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Inter-year Seasonal Variation in Heat Content of Northwest Atlantic Shelf Waters and their Correlation with Temperature Indices by Region

by

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Abstract

Inter-year seasonal variations in heat content of the Nova Scotia shelf, Georges Bank, Gulf of Maine, and eastern USA shelf waters and in local temperature indices are described.

Revealed correlations between heat content and indices suggest the possibility of using the latter as indices reflecting the variations in heat content throughout the investigated areas.

Introduction

The studies on long-term fluctuations in the water temperatures in the Northwest Atlantic shelf waters are in progress. The investigation into the inter-year seasonal variability of heat content and search for the ways of its presentation using more accessible temperature indices observed within the limited parts of the shelf are the major aspects of these studies.

Inter-year seasonal variations in the temperature background for the Nova Scotia shelf, Georges Bank, the Gulf of Maine and eastern part of the USA shelf (the northern part of the Mid-Atlantic bend) areas were reported earlier by Karaulovsky and Sigaev (1976). In their paper the mean long-term seasonal temperatures relative to depths 0, 50, 75 m and bottom - 200 m and the anomalies by year were given based on averaged numerous observations for 1962-1972 according to a grid of the 20 x 30 degree squares.

Inter-year fluctuations in certain temperature characteristics for separate parts of the shelf or representative points were presented by Sigaev (1969) for the 1959 through 1968 period. The North-East Channel between Georges and Browns Banks, and Emerald Deep on the Nova Scotia shelf were attributed to these characteristic localities.

The minimum temperature of the intermediate cold layer in both regions and the depth of the 5°C isotherm in Emerald Deep were taken as temperature indices. The long-term observations made by AtlantNIRO along the standard sections III and VI intersecting the above-mentioned regions, in addition to random observations close to selected points along the sections made it possible to continue the series of monthly indices until 1976. Thus, the materials available to date allow to estimate qualitative and quantitative correlation between the fluctuations in heat content by the region on the whole and the index fluctuations in order to substantiate these indices as heat content indices. For this purpose, the mean seasonal values of the water temperature deduced provisionally from the mean long-term values and anomalies (Karaulovsky and Sigaev, 1976, tables 1, 2) and the indices for the 1962 to 1972 period were used.

Materials and Methods

The mean seasonal values are calculated from the formula:

$$Ti = T + \Delta Ti$$

where Ti is the season value for any one year, T is the mean long-term season value and Ti is the anomaly value.

From the calculated values the plots of seasonal variability of heat content are built (figs. 1-4) for each region and selected depth. The index values by season and year are given as curves in fig. 5. From the preliminary qualitative estimation of heat content and index variability plots the correlation between these was computed using the method of pair correlation recommended in the book of Kudriavaja (1951). The calculation was based on 92 versions of which the cases with the coefficients of 0.50 and less were later excluded. Correlation rates (R) were calculated according to the formula:

$$R = \frac{\sum \Delta \;\; x \;\; \Delta Y}{G \; x \; Gyn}$$

For the rest of the versions the probable deviation of a correlation rate (E), correlation reliability and adequacy of a series length $(\frac{R}{E})$, and regression coefficients (A, B) were calculated according to formulae:

$$E = \pm \; 0.67 \; \frac{1 - R^2}{n} \; ; \quad A = R \; \frac{Gy}{Gx} \; ; \qquad B = \bar{Y} - A\bar{x}$$

Simultaneously, regression equations of $Y = Ax + B$ type were deduced.

For tentative estimation of regression equations the recurrence rate was calculated (although the series was short and contained only 11 terms) according to the formula :

$$P = \frac{k}{n} \; 100\%$$

where P is the recurrence rate in per cent, K is the number of cases meeting the following condition

$$(G obs. - G \; calc.) = (Y max - G \; min) \; x \; 0.2$$

and n is the total of cases.

The results of correlation are given in table 1. All calculations were made according to the standard program by means of the AtlantNIRO computer "MIR - 1".

Results of Qualitative Analysis of Heat Content and Index Variations

A decrease in heat content after 1963 and its increase since 1966-1967 are characteristic of the majority of curves pertinent to winter, spring and summer seasons (figs. 1-3). In winter and in summer, for instance, this peculiarity emerged in all three areas at all depths, and in spring in all cases except at the depth of Om in the Gulf of Maine, where the intermediate peak was observed in 1965. Almost all curves have identical trends during the 1962 to 1972 period, although in some years the temperatures differ by area and depth. A declining trend observed after 1966-67 affected exclusively the surface layer of the Nova Scotia shelf waters in the winter and summer seasons. The intermediate minimum in 1968 was observed on Georges Bank in the winter at 0 and 50 m. The intermediate maximum in the 1968 spring was recorded at 0 m in the Gulf of Maine and at all depths over the Nova Scotia shelf. The summer of 1968 was characterised by increased temperature over the Nova Scotia shelf (50 m, 75 m and immediately above the bottom).

In 1969 a rise in temperature was observed in the winter over the Nova Scotia shelf (0.50 m) and on Georges Bank (only at 75 m); in spring in the Gulf of Maine (only at 50 m) and on Georges Bank at all depths; in summer in the Gulf of Maine (0.50 m) and on Georges Bank at all depths.

Subsequently, relative decline in heat content was recorded in 1970-71 in subsurface layers of the Georges Bank area and the Gulf of Maine in the winter, spring and summer. Also worthy of note is that in all cases of decline in heat content since 1967-1968 its values fell as low as the lowest level of 1964-66. It was only in 1970 and 1971 that the level of heat content in the Gulf of Maine (50 m) declined lower than in 1964-66.

There is a considerable difference between the plots for the fall period (fig. 4) and those for the winter, spring and summer in that the former are, as a rule, in phase opposite to the latter and have larger fluctuation amplitude. Besides, in the fall curves a sharp inter-year variability can be seen during shorter time intervals. These peculiarities of inter-year fall changes probably reflect instability of the fall processes resulting from reconstruction of hydrometeorological fields during the transition period between the summer and winter seasons. The pattern of changes is similar in all the fall curves irrespective of the area or depth except at the 75 m depth in the Gulf of Maine, where a trend towards a gradual decline is observed after 1966.

The indices depicted in fig. 5 undergo the same changes as the majority of curves in figs. 1-3 do. Relatively high values in 1962-63, a decline in 1964-66 and gradual increase since 1966 are clearly seen. Due to this similarity the correlation degree between the two types of characteristics during the 1962-1972 time interval was checked. A series of indices for more prolonged time period is shown in fig. 6 indicating a fall in temperature on the Nova Scotia shelf after 1972 and a sharp decline on Georges Bank in 1974 followed by a sharp increase in 1975. A trend towards gradual increase was observed after 1974-75 in both areas. Separate falls and rises against the background of a general trend seen on both the curves of heat content and indices may be related to overlapping of advection processes in the intermediate and near-bottom layers and seasonal variability. It should be noted, that little is known about the long-term contribution of advection processes into seasonal changes of heat content in the Northwest Atlantic shelf areas. More information is needed on understanding the advection processes in the investigated area which are mainly related to fluctuations of the Labrador Current and Gulf Stream in time and space. Thus, qualitative estimation of heat content and index fluctuations revealed the similar variability trend in the winter, spring and summer seasons and indicated that the fall changes were rather characteristic of the transition period between summer and winter and did not reflect the general trend.

The analysis also indicated the periods of relative rise and fall of temperature and occasional sharp declines and rises in heat content. So, a warm period was noted in 1962-69, a cold period in 1964-66, a gradual rise in temperature in 1967-72 and the unstable period in 1973-75 with sharp declines and rises.

Results of Relationship Analysis and Summary

In calculation of coefficients the values of indices and values of the mean seasonal temperatures were taken as independent and dependent variables respectively. The calculations were aimed at determining of how much the fluctuations of indices reflect those of heat content (in this case inter-year fluctuations of mean seasonal values of the water temperature) by area and by depth. As noted above, a total of 92 versions had been considered and the cases of unstable and unreliable relationships eliminated after calculations. The rest of the versions can be seen in table 1. For comparison, in addition to all versions of stable and reliable relationships some cases of unstable relationships are given.

Dependences relating to the winter, spring and summer seasons are direct,as a rule, except for relationships with the depth index of the 5°C isotherm. There exists, for instance, a direct correlation between the winter values of the mean seasonal temperature and the maximum temperature of the intermediate cold layer along the section III, which means that the increased value of this index is indicative of increased heat content at 0 and 50 m in the Georges Bank area, and vice versa. This is also the case in the areas of the Gulf of Maine and USA shelf. There exsist assessory correlations between the index "Tmin III" and the winter temperatures in the Gulf of Maine and the summer temperatures on the USA shelf throughout the 0-200 m horizon. This suggests that heat content in these areas both in winter and summer is largely affected by local hydrometeorological peculiarities and to a lesser degree by the adjacent areas. Except the spring period, the index "T min VI" is closely correlated with the water temperature on the Nova Scotia shelf and in the Gulf of Maine. Close correlation between the third index "H (5°C) VI" and the mean seasonal water temperatures were noted only for the Nova Scotia shelf. These correlations appeared to be inverse. Physically, it means that the increased depth of the 5°C isotherm, that may be considered as a boundary between the intermediate cold layer and warmer near-bottom water mass, indicates the increase in the strength of the cold intermediate layer and subsequently a fall of temperature. In winter, the correlation with this index was observed at 75 m and bottom-200 m, in spring at 50, 75 m and bottom-200 m and in summer throughout the water column. All cases of correlation between the fall temperatures and indices "T min III" and "T min VI" have inverse dependence, while correlations with "H (5°C) VI" are directly dependent. It was to be expected, since the inter-year trend of fall changes opposes the general one which persists through the winter, spring and summer and is responsible for the index fluctuations.

In 34 cases out of 36 given in table 1 the coefficients exceed 0.60, in 15 they exceed 0.70 and in 4 cases they are over or equal to 0.80. The correlations were real in 24 cases (by the criterion $\frac{R}{E} > 6$. The series length was adequate in 4 cases (by the criterion $\frac{R}{E} > 10$). Recurrence of "Y" deduced from the equations and persisting within the limits of the 20% amplitude of a natural series, exceeded 50% in 35 cases, 60% in 21 cases and 70% in 8 cases.

Thus, "T min III", "T min VI" and "H (5°C) VI" may be used as the indices of heat content for different areas. From the results available the equations with the coefficients $R > 0.60$, reality criterion $\frac{R}{E} > 6$-10 and recurrence rate of 60% or more may be recommended. To continue the series of mean seasonal values of indices, at least monthly observations are needed along the sections III and VI shown in fig. 5.

The following conclusions may be drawn from the above-stated:

1. The analysis of the mean seasonal water temperature and indices for 1962 to 1976 period revealed the following fluctuation periods in heat content: 1962-63 - rise in temperature, 1964-66 - a fall of temperature, 1967-1972 - a rise in temperature, 1973-1975 - the unstable period, 1976 - a trend towards a rise in temperature.

2. As is evident from the qualitative and quantitative estimate of correlation between the mean seasonal values and indices with regard for physical justification, the fluctuations of indices reflect the variability of heat content in some areas, which means that they may be used for estimating the water heat content in the studied areas.

Discussion

To calculate the correlation factors, the formula suitable for relatively prolonged series was used, while the series analysed contained just 11 terms. The comparison of results with those obtained by another formula commonly used in biometry:

$$R = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - (\sum x)^2}\ \sqrt{n\sum y^2 - (\sum y)^2}}$$

showed that the factor values were underestimated by 0.1 on the average. Therefore, more prolonged series might provide higher reliability level of equations.

Both the indices and the mean seasonal temperature values by area and depth level may prove useful in studying the inter-year seasonal fluctuations in the zoo-and ichthyoplankton abundance, as well as abundance fluctuations of the fish and invertebrates inhabiting the shelf waters from the Hudson Canyon to the Laurentian Channel. The correlation between the mackerel young-of-the-year stock size in ICNAF Subareas 3-6 reported by Garrod (1975) and the "T min III" index for the time series for the 1968 to 1975 period may be taken as an example of direct correlation between the fluctuations in the fish abundance and variations in heat content of the waters. This correlation appeared to be reliable at the correlation factor of 0.71 in spite of inadequacy of the series length.

Acknowledgements

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Table 1. Correlation parameters and regression equations. (G.B. - Georges Bank, G. M. - Gulf of Maine, N. Sc. - Nova Scotia, Sh.US - USA shelf.)

SEASON	Y/X	R	E	R/E	recurrence %	Y=Ax+B
WINTER	T 0m,G.B. / T min III	0.73	009	7.89	54	Y=078x+22
WINTER	T 50m,G.B. / T min III	060	0.13	465	54	Y=097x+2.5
SPRING	T 0m,G.B. / T min III	064	0.12	5.47	54	Y=0.65x+4.7
SPRING	T 50m,G.B. / T min III	0.66	0.11	5.86	54	Y=0.68x+3.8
SPRING	T 75m,G.B. / T min III	0.56	0.14	4.02	54	Y=0.59x+4.0
SPRING	T 200m,G.B. / T min III	0.68	0.11	6.21	64	Y=0.65x+4.4
AUTUMN	T 50m,G.B. / T min III	-0.72	0.10	7.55	54	Y=16.1-0.97x
AUTUMN	T 75m,G.B. / T min III	-0.73	0.09	7.72	63	Y=13.6-0.81x
SUMMER	T 75m,G.M. / T min III	0.73	0.10	7.64	45	Y=0.38x+4.0
AUTUMN	T 50m,G.M. / T min III	-0.70	0.10	6.66	63	Y=11.0-0.56x
AUTUMN	T 75m,G.M. / T min III	-0.62	0.12	5.0	63	Y=9.6-0.4x
WINTER	T 50m,Sh.US. / T min III	0.64	0.12	5.26	63	Y=1.44x+3.4

SEASON	Y/X	R	E	R/E	recurrence %	Y=Ax+B
SPRING	T 50m,Sh.US. / T min III	0.68	0.11	6.21	54	Y-055x-49
SPRING	T 200m,Sh.US. / T min III	0.67	0.11	6.09	54	Y=0.6x+5.8
AUTUMN	T 50m,Sh.US. / T min III	-0.65	0.12	5.49	73	Y=14.9-0.56x
AUTUMN	T 200m,Sh.US. / T min III	-0.63	0.12	5.14	54	Y=13.2-0.42x
WINTER	T 50m,N.SC. / T min VI	0.66	0.11	5.89	64	Y=0.44x+1.3
SUMMER	T 0m,N.SC. / T min VI	0.72	0.10	7.50	73	Y=088x+4.1
SUMMER	T 50m,N.SC. / T min VI	0.71	0.10	7.13	54	Y=0.59x+3.0
SUMMER	T 75m,N.SC. / T min VI	0.62	0.12	5.02	63	Y=0.61x+2.1
SUMMER	T 200m,N.SC. / T min VI	0.62	0.12	4.96	63	Y=0.61x+4.3
AUTUMN	T 75m,N.SC / T min VI	-0.84	0.06	13.42	73	Y=6.2-0.82x
AUTUMN	T 200m,N.SC. / T min VI	-0.83	0.06	13.06	73	Y=7.8-0.8x
WINTER	T 200m,G.M. / T min VI	0.66	0.11	5.83	73	Y=0.38x+4.5

SEASON	Y/X	R	E	R/E	recurrence %	Y=Ax+B
SUMMER	T 75m,G.M. / T min VI	0.69	0.10	6.62	54	Y-0.47x-4.5
SUMMER	T 200m,G.M. / T min VI	0.68	0.11	6.31	64	Y=0.54x+4.8
WINTER	T 75m,N.SC / H(5c) VI	-0.69	0.11	6.42	54	Y=4.2-0.12x
WINTER	T 200m,N.SC / H(5c) VI	-0.69	0.11	6.48	64	Y=6.0-0.14x
SPRING	T 50m,N.SC / H(5c) VI	-0.69	0.11	6.44	54	Y=3.2-0.1x
SPRING	T 75m,N.SC / H(5c) VI	-0.74	0.09	8.20	54	Y=3.8-0.12x
SPRING	T 200m,N.SC. / H(5c) VI	-0.74	0.09	8.27	64	Y=6.4-0.14x
SUMMER	T 0m,N.SC. / H(5c) VI	-0.80	0.07	11.04	73	Y=18.5-0.18x
SUMMER	T 50m,N.SC. / H(5c) VI	-0.78	0.08	10.04	73	Y=5.9-0.12x
SUMMER	T 75m,N.SC. / H(5c) VI	-0.78	0.08	9.78	73	Y=5.3-0.14x
SUMMER	T 200m,N.SC. / H(5c) VI	-0.80	0.07	10.69	64	Y=7.5-0.14x
AUTUMN	T 200m,N.SC. / H(5c) VI	0.70	0.10	9.63	64	Y=0.24x+2.9

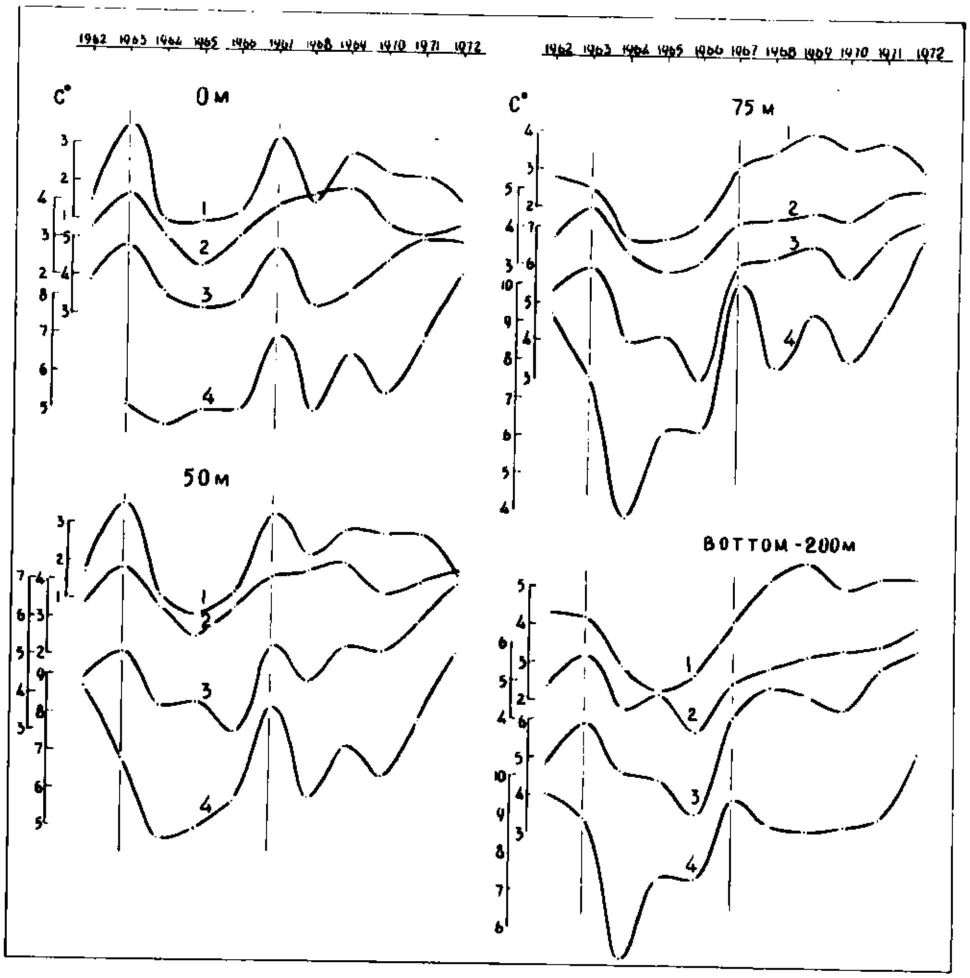

Fig. 1. Inter-year fluctuations in the mean seasonal water temperatures in winter in the Northwest Atlantic shelf area in 1962-72. Here and below: 1 - Nova Scotia shelf, 2 - Gulf of Maine, 3 - Georges Bank, 4 - USA shelf.

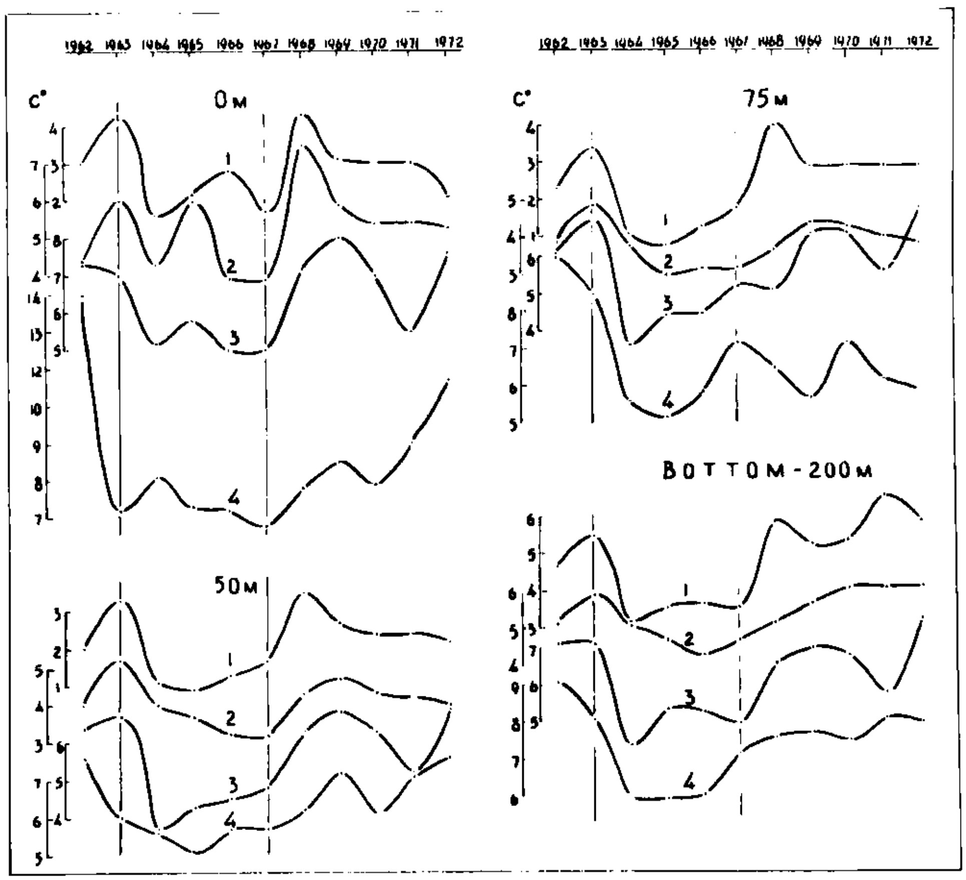

Fig. 2. Inter-year fluctuations in the mean seasonal water temperatures in the Northwest Atlantic shelf area in 1962-1972.

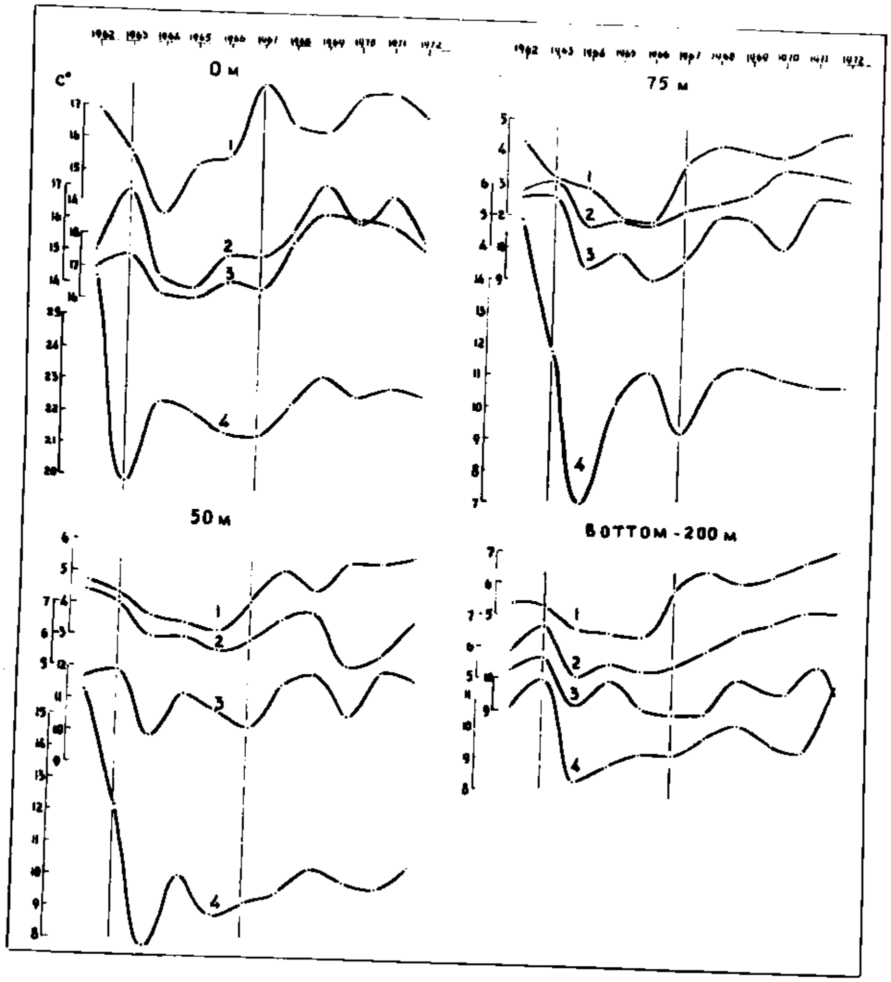

Fig. 3. Inter-year fluctuations in the mean seasonal water temperatures in summer in the Northwest Atlantic shelf area in 1962-72.

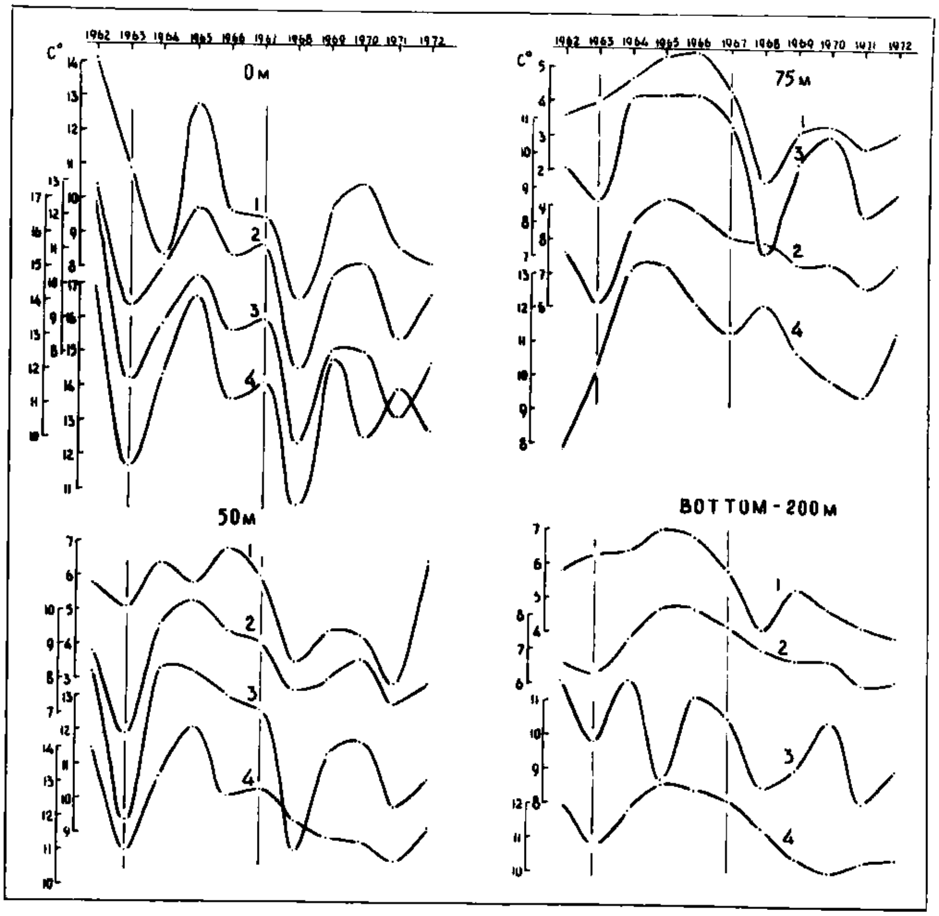

Fig. 4. Inter-year fluctuations in the mean seasonal water temperatures in the fall in the Northwest Atlantic shelf area in 1962-1972.

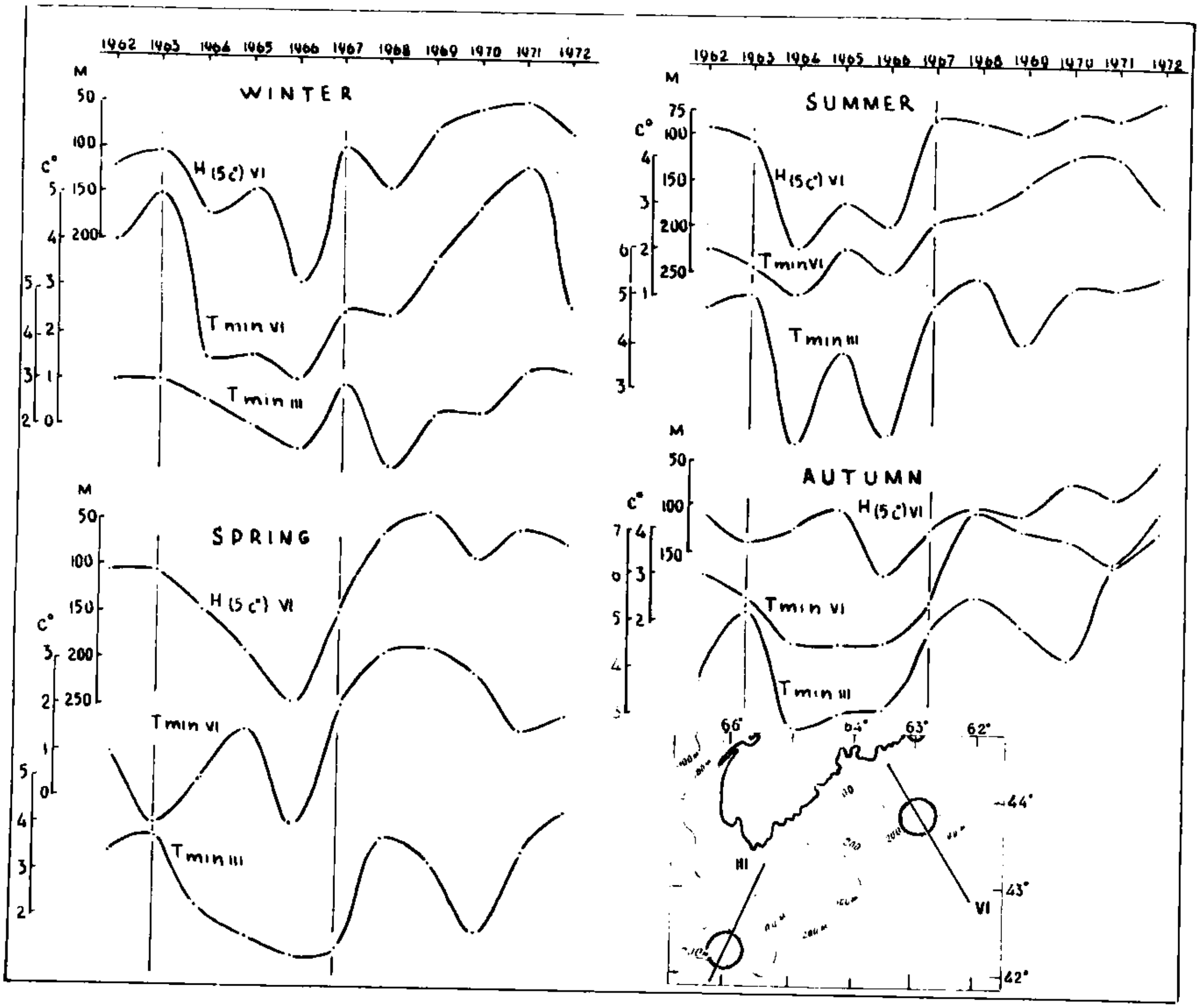

Fig. 5. Inter-year fluctuations in the mean seasonal water temperatures in the local shelf regions in 1962-72.

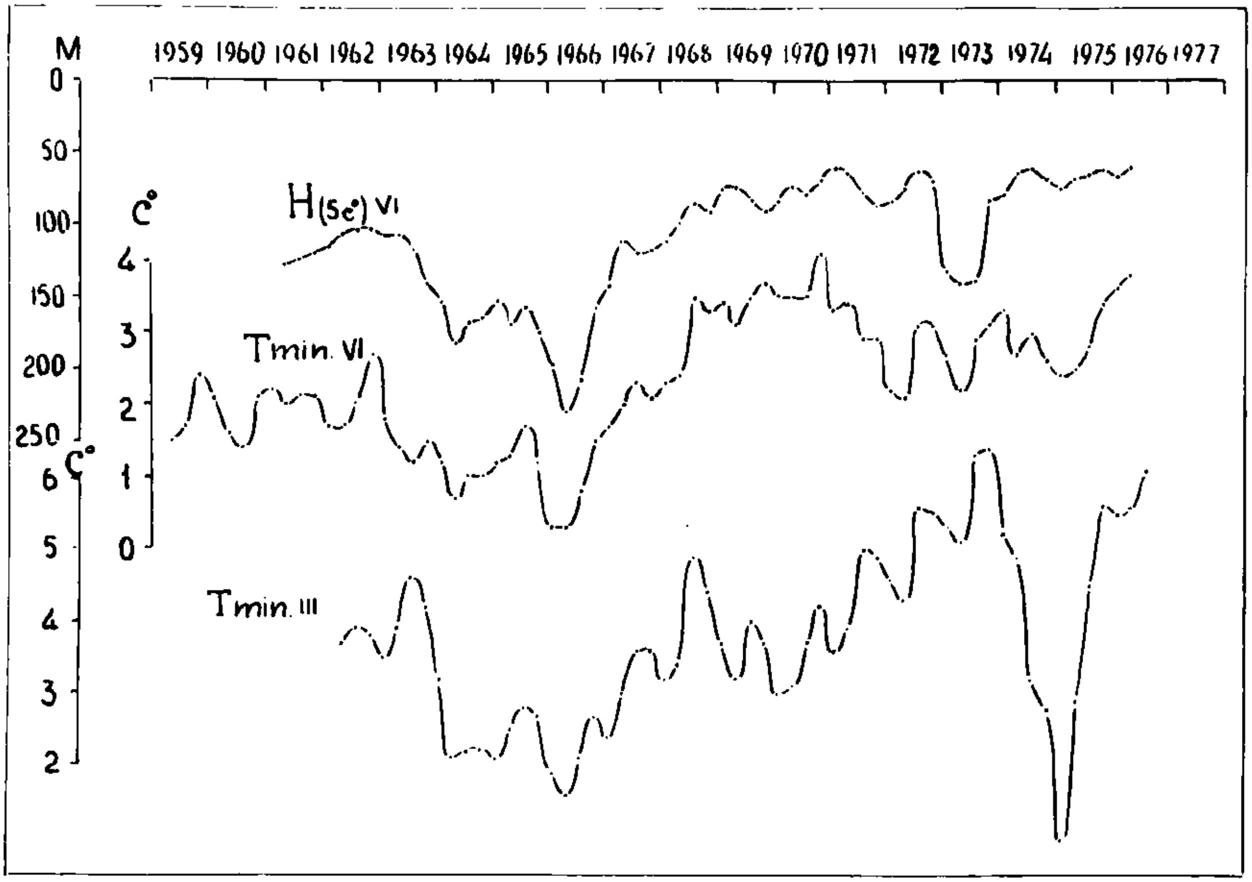

Fig. 6. Long-term run of the heat content indices during the 1959-76 period.