INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES

RESTRICTED

Serial No. 1861
(D.c.1)

ICNAF Res.Doc. 67/70

ANNUAL MEETING - JUNE 1967

A COMPARISON OF CURRENT AND LONG-TERM TEMPERATURES OF CONTINENTAL SHELF WATERS, NOVA SCOTIA TO LONG ISLAND

by

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Abstract

Offshore temperature conditions 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. Charts showing the distribution of temperature at the surface, 20 meters, 50 meters, and 100 meters and of temperature anomalies at the surface, 20 meters, and 50 meters are presented. At most locations and depths the 1964-66 temperatures were appreciably colder than the 1940-59 mean values. The magnitude of the negative anomalies tended to be greatest in areas off the edge of the continental shelf. Temperatures in March 1953 were warmer than the 1940-59 mean values. These trends paralleled trends observed at coastal stations as exemplified by Boothbay Harbor, Maine temperatures. The reliability of the use of coastal temperatures for indexing offshore conditions, the possible biological effects of warming and cooling trends, and the causes of these trends are discussed.

Introduction

It is the purpose of this paper to provide a summary of current and long-term temperature conditions during March, May-June, September, and December in the Continental Shelf area bounded by longitudes 64° W. and 72° W. The long-term temperature data is for the period 1940-59 and the source of this information is the file of bathythermograph and oceanographic station observations at the Woods Hole Oceanographic Institution. The current temperature data were collected on a series of eight quarterly environmental surveys made by the U. S. Bureau of Commercial Fisheries during the period December, 1964 - September, 1966. These surveys were conducted during a period of severe drought in the New England area and afford an opportunity to compare recent inshore and offshore temperatures with long-term means.

Analysis of the Data

The initial monthly tabulation of the 1940-59 temperature data was made on a basis of 10-minute quadrangles at depths of 1, 10, 20, 30, 40, 50, 75, 100, 150, 200, and 250 meters. In this report these data have been grouped in terms of 30-minute quadrangles.

Observations for any month within a given year were weighted in favor of certain days (dates), so that in determining monthly means all data for a given day were averaged and monthly means based on the number of days observations rather than on the total number of observations. Some of the inshore quadrangles included daily observations made at lightships. To eliminate the bias of the data in these quadrangles due to the preponderance of lightship observations, 10-day mean values of lightship observations were determined for each month and these values treated as three observations.

Because of the paucity of observations in certain months, the 1940-59 monthly mean values at specific depths were plotted and smooth curves showing the seasonal cycle of temperature were drawn as described by Fuglister (1947). In drawing these curves the greatest weight was given to mean values for months having the most years represented. The resultant curves for specific depths in adjacent quadrangles showed a close similarity, so that occasional inconsistancies in the data were quite obvious. A sample of seasonal temperature curves and the corrections applied at the surface, 50 meters, and 100 meters is shown in Figure 1. The correction applied to monthly mean values based on a small number of observations was often considerable and in some cases where only a few years were represented the corrected value was outside the range of the observed temperatures.

All 1940-59 mean temperature values were read from these seasonal curves and isotherms were drawn on a basis of corrected values entered at the center of each 30-minute quadrangle. The 1940-59 May-June mean temperature values are based on an average of the corrected values for these two months. Temperature distributions based on the quarterly environmental survey data were determined from in situ bathythermograph observations.

Accuracy of the Data

The greatest single source of error in the 1940-59 mean temperature data was faulty navigation. Position errors were not always easy to detect, but in relatively shoal water (<250 meters) a comparison of the bathythermograph and/or echo sounder depth with chart soundings usually would reveal the error. There were relatively few errors due to defective instruments and these were usually easily detected. A considerable amount of personal judgement was involved in deciding what observations were in error and generally this decision was withheld until a comparison could be made with supplementary observations.

Validity of the Data

Iselin (1955) has discussed the complications of obtaining a synoptic picture of the distribution of physical and chemical properties in coastal waters characterized by strong tidal and non-tidal currents and short-period internal waves. It is obvious that when observations are averaged for an area as large as a 30-minute quadrangle for a period as long as a month, that only the most general approximation of reality is obtained. This fact is evidenced by the appreciable ranges in monthly temperature values observed in most quadrangles and at most depths and by the greater sharpness of horizontal and vertical gradients based on quarterly environmental survey data compared to those based on 1940-59 mean data. The validity of the temperature estimates based on monthly mean values varies with season, conforming more to actual conditions during the winter months when only weak temperature gradients are present over most of the area than in summer, a period of strong horizontal and vertical stratification.

Examples of short-term temperature fluctuations at anchor and parachute drogue stations and at "repeat" sections in the Gulf of Maine-Georges Bank area during the summer months are shown in Figure 2. The variations in temperature observed in a specific water mass and at specific locations were considerable and it is apparent that internal waves as well as advection were a contributing factor. Although there are serious limitations imposed by the methods used, whereby temperature values based on long-term averages are used to interpret conditions in a region characterized by large temporal and spatial fluctuations, the method does appear to provide a general picture of the major temperature features to which specific cruise data may be compared.

Distribution of Temperature

The distribution of temperature during March, May-June, September, and December at the surface, 20 meters, 50 meters, and 100 meters based on 1940-59 mean values and 1964, 1965, and 1966 quarterly environmental survey data is shown in Figures 3 - 18.

In general, the 20-year mean and specific year seasonal and areal temperature trends at all depths were similar, with minimum temperatures occurring in March and inshore and maximum temperatures occurring in September and offshore. As would be expected, the temperature gradients based on survey cruise data were much sharper than those based on 1940-59 mean values. The contrast in the complexity of the distribution patterns based on 1940-59 mean and survey cruise data was greatest in September. The most striking feature of the data is that with but few exceptions the survey cruise temperatures were lower than the 1940-59 mean temperatures during all months and at all depths and locations.

Temperature Anomalies

To better assess current temperature trends, temperature anomalies were computed as the difference between the monthly mean for a specific year and the monthly mean for the base period 1940-59. In determining 1940-59 means, 30-minute quadrangle values within one-degree or half-degree quadrangles were averaged. Monthly means for specific years were determined by averaging all station data within one-degree or half-degree quadrangles. Values from survey cruise stations located on whole degree latitude or longitude lines were entered in the quadrangle immediately to the south or west. Monthly temperature anomalies at the surface, 20 meters, and 50 meters for specific years are shown in Figures 10 - 14.

With the exception of surface values along the New England coast during May-June 1965 and 1966, 20-meter values in the Wilkinson Basin area in September 1965, and surface and 20-meter values in the central and western Gulf of Maine and off the southwest coast of Nova Scotia in September 1966, all temperature anomaly values were negative. Although not illustrated, all 100-meter anomalies were negative with the exception of positive values at the extreme south-easterly quadrangle during May-June 1965 and 1966. Considering that at most locations and seasons the survey cruise temperature data was characterized by marked short-term fluctuations and that the temperature data for any quadrangle represents a sampling period of less than 12 hours, the temperature anomaly data are remarkably consistent.

In general, the greatest negative anomalies occurred south of Georges and Browns Banks. The boundary between high and low negative values roughly paralleled the 100 meter isobath. The most marked exception to this usual situation was the occurrence of an area of relatively high negative anomalies at the 20-meter level southwest of Nova Scotia in September 1965. The highest positive anomalies (> 2°C) occurred in this same general area at the surface and 20 meters in September, 1966.

A surface water cooling trend commencing in the middle 1950's has been observed at Atlantic coast stations from Halifax, Nova Scotia to Cape Hatteras (Lauzier 1965, Stearns 1965). This cooling trend has been most pronounced along the coast between Cape Sable and Long Island. One of the most complete series of inshore temperature records are the observations made at Boothbay Harbor, Maine. These daily records have been maintained since 1905 and show that preceeding the current cooling period there was a significant warming period commencing about 1945 and reaching a maximum during 1952-53. This warming trend was discernible in offshore data as well (Taylor, Bigelow, and Graham 1957).

In Figure 15 temperature anomalies at the surface, 20 meters, and 50 meters during March 1953 (Albatross III Cruise 46, 19 March - 2 April) relative to the March 1940-59 mean are plotted. The anomalies in all areas and at all depths were positive and tended to be highest over shoal water areas.

Seasonal surface temperature curves based on monthly mean temperature values at Boothbay Harbor, Maine for the period 1940-59, 1953, 1964, 1965, and 1966 are shown in Figure 16. Temperature data for the period 1940-55 are from Bumpus (1957). Subsequent data were obtained from the files at the Woods Hole Oceanographic Institution. With the exception of January and February 1964 and May 1965, all monthly mean temperatures in the 1960's were colder than the 1940-59 means. The seasonal magnitude of the negative anomalies at Boothbay Harbor and of the anomalies observed in the immediate offshore region during the 1960 survey cruises were similar. For example, the May-June survey data showed a slight positive anomaly for the quadrangle immediately adjacent to Boothbay Harbor in 1965 and May was the only month in 1965 in which the Boothbay monthly mean temperature was not lower than the 1940-59 mean. During most months in the 1960's the negative anomalies in deep-water offshore areas were greater than the negative anomalies at Boothbay Harbor.

The 1953 Boothbay Harbor monthly mean temperatures were appreciably warmer than the 1940-59 means. In March 1953 the positive anomaly at Boothbay Harbor was greater than that in any offshore area. A comparison made of monthly mean temperatures at Boothbay Harbor during the periods 1906-27 and 1928-49 by Taylor, Bigelow, and Graham (1957) showed significant increases in winter temperatures (November - February) but slight decreases in summer temperatures (July - September) during the latter period. In 1953, however, although the anomalies were greater in the winter, the anomalies were positive during all months. The similarity of the temperature trends at Boothbay Harbor and offshore areas in the 1960's would indicate that at least during the peak of the warming period temperatures were warmer during all months in the majority of offshore areas as well.

Discussion

A comparison of offshore temperatures for the years 1953-54 and 1912-26 made by Taylor, Bigelow, and Graham (1957) indicated an increase of from 0.5° to 2.0°C throughout the water column since the period 1912-26 in most parts of the Gulf of Maine. Lauzier (1965) showed that bottom temperature trends on the Scotian Shelf and in the Bay of Fundy were similar to the surface temperature trends at St. Andrews, N. B. and Boothbay Harbor, Maine although the rate of cooling during the late 1950's and early 1960's was more pronounced within the bottom water.

The 1964-66 survey cruise data further document the fact that similar temperature fluctuations occurred offshore and within water masses as well as at the surface. Although temperature anomalies tended to be greater in the deeper water along the edge of the continental shelf, the trends in inshore temperature were reflected in most offshore areas. The consequence of these observations is that we may now place more reliance on the use of inshore temperature observations as an index to offshore conditions.

Taylor, Bigelow, and Graham (1957) concluded that there had been no obvious general change in the composition of the fish or invertebrate fauna in the Gulf of Maine as a consequence of the warming trend during the early 1950's. To my knowledge, there is also no evidence of a conspicuous change in faunal composition during the current cooling period. However, there does appear to be a consequence of these temperature fluctuations that warrants investigation.

~~List of Tables with Legend~~:

Table 1. - March and April mean temperatures at Boothbay Harbor and the March/April ratio of haddock egg abundance on Georges Bank, 1953, 1955, and 1956.

YEAR	Temperature, °C.		March/April Egg abundance ratio
	March	April	
1953	6.1	7.5	7.3
1955	4.2	6.9	2.7
1956	3.2	5.3	1.3

An unpublished analysis of the distribution and abundance of Calanus finmarchicus based on collections made during the 1953 and 1955 egg and larval surveys revealed that there was also a difference in the timing of the vernal augmentation of the stock of Calanus during these two years. The developmental stages encountered in the cruises of 1953 indicate that in that year the main spawning of the overwintering stock occurred in February and that the progeny of that spawning reached maturity in late May. In 1955 the overwintering stock did not spawn until March and the second generation did not reach maturity until late June. It is highly probable that both these factors (spawning time and availability of suitable size food organisms) influence the survival rate of larval and juvenile fish.

For example, the timing of haddock spawning appears to be regulated in part by temperature. Fish egg and larval surveys conducted during 1953, 1955, and 1956 showed that the main spawning on Georges Bank occurred during March and April at prevailing water temperatures ranging from 4° to 7°C (Colton and Temple 1961). Spawning began at about the time of the commencement of vernal warming. In Table 1 are tabulated the March and April mean temperatures at Boothbay Harbor during 1953, 1955, and 1956 and the March/April ratio of egg abundance on Georges Bank during these same years. With the decreasing March and April mean temperatures during succeeding years there was a corresponding delay in the time of maximum spawning on Georges Bank as indicated by the decrease in the March/April egg abundance ratio.

Lauzier (1965) suggested that variations in the degree of upwelling due to fluctuations in the intensity of westerly winds could effect short-term changes in annual temperatures along the Canadian Atlantic coast. However, the nature of the distribution of temperature and of negative anomalies observed during the survey cruises of 1964-66 give evidence that temperature trends recorded at most Atlantic coast stations are not caused by variations in local conditions such as upwelling and river runoff, but are due in large measure to changes in the relative position and degree of mixing of coastal and oceanic water masses. An example of this is the fact that the gradient of negative anomalies which occurred off the edge of the continental shelf was least during September a period in which indications of intrusions of Slope and Gulf Stream water onto the southern edge of Georges Bank have been most frequently observed (Colton 1961). It would appear also that the change in sign of the anomalies observed off the southwest coast of Nova Scotia in SEPTEMBER 1965 (negative) and 1966 (positive) resulted from a variation in the degree of influx of Nova Scotian current water into this area during these years.

It has been postulated by Iselin (1940) and Stommel (1958) that the degree of mixing of coastal and oceanic water and the resulting warming or cooling of North Atlantic coastal water is related to fluctuations in the strength of the North Atlantic gyre. Bjerkness (1963) and Rodewald (1963) have related these changes in oceanic circulation to variations in atmospheric circulation due to changes in the relative strengths of the Bermuda-Azores High and the Icelandic Low. The cooling trends have been associated with a constriction and warming trends with an expansion of the warm oceanic water mass.

Summary

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.

The 20-year mean and specific-year seasonal and areal temperature trends were similar, with minimum temperatures occurring in March and inshore and maximum temperatures occurring in September and offshore.

During all seasons and at most locations and depths the 1964-66 temperatures were appreciably colder than the 1940-59 mean values. 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.

The trends in offshore temperatures at the surface and within water masses paralleled trends in surface temperatures at Boothbay Harbor, Maine and attest the use of inshore temperature observations in indexing offshore conditions.

A delay in the timing of maximum haddock spawning on Georges Bank during 1953, 1955, and 1966 and of the vernal augmentation of the stock of Calanus finmarchicus in the Gulf of Maine during 1953 and and 1955 was associated with decreasing Boothbay Harbor, Maine temperatures.

The nature of the distribution of temperature and of negative anomalies observed during 1964-66 suggest that temperature trends recorded at most Atlantic coast stations are due in large measure to the relative position and degree of mixing of coastal and oceanic water masses.

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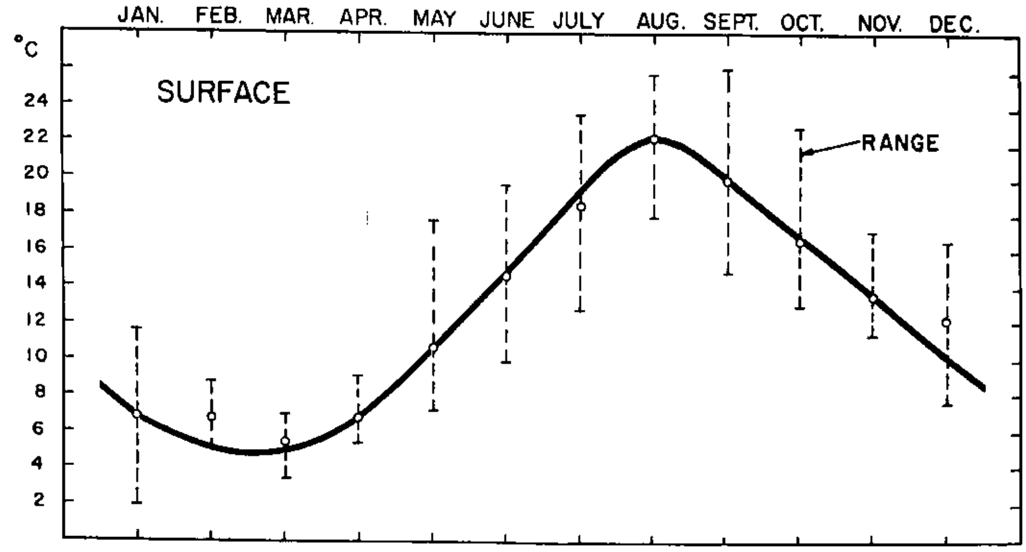
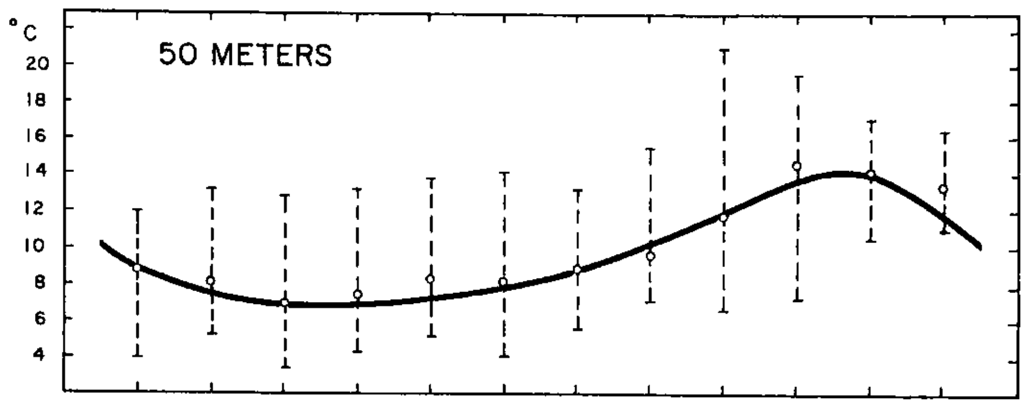
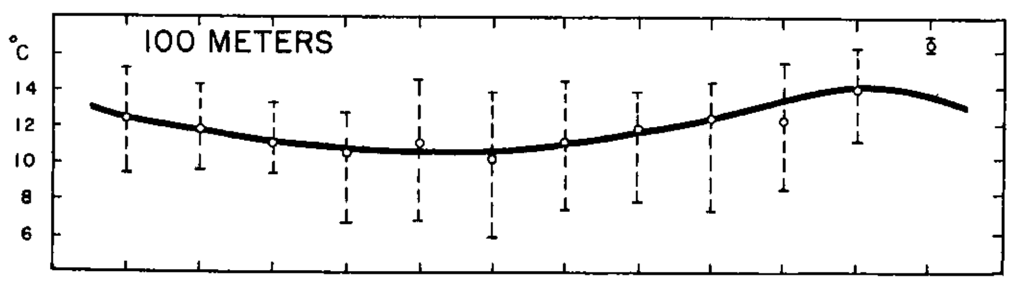


	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
NO. OF OBSERVATIONS	37	11	22	20	54	105	114	97	127	48	37	16
NO. OF DAYS	11	9	7	12	14	25	28	26	35	20	9	4
NO. OF YEARS	7	5	5	6	9	11	11	13	14	11	6	3
AVERAGE TEMP.	6.9	6.8	5.5	6.8	10.7	14.7	18.5	22.3	20.0	16.7	13.7	12.4
CORRECTED TEMP.		5.2	5.0				19.2			16.8		10.4



	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
NO. OF OBSERVATIONS	35	10	22	18	53	95	107	97	125	40	36	14
NO. OF DAYS	9	8	7	11	14	24	25	26	34	17	9	4
NO. OF YEARS	6	5	5	7	9	11	9	13	13	9	6	3
AVERAGE TEMP.	8.8	8.2	7.0	7.5	8.4	8.2	8.9	9.7	11.8	14.7	14.3	13.5
CORRECTED TEMP.		7.6		7.0	7.4	8.0		10.4	12.0	13.9		11.8



	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
NO. OF OBSERVATIONS	24	4	19	10	43	60	69	57	68	25	18	7
NO. OF DAYS	7	4	7	5	12	18	19	17	24	14	6	2
NO. OF YEARS	6	4	5	5	9	9	7	8	12	9	4	1
AVERAGE TEMP.	12.3	11.7	11.0	10.5	10.5	10.1	11.0	11.8	12.3	12.2	13.9	16.4
CORRECTED TEMP.		11.6				10.6						13.6

Figure 1. - Seasonal temperature curves and temperature corrections applied for 30-minute quadrangle, 40°00'N. - 40°29'N, 70°30'W - 70°59'W.

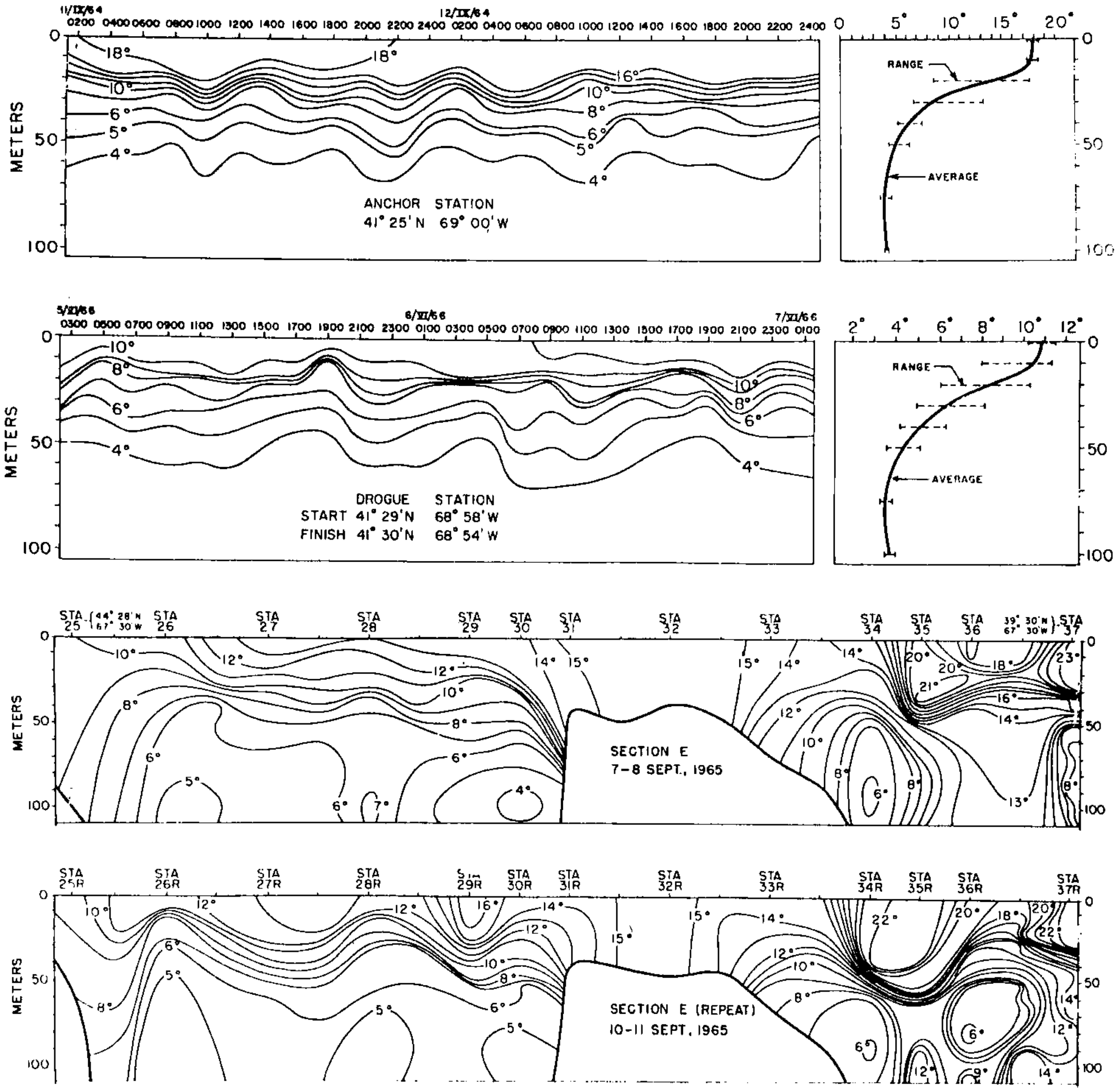


Figure 2. - Temporal variations in the distribution of temperature at anchor and drogue stations and at repeat sections.

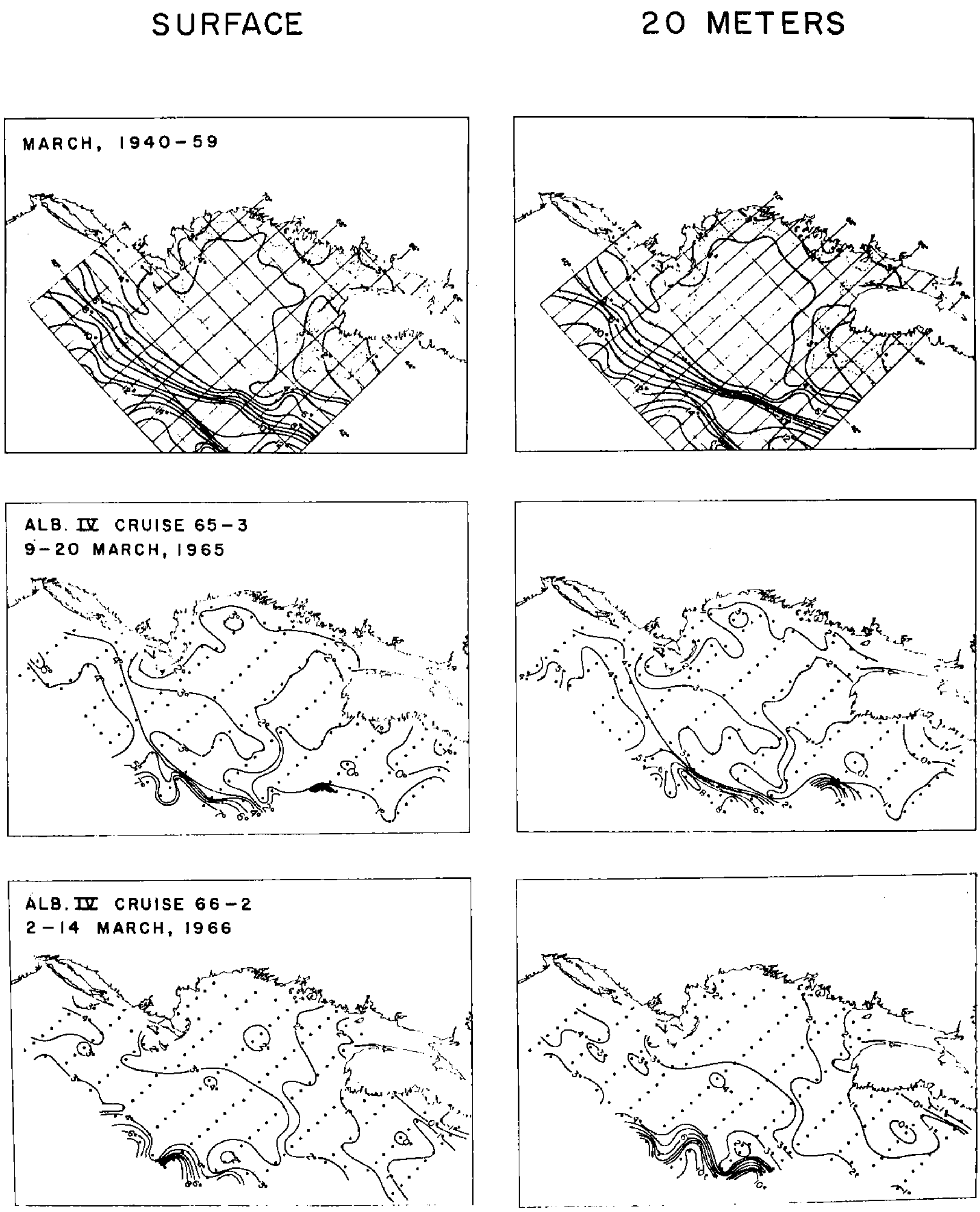


Figure 3. - Temperature distribution at the surface and 20 meters, March 1940-59, 1965, and 1966.

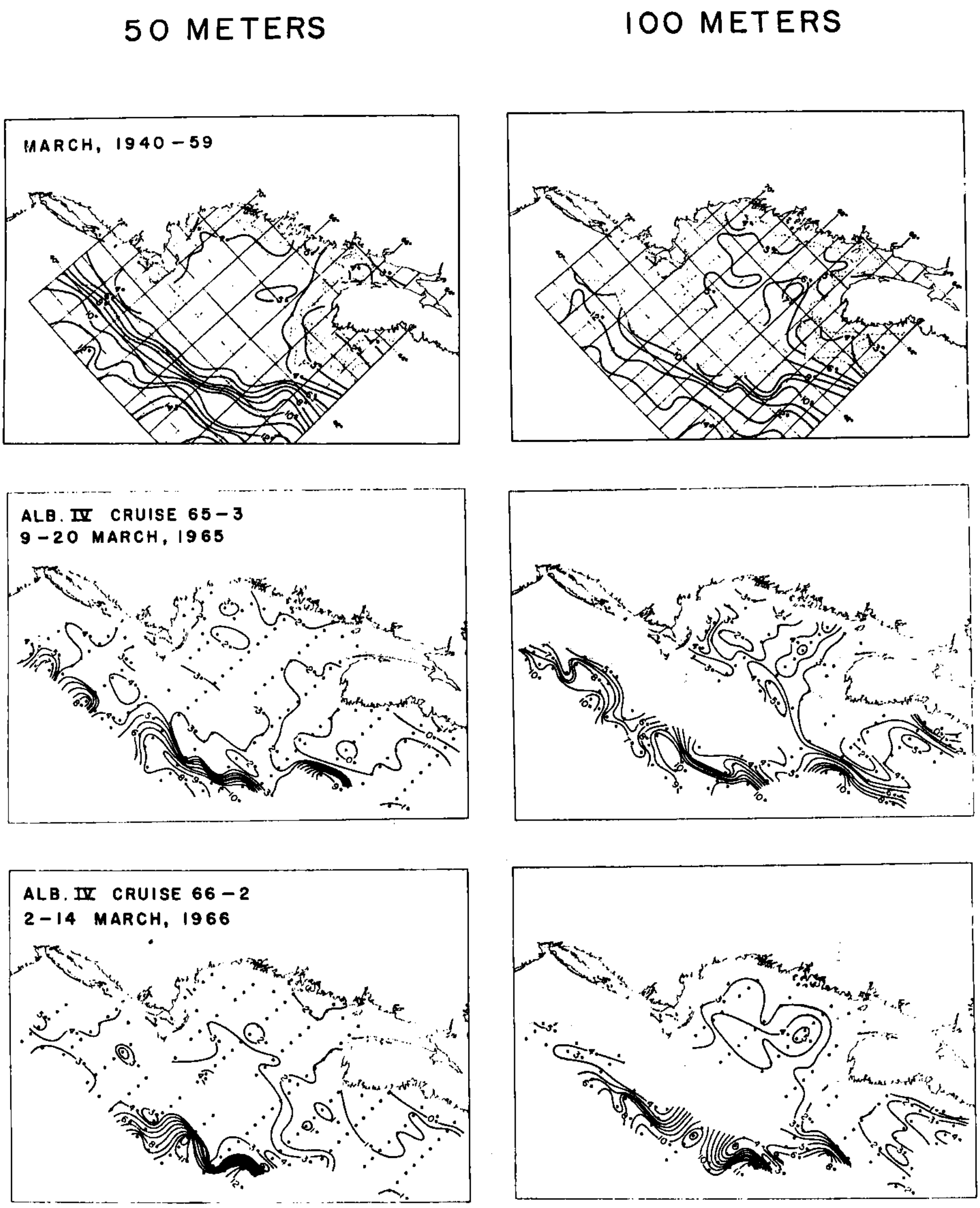


Figure 4. - Temperature distribution at 50 and 100 meters, March 1940-59, 1965, and 1966.

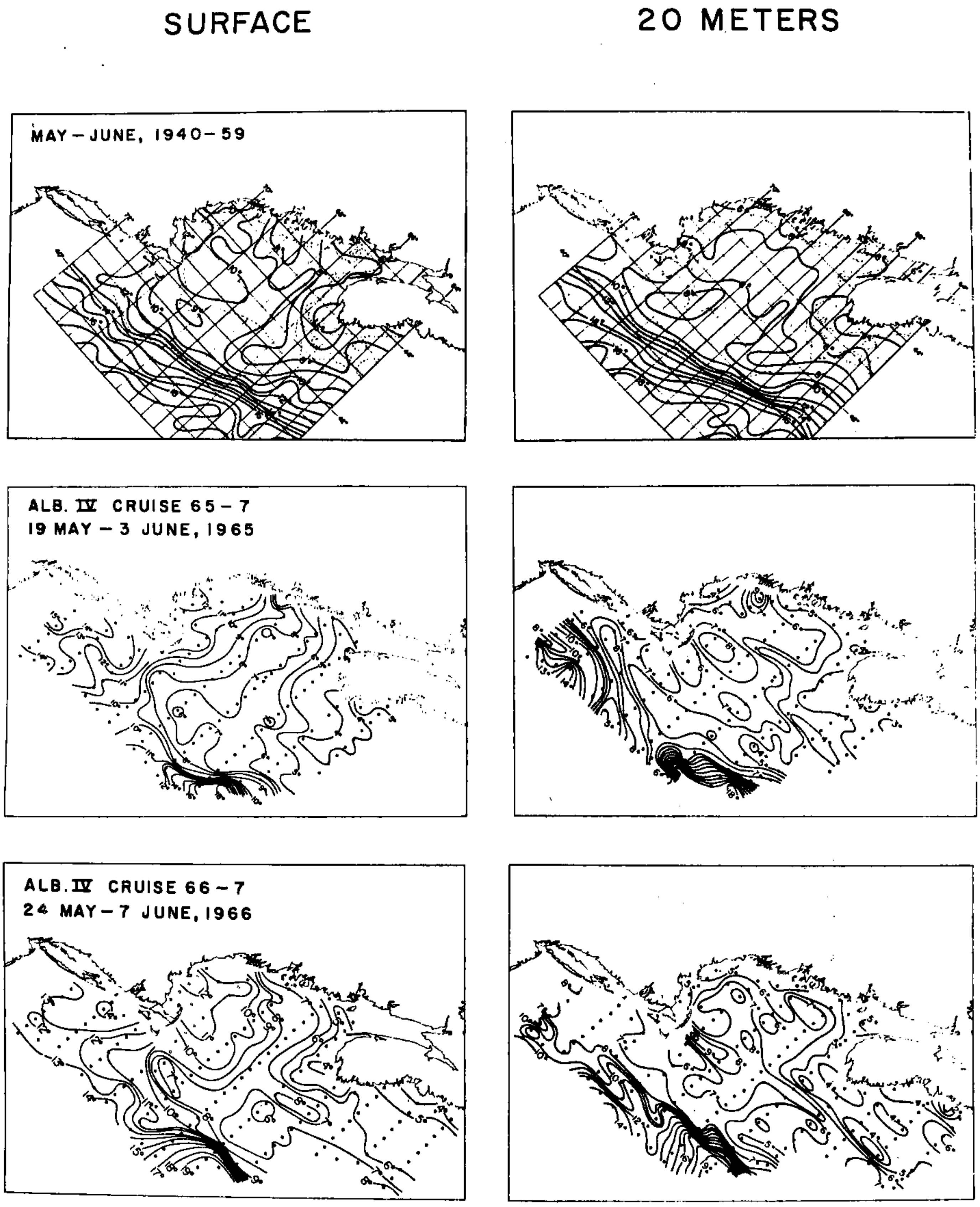


Figure 5. - Temperature distribution at the surface and 20 meters, May-June 1940-59, 1965, and 1966.

50 METERS | 100 METERS

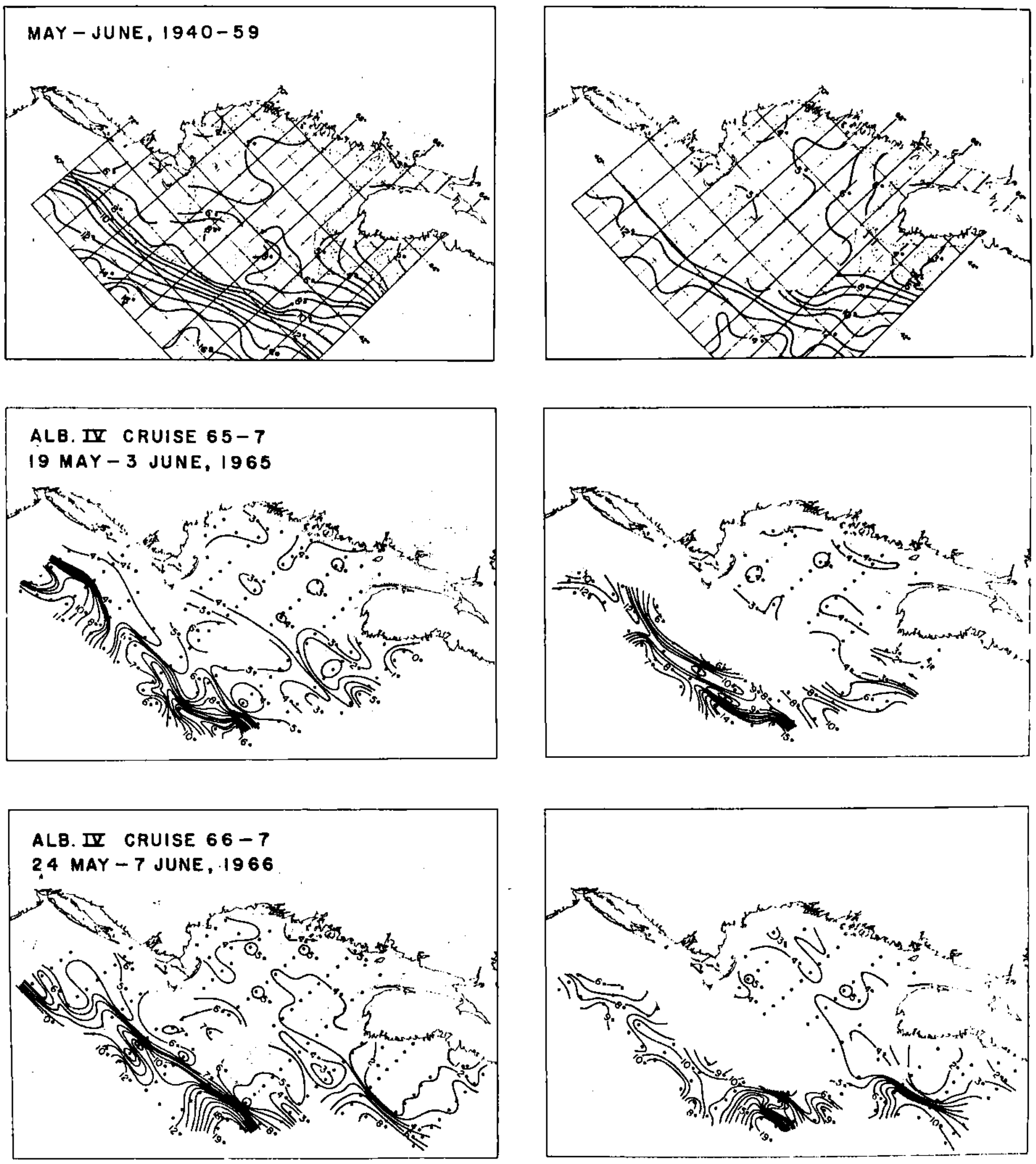


Figure 6. - Temperature distribution at 50 and 100 meters, May-June 1940-59, 1965, and 1966.

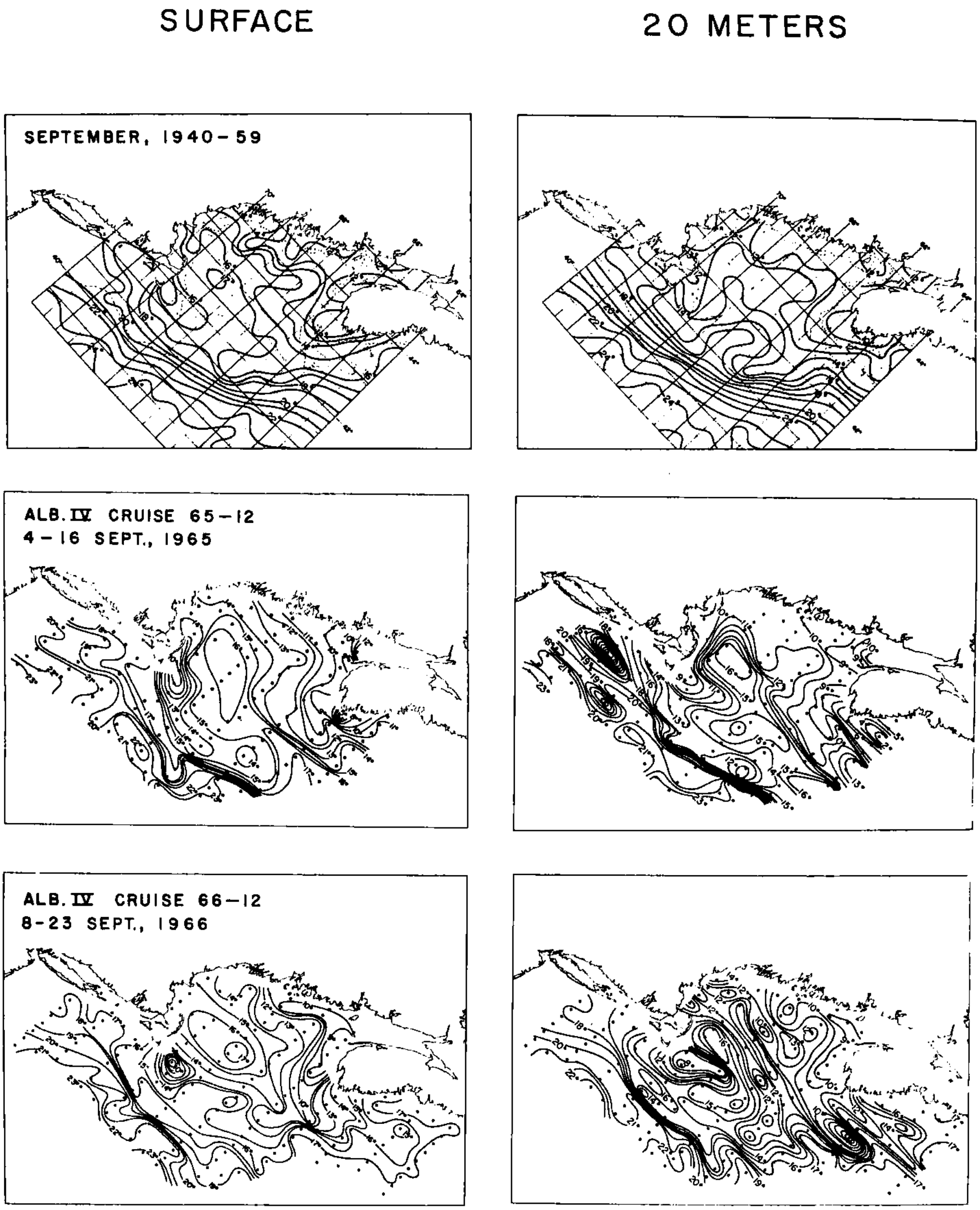


Figure 7. - Temperature distribution at the surface and 20 meters, September 1940-59, 1965, and 1966.

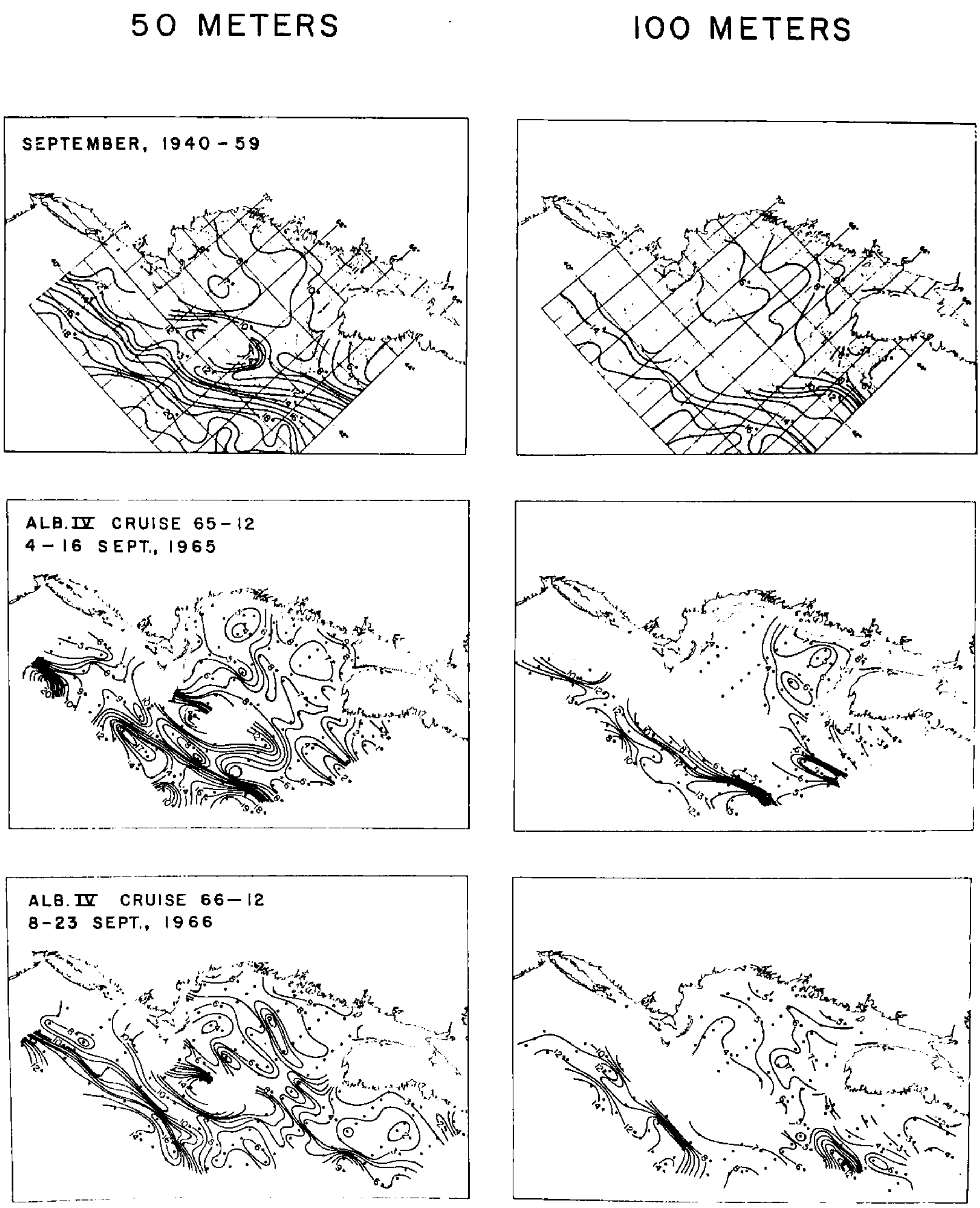


Figure 8. - Temperature distribution at 50 and 100 meters, September 1940-59, 1965, and 1966.

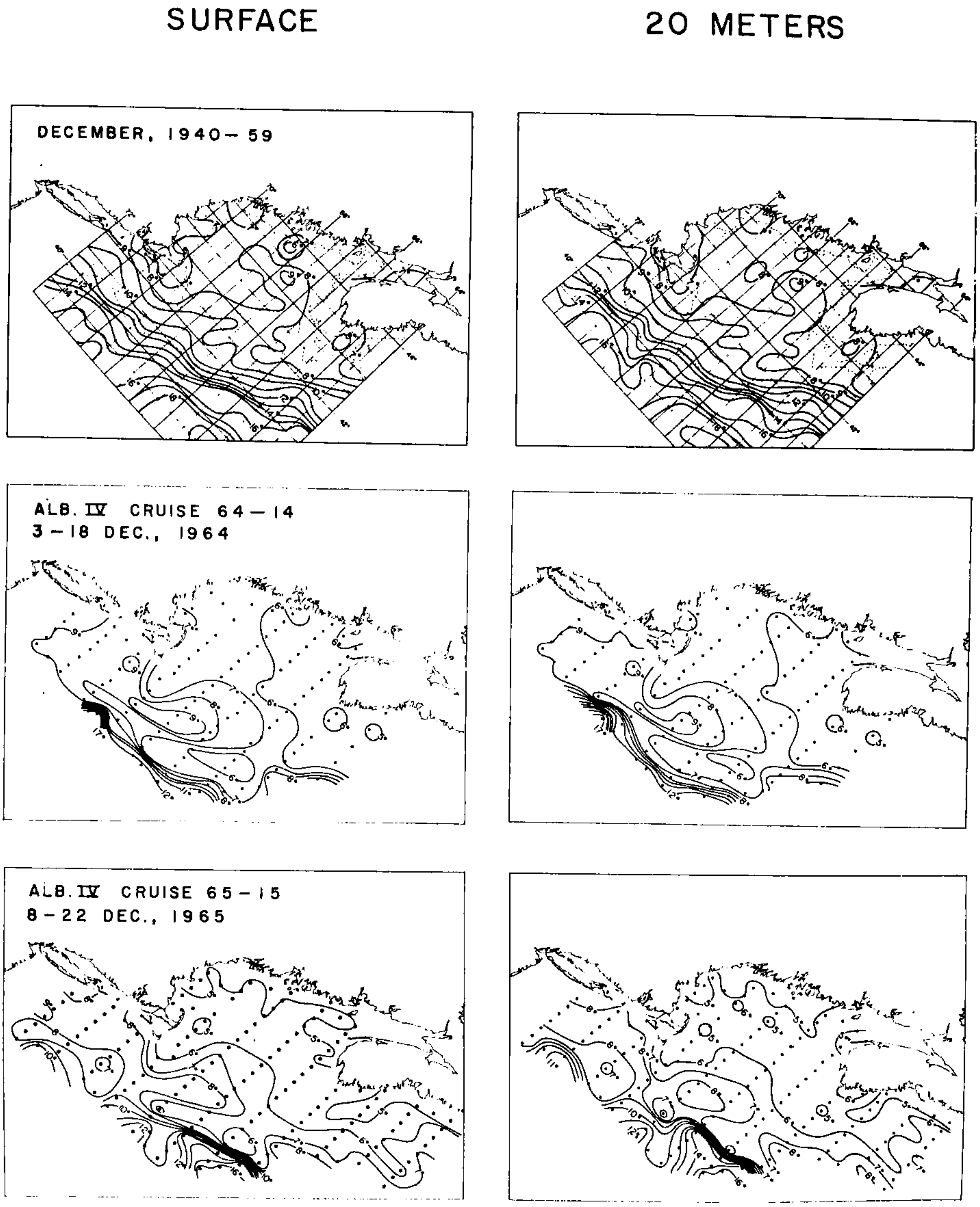


Figure 9. - Temperature distribution at the surface and 20 meters, December 1940-59, 1964, and 1965.

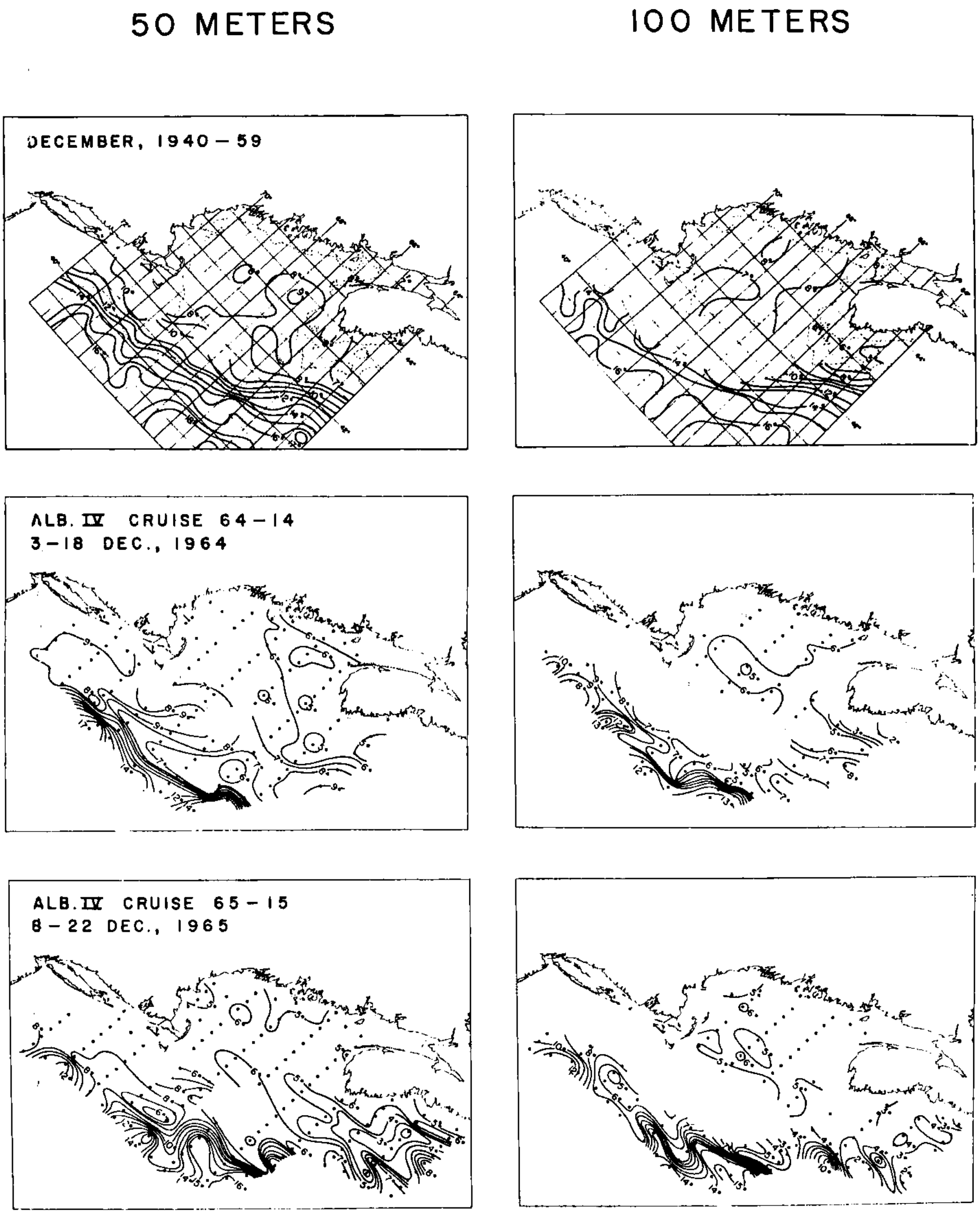


Figure 10. - Temperature distribution at 50 and 100 meters, December 1940-59, 1964, and 1965.

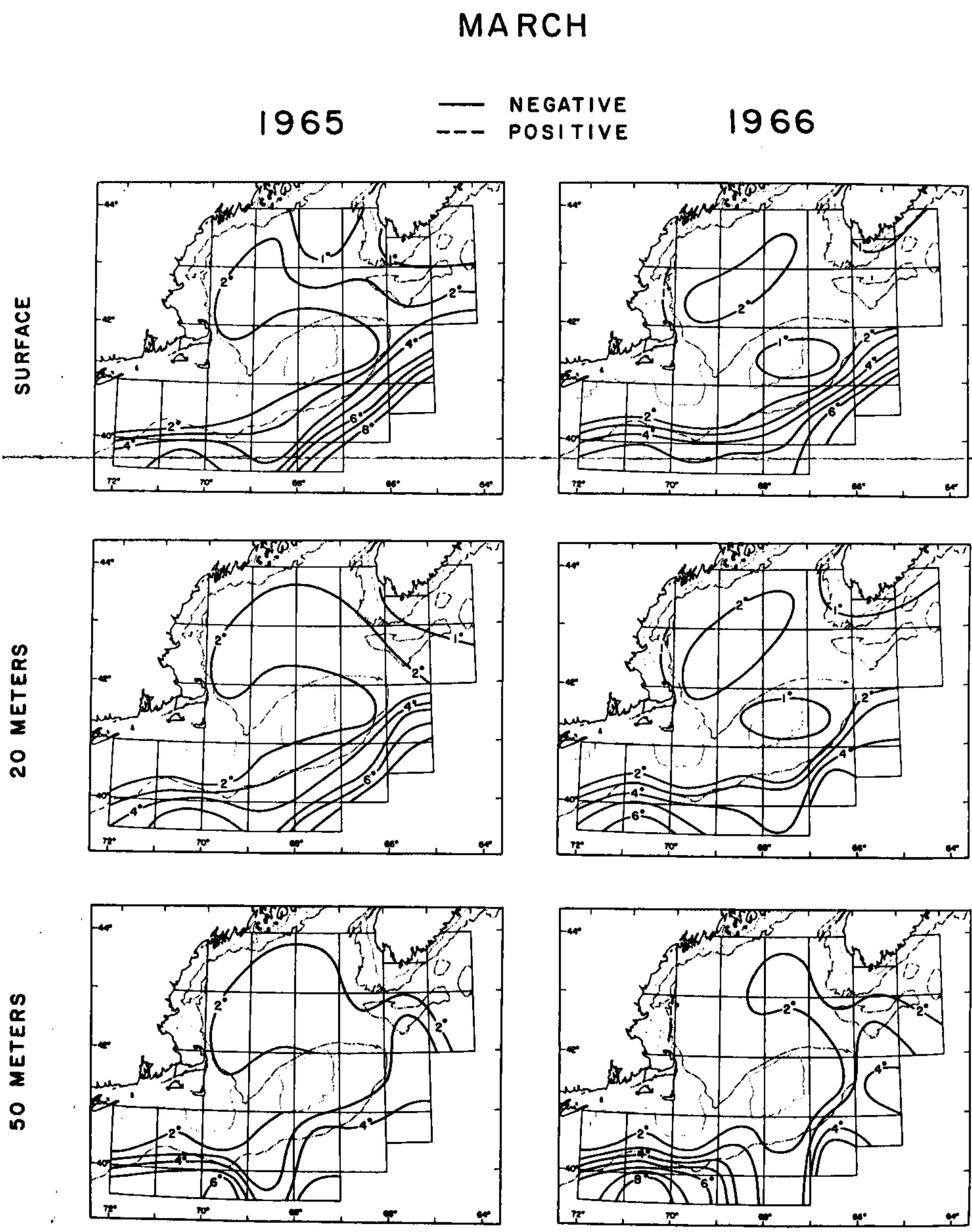


Figure 11. - Temperature anomalies at the surface, 20 meters, and 50 meters, March 1965 and 1966.

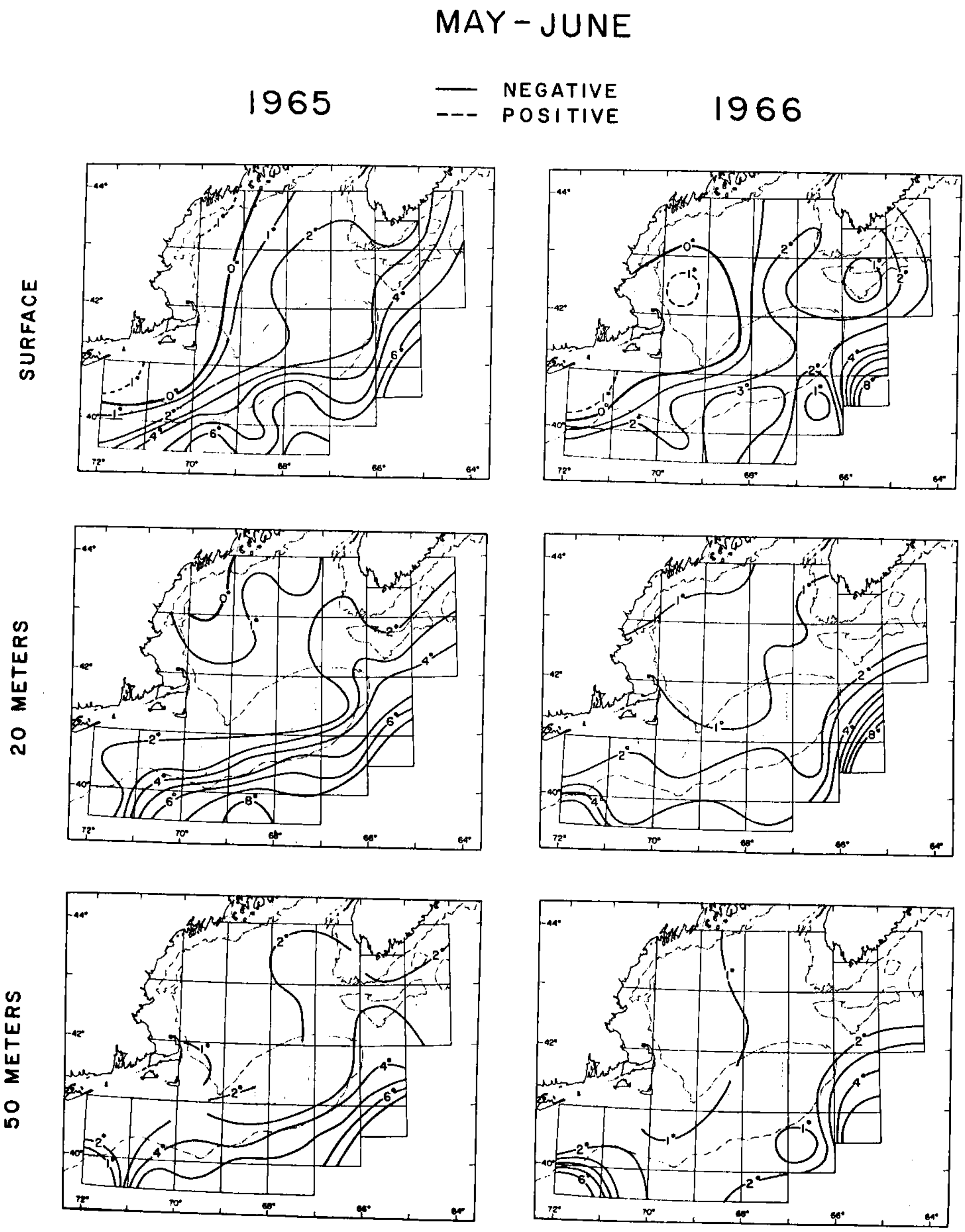


Figure 12. - Temperature anomalies at the surface, 20 meters, and 50 meters, May-June, 1965 and 1966.

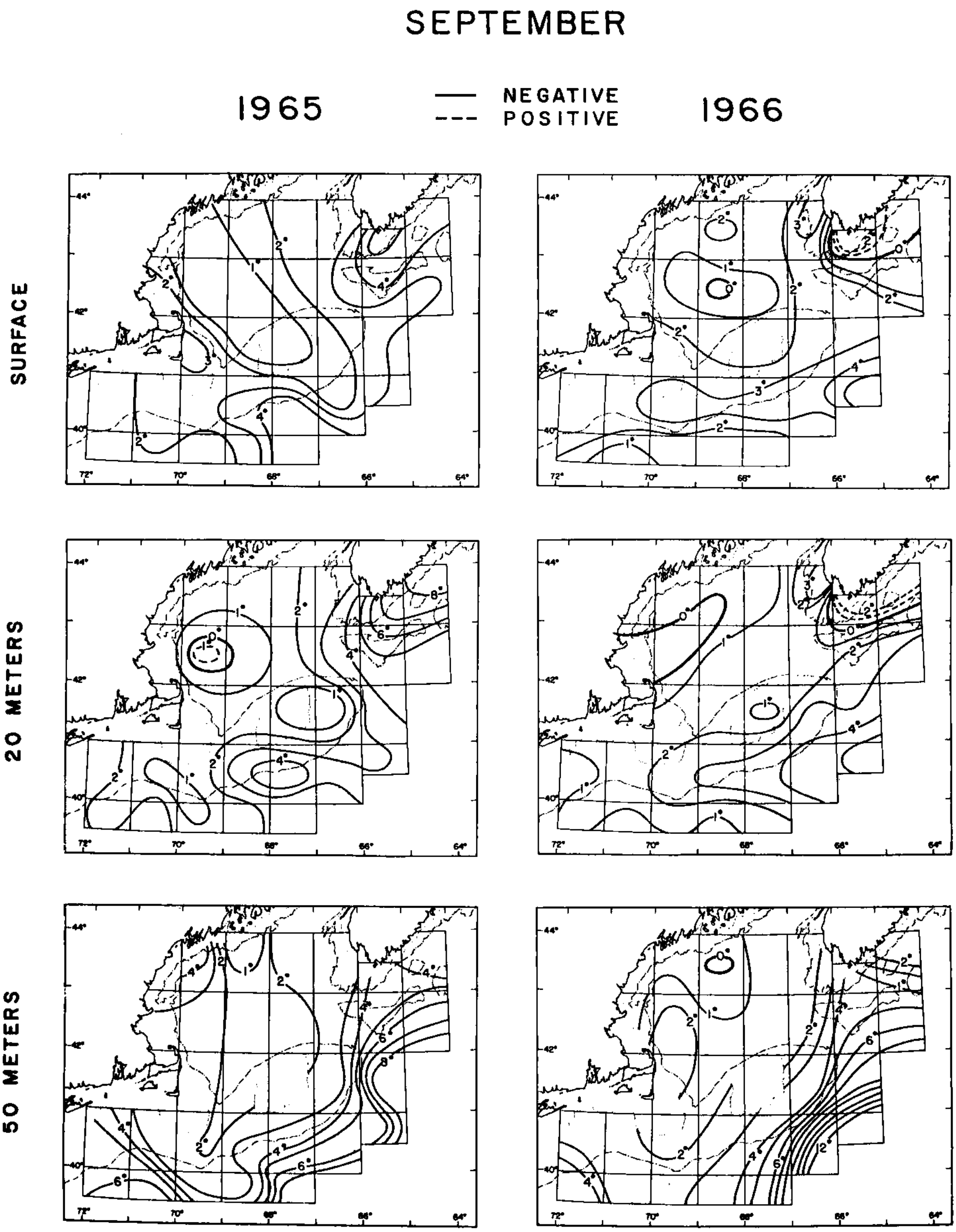


Figure 13. - Temperature anomalies at the surface, 20 meters, and 50 meters, September, 1965 and 1966.

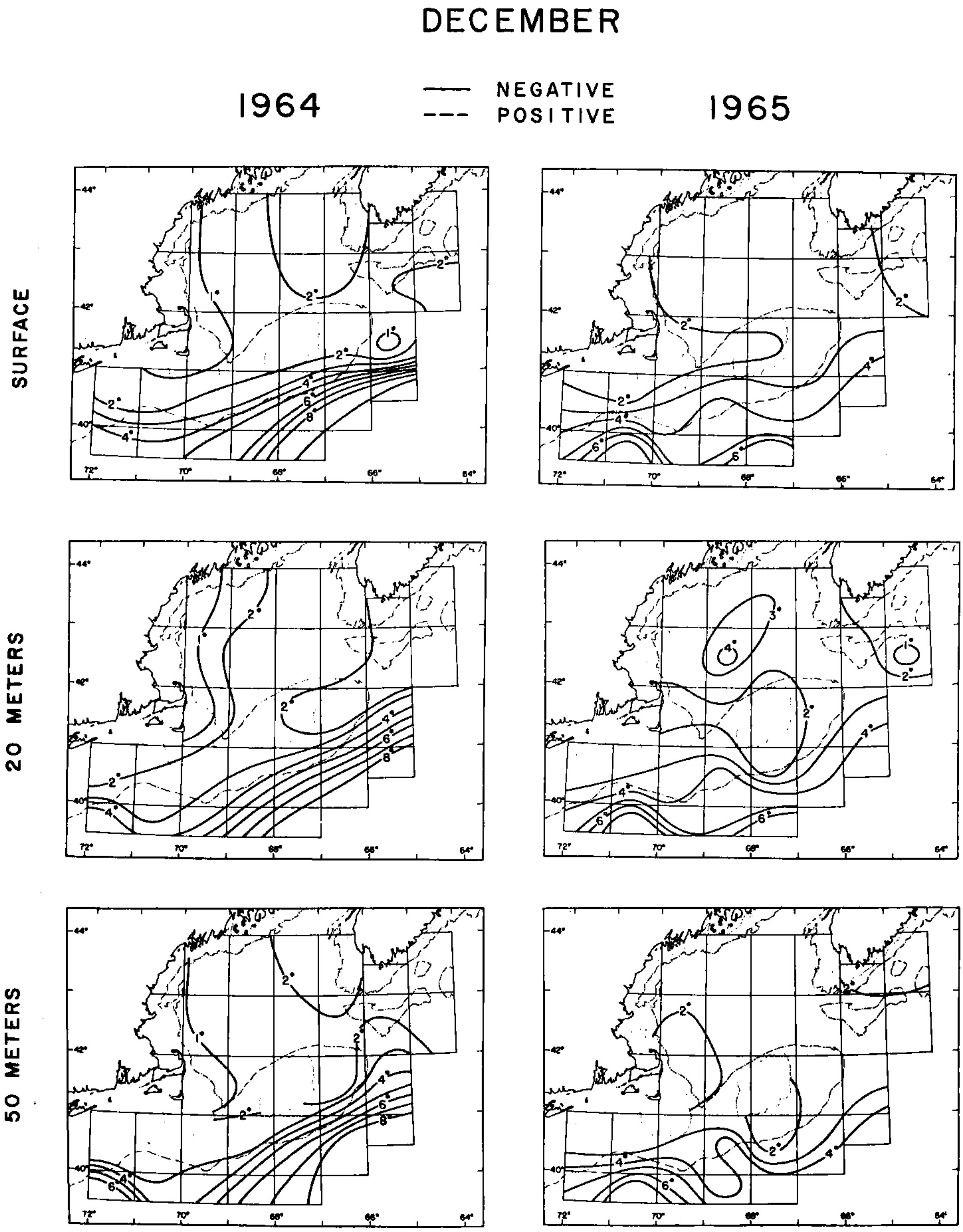


Figure 14. - Temperature anomalies at the surface, 20 meters, and 50 meters, December, 1964 and 1965.

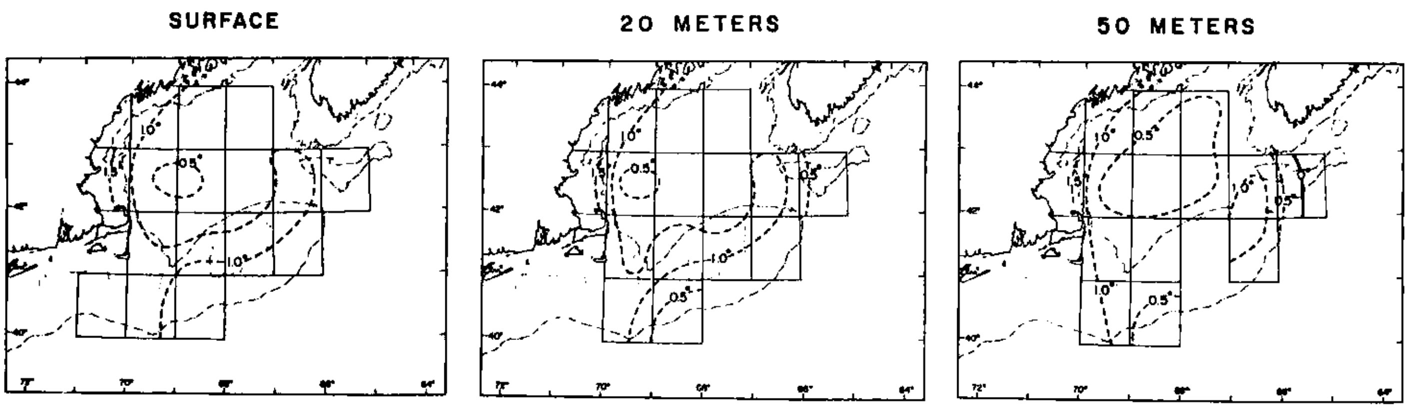


Figure 15. - Temperature anomalies at the surface, 20 meters, and 50 meters, March, 1953.

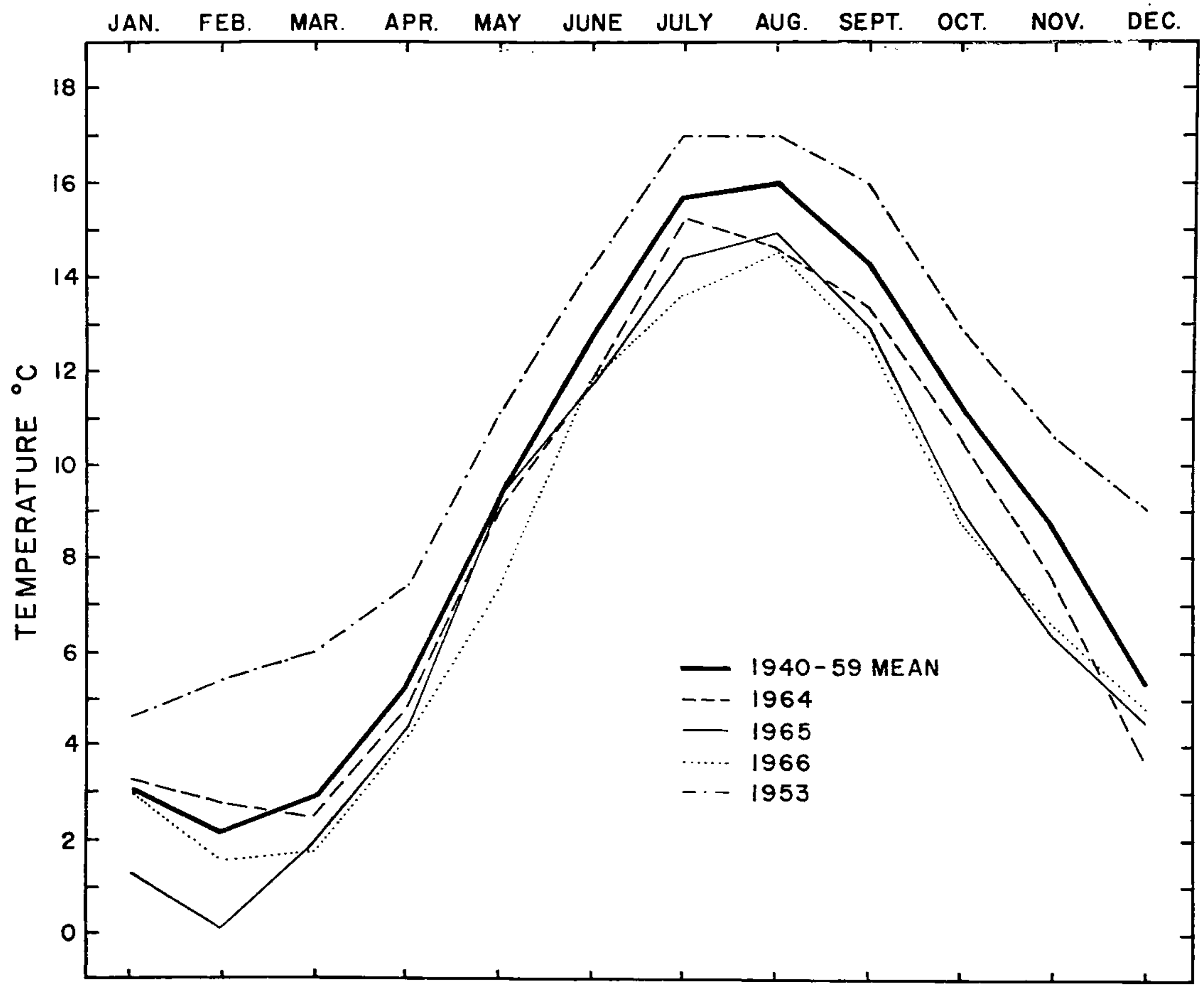


Figure 16. - Seasonal temperature curves Boothbay Harbor, Maine, 1940-59, 1953, 1964, 1965, and 1966.