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Forecasting the fluctuations of water mass limits on the Scotian Shelf and Georges Bank

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The modern development of deep-sea fisheries makes it even more necessary to have timely fishery forecasts (from a year to several days and hours). Such forecasts can be made based on knowledge of the following factors:

1) The biology of the species fished;
2) The response of those species to the abiotic and biotic factors of their surroundings, and
3) The changes in hydrological structure of waters within certain periods of time.

When information on the first two points is available the hydrological prognosis can be actually a fishery forecast.

For most fish species, water temperature is one of the most essential and, at the same time, one of the most variable environmental factors. Some researchers have determined the temperature range of existence of a species as the range of its maximum concentrations (Jean (1965), Edwards (1964), McCracken (1965)). Whereas others, Glebov (1938), Marty (1956) and Manteifel (1955), have emphasized the role of frontal zones in the formation of commercial concentrations of fish.

Investigations of the living conditions for herring in the Georges Bank area have been completed by Pakhoroukov (1961), Benko and Wilson (1962), Zinkevich (1966) and Bryantsev (1964). In this paper, the authors have based their deliberations on the assumption that the prediciticn of changes in frontal zones or in limits of water masses could be regarded as a forecast of the displacement of some fish species. In this connection the following studies have been completed:

1) an analysis of water masses on the Scotian Shelf and Georges Bank;
2) a study of the temperature change of extricated waters;
3) an outline of the limits of water masses;
4) a study of the spectrum of fluctuation of the vertical limits of water masses based on data obtained from two long-term stations;
5) a study of tidal fluctuations of a level of bottom water masses based on data collected at two long-term stations;
6) determination of the relationship between the elements of atmospheric circulation and fluctuations of the limits of water masses;
7) revelation of interrelation between the above-mentioned (4) fluctuations of the vertical limits of bottom waters (based on data from long-term stations) and the extent of their proliferation onto the Shelf (based on data from hydrological surveys carried out during the period in which the long-established stations were operating).

A. Analysis of water masses and determination of their limits

On the Scotian Shelf and Georges Bank a specific feature of the hydrological structure of the water is its triple layer character (in summer). Hachey (1953), McLellan (1954)and Bryantsev (1962, 1963) have analyzed the water masses of the area using different approaches to the problem. Hachey identified the three characteristic layers. McLellan used TS analysis with the help of a five-dotted nomogram. V.T.Timofeev made a general analysis of the water masses which we have applied using a three-dotted nomogram. In all cases, the three characteristic layers were identified.

In the present analysis, it is assumed that the main sources of the waters in the area under investigation are:

1) the waters of the Gulf Stream which, according to Stommel (1963), are formed by the Florida and Antilles Currents (these waters are characterized by high salinity and temperature);
2) the waters of the Labrador Current which originate in Baffin Bay and are characterized by a low temperature;
3) the local coastal waters which are freshened by the continental run-off.

These three sources form the above-mentioned layers or water masses in this area with their innate characteristics as follows:

1. <u>The coastal water mass</u> is characterized by the lowest salinity, 30.0-32.5‰. Seasonal variation of temperature is from 0-3°C in winter to 16-18°C in summer. This water mass is a surface layer which increases in thickness landward and decreases to insignificance outside the continental shelf. The average depth of the lower limit is about 50 meters.

2. <u>The Labrador water mass</u> is characterized by intermediate minimum temperatures from Banquereau Bank to Cape Hatteras. Salinities range from 32.5 to 33.5‰, temperatures from -1.0°C on the northeast edge to 8°C on the south slopes of Georges Bank. The lower limit is located at average depths of 90 to 150 meters.

3. <u>The bottom water mass</u> is of oceanic origin. These waters are connected with the Gulf Stream and reach the continental shelf through the deep-sea canyons and deeps. Salinities are over 33.5‰ and reach 35.0‰; temperatures vary depending on the latitude and the season from 3° to 12°C.

In winter, the coastal and the Labrador water masses unite into one cold surface layer. We assume that, since each of these water masses is a part of the greater water volume, the vertical and horizontal fluctuations of the boundaries of the layers are connected with variations in these volumes in the entire area from the place of origin to the investigated region.

Such fluctuations can be governed by variations in the baric field above a major part of the ocean. This mechanism could be understood through comparison of the variations in the baric field with the recorded fluctuations of the boundaries of water masses, at least in the vertical plane, at certain points of the area.

But, first of all, these borders must be determined. From an analysis of TS diagrams and a general study of the changes in hydrological characteristics, it was found that irrespective of season and coordinates the 32.5‰ isohaline can be taken as the boundary between the coastal and Labrador waters and the 33.5‰ isohaline as the boundary between the Labrador and bottom waters. At the same time, the water temperatures, as a less constant character, change considerably from season to season as well as from the southwest to the northeast margins of the area.

The seasonal and spatial changes were studied using data collected from 4,655 hydrological stations made by AtlantNIRO from 1960 to 1965.

The area investigated was divided conventionally into 6 zones (Fig. 1). Each zone covered one degree of latitude. The temperatures were grouped by months, zones and water masses. Surface temperatures were used to identify the coastal waters, minimum temperatures within the intermediate layer to identify the Labrador waters and maximum temperatures within the zone of intermediate maximum or the bottom temperature to identify the bottom waters. Figure 3 shows the seasonal and spatial changes plotted as mean temperature values.

The accuracy of the curves naturally diminishes due to the different amounts of data available from different zones and months. We believe, however, that the available data express a general qualitative trend of temperature change.

As seen in Fig. 2, the seasonal change in each water mass has a different trend. The coastal waters have a minimum temperature value in March and maximum in August while the waters of the intermediate and bottom layers change in a different way.

The intermediate layer has a second peak in autumn when a density convection and the surface layer intermingle with the intermediate one raising the absolute value of the temperature at these depths.

No regularities can be observed in the seasonal variability of the bottom layer excepting the maximum in May which is apparent in almost all zones.

The spatial changes in the three water masses are more alike than the seasonal ones. In all instances there is a lowering of temperature from south to north. This typical tendency is disturbed by causes of a seasonal character (cooling and convection; disproportionate cooling and warming) as well as by peculiarities of bottom configuration in each zone (presence of shallow areas where warming is more intensive, availability of submarine canyons with warm bottom waters affecting the above layer, etc.)

Results of investigation of the temperature changes show that it is impossible to determine permanent temperature ranges for water masses. Different isotherms would correspond to their borders at different times and in different parts of the shelf.

Nevertheless, with allowance for changes, the limits of the water masses can be drawn as certain isotherms. Moreover, the temperature is a factor more easily observed at long-term stations. To study fluctuations of the limits of water masses we occupied 4 such stations in the area of the Scotian Shelf and Georges Bank in different seasons from 1964 to 1966. Three of these stations were occupied for 15 days and one for 30 days (Fig. 4). The stations were made in the following way: an autonomous buoy station was set down at a certain point at a depth of 210 meters. It was equipped with a buoy-carrier submerged at a depth of 10-20 m, with automatic current recorders placed at depths of 10, 75 and 200 meters, with bottom anchors, with a base between anchors and with a signal buoy. The vessel drifted in the vicinity of a signal buoy, and when weather permitted she anchored. Hourly observations with the aid of the bathythermograph were carried out from the vessel and every 6 hours bathometer measurements were taken. As a result, a continuous picture of temperature variations within the 0-200 meter layer was obtained during the whole period at each station.

Figure 5 shows a part of a graph of the temperature variation registered at Station N 183. The precision with which the isotherms are drawn are greater here due to the fact that the depths with integral value of temperature were taken from the hourly bathythermograph curves, i.e. the depths of location of isotherms.

Using temperature and salinity data collected from long-term stations, Fig. 6 presents histograms showing the correspondence of temperature values to salinity of 32.5 and 33.5‰, i.e. to the limits of water masses. If several isotherms corresponded to the mentioned isohalines (Stations N 46 and 183) we chose the one which was closest to the zone of maximum temperature gradient. The continuity of the isotherm during the course of the whole period of observations was taken into account.

Thus, in each individual case we had the limits of water masses expressed by certain isotherms, the location of which was registered every hour. At Station N 183 the boundary between the coastal and the Labrador waters was the 7° isotherm, between the Labrador and the bottom waters was also 7° but after the intermediate minimum; at Station N 46 it was 5°, at Stations N39 and N 40 the border of bottom waters was the 3° isotherm. In Fig. 5 these curves are drawn thicker. Let us assume that for the sake of convenience the first of the mentioned limits, its hourly and average diurnal values of depths will be marked by Ha and the second one by Hb. Having a series of values of Ha and Hb from four points of the area (Ha-183, Hb-183, Ha-46, Hb-46, Hb-39 and Hb-40) we can carry out a study of the fluctuations of the vertical limits of water masses.

B. <u>Study of periodic fluctuations and their precalculation</u>

In order to determine the character of short-period fluctuations of water mass limits, the hourly readings of Ha and Hb were analyzed with special reference to their periodicity.

Similar investigations to reveal the periodicity and to determine the internal waves were carried out in earlier works by Seiwell (1937, 1940), Glynsky

(1963) and Boris (1965). These authors used data on the vertical variations of isotherms and isohalines as well as data relating to changes of temperature, salinity and density at standard levels. The following methods of analysis were applied: harmonic, spectral and periodogram after Shuster and Ceylon. These authors distinguished the following periods:

Table 1. Internal wave periods as determined by some researchers.

Name of researcher	Period (in hours)				
H.R.Seiwell	5	8	12	24	
N.T.Glynsky	7	12.4	16	24.8	28-30
L.I.Boris	8	12	24		

In this paper, a method of periodogram analysis of data after Shuster (6) was used with some modifications. In case of a long series (over 300 terms) the rounding-off of values of short period amplitudes is obviously necessary because the time of our observations lasted exactly one hour whereas actual periods do not coincide with the whole hours. Therefore in calculating amplitudes all values of the series were not used but only 10 lines of readings for each period. The calculations were processed through the electronic computer "Promin".

Boris (1965) completed the treatment of data collected at Stations N 46 and N 183 for the purpose of determining the character of internal waves. She had employed the spectral analysis and autocorrelation method for analysis of series of hourly readins of depths of corresponding isotherms and isopycnics (in case of Station N 46). Calculations were made on a large electronic computing machine (BESM-2). The spectral analysis of data collected at Stations N 39 and 40 was carried out with the help of the electronic computer "Setoun". A general scheme of calculations other than the method of rounding-off was drawn up in conformity with principles laid down by Yampolsky (1965). In the long run we had received a table of dominant periods on the basis of major and minor peaks of periodograms and results of spectral analysis. The values of the latter are inserted in brackets beside the figures obtained from periodograms (Table 2).

The periodograms of fluctuations of the limit of the bottom water mass are shown in Fig. 7 and values of amplitudes in Table 3.

The values of periods obtained (Table 2) were generally similar to those which are set out in Table 1, i.e. our spectrum is similar to that for which periods had been found by other scientists in various points of the world ocean.

Our analysis compared two 15-day series making one 30-day series which had been treated separately for uniformity. As was ascertained the amplitudes of identical periods are different and values of the periods themselves change slightly.

It should be noted here that inaccuracy of the method plays a certain part but it can be supposed that all observed fluctuations except the tidal ones are mainly quasi-periodical.

The 12-hour period has proved to be most stable. It is undoubtedly of tidal origin. As seen in Table 3 and Fig. 7 the amplitudes in the 12-hour period were, in most cases, greatest. The amplitude becomes greater on deeper grounds and closer to the Bay of Fundy.

Glynsky (1963) quotes the interesting inferences of Reed who, after having analysed observations made at three synchronous long-term stations off the US Pacific coast between 35° and 37° north, "came to conclusion that internal waves with a tidal period could occur in the vicinity of the coastline and islands whereas at a distance from them the internal waves have a whole spectrum of periods without a prominent domination of any period".

In considering the tidal fluctuations of the limit Hb at all 4 stations, it can be concluded that the amplitude of the tidal period of internal waves not only becomes bigger closer to the shore, but the amplitude changes also depending on the magnitude of the tide near the coastal line.

At Station N 183, most distant from the coast, the tidal range is smaller than that at Stations N 39 and 46.

Table 2. Periods of hourly values of Ha and Hb at long-term stations obtained by means of periodogram-analysis and spectrum analysis (values in brackets).

Station numbers	series of hourly values	Periods (in hours); in brackets are the periods with highest value of spectral function
183	Ha	4 (3.5) 12 (2.5) 15 17 (16.3) 19 26 30 (31.0)
	Hb	6 9 (12.5) 17 (16.5) 19 22
46	Ha	4 7 (6.0) 12 (12.5) 18 119.3 25 (26.5) 29
	Hb	4 6 (6.0) 9 12 (12.5) 16 21(19.3) 24.31
39-a	Hb	5 (5.6) 9 12 (12.5) 16 (15.7) 19 27(27.3)
39-	Hb	6 (5.6) 10.12 (12.5) 17 24 30
40	Hb	7 (7.0) 10 (10.0) 12 (11.3) 17 21 (19.6) 26 33

Table 3. Peak values (m) standing out against periodograms

Station numbers	Periods (hours) limits	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
183	Ha		5.0					5.6			5.6			4.3		3.2	3.4								2.0				5.3					
	Hb				3.9						8.9					4.7	5.5				4.0													
46	Ha		2.3			2.8					9.7						2.3			4.7			4.4							3.1				
	Hb		5.0		5.4			3.9			31.7				3.4																			
39-a	Hb			6.6				7.2			18.7				4.0		4.1									6.5								
39-	Hb				5.3				4.8		11.2					5.3				7.7									5.2					
40	Hb					3.9			8.4		5.6					10.2				7.2					12.1								7.6	

Table 4. Harmonic constants estimated on the basis of data from stations N 46 and 39

Station number	Harmonic constant	Waves Ao	M_2	S_2	N_2	K_2	K_1	O_1	P_1	Q_1	M_4	M_6	MS_4
46	H(M)	37.3	31.3	5.5	6.3	1.5	2.7	9.3	0.9	1.9	6.8	2.3	
	K°												
	(IV		336.0	17.8	336.0	17.8	74.8	345.2	74.8	345.2	218.8	95.7	0.5
39	H(M)	8.1	14.9	2.1	4.1	0.6	1.8	2.2	0.6	0.4	0.9	1.6	
	K°												
	(+ IV		21.6	70.4	341.1	70.4	293.0	56.7	29.3	56.7	16.5	353.0	274.6

Station N 40 is comparatively close to the coast but the amplitude of the 12-hour period here is less than the amplitude of the 10-hour period. This is apparently due to the fact that, in the area of the northeast coast of Nova Scotia and Cape Breton (the nearest shore), the tides are much weaker than in the Bay of Fundy.

Thus, in the region of Stations N 46 and 39, the tidal fluctuation is the greatest from the point of view of its range.

It seems possible, therefore, to precalculate the fluctuation of the upper limit of the bottom waters (Hb) in these regions by the application of harmonic constants as in precalculating the level in certain points near the coast. A total of 366 hourly readings of Hb-46 and 720 hourly readings of Hb-39 represent series of depths (in meters) which can be treated by means of Darvin harmonic analysis (Beriozkin, 1947) similar to the processing of tidal data. For simplicity of calculation all values of Hb were cut by 100 m. The curves were not rounded off. The harmonic constants obtained are shown in Table 4.

In the middle of a period of observations on the basis of harmonic constants of 4 major waves only (M_2; S_2; K_1 and 0_1) we have precalculated the limit of Hb for some days ahead.

The correspondence between the unrounded natural curve (solid line) and the precalculated one (dotted line) is satisfactory (Fig. 8).

When making a preliminary calculation of a limit of bottom waters for some time in advance one should bear in mind that the mean level (Ao) could change. Thus, as a result of the analysis, an idea of periodic and quasi-periodic fluctuations of the limits of water masses during periods from 4 to 30 hours was obtained. Tidal (semi-diurnal) fluctuations in two regions have proved to be of such magnitude and are so stable that it is possible to precalculate them on the basis of the harmonic constants obtained.

In addition, the spectrum obtained of both tidal and other periods was used to correct mean diurnal values of Ha and Hb. Before to average the hourly values for each date we had excluded the received periodic fluctuations from the observed series.

C. <u>The study and forecast of non-periodic fluctuations</u>

After excluding the fluctuations of a periodic nature we get new series of Ha and Hb. We assume further that the remaining changes are mostly of advective origin. Consequently, in order to predict fluctuations of vertical levels of water masses of non-periodic character, it is necessary to know the original state of the Gulf Stream and Labrador currents. From our knowledge of the role of wind conditions in the formation of a regime of oceanic currents, we have chosen as arguments the relevant indicators of atmospheric circulation. Such an approach is not only expedient but necessary when there is no adequate direct evidence of variability of currents themselves.

As was expected, the correlation analysis showed that the local meteorological processes (pressure, wind, air temperature) as registered aboard the vessel during the operation of long-term stations have not reflected the variability of oceanological elements. There were exceptional situations when meteorological processes at a confined point reflected those over an expanded area or when local processes were a decisive factor (winter cooling of shallow grounds of the shelf which the Gulf Stream water practically never influences etc.).

It is natural that, in forecasting the advective changes in the hydrosphere, one considers it more expedient to take into account the atmospheric processes in the entire area. The extention of the area and the density of dots in it depend on a timeliness of the forecast, variability of a phenomenon and some other factors.

The pressure was taken from the synoptic bulletins of the USSR Hydro-Meteorological Centre.

For numerical presentation of pressure fields the analytic expression of the latter through the Chebyshev's polynoms was applied. Expansion factors as elemental air transports have been compared graphically and correlatively, synchronally and by shifts with vertical limits of water masses Ha and Hb. The best relations were obtained with the coefficients of expansion of a pressure field limited by parallels 55° North - 35° South and meridians 80° West - 60° West and constituted of 25 points 5° apart by latitude and longitude. The optimum shifts with the interval of 24 hours lay with a range of 1 to 4 days. With application of the pair correlation method the optimum arguments - factors of expansion of the pressure field were found. Under the program of multiple correlation with application of least squares method we found regression equation with different variations of arguments. In doing so we calculated statistic criteria of equation evaluation - correlation coefficient, Fischer criterion with 10% level of significance, security (percentage of errors not going beyond 1/5 amplitude). These data are partially set out in Table 5. On the whole, a character of influence of atmospheric processes on vertical limits of water masses in the area of Georges Bank and Scotian Shelf is rather complicated one. It does not appear feasible, thus far, to restore a comprehensive scheme of physical interpretation of the obtained forecasting dependences. On this basis the equation of multiple correlation contains some other first coefficients of expansion apart from those which serve as optimum arguments based on the results of pair correlation.

Here we took into account not only the influence of any prevailing air transport but also its transfer to other transports which could play a significant part under specific pressure and hydrological consitions. As a rule, the major role is played by elemental meridianal (A_{20}, A_{10}) and latitudinal (A_{01}, A_{02}) air transports which cause direct strengthening (weakening) of warm and cold water inflow on the shelf as well as positive and negative setup effect.

In case of the three-layer hydrological structure (stations N 183 and 46), the effect of optimum arguments on Ha and Hb is reverse. Thus, for instance, at Station N 183 the optimum argument is coefficient A_{20}. When A_{20} is positive air currents in the western part of the chosen pressure field are directed from north to south. This coefficient can generally serve as an analogue of the Labrador-Gulf Stream Current system. Station N 183 is olcated in the eastern part of the chosen pressure field, i.e. in the zone of south transfers when A_{20} is positive. In such a case the physics of the process becomes more evident.

Table 5. Statistic criteria of evaluation of forecasting equations.x/

Station numbers	Function	Optimum arguments	Coefficient of pair correlation with optimum argument	Remaining arguments in case of multiple correlation	Coefficient of multiple correlation	Timeliness in days	Security in %	Real availability of relation
183	Ha	A_{20}	0.82	Aoo, Ao_1 Ao_2, A_{10} A_{11}	0.960	1	100	yes
183	Hb	A_{20}	-0.83	Aoo, Ao_1 Ao_2, A_{10} A_{11}	0.908	1	100	yes
46	Ha	Ao_1	-0.93	Aoo, Ao_2 A_{10}, A_{20}	0.958	1	100	yes
46	Hb	Ao_1	0.91	Aoo, Ao_2 A_{10}, A_{20}	0.844	1	76	no
39xx/	Hb	Ao_2	0.51			2	64	yes
40	Hb	A_{10} A_{02} A_{01}	-0.67 -0.64 -0.53	A_{10} A_{02} A_{01}	0.780	3	62	yes

x/ Example of regression equation (St.183, Hb):

$$Hb = 115.510 + 0.645\ Aoo + 3.808\ Ao_1 - 0.972\ Ao_2 + 1.860\ A_{10} - 10.574\ A_{20} - 2.999\ A_{11}$$

xx/ All data based on pair correlation

With the growing of A_{20} Ha increases and Hb drops (increase of H means lowering of level and decrease of H indicates its rising), i.e. the volume of local waters becomes larger as the volume of the Labrador waters drops and the volume of the Gulf Stream waters expands.

It can be assumed that, in the area studied, along with intensification (weakening) of inflow of the Gulf Stream waters, the abatement (increase) of a flux of cold waters from the Labrador Current occurs. Moreover, this phenomenon is predetermined by atmospheric circulation. At Station N 46 optimum argument is coefficient A_{01} indicating a zonal transfer. When A_{01} is positive the air currents are directed from west to east and when its meanings are negative from east to west. If the western transfer grows Ha diminishes and Hb increases, i.e. the volume of the local and Gulf Stream waters abate and the volume of the Labrador waters increases. It can be assumed that such a phenomenon is conditioned by the fact that the western flow drives the local waters off the shelf and deflects the inflow of the Gulf Stream waters seaward away from the shelf.

In the case of the double-layer structure (Stations N 39 and 40), the prevalence of advective or driving-in or-out effect is less profound. Both processes obviously act in the aggregate and it was actually ascertained that at Station 40 the optimum arguments are A_{10} , A_{02} and A_{01} coefficients, i.e. both the meridian and zonal transfers. At Station N 39 the optimum argument is A_{02} coefficient but the relation with Hb is direct in contrast to that at Station N 40 where it is reverse. In such a case, it is difficult to attribute the influence of latitudinal currents solely to drive-in and-out effect. These currents probably cause advective changes too in a certain way. So, in principle, we have arrived at the possibility of predicting the non-periodic fluctuations of vertical limits of the water masses with a timeliness ranging from 1 to 3 days. Moreover, it appears feasible to take into account the variations of the mean level while precalculating the tidal fluctuations.

Our forecasting dependences are of a dotted nature, i.e. they are based on the local empiric relations which were deduced from the data of individual buoy stations.

The representativeness of such relations depends on the agreement of oceanological processes in a certain point and within a field. To study this question fully is impossible because of the lack of surveys throughout the area during the completion of long-term stations N 183 and 46. It must be mentioned, however, that during the time Stations N 39 and 40 were occupied, several surveys were made throughout the area - four surveys during the occupation of Station N 39 and two during the occupation of Station N 40.

The visual analysis of inflows of warm and cold waters, as well as the comparison of mean values of temperature and salinity in the entire area with mean characteristics of vertical limits of water masses at buoy stations, showed that there is good agreement between the variations of the level of bottom waters and the extent of their penetration into the shelf area.

Consequently there are grounds for believing that the local dependences will be representative for certain regions of the shelf. It would be possible to study this question more thoroughly and to verify the justifiableness of the equations as new material of observations becomes avavailable.

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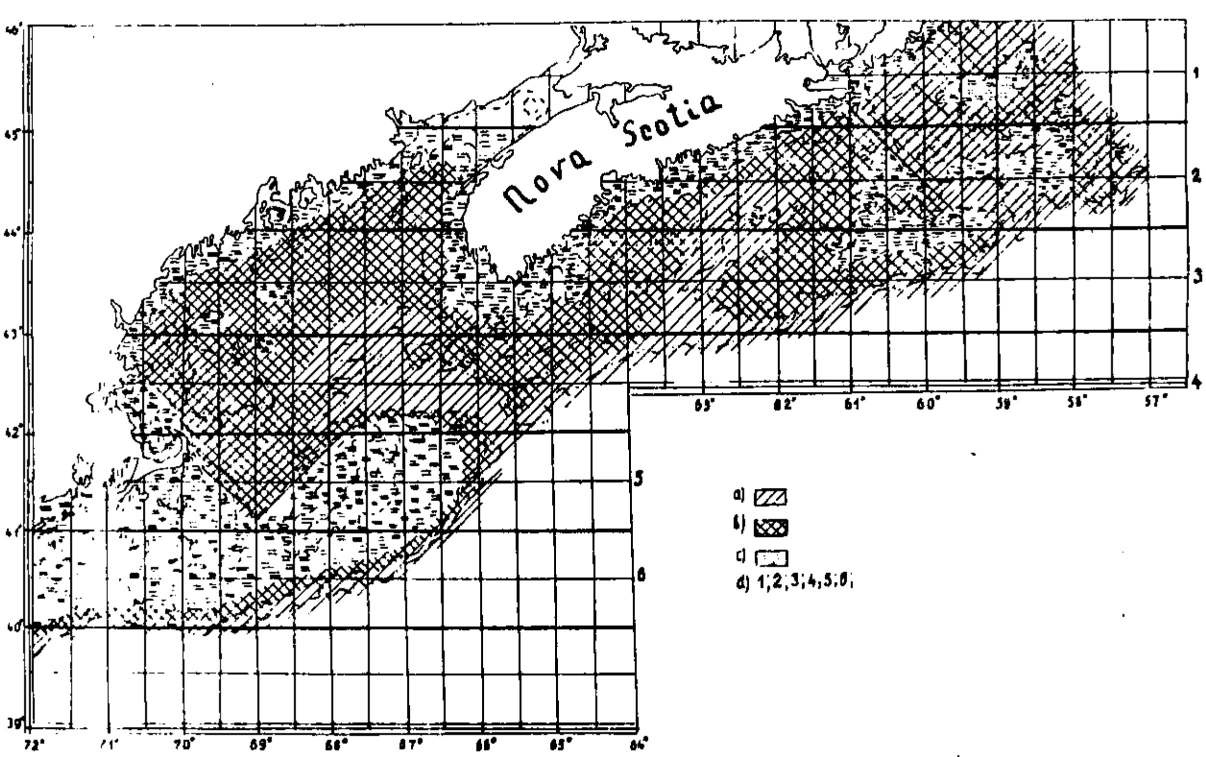

Fig. 1. Disposition of water masses in bed plane; division of area into zones: (a) bottom water mass; (b) Labrador water mass; (c) coastal water mass; (d) zone numbers (see right margin of figure)

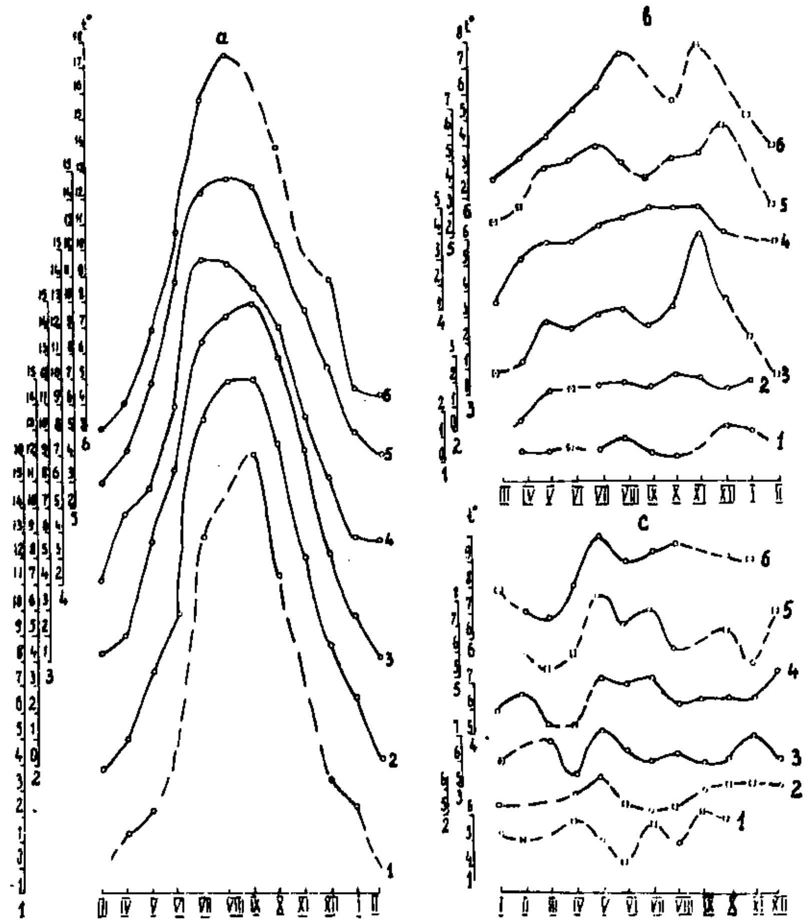

Fig. 2. Seasonal variation of mean values of water temperature: (a) coastal water mass; (b) Labrador water mass; (c) bottom water mass.

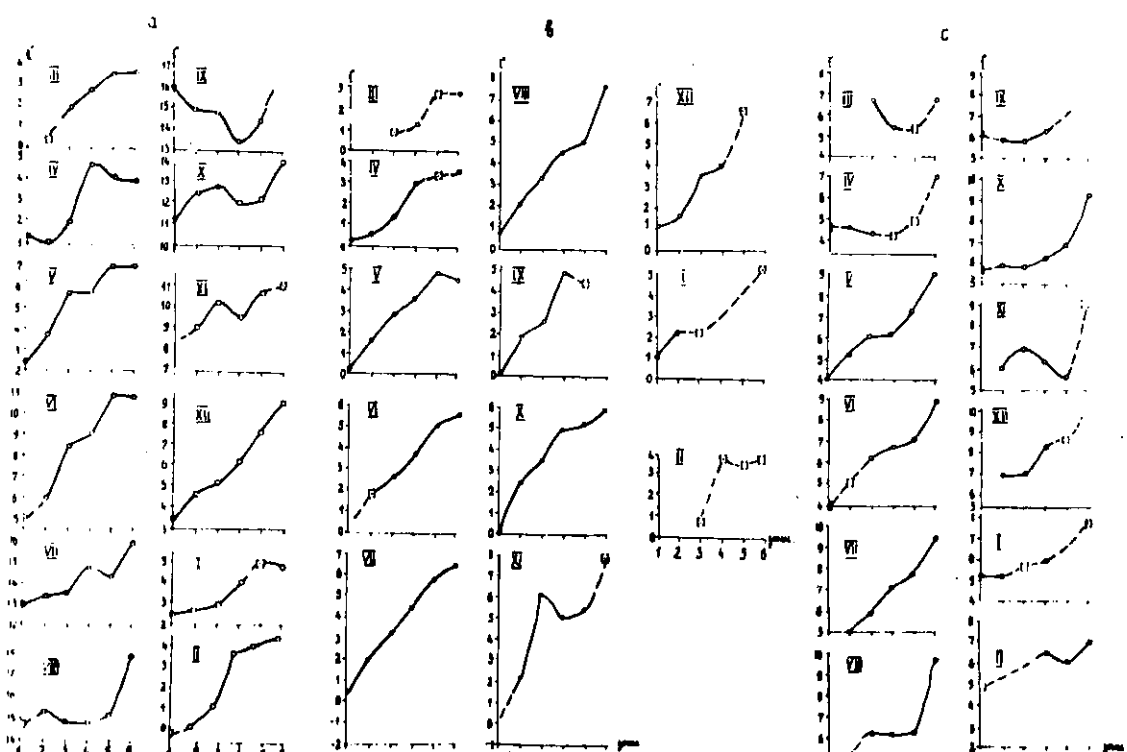

Fig. 3. Zonewise variations of mean values of water temperature(by latitude): (a) coastal waters; (b) Labrador waters; (c) bottom waters.

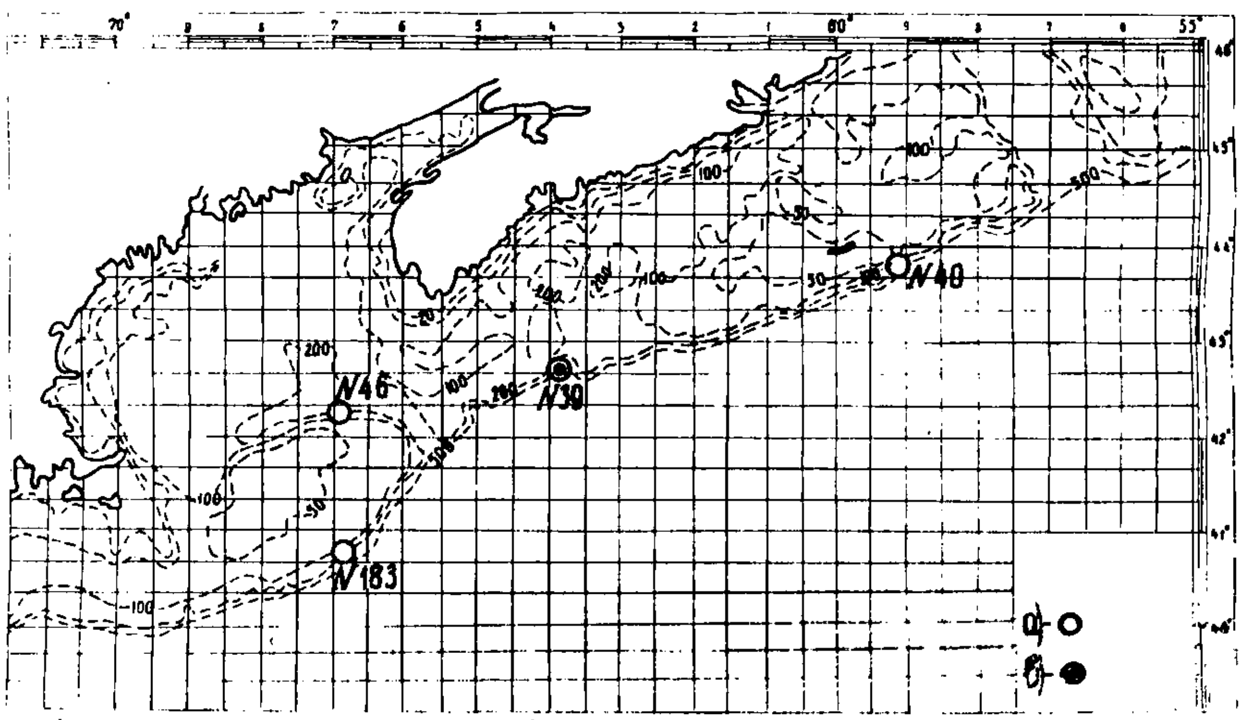

Fig. 4. Location of long-term stations: (a) 15-day stations; (b) 30-day stations

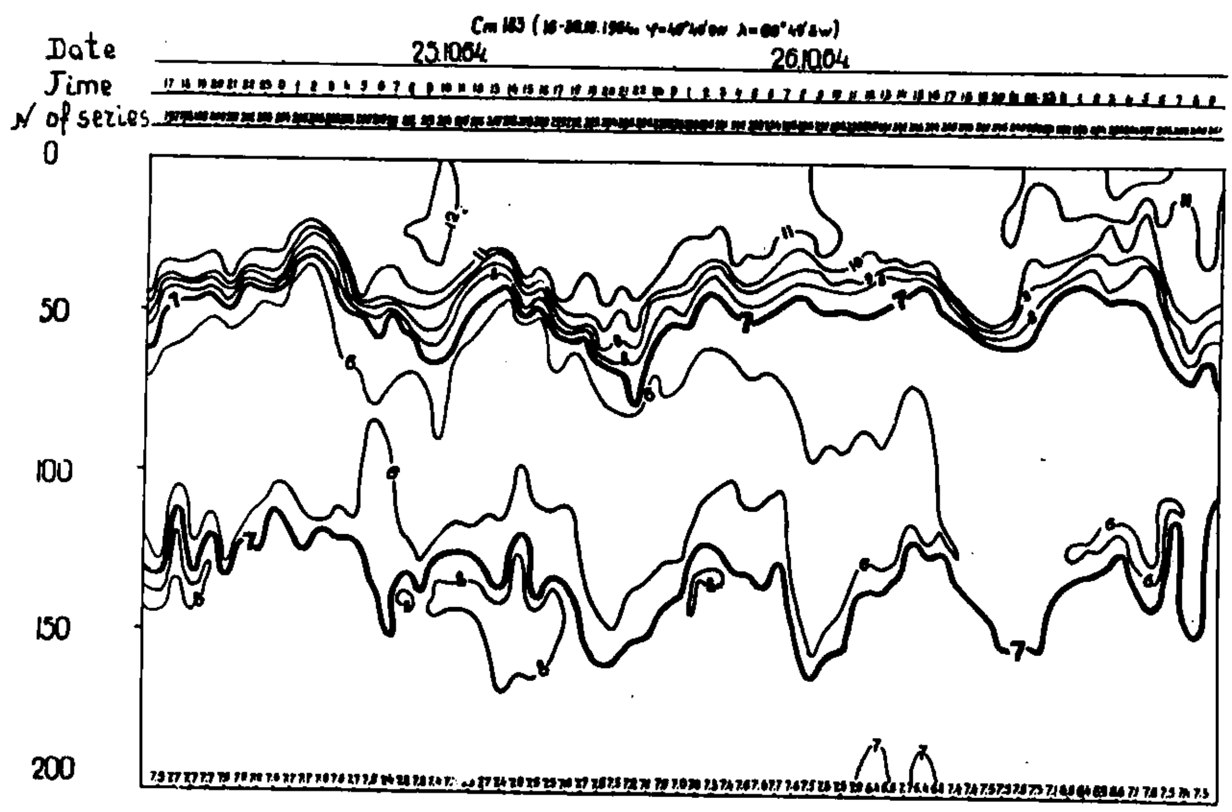

Fig.5. Temperature variations within a layer of 0-200 m on the southern slopes of Georges Bank (Station N 183, a part of graph).

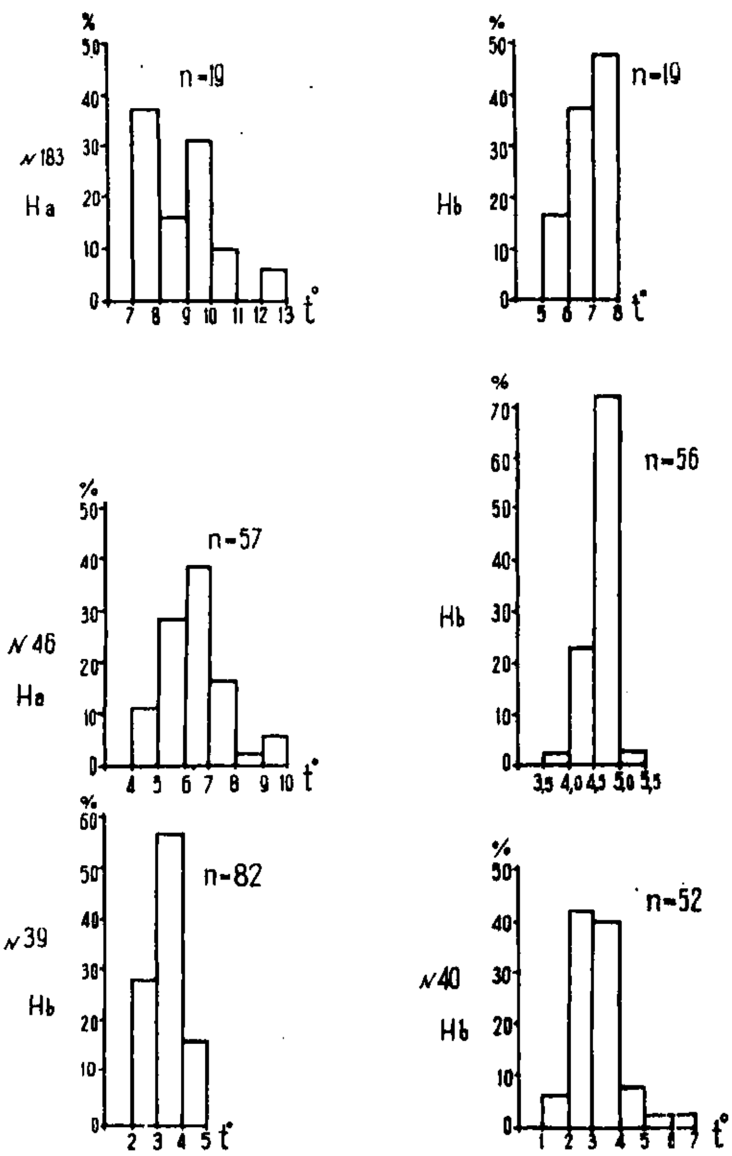

Fig. 6. Histograms of temperature readings corresponding to isohalines 32.5 and 33.5% (based on data of long-term stations).

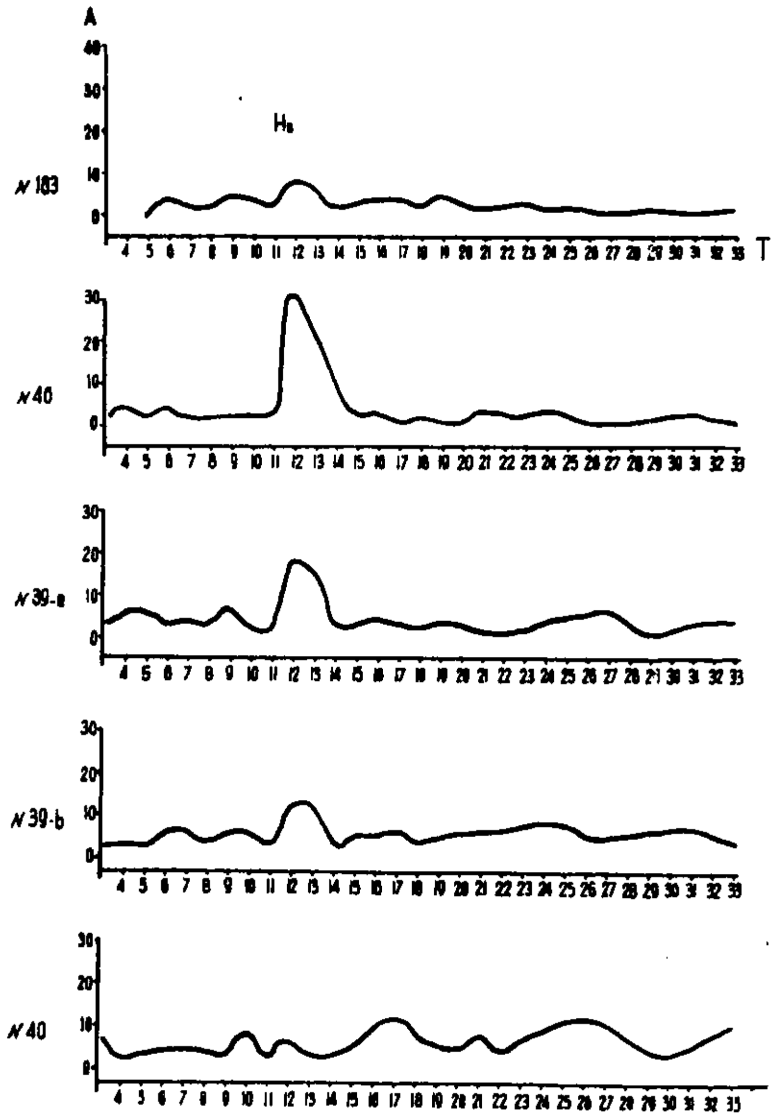

Fig. 7. Periodograms of fluctuations of the level of the bottom water mass (Hb) at long-term stations (T-period in hours, A-magnitude of amplitude in meters).

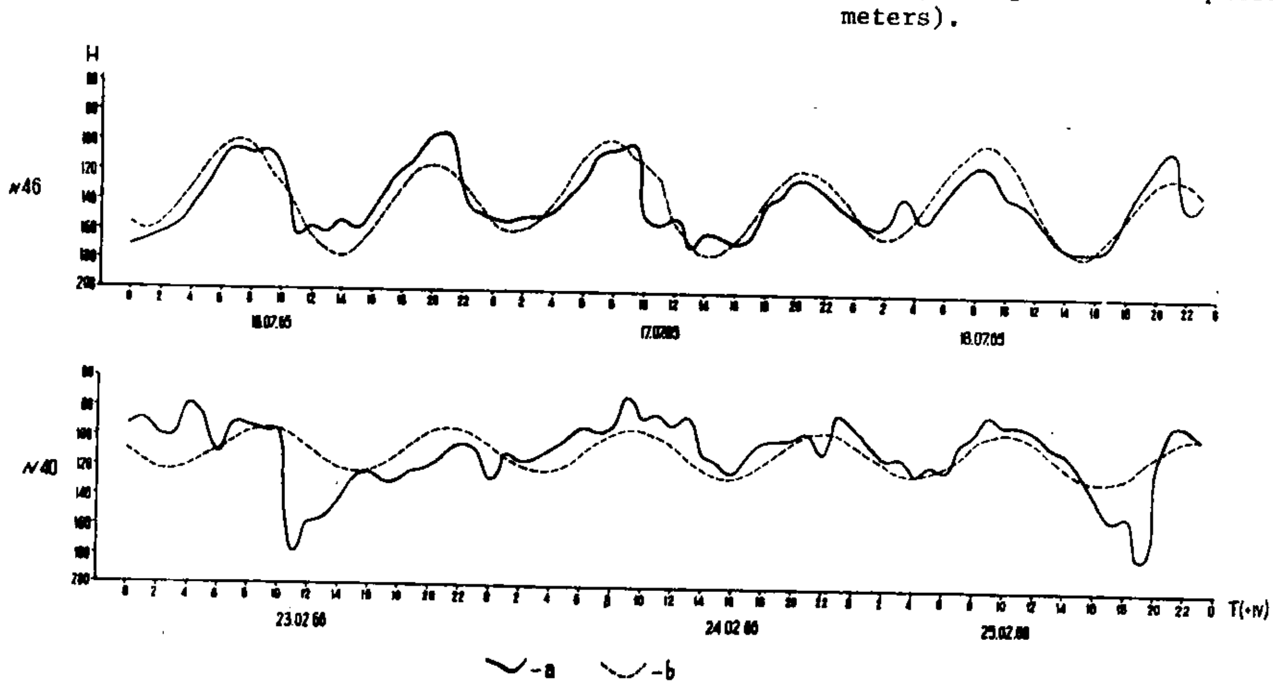

Fig. 8. Depths of the upper level of the bottom water mass: (a) curve plotted on the basis of observed values (without rounding off); (b) pre-calculated curve.