NOT TO BE CITED WITHOUT PRIOR REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N697

NAFO SCR Doc. 83/VI/41

SCIENTIFIC COUNCIL MEETING - JUNE 1983

Results of the Soviet Oceanographic Investigations in accordance with the Flemish Cap Project in 1977-1982

by

B. P. Kudlo, V. A. Borovkov and N. G. Sapronetskaya
Polar Research Institute of Marine Fisheries and Oceanography (PINRO)
6 Knipovich Street, Murmansk, USSR

Abstract

The investigations of the surface water circulation carried out in the course of the Flemish Cap Project realization are summarized in the paper. It is shown that geostrophic model approximates well the qualitative peculiarities of local circulation. On the basis of analysis of hydrographic survey data the types of water circulation over the Bank are singled out and corresponding to them features of hydrochemical element field structures are determined. Regularities of the circulation form variability and biological effects of the latter are considered.

Introduction

The program of International oceanographic investigations on the Flemish Cap Bank developed by the ICNAF Subcommittee Working Group on Environment in May 1977 was approved by the ICNAF Annual Meeting held in the same year. The main task of the program was studying the effect of biotic and abiotic factors upon reproduction of the commercial fish stocks. The Flemish Cap Bank was chosen for the survey due to its comparatively small area and occurrence there of isolated commercial fish populations.

The program formulated by the Working Group envisaged a detailed study of environmental variability, hydrobiological and ichthyological observations as components of the Bank waters ecosystem.

The paper involves the main results of oceanographic investigations in conformity with the Flemish Cap Project.

The results of the previous studies on water circulation in fishing areas of the Northwest Atlantic (Buzdalin and Elizarov, 1962; Kudlo and Burmakin, 1972; Kudlo and Borovkov, 1975; Kudlo, Borovkov and Boytsov, 1976; Kudlo and Boytsov, 1977) indicated the existence of anticyclonic water gyre in the central shallow part of the Bank. Further studies (Kudlo and Borovkov, 1977; Kudlo and Boytsov, 1979) showed that the cod year class strength depended mainly on the dynamic state of anticyclonic water circulation on the Flemish Cap Bank during early ontogeny stages, rich (poor) year classes appearing in the years with intensified (weakened) water circulation respectively. The probable mechanism of revealed relationship will be mentioned below.

Basing on the researches done the oceanographic part of the Flemish Cap Project was aimed at studying the variability of dynamic water state on the Bank and biotic effects of above variability.

Material and methods

According to recommendations of the Working Group the ground limited by 44°00' and 46°30'W, 46°20' and 48°20'N was chosen for oceanographic surveys on the Bank. It was divided into rectangles 20 minutes by latitude and 30 minutes by longitude, and represented a regular grid consisting of 42 hydrographic stations. The data of hydrographic observations made by standard grid of trawl stations as well as the observations on standard hydrographic sections along 47°N and 45°W crossing over the central part of the Bank were used.

In all 27 hydrographic surveys of the Bank were carried out for the period from December 1977 to April 1982 on the PINRO research vessels including 15 by the ground grid, 8 by grid of trawl stations and 4 as separate sections (Table 1).

The data collected during hydrographic surveys were treated by dynamic method interpreted by N.N.Zubov (Zubov and Mamaev, 1956). The 200 db level was taken for a zero surface.

It is known that the results of calculations of marine current elements obtained by dynamic method depend greatly on observance of some conditions of its application (Zubov and Mamaev, 1956; Fomin, 1961). Unfortunately, it is rather difficult to determine these conditions in each concrete case.

The comparison between dynamic charts and tracks of drifting buoys the position of which is monitored daily by satellites is very promising for studying the reliability of geostrophic water circulation course determined by dynamic method. Such buoys were released by Canadian researchers in conjunction with the program of the Flemish Cap Experiment (Ross, 1980). Each of six buoys released from January 1979 to May 1980 drifted within the Bank limits for 32 to 72 days. The mean drift cycle lasted 50 days. The comparison between the charts of geostrophic circulation at 0-200 db plotted according to data of hydrographic observations made on the ground by Canadian R/V "Hudson" (Gagnon, 1980) and Soviet vessels (Kudlo and Borovkov, 1980), and tracks of drifting buoys (Ross, 1980) for periods close in time to hydrographic surveys showed the following.

Dynamic charts indicate the quasi-steady anticyclonic water gyre existing over the Bank. The tracks of drifting buoys are similar supporting the resemblance between the course (configuration) of current lines obtained by dynamic method and existing in nature water circulation. Hence, the schemes obtained by dynamic method depict rather truly the water circulation system existing on the Flemish Cap Bank, at least, relative to water motion direction. These conclusions are persuasevely indicative of possible application of geostrophic circulation charts for ecological investigations.

Results and discussion

The charts of geostrophic water circulation on the Bank constructed according to data of separate surveys for 1977-June 1981 (Table 1) are published in the ICNAF-NAFO issues (Borovkov and Kudlo, 1980, 1981, 1982; Kudlo and Borovkov, 1980). A series of 4 charts for March to June 1979 is presented in Fig.1. Charts plotted during the last three surveys in late 1981 and April 1982 are shown in Fig.2.

The qualitative analysis and comparison of the whole series consisting of 27 dynamic charts showed that anticyclonic gyre was the prevailing form of water circulation on the Bank (Figs 1 and 2). However, along with that some other forms of water motion were observed over the Bank in separate periods. On the whole, it became possible to single out four types of water circulation (Table 2). The first two types - V and V_L - differ slightly from each other by pattern of water circulation and, in fact, might have been taken for subtypes of one type under action of which a general clockwise water motion is observed on the Bank. Dynamic situations corresponding to above types are shown in Figs 1 and 2. The water circulation of $V+V_L$ types accounts for 66.7% of the total number of surveys, i.e. it is the prevailing form of water circulation.

The type T_M (Table 2, Fig.3) under action of which the transient flow crosses the Bank as if washing it, is exactly opposite to types V and V_L. The circulation frequency of this type accounts just for 7.4%.

And finally, the fourth type M involves the water circulation when both the local gyres and transient flow across the Bank occur simultaneously, i.e. the water circulation pattern is of mixed nature (Table 2, Fig.3). The frequency of this type accounts for 25.9%.

On the basis of above data it is safe to regard the anticyclonic water gyre on the Flemish Cap Bank as quasi-steady. The obtained results agree with the data on mean water circulation collected during observations for 1962-1978 (Kudlo, Burmakin, Sterkhov, 1980).

Surely, the data available are insufficient for obtaining the reliable statistic characteristics of circulation processes. Table 3 the data of which give a rough idea of the type frequency shows the following. Prevailing types V and V_L are observed all the year round while type T_M (the transient flow across the Bank) - only in winter months. The circulation of mixed nature (type M) seems to be observed all the year round.

The analysis of data obtained during hydrochemical observations permitted to reveal concentrations of dissolved oxygen and biogenous substances peculiar for each circulation type.

Thus, for instance, in the presence of anticyclonic vortex (type V) over the central shallow part of the Bank a local minimum of absolute and relative content of dissolved oxygen is usually observed in the surface layer (Fig.4 a,b) while the local maximum of oxygenation coupled with a lower concentration of mineral phosphorus and silicon - in the intermediate layer (Fig.4 c). Under action of V_L circulation type the general pattern of hydrochemical element distribution is the same as for type V though rather some than one partial minima of biogeneous substance concentration are observed in the intermediate layer over the shallow part (Fig.4 d). It follows from the comparison with dynamic charts that these minimums coincide, as a rule, with local centres of a vast anticyclonic gyre rotation.

The revealed peculiarities of field structure of hydrochemical characteristics may be interpreted in the following way. Due to convergence the oxygenated surface waters flow from peripheral to central part of the vortex spending on their way much more oxygen for redox processes than consuming it as a result of phytoplankton photosynthesis. Nevertheless, more oxygen is left in the surface layers than in lower ones and, so, downwelling in the central part of the vortex is followed by the effect of a higher intermediate waters aeration. On the other hand, before flowing to the central part of the gyre the surface waters spend a considerable portion of biogeneous salts for proceeding of biological processes. As the concentration of these salts increases fast while passing from photic to intermediate layer the replenishment of their deficiency may just take place during upwelling of intermediate waters to the surface layer. A combination of upwelling in periphery of the vortex and downwelling in its central part is, thus, responsible for funnel-shaped distribution of biogeneous substances.

In the periods when water circulation over the Bank is in the form of meandering flow (T_M and M types) the distribution of hydrochemical elements is of another pattern. In the upper layer, approximately to 50 m depth, the distribution of oxygen and biogenous salts does not display local extrema in the shallow zone (Fig.5 a, c) while in the intermediate layer the regions with higher or lower concentrations of biogenous substances are traced to be formed in the zone (Fig.5 b, d). Since the location of these regions nearly coincides with that of cyclonic and anticyclonic meanders on the charts of geostrophic circulation one may assume that peculiarities of hydrochemical element field structure result also from the water dynamics.

For determining the reasons of water circulation variability there was made a comparative analysis of atmospheric processes preceding the formation of each dynamic situation and its groups in accordance with the suggested types. For this purpose lots of daily weather maps constructed by the USSR Hydrometeorological Centre for northern semisphere were used in the analysis concurrent with a series of charts of the surface dynamic topography. As a result of of qualitative comparisons, it was discovered that the change in the type of geostrophic water circulation is connected with the storm activity in the Flemish Cap area. It is established, in particular, that in periods of its weakening which are characterized by the continuous absence of strong storms the water circulation over the Bank is mainly in the form of anticyclonic vortex (types V and V_L). On the contrary, just after strong storms connected, as a rule, with deep baric depressions and also during successive one- or two-week period there observed over the shallow part meandering flows typical of T_M and M circulation types. The latter are formed both during relatively slow passage of deep atmospheric cyclones over the central part of the Bank as it was proved earlier (Borovkov and Kudlo, 1980), and at higher speed of motion or other positions of such cyclone tracks.

The fact of revealing the storm effects lasting from some days to some weeks after their passage across the Bank is indicative, first, of quick adaptation of the mass field to changed under action of strong winds field of motion and, secondly, of comparatively long "life" of disturbances generated by the storm. The similar conclusions were drawn during investigations of tropical cyclone traces (hurricanes and typhoons) in southern seas and open parts of oceans (Leipper, 1967; Pudov , Varfolomeev and Fedorov, 1978; Tunegolovets, 1976; Fedorov, 1979).

When analysing the variability of water circulation over the Bank the question arises why the most frequent dynamic formations are of anticyclonic nature? The Taylor's theory of columns using in its basis a principle of potential vortex conservation answers this question. It is shown theoretically (Huppert, 1975; Huppert and Bryan, 1976; Mc-Cartney, 1975) and experimentally (Davis, 1972; Taylor, 1923) that realization of this principle leads to formation in the flow of anticyclonic dynamic disturbances - vortex, meander and also their combination - over topographic features like mountains, guyots and banks.

The conclusions being drawn from the Taylor's theory of columns indicate the reasons of variability of current reaction and pattern of these reasons effect which is of great interest for applied investigations. Huppert and Bryan (Huppert and Bryan, 1976) elucidated a phenomenon which is worth of notice as far as the aim of our paper is concerned. According to this the form of topographically generated dynamic disturbance is dependent on the relation of the following three parameters: degree of fluid stratification, height of the feature and velocity of oncoming flow. Under conditions of kinematically homogenous current and uniformly-stratified medium, for weaker flow and/or strong stratification when there is not sufficient energy available to lift the fluid through a vertical displacement comparable to the height of the feature, the part of the fluid is forced to move laterally around the feature. In this case the disturbance of flow over the feature is in the form of anticyclonic vortex while at high speed of motion and/or weak stratification it is in the form of anticyclonic meander.

If to assume that changes in velocity of oncoming to the Flemish Cap Bank flows are of wind nature this theoretical relationship agrees well with the existence of meandering currents after passage of strong winds and prevalence of anticyclonic vortex in periods of weak storm activity.

To have a clearer view of revealed by empirical method relation mechanism the special investigations are necessary to be carried out by means of more realistic analytic or numerical hydrodynamic models. However, on the basis of available data one may try to determine regularities of temporal variability of water circulation form over the Bank without elucidating this mechanism. In particular, it is possible to define the pattern of seasonal variations in circulation form more reasonably than it is done in the paper (Borovkov and Kudlo, 1980). In order to have this estimate let us use the analysis of seasonal variations in storm activity in the Bank area. The frequency of storm winds and their mean speed,values of which are shown in Fig.6 for each month, may serve as characteristic of this activity. The climatic data taken from the Atlas of Oceans (Anon., 1977) were the basis of the Fig. construction. As is seen from the Fig. the annual variations in these characteristics are pronounced and identical, with maximum in late winter (February) and minimum in mid-summer (July). On account of revealed empirical relation, accordingly, it should be expected that during long-term mean period the frequency of T_M and M circulation types will be maximum in February and minimum in July.

Let us consider now what follows from the estimate based on the relationship deduced in the paper (Huppert and Bryan, 1976). Since the parameter Nh/U_o is an argument in this relationship where N - the Brunt-Väisälä frequency, h - height of feature and U_o - flow velocity, it is necessary, first of all, to estimate seasonal variations of values involved in it excluding, of course, h. Due to lack of proper data it is impossible to define directly variations in velocity of flow oncoming to the Bank, therefore, let us assume that value U_o is proportional to the wind velocity in the area. Under this condition we may use, obviously, already available data (Fig.6). For estimating the seasonal variations of the last component - the Brunt-Väisälä frequency - the long-term mean monthly values of conventional water density on stations of oceanographic section "Flemish Cap" may serve as initial data (Kelley, 1980). On the basis of these data we determined N value as mean for layer from the surface to near-bottom depth in accordance with the simplified formula

$$N = \left[\frac{g}{\rho_0} \frac{\partial \sigma_t}{\partial z} \cdot 10^{-3} \right]^{1/2},$$

where all the symbols are generally accepted. It follows from the analysis of calculations that seasonal variations of water stratification over the Bank are in the form of a curve with two extrema falling, as a rule, on February/March (minimum) and August/September (maximum) (Table 4). Combining the data on wind and stratification degree, and bearing in mind the above assumptions it is easy to imagine that intra-annual variations of parameter Nh/U_0 are also in the form of the curve with two extrema one of which (minimum) falls on February (or March) and another (maximum) - on the period from July to September. According to the Huppert and Bryan's relationship it means that as regards to climate the meander is most likely to appear over the Bank in late winter and least of all - during the period from mid-summer to early autumn. This conclusion is, obviously, well coordinated with the estimate based on the empirical relation.

Due to scantiness of the information it is so far impossible to verify the above assumptions by means of instrumental measurements and calculation data on water circulation over the Bank. None the less it is symptomatic that both cases of "clear" meandering of flows over the shallow part of the Bank (T_M type) were just registered in February/March (Table 3).

Variability of ichthyoplankton decrease and connected with it variability of commercial fish reproduction is practically one of the most important biological effects of spatial-temporal variations in horizontal water circulation over the Flemish Cap Bank. In this case by the decrease is meant an irrevocable loss of ichthyoplankton portion during its transport by the currents beyond the Bank limits. For example, observations over the distribution of cod eggs and larvae in the Flemish Cap area (Serebryakov, 1967) are indicative of this effect existence. It is clear that the minimum loss is just possible in the case when the bulk of ichthyoplankton performs closed passive migrations over the Bank. In its turn, it is likely to occur under conditions of closed water circulation being as observations and calculations show in the form of anticyclonic vortex. The destruction of this vortex and formation of meandering flows over the Bank means elimination of features for mass transport of ichthyoplankton into the ocean. Thus, the stability of anticyclonic vortex is one of the main factors regulating the ichthyoplankton conservation within the Flemish Cap ecosystem.

On this basis and considering the foregoing notions about climatic yearly variations in the vortex destruction frequency it is naturally to suppose that the probability of ichthyoplankton conservation over the Bank should also vary on the average over a year with the maximum being observed in summer. Hence, the survival and living conditions in the surveyed area are relatively favourable for fish species which early development occurs in pelagic zone just in spring and summer, and unfavourable for fish the larvae of which are transported by the surface currents in winter. Under conditions of larvae conservation over the Bank the seasonal differences seem to be the reason for the prevalence over constant ichthyofauna representatives of bottom fish (mainly redfish and cod) related to the first of above groups and for practical absence of such pelagic fish as capelin and sand-eel included in the second group.

Year-to-year differences between conditions of ichthyoplankton conservation are, obviously, one of the reasons for variability of commercial fish year class strength on the Flemish Cap Bank. In particular, one may expect the formation of rich (poor) year classes of cod and redfish if in the periods between appearance of corresponding ichthyoplankton generations and larvae ability acquired to avoid a considerable transport by the currents takes place a high (low) frequency of circulation types V and V_L or a low (high) frequency of T_M and M types respectively. To check this assumption both extra data on biology of fish at early developmental stages and reliable information on variations in water motion over the Bank are necessary. Creating the system of satellites for the ocean surface level measurements will open wide prospects for organization of local water circulation monitoring. Still the standard oceanographic surveys frequent enough (in 1.5-2 weeks) may also serve as control means since the initial data on spatial-temporal variations in circulation are obtained on the basis of regular measurements.

References

Anon. 1977. Atlas of oceans. Atlantic and Indian Oceans. Izdatel'stvo MO SSSR, VMF, Leningrad, 306 p.

Borovkov, V.A., and B.P.Kudlo. 1980. Results of USSR Oceanographic observations on Flemish Cap, 1977-78. ICNAF Selected Papers No.6, p.47-52.

Borovkov, V.A., and B.P.Kudlo. MS 1981. Water circulation in the Baffin Land, Labrador, Newfoundland and Flemish Cap areas in 1980. NAFO SCR Doc. 81/VI/79, Serial No. N364, p.12.

Borovkov, V.A., and B.P.Kudlo. MS 1982. Geostrophic circulation of water in the Labrador and Newfoundland areas in spring-summer 1981. NAFO SCR Doc. 82/VI/17, Serial No. N505, p.9.

Buzdalin, Y.I., and A.A.Elizarov. 1962. Hydrological conditions in the Newfoundland banks and Labrador areas in 1960. In: Soviet Fisheries Investigations in the Northwest Atlantic, VNIRO-PINRO, Moscow, p.155-171.

Davis, P.A. 1972. Experiments on Taylor columns in rotating stratified fluids. -J.Fluid Mech., vol.54, No.4, p.691-717.

Fedorov, K.N. 1979. On the slow relaxation of hurricane thermal trace in the ocean. Doklady AN SSSR, vol.245, No.4, p.960-963.

Fomin, L.M. 1961. Theoretical bases of dynamic method and its application in oceanology. Moscow, izdatel'stvo AN SSSR, 192 p.

Gagnon, J. 1980. Real-time oceanographic data transmitted during the 1979 Flemish Cap (47°N, 45°W) International Experiment. MEDS Canada, Data Record Series No.1.

Huppert, H.E. 1975. Some remarks on the initiation of inertial Taylor columns. -J. Fluid Mech., 67, p.397-412.

Huppert, H.E., and K.Bryan. 1976. Topographically generated eddies. - Deep-Sea Res., vol.23, p.655-679.

Keeley, J.R. 1981. Mean conditions of potential temperature and salinity along the Flemish Cap section. -Mar. Environ. Data Serv., Techn. Rep. No.9, 148 p.

Kudlo, B.P., and V.V.Burmakin. 1972. Water circulation in the South Labrador and Newfoundland areas in 1970-71. ICNAF Redbook 1972, part III, p.27-33.

Kudlo, B.P., and V.A.Borovkov. MS 1975. Circulation of waters in the ICNAF area in 1973-1974. ICNAF Res. Doc. 75/79, Ser. No. 3506, 12 p.

Kudlo, B.P., V.A.Borovkov, and V.D.Boytsov. MS 1976. Circulation and salinity of waters in the Davis Strait, South Labrador and Newfoundland areas in 1974-75. ICNAF Summ. Doc. No. 76/VI/70, ser. No. 3874, 14 p.

Kudlo, B.P., and V.A.Borovkov. 1977. Hydrologic regime of the Labrador Current and reproduction of the commercial fishes. Tezisy dokladov. I syezd sovetskikh okeanologov, vyp.II:133-134.

Kudlo, B.P., and V.D.Boytsov. MS 1977. Circulation and salinity of waters in the South Labrador and Newfoundland in 1975-1976. ICNAF Res. Doc. 77/VI/36, Ser. No. 5061, 8 p.

Kudlo, B.P., and V.D.Boytsov. 1979. The effect of water dynamics on year-class strength of cod on Flemish Cap. ICNAF Sel. Papers No.5, p.7-9.

Kudlo, B.P., and V.A.Borovkov. MS 1980. Some results of the USSR oceanographic investigations in accordance with the Flemish Cap Project in 1979. NAFO SCR Doc. 80/VI/54, Serial No. N091, p.9.

Kudlo, B.P., V.V.Burmakin, and V.S.Sterkhov. 1980. Geostrophic circulation of Northwest Atlantic waters from Davis Strait to Newfoundland, generalized from 1962 to 1978 data. ICNAF Sel. Papers No.6, p.53-54.

Leipper, D.L. 1967. Observed ocean conditions and hurricane Hilda, 1964. J.Atmos. Sci., 24(2), p.182-196.

Mc-Cartney, M.S. 1975. Inertial Taylor columns on a beta plane. - J.Fluid Mech., 68, part 1, p.71-96.

Pudov, V.D., A.A.Varfolomeev, and K.N.Fedorov. 1978. Vertical structure of a typhoon trace in the upper ocean. Okeanologia, vol.18, No.2, p.218-225.

Ross, C.K. MS 1980. The drift of satellite-tracked buoys on Flemish Cap, 1979-80. NAFO SCR Doc. 80/IX/127, Serial No. N199, p.12.

Serebryakov, V.P. 1957. Cod reproduction in North-West Atlantic. -Trudy PINRO, vyp.20, p.205-242.

Taylor, G.I. 1923. Experiments on the motion of solid bodies in rotating fluids. -Proceedings of the Royal Society of London, A, 104, p.213-218.

Tunegolovets, V.P. 1976. Transformation of the ocean temperature field after passage of a tropical cyclone (Taking as an exemple the typhoon "Tess" (1975)). Meteorologia i gidrologia, No.12, p.60-66.

Zubov, N.N., and O.J.Mamaev. 1956. The dynamics method of calculating elements of sea current. Gidrometeoizdat, Leningrad, 115 p.

Table 1 A list of oceanographic surveys carried out by the Soviet vessels on the Flemish Cap in 1977-1982

NN	Vessel, No. of cruise	Date of observations	No. of stations with T, S determined	No. of stations with O_2:P:Si determined
I	2	3	4	5
I	"Protsion", 16	6-26 Dec 1977	28	-
2	-"-	12-22 Jan 1978	3I	-
3	-"-	3-12 Feb 1978	39	-
4	-"-	20-27 Feb 1978	42	-
5	"Protsion", 17	24 May-02 Jun 1978	43	39:38:38
6	-"-	17-29 Jul 1978	5I	30:3I:30
7	"Persey-III", 20	26 Jul-01 Aug 1978	36	-
8	"Suloy", 2	20 Mar-07 Apr 1979	34	I7:I7:-
9	"Gemma", 17	07-20 Apr 1979	42	2I:42:42
I0	-"-	03-10 May 1979	42	42:-:-
II	"Suloy", 2	05-18 Jun 1979	34	8:8:-
I2	"Suloy", 3	01-40 Sep 1979	43	3I:3I:-
I3	"Protsion", 20	19 Mar-01 Apr 1980	56	56:56:47
I4	"N.Kononov", 2	23 Apr-03 May 1980	33	I8:I8:I7
I5	"Protsion", 20	02-12 May 1980	56	56:56:55
I6	"Protsion", 20	01-11 Jun 1980	56	56:56:56
I7	"N.Kononov", 2	24 Jul-01 Aug 1980	36	25:II:II
I8	"Protsion", 21	03-15 Aug 1980	47	40:20:20
I9	"Gemma", 23	22 Mar-05 Apr 1981	48	-
20	"Gemma", 23	06-16 Apr 1981	33	-
2I	"Gemma", 23	23-30 Apr 1981	47	-
22	"Gemma", 23	21-30 May 1981	48	-
23	"N.Kononov", 4	1-8 Jun 1981	26	I6:I6:I4
24	"Protsion", 24	27 Oct-05 Nov 1981	46	-
25	"Persey-III", 26	2-8 Dec 1981	29	I8:I8:I8
26	"Suloy", 25	17-30 Apr 1982	3I	-

Table 2 Types of geostrophic water circulation on the Flemish Cap Bank and their frequency according to observations made in 1977-1982

Characteristic of water circulation types	Conventional symbols of types	No. of surveys with given type of water circulation observed	No. of surveys with given type of water circulation observed,%
Vast pronounced anticyclonic water gyre	V	I2	44,5
General anticyclonic water gyre with some local centres of rotation within its limits	V_L	6	22,2
Transient meandering water flow across the Bank	T_M	2	7,4
Circulation of mixed nature involving indications of types V, V_L and T_M	M	7	25,9

Table 3 Frequency of types of geostrophic surface water circulation over the Flemish Cap Bank (by the data of surveys for 1977-1982)

Month	No. of surveys	Types of circulation			
		V	V_L	T_M	M
Jan	2*	2			
Feb	2			I	I
Mar	3	I		I	I
Apr	5		4		I
May	4	3			I
Jun	3	2	I		
Jul	3	I			2
Aug	I				I
Sep	I		I		
Oct	-				
Nov	I	I			
Dec	2	2			
Total	27	I2	6	2	7

* including the survey of Canadian R/V "Hudson" carried out on 15-22.01.1979

Table 4 Extrema of yearly variations in water stratification degree (mean Brunt-Väisälä frequency in the layer from surface to bottom) on the stations of Flemish Cap section

No. of stations	Positions		Depth, m	Minimum		Maximum		$\frac{N_{max}}{N_{min}}$
	N	W		Onset	$N_{min} \cdot 10^3 s^{-1}$	Onset	$N_{max} \cdot 10^3 s^{-1}$	
II	47°00'	46°50'	I024		2,5		5,0	2,0
I2	47°00'	46°40'	I000		2,4		5,0	2,I
I3	47°00'	46°29'	807		2,5		6,7	2,7
I4	47°00'	46°0I'	308		4,2		9,5	2,3
I5	47°00'	45°30'	245		5,I		I0,5	2,I
I6	47°00'	44°59'	I52		4,2		I5,0	3,6
I7	47°00'	44°26'	I58		2,8		I0,I	3,6
I8	47°00'	44°05'	327		4,8		6,8	I,4
I9	47°00'	43°45'	674		3,7		5,8	I,6
20	47°00'	43°24'	I284		2,8		5,0	I,8

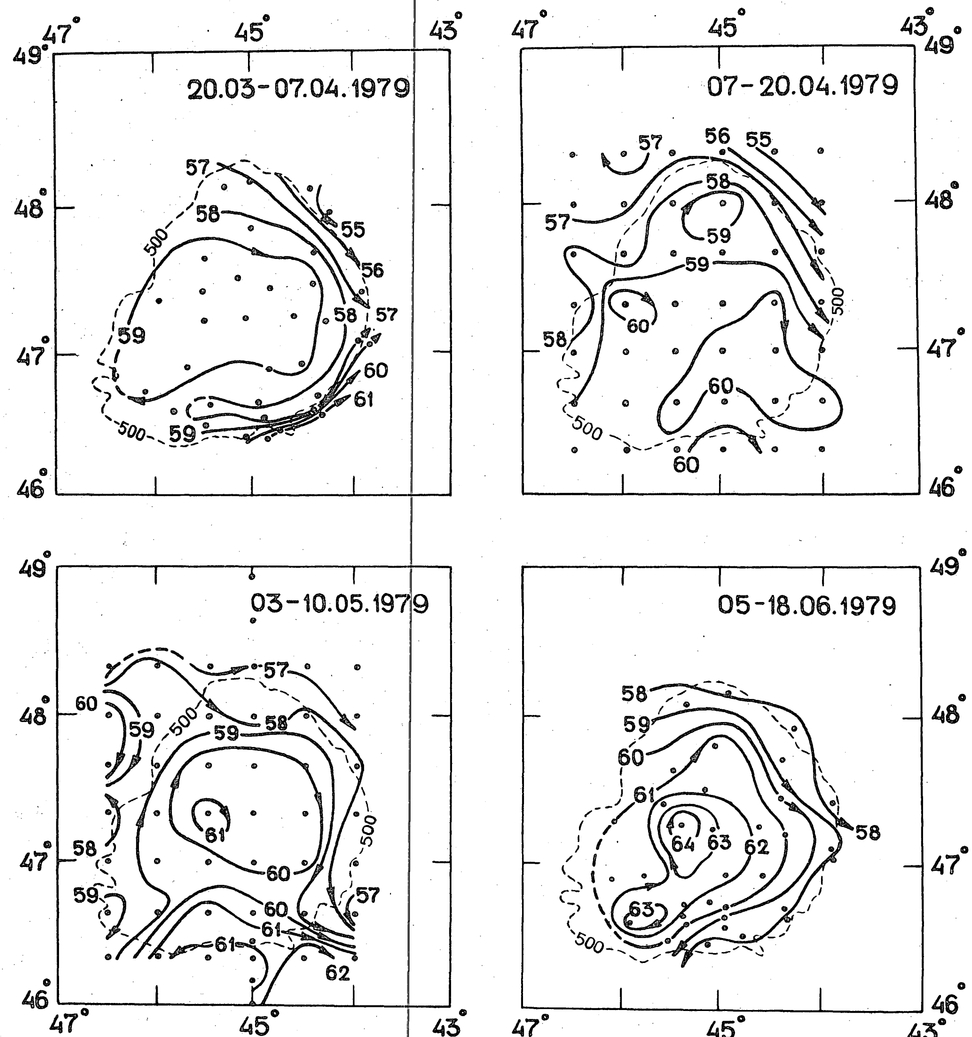

Fig.1 Charts of geostrophic surface water circulation over Flemish Cap relative to 200 db level in March/April and June 1979 ("Suloy",cruise 2) and in April/May 1979 ("Gemma", cruise 17).

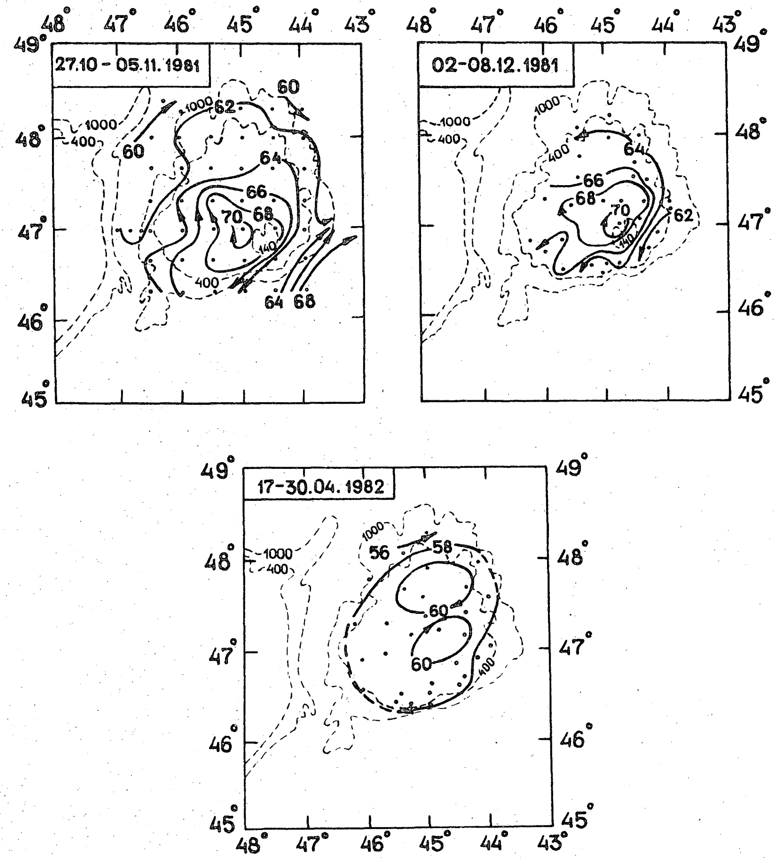

Fig.2 Charts of geostrophic surface water circulation over Flemish Cap relative to 200 db level in October/November 1981 ("Protsion", cruise 24), in December 1981 ("Persey-III", cruise 26) and in April 1982 ("Suloy", cruise 25).

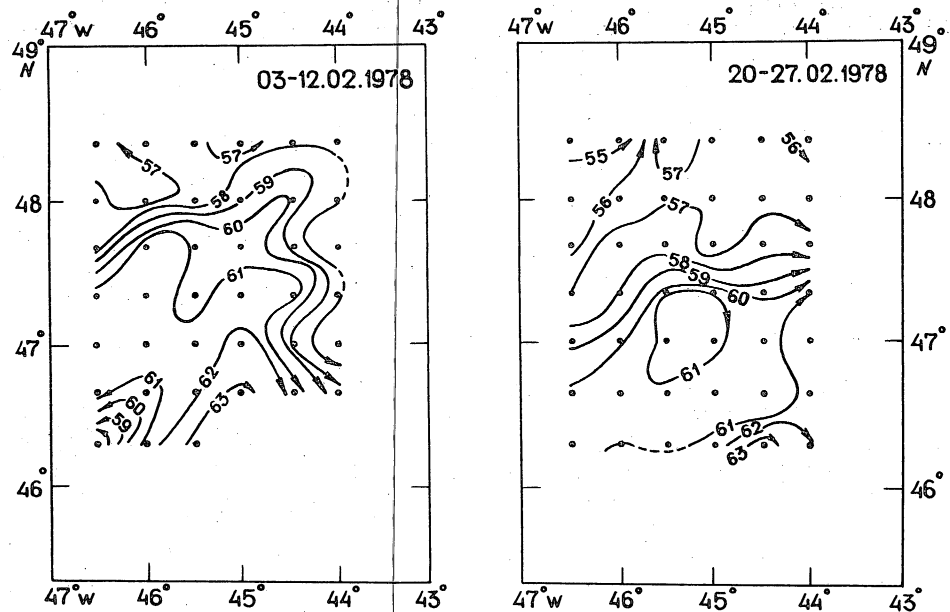

Fig. 3 Charts of geostrophic surface water circulation over Flemish Cap relative to 200 db level according to data from cruise 16 of "Protsion": 3-12 February 1978 - T_M type; 20-27 February 1978 - M type.

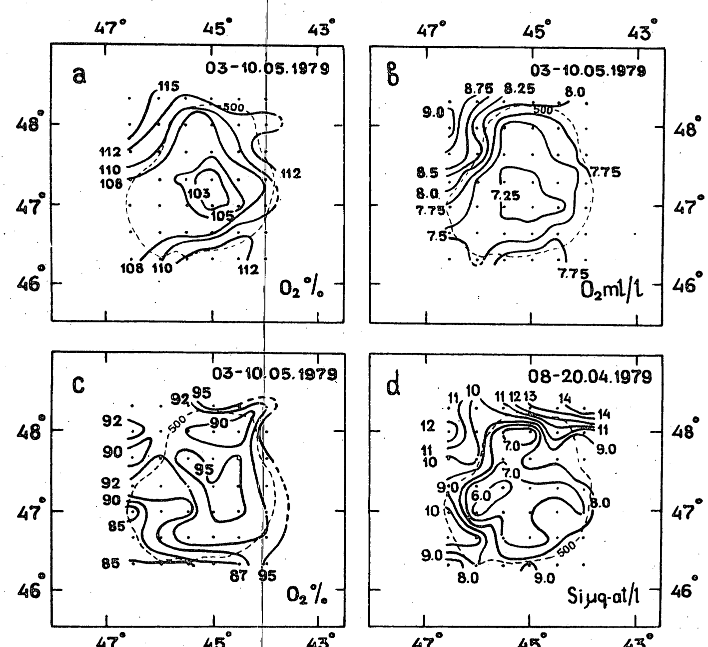

Fig. 4 Distribution of hydrochemical elements in the Flemish Cap Bank waters at circulation types V and V_L

a - relative content of oxygen (%) on the surface in May 1979,

b - absolute content of oxygen (ml/l) on the surface in May 1979,

c - relative content of oxygen (%) at 100 m depth in May 1979,

d - concentration of silicon (mkg-at/l) at 100 m depth in April 1979.

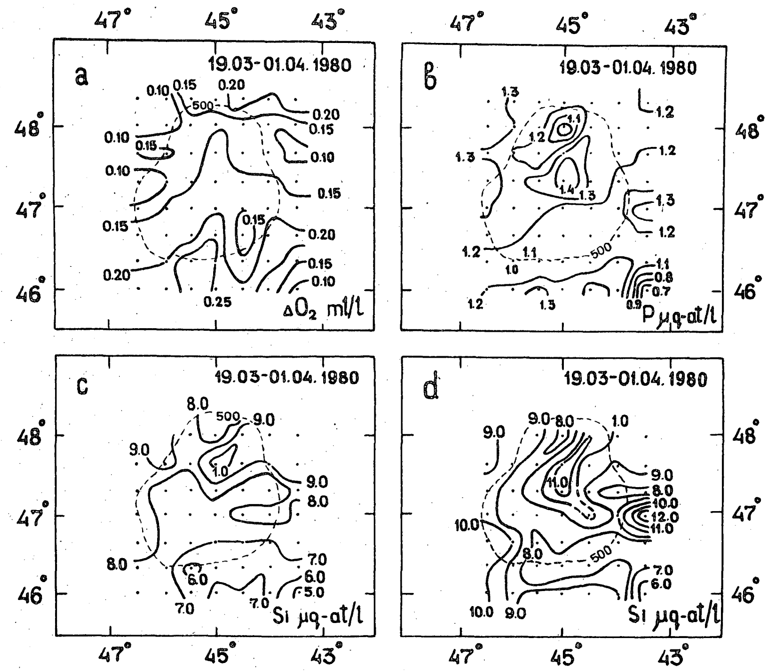

Fig.5 Distribution of hydrochemical elements in the Flemish Cap Bank waters in March 1980 (T_M circulation type)

a - mean value of oxigenation (ml/l) in the layer from the surface to compensation depth,

b - concentration of phosphates (mkg-at/l) at 100 m depth,

c - concentration of silicon (mkg-at/l) at 50 m depth,

d - concentration of silicon (mkg-at/l) at 100 m depth.

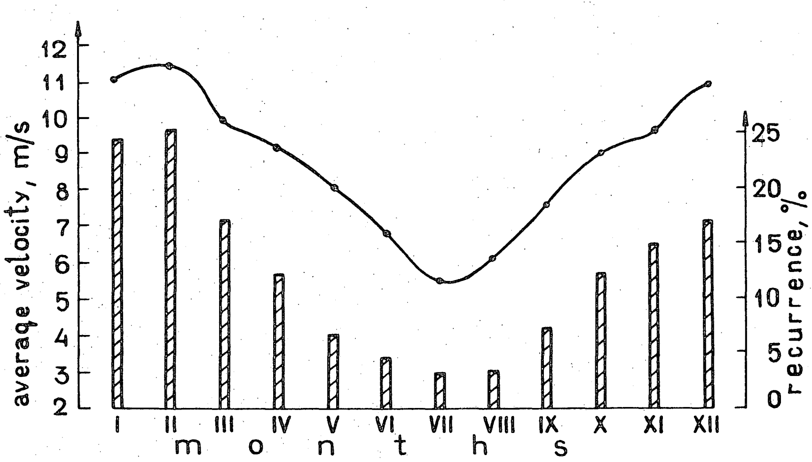

Fig.6 Climatic yearly variations in wind frequency at the speed of ⩾ 16 m/s (diagram) and in mean wind velocity (curve) in the Flemish Cap area (47°N, 45°W).