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Preliminary Results of Oceanographic Observations Undertaken by PINRO According to the Program of International Research on the Flemish Cap Bank in 1977/78

by

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Abstract

In accordance with the data on seven bathymetric surveys undertaken by research vessels of PINRO in the Flemish Cap Bank area in 1977/1978, the calculations and analysis of geostrophic circulation and estimate on water masses distribution were carried out. Quasi-stationary system of the main elements of circulation including the anticyclonic gyre over the bank was observed. The existence of water convergence inside the cycle was ascertained by means of analysis.

The opinions concerning the cycle nature were expressed, the most probable factors causing its variability were pointed out, particular ecological consequences of this variability not discussed earlier were marked.

Introduction

In May 1977 the program of international oceanological observations on the Flemish Cap Bank was developed at the ICNAF Environmental Working Group Meeting where representatives from Canada, the USA, Poland and the USSR participated. This program was approved and recommended by the 1977 ICNAF Annual Meeting for execution to the ICNAF member-countries interested in solving the problems advanced in program.

The main problem of the program is to reveal the regularities of influence of abiotic and biotic factors upon the reproduction of commercial fish stocks in this area.

The Polar Research Institute started to carry out the oceanological observations according to the program in late 1977, the greatest attention being paid to investigations on the peculiarities of horizontal circulation of waters. The preconditions for these investigations were arisen in previous elaborations of the problem of abundance dynamics of the Flemish Cap Bank cod year classes, therefore it was reasonable to refer to those elaborations beginning with a short characteristic of the currents in the Flemish Cap Bank area.

Apparently, the first contribution to their studying is the paper by D.J.Matthews (1914), where on the basis of the data of the expedition aboard the vessel "Scotia" in 1913 it was shown that near the northern extremity of the Grand Bank the Labrador Current was divided into three branches and one of them, the eastern one, moved eastwards the northern Flemish Cap Bank (Smith, Soule and Mosby, 1937). Mainly the systematic observations undertaken by the US Coast Guard according to the program of the International Ice Patrol favoured the further development of studying the currents surrounding the slopes of the bank. In particular, it had been already stated at an early stage of researches, that the water flows registered off the southern bank slopes were of the North Atlantic Current system origin (Smith, Soule and Mosby, 1937).

In late fifties a rapid growth of fishery on the Flemish Cap Bank was accompanied by greater interest to oceanological problems, and for the first time the most complete data on the currents field had been obtained on the basis of analysis of materials of the 1958-1960 Soviet expeditions (Yelizarov & Prokhorov, 1958; Buzdalin & Yelizarov, 1962).

In accordance with the results of the above-mentioned works the total circulation of waters over the Flemish Cap Bank consists of the following main links. The Labrador Current branch transporting the waters of relatively low temperature and salinity was observed over the northern and, partially, eastern slopes of the bank. A.A.Yelizarov and V.S.Prokhorov (1958) called this branch the Flemish Cap Current; this name will now be used in the paper. At the latitude of the southern slopes of the bank these waters interact with warmer waters of higher salinity transported by the North Atlantic Current. The latter carries along the predominant mass of the Flemish Cap Current waters in the east and north-east directions. The anticyclonic gyre that is in direct contact with the Flemish Cap Current exists in the central shallow zone.

The mentioned main elements of the currents field were repeatedly registered while analysing the results of subsequent PINRO expeditions (Kudlo & Burmakin, 1972; Kudlo & Borovkov, 1975; Kudlo, Borovkov & Boytsov, 1976; Kudlo & Boytsov, 1977). On this basis it was supposed that the currents system over the bank which formed the foundation of hypotheses concerning the causes of abundance fluctuations of the Flemish Cap cod year classes was of quasi-stationary character (Kudlo & Borovkov, 1977; Kudlo & Boytsov, 1978). The empiric relationships showing that the abundance of the cod year classes depends mainly upon the dynamic state of anticyclonic gyre in the period of early stages of cod ontogenesis and in the years with strengthened (weakened) water circulation, the rich (poor) year classes appear. The mechanism of revealed correlation was expressed by the following circuit of supposed relationships: the variations in cycle intensity caused the corresponding changes of waters convergence in its central part, and the latters in their turn indicated the accumulation rate of pelagic eggs, larvae and fingerlings and also of phyto- and zooplankton on the bank. At last, the provision of larvae with food and also conservation of pelagic fry within the bank limits varied from year to year in relation to accumulation of organisms and microalgae in the shallow zone. It should be noted that the last factor is probably the most important for the Flemish Cap cod reproduction, i.e. it is chiefly this factor that controls directly the abundance of fish year classes at least before the start of their exploitation in fishery.

Despite a seeming lack of contradictions in logic constructions it was necessary to control the correctness of the abovementioned scheme and for that purpose the reliability of the main assumptions was, first of all, to be verified. The trend of our investigations to learn the character of the water circulation changes and convergence existence over the bank is explained just by this factor.

Materials and methods

Existing views on horizontal water circulation in the Flemish Cap Bank area were formed on the basis of analysis of the dynamic topography fields. Direct instrumental measurements of currents over the bank were not numerous; the only paper is known, in which the results of such observations were published (Hill et al., 1975). Unfortunately, we have to state that for insufficient volume of data it was impossible either to confirm or to disprove that idea. The conducting of continuous measurements of currents even in some points of space is a complex problem at present time, therefore the only real way of solving the given problem is still the use of indirect methods of currents determination. The dynamic method, the most tested and suitable for practice was chosen among the existing methods.

The main initial materials for analysis of water circulation were the data on temperature and salinity measurements on standard sections approximately of 300 hydrological stations carried out in the bank area in winter 1977/1978 during cruise 16 and also in summer 1978 in cruise 17 of the RV "Protsion" and in cruise 20 of the FRV "Persey-III".

During cruise 16 of the RV "Protsion" four bathymetric surveys were carried out, the observations in the first two surveys (December-January) were of reconnoitring character and were mainly conducted on two mutually perpendicular sections-latitudinal one along 47°N (Flemish Cap) and meridional one along 45°W, crossing over the top of the bank. The next two stages of observations were undertaken in February on the ground limited with meridians of 44°00' and 46°30'W and latitudes of 46°20' and 48°20'N and represented a regular grid of stations with an interval of 20' at latitude and 30' at longitude.

In cruise 17 of the RV "Protsion" the observations on the ground were continued and the surveys were carried out twice - since late May throughout early June and in the second half of July. In late July the bathymetric survey by the standard grid of trawl stations over the bank area was undertaken from board the FRV "Persey - III" (cruise 20).

To investigate the water circulation in the area observed according to the above-mentioned data of researches a series of the charts of dynamic sea surface topography in relation to the 200 dbar level was drawn up. To choose the reading surface we took into account the long-term experience, that showed that the level was reasonable to use while studying the currents in the shallow zone. In addition to that on the basis of the ground survey data the estimates of fields of geostrophic currents by the method suggested by I.P.Belyayeva had been made (Belyayeva, 1964). In accordance with this method the zone and meridional components of currents velocities which were estimated with an assumption of absence of movement near the bank bottom, i.e. relatively not horizontal dynamic 0-surface, had been determined first. Dynamic heights of stations taken in pairs were brought about the same level by Somov's method (Zubov, Mamayev, 1956). The components of currents velocities in points situated inside the grid area were calculated by the three-point scheme; in localities situated at the corners of the ground - by the two-point formula, and for the rest stations in contour - by the complex method. Then the resulting vectors of currents velocity at standard depths of each ground station were found by components and on their basis the schemes of geostrophic currents for different depths and time periods were compiled.

Results

Proceeding to analyse the water movement over the Flemish Cap Bank in the periods of surveys let us refer to the schemes of flow lines distribution of surface geostrophic currents, which are given in Figs.1 and 2.

Such well-known elements of circulation as the Flemish Cap Current, which surrounded the bank along its northwest, north and northeast slopes and a part of the North Atlantic Current, passing nearby and directly over the southeast slopes, are revealed in these schemes. As seen from comparison of the dynamic topography fields, the velocities, directions and positions of the main currents undergo essential space-time variations, nevertheless, the constant availability of these currents in the bank area does not raise doubts.

In the figures given another feature of total circulation such as anticyclonic gyre, that was situated usually in the central part of the bank and was of incorrect form, is distinctly traced. While comparing the schemes it is easy to notice the differences in areas and configurations of the regions delimited by closed isohypses and also the differences in number and density of these isohypses, that is the evidence of continuous evolution of the gyre mentioned. For some period in winter 1977/1978 (Fig.1), when time intervals between successive surveys were comparatively short the evolution process of streams system can be confidently interpreted as transfer from the developed anticycle (December) through the decline stage (January) to disappearance of the cycle (first half of February) and after that - to the restoration stage of the previous circulation form (the last decade of February). It should be noted that the interchange of the gyre winter developmental stages took place at its almost invariable position in space and the period of anticyclonic circulation availability considerably exceeded the period of its absence; the latter probably constituted about fortnight.

As regards the summer of 1978, the course of anticyclone development for this period is beyond estimation because of irregularity of observations. It should be stressed, however, that the anticyclone existed in all the periods of summer surveys slightly changing its position over the bank(Fig.2).

Proceeding from the above-stated and taking into account the experience of analysis of geostrophic circulation over the bank, stored for a number of years, it may be stated with good reason that the main currents system in the Flemish Cap Bank area is quasi-stationary, i.e. it exists almost constantly in this area.

Now the currents vertical structure will be analysed with the help of the data of the bottom geostrophic circulation estimate, the part of which is given in Fig.3.

It results from the comparison of the synchronous vectorial currents fields on the surface and at the depth of 100 m, given in the figure, that in every concrete dynamic situation currents, as a rule, slowed down with the increase in depth keeping the same direction. The noted regularity is characteristic not only for the upper 100-m layer; it becomes apparent in the remaining water masses as the analysis of the circulation in lower depths showed. By the way, visible in Fig.3 coordination of the received relatively different reading levels of flow lines and vectors of surface currents, i.e. invariance of directions of the surface geostrophic movement partially proves that.

Proceeding from the foregoing it becomes clear that the elements of circulation in the bank area, including anticyclonic gyre, are distributed from the surface to the bottom and therefore experience the influence of bottom topography. The last circumstance is rather important for understanding the anticyclone nature, but this problem will be discussed later.

To verify qualitative conformity of the geostrophic circulation to the real currents system the problem of origin and distribution of water masses in the area surveyed will be dealt with. For this purpose Fig.4 is considered, in which the charts of temperature and salinity distribution in the upper quasi-homogeneous 100-m layer for every cycle of observations on the ground in February 1978 are given. It is seen from the figure that waters of 3.0-4.5° temperature and 34.1-34.3°/.. salinity prevailed over the bank in the period of both surveys, and waters with relatively high heat and salts content were observed just over the southeast slope. According to thermohaline characteristics waters over the bank are attributed to mixed which are formed in the time of interaction of the arctic and central North Atlantic water masses, but peculiarities of hydrological elements distri - bution are indicative of the fact that the ratio of initial water masses in their mixture is unequal in different areas. Arctic waters prevailed in the mixture over the greatest part of the bank, this proportion being rather homogeneous in space; the Atlantic waters were the main component only over the south-eastern slope of the bank.

Comparative analysis of the available data shows that the general character of water distribution and ratio types of content of parent water masses in the mixture remained invariable with different peculiarities of the location of the border between modifications of mixed waters and with availability of some changes of their thermohaline state.

If the given information is compared with the notions about horizontal water movements in the bank area that are given in the schemes of geostrophic circulation, it is easily seen that on the whole they coordinate with each other. Therfore, it may be inferred that conclusions about direction, localization and constancy in time of the main currents over the Flemish Cap Bank, made while analysing these schemes, reflect the real state of things rather well.

On the basis of the available data we shall try to prove the presence of water convergence in the central part of the anticyclonic gyre. For this purpose the fact should be paid attention to that anticyclone is always formed from mixed waters of the eastern Labrador Current, which are transported to the bank area by the Flemish Cap branch, and is located inside these waters area. Taking this into consideration it should be admitted that disturbance of the masses field in the zone of the gyre is not connected with the outside source of the alien less dense waters. As regards climatic factors resulting in rising the temperature or water freshening, they should not be taken into consideration as well, because the spatial scale of the effects produced by them is incomparable with the scale of the disturbance under review: the maximal horizontal dimensions of the latter make up just 150-180 km. Thus, it is believed that the formation of the negative anomaly of water density in the zone of the gyre is conditioned by pure dynamic factors, namely by convergence of horizontal streams and lowering of upper, less dense waters in the central part of the gyre. The distinctive flexure of isohalines, visible in the bottom of Fig.5 (Fig.4 as well) may serve the qualitative confirmation of the presence of descending movement inside the gyre.

Thus, the results of investigations carried out testify to the fact that earlier suppositions about existence of the quasi-stationary anticyclonic gyre over the Flemish Cap Bank and the zone of currents convergence inside it quite correspond to reality. In this connection the problem of the reasons of changeability of the gyre arises being rather important both from the scientific and practical points of view. To settle the problem it is necessary to determine first of all due to what the considered gyre exists, i.e. to settle the problem of the nature of this formation. In our opinion it is important to pay attention to the quasi-stationary character. The matter is that all synoptical oceanic eddies known from literature (summary in /Fizika okeana, 1978/) analogous to the considered gyre by a number of signs (rotatory movement, horizontal and vertical dimensions), differ radically from it by their ability for translational movement in space at a distance of hundreds of kilometers. This exclusiveness of the Flemish Cap anticyclone suggests an idea of existence of especially powerful factor which forms and stabilizes water circulation over the bank. As the comparison of conditions of dynamic formations availability showed, only the rise of the bottom unique by morphological characteristics, i.e. the Flemish Cap Bank proper, may be such a factor. Of course, the influence of this factor which results in existence of the above-mentioned peculiarities of the fields of density and velocity, is connected with the Flemish Cap Current passing in the bank area.

Judging by availability of temporal variations of dimensions, form and intensity of the gyre, the absolute and relative contribution of influence of bottom configuration is not constant. It is natural to connect this inconstancy in synoptical scale with intensity variations and dislocation of the Flemish Cap Current axis, the decrease in influence of bottom configuration and, consequently, the gyre extinction is being supposed to occur owing to the decrease in velocity or moving away of the mentioned current to the bank periphery. The results of the theoretical investigations by A.S.Sarkisyan (Sarkisyan, 1977) from which follows that the influence of bottom topography on the currents in the upper layer of the ocean decreases with the growth of the distance from the surface to the bottom, partly corroborate the reality of such an effect.

Besides the above-mentioned factors the decisive part in the gyre extinction and liquidation may be played by its interaction with one or several cyclonic systems of drift currents (depending on the stage of gyre development), which arises at the time when the centre of slowly moving atmospheric cyclone or the series of cyclones alternating in short periods of time pass over the bank. The comparison of geostrophic circulation schemes with the data of the daily synoptical charts which showed that in winter 1977-1978 the most frequent appearance of the cyclones over the bank (January 31, February 5 and 9) almost coincided in time with the sharp deformation of the currents field in the central part of the bank, was the basis for this supposition.

In this connection and also treating atmospheric cyclones passing over the bank as a casual event, it may be assumed that in the long-term mean plan the probability of anticyclonic water circulation breach grows in autumn-winter period, i.e. in the period of the cyclone being more active in the atmosphere, and decreases in summer when cyclogenesis weakens. Besides, differences in the intensity of drift cyclonic currents connected with the fenomenon that winter cyclones are usually more active than summer ones promote the stated seasonal prevalence.

The reality of such changes of the stability of the anticyclonic water gyre within the year is confirmed by strongly pronounced anomaly of composition of the ichthyofauna constant representatives of the Flemish Cap Bank. This anomaly is to the effect that capelin and sand eel which together predominate in abundance among the commercial fish on the Newfoundland banks, are almost never found on the bank. On the other hand, it is common knowledge that at least two species of the dwelling on the Flemish Cap Bank demersal fish - cod and redfish - form independent populations. The existence of the latters testifies to the fact that relative safety of pelagic eggs, larvae and fingerlings of cod and redfish is provided over the bank in the period between spawning and descending of young fish to the deep layers or to the bottom, which can be correlated with the period from the end of the last winter to the beginning of the next one. As the safety of passive migrants depends mainly on their accumulation in the zone of currents convergence, i.e. on the hydrodynamic trap functioning, it becomes clear that in the mentioned period of a year the anticyclonic gyre exists constantly or disappears only for very short periods of time. As regards capelin and sand eel, the safety of juveniles of these fish, which are not yet quite able to swim actively, but make daily vertical migrations from the bottom to the surface layers and back, depends on the circulation conditions throughout the first year of life. Apparently, almost complete absence of these species on the bank is the consequence of unstability of anticyclonic gyre in winter. This supposition completely coordinates with the above-mentioned reasons.

In conclusions let us pay attention to the fact which has been mentioned in the statement, namely, the dependence of the reproduction of the Flemish Cap Bank cod and redfish on the same regulating factor. If it is true fluctuations of year classes abundance of the mentioned species may seem at first sight to be fully coordinated. But in fact the things are somewhat different. As the analysis of age composition of catches for a long-term period showed (Templeman, 1976), in the fifties-sixties of the current century the most abundant redfish year classes appeared in 1959 and 1963 and the strongest cod year classes - in 1958 and 1962; cod year classes of 1959 and 1963 were estimated as relatively abundant. What is the lack of coincidence of peaks of relative abundance of these fish year classes caused by?

We think it possible to explain this the following way. It is common knowledge that definite distinctions exist in location and size of areas, and terms of cod and redfish mass reproduction within the bank area limits. On account of these distinctions ichthyoplankton of different species of fish is kept over the bank unequally, because, firstly, the anticyclone gyre is comparatively small in size and that is why it cannot control all the bank areas where the fish reproduction takes place; secondly, the hydrodynamic trap effect changes in time. In the final analysis all this may provoke some difference in survival of pelagic larvae and fingerlings of different species of demersal fish and,therefore, different relative abundance of species generations.

On the whole the investigations carried out testify to the important role of water dynamics in reproduction of commercial fish dwelling on the Flemish Cap Bank, and also to the complicacy of the mechanism of this factor influence. In this connection the necessity to carry out further investigations of the regularities of variations of water circulation, ichthyoplankton distribution and its survival is justified. Undoubtedly, such investigations will be the basis for creation, in particular, of more perfect models of dynamics of year classes abundance.

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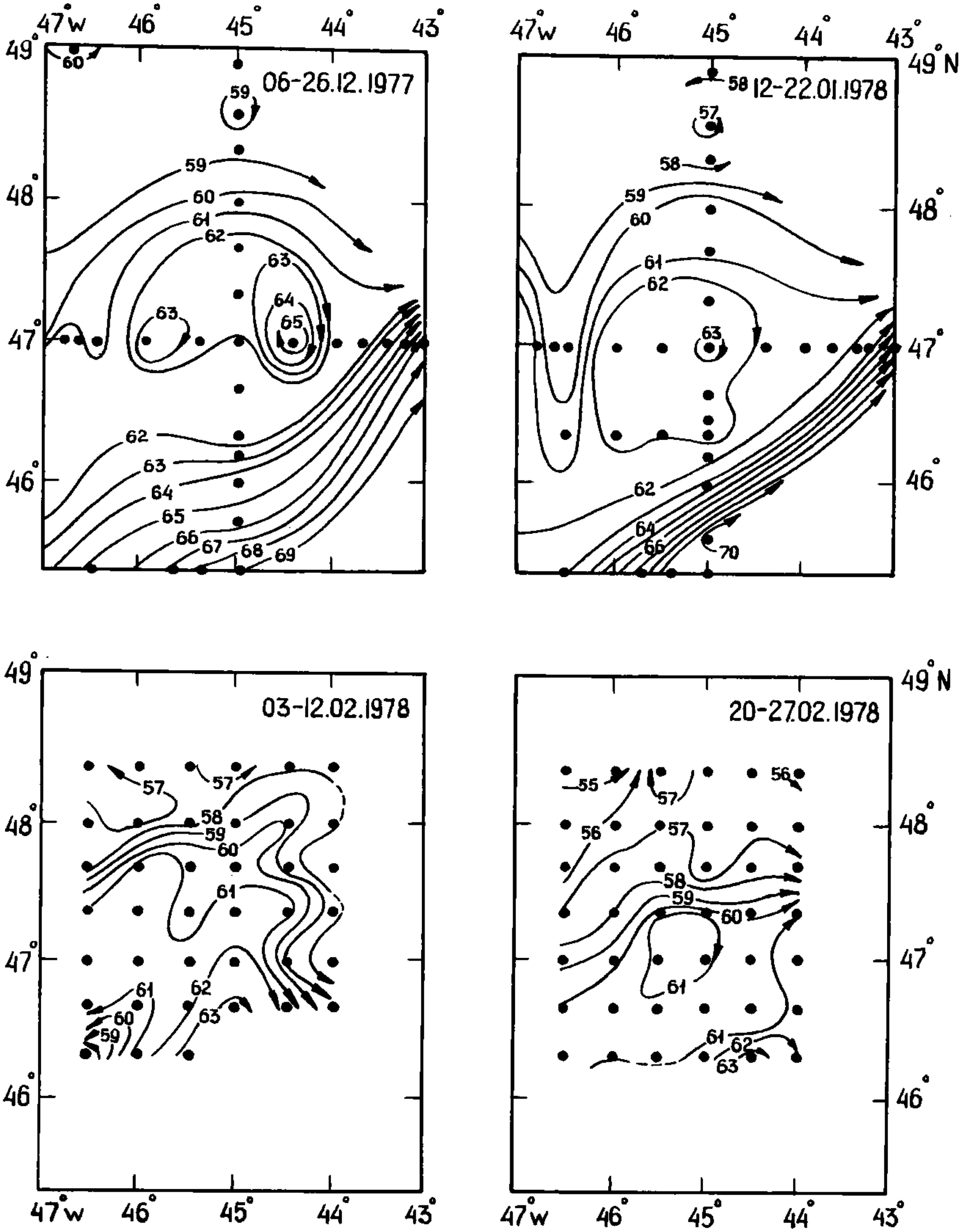

Fig. 1. Conventional dynamic topography of the surface relative to 200dbar level in the Flemish Cap Bank area in the periods of observations performed in winter 1977-1978. Conventional dynamic heights are given in dyn. cm.

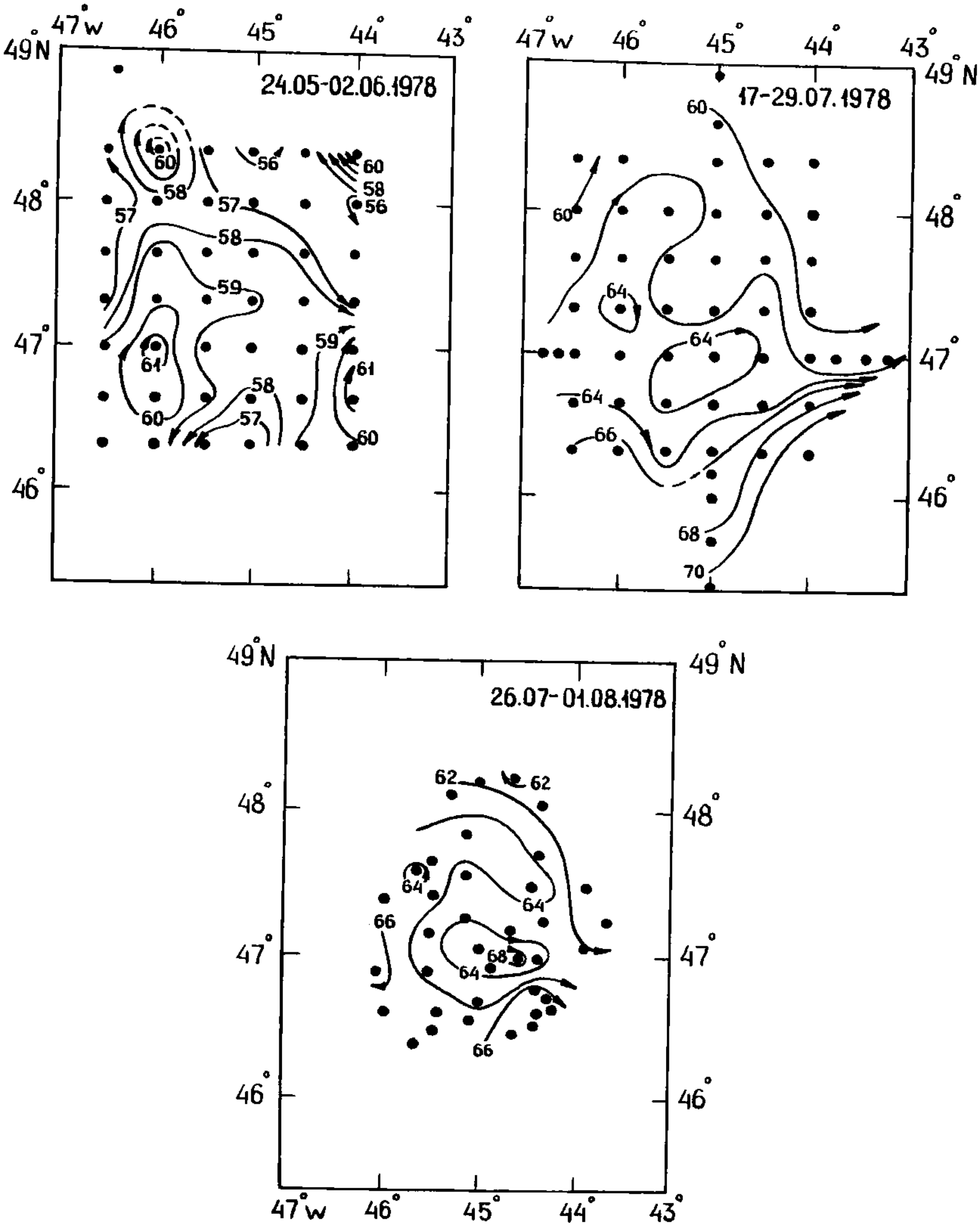

Fig. 2. Conventional dynamic topography of the surface relative to 200dbar level in the Flemish Cap Bank area in the periods of observations performed in summer 1978. Conventional dynamic heights are given in dyn. cm.

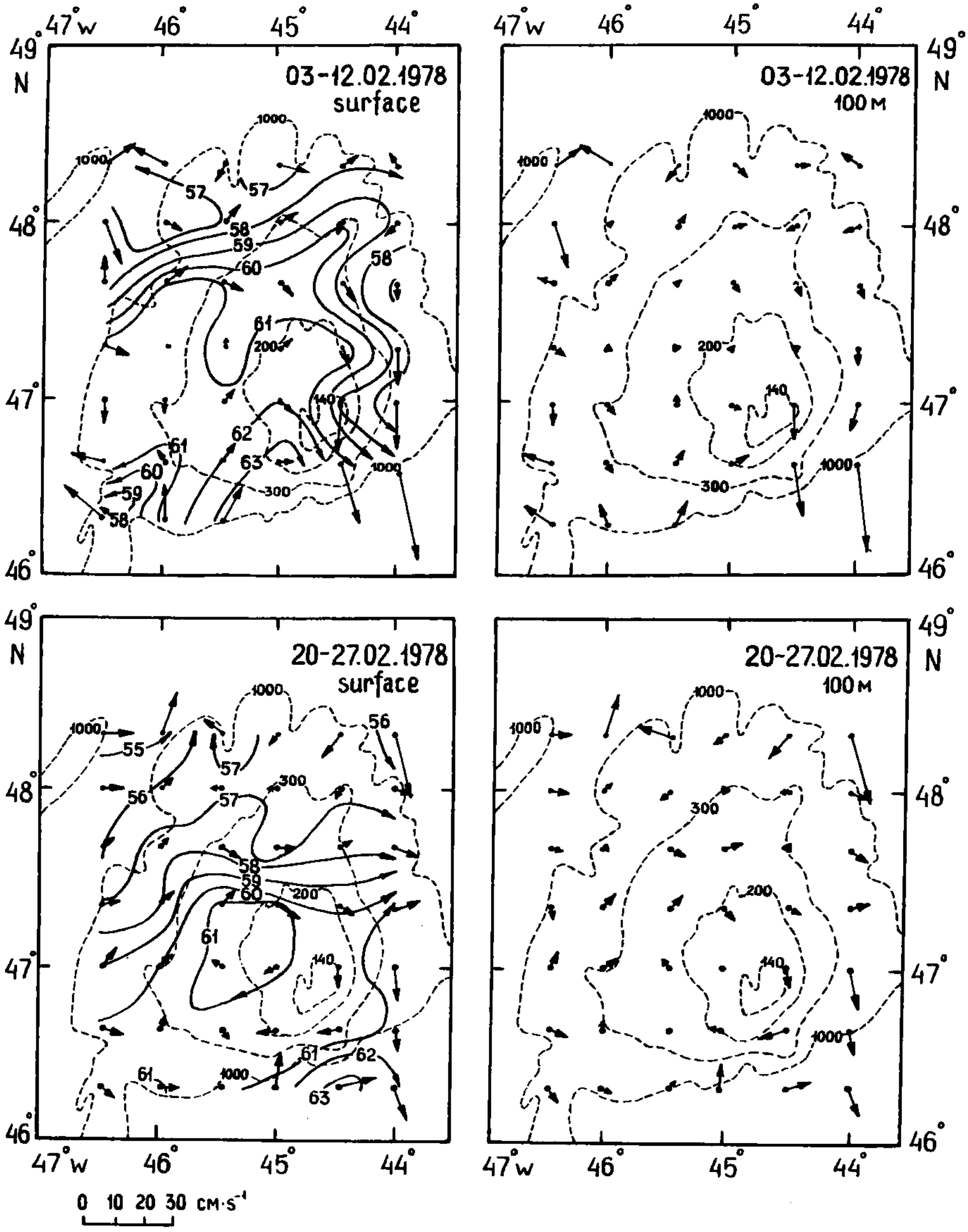

Fig. 3. Geostrophic water circulation over the Flemish Cap Bank in some periods of February 1978. Solid lines - isolines of conventional dynamic height (dyn. cm.) of the surface relative to 200dbar level, broken lines - isobaths in metres. Vectors show direction and velocity of currents calculated from near-bottom depth of observations.

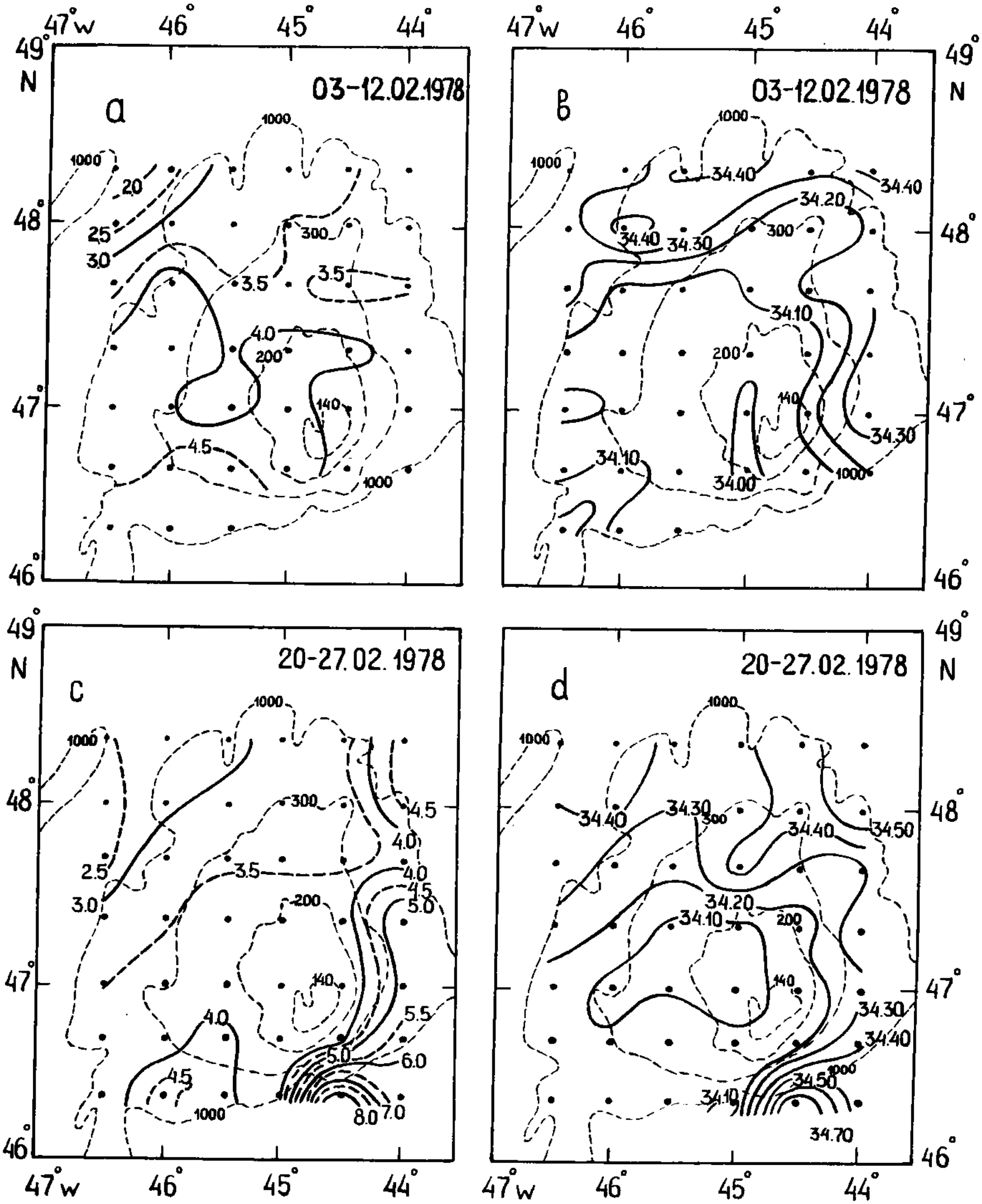

Fig. 4. Horizontal distributions of mean temperatures (a, c) and salinity (b, d) in the upper 100-m layer over the Flemish Cap Bank in February 1978. Isotherms are drawn at an interval of 0.5°C, isohalines - 0.1)/₀₀. Thin broken lines - isobaths in m.

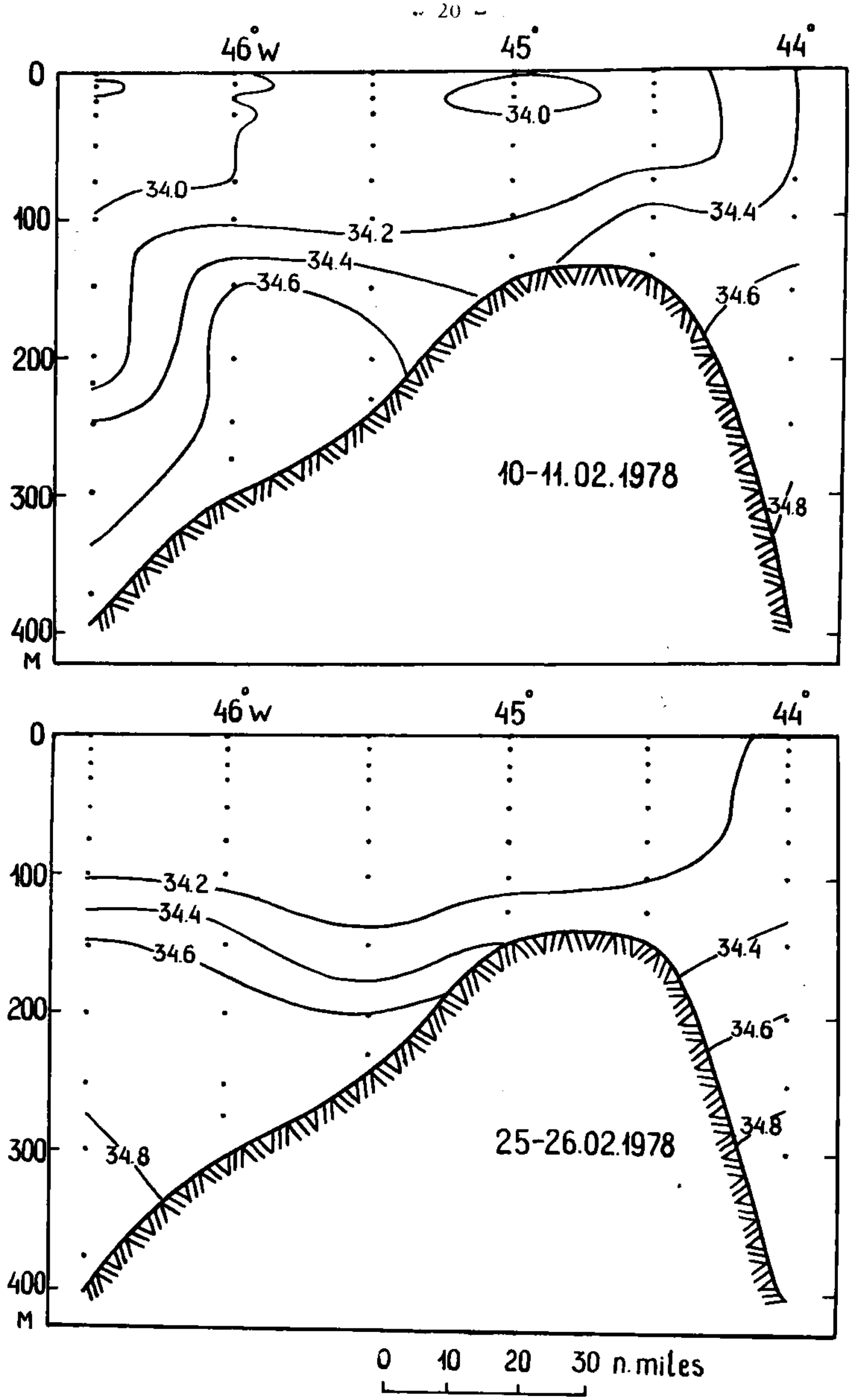

Fig. 5. Vertical distributions of salinity on the section along 47°N in February 1978. Isohalines are drawn at an interval of 0.2°/₀₀.