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Long-term variations in heat content of the waters on the Northwest Atlantic Shelf

by

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Introduction

In this paper the results of studies on long-term variations in water temperatures in New England and Nova Scotia areas according to observation data obtained by AtlantNIRO for 1962 - 72 are presented. The paper is of certain interest in explaining of biological phenomena relevant to variation in plankton composition and abundance, as well as in spawning conditions of commercial fish species. The results may help to establish a connection between a trend in water temperature variation and a change in fish stocks for the same period of time.

Material and methods

In the paper the measurements of water temperature variations on the Nova Scotian shelf, in the Gulf of Maine, on Georges Bank and the USA shelf for 1962 - 72 were used.

The measurements were made both during fulfillment of the standard hydrological surveys and during searching and fishing operations. A total of 70 000 measurements was used. All the observations were grouped by conventionally adopted " squares " with the sides of 20' and 30' in latitude and longitude, accordingly (fig. 1). Mean seasonal water temperature values were calculated for each " square " centre providing the observation data were available for no less than 3 years. The charts of mean long-term water temperature values distribution by seasons for 0, 50, 75 m horizons and bottom - 200 m were drawn. The first three horizons chracterize a distribution and concentration of plankton and ichthyoplankton, while the horizon bottom - 200m - the commercial fish aggregations.

Due to unequal intensity of observations during the calendar year the following seasons have been chosen: winter, January - March; spring, April - May; summer, August - September; autumn, October - November. A total of 16 charts has been drawn.

The charts of water temperature anomalies for the observational period by the same seasons and horizons have also been calculated and drawn. Water temperature anomalies were calculated by the formula $\Delta t = T - \bar{T}$,

where Δt is the temperature anomaly in °C,

T is the observed temperature,

$\bar{T}$ is the seasonal mean long-term temperature.

A total of 176 charts has been drawn. They are too numerous to be enclosed here,so they are supposed to be incorporated into the Atlas.

The analysis of heat content variation was made by four geographical areas (fig. 1):

Nova Scotian shelf - I,
Gulf of Maine - II,
Georges Bank - III,
USA shelf - IV.

By means of planimetry, mean long-term water temperatures by seasons (table 1) and temperature anomalies (table 2) were determined for these areas. Abundant observations made it possible to calculate temperature anomalies to 0.1°C, unlike to earlier paper by the same authors (Karaulovsky, Sigaev, 1970) where the anomalies were grouped by the gradations chosen.

Discussion

The results of observations showed a complicated nature of mean seasonal water temperature anomaly variations (fig. 2). The highest anomaly variability was observed at the surface (0 m) and ranged from + 4°C to - 3.7°C. The lower but, nevertheless, significant variability was observed in the Gulf of Maine (from +2°C to - 2.9°C). Within this layer the winters of 1962 - 63 and 1965 - 66 were the most warm periods,while the autumn of 1968 was the coldest.

The variations in water temperature anomalies at the horizons of 50, 75 m and bottom - 200 m ranged, mainly, between + 1.5°C and - 1.5°C in all the subareas. In 1964 maximum temperature fall occurred in the USA shelf area and constituted - 3.6°C; in other subareas it was about - 2.5°C.

The varations of temperature anomalies within the whole water column were similar to those at lower horizons: maximum temperature fall in 1964, in autumn 1968 and winter 1971 - 72 and temperature rise in winter 1962 - 63, in autumn 1965 and summer 1972.

The analysis of mean annual water temperature anomalies demonstrated the highest variability in the USA shelf area and the lowest - in the Gulf of Maine. The fesults allowed to record the temperature fall all over the area in 1964 and on the USA shelf in 1970, and a general temperature rise to + 1°C in the area beginning from 1969 (fig. 3a).

The variations in temperature anomalies at the surface and at 50 m horizon indicated their decrease till 1964 and further variations around the mean long-term values with an increase by 1972 by + 1°C.

Correlation factors of water temperature ranged at those horizons between 0.60 on the Nova Scotian shelf and 0.84 on the Georges Bank (table 3).

The variations of temperature anomalies at the horizons of 75 m and bottom -200 m reflected the pattern of long-term temperature variations: maximum temperature fall in 1964 and temperature rise by 1972 by + 3°C with a pass through the mean long-term value in 1967 at the horizon of 75m and in 1968 - at the horizon bottom - 200 m. Correlation factors of water temperatures at these horizons ranged between 0.77 on the USA shelf and 0.89 - 0.90 in other areas (table 3).

A high water temperature correlation on Georges Bank within the whole column should be noted. Correlation factor for 0 m - bottom - 200 m reached 0.92 wich allowed to judge on variations in prebottom layer by variations in surface temperature. However, correlation factors of water temperature obtained for temperature forecast for different periods of time appeared to be low. So, the factors correlating winter temperatures with spring and summer ones comprised only 0.26 and 0.60 and became negative with autumn temperatures (from - 0.07 to - 0.25). Correlation factors of water temperature for Georges Bank comprised only 0.13, 0.39, 0.17 and 0.12 when the periods of observation were shifted by half of the year, one, two and three years. In other areas correlation factors were also low.

According to a smoothed curve of temperature anomalies run in the area as a whole, a temperature fall was recorded in 1964 and a gradual temperature rise to + 0.7°C by 1972 (fig. 3 b).

The results obtained showed a good agreement with the results of treatment of coastal and inshore stations and lightships material (Chase, 1967; Lauzier, 1965 a, 1965 b; Welch, 1967), as well as of fragmentary surveys of individual parts of the area for certain time periods (Colton, 1968) and by various indices for a series of years (Sigaev, 1969).

Due to a relatively short set of observations a revealing of periodicity in heat content does not seem possible. Nevertheless, mean seasonal water temperature anomalies (table 2) indicate a trend towards a seasonal shift of cooling in the long-term raw: winter in 1964 - 66; spring and summer in 1965 - 67 and autumn in 1969 - 72.

The variations of water temperature in winter, spring and summer occur within a single phase: maximum cooling in 1964 - 66 and temperature rise in the following years. The variations of water temperatures in autumn occur within an antiphase with the above mentioned seasons (excluding

Georges Bank area where the anomaly in 1970 was + 0.5°C) (fig. 4).

A consideration of variations of water temperature anomalies according to conventionally chosen "squares" showed sharper variations (from - 6°Cto + 8°C) over the offshore periphery of Georges Bank resulting from the interaction of the Gulf Stream and Labrador Current waters. In this area the variations are weaker on the surface which can be attributed to a remoteness of the area from the shore and, hence, a decrease of the continental air masses influence.

In other areas most significant variations were observed both along a 200 m isobath and in the regions of the East and South Channels; in spring and autumn, however, such fluctuations were recorded on the shoals along the coastal line of the USA and Canada.

In our opinion, sharp variayions of water temperature anomalies on the USA shelf result from unification of two subareas with different climatic conditions into one area (Colton, 1964).

A certain discrepancy of the results obtained now and in earlier paper by the same authors (Karaulovsky, Sigaev, 1970) can be atributed to a lack of data used in the previous paper.

Conclusion

In the period of 1962 - 1972 a cooling was observed beginning from 1962 with the maximum in 1964, followed by an annual temperature rise by 0.2°C.

Table 1. Mean long-term values of water temperatures.

Subarea	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Season	Surface				50 m				75 m				Bottom - 200m			
Winter	2.1	3.4	4.3	6.3	2.3	3.7	4.8	7.1	3.0	4.0	5.5	8.6	4.5	5.3	5.8	8.8
Spring	2.8	5.5	6.4	8.4	2.1	3.9	5.6	6.3	2.4	3.7	5.8	7.2	4.9	5.2	6.2	7.2
Summer	16.1	15.5	17.4	22.0	4.3	6.8	11.1	9.8	3.4	5.7	10.6	10.7	5.6	6.2	10.0	9.9
Autumn	9.9	10.5	12.9	14.3	5.4	8.6	11.6	12.4	3.9	7.7	9.9	11.5	5.6	7.0	10.0	11.4

Table 2. **Water temperature anomalies**

Subarea	Surface															
Year	I'	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
	Winter				Spring				Summer				Autumn			
1962	-0.6	-0.1	-0.4	-	-0.2	-1.1	1.0	5.6	0.8	-0.5	-0.4	4.2	4.2	2.4	4.0	2.6
1963	1.4	0.8	0.5	-	1.4	0.5	0.6	-1.2	-0.5	1.4	0.0	-2.2	1.0	-1.1	-1.1	-1.2
1964	-1.1	-0.3	-0.7	-1.7	-1.2	-1.2	-1.2	-0.3	-2.4	-1.3	-1.2	0.3	-1.5	0.1	0.5	1.5
1965	-1.1	-1.1	-1.1	-1.3	-0.6	0.5	-0.6	-1.1	-0.9	-1.6	-1.3	0.0	2.9	1.8	1.9	3.8
1966	-0.9	-0.3	-0.9	-1.3	0.0	-1.6	-1.4	-1.2	-0.6	-0.6	-0.8	-0.6	-0.2	0.4	0.3	0.8
1967	1.1	0.5	0.5	0.7	-1.1	-1.6	-1.4	-1.6	1.7	-0.6	-1.0	-0.7	-0.4	0.7	0.6	1.3
1968	-0.6	-	-1.0	-1.3	1.5	2.0	0.8	-0.6	0.4	0.2	0.5	0.3	-2.8	-2.9	-3.0	-3.7
1969	0.7	1.0	0.6	0.2	0.3	0.4	1.6	0.1	0.3	1.7	1.4	1.2	-0.1	-0.2	-0.3	0.6
1970	0.2	0.1	0.2	-0.8	0.2	-0.1	0.6	-0.5	1.4	0.5	1.2	0.6	0.6	0.2	-0.3	-1.7
1971	0.1	-0.2	0.9	0.6	0.2	-	-0.9	0.6	1.5	1.4	1.1	0.9	-1.2	-2.0	-2.2	-0.3
1972	-0.6	0.5	0.7	2.4	-0.7	-0.2	1.2	2.3	0.8	0.0	0.4	0.7	-1.7	-0.7	-0.6	-1.5

Subarea	50 m															
Year	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
	Winter				Spring				Summer				Autumn			
1962	-0.6	-0.3	-0.4	-	-0.1	0.1	0.8	1.3	0.4	0.6	0.6	6.0	0.4	0.2	2.1	1.6
1963	1.2	0.6	0.3	-	1.2	1.3	1.1	-0.3	0.0	0.2	0.8	2.5	-0.3	-2.2	-2.2	-0.9
1964	-1.2	-0.4	-1.1	-2.4	-1.0	0.1	-1.9	-0.7	-0.7	-0.8	-1.2	-2.0	1.0	1.0	2.2	0.8
1965	-1.7	-1.2	-1.0	-2.1	-1.2	-0.2	-1.3	-1.2	-0.9	-0.8	0.1	0.2	0.4	1.7	2.1	2.2
1966	-1.2	-0.4	-1.8	-1.4	-0.8	-0.7	-1.1	-0.6	-1.1	-1.2	-0.4	-1.0	1.4	0.8	1.4	0.2
1967	1.0	0.4	0.5	1.1	-0.4	-0.7	-0.8	-0.6	-0.2	-0.9	-0.9	-0.6	0.6	0.5	1.0	0.4
1968	-0.1	-	-0.4	-1.3	1.4	0.4	0.7	-0.1	0.8	-0.2	0.4	-0.3	-1.9	-0.9	-3.1	-0.5
1969	0.6	0.8	0.5	0.1	0.6	0.8	1.2	0.9	0.2	0.0	0.8	0.5	-1.0	-0.6	-0.3	-1.0
1970	0.5	0.0	0.4	-0.7	0.3	0.4	0.7	-0.2	1.1	1.6	-0.5	0.1	-0.1	0.0	0.1	-1.1
1971	0.5	0.3	1.2	0.8	0.3	-	-0.4	0.9	1.1	1.3	0.9	-1.0	-2.5	-1.3	-1.8	-1.7
1972	-0.6	0.6	1.2	2.6	0.1	0.1	1.3	1.3	1.3	0.2	0.7	0.6	1.1	-0.7	-1.0	-0.7

- continued

Table 2. continued

Subarea / Year	Winter I	Winter II	Winter III	Winter IV	Spring I	Spring II	Spring III	Spring IV	Summer I	Summer II	Summer III	Summer IV	Autumn I	Autumn II	Autumn III	Autumn IV
	75 m															
1962	-0.2	-0.3	-0.2	-	-0.1	0.2	0.3	2.3	0.9	0.1	1.0	5.2	-0.3	-0.1	-0.3	-3.7
1963	-0.5	0.5	0.4	-	1.0	1.2	1.2	1.2	-0.2	0.4	1.0	1.1	0.1	-1.6	-1.3	-1.3
1964	-1.8	-0.7	-1.5	-4.8	-1.3	0.1	-2.2	-1.6	-0.5	-1.0	-1.2	-3.7	0.8	0.7	1.7	1.6
1965	-1.8	-1.2	-1.4	-2.5	-1.6	-0.7	-1.4	-2.0	-1.4	-0.8	-0.7	-0.5	1.4	1.5	1.8	1.8
1966	-1.4	-0.9	-2.6	-2.5	-1.1	-0.5	-1.3	-1.3	-1.5	-0.9	-1.5	0.5	1.5	1.1	1.8	0.6
1967	0.1	0.1	0.5	1.4	-0.6	-0.5	-0.6	0.0	0.3	-0.4	-0.9	-1.4	0.4	0.4	0.9	-0.2
1968	0.5	-	0.7	-0.8	1.6	0.0	0.7	0.7	0.9	-0.2	0.5	0.4	-2.2	0.2	-2.8	0.6
1969	1.0	0.4	1.0	0.6	0.5	0.7	0.8	1.5	0.8	0.1	0.4	0.7	-0.8	-0.4	-0.2	-0.8
1970	0.6	0.2	0.2	-0.6	0.5	0.6	0.8	0.0	0.6	0.9	-0.5	0.4	-0.6	-0.4	0.6	-1.6
1971	0.8	0.8	1.2	0.6	0.5	-	-0.2	1.0	11	0.8	1.1	0.2	-1.2	-1.1	-1.7	-2.1
1972	0.0	1.0	1.7	2.6	0.5	0.1	1.5	1.3	1.4	0.6	1.1	0.2	-0.8	-0.4	-1.1	-0.2

Subarea / Year	Winter I	Winter II	Winter III	Winter IV	Spring I	Spring II	Spring III	Spring IV	Summer I	Summer II	Summer III	Summer IV	Autumn I	Autumn II	Autumn III	Autumn IV
	Bottom - 200 m															
1962	-0.2	-0.4	-1.0	-	-0.2	-0.1	0.9	1.9	-0.2	-0.3	0.3	0.7	0.2	-0.4	1.6	0.6
1963	-0.3	0.4	0.1	-	0.6	0.7	0.9	0.9	-0.3	0.5	0.7	1.6	0.7	-0.7	-0.2	-0.6
1964	-1.6	-1.0	-1.2	-3.6	-1.7	-0.1	-1.8	-1.2	-1.0	-1.1	-0.8	-1.6	0.8	0.8	1.6	0.4
1965	-2.2	-0.6	-1.4	-1.5	-1.3	-0.5	-0.8	-1.2	-1.1	-0.7	0.0	-1.1	1.4	1.2	-1.5	1.2
1966	-1.8	-1.6	-2.3	-1.5	-1.2	-0.9	-0.9	-1.1	-1.2	-0.9	-0.8	-0.7	1.2	1.2	1.1	1.0
1967	-0.4	-0.3	0.3	0.6	-1.3	-0.5	-1.2	0.0	0.3	-0.7	-1.0	-0.7	0.2	0.7	0.5	0.7
1968	0.7	-	1.1	0.0	1.0	0.0	0.4	0.4	0.9	-0.2	0.0	-0.1	-1.5	0.0	-1.5	-0.1
1969	1.2	0.4	0.9	-0.2	0.4	0.5	0.8	0.5	0.6	0.4	0.1	0.3	-0.3	-0.3	-1.0	-1.0
1970	0.5	0.6	0.5	-0.1	0.5	0.9	0.6	0.3	0.8	0.7	-0.3	-0.3	-0.9	-0.3	0.4	-1.4
1971	0.8	0.7	1.6	0.1	1.7	-	-0.4	0.9	1.3	1.1	0.6	-0.5	-1.4	-1.0	-2.0	-1.1
1972	0.8	1.2	2.1	1.9	1.0	0.9	1.6	0.8	1.7	1.1	0.8	1.6	-1.7	-0.9	-1.0	-1.0

Table 3. Correlation factors between water temperatures at various horizons.

Horizons / Subarea	I	II	III	IV
0 - 50 m	0.60	0.69	0.84	0.69
0 - 75 m	0.54	0.46	0.67	0.48
0 - bottom -200m	0.55	0.49	0.92	0.56
50 - 75 m	0.75	0.87	0.91	0.79
50 - bottom - 200m	0.79	0.79	0.91	0.83
75 - bottom - 200m	0.90	0.89	0.89	0.77

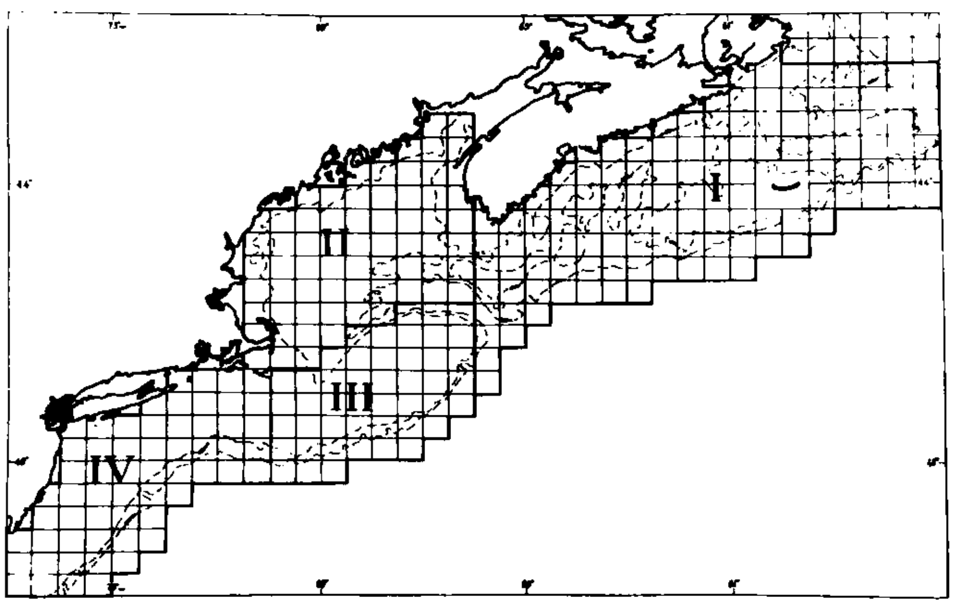

Fig. 1. Investigated area divided into conventional "squares".

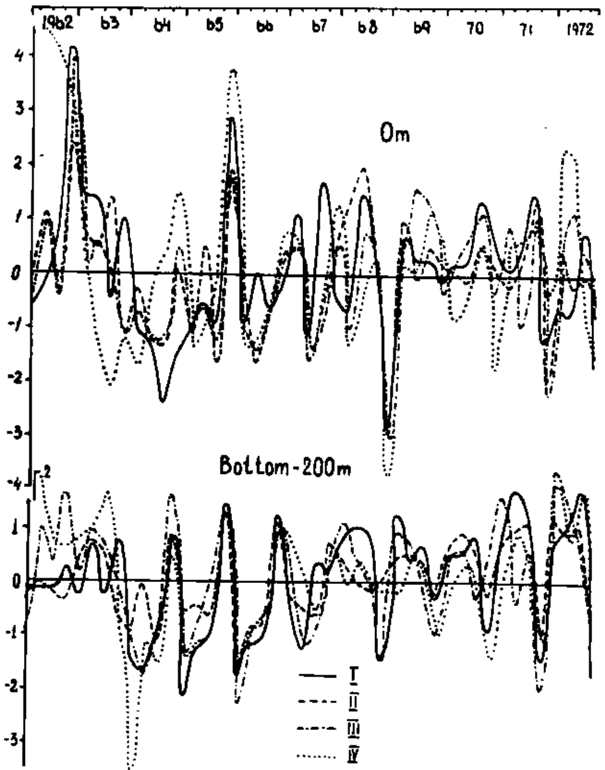

Fig. 2. Run of mean seasonal anomalies of water temperatures by horizons selected.

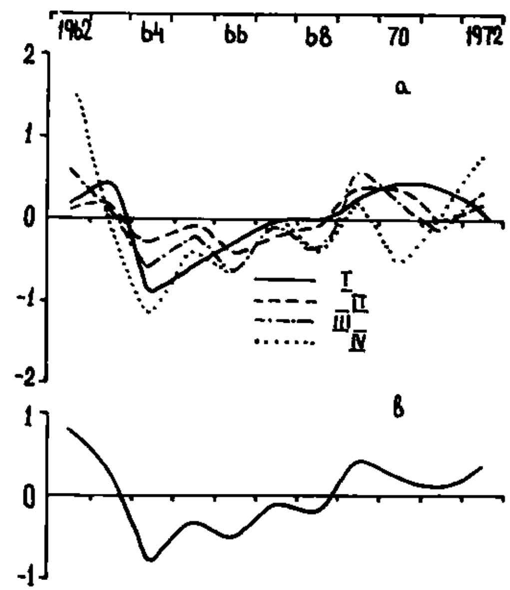

Fig. 3. Run of mean annual anomalies of water temperatures:
a. by subareas
b. over the whole area.

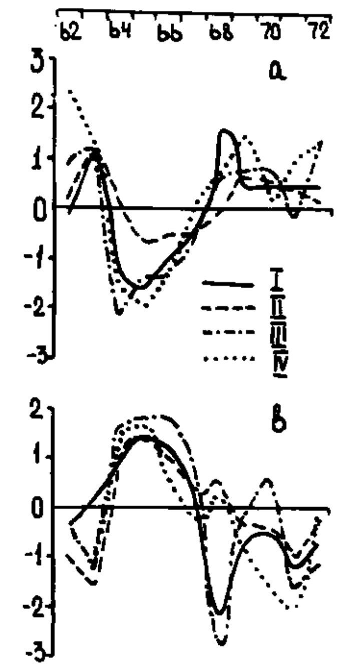

Fig. 4. Run of mean seasonal anomalies of water temperatures by subareas:
a. spring
b. autumn.