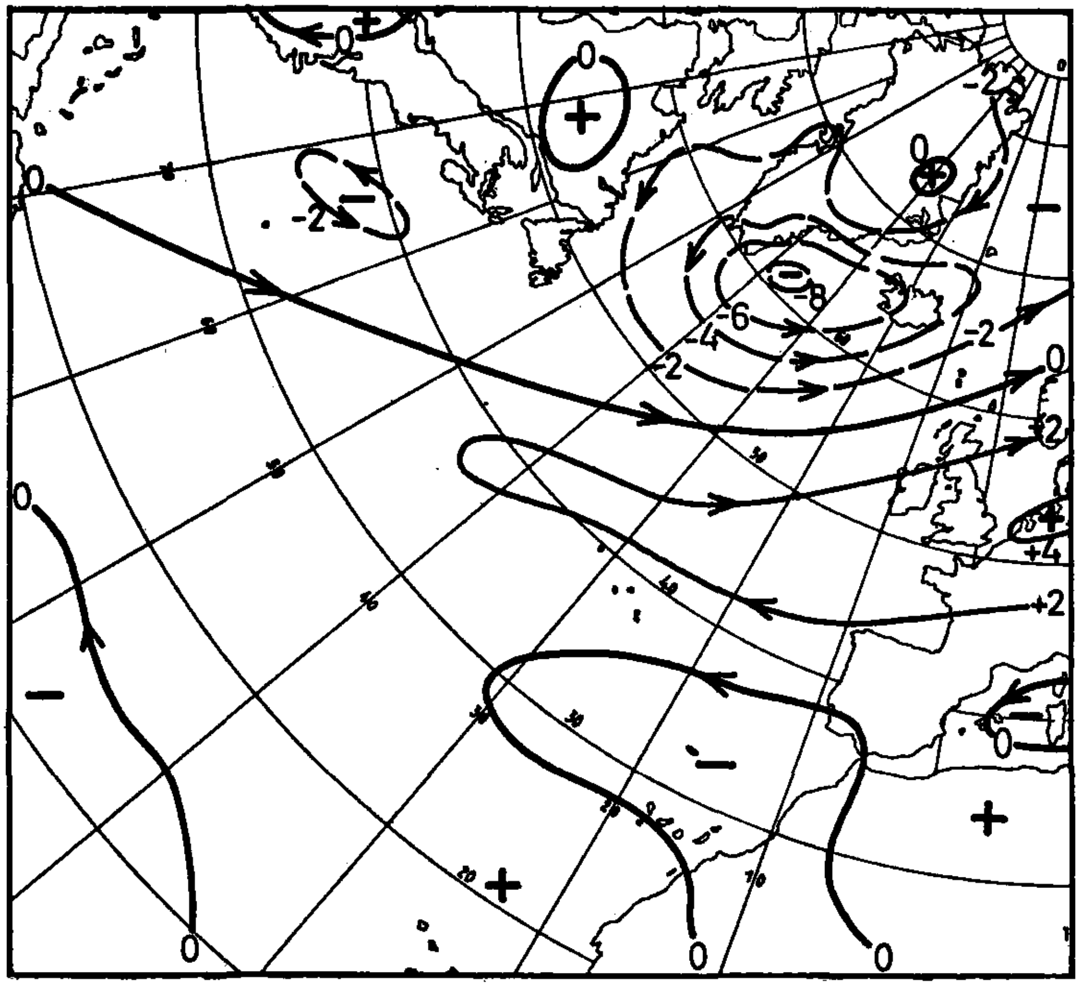

Fig. 14. Mean pressure deviation (mbar) from normal for the month of October during the period 1961-65.

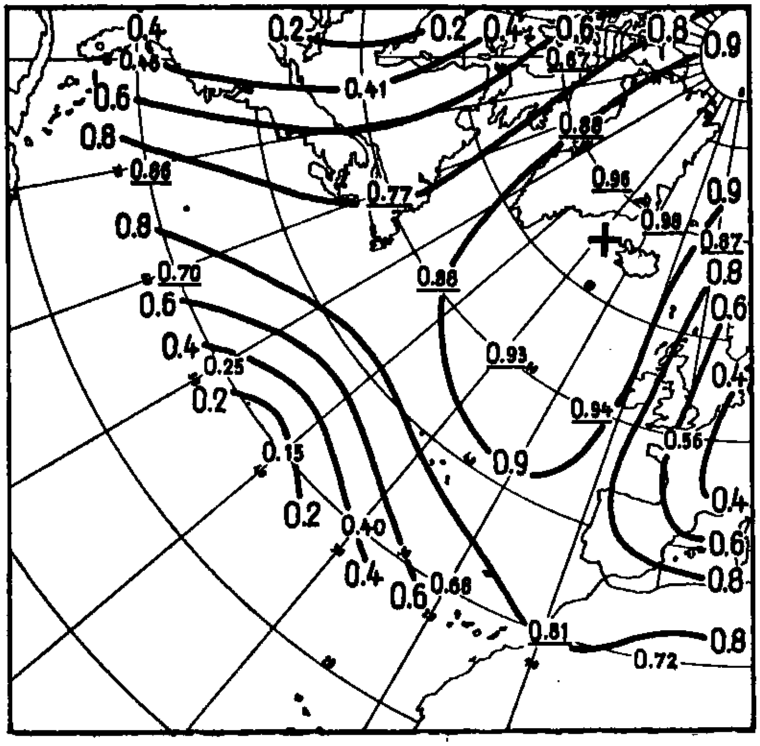

Fig. 15. Correlation between the October pressure anomalies of the periods (1956-60) and (1961-65).

Recent trends in temperature variations in ICNAF Subarea 4[1]

by Louis M. Lauzier
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Introduction

A review of previous studies of fluctuations of marine climate in the Northwest Atlantic was presented at the ICNAF Environmental Symposium in 1964. The long-term temperature variations, for Subarea 4, were based on observations from the 1920's to 1962 (Lauzier, 1965*a*). A subsequent study (Lauzier and Marcotte, 1965) of the marine climate in the southwestern Gulf of St. Lawrence (4T) was also based on observations to 1962. The year 1964 has been reported as "another cold year" (Lauzier, 1965*b*).

In this paper it is intended to emphasize the temperature fluctuations during the past 17 years, 1951-66, in the Subarea 4. This means a necessary overlap from the previous studies (to 1962) to assure continuity and to cover the entire recent cooling period. The cooling period is also given its proper perspective with respect to the previous fluctuations.

Data

Recent data used here have been collected by all agencies in the oceanographic community of eastern Canada. Shore establishments were responsible for some of the monitor stations and the observations at depths were carried out from CSS *Hudson*, CSS *Baffin*, CNAV *Sackville*, CGS *A.T.Cameron*, *Sambro* Light Vessel (LV), *Lurcher* Light Vessel (LV) and M/V *Mallotus*. Location of monitor stations and sections are shown in Fig. 1.

Surface temperature - air temperature

Trends of surface temperature at St. Andrews, New Brunswick are representative of the surface temperature variations over a large segment of the Continental Shelf. The St. Andrews series is represented in Fig. 2 along with longer air temperature series from Sable Island and Halifax, Nova Scotia. The close relationship between the three curves has been discussed previously (Lauzier, 1965*a*). The similarity in the recent cooling trends of the three series is a continuing feature.

Various trends in surface temperature were observed in the south-

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[1] Submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/66

western Gulf of St. Lawrence. As seen in Fig. 3, the temperature trends at Grande Rivière are closely related to those of St. Andrews but the trends around the Magdalen Islands, at Entry Island, indicate a prolonged warming period followed by a short cooling period. Figures 2 and 3 show some of the changes in the marine climate as indicated by temperature fluctuations over the years. The recent cooling period, during the last 15-16 years, will be shown in more detail as observed in bottom temperature variations.

Bottom temperatures

Three sectors in Subarea 4 have been monitored. The bottom temperature series are, to a large extent, discontinuous. The data are shown either as mean seasonal anomalies for layers where seasonal variations are significant or as mean seasonal temperatures for layers not affected by seasonal changes.

In the Bay of Fundy-Gulf of Maine, bottom temperature anomalies, at 90 m, are represented in Fig. 4 and compared with the surface temperature series for St. Andrews. Temperature trends of bottom temperatures at Prince 5 Station and at *Lurcher* LV are very similar to the surface temperature trend at St. Andrews. The temperature range is greater at *Lurcher* and less at St. Andrews than at Prince 5. The short-term variations or year-to-year variations at these three stations are generally related to each other.

It would be premature to say that 1966 is the beginning of a warming or indicate some relaxation from the cooling as it would have been the case of 1961 and 1962. These two years were followed by cold years. The coldest year in the last 22 years was in fact 1965.

On the Central Scotian Shelf and Halifax area, the bottom temperature trends are related to those of the Bay of Fundy-Gulf of Maine area. The year-to-year variations are also generally related to the previous group but the range of temperature is greater mainly on Emerald Bank (Fig. 5). The bottom temperature anomalies on Emerald Bank are more variable than at *Sambro*, *Lurcher* or Prince 5 Station. Such variability has the disadvantage of either masking the general temperature trend or decreasing the significance of the trend. Greater variability of bottom temperature is observed as we approach the edge of the Continental Shelf. At *Sambro* LV and at *Lurcher* LV, the rate of cooling is of the same order of magnitude, 0.20°C per year and 0.21°C per year respectively. On Emerald Bank, however, the cooling appears to be accentuated with 0.25°C per year.

Quarterly averages of the maximum temperatures within warm deep layers are represented in Fig. 6. These layers are not subjected to seasonal variations. In Emerald Basin (formerly known as Scotian Gulf) the range of temperature variation is nearly equal to the range of temperature anomalies at *Sambro* LV and *Lurcher* LV. In Cabot Strait, the maximum temperature variations at the core of the warm deep layer indicate a definite cooling starting only in the late 1950's, as compared to early 1950's for other bottom temperature series. Observations in Cabot Strait are less frequent than at other stations and the range of temperature variations appears to be half of the range in Emerald Basin.

Discussion

The cooling trend experienced in Subarea 4, from the early 1950's, is still continuing in the middle 1960's. The average rate of cooling during the last 15 or 16 years is of the order of 0.19°C per year. The St. Andrews surface temperature variations are representative of bottom temperature variation over a large segment of the Scotian Shelf.

At the time of the previous warming period, for most of the 1930's and 1940's, the temperature increase was greatest during the winter months. Now, for the recent cooling period, the temperature decrease is greatest during the summer and autumn months in the Bay of Fundy area, St. Andrews and *Lurcher* LV, and during the winter months in Halifax area, *Sambro* LV.

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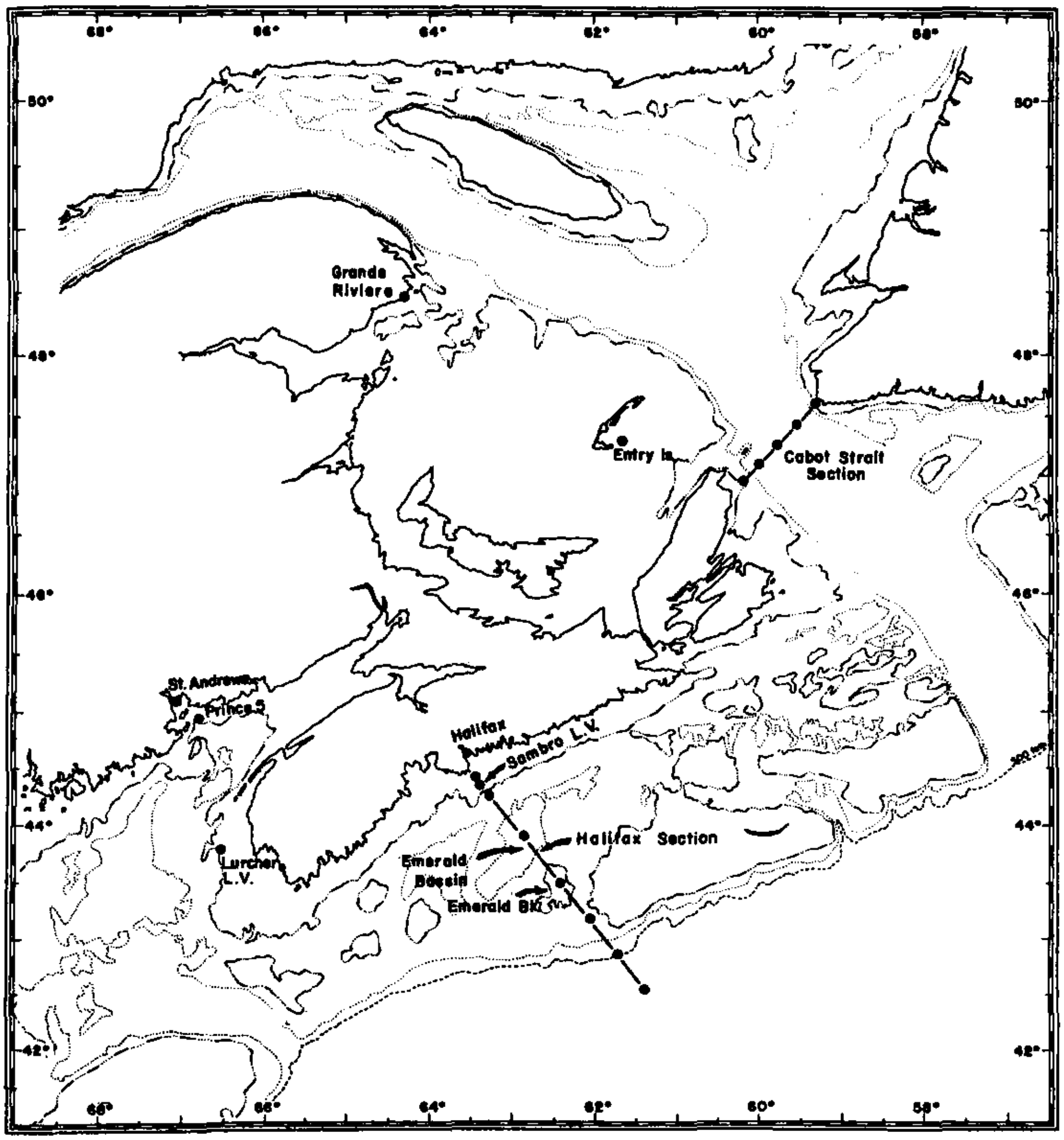

Fig. 1. Location of stations and sections.

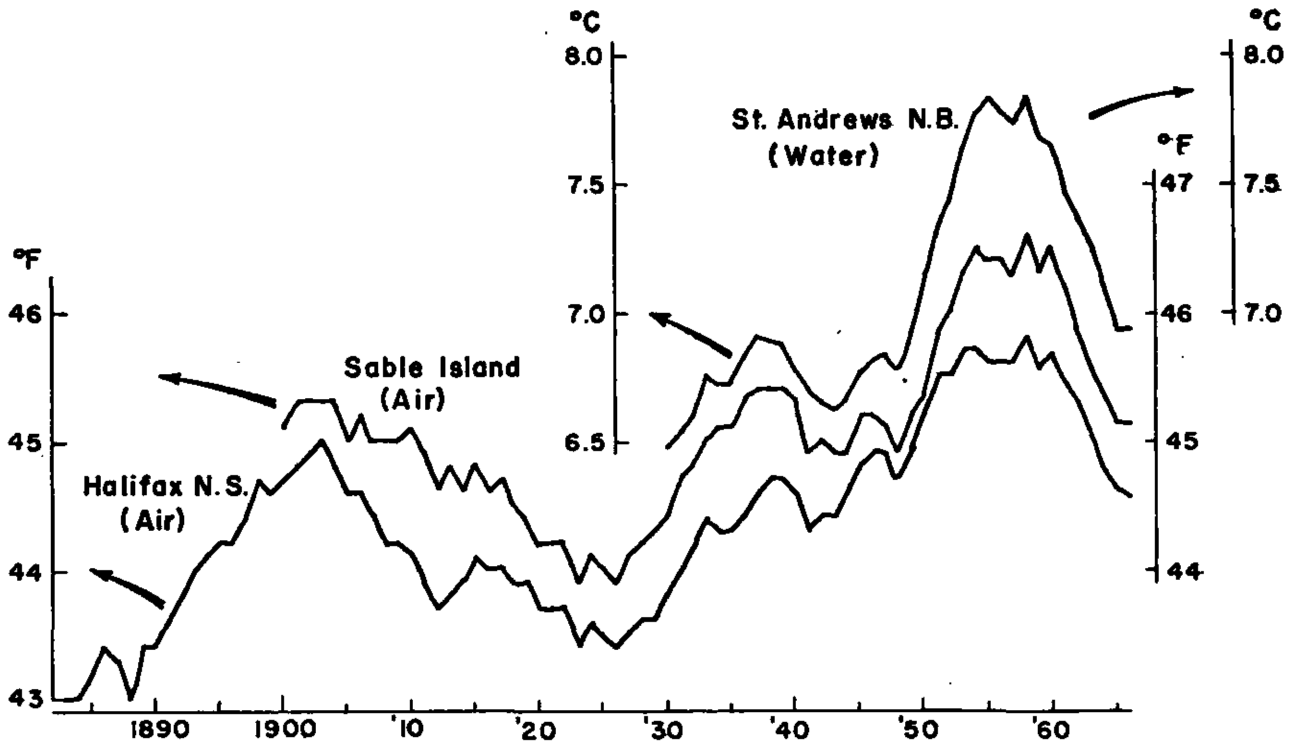

Fig. 2. Surface water temperatures at St. Andrews, N.B. Air temperatures at Sable Island and Halifax, N.S. Ten-year moving averages of annual means credited to the last year of the period.

Fig. 3. Surface water temperatures (May-August) at Entry Island, St. Andrews and Grande-Rivière. Ten-year moving averages credited to the last year of the period.

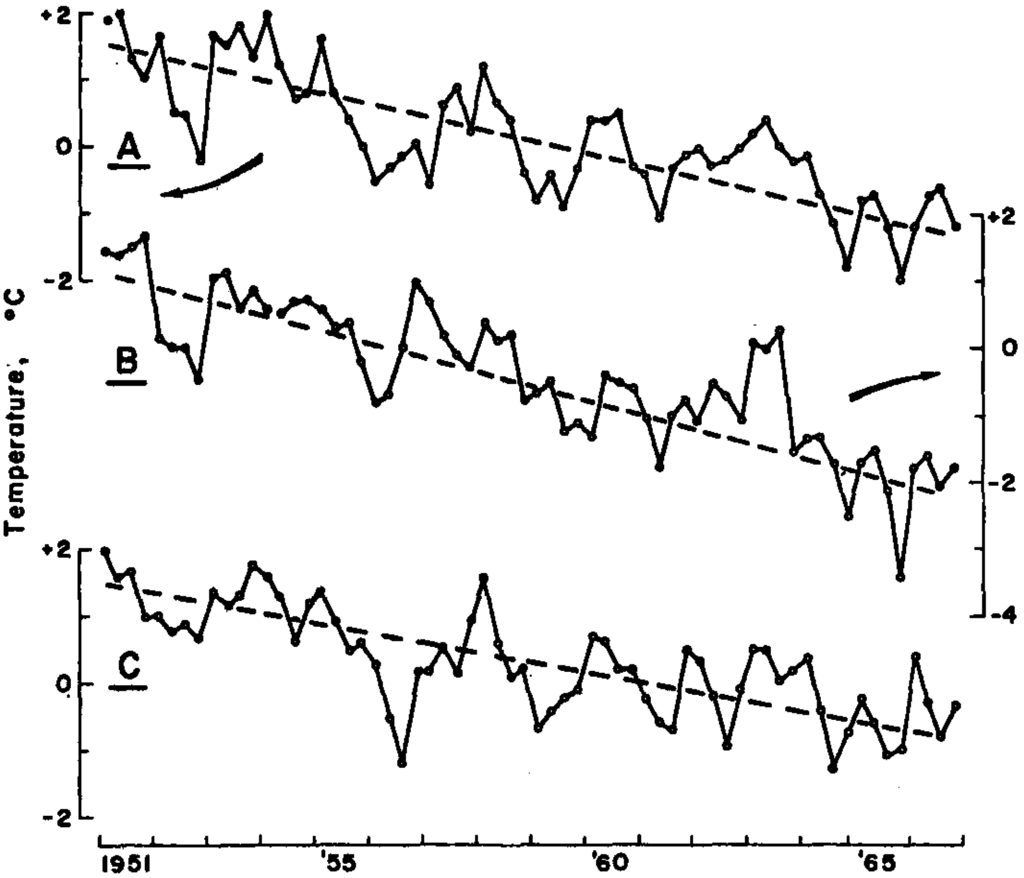

Fig. 4. Quarterly deviations of the water temperatures: (A) Prince 5 Station, bottom temperatures, average 1924-1960; (B) *Lurcher* LV, bottom temperatures, average 1950-1959; (C) St. Andrews, surface temperatures, average 1921-1960. The dashed lines represent temperature trends.

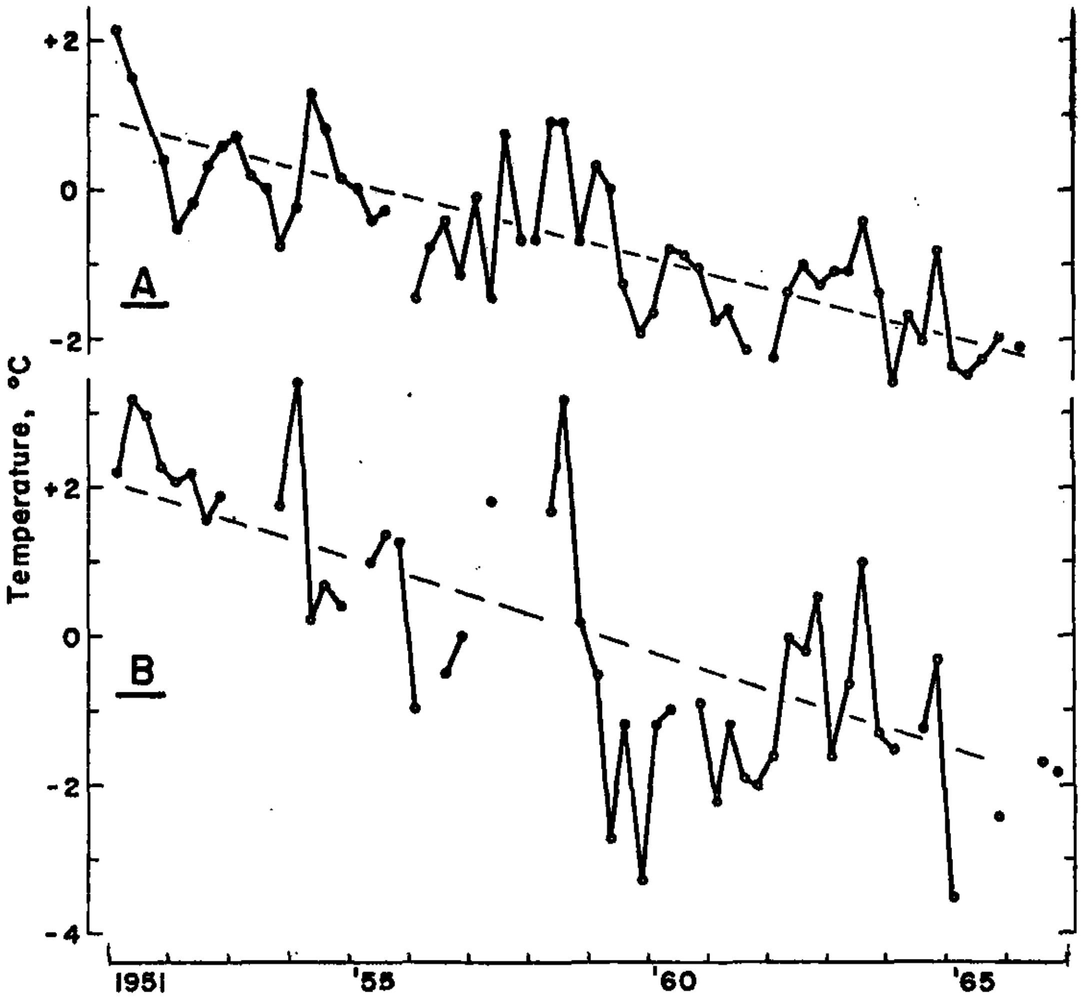

Fig. 5. Quarterly deviations of water temperatures: (A) *Sambro* LV, bottom temperatures, average 1949-1959; (B) Emerald Bank, bottom temperatures, average 1950-1964. The dashed lines represent temperature trends.

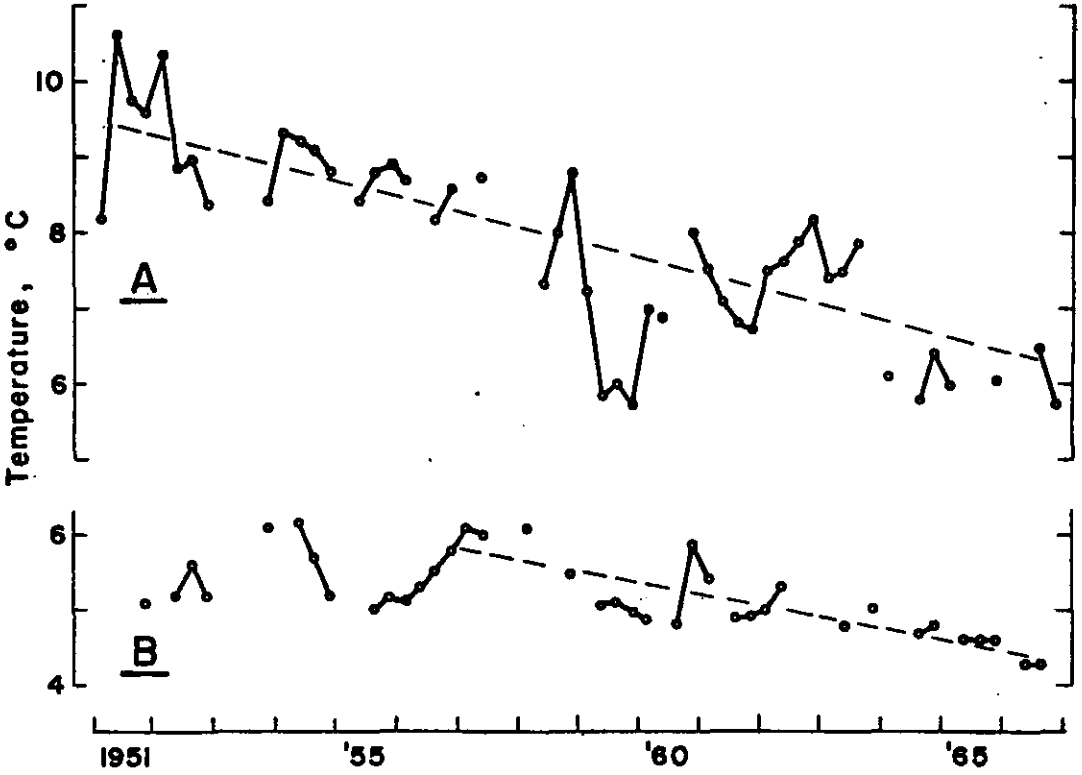

Fig. 6. Quarterly averages of water temperatures: (A) Maximum temperature within bottom layer of Emerald Basin; (B) Maximum temperature at the core of warm deep layer in Cabot Strait. Dashed lines represent temperature trends.

Trends of mean monthly sea water temperatures, 1950-1966, at Boothbay Harbor, Maine[1]

by Walter R. Welch
US Bureau of Commercial Fisheries
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A marked change in the trend of surface sea water temperature has taken place along the Maine coast. The warming trend in progress during the early 1950's reached its peak in 1953 and since then the temperature has shown a general decline. The changes have been documented by the US Bureau of Commercial Fisheries Biological Laboratory at Boothbay Harbor, Maine. The temperature records, beginning in 1905, were obtained several times daily by bucket and thermometer, and since 1950 have been tabulated as hourly readings from a continuously recording thermograph with its bulb fixed at 5.5 ft below mean low water.

Monthly and annual means and deviations of means are used here to demonstrate changes. A base period, 1950-59, was first selected. This 10-year period cannot be regarded as a normal period since it includes the highest temperatures of a warming trend; but precedence has been set for its use in comparing oceanographic data.

Ten-year means for each month of the base period were determined from individual monthly means (Table 1). The deviation of each monthly mean from the corresponding monthly mean of the base period was calculated and used to construct Fig. 1A. The annual mean for the base period was likewise determined and the deviation of each annual mean from the annual mean of the base period was used to plot the solid line in Fig. 1B, each point of which is at the midpoint of the year. The temperatures for the three warmest months of the years of the base period were averaged to obtain a base period mean. Then the deviation of the mean for the warm period of each year from the base period mean was used to plot the broken line in Fig. 1B, each point of which is at the midpoint of the 3-month warm period. The deviations of the 3-month cold periods of each year were obtained in the same way and plotted as the short-dashed line in Fig. 1B.

Deviations of monthly means (Fig. 1A) show the end of the warming trend in 1953 and the subsequent cooling trend. This figure also shows that the month-to-month deviations have been more erratic since the temporary check in the downward trend occurred between 1959 and 1963. The deviations of annual means (Fig. 1B) illustrate the same trends. Their comparisons with the

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[1] submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/37

deviations of the warm and cold periods of each year are made to show that, while both summer and winter temperatures have followed the same downward trend as the annual means, greater decreases have taken place during the winters. This figure also shows that the deviations of the cold periods have become more extreme since the temporary check in the downward trend. Other investigators have noted that the greatest increases in both air and water temperatures during the upward trend also occurred during the colder part of the year.

Environmental changes, particularly trends such as those discussed here, are well recognized as being vitally important to ecosystems. The Boothbay Harbor Laboratory will continue its program of recording environmental variables and analyses of such changes and trends.

Table 1. Mean sea water temperatures, Boothbay Harbor, Maine, °C.

	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	Base Period Mean 1950-59
Jan.	5.1	6.1	5.2	4.7	4.2	5.5	3.4	3.7	4.3	2.2	3.9	3.3	3.3	2.8	3.3	1.3	3.0	4.4
Feb.	3.0	4.1	4.2	5.5	3.5	3.5	3.2	3.8	2.8	1.9	2.2	1.7	0.6	2.4	2.8	0.1	1.6	3.6
March	3.4	4.7	4.2	6.1	5.0	4.2	3.2	4.1	3.0	1.7	2.2	2.5	1.8	3.5	2.5	1.9	1.8	4.0
April	4.3	7.0	6.4	7.5	7.0	6.8	5.3	6.3	5.4	5.1	4.3	5.1	5.0	5.2	4.8	4.4	4.2	6.1
May	8.7	10.7	9.8	11.2	10.2	10.4	8.2	10.2	8.8	8.2	10.0	7.9	7.8	9.3	9.0	9.3	7.4	9.6
June	13.2	14.3	13.5	14.3	13.9	13.6	12.3	14.4	11.3	11.4	13.0	12.8	12.4	13.3	11.8	11.7	11.9	13.2
July	17.1	17.3	17.2	17.2	15.9	16.8	14.8	15.2	14.1	15.0	14.7	15.0	14.2	15.8	15.3	14.5	13.7	16.1
August	17.1	17.6	17.0	17.1	15.4	17.0	16.0	15.2	15.0	15.5	15.9	15.4	15.9	15.4	14.7	15.0	14.6	16.3
Sept.	13.6	16.6	15.9	16.1	14.8	15.0	14.6	14.2	13.4	14.4	13.8	15.4	14.0	13.7	13.4	13.0	12.7	14.9
Oct.	12.3	12.8	12.4	13.0	13.2	12.7	11.8	10.5	10.4	11.0	10.7	10.6	11.1	11.5	10.6	9.1	8.8	12.0
Nov.	10.3	10.6	8.3	10.7	10.4	10.0	10.0	8.6	8.5	8.1	9.2	8.0	8.2	9.0	7.6	6.4	6.6	9.6
Dec.	7.7	8.0	6.5	9.1	8.1	4.9	7.1	6.0	4.9	5.5	5.6	5.1	5.3	4.8	3.7	4.5	4.8	6.8
Annual Mean	9.6	10.8	10.1	11.1	10.2	10.0	9.2	9.4	8.5	8.3	8.9	8.5	8.1	8.8	8.3	7.7	7.6	9.7
Mean for 3 warm months	15.9	17.2	16.7	16.8	15.4	16.3	15.1	14.9	14.2	15.0	14.8	15.3	14.7	15.0	14.5	14.2	13.7	15.8
Mean for 3 cold months	3.6	5.0	4.5	5.4	4.2	4.4	3.3	3.9	3.4	1.9	2.8	2.5	1.9	2.9	2.9	1.1	2.1	4.0

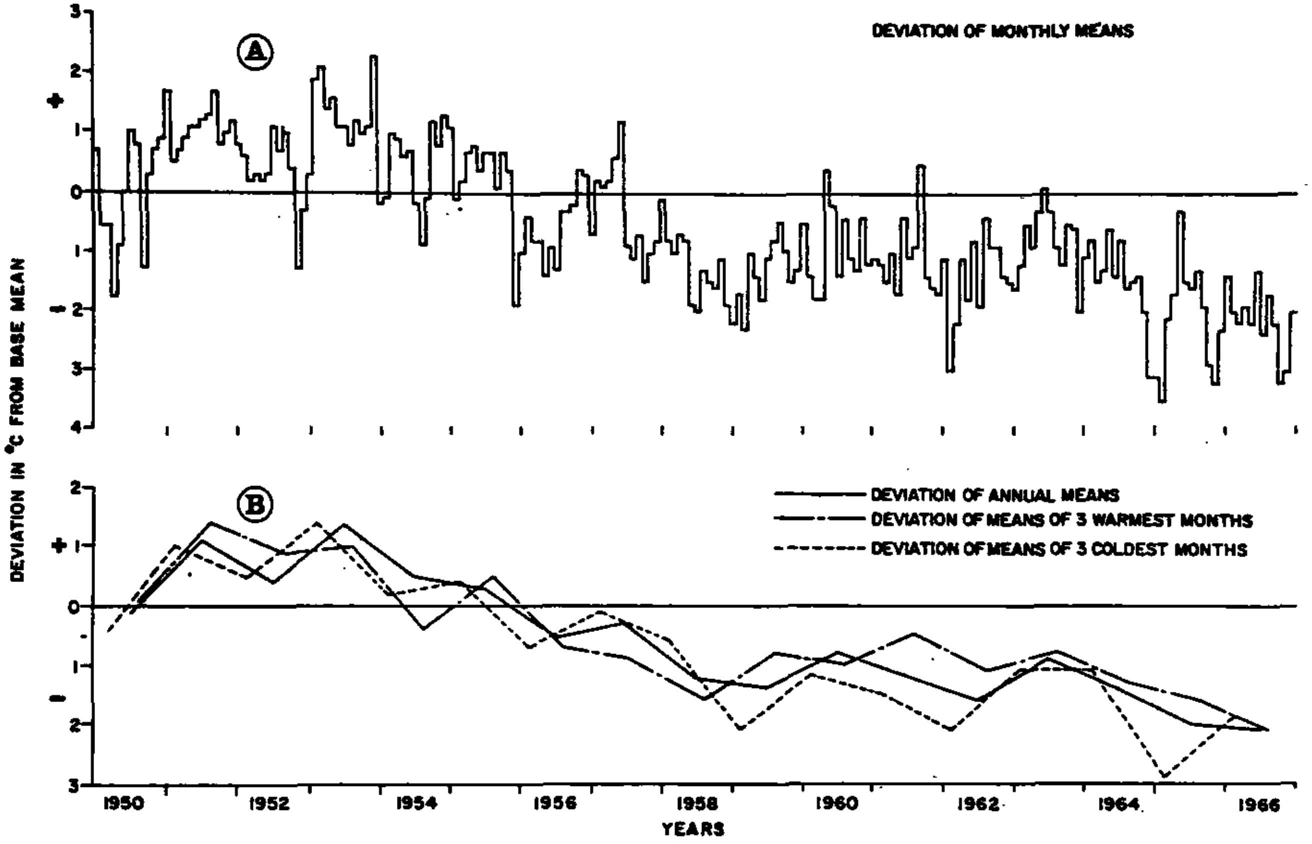

Fig. 1. Deviations in surface water temperature from base mean, Boothbay Harbor, Maine, 1950-1966.

Recent trends of temperature along the New England coast[1]

by Joseph Chase
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In a study (Bumpus and Chase, 1965) of observations made through 1963, it was found that air and water temperatures along the New England coast had undergone similar fluctuations. There were maxima in about 1931 and 1952 and the general trend for the first half of this century was upward. It had previously been pointed out by Taylor, Bigelow and Graham (1957) that most of the long period rise had taken place in the winter months although some of the short period oscillations were apparent in the summer data as well.

The curves (Bumpus and Chase, 1965) of 5-year means of air temperatures at Boston, Massachusetts and New Haven, Connecticut, combined, and of water temperatures for February, August, and the year at Boothbay Harbor, Maine have been extended with the inclusion of data for 1964, 1965, and 1966 (Fig. 1 and 2). The continued downward trend prevailing since the high levels of about 1952 is apparent in each curve although the rate of descent has slowed down in some cases. The descent of summer temperatures since 1950-53 to the present has been small.

The recent Boston and New Haven winter air temperature means are comparable with those of the previous minima of about 1946 and 1918. The recent Boothbay Harbor means for August are about equal to those of the minimum of about 1941 which were the lowest on record. The recent annual and February means have not yet reached the levels of previous minima.

Various series of temperature observations have been made at Portland (Maine) Lightship, Boston (Massachusetts) Lightship, and Nantucket Shoals (Massachusetts) Lightship. The most recent series, begun in late 1955, is part of a program of bathythermograph observations made by the US Coast Guard in cooperation with the Woods Hole Oceanographic Institution and the US Fish and Wildlife Service.

Surface temperature data from this series are presented in Tables 1-3 with averages from previous series sorted according to small changes in lightship location or to length of series. Table 4 contains surface data from the Woods Hole (Massachusetts) Oceanographic Institution. These data show good agreement with the trends at Boston, New Haven, and Boothbay Harbor in respect to the general warming during the first half of this century and the recent cooling. This recent surface cooling is apparently less prominent in

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[1] submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/68
Contribution No. 2008, Woods Hole Oceanographic Institution

the summer months but the short record of bottom temperatures from the same program shows cooling in all seasons.

Thus, the temperatures of New England have had similar trends to those of the surface water in St. Andrews, New Brunswick (Lauzier, 1965) and in various areas in the North Atlantic (Beverton and Lee, 1965, and Mitchell, 1963). They are apparently compatible with the progression of temperature trends across the North Atlantic from St. Andrews to Europe reported to have been noted recently by Rodewald (Costlow, 1967).

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Table 1. Sea Surface Temperature at Portland (Maine) Lightship.
°C

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	A
1925-41	2.9	1.6	1.6	3.1	7.0	11.5	14.3	14.9	13.6	10.2	9.3	4.9	7.9
1947-56	4.5	3.3	3.1	4.7	7.7	11.3	15.4	16.1	13.9	12.3	8.8	6.6	9.0
1956	3.4	3.8	2.3	3.8	6.8	10.4	15.1	14.7	13.7	11.3	9.3	6.6	8.4
1959	-	3.6	3.2	4.4	8.5	12.4	16.8	16.8	14.8	10.6	8.3	5.2	-
1958	4.4	3.7	3.9	6.4	8.0	10.2	15.2	15.3	13.6	(11.4)	8.7	5.9	(8.9)
1959	4.3	3.2	2.8	5.1	8.3	9.8	14.2	14.9	13.2	-	-	6.4	-
1960	4.3	(3.1)	2.8	4.6	9.3	13.2	14.7	15.7	(13.7)	12.1	9.0	6.4	(9.1)
1961	3.3	2.2	2.6	3.4	6.3	10.6	14.0	15.6	14.0	11.4	8.9	6.5	8.2
1962	4.6	3.4	2.4	4.6	7.4	12.4	13.8	15.3	13.7	10.7	6.8	5.0	8.3
1963	3.2	3.0	3.2	5.2	-	12.4	15.7	15.5	13.2	12.0	8.8	5.0	-
1964	3.5	3.1	2.4	4.2	7.7	11.1	15.5	13.7	12.4	9.6	7.8	5.4	8.0
1965	2.8	0.4	1.8	4.0	8.4	11.0	14.6	14.4	13.0	9.7	6.7	4.1	7.6
1966	3.4	2.5	2.1	4.8	7.1	11.9	15.1	15.3	14.0	10.5	7.4	4.9	8.3

Table 2. Sea Surface Temperature at Boston (Mass.) Lightship.
°C

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	A
1925-41	3.5	2.1	2.1	4.1	8.1	13.3	15.6	16.8	15.8	12.2	8.8	5.9	9.0
1956	3.3	2.5	2.5	4.3	7.1	12.6	16.1	17.9	14.8	12.3	10.1	6.9	9.2
1957	4.2	2.3	3.4	5.3	9.6	15.3	17.6	17.9	15.3	12.1	10.1	5.1	10.0
1958	5.0	2.6	-	5.9	9.4	11.6	14.8	14.7	13.6	12.0	8.9	6.4	-
1959	3.6	2.3	2.5	5.3	9.6	13.3	15.4	18.0	17.7	13.5	9.8	7.1	9.8
1960	4.4	3.6	2.7	5.2	10.8	14.7	14.7	17.5	16.5	12.2	9.6	6.6	9,8
1961	3.3	3.2	2.9	4.4	8.2	12.4	16.2	17.0	17.2	13.4	9.9	7.1	9.6
1962	4.2	2.8	2.6	5.5	8.8	13.8	-	15.9	15.9	12.3	9.1	6.7	-
1963	3.9	2.5	2.4	5.0	8.7	13.6	18.1	16.7	14.4	12.8	-	6.7	-
1964	-	2.5	2.8	4.6	9.6	12.6	16.7	15.8	16.1	10.8	8.8	5.4	-
1965	-	1.1	1.8	3.3	9.9	14.1	14.9	15.5	13.6	10.4	7.6	5.5	-
1966	3.6	1.8	2.4	4.9	7.6	13.5	16.0	15.4	16.0	10.6	-	-	-

Table 3. Sea Surface Temperature at Nantucket (Mass.) Lightship.
°C

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	A
1896-1912	4.3	2.9	3.3	4.5	6.9	10.6	14.2	17.1	15.8	13.7	10.4	6.6	9.2
1923-41	5.1	3.6	3.3	4.6	7.0	10.9	14.3	17.1	16.0	13.2	11.0	9.4	9.4
1947-52	6.3	5.3	5.0	6.6	8.1	12.7	16.3	18.8	17.7	15.2	12.0	9.4	11.1
1953-55	5.6	5.7	4.7	6.2	8.4	11.3	14.9	14.9	15.2	12.4	10.8	-	-
1956	5.4	4.7	3.8	4.7	7.5	11.3	14.4	15.8	18.4	15.7	12.8	-	-
1957	-	4.4	5.2	-	-	-	-	-	-	14.8	-	-	-
1958	-	4.3	-	5.6	7.6	-	-	17.2	-	-	-	-	-
1959	3.7	3.4	3.3	4.2	6.6	9.2	12.1	12.6	13.6	11.3	8.8	5.7	7.9
1960	(5.9)	(5.2)	3.6	4.9	7.2	9.8	13.2	17.6	16.7	14.2	11.1	8.1	(9.8)
1961	4.6	3.4	4.2	5.1	6.6	10.4	16.3	17.1	19.1	15.8	10.9	7.8	10.1
1962	5.5	-	4.4	6.4	-	-	-	16.6	14.6	12.9	-	5.8	-
1963	-	(3.9)	4.0	5.8	9.0	11.9	15.1	16.4	15.5	13.3	11.0	-	-
1964	5.2	4.0	4.3	4.8	7.8	9.5	13.6	16.0	15.1	12.3	10.4	7.0	9.2
1965	-	3.6	3.6	3.8	6.3	9.7	15.6	17.8	15.0	12.8	10.1	7.5	-
1966	4.9	2.8	3.5	4.7	6.7	11.6	16.8	17.7	16.5	13.1	10.3	8.6	9.8

Table 4. Sea Surface Temperature at Woods Hole, Mass.
°C

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	A
1880-1956	1.1	0.2	1.8	6.1	11.4	16.7	20.6	21.3	19.4	14.9	9.7	4.3	10.6
1927-50	1.4	0.3	1.9	6.3	11.4	16.4	20.8	21.3	19.3	14.9	9.9	4.3	10.7
1951-56	2.0	1.4	3.4	7.0	11.8	17.2	21.3	21.8	19.9	15.7	10.6	5.4	11.4
1956	0.2	1.0	1.8	5.3	9.9	16.1	20.0	21.2	19.2	14.8	10.9	6.6	10.6
1957	0.7	1.3	3.4	7.1	12.9	18.7	22.2	21.8	20.5	15.4	11.2	6.3	11.8
1958	2.8	0.0	2.2	6.7	11.0	15.8	19.6	21.1	18.9	14.3	10.1	2.5	10.4
1959	-0.4	-0.4	1.9	6.2	11.7	16.6	20.4	21.6	20.9	16.6	10.3	5.7	10.9
1960	+1.4	+1.5	1.0	5.4	11.9	17.4	21.1	21.3	19.4	15.4	10.6	4.0	10.9
1961	+0.3	-1.0	2.1	5.6	10.7	16.4	19.6	21.4	21.0	16.2	10.5	4.9	10.7
1962	1.6	+0.1	2.2	7.9	12.1	17.8	20.1	21.0	18.9	15.1	9.0	4.2	10.8
1963	0.0	-1.0	1.6	6.6	11.7	17.2	20.8	21.5	17.9	15.0	11.1	4.5	10.6
1964	0.5	+0.2	2.8	6.2	12.4	16.9	20.7	20.4	19.3	14.4	10.6	4.9	10.8
1965	0.9	-1.2	1.8	5.0	11.6	16.6	20.3	21.9	18.8	14.3	9.2	5.0	10.4
1966	1.2	-0.1	2.9	6.3	10.5	16.5	21.1	21.2	19.2	14.7	10.7	5.6	10.8

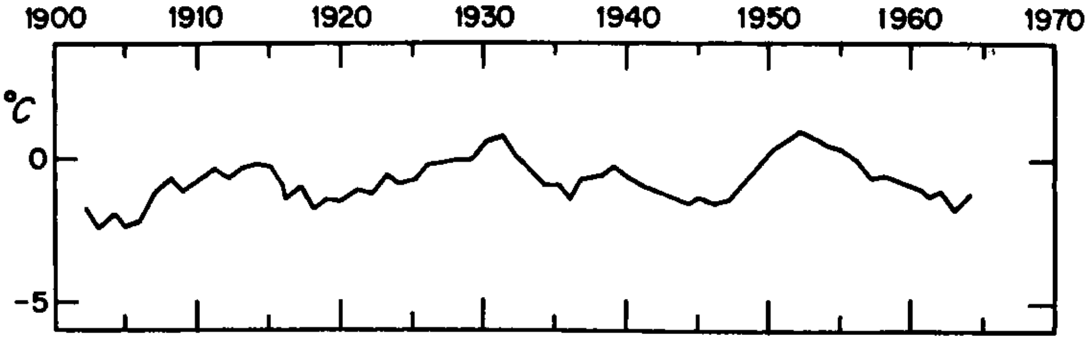

Fig. 1. 5-yr means of winter (Dec, Jan, Feb) air temperature at Boston, Massachusetts and New Haven, Connecticut, combined.

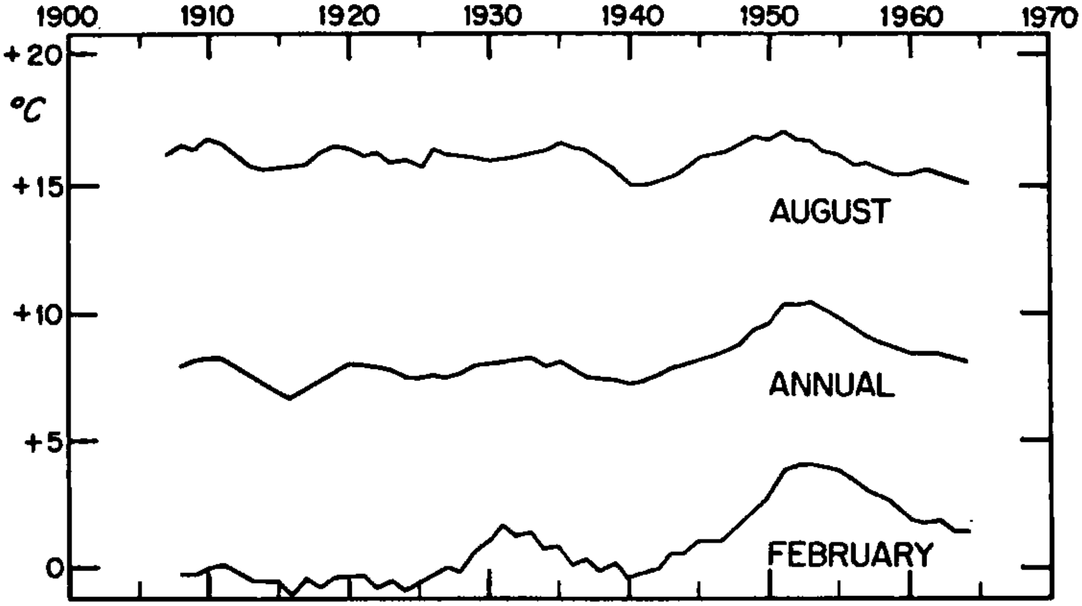

Fig. 2. 5-yr means of water temperature at Boothbay Harbor, Maine for August, the year, and February.

A comparison of current and long-term temperatures of Continental Shelf waters, Nova Scotia to Long Island[1]

by John B. Colton, Jr.
US Bureau of Commercial Fisheries
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Abstract

Offshore temperatures during December 1964 and 1965, March 1953, 1965 and 1966, May-June and September 1965 and 1966 are compared to 1940-59 mean values for these months. Although long-term mean temperatures were used to interpret conditions in a region characterized by short-term temperature fluctuations, the method does appear to provide a semblance of the major temperature conditions to which specific cruise data may be compared. During all seasons and at most locations and depths the 1964-66 temperatures were appreciably colder that the 1940-59 mean values (Fig. 1-4). The magnitude of the negative anomalies was greatest in areas off the edge of the Continental Shelf. Temperatures in March 1953 were warmer than the 1940-59 mean values (Fig. 5). The nature of the distribution of temperature and of negative anomalies suggest that the temperature trends observed are due in large measure to the relative position and degree of mixing of coastal and oceanic water masses. The trend in offshore temperatures at the surface and within water masses paralleled trends in surface temperatures at Boothbay Harbor, Maine. These correlations substantiate the use of inshore temperature observations in indexing offshore conditions.

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[1] Submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/70 published *in extenso* in ICNAF Research Bulletin No.5, 1968

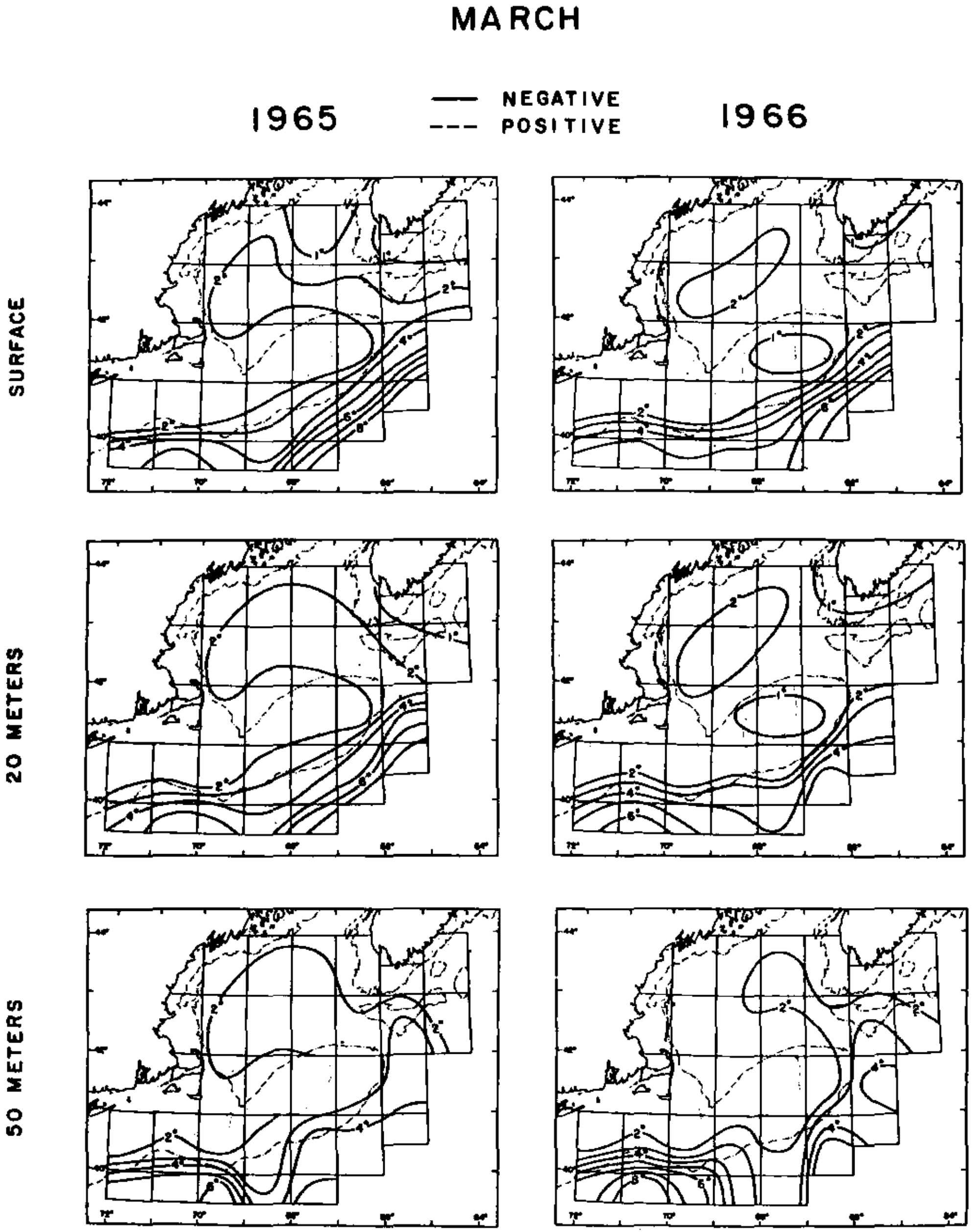

Fig. 1. Temperature anomalies at the surface, 20 m, and 50 m, March 1965 and 1966.

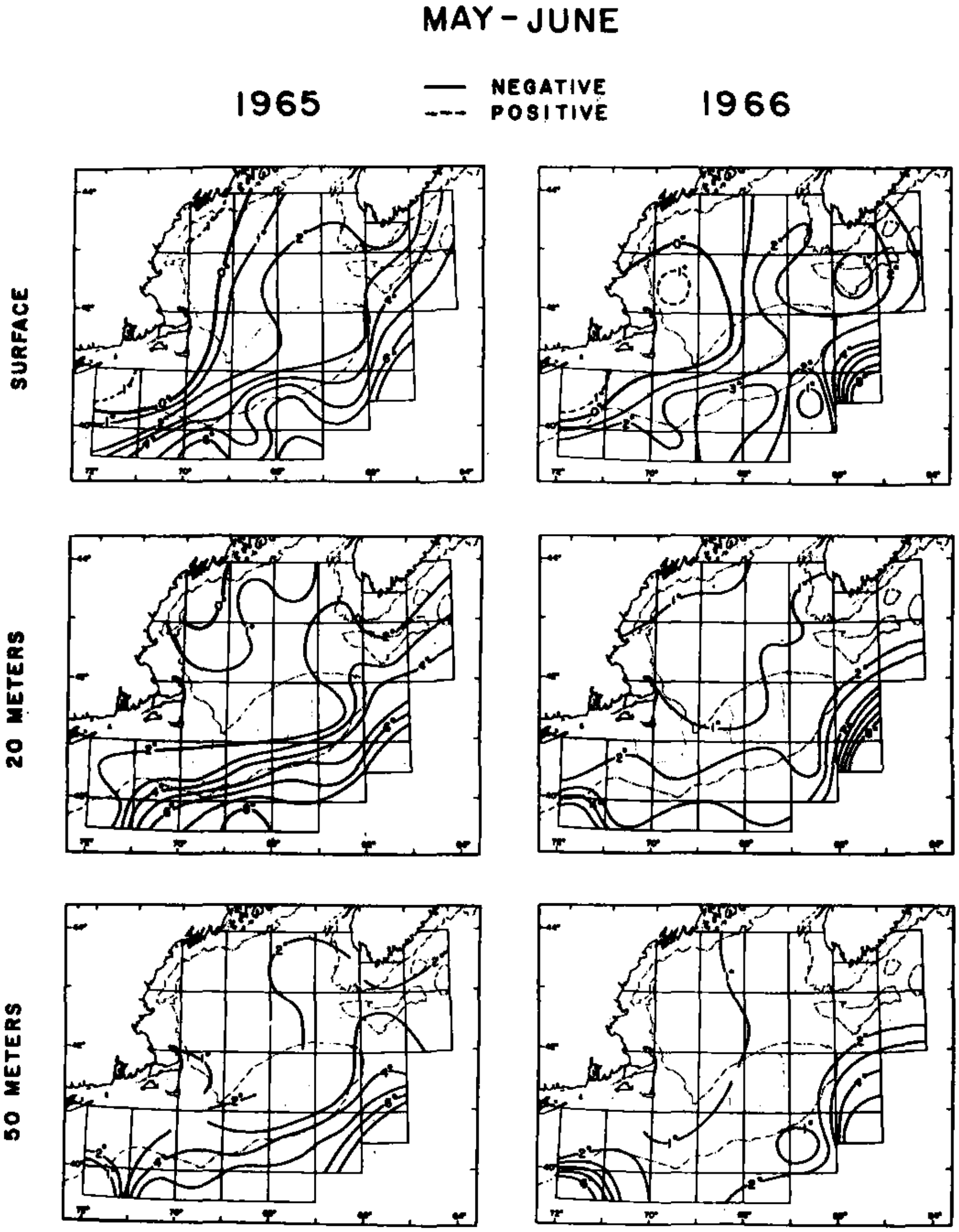

Fig. 2. Temperature anomalies at the surface, 20 m and 50 m, May-June 1965 and 1966.

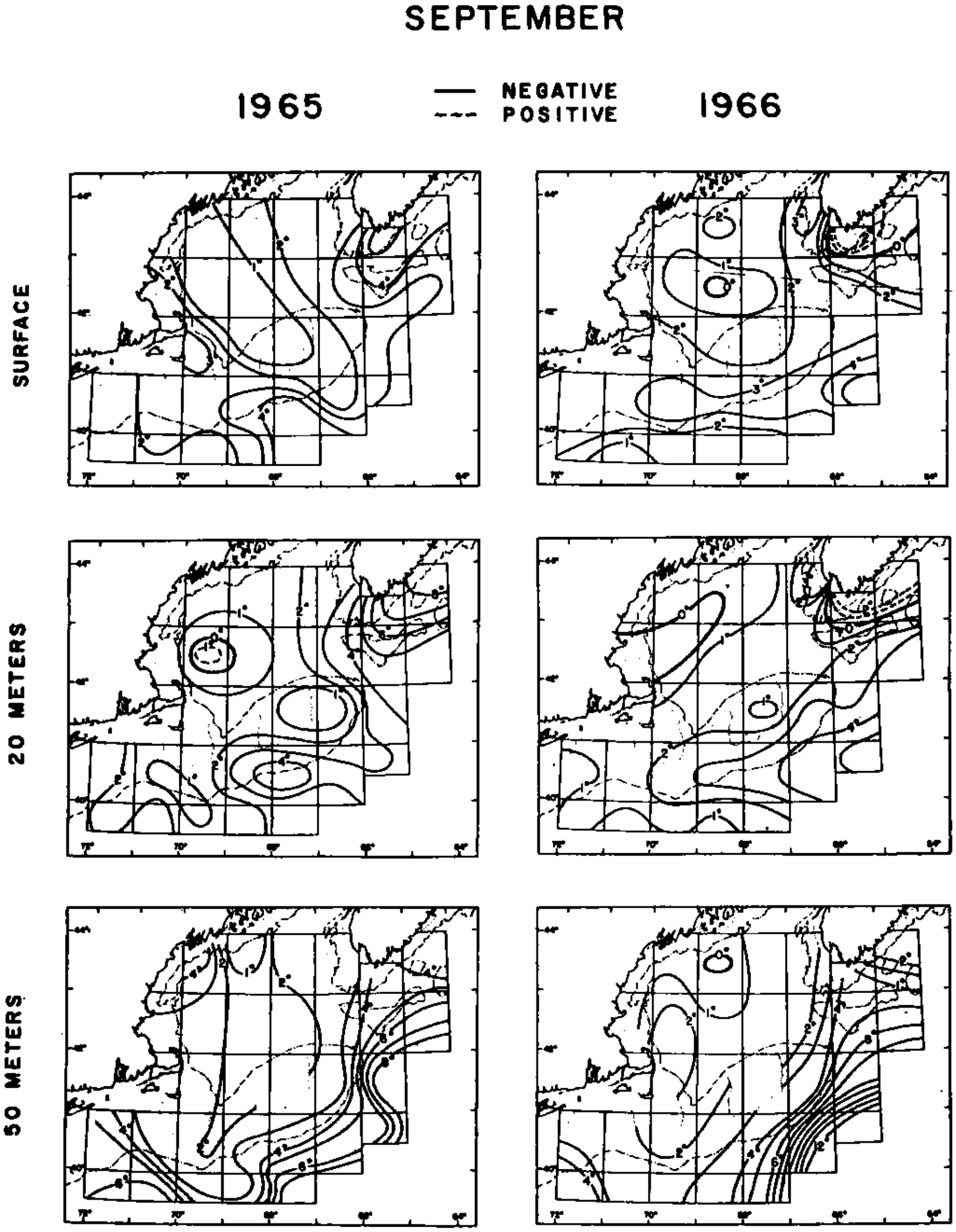

Fig. 3. Temperature anomalies at the surface, 20 m and 50 m, September 1965 and 1966.

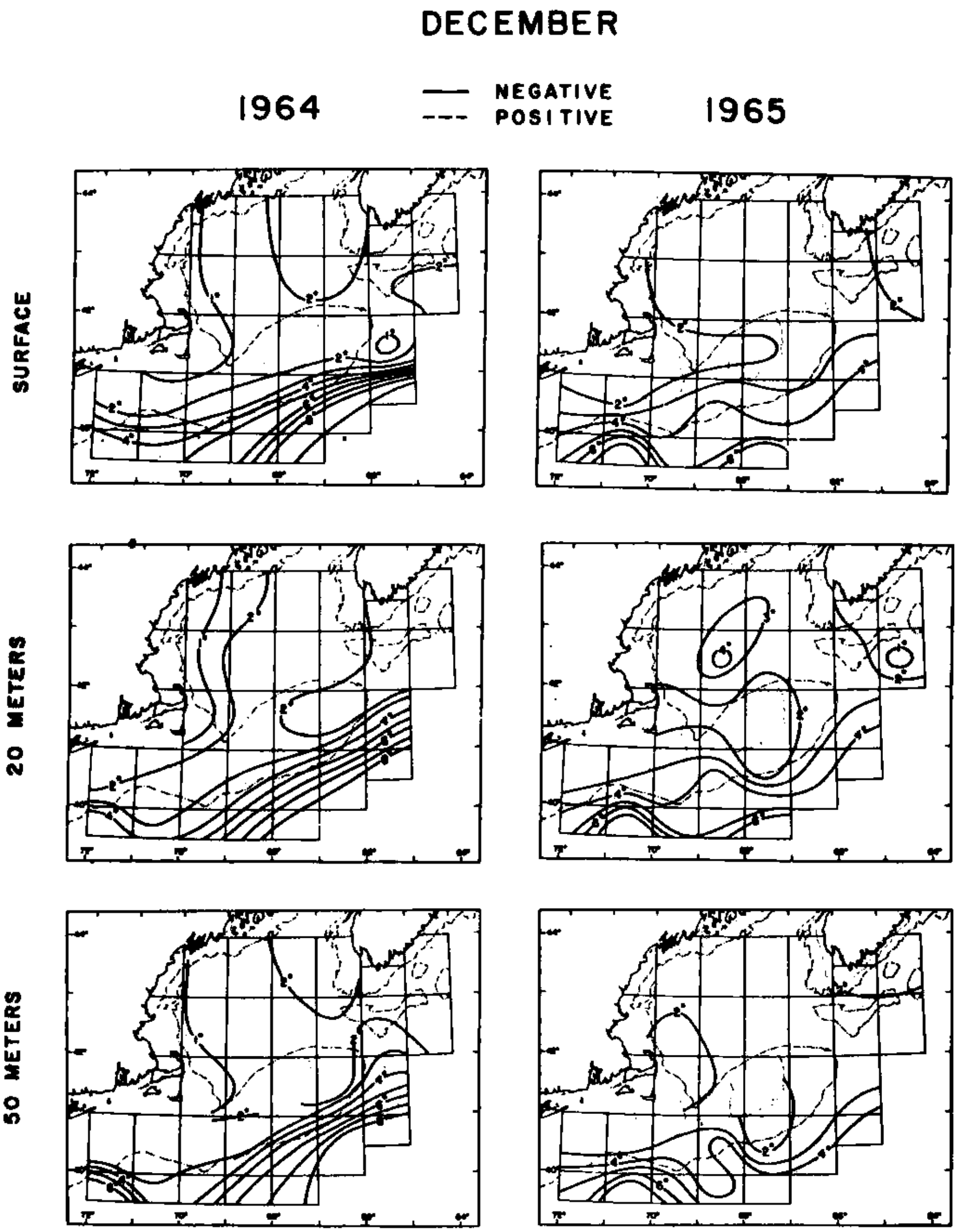

Fig. 4. Temperature anomalies at the surface, 20 m and 50 m, December 1964 and 1965.

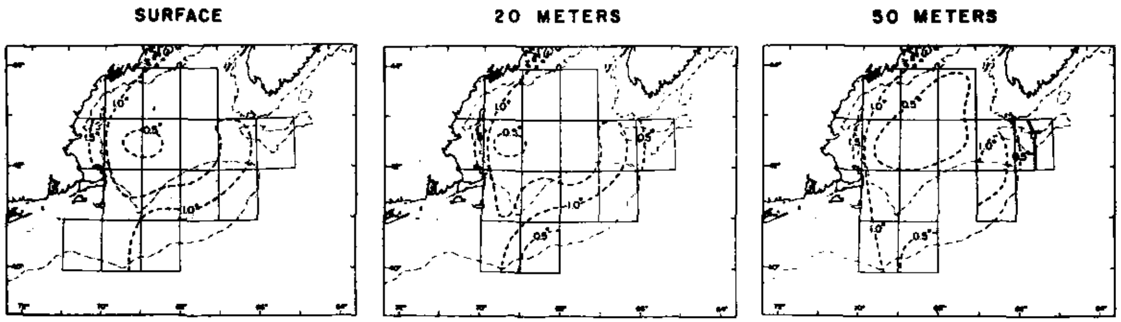

Fig. 5. Temperature anomalies at the surface, 20 m and 50 m, March 1953.

Large-scale sea surface temperature anomalies in the Northwest Atlantic from February to July in relation to monthly mean surface pressure[1]

by A. J. Lee, Fisheries Laboratory, Lowestoft, UK;
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Fleet Numerical Weather Facility, Monterey, California, USA

Introduction

The importance and application of sea surface temperature (SST) anomalies to numerous fisheries, climatological and other problems has been ventilated in numerous publications during the past fifty years. A thoroughly systematic study of these anomalies has, however, been hampered by the lack of systematic synoptic SST analyses. Twice daily synoptic numerical hemispheric SST analyses are now available at Fleet Numerical Weather Facility (FNWF), Monterey, starting mid-1962 (Carstensen and Wolff, 1966). A brief analysis is made below of the large-scale monthly mean SST anomalies in the Northwest Atlantic from February to July for the years 1963 to 1966 (inclusive).

An attempt is made to relate these anomalies to the atmospheric circulation. According to Ekman's (1905) theory, the direction of wind current at the surface is 45° to the right in the northern hemisphere and the current speed decreases with depth while the deflection becomes larger until, at a "depth of frictional influence", the direction of the current is opposite to that at the surface. Although Ekman's theory has been useful in many theoretical studies, it has not been verified in detail in the field. It cannot be applied to practical situations because the conditions under which the problem was solved do not exist in nature (Belinsky and Glagoleva, 1960). A number of reliable investigations indicate that the wind current in offshore areas in middle latitudes is deflected less than 20° to the right of the surface wind (Bowden, 1953 - 18°; Gaul and Stewart, 1960 - 15°; Lisitzin, 1938 - 12°). In the latitudes of the ICNAF Area the surface wind is 15-20° to the left of the geostrophic wind (Carstensen, personal communication). The latter is in the direction of the isobars on mean surface pressure charts and so we take the surface wind-driven current as being approximately parallel to those isobars.

Data

The synoptic hemispheric sea surface temperature analysis at FNWF is made with a 125 x 125 grid (mesh size of about 100 nautical miles), but climatology is saved in a standard FNWF 63 x 63 grid (mesh size about 200 nautical miles). The present computations were made with this standard FNWF 63 x 63

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[1] Submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/73

grid, and so only large-scale features can be studied in this scale.

The long-term (1946-65) monthly mean SST has been obtained from the unpublished work of Mrs. M. Robinson, Scripps Institution of Oceanography, and Miss E. Schroeder, Woods Hole Oceanographic Institution, and put into the FNWF grid. The monthly mean anomalies have been computed by subtraction and plotted on a Calcomp plotter as whole degree C isopleths and maximal-minimal values (x 10). Areas of negative anomaly have been hatched. Exact values at gridpoints are available at FNWF. The monthly mean surface pressure charts are computed from 6-hourly numerical surface analyses at FNWF. The isobars are at 4 mb intervals; maximal and minimal values are x 10 but with the number of hundreds omitted. Only a selection of pertinent charts (Fig. 3-14) are reproduced here and they cover no more than the North Atlantic sector. If the complete hemisphere were to be shown, on the largest possible scale consistent with the size of this publication, then there would be difficulty in reading the isopleth values and the maxima and minima as written by the Calcomp plotter. Fig. 3-10 show the mean surface pressure and SST anomalies in one month, March, in each of the years 1963-66; Fig. 9 and 11-14 show the SST anomalies in one year, 1965, in each of the months January-May.

The accuracy of hemispheric SST analyses is principally determined by data density in sparse areas (Fig. 1) and by grid size in areas with sharp gradients (Fig. 2). Data are generally sparse along the East Greenland coast and in the Davis Strait. For this reason, not much mention is made of these areas in the analyses which follow below.

Descriptive analyses of monthly mean anomalies in relation to surface winds

February

1963: A positive SST anomaly over Grand Banks (max +2.7°C) is apparently caused by warm advection from the Gulf Stream as a result of the "zusatswinde" (Rodewald, 1960) of the monthly mean low centered over the Labrador coast.

A negative SST anomaly in the southeastern part of the Labrador Sea and south of Greenland is caused by advection of cold water along the west coast of Greenland, driven by winds around the same low.

1964: The positive anomaly over the Continental Slope off Newfoundland and south of the Gulf of St. Lawrence is probably caused by relatively strong southwest winds which intensify the Gulf Stream flow. However, the mean SST of this month is relatively unreliable due to missing SST analyses during 10 days in the first part of the month.

1965: The negative anomaly over Grand Banks, the Continental Slope south of Newfoundland and off the Gulf of St. Lawrence (min -4.3°C) is apparently caused and/or maintained by northwest winds over the area driving cold water from the Gulf of St. Lawrence and from the Labrador Current towards the southeast.

1966: A negative anomaly over the Continental Slope from Georges Bank (min -3.5°C) to the southeast tip of Grand Banks (min -4.3°C) is caused and maintained by north and northwest winds as in February 1965.

March

1963: A positive anomaly occurs over the southern slopes of Grand Banks (max +4.8°C) and in American coastal waters to Cape Hatteras (max +3.8°C). The northern portion of this anomaly is apparently caused by an increased flow of Gulf Stream water at the surface as a result of relatively strong winds blowing approximately along the Gulf Stream axis and belonging to the circulation of the monthly mean low centered at 57°N, 30°W.

A negative anomaly in the Labrador Sea persists and is maintained by the same winds as in February.

1964: The positive anomaly found in February on the Continental Slope and south of Newfoundland has changed to a negative anomaly (min -3.1°C), apparently caused by north-northwest winds associated with the prolonged monthly mean low centered at 58°N, 36°W. However, the February 1964 mean SST analysis was unreliable due to missing analyses on the climatological tape.

1965: A negative anomaly over the southern slopes of Grand Banks and over the Continental Slope south to Georges Bank (min -3.5°C) persists from February 1965, and is maintained by the same winds as in February. This is the second month in this analysis series when a number of days of SST analyses are missing in the middle of the month.

1966: A negative anomaly on the Continental Slope from Georges Bank (min -3.7°C) to the southeastern slope of Grand Banks (min -3.1°C) persists from the previous month. Winds over the area are relatively weak and the anomaly can only be explained on the basis of persistence.

April

1963: The positive anomaly over the southern slopes of Grand Banks and in North American coastal waters persists (max +3.5°C). Apparently, it is caused by winds oriented in the west-east direction, which are due to the prolonged monthly mean low centered northeast of Newfoundland and which intensify the Gulf Stream flow at the surface.

1964: The negative anomaly south of Grand Banks persists from the previous month, March 1964, (min -3.3°C), and is maintained by north-northwest winds along the Labrador coast and the north coast of Newfoundland.

1965: The negative anomaly over the southern slopes of Grand Banks and over the Continental Slope south to Georges Bank persists (min -3.6°C) and is caused and maintained by the same winds as in February and March 1965.

1966: The negative anomaly over the Continental Slope from Georges Bank to the southern slope of Grand Banks persists but has decreased in intensity (min -2.4° and -2.1°C respectively). The anomaly can be explained mainly on the basis of persistence. Only slight advection of cold water from the Gulf of St. Lawrence and the Labrador Current is possible with the mean winds prevailing in this month.

The positive anomaly in the Irminger Sea and south of Greenland can be explained by increased advection of warm North Atlantic drift water into the Irminger Gyral by the winds belonging to the low centered at 51°N, 25°W.

May

The Icelandic low is relatively weak in this month. The heating of the sea surface by heat exchange is also intensifying in May. Thus, most anomalies change relatively rapidly in this month and are mainly explainable by persistence. New pronounced anomalies occur in May over the Gulf Stream proper. These are caused in April/May by the changing "push" of the circulation around the Bermuda-Azores high.

1963: A positive anomaly persists over the southern slope of Grand Banks (max +3.2°C) and on the North American Continental Slope south to Georges Bank, but has decreased in intensity. This anomaly is explainable only on the basis of persistence. A negative anomaly occurs over the Gulf Stream proper (min -5.1°C).

1964: The negative anomaly south of Grand Banks found in April has decreased considerably. The Icelandic low is in its "normal" position and the month can be characterized as a close to "average" month.

1965: The negative anomaly south of Grand Banks and over the Continental Slope of North America has decreased from the previous month (min -2.1°C). A positive anomaly exists over the Gulf Stream proper (max +3.9°C). Winds are weak over the Northwest Atlantic.

1966: The negative anomaly on the Continental Slope from Grand Banks to Georges Bank persists but has weakened considerably. There is a negative anomaly over the Gulf Stream proper (min -3.3°C).

June

1963: The positive anomaly from previous months over the Continental Slope from Georges Bank to Grand Banks still persists but has decreased considerably (max +1.7°C). The negative anomaly over the Gulf Stream proper still persists but has decreased in intensity considerably (min -1.9°C).

1964: There is a weak negative anomaly on the slopes of Grand

Banks (min -1.5°C) and a positive anomaly over the Gulf Stream proper (max +2.0°C).

1965: The sea surface temperature data for this month are missing.

1966: A weak negative anomaly persists over the Continental Slope and south of Grand Banks (min -1.6°C).

July

1963: A slight positive anomaly in the Northwest Atlantic, reaching the southern part of the Labrador and Irminger Seas is explainable by advection caused by prevailing winds.

1964: A small part of the negative anomaly of the previous month remains over Georges Bank only (min -1.2°C). The rest of the area off the North American coast, including the Gulf Stream proper, has a positive anomaly. A negative anomaly in the Labrador and Irminger Seas can be explained by advection due to winds belonging to the low centered over Greenland.

1965: The sea surface temperature data for this month are missing.

1966: The weak negative anomaly from the previous month is barely recognizable and is located now over part of the Gulf Stream. A negative anomaly in the southern part of the Labrador Sea is apparently caused by prevailing winds pushing cold Labrador Current water into this area.

Discussion

The SST anomaly patterns vary over the North Atlantic, both negative and positive anomaly areas are present in any given month. Greatest anomalies (by magnitude) occur in North American coastal waters, and over the banks, Continental Slope, and Gulf Stream area in the Northwest Atlantic.

SST anomalies in the North Atlantic area are brought about by the interaction of a number of factors. Winds have both a thermal effect and a dynamic effect which tend to reinforce each other. Thus, a northerly wind generally drives more cold water from high latitudes southward, but it also reduces the SST by bringing about a loss of sensible and latent heat from the sea to the air; a southerly wind has the opposite thermal and dynamic effects. This combination of the advective effect and the thermal effect brought about by the atmospheric pressure distribution can be recognized as one of the principal causes of our SST anomalies during winter and early spring.

The SST anomalies are most pronounced in February and March and decrease in intensity towards July.

Only the winter of 1963 had positive anomalies on the North American Continental Shelf and Slope in the Northwest Atlantic. The winters of 1964, 1965 and 1966 had negative anomalies; winter 1965 being the coldest (Fig. 15).

The winter anomalies are formed in late fall and early winter and tend to persist through late winter and spring. Of 18 intermensal changes studied only one changed from positive to negative anomaly in the North American Continental Shelf/Slope area (February-March 1964). This change is also questionable, as the monthly mean SST for February 1964 was computed from incomplete records.

The corresponding monthly mean surface pressure patterns also show considerable persistence from month to month. The change of these patterns occurs mostly during a change of season (in general in May and November).

The persistency of the anomalies promises a useful tool for long-range prediction.

The present available data can enable studies to be made of the influence of these anomalies on (i) spawning time/place displacement (ii) survival of larvae (iii) occurrence and availability of fish to fisheries, *e.g.*, if the survival of haddock larvae is dependent on temperature as well as drift, it can be assumed that of the years 1963-66, only 1963 gave a successful year-class of this species on Georges Bank and Grand Banks, as this is the only year with a positive anomaly over the months February-July (Fig. 15).

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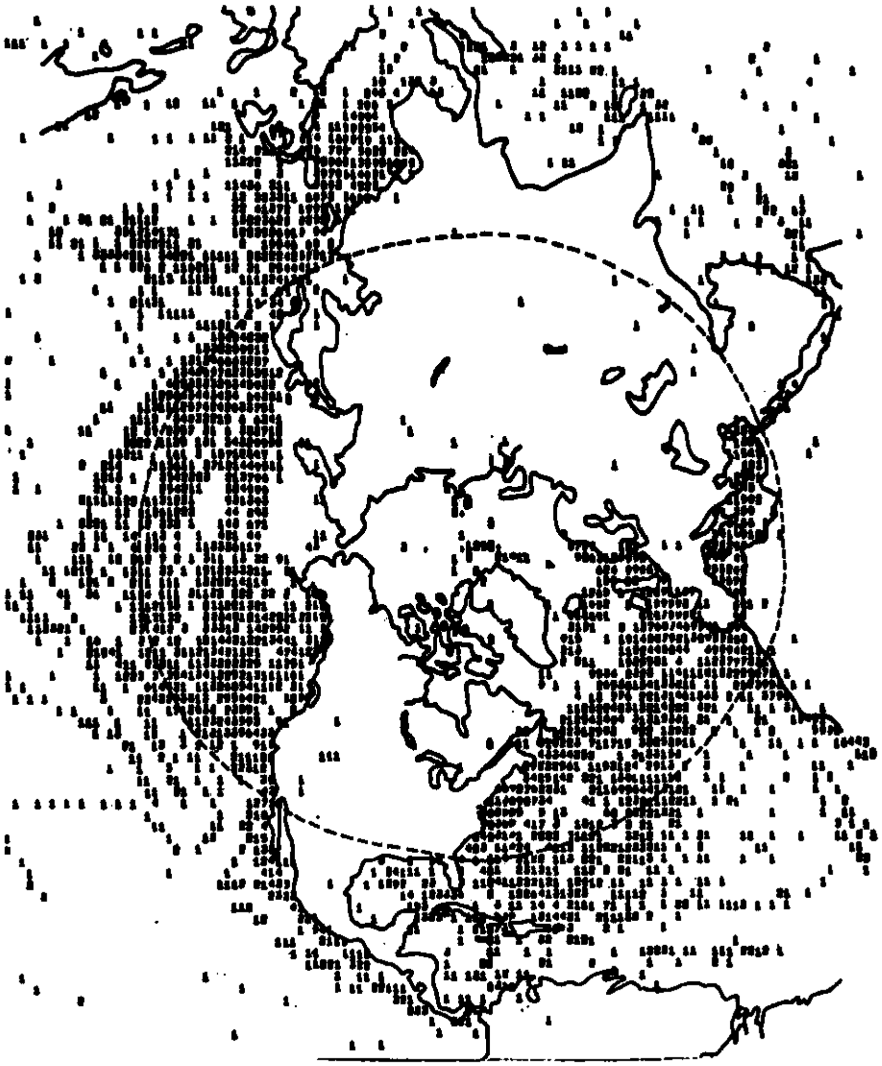

Fig. 1. Density of synoptic sea surface temperature reports during the 3 1/2 days ending at 0000 hrs GMT on 13 March 1967. The numbers indicate the number of reports under the area of the figure. 9 means 9 or more reports.

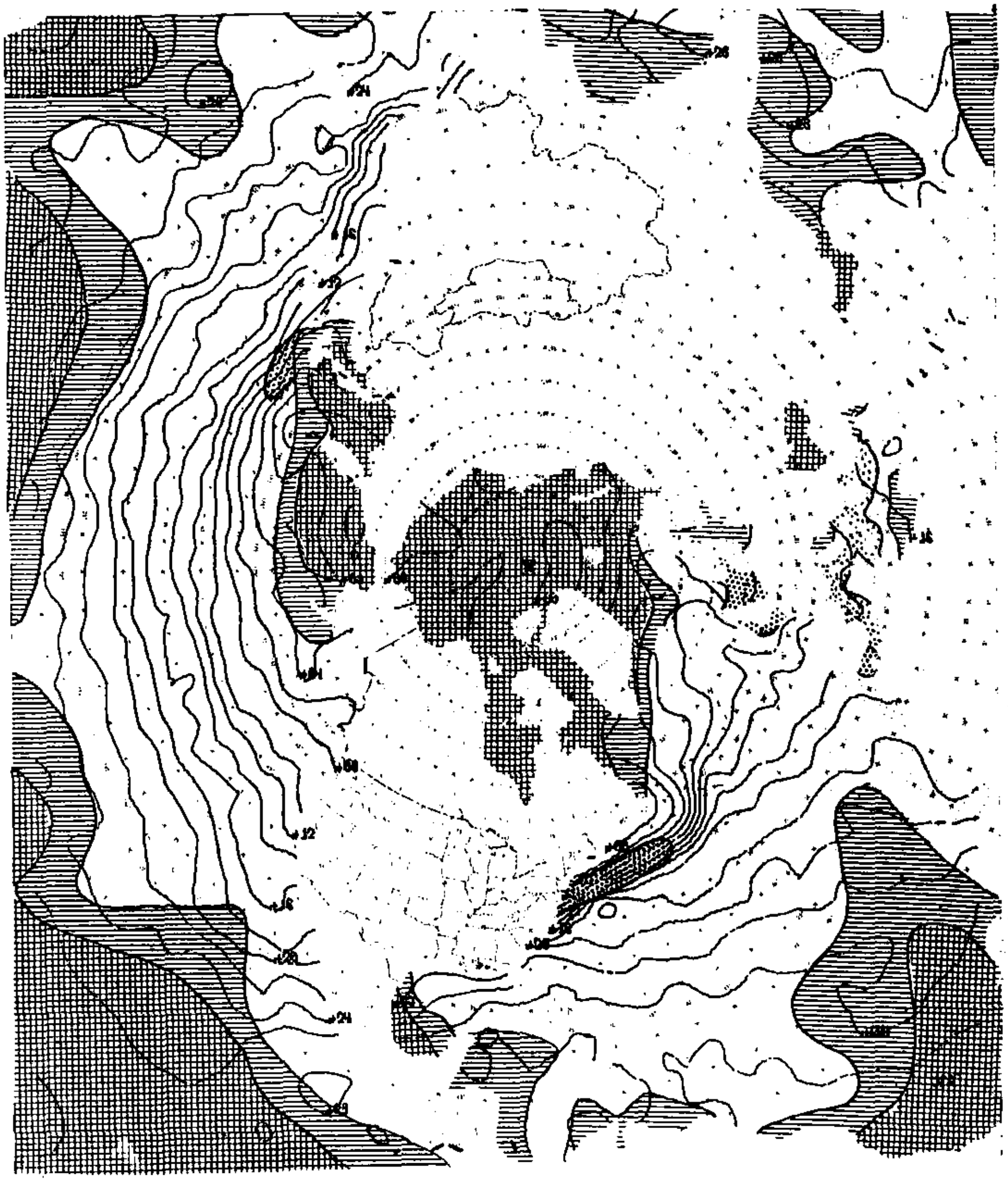

Fig. 2. Hemispheric sea surface temperature analysis at 0000 hrs GMT on 13 March 1967. The areas where the grid size limits the accuracy are dotted. Those where a low density of observations decreases the accuracy are hatched, and those where the analysis is unreliable owing to lack of observations are cross-hatched.

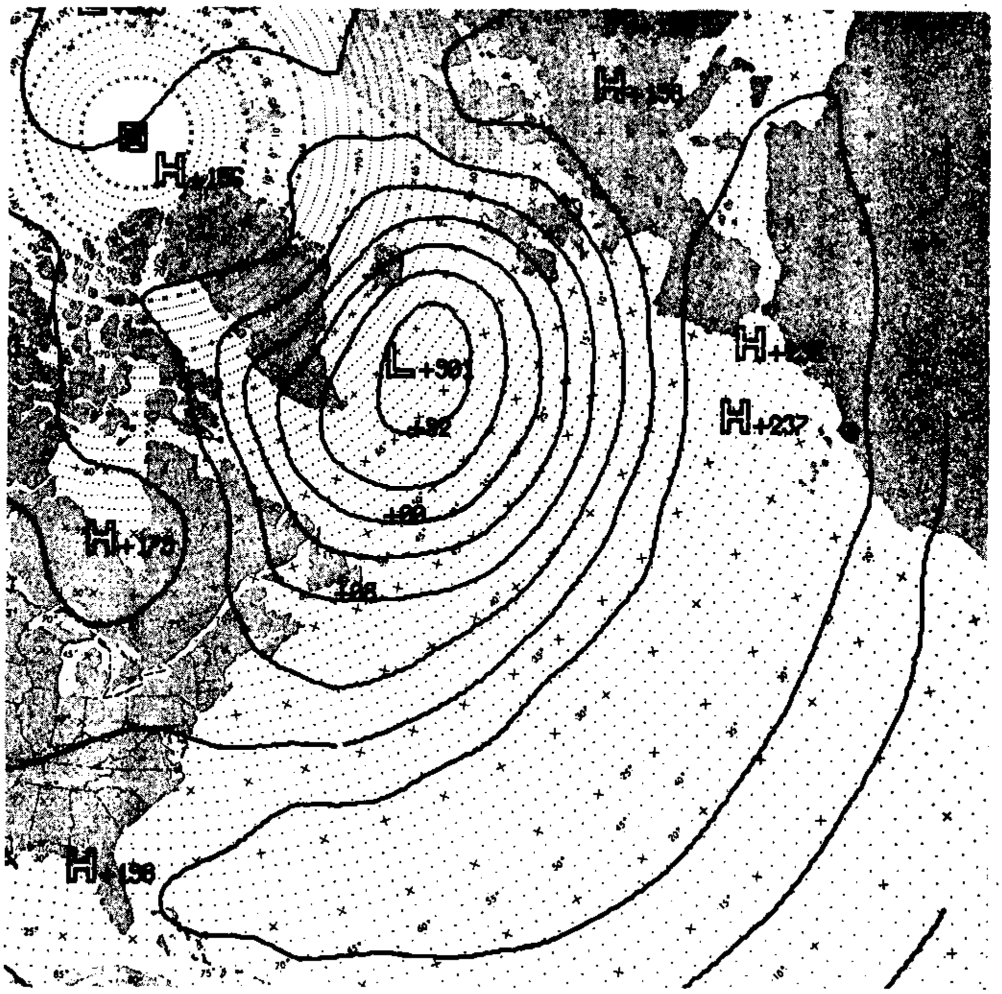

Fig. 3. Mean surface pressure: North Atlantic: March 1963.

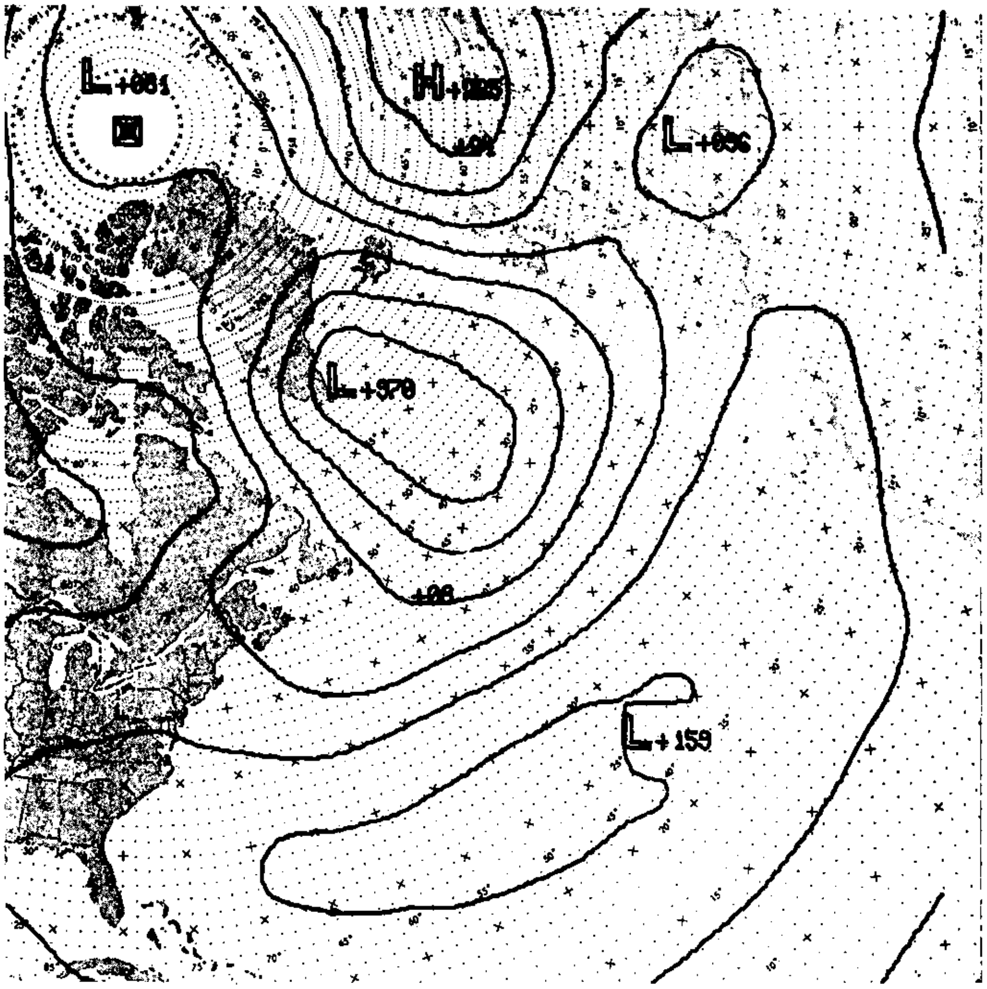

Fig. 4. Mean surface pressure: North Atlantic: March 1964.

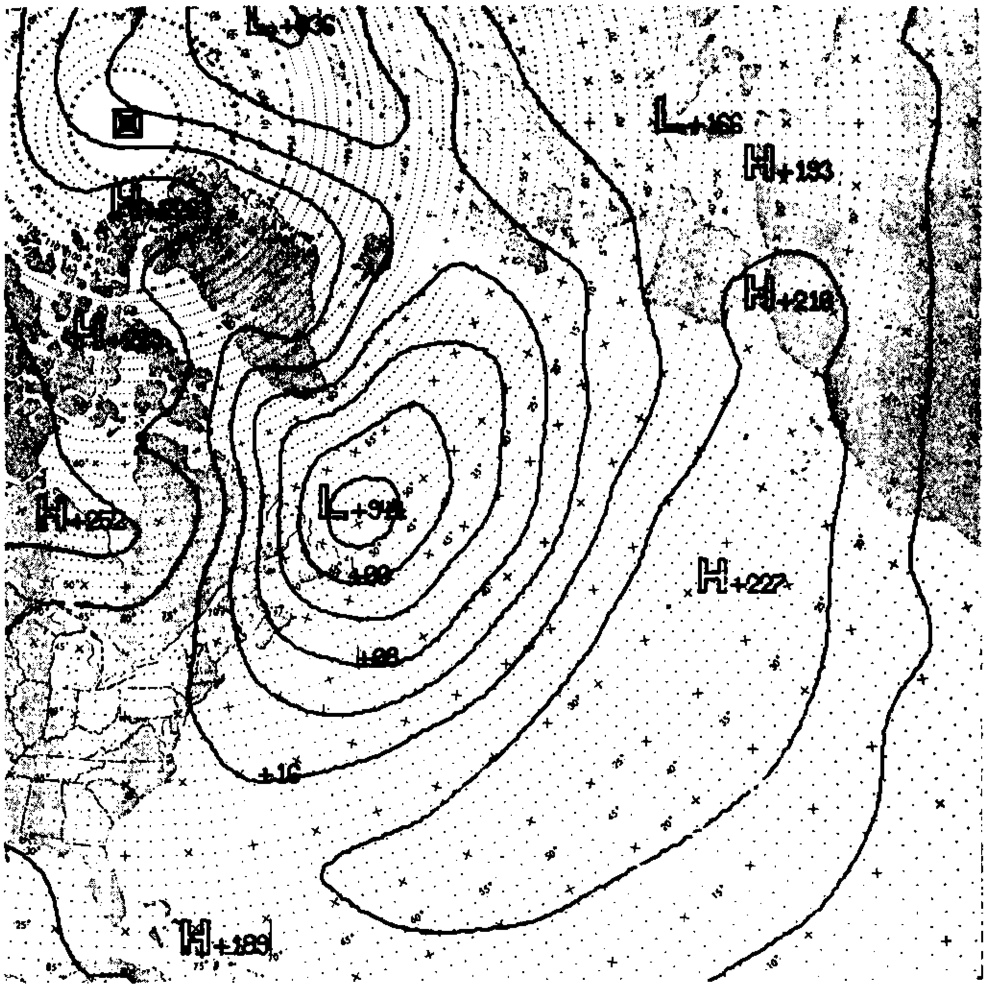

Fig. 5. Mean surface pressure: North Atlantic: March 1965.

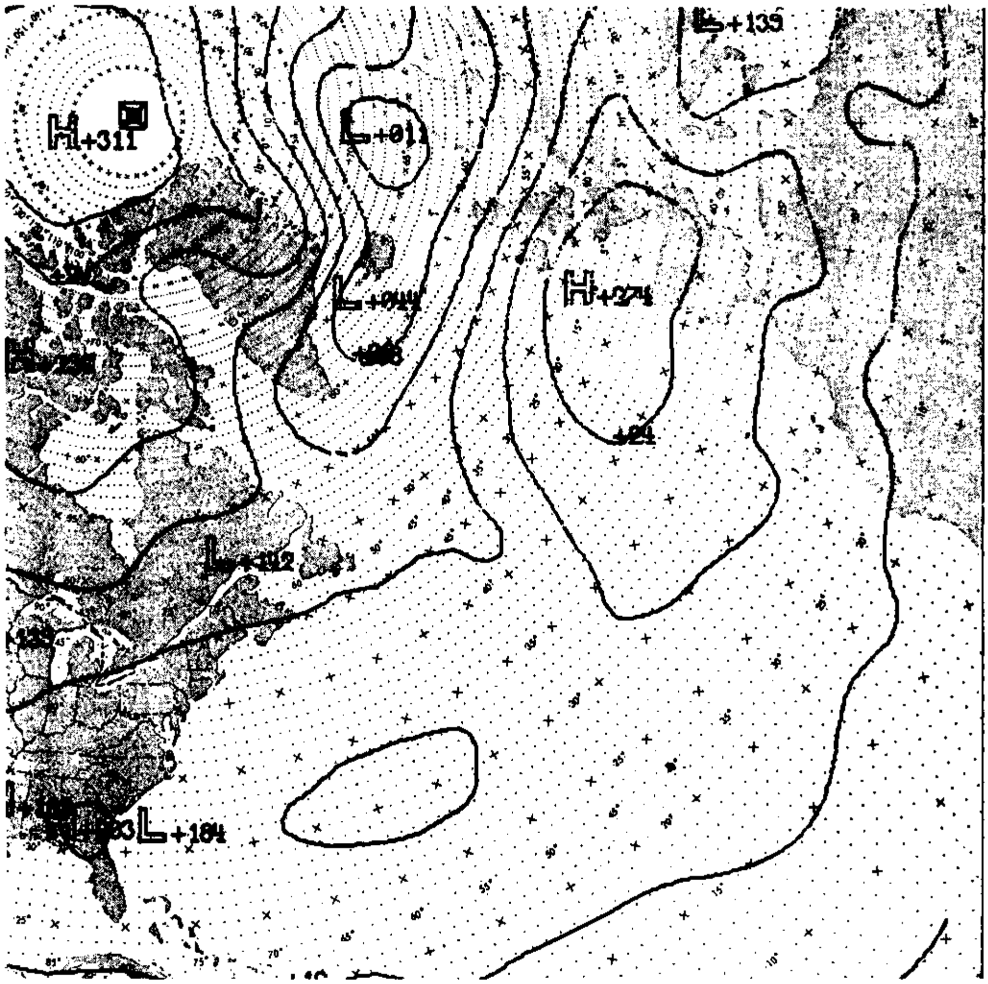

Fig. 6. Mean surface pressure: North Atlantic: March 1966.

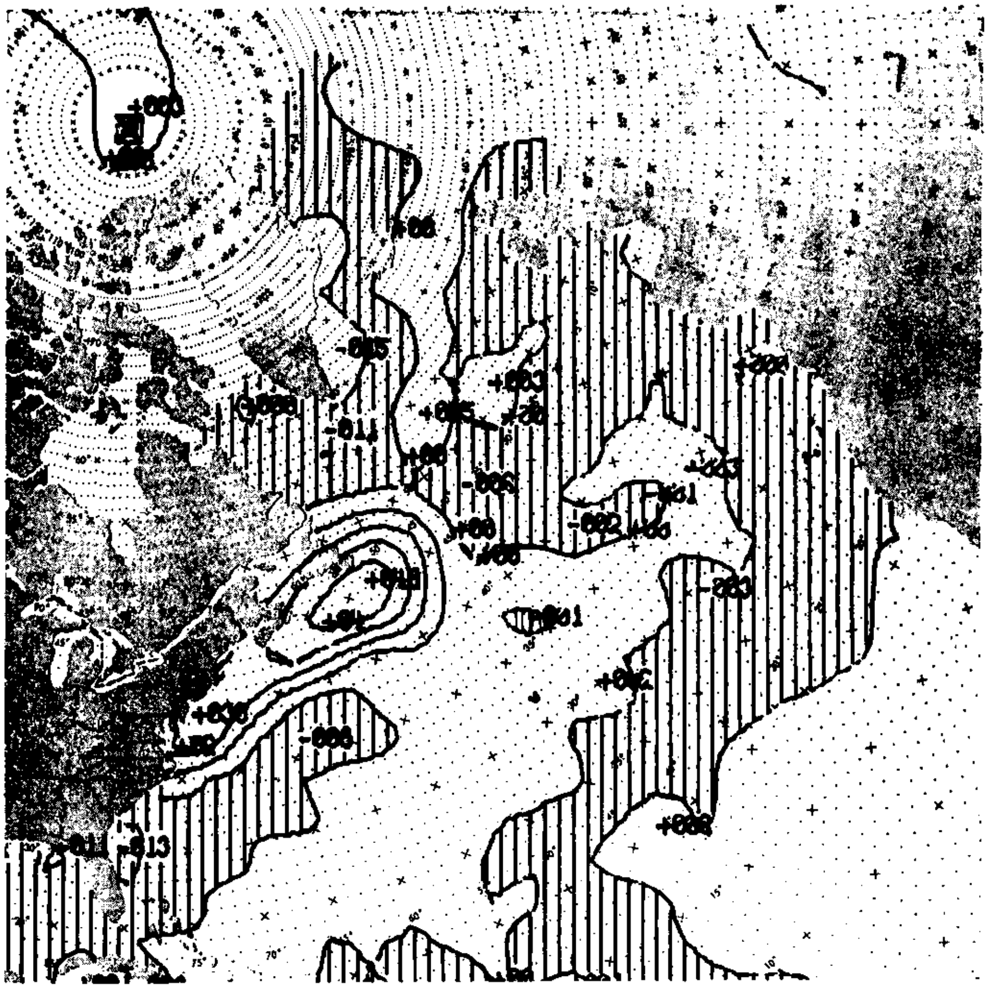

Fig. 7. Sea surface temperature anomaly: North Atlantic: March 1963.

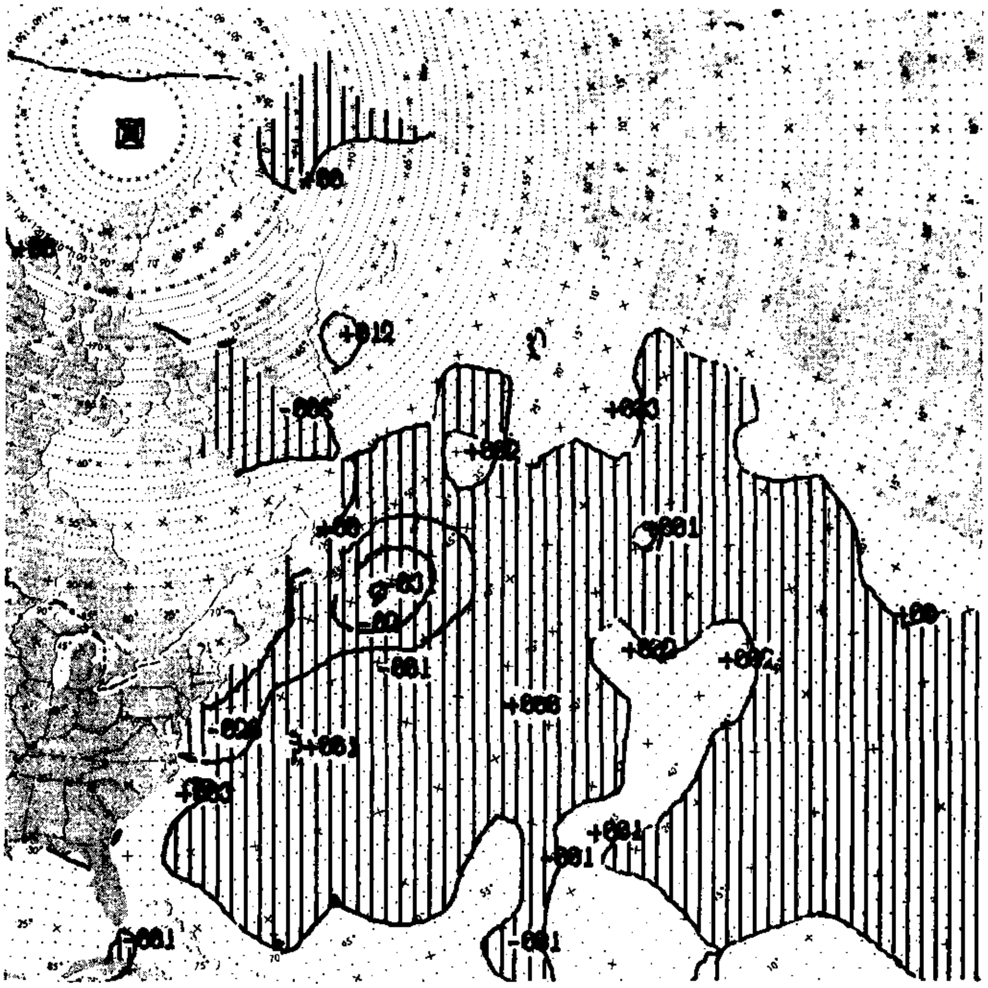

Fig. 8. Sea surface temperature anomaly: North Atlantic: March 1964.

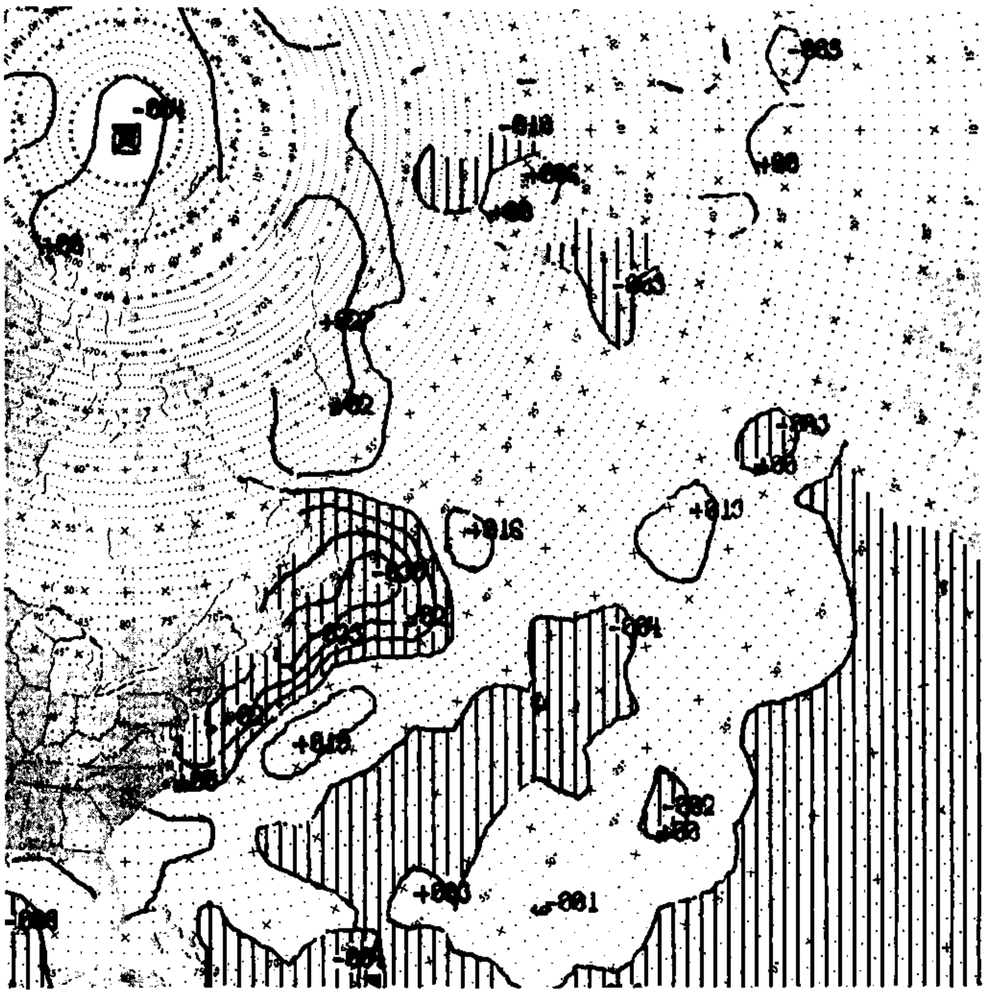

Fig. 9. Sea surface temperature anomaly: North Atlantic: March 1965.

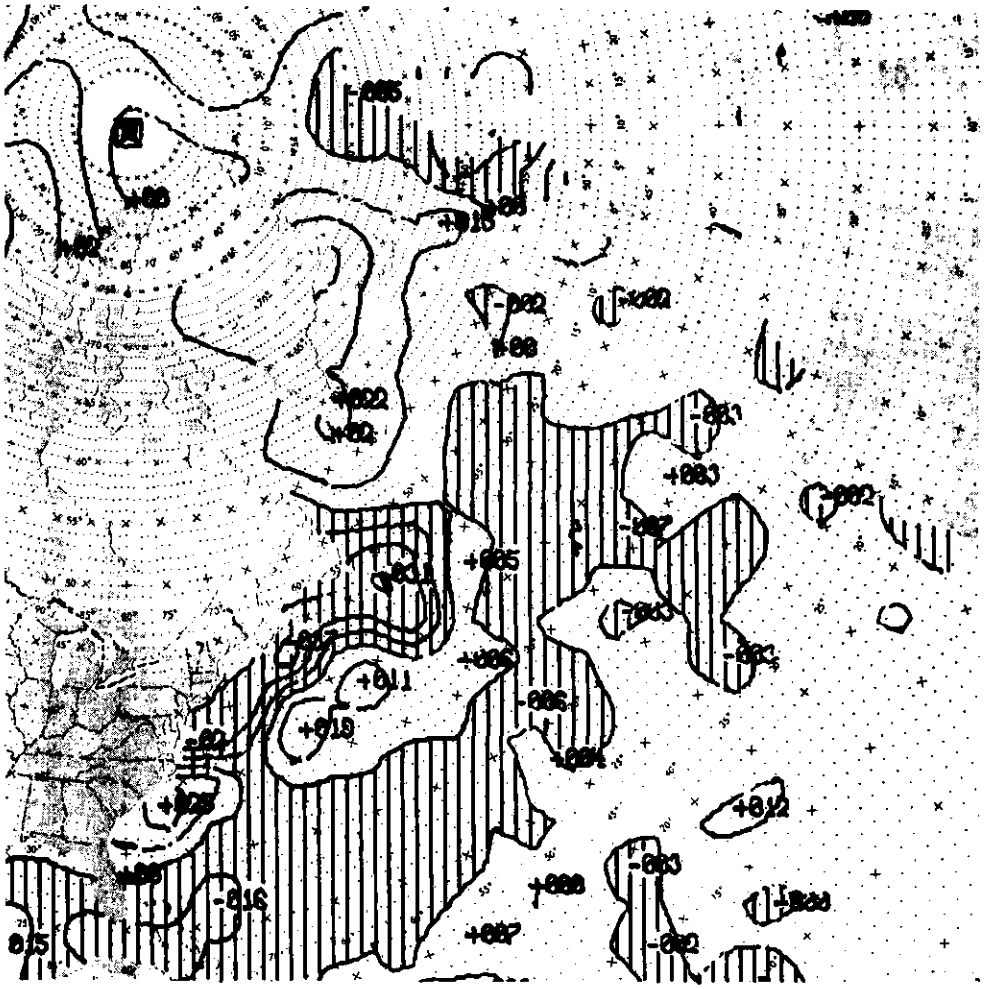

Fig. 10. Sea surface temperature anomaly: North Atlantic: March 1966.

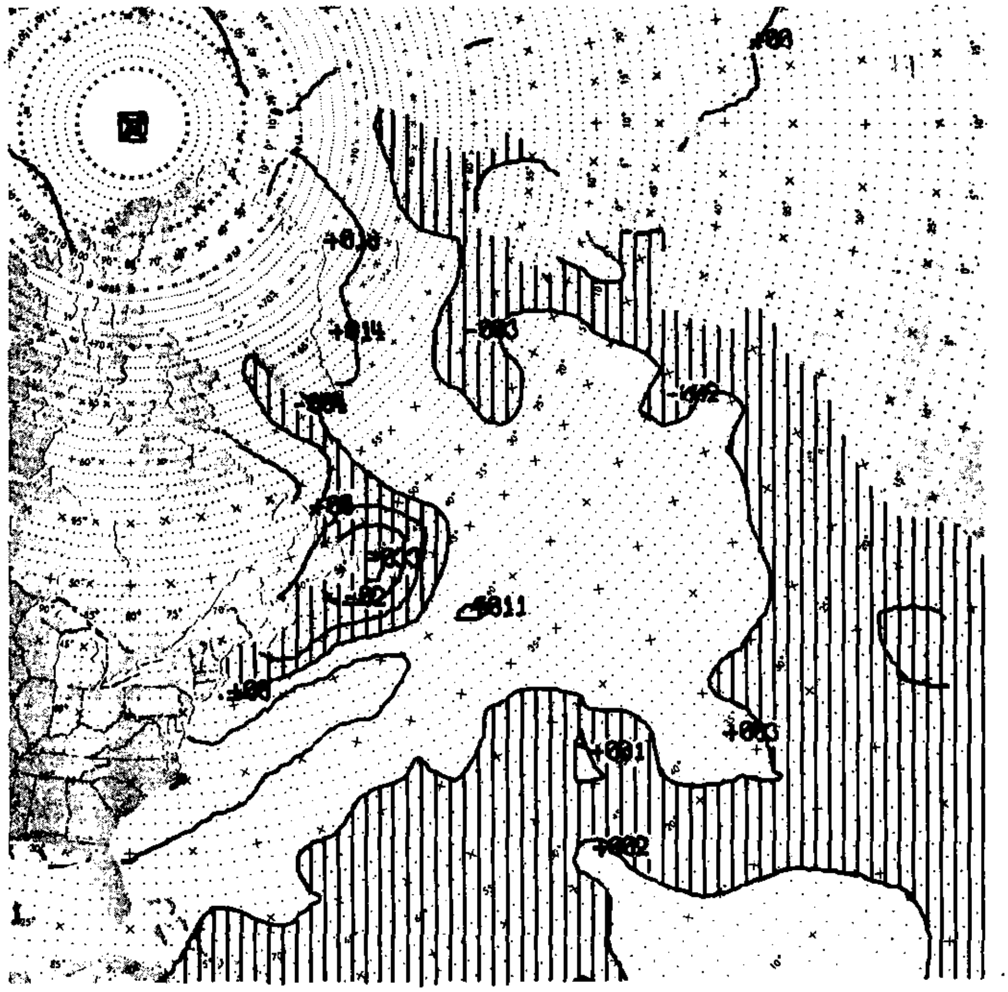

Fig. 11. Sea surface temperature anomaly: North Atlantic: January 1965.

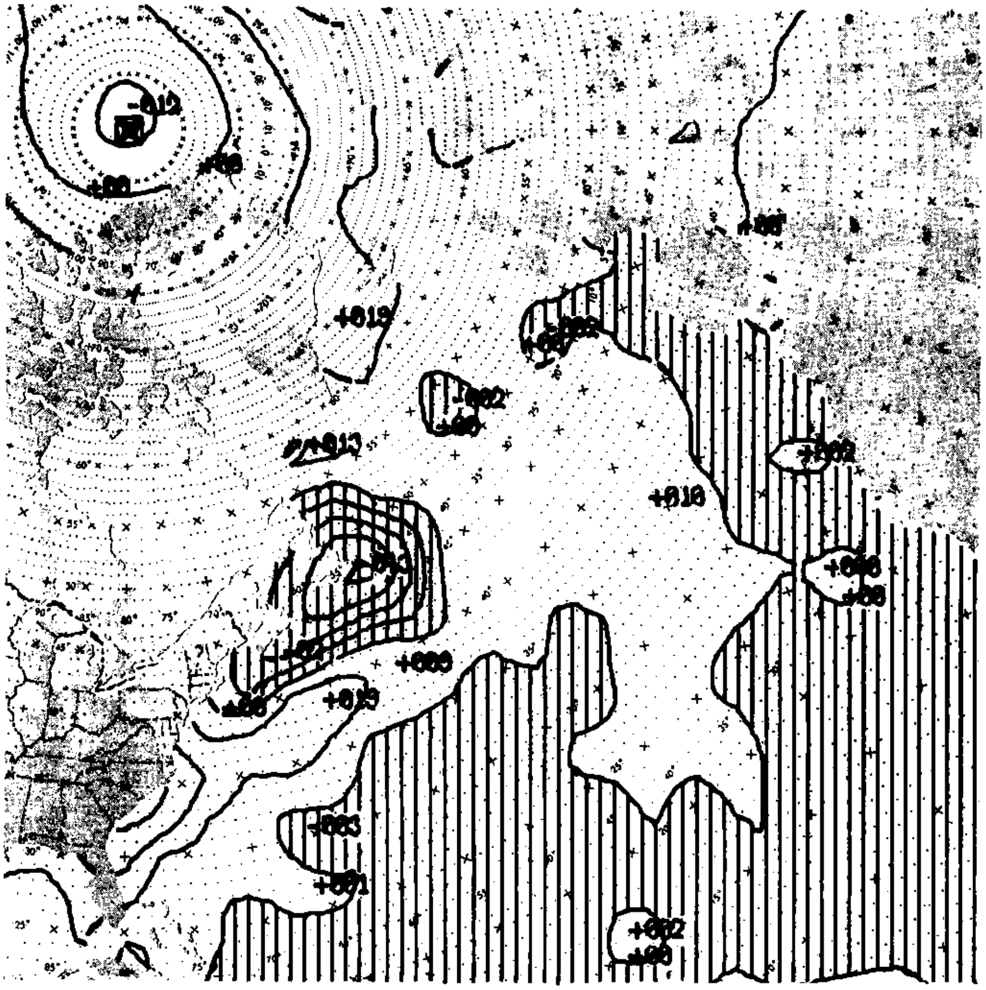

Fig. 12. Sea surface temperature anomaly: North Atlantic: February 1965.

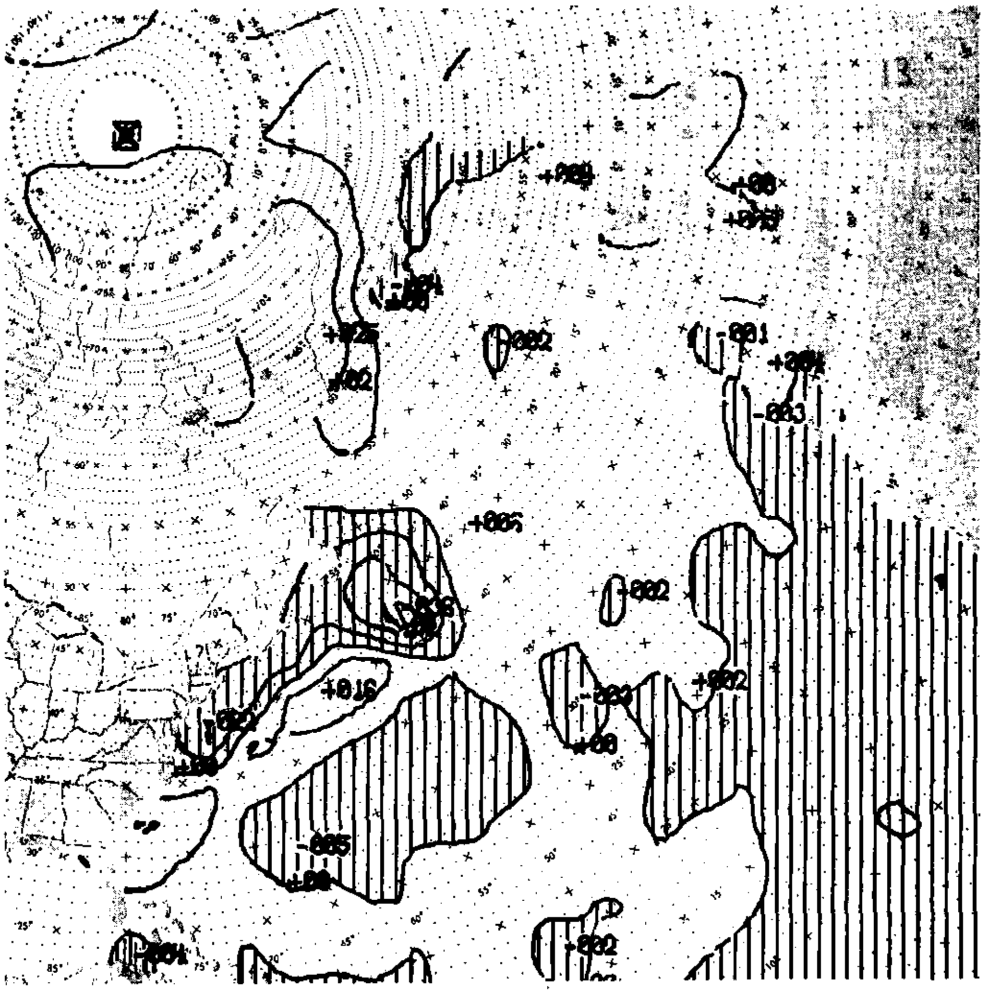

Fig. 13. Sea surface temperature anomaly: North Atlantic: April 1965.

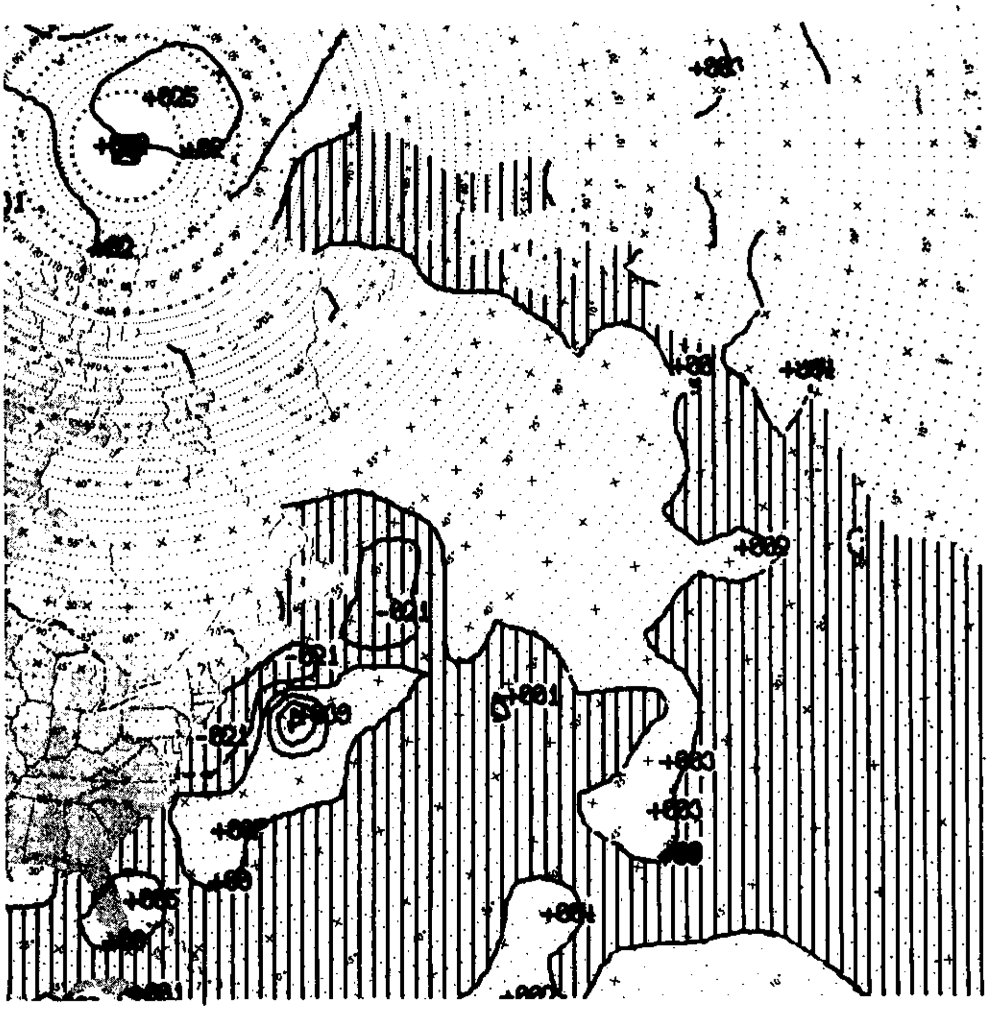

Fig. 14. Sea surface temperature anomaly: North Atlantic: May 1965.

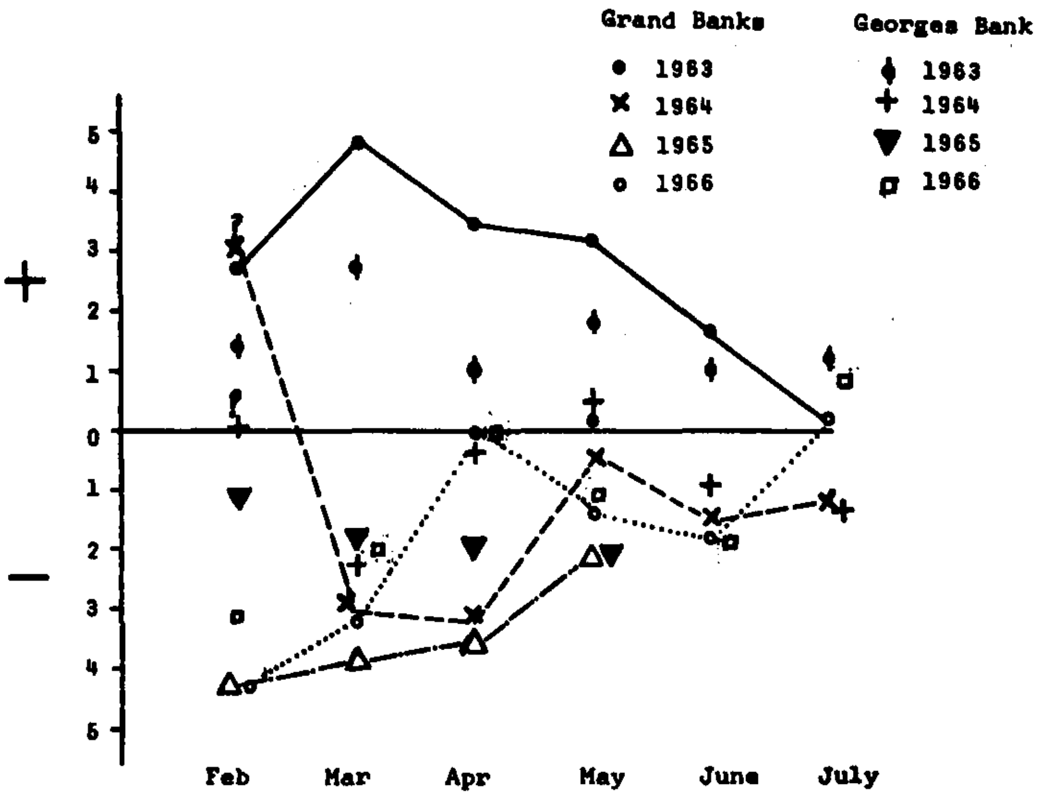

Fig. 15. Maximal and minimal anomalies of sea surface temperature (in °C) on the Grand Banks and Georges Bank from February to July in the years 1963-1966.

Anomalies of sea temperature at Station 27 off Cape Spear and of air temperature at Torbay-St. John's[1]

by Wilfred Templeman
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Biological Station, St. John's, Newfoundland

Introduction

For the past 17 years, temperatures at standard depths from surface to bottom have been taken once or twice monthly at station 27 situated 2 nautical miles off Cape Spear, near St. John's, Newfoundland at 47°31'50"N, 52°35'10"W in 176 m.

To produce an average temperature for a year or part year, the temperatures were first adjusted to the mid-monthly temperature and the average mean yearly temperature per 25 m water column calculated from the mid-monthly temperatures without allowance for the differing number of days in the months.

The mean yearly (calculated from mean daily and then mean monthly as above) air temperatures now taken at the Torbay Airport near St. John's, but formerly taken at St. John's, have all been adjusted to the Torbay level since they were taken at both places for an overlapping number of years. (For details of methods both for water and air temperatures, see Templeman, 1965.)

Templeman (1965) calculated the yearly temperature anomalies for Station 27 and the air temperature at Torbay on the bases of the average yearly temperatures, water and air respectively, for 1950-62 and for the air temperatures at St. John's-Torbay also for 1872-1962. The present paper extends the period of temperature-anomaly comparison to 1966, but base-line averages have not been recalculated and the present comparisons are with the 1950-62 and the 1872-1962 base-line averages as above.

Anomalies of water temperature at Station 27

In yearly temperatures (Fig. 1), January-May (Fig. 2) and June-December (Fig. 3), the pattern of average temperature by year in the water column and its different portions is usually fairly similar, although there is naturally a greater amplitude of variation in the upper layers. There is also a close relation in trend, especially in the upper water layers, with the air temperature.

[1] submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/26

The general trend during this period in the yearly water temperatures (Fig. 1) has been fairly well balanced about or near the average, but with less yearly variability in recent years and with an upturn in 1966.

In the sea temperatures for January-May (Fig. 2), there was a slight decline over most of the period but no great or extensive departures from the average and with an upturn in 1966.

The June-December sea temperatures (Fig. 3) have also shown no very definite trends, possibly slightly downward in the deeper layers but well balanced above and below the average in the upper layer and in the whole water column.

Anomalies of air temperature, Torbay-St. John's

Years 1950-66

For the years 1950-66 (Fig. 2), in the period December-April the air temperatures showed close agreement in relative trend from year to year (allowing for the greater amplitude of the air temperature variations) with water temperatures at all levels. At this time of year, local or local regional air temperatures apparently have the over-riding influence in the water column to the depth of this station.

For this period of years also, the May-November air temperatures (Fig. 3) were usually closely related in trend to the June-December water temperatures, the agreement being best in the upper layers. Deeper down, and on the average for the whole water column, agreements in trend with air temperatures were usually present, but especially in the deeper layers there were enough differences to show outside influence, presumably of the southward-moving Labrador Current. Also, offshore and onshore winds and internal waves would have more effect in summer and autumn, when temperatures from top to bottom are very variable, than in winter and spring when temperatures are little different from surface to bottom.

The yearly air temperatures (Fig. 1) show the average effects of the winter-spring and summer-autumn relationships and provide generally excellent agreements between air and surface water layer temperature trends, with fairly good but less agreement at the deeper levels.

Years 1872-1966

Because the air temperatures at Torbay-St. John's and the water temperatures at Station 27 off Cape Spear show an excellent relationship in trend but regular year-round water temperatures are only available for this station since 1950, the air temperatures for the St. John's (more recently Torbay) area which are available since 1872 should be indicative of water temperature changes in trend during this period. Over this period the December-April and May-November temperature trends (Fig. 4) show some differences. The December-April temperatures were at their lowest in the early part of the period, then ran through a period of fluctuating higher than average temperatures in the 1890's and early 1900's. Temperatures declined to lows in the early to mid-1920's and rose to their highest level in the whole period in the early to mid-1950's.

The May-November trend is often opposite to that of December-April. Temperatures for May-November were close to the average at the beginning of the period and gradually declined to their lowest level in the early 1900's. From this they gradually increased but were usually below average until the early 1920's, reaching their highest level in the 1930's, and have since declined a little but remained usually above the average.

The temperature trend for the whole year began from a low point in the early part of the period, about or shortly after 1880, and rose slightly but remained generally below average until the late 1920's, increased to its highest level in the 1950's and has declined in recent years but is still above average.

The often different or opposite trends of the winter-early spring (called winter in discussion), late spring, summer and autumn (called summer in discussion) temperatures are presumably related in some way and need an explanation.

The winter temperatures show two long-period fluctuating changes of which the first was about 50 years or longer, and the second has thus far lasted about 40 years but is evidently incomplete. In each of these periods, the winter temperatures have varied through a greater amplitude than the summer temperatures.

The recent period in summer temperatures could be considered to have lasted since about 1902, that is for 64 years, and is still incomplete.

Acknowledgments

I am grateful to the scientists and technicians of the St. John's Station who over the years have taken so many temperatures at Station 27 and particularly, to Mr A. G. Kelland who has been most closely associated with the hydrographic work at the St. John's Station. I am grateful also to the Meteorological Service and Mr C. F. Rowe of the Torbay Meteorological Station of the Department of Transport for records of the Torbay-St. John's area temperatures.

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Templeman, W., 1965. Anomalies of sea temperature at Station 27 off Cape Spear and of air temperature at Torbay-St. John's. *Spec. Publ. int. Comm. Northw. Atlant. Fish.*, No. 6: 795-806.

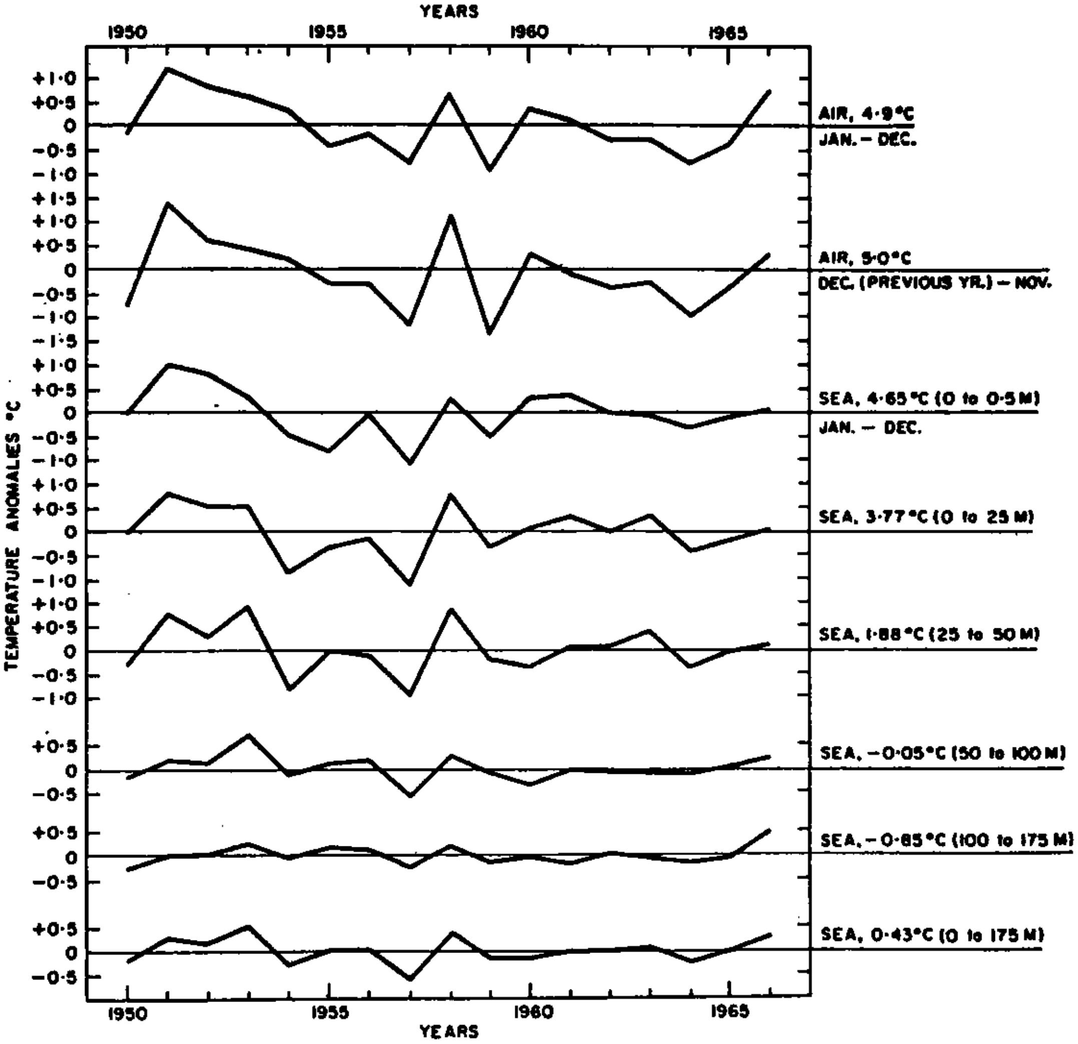

Fig. 1. Anomalies of yearly sea-surface and water column temperatures at Station 27 and of air temperatures at Torbay-St. John's, for 1950-66 from the average yearly temperatures for 1950-62.

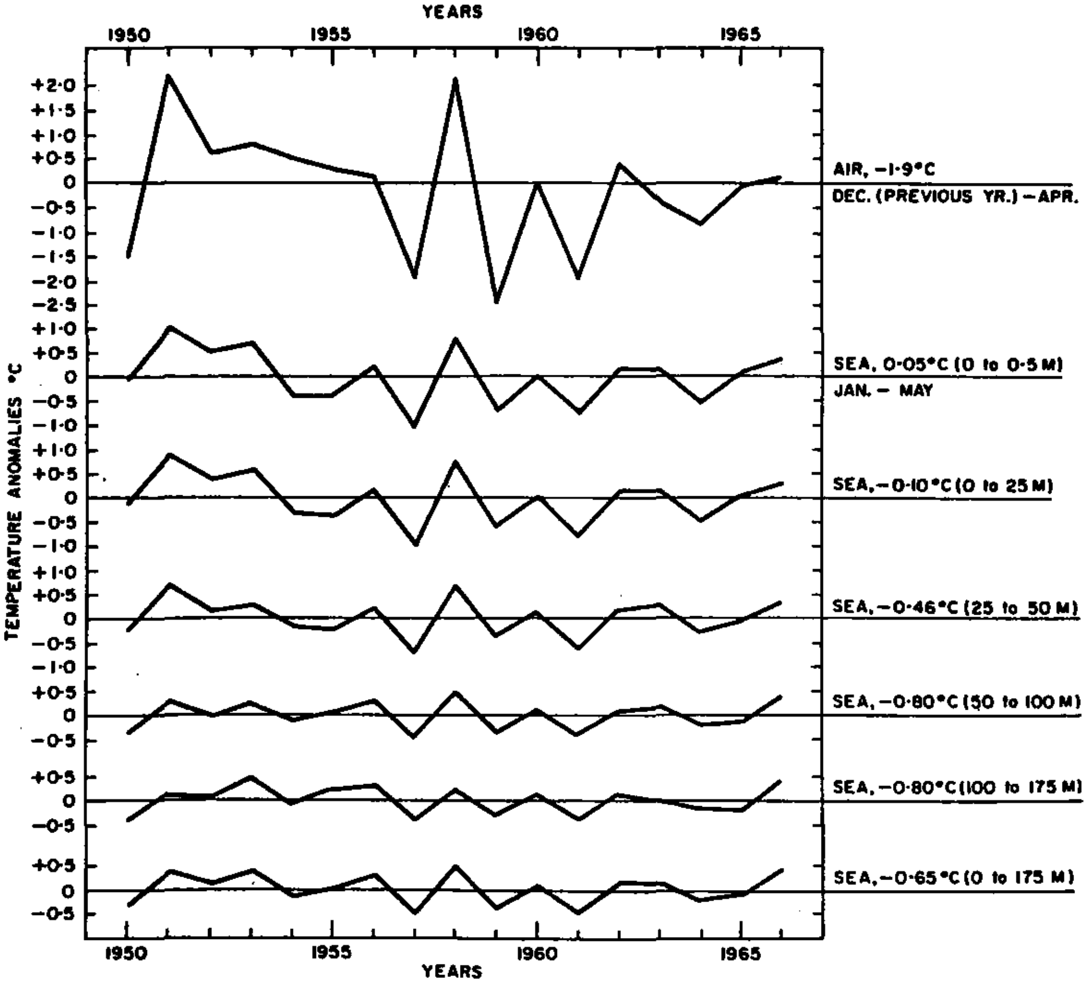

Fig. 2. Anomalies of yearly January-May sea-surface and water column temperatures at Station 27 and of December (of previous year) - April air temperatures at Torbay-St. John's, for 1950-66 from the average temperatures during these periods for 1950-62.

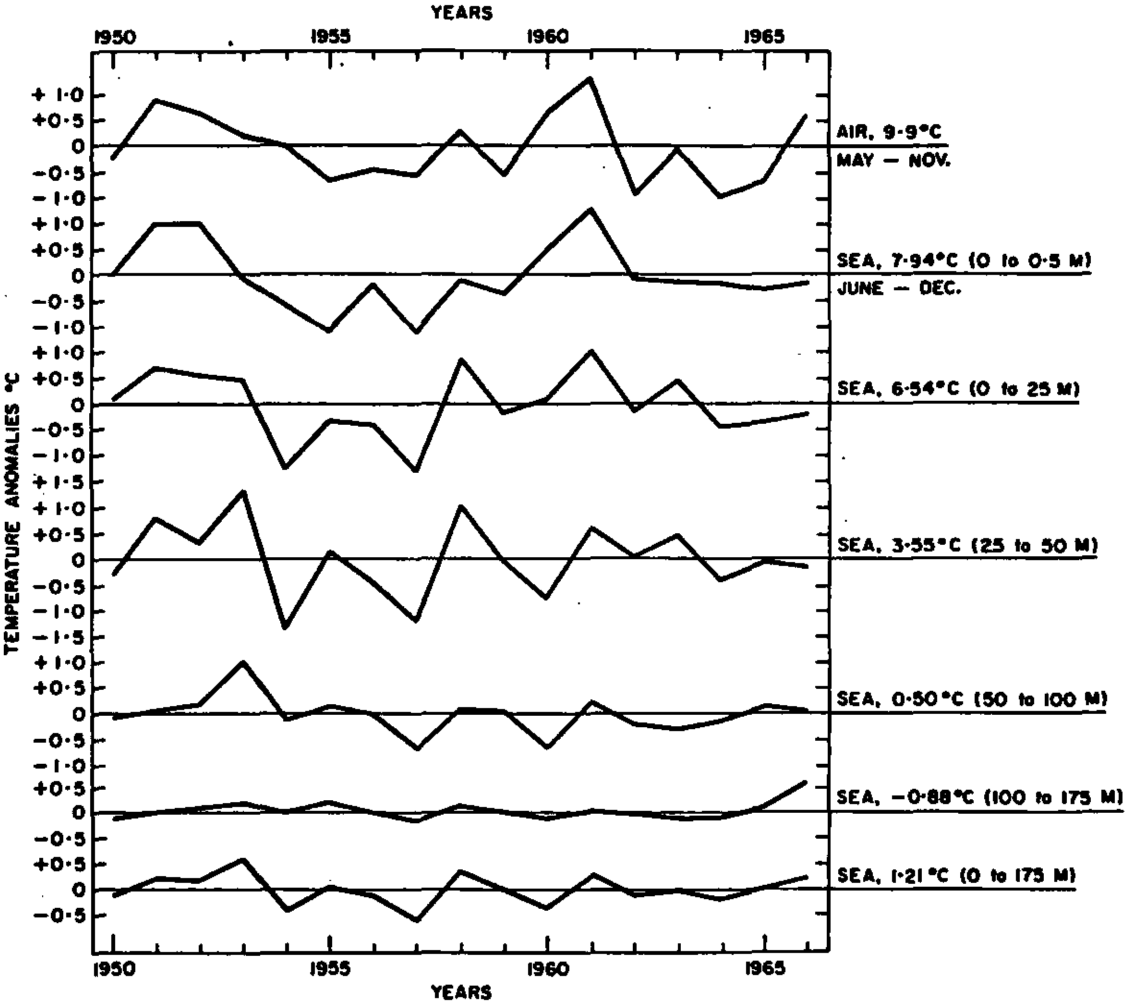

Fig. 3. Anomalies of yearly June-December sea-surface and water column temperatures at Station 27 and of May-November air temperatures at Torbay-St. John's for 1950-66 from the average temperatures during these periods for 1950-62.

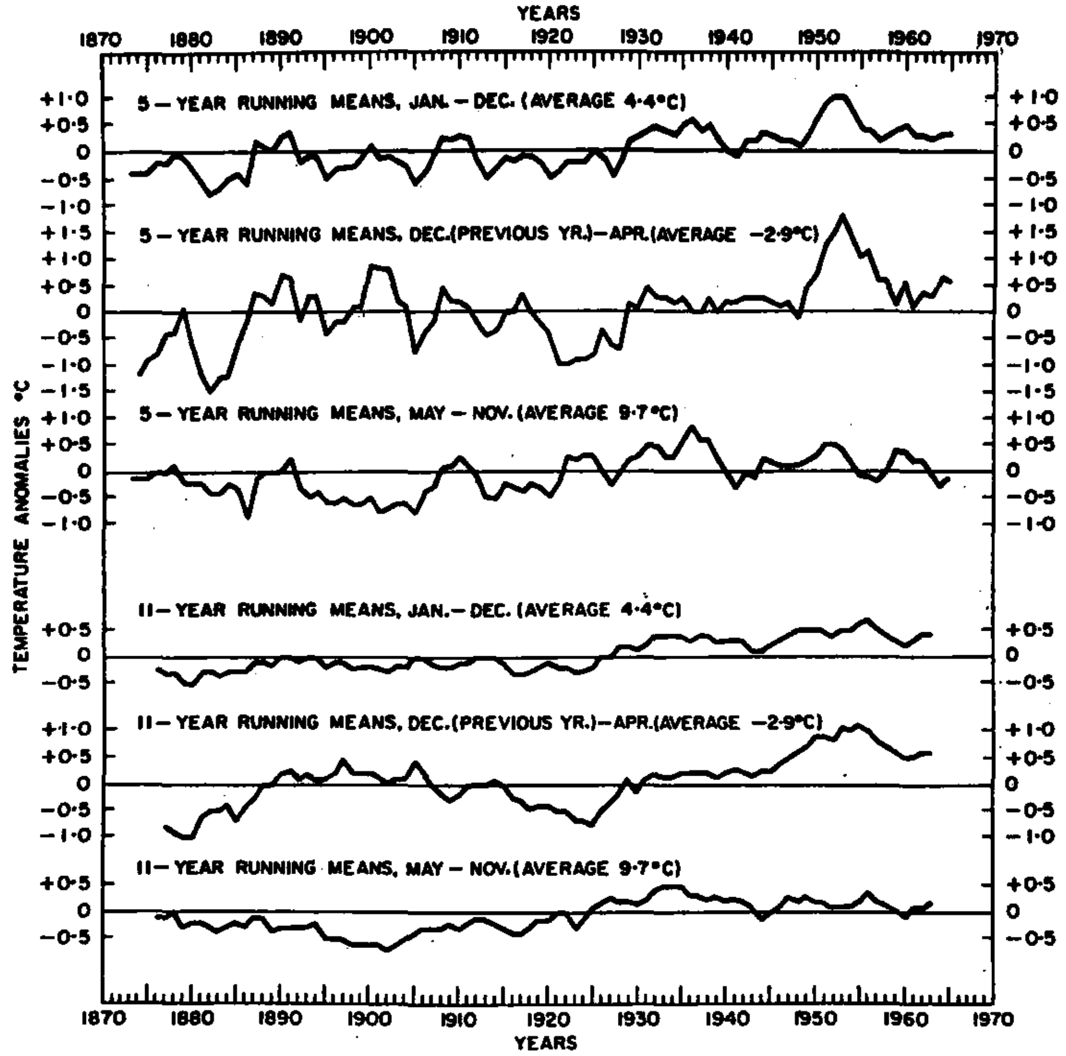

Fig. 4. Five-year and eleven-year anomalies of running means of air temperatures at Torbay-St. John's for 1872-1966 from the averages for 1872-1962. (The running means are attributed to the median year. The December-April average air temperature in the corresponding figure of Templeman, 1965 (Fig. 5) should be -2.9°C instead of 2.9°C.)

Temperature variations in the West Greenland area since 1950[1]

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This paper gives a short review of the variation of air temperature at three stations, of the variation of sea surface temperature anomalies and of some characteristic features of the variation of the temperature in the deeper water layers off West Greenland. For comparison, air temperatures and sea surface temperatures from earlier years are also considered.

Air temperature

Fig. 1 shows the 5-year running means of annual mean temperature at the three meteorologic stations, Ivigtut (61°12'N-48°10'W), Godthaab (64°11'N-51°43'W) and Jacobshavn (69°12'N-50°02'W) on the west coast of Greenland. Where observations for a few months are missing, temperatures have been calculated by interpolation from anomalies of neighbouring months.

After the rise in temperature in the late 1920's and the beginning of the 1930's, the temperatures decreased again to a minimum in the beginning of the 1950's. In the last half of the 1950's, the temperature has again been increasing slightly. The variation in temperature has been much greater in the northern part of the West Greenland area than in the southern.

Fig. 2a, 2b and 2c show the 5-year running means of the difference between summer temperature and winter temperature, where the summer temperature is the mean for the months June, July and August, and the winter temperature the mean for December, January and February. There has been very great variation in the annual amplitude, especially in the northernmost part of the area. When the rise in temperature occurred the annual amplitude decreased and during the minimum about 1950, the annual amplitude rose to a new maximum.

In the northern part of the area, the variation in the annual mean temperature is, in fact, mainly due to variation in the winter temperature.

Sea temperature

Fig. 3 presents the variation of sea surface temperature anomalies for area A_1 (West Greenland waters) and B (South Greenland waters) calculated from the sea surface anomalies given by Jens Smed.

The general trends for the sea surface temperatures are the same as

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[1] submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/59

those for the air temperature.

After the decrease in temperature to a minimum in the beginning of the 1950's, the temperatures have had a distinct increasing trend in the late 1950's and beginning of the 1960's, both in the West Greenland and the South Greenland area.

Subsurface temperature

The best data on subsurface temperatures is probably that from the standard sections worked by R/V *Dana* and M/C *Adolf Jensen* across the West Greenland Banks in July. For some of the most frequently worked stations the mean values and anomalies were calculated for different water layers and the result is given in the table below. Fig. 4 illustrates the variation in temperature from 1950 to 1966 at three of the stations, for the water layer between 200 m and 300 m at the stations west of Fylla Bank and west of Great Hellefiske Bank, and at 300 m in the northwestern part of the Disko Bay. The temperatures have generally had an increasing trend during the period and especially since 1963 this increase has been very strong.

Off Fylla Bank, the temperature seems to have culminated in 1964 or 1965, but in the area from Great Hellefiske Bank and northwards the temperatures were still increasing up to 1966.

The reason for this increase in temperature is doubtful, but it seems likely that it could be due to a less severe winter cooling in the area south and east of Greenland.

66°37' N - 57°05'W. x) (W. of Great Hellefiske Bank). Temperatures, July.

Depth interv.	Mean value	Anomalies.											
		1950	52	53	54	55	57	58	59	61	63	64	66
0- 50	2.14	-0.1	0.9	1.4	0.0	0.1	-0.8	0.2	-0.6	1.5	-0.6	0.1	-1.0
50-100	1.14	0.0	0.2	0.8	-0.2	0.2	-0.9	-0.4	-0.5	-0.3	0.5	0.2	0.6
100-200	1.83	-0.1	-0.9	0.6	-0.5	-0.2	-0.3	-0.3	-0.4	-0.2	0.5	0.4	1.7
200-300	2.81	-0.6	-1.5	0.6	-0.6	-0.6	-0.1	0.0	-0.1	0.1	0.2	0.8	1.7
300-400	3.42	-0.6	-1.4	0.2	-0.4	-0.4	0.1	0.2	-	0.0	0.2	0.8	1.4
400-500	3.78	-	-1.3	-0.1	-	-0.1	0.0	0.1	-	0.4	-0.7	0.6	1.0

x): For the years 1959, 1961 and 1964 the position is: 66°41'N-56°38'W.

65°06N - 56°30'W (W of Little Hellefiske Bank)

Depth interv.	Mean value	Temp.anomalies												
		1950	52	53	54	55	56	57	58	59	61	63	64	66
0- 50	2.10	-0.95	0.20	1.65	0.90	-1.05	-2.45	-0.65	0.40	0.65	0.15	0.85	1.40	-1.15
50-100	0.21	0.04	-0.81	1.24	-0.31	-0.26	-1.51	-1.61	-0.11	-0.21	1.14	1.44	1.49	-0.51
100-200	1.39	-0.29	-0.69	0.41	-0.44	0.51	-1.49	-2.09	-0.19	-0.49	1.26	0.86	1.61	1.01
200-300	3.11	-0.11	-1.56	0.19	-0.21	0.35	0.09	-2.21	0.09	-0.61	0.24	0.24	1.59	1.89
300-400	3.90	-0.75	-1.95	0.20	0.30	-0.10	0.90	-1.15	0.10	-0.10	-0.15	0.20	1.15	1.40
400-500	4.05	-0.75	-1.95	0.35	0.20	0.40	0.75	-0.55	-0.40	-0.20	0.05	0.45	0.90	0.80
500-600	3.85	-0.35	-1.05	0.60	-	0.60	0.55	-0.25	-1.05	-0.20	0.40	0.70	1.00	-0.95

63°44'N - 54°30'W. (Fylla Bank 6.) Temperature July.

Depth interv.	Mean value	Temp.anomalies 1950	52	53	54	55	56	57	58	59	60	61	63	64	65	66
0- 50	3.20	1.0	-2.0	0.2	1.0	-3.0	-0.3	1.9	0.2	0.4		0.1	1.0	1.6		-2.0
50-100	3.00	1.0	-2.8	-0.3	0.1	-2.7	0.0	0.6	-0.2	0.4		0.1	0.4	2.4		-2.0
100-200	3.30	0.6	-2.6	0.1	0.2	-1.6	0.8	0.6	0.6	0.4		0.2	0.1	2.1		-0.2
200-300	3.96	0.0	-2.1	0.1	0.0	-0.9	0.3	0.2	0.1	0.2		0.0	0.2	1.3		0.8
300-400	4.22	-0.2	-1.4	0.0	0.0	-0.2	0.1	-0.1	0.0	-0.1		0.0	-0.1	0.9		1.0
400-600	4.27	-0.1	-0.9	0.0	-0.2	0.0	-0.1	-0.2	-0.1	-0.1		0.1	-0.1	0.6		0.8
600-800	4.14	-0.1	-0.4	0.0	-0.2	0.0	-0.3	-0.2	-0.1	-0.1		0.1	0.1	0.4		0.8
800-1000	3.90	-0.2	-0.3	-0.1	-0.2	0.0	-0.2	-0.2	-0.1	0.0		0.2	0.2	0.2		0.6

63°53'N - 53°22'W. (Fylla Bank 4.) Temperatures July.

Depth interv.	Mean value	Temperature anomalies 1950	52	53	54	55	56	57	58	59	60	61	63	64	65	66
0- 50	2.07	0.1	-0.1	1.2	-0.4	-1.5	0.8	-0.9	-1.0	-0.3	0.2	1.7	0.3	0.2	0.0	-0.5
50-100	1.33	0.9	-1.2	1.0	-0.1	-1.0	0.6	0.4	-0.6	-0.1	-0.2	0.4	0.3	0.2	0.4	-0.4
100-200	1.85	0.4	-1.8	0.6	0.6	-1.0	1.2	1.2	-0.8	-0.6	0.0	-0.1	0.1	0.2	0.3	-0.2
200-300	2.88	0.4	-2.3	0.6	0.4	-0.5	0.9	0.3	0.1	-1.0	0.3	-0.4	0.5	0.6	0.7	0.4
300-400	3.79	0.1	-2.9	0.5	-	-0.2	0.4	0.0	0.5	-0.3	0.4	0.4	-1.9	0.8	1.0	1.0
400-500	4.22	-0.3	-2.2	0.3	-	-0.3	0.0	-0.2	0.0	0.1	0.3	-0.3	-0.6	0.7	1.2	1.2

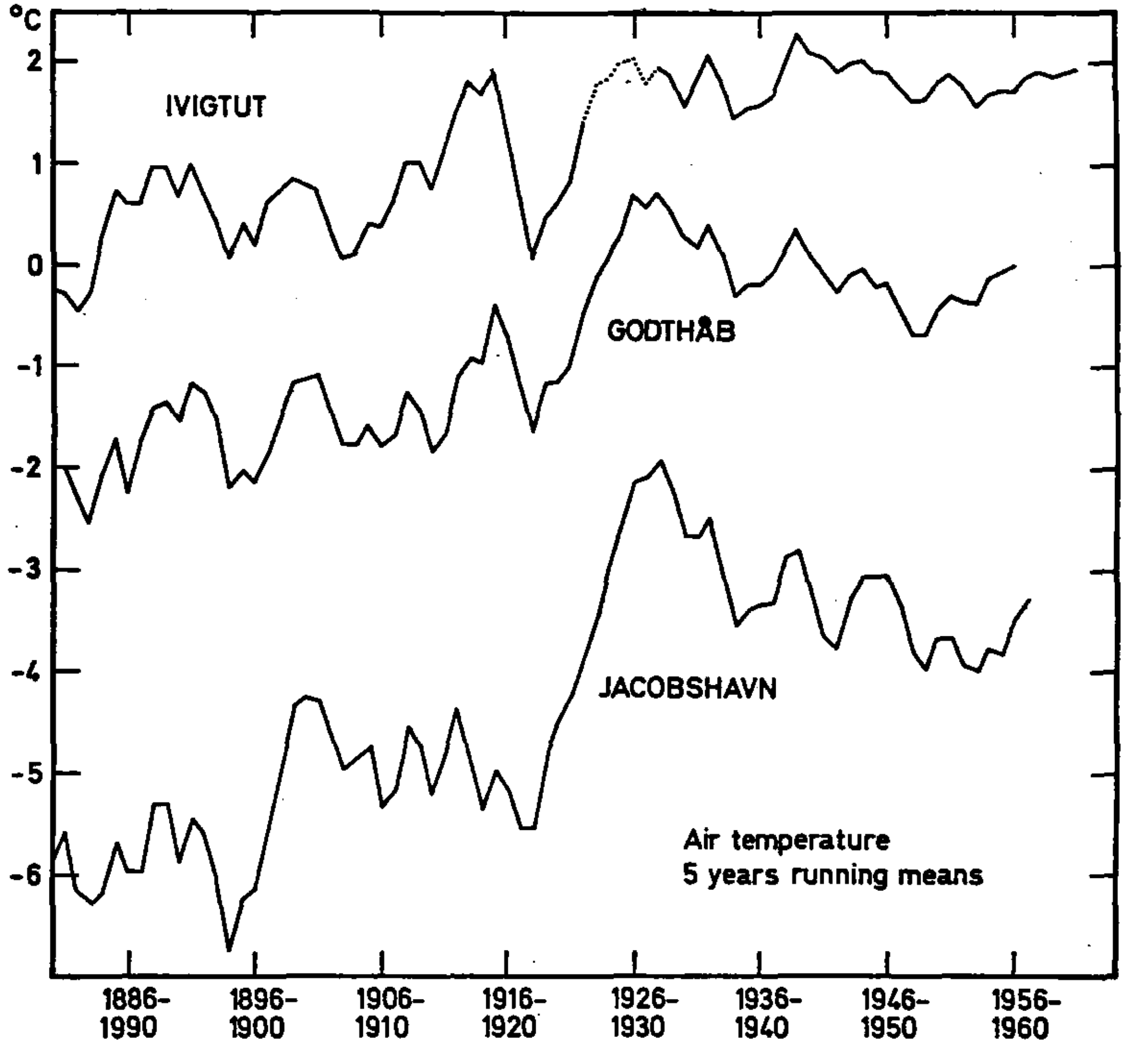

Fig. 1. Annual mean air temperature at Ivigtut, Godthaab and Jacobshavn, 5 years running means.

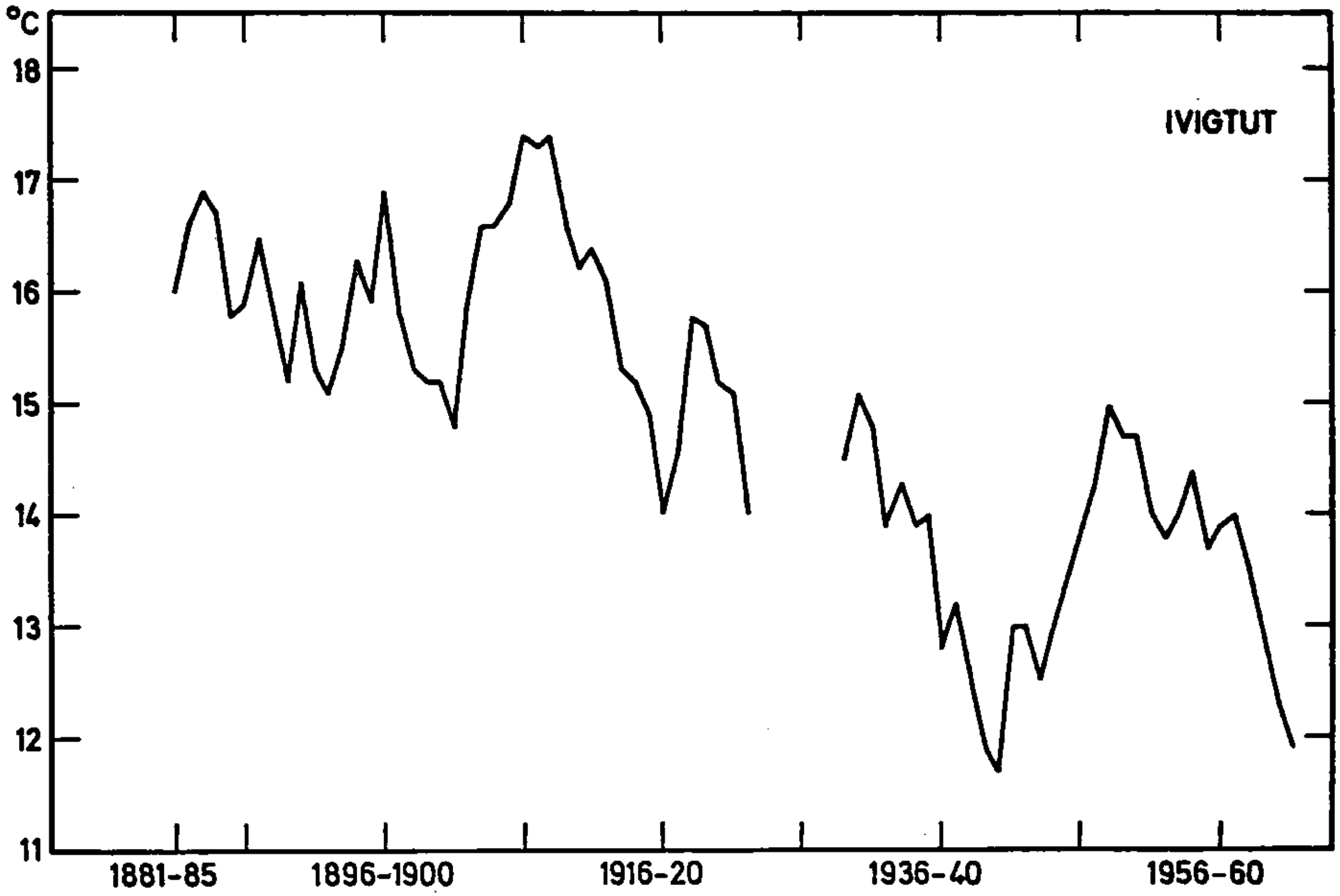

Fig. 2a. Difference between summer temperature and winter temperature at Ivigtut. 5 years running means.

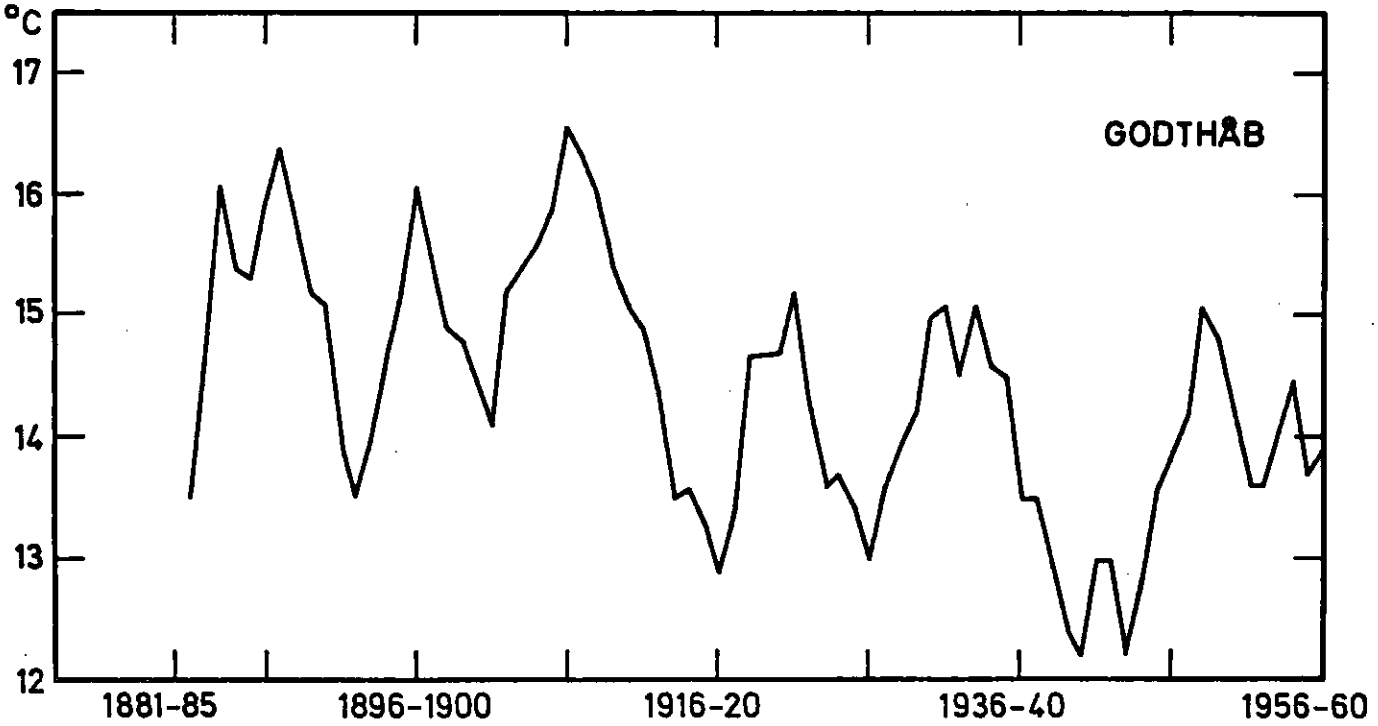

Fig. 2b. Difference between summer temperature and winter temperature at Godthaab. 5 years running means.

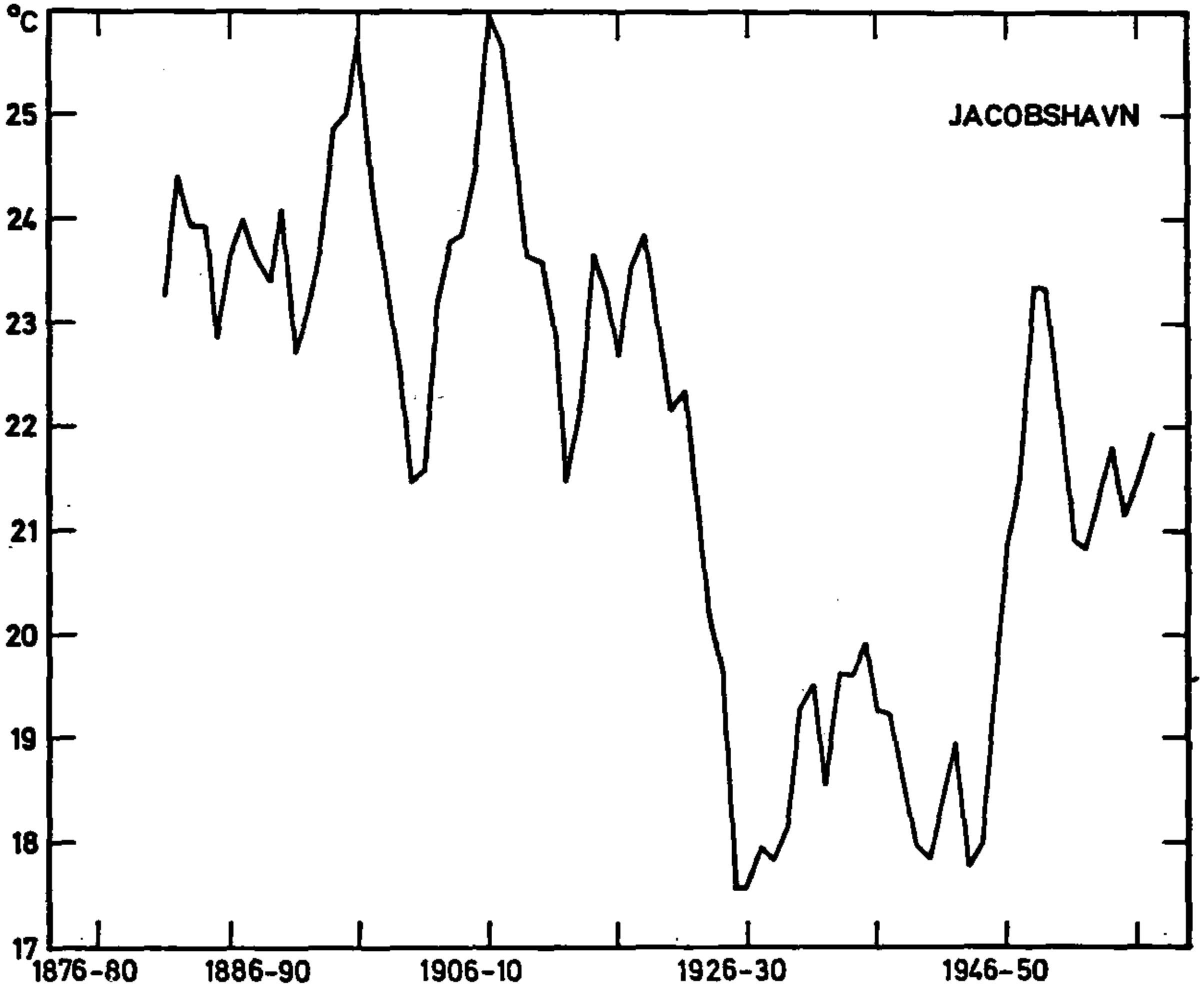

Fig. 2c. Difference between summer temperature and winter temperature at Jacobshavn. 5 years running means.

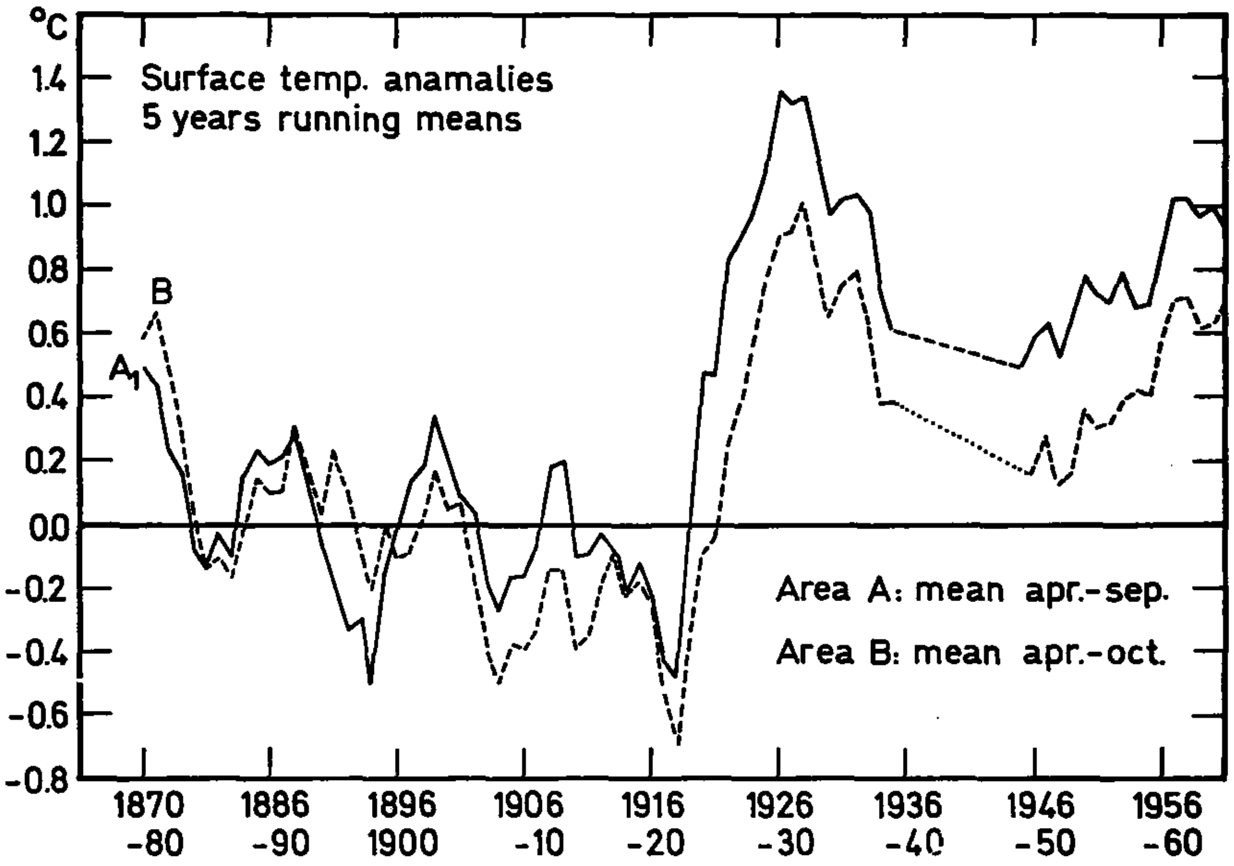

Fig. 3. Sea surface temperature anomalies for area A_1 (West Greenland) and area B (South Greenland), 5 years running means.

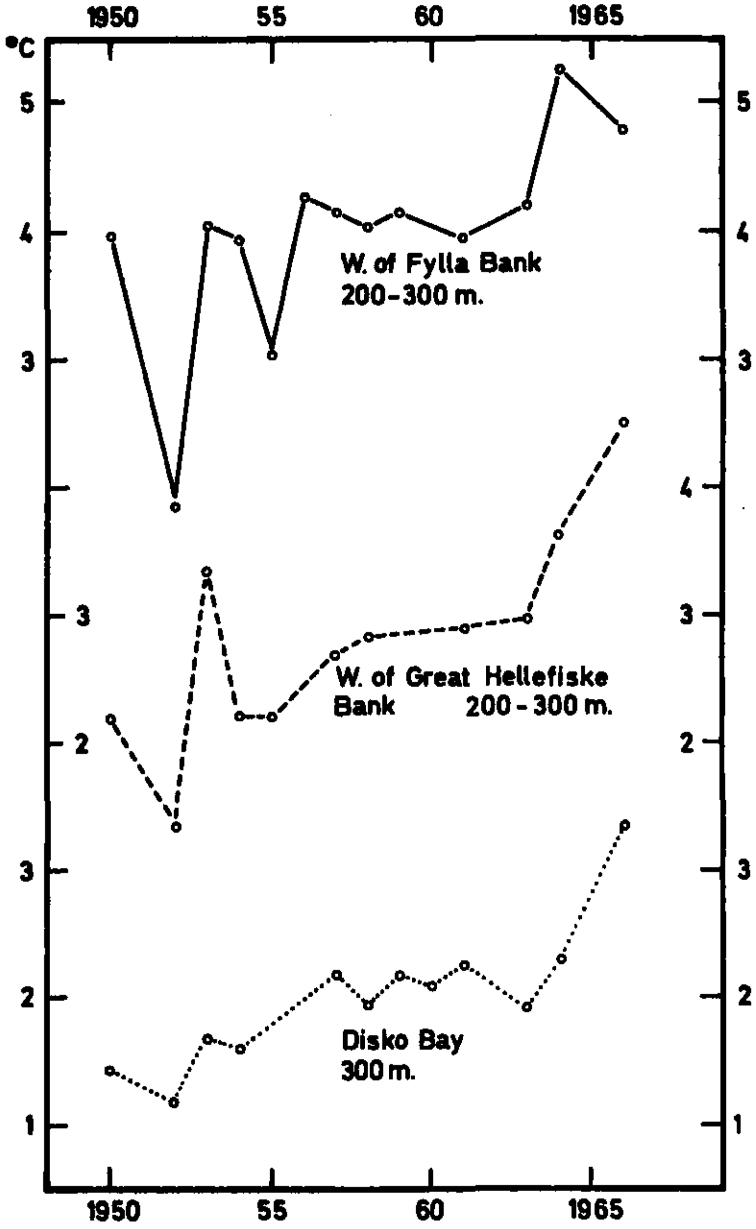

Fig. 4. Temperatures for July. W of Fylla Bank (63°44'N-54°30'W), west of Great Hellefiske Bank (66°37'N-57°05'W) and in Disko Bay (69°17'N-52°40'W).

Hydrographic fluctuations off West Greenland during the years 1959-1966[1]

by Johan Blindheim
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Introduction

Research vessels from the Institute of Marine Research, Bergen, have investigated the waters off West Greenland in March-April since 1959. The principal aim of these cruises was to study the stock of cod in the area during the spawning season, and record hydrographic factors important for the recruitment and distribution of cod.

At the meeting of the Research and Statistics Committee of the International Commission for the Northwest Atlantic Fisheries held in Madrid in 1966, it was recommended to obtain synthesis of hydrographic and meteorological fluctuations observed in the ICNAF Area during the recent years. The present paper is intended to contribute to the preparation of such a synthesis.

Materials and methods

The material dealt with here consists mainly of observations during the period March-April, but in a few cases, observations made during the first days of May are included. Since 1959, cruises to the West Greenland waters have been repeated every year, and data collected to 1966 are worked up, allowing a period of 8 years to be studied. More or less the same program has been followed every year. Usually 4 or 5 hydrographic sections have been worked seaward from the coast between Noname Bank and Lille Hellefiske Bank. Further to the north, navigation has been hindered by ice, except for a narrow lane along the coast. The most northern station on each cruise was usually located off Holsteinsborg in about lat 66°30'N to 67°N.

From 1959 to 1962, the hydrographic stations were worked to a maximum of 2,000 m depth, but since 1963 all stations have been worked to the bottom regardless of depth.

The lengths of the sections have varied some with the time available, ice conditions and weather conditions, but generally the sections are longer in the years since 1963 than in the previous years. The station grid worked in 1966 is shown in Fig. 1.

The study of the waters of the West Greenland Current is based on the data from the sections worked off Frederikshaab and off the Dana Bank.

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[1] Submitted to the 1967 Annual Meeting of ICNAF as ICNAF Res.Doc.67/27

These sections are situated south of the area where the greater portion of the West Greenland Current bends westward, and will presumably give good information about the inflow carried by this current.

Temperature and salinity

1959

In 1959 a section was worked both off Frederikshaab (Fig. 2) and off the Dana Bank. The temperature in the upper 100 m was above 0°C throughout these sections, and only close to the shore was the temperature below 0.5°C. The salinities in the same layers were below 34‰ over the inner part of the Shelf, on the outer part being around 34.1‰. The Irminger component of the current exhibited salinities slightly above 34.90‰ with associated temperatures mainly below 4.50°C. In the section off Frederikshaab, the temperature was higher than 4.50°C only in a small core between 400 and 500 m depth. Off Dana Bank the highest temperature was 4.35°C.

1960

Fig. 3 shows a section in April 1960 off Frederikshaab. The temperatures in the upper 100 m varied between 1°C at depths less than 30 m over the inner part of the Shelf, and about 3°C at 100 m depth farther out on the section. The corresponding salinities varied between about 33.9‰ close to the shore and 34.5‰ at the western end of the section.

The salinity of the Irminger component exceeded 34.90‰ from 300 m downward. Off the slope relatively large water masses exhibited salinities above 34.95‰ with corresponding temperatures up to 4.72°C.

1961

The conditions in 1961 were apparently not very different from those in 1960. Fig. 4 shows the section toward the southwest from Dana Bank. In the upper layers the distribution of temperature and salinity was almost the same as in 1960. The salinities in the Atlantic component of the West Greenland Current exceeded 34.95‰ between approximately 300 m and 500 m depth, but no temperatures higher than 4.43°C were observed.

1962

In 1962 no section was worked off Frederikshaab or on Dana Bank, but according to the sections off Noname Bank and across Fylla Bank, the temperatures in the upper layer were generally lower than in the previous years. The conditions in the Irminger component showed no features much different from those in the previous years.

1963

Fig. 5 shows a section off Frederikshaab from 1963. Rather low temperatures were observed over the Shelf, and salinities below 34.00‰. Off the Shelf, however, the temperatures were high from the surface to 100 m depth, mostly between 2° and 3°C. The corresponding salinities were between 34.25 and 34.75‰. The Irminger component was not well developed, its mean temperature being about 4.2°C, the maximum 4.45°C. Off the slope salinities were slightly above 34.90‰ at depths greater than approximately 200 m.

1964

A section from across Dana Bank in 1964 is illustrated in Fig. 6. The salinities in the upper layers were mainly below 34.00‰ and in the greater part of the section the temperatures were below 0°C at depths less than 50 m. The isotherm for 2°C was situated at about 100 m depth.

The temperatures of the Irminger component were considerably higher in this section. Relatively large water masses were warmer than 4.50°C with corresponding salinities around 34.90‰. Just off the slope, the temperature exceeded 5.0°C between 450 and 600 m depth. The maximum temperature in this extremely warm core was 5.16°C, and the salinity 34.96‰.

1965

The section off Dana Bank in 1965 is illustrated in Fig. 7. Over the Shelf temperatures were below 0°C in the surface layer outward to about 50 nautical miles off the coast. At the western end of the section, 70 nautical miles off the coast, the temperature was about 0.8°C near the surface and 3.9°C at 100 m depth. Throughout the section the salinities of the surface layer were below 34.00‰, and over the Shelf even below 33.5‰.

The highest temperatures of the Irminger component off the slope were found at relatively moderate depths, between 150 and 500 m. The temperatures exceeded 4.50°C, the maximum of 4.81°C being observed at 250 m depth. The salinity of this water was 34.90‰. Salinities exceeding 34.90‰ were encountered downward from 400 m depth, but no values higher than 34.93‰ were observed.

1966

In 1966 (Fig. 8) subzero temperatures were observed in the upper 50 m over the Shelf off Frederikshaab. The salinities were between 33.00‰ and 33.5‰. Outside the Shelf area the salinities in the upper 100 m were well above 34.00‰, and temperatures were also high, approximately 4.4°C at station 124 about 60 nautical miles off the coast.

The Irminger component exhibited extreme conditions; the temperatures were above 4.50°C at depths between approximately 100 and 700 m at some distance from the slope. In the slope area such high temperatures were observed down to about 1,000 m depth. As shown in Fig. 8 there were also great water masses with temperatures above 5.00°C. A maximum of 5.28°C were observed at 300 m depth. The associated salinities were also high, and the figure shows that an intermediate layer with salinities above 34.95‰ was found along the whole section between approximately 150 and 450 m depth. In this layer most of the observed salinities were slightly below 35.00‰, mostly 34.98‰. At station 123, 35.001‰ was observed at 300 m and 35.000‰ at 400 m depth.

Off Dana Bank the conditions of the Irminger component were similar to those off Frederikshaab; great water masses with temperatures above 5.00°C and salinities up to 34.99‰ were observed. In the surface layer, the temperatures were below 0°C in the greater part of the section, and the salinities were considerably below 34.00‰.

Surface temperatures

A comparison of these sections for the different years reveals that there have been fluctuations in the Atlantic inflow of the West Greenland Current as well as in the conditions of the upper layers strongly influenced by the Polar component of the West Greenland Current. There is no rule that the upper layer should be warm when the Irminger component is well developed. Thus, in 1959, the waters of the upper layers were relatively warm but the temperatures and salinities of the Irminger component were rather low. The observations from 1960 revealed a warm surface layer at the same time as the Irminger component was well developed. In 1964 and particularly in 1966, however, the Irminger component was extremely well developed, but the temperatures and salinities of the upper layers were relatively low.

The temperature variations in the upper layers, indicated by the hydrographic sections, may best be illustrated by horizontal temperature charts. Such charts were therefore prepared at 4 m depth for all the 8 years, based on observations from sea surface thermographs. The charts for 1961 and 1966 are shown in Fig. 9 and 10. The years 1959, 1960 and 1961 stand out as warm years and of these 1961 shows the most extreme conditions. In this year, subzero temperatures were observed only in Julianehaab Bay and a few places very close to the coast farther to the north. North of lat 66°N temperatures below -1°C were observed at some distance from the coast. Temperatures above 1°C were found over the slope as far north as approximately 65°30'N. Over the Lille Hellefiske Bank the temperatures were between 0.5 and 1°C, but south of this bank the isotherm for 1°C followed the coastline at a distance of about 15 to 30 nautical miles.

The conditions in 1959 and 1960 were similar to those in 1961, even though temperatures above 1°C did not extend so far to the north in these years. In 1959 there was also more cold water along the coast than in 1961.

In 1962, no temperatures above 0°C were observed north of 66°N, and the temperatures above 1°C seemed to extend to about 63°N. This is, however, a rough approximation since all observations were made within 60 to 70 nautical miles off the coast. In the Shelf area, waters with temperatures below 0°C were observed along the whole coast, its extension being about 15 to 30 nautical miles off shore. The isotherm for 0°C bent to the west and southwest at about 65°45'N.

In 1963, the conditions of the surface layer south of about 64°N were apparently not very different from those in 1962. North of this latitude, however, only subzero temperatures were observed, and compared with the preceding years this means considerable decrease. The largest temperature decrease occurred in the area of northern Fylla Bank and Lille Hellefiske Bank.

The chart for 1964 shows that temperatures above 1°C were not observed north of 62°N, and even at 60°N temperatures above 1°C were observed only in a narrow belt off the slope extending over hardly 2 degrees of longitude. This year the cold waters from the Labrador area were apparently extended farther to the east, and in 62°N, west of 54°W, the temperatures were below 0°C. Northward from this latitude only a narrow tongue of water warmer than 0°C extended toward 64°N.

In 1965, the surface temperatures were generally a little higher than in 1964. This was particularly true for the western part of the area investigated where the westerly cold waters this year did not extend so far east to influence the conditions.

Fig. 10 shows that for 1966 very low temperatures were observed north of about 62°30'N. This year a relatively sharp front developed in the east-west direction, and the isotherms for 0°C and 2°C were close to each other. North of 63°N no temperatures above -0.5°C were observed, and northward from this latitude the year 1966 obviously revealed a colder surface layer than the previous years since 1959. South of 62°N, however, the temperatures were rather high at some distance from the coast.

Surface temperatures - air temperatures

In order to compare the temperature fluctuations in the surface layer with the climatic conditions, monthly mean temperatures from three meteorological stations have been scrutinized. These stations are: Ocean Weather Station "B" in 56°30'N, 51°00'W, Prince Christian Sound near Cape Farewell, and Egedesminde in Disko Bay. The mean temperatures are taken from monthly climate charts prepared for the Institute of Marine Research by the Meteorological Institute in Bergen. The variations of the mean temperature for the period December-March in each winter are illustrated by Fig. 11. The coldest winters occurred in the years around 1960, while the winters in the years 1963-1965 were relatively mild. Consequently, there seems to be little relationship between the temperatures in the surface layer in the Davis Strait and the mean air temperature during the preceding winter. The reason for the lack of a relationship may be to some degree that the temperature observations at these meteorological stations are not representative for the area investigated, and that the wind conditions also have an influence. The latter possibility would explain the great eastward extension of the cold waters from the Labrador side in 1964, as due to a prevailing westerly wind during the previous months.

Surface salinity and stability

The salinity in the upper layers seems also to be of great importance since it varies considerably in the different years. Fig. 12 illustrates the variations in the mean salinity for the years between 0 and 50 m depth in the sections across Fylla Bank. The year 1961 had the highest value of 34.26‰, while 1965 and 1966 only had 33.36‰ and 33.54‰ respectively. These variations in salinity influence the stability in the upper layers, and again the temperature conditions, agreeing well with the observations made in the area. It seems, therefore, clear that during the winter the temperature of the upper layers depends more on the stability than on the air temperature. Fig. 13, with mean sigma-t curves for the sections across Fylla Bank in 1960 and 1966, demonstrates clearly that there was a more stable stratification in the upper 200 m in 1966 than in the former year. An example of extreme conditions is shown in the sigma-t curves for station 86 in 1965 and station 259 in 1961 (Fig. 14) both situated on the western slope of the Lille Hellefiske Bank. The figure demonstrates clearly that the stratification of the water masses was far less stable in 1961 when the salinities in the surface layer were high, than in 1965. Thus, low salinities in the surface layer create very stable stratification, and the convection resulting from the winter cooling will not reach deep. Thereby, the loss of heat takes place only in a thin surface layer. A more saline surface layer creates less stability, thus permitting a deeper convection during winter cooling. The heat will then be drawn from a considerably thicker layer, extending down to a depth of several hundred metres. However, a smaller temperature decrease near the surface will consequently occur.

Also, the high temperature in the Irminger component of the West Greenland Current in 1964 and 1966 may to some degree be explained by the lack of deep-reaching convection in these years.

Surface temperature - cod

It is possible that the variations of temperature in the upper layers influence the behaviour of the cod in such a way that it finds preferable temperatures at different depths in the different years, as indicated by the varying fishing depths with bottom longline on the cruises. In 1960 and 1961 the mean fishing depth was 155 and 210 m respectively, while in 1964 and 1966 it was 260 and 270 m respectively. The varying fishing depths are probably determined by the temperatures on the fishing grounds, which in 1964 and 1966 to some degree excluded the cod from the Banks at depths less than say 200 m.

Summary

Hydrographic data from the West Greenland waters in March-April during a period of 8 years, from 1959 to 1966, were studied. The study is mainly based on sections worked off Frederikshaab and off the Dana Bank. It is shown that changes occur in temperature, salinity and also in vertical extent of the Irminger component of the West Greenland Current. Thus, in 1960 and particularly in 1966, the Irminger component was well developed. Such changes may be due partly to fluctuations in the main structure of the Irminger Current, but also to the extent of the convection during the different winters. The depth of convection is dependent upon the salinities in the surface layer, where considerable variations from one year to the next are observed. In the years around 1960, the salinity in the surface layer was relatively high, but decreased in later years, resulting in a cold and very stable surface layer in the years 1964-1966. In the years 1959-1961, a considerably warmer surface layer was observed, with convection reaching deeper because of less stability.

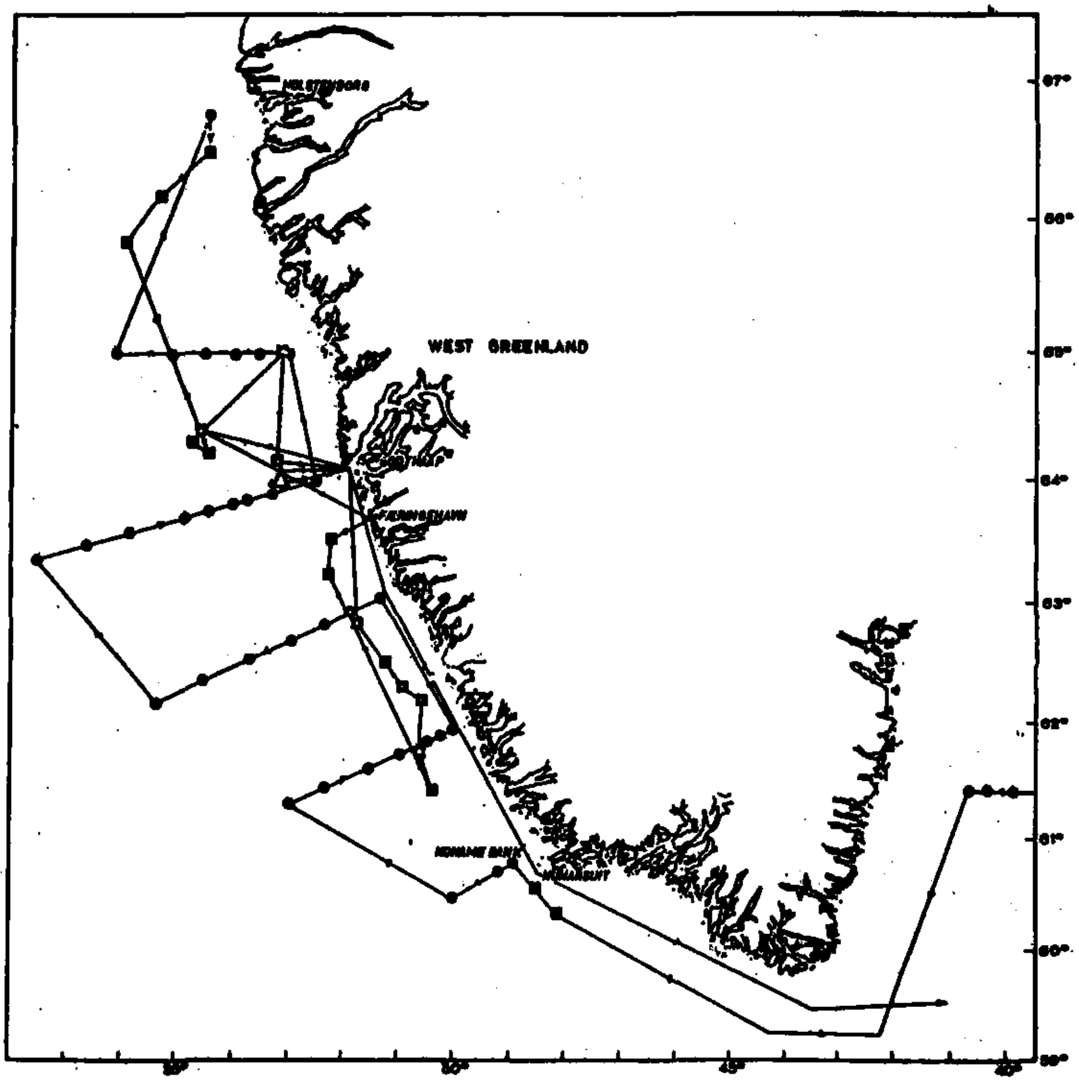

Fig. 1. Station grid for 1966.

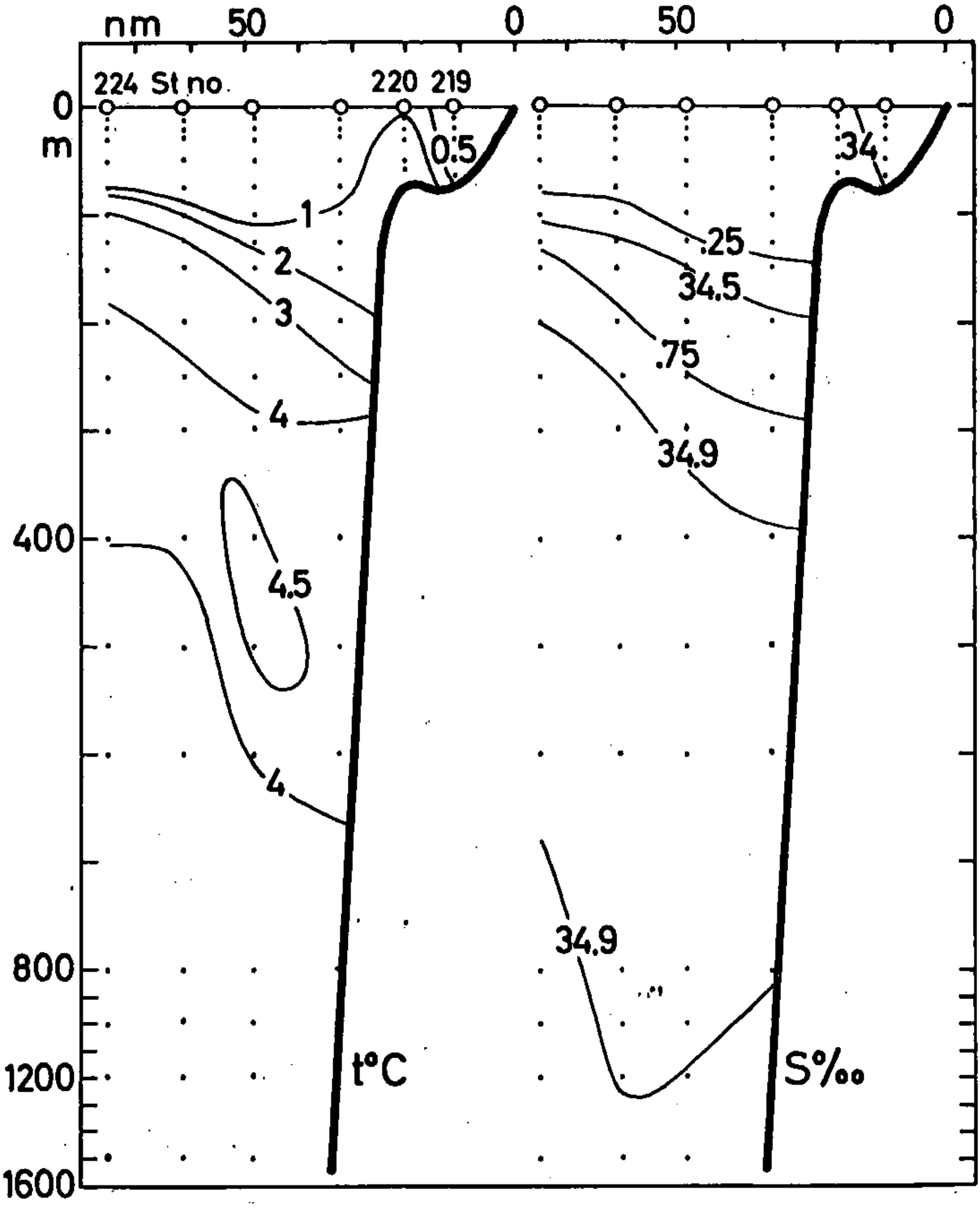

Fig. 2. Hydrographic section off Frederikshaab, 11 April 1959.

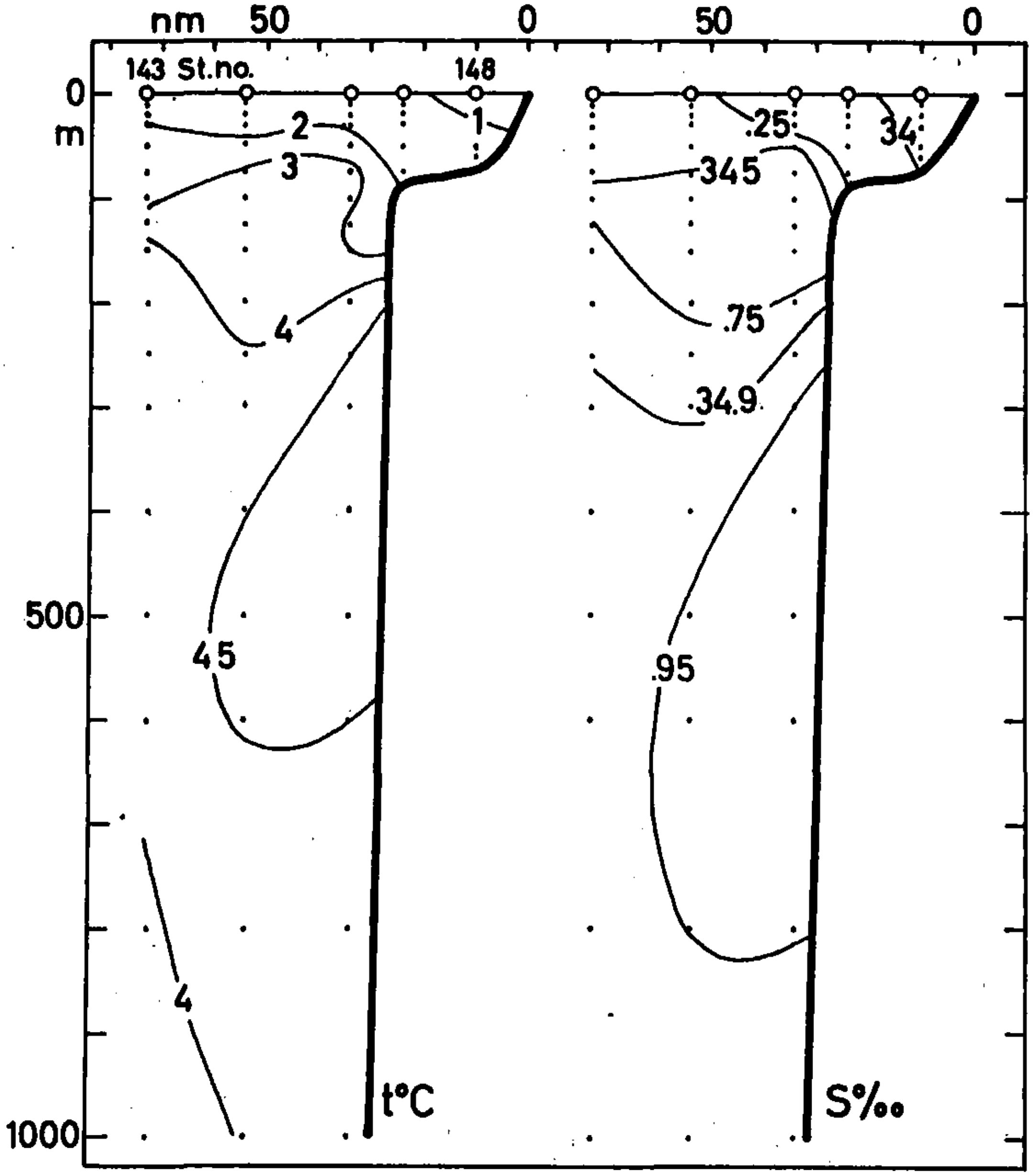

Fig. 3. Hydrographic section off Frederikshaab, 7-8 April 1960.

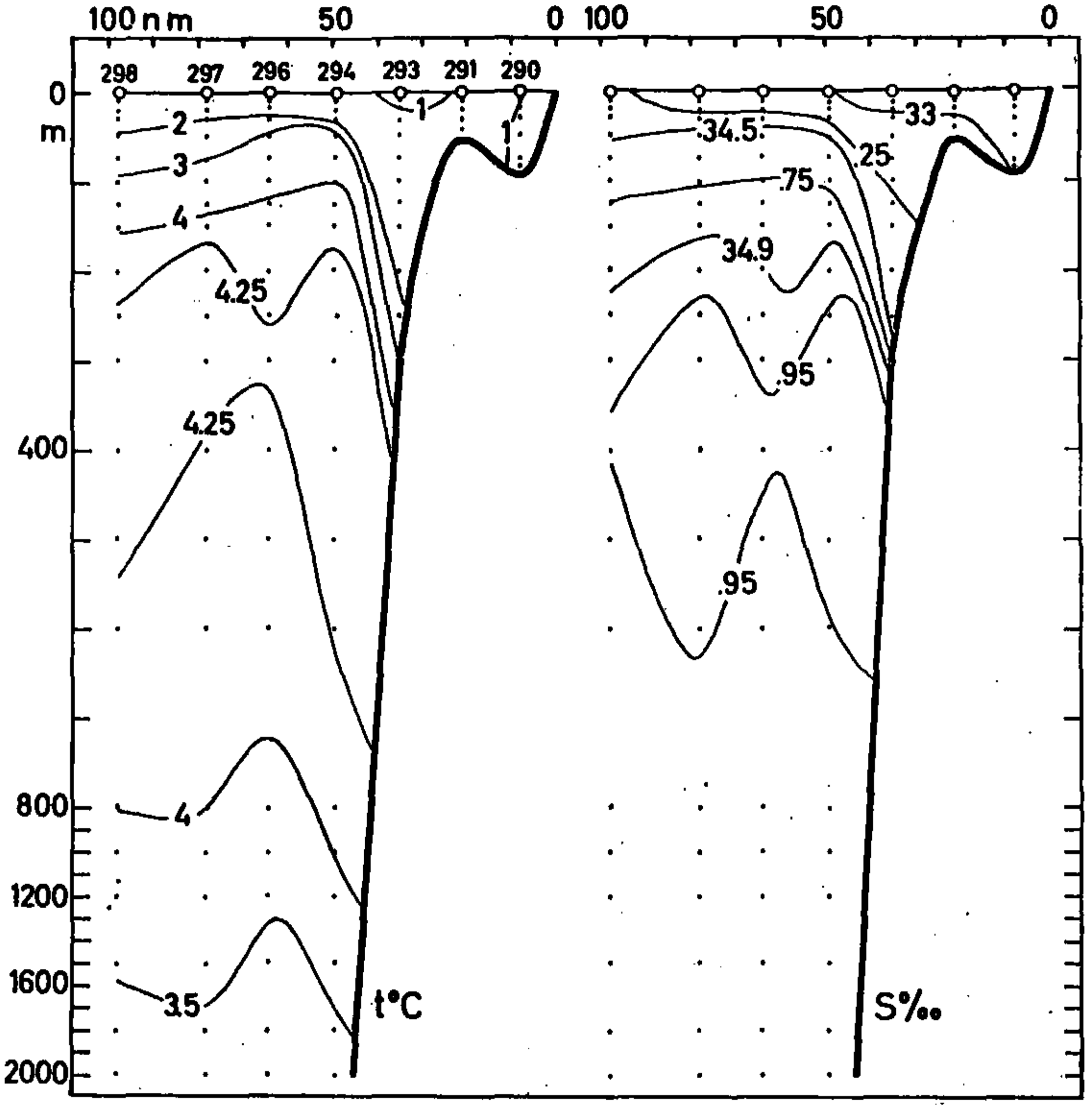

Fig. 4. Hydrographic section off Dana Bank, 3-5 April 1961.

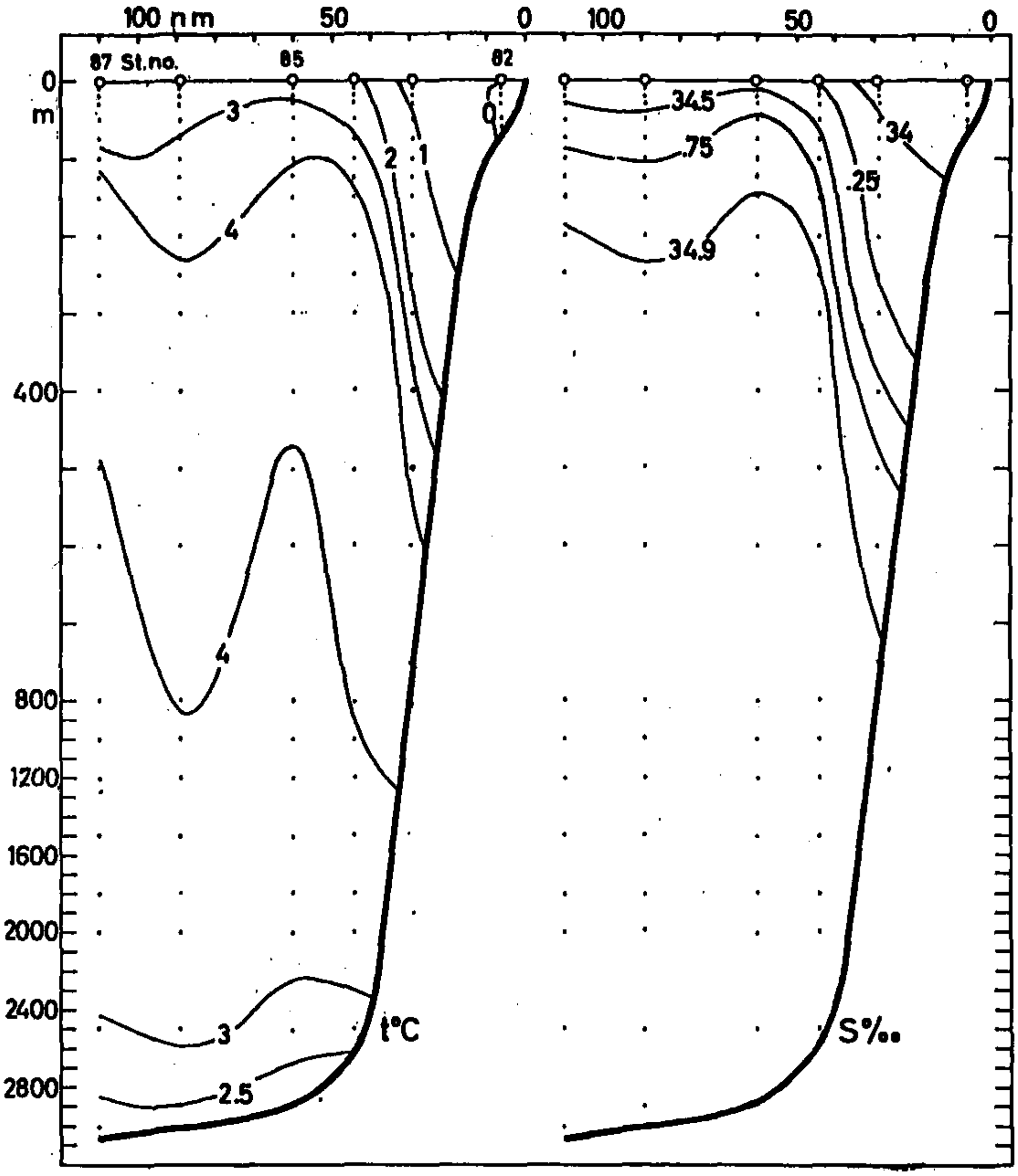

Fig. 5. Hydrographic section off Frederikshaab, 11-12 April 1963.

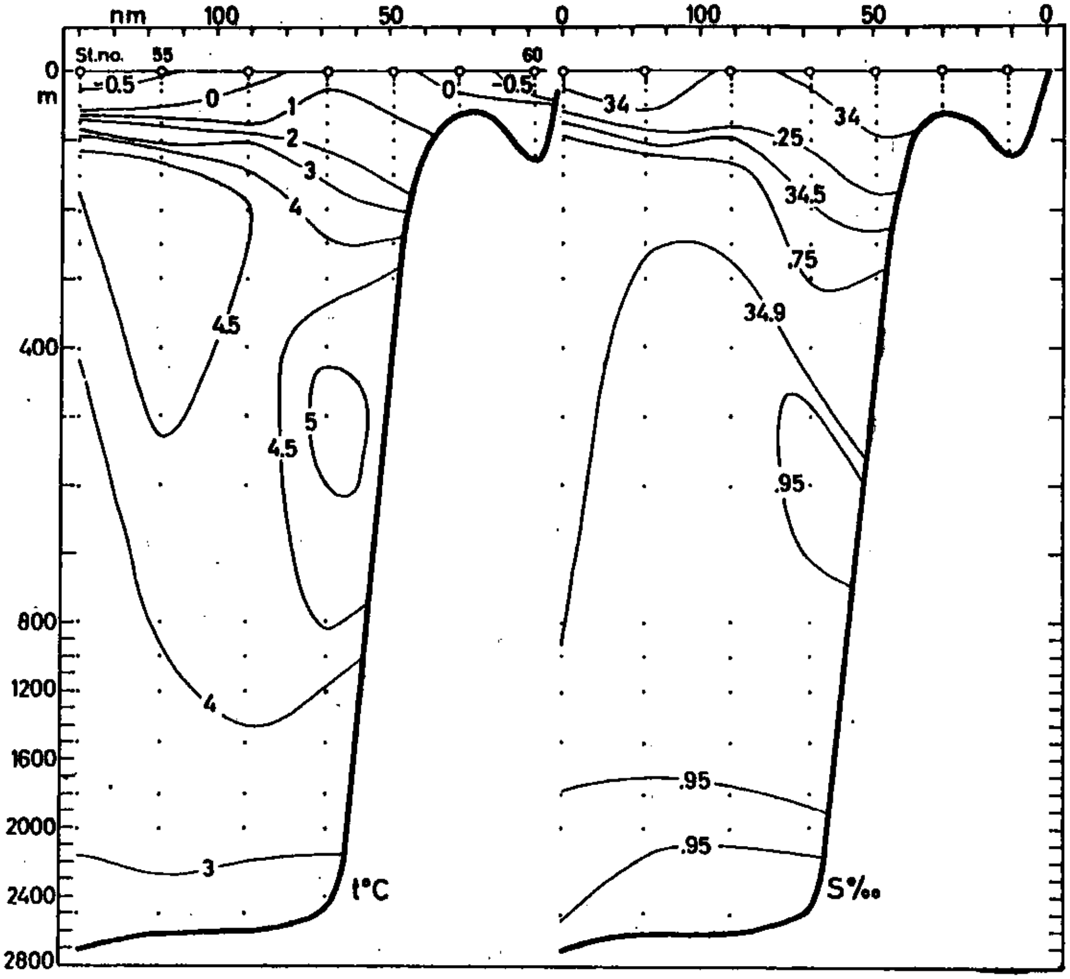

Fig. 6. Hydrographic section off Dana Bank, 14-15 April 1964.

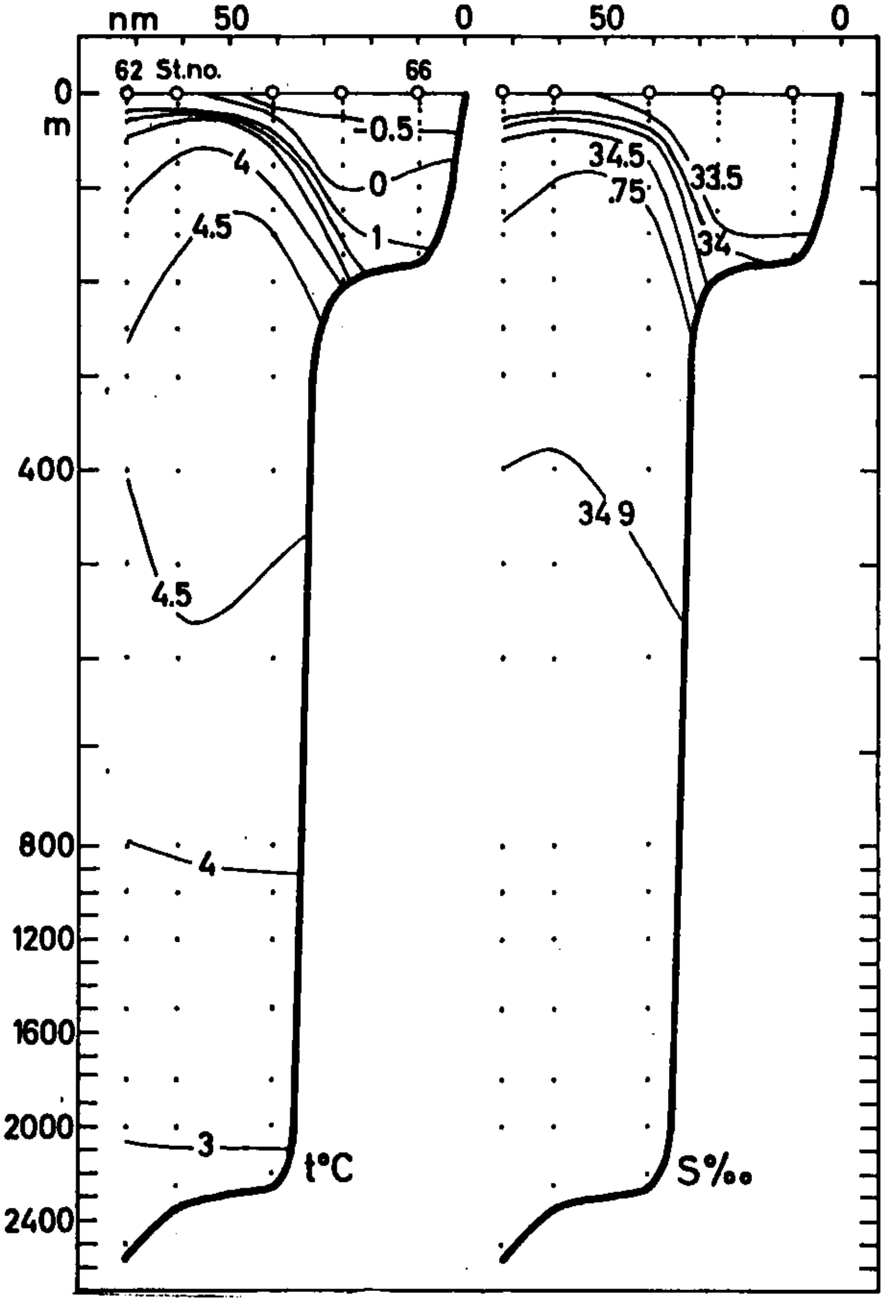

Fig. 7. Hydrographic section off Dana Bank, 10-11 April 1965.

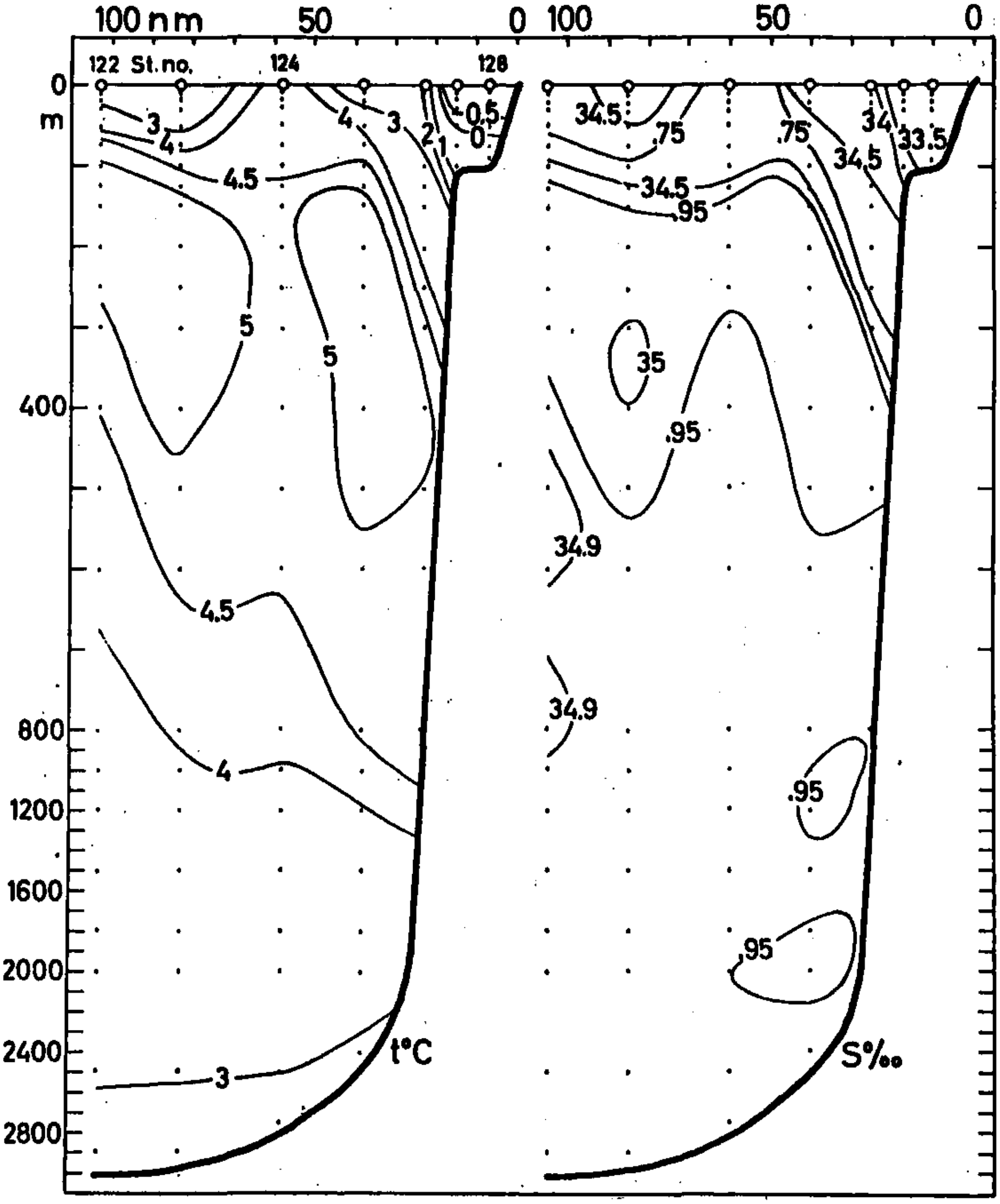

Fig. 8. Hydrographic section off Frederikshaab, 30-31 March 1966.

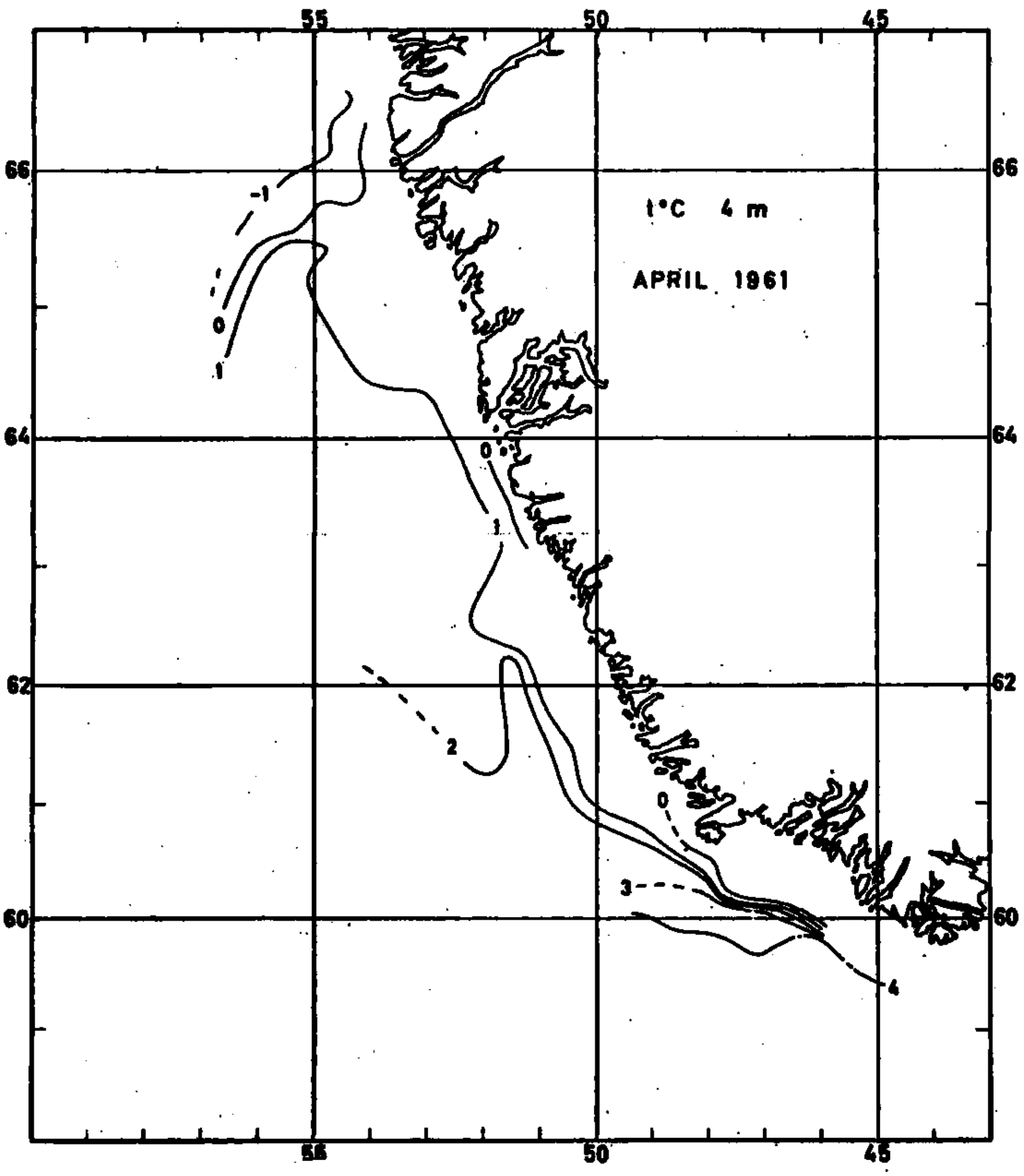

Fig. 9. Temperature distribution at 4 m depth in April 1961.

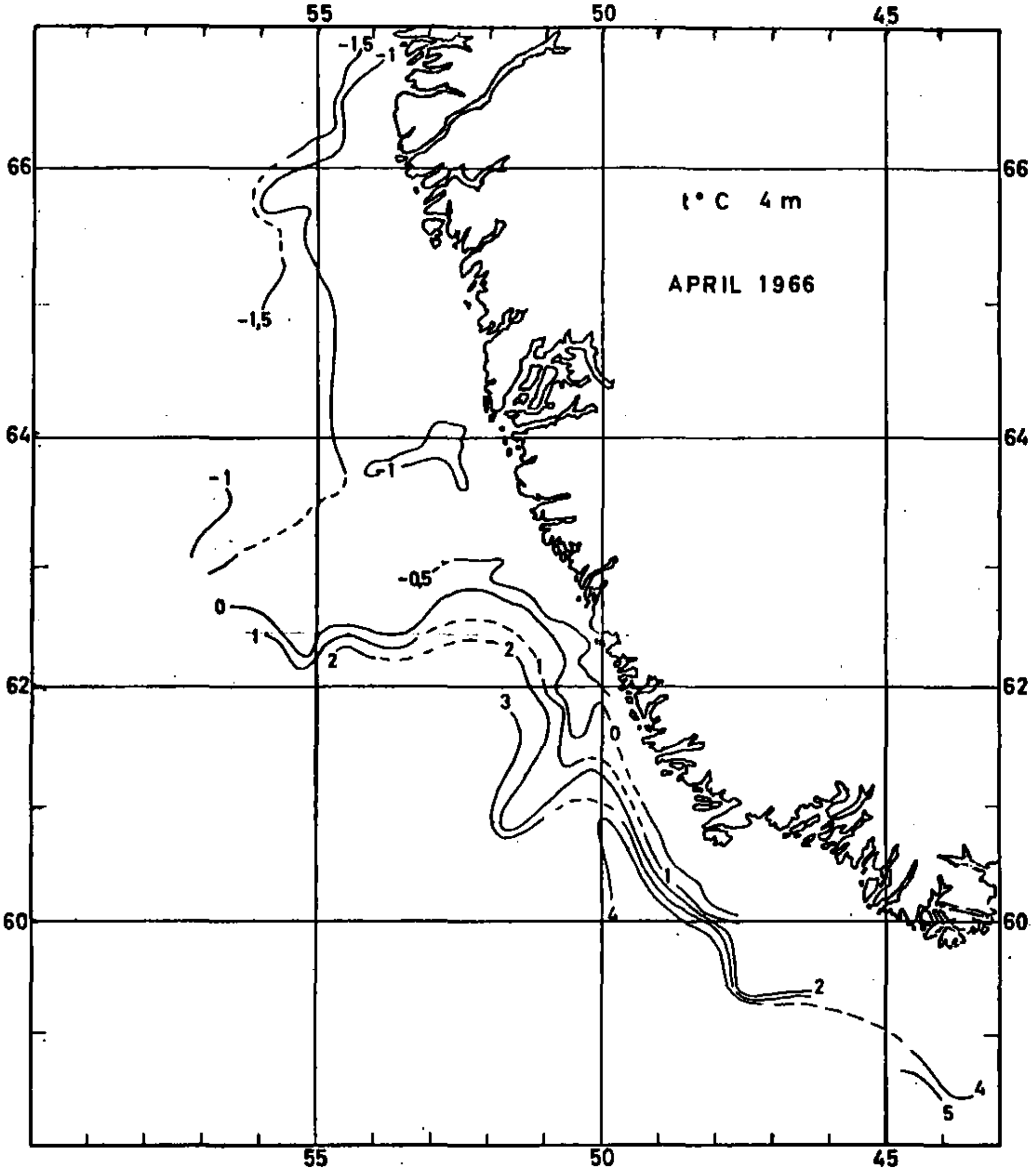

Fig. 10. Temperature distribution at 4 m depth in April 1966.

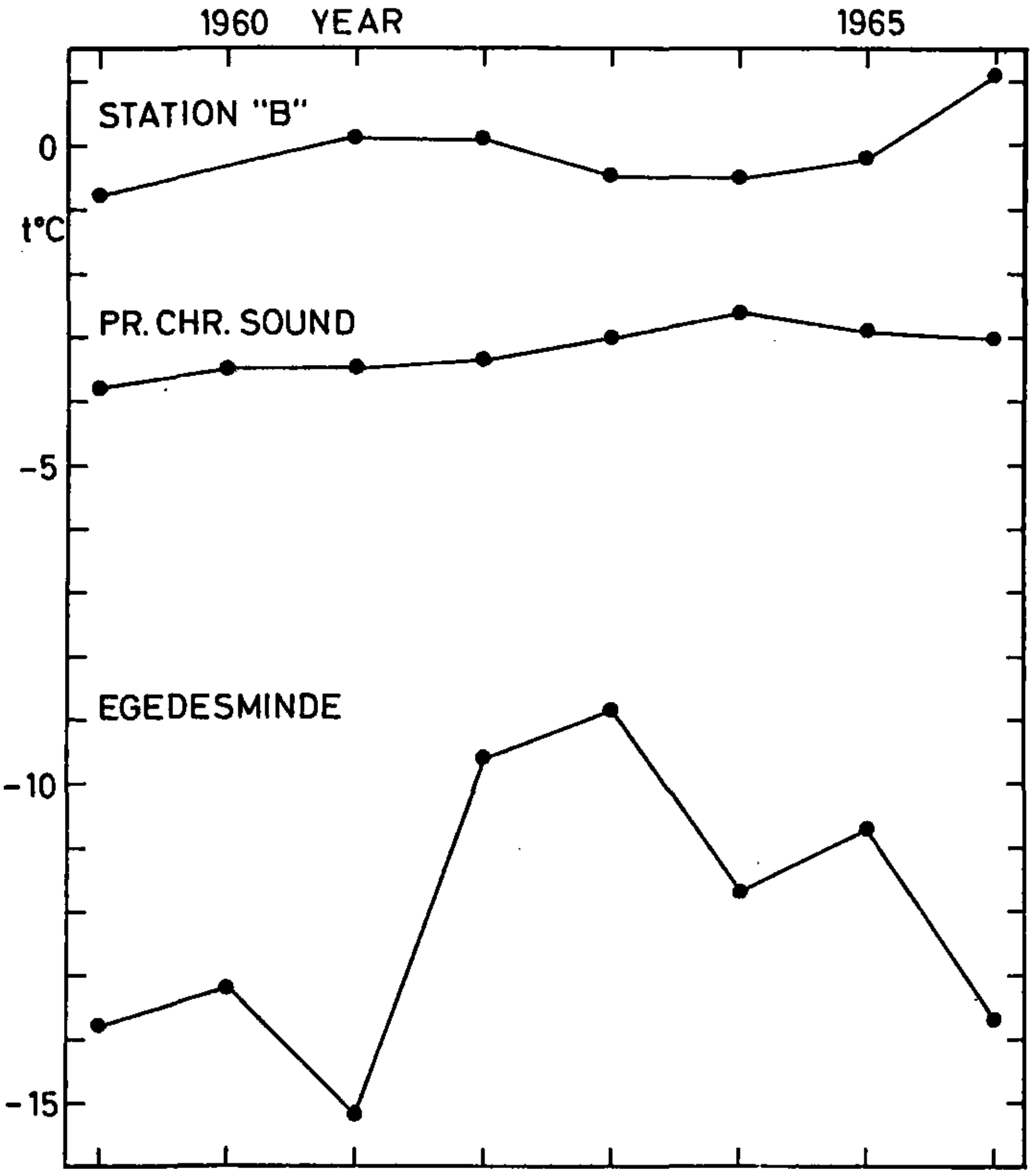

Fig. 11. Mean air temperature for the period December-March during the winters 1959-1966 at the following meteorological stations: Ocean Weather Station "B", Prince Christian Sound and Egedesminde.

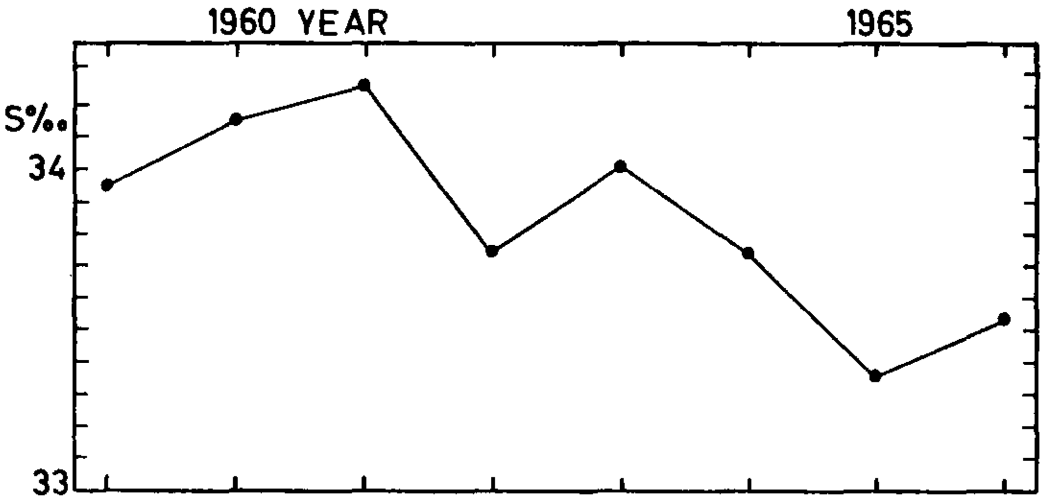

Fig. 12. Mean salinity between 0 and 50 m depth in the different sections across Fylla Bank.

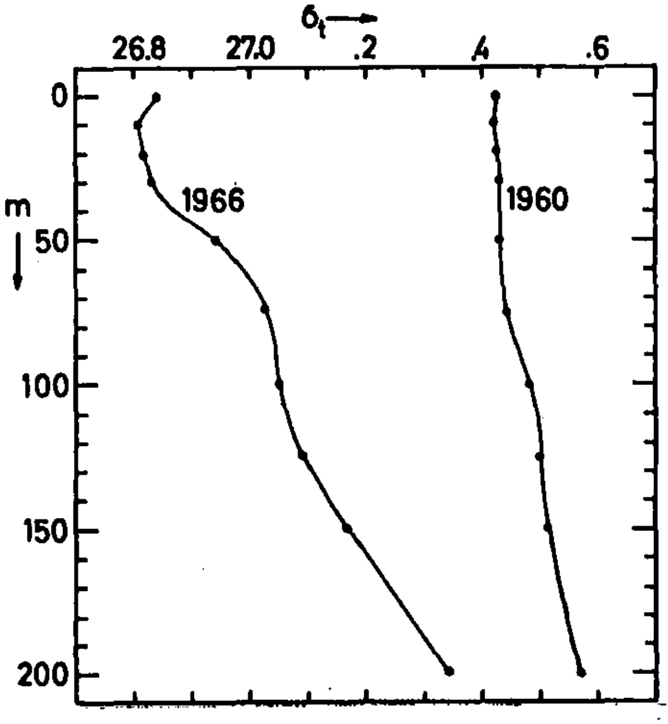

Fig. 13. Mean sigma-t curves for the sections across Fylla Bank in 1960 and 1966.

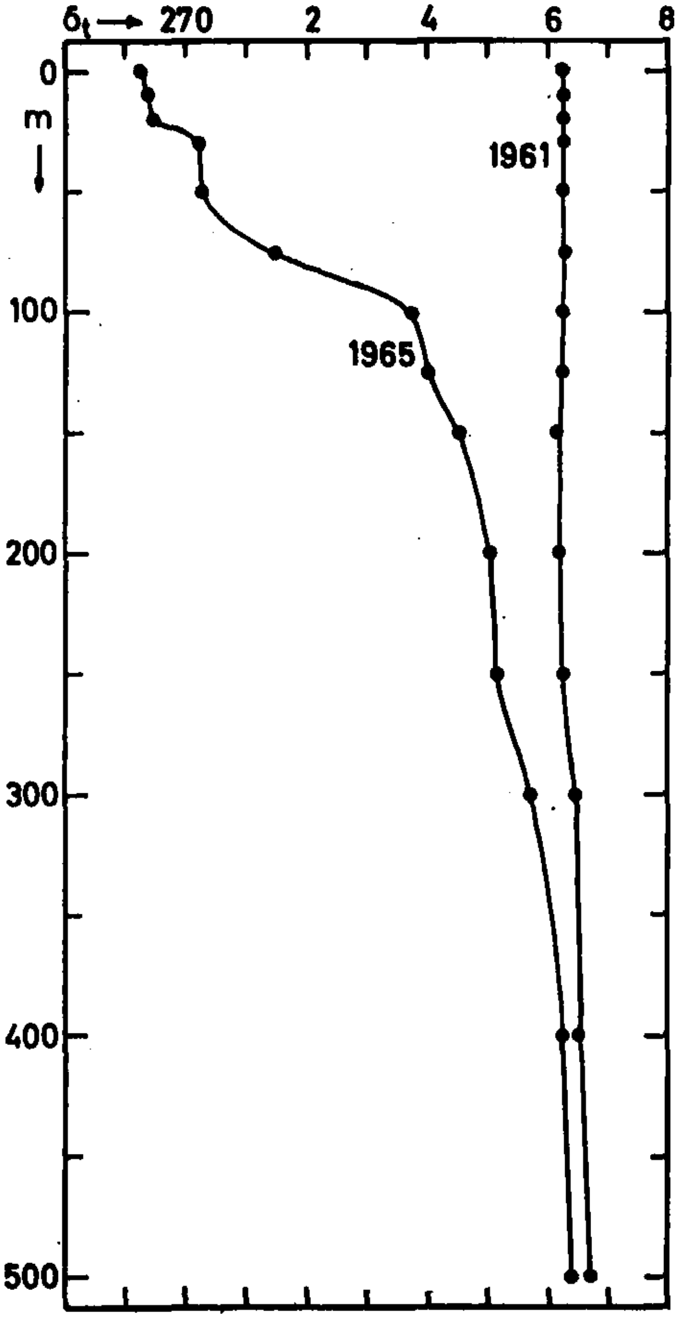

Fig. 14. Sigma-t curves for two hydrographic stations showing great difference in stability. The stations are worked over the western slope of Lille Hellefiske Bank in 1961 and 1965.