POLISH POLAR RESEARCH (POL. POLAR RES.) POLSKIE BADANIA POLARNE	7	4	353—369	1986

Alfred GRELOWSKI, Andrzej MAJEWICZ, Marianna PASTUSZAK

Department of Oceanography, Sea Fisheries Institute
Al. Zjednoczenia 1, 81-345 Gdynia, POLAND

Mesoscale hydrodynamic processes in the region of Bransfield Strait and the southern part of Drake Passage during BIOMASS — SIBEX 1983/84*

ABSTRACT: The attempt was made to describe the dynamics of water masses in the southern part of the Drake Passage and the Bransfield Strait in the time period from December 1983 to January 1984. The dynamic topography at the surface (referred to 500 dbar surface) allowed to define the eastward flow of water in the Bransfield Strait and to observe, in the same region, the presence of a rather weak counter-current of the Weddell Sea origin. In the Drake Passage, a general north-eastern direction of water flow of the Bellingshausen Sea was found. In the Bransfield Strait, as well as in the Drake Passage, the relative velocities of geostrophic flow were low: 0.22 and 0.06 m s^{-1}, respectively. The analysis of Rossby and eddy numbers and Rossby radius made it possible to regionalize the dynamic phenomena but could not be fully used for their classification.

Key words: Antarctica, hydrodynamic processes

1. Introduction

Regions of intensive water dynamics create many interesting hydrological phenomena and also influence the state of plankton concentrations as well as forms of its occurrence. That is why more and more attention is paid to such regions, and especially to conditions of their formation. The concurrent phenomena and their influence on ecological conditions were also of interest to some authors (Stavn 1971, Witek et al. 1981).

The hydrology of the Bransfield Strait is under influence of phenomena occurring in waters of the surrounding regions. Waters present on the western shelf of the Antarctic Peninsula and in the Drake Passage enter the Bransfield

* This work was done within the problem MR-I-29A. The expedition was financed by the Polish Academy of Sciences and the Sea Fisheries Institute.

Strait from the north while waters from the Weddell Sea reach it from the east (Clowes 1934, Gordon and Nowlin 1978).

Nowlin, Whitworth and Pillsbury (1977) distinguish four zones in the Drake Passage (Fig. 1), starting from the north towards the south: Subantarctic Zone, Polar Frontal Zone, Antarctic Zone, Continental Zone. In between these zones there are the following hydrological fronts: Subantarctic Front, Polar Front and furthest south — the so called Continental Water Boundary (after Sievers and Emery 1978).

Polish investigations carried out in 1983/84 in the Drake Passage covered only the Antarctic Zone and the Continental Zone.

East of Bransfield Strait there is a region of confluence of cold water inflowing from the Weddell Sea with a slightly warmer water flowing

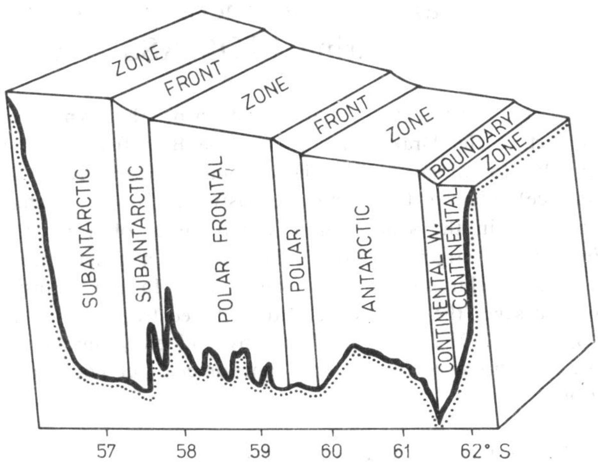

Fig. 1. Schematic illustration of four zones of water masses and three crosswise fronts in the Drake Passage (from Cape Horn to Livingstone Island; after Nowlin and Clifford 1982)

through the Drake Passage and coming from the Scotia Sea. This region was called the Weddell-Scotia Confluence by Gordon (1977) and was defined in detail by Patterson and Sievers (1980). The bottom topography, especially the existence of the South Scotia Ridge, where waters from the Weddell and Scotia Seas mix together, creates favorable conditions for the formation of the Weddell-Scotia Confluence.

Waters in the Bransfield Strait have a complicated structure of water masses (First Post Fibex — 1982); this is due to their different origin as well as different currents circulation (Gordon and Nowlin 1978). Very often waters from the Weddell Sea flow westwards along the Antarctic Peninsula and they even reach the Trinity Island. These waters on their way, most probably, mix together with waters inflowing into the Bransfield Strait through the Gerlache Strait (Clowes 1934).

2. Material and methods

The analysis of water masses dynamics was based on the results of temperature and salinity measurements. The measurements were performed with STDO Bissett-Berman sound (model 9040) at 73 hydrological stations out of which XIII hydrological profiles were separated. The investigations were carried out in the Drake Passage, the Bransfield Strait, the Weddell Sea in the time period from December 10, 1984 to January 08, 1984 (Fig. 2).

The horizontal distributions of distinguishing, characteristic parameters, being typical for the entire region and not only for particular existing water masses, were chosen to show the extent of Weddell Sea waters in the investigated area. On the basis of the analysis of temperature and density distributions in particular sections the isotherm $-0.8°C$ and isopycne $\sigma_{\theta} = 27.5$ were chosen to show on maps their depth of occurrence (Figs. 3,5). Temperature and density distributions allowed to designate the extent of Weddell Sea waters in the deep layers. Additionally salinity distribution was used to define the extent of this water at the surface (Fig. 4).

The dynamic depths, referred to 500 dbar level, were calculated and the method described by Zubov and Mamaev (1956), was used. These calculations allowed to draw the map of surface geostrophic currents and thus to describe the water movements. The dynamic depths were used for the calculations of the velocity of geostrophic currents and further for the calculation of volume transport at chosen sections (Fig. 7). In diagrams shown in Fig. 7, the unit 10^6 m^3 s^{-1} was accepted and additional numbers on the diagrams show the amount of flowing water at particular sections. The area of each rectangle in Fig. 7 is proportional to volume transport of water between particular stations, while the height of each rectangle is proportional to flow intensity.

The large size of the investigated region and big distances between hydrological stations did not allow to classify univocally the dynamic phenomena. In the light of these facts the term "eddy" seems to be controversial sometimes and that is why in the text term "whirl" was used instead.

When defining the scale of dynamic phenomena in characteristic areas with significant condensation or deflection of isolines of heights of dynamic topography the analyses of Rossby number (R_o) and deformation Rossby radius R_d (R_d — according to Pedlovsky 1979), were used.

The Rossby number was calculated from the formula:

$$R_o = \frac{V_{max}}{r \cdot f}$$

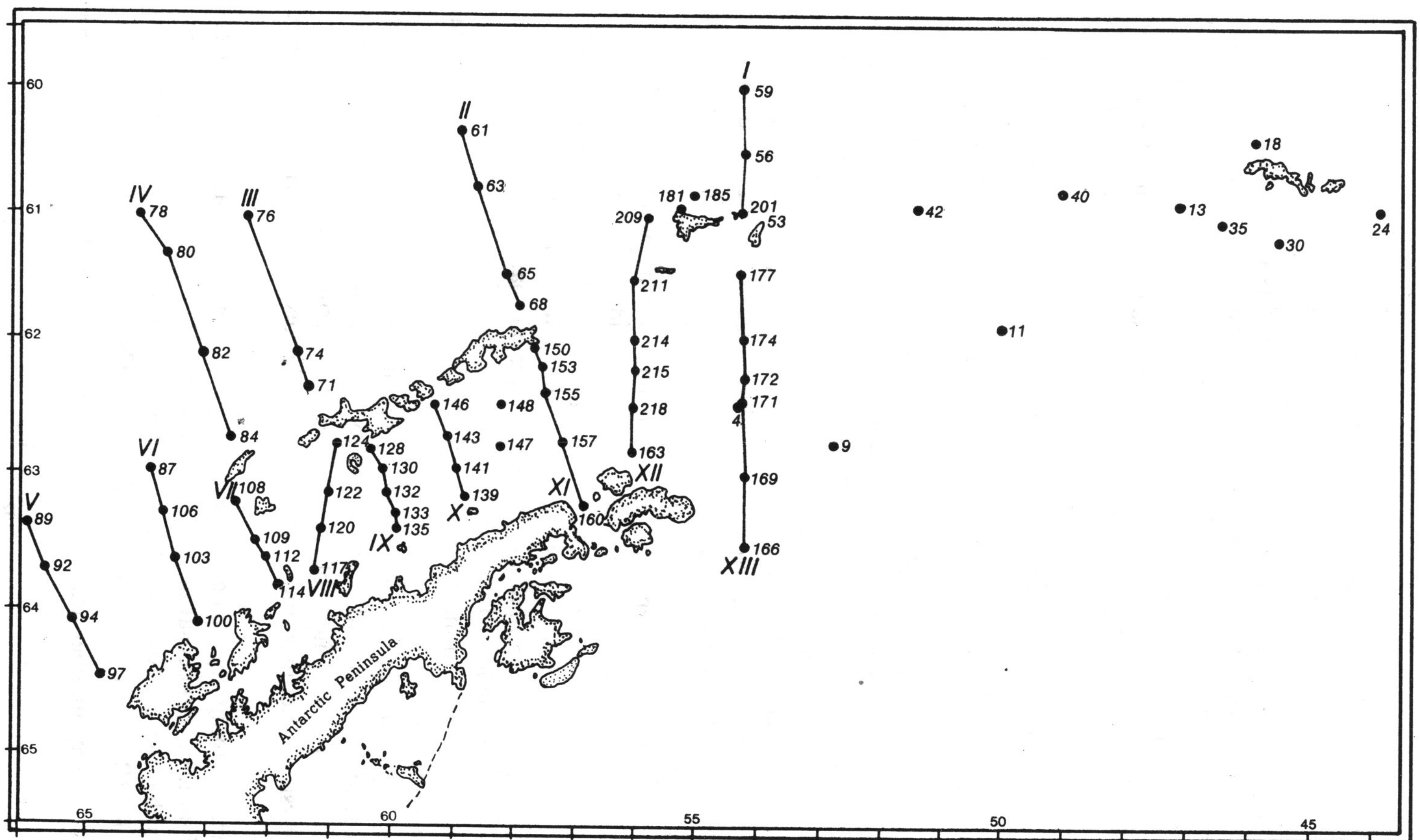

Fig. 2. Map of oceanographic stations and profiles investigated onboard R/v "Profesor Siedlecki" within the BIOMASS-SIBEX programme in the time period from December 10, 1983 to January 8, 1984.

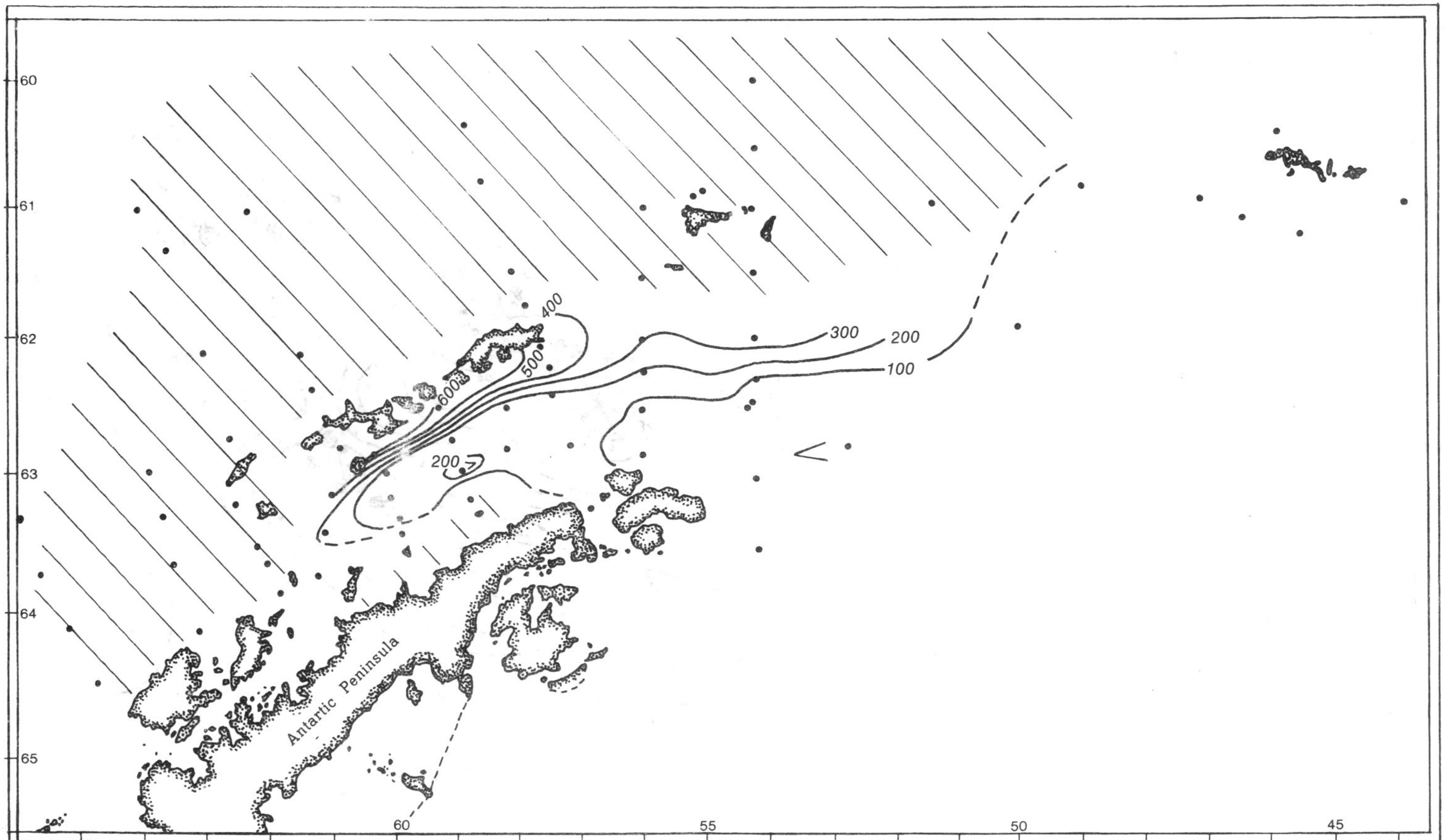

Fig. 3. Depth (m) of occurrence of isotherm $-0.8°C$ in waters where the temperature decreases with depth.

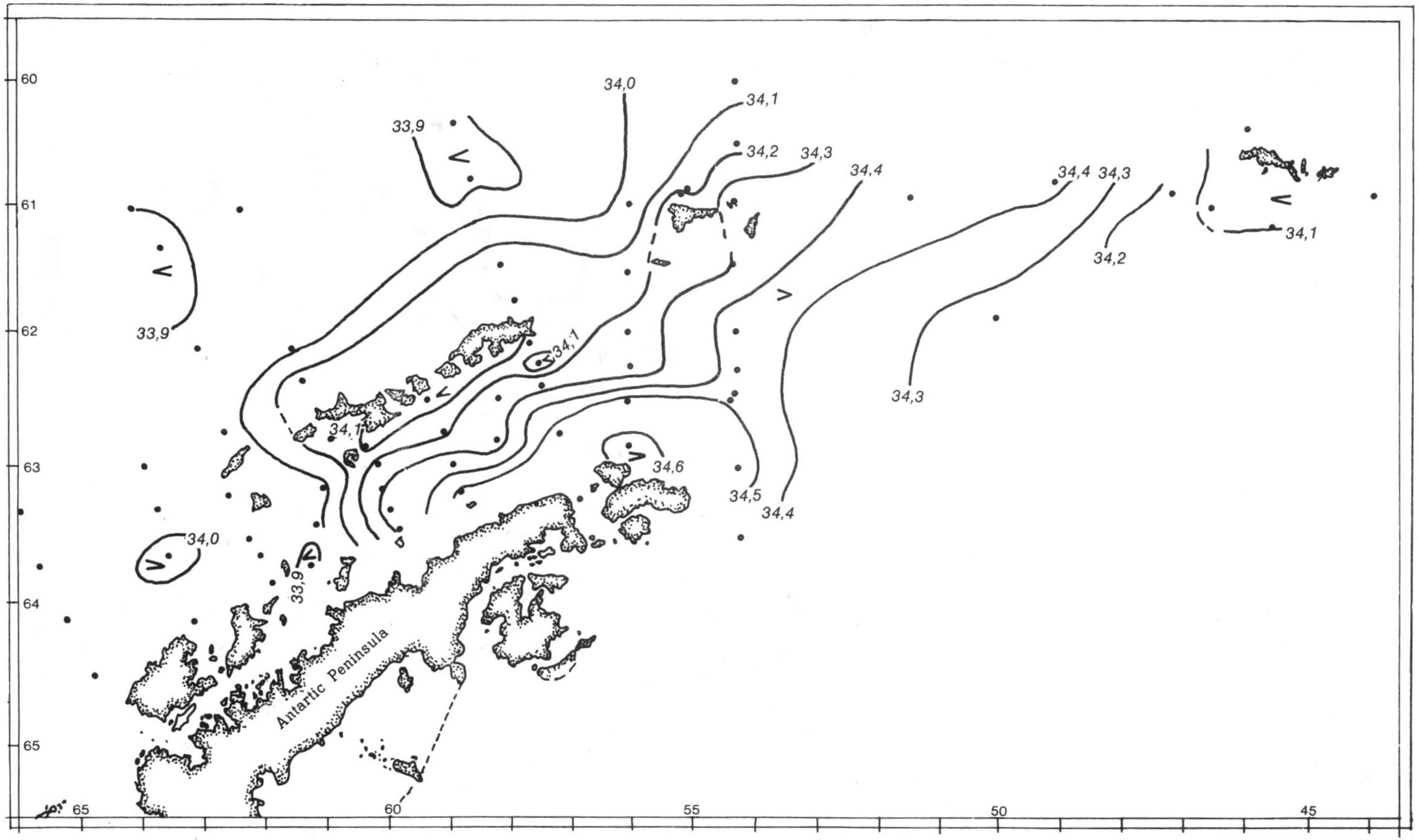

Fig. 4. Distribution of surface salinity ($\times 10^{-3}$).

where:
V_{max} — the highest linear geostrophic velocity,
r — the whirl radius (distance between V_{max} and te supposed axis of rotation),
f — Coriolis parameter.

The deformation Rossby radius was calculated from the formula:

$$R_d = \frac{1}{f}\left[g\frac{\Delta\varrho}{\varrho}H\right]^{1/2}$$

where:
g — acceleration of gravity,
H — thickness of the layer in which the disturbed density distribution was observed,
$\Delta\varrho$ — vertical change of density at the distance H.
The coefficient being the ratio of deformation radius (R_d) and whirl radius (r_o) was also calculated on the basis of Nof's formula:

$$\frac{R_d}{r_o} = [R_o-(1-R_o):3]^{1/2}$$

This coefficient was independently calculated twice; once using the Nof's formula (R_d/r_o) and the second time on the basis of the ratio R_d/r where:
R_d — was calculated according to Pedlovsky's formula, and
r — was found from the density profiles (as a horizontal radius of whirl). Having these two numbers, it was possible to check the correctness of all assumptions leading to the determination of parameters characterizing the whirls and other disturbances of flow.

Additionally, the whirl numbers N_E, reflecting the horizontal structure of water density, were calculated for the regions with complicated dynamic topography. According to Wyrtki et al. (1976), these regions show elevated values of kinetic energy and thus there is considerable possibility for whirls occurrence. The eddy numbers (N_E) were calculated from the formula:

$$N_E = \frac{D \cdot 10^2}{(R \cdot f)^2}$$

where:
D — difference between dynamic heights in whirl and surrounding waters,
R — eddy radius.
Wilkinson (1972) calculated the eddy number for well developped eddies in different oceans in the zones: 29°S to 40°S and 29°N to 40°N and found that it equaled 3.55×10^{-2}. Reckoning of this eddy number for the region of the Bransfield Strait, taking into account the different Coriolis parameter, gave the result:

$$N_- = 1{,}47 \times 10^{-2}$$

3. Results

Temperature and salinity are characteristic parameters on the basis of which it was possible to deduce the origin and transformation of water masses. Horizontal and vertical distribution of density which are the function of temperature and salinity gives a reflection of dynamic processes taking place in water.

The depths of occurrence of isotherm — 0.8°C are shown in Fig. 3; they present the extent of penetration of Weddell Sea Water in the Bransfield Strait. In this figure only depths below which the temperature decreases were marked but areas where temperatures below −0.8°C were only related to seasonal occurrence of thermal minimum in the winter modification of Antarctic Surface Water were not marked (below this minimum temperature increases).

Waters in the investigated part of the Weddell Sea were characterized by low temperatures and the isotherm −0.8°C was present at the surface in the most part of that region. On the shelf, along the Antarctic Peninsula, waters were generally warmer and this isotherm was not observed. In the middle part of the Bransfield Strait, along the axis, it was observed at the depths from 100 to 200 m, while in the northern part of the Strait, along the South Shetlands Archipelago, it occurred much deeper and the maximum depth of 650 m was noted in the vicinity of Livingston Island.

The distribution of salinity at the surface (Fig. 4) gives additional information on the distribution and extent of water masses of the Weddell Sea origin. According to Patterson and Sievers (1980) waters of the Weddell Sea and waters being under the Weddell Sea influence are distinguishable by increased surface salinity. The highest surface salinity of 34.6×10^{-3} was observed near d'Urville Island and a little bit lower, but still high (34.5×10^{-3}), on the shelf of the Antarctic Peninsula. High salinity values were observed in the investigated part of the Weddell Sea between Elephant Island and the South Orkney Islands and also in the whole Bransfield Strait where the condensation of surface isohalines makes a characteristic front. In the Drake Passage and on the western shelf of the Antarctic Peninsula the surface salinity values were lower (to 34.0×10^{-3}), but typical for the Antarctic Zone (Atlas Antarktiki 1969). In the Continental Zone, on the northern side of the South Shetlands Archipelago, and towards the north of the Elephant Island, the salinity values ranged from 34.1 to 34.2×10^{-3}.

The distribution of spatial occurrence of isopycnes of denstity $\sigma_\theta = 27.5$ signifies the baroclinic density distribution at particular profiles (Fig. 5). This isopycne ($\sigma_\theta = 27.5$) was chosen to compare water masses in the layer down to 500 m in the largest possible area.

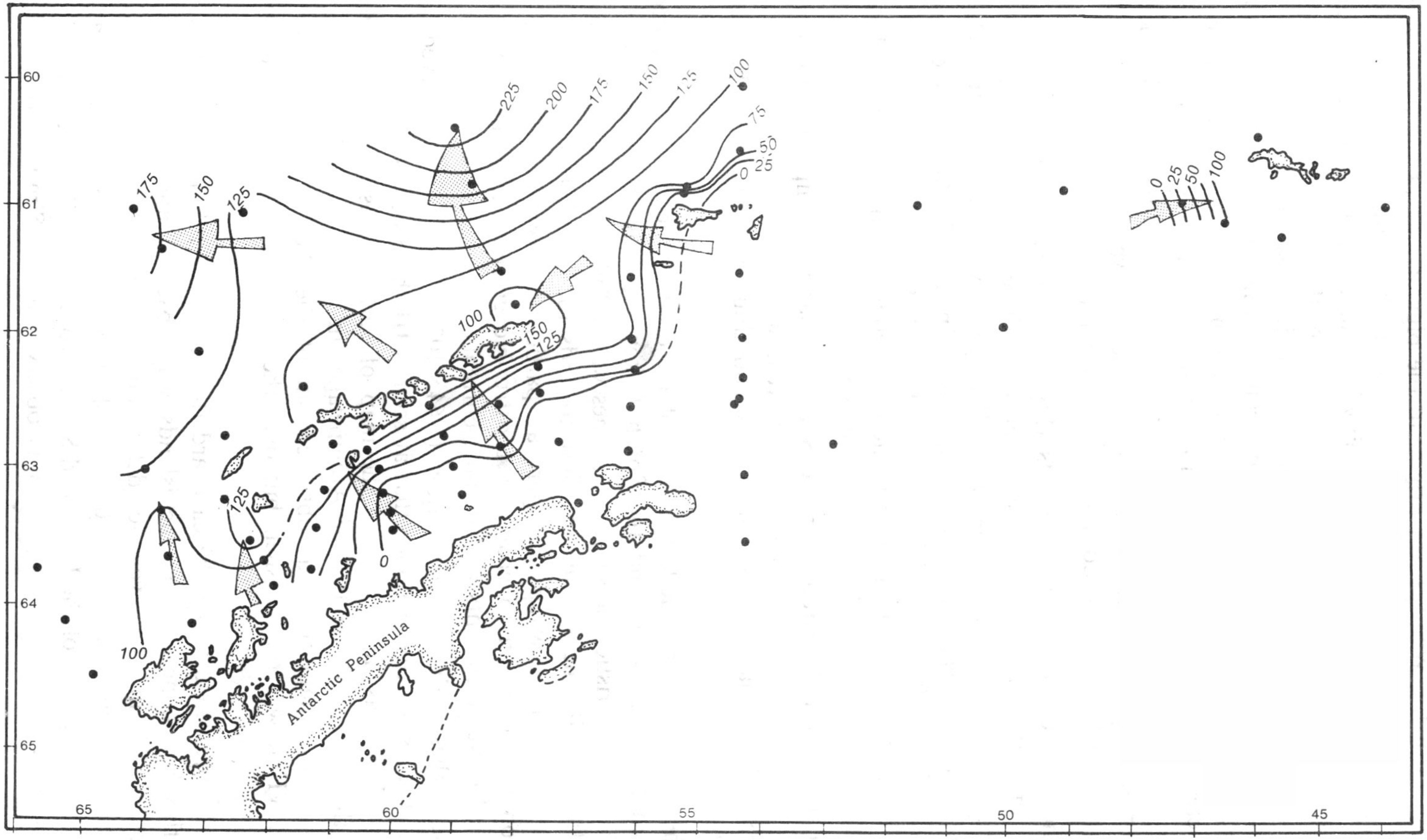

Fig. 5. Depth (m) of occurrence of isopycne $\sigma_\theta = 27.5$.

Waters of the Weddell Sea origin, in the biggest part of the investigated region, showed a surface density higher than 27.5 with the highest value of 27.8, observed in the region of Joinville Island. In the Bransfield Strait, the isopycne 27.5 lay along its axis and spread out from Tower Island to Elephant Island. Towards the north from its position in the Bransfield Strait, there was observed the significant sinking of 27.5 density plane (down to 150 m), and thus oblique arrangement of isopycnes which is characteristic for well formed hydrological front. In the Drake Passage, northwards from King George Island, the next and relatively rapid sinking of isopycne $\sigma_\theta = 27.5$, from 100 to over 200 m, was observed. This fact reflects the occurrence of convergence in Antarctic.

The map of geostrophic currents (Fig. 6) referred to 500 dbar, allows for a quantitative description of water flow direction in the investigated region. Generally, waters in the Drake Passage as well as in the Bransfield Strait have northeastern direction of flow. In the Drake Passage, two anticyclonic whirls, reflected in the deflection of isolines of dynamic depth, were observed. One of them was noted northwards from Smith Island, the other — northwards from King George Island.

In the Bransfield Strait near the South Shetlands Archipelago, the condensed distribution of isolines was observed, while in the region close to Antarctic Peninsula — a very small differentiation of dynamic heights was found.

The broad cyclonic deflection of isolines of dynamic depth was noted between Elephant Island and the South Orkeny Islands and less extensive but also characteristic deflection of isolines was found in the entrance of the Bransfield Strait where waters outflow towards the Weddell Sea.

The diagram of water transport at particular profiles (Fig. 7) gives additional information to charts of geostrophic currents and shows water balance for main currents and counter-currents.

The highest value of water flow (1.64×10^6 m^3 s^{-1}) was observed at profile II. It is worthy of notice that at section III there occurred a counter-current which was not visible on the map of surface geostrophic currents.

In the region of the Palmer Archipelago, in the 0—500 dbar layer at section V, the main flux was observed out of the shelf while at sections VI and VII it was on the shelf but over the localities with greater depths of 800—1000 m.

In the Bransfield Strait the eastward flow of 1.08×10^6 m^3 s^{-1} with the main flux pronounced along the islands was observed and it was visible at section IX in the cyclonic deflection of the geostrophic current. At the same time the westward flow of 0.46×10^6 m^3 s^{-1} was found. In the remaining part of the Bransfield Strait (profiles X, XI), the dominating eastward flow of 1.2×10^6 m^3 s^{-1} was observed again. Simultaneously the

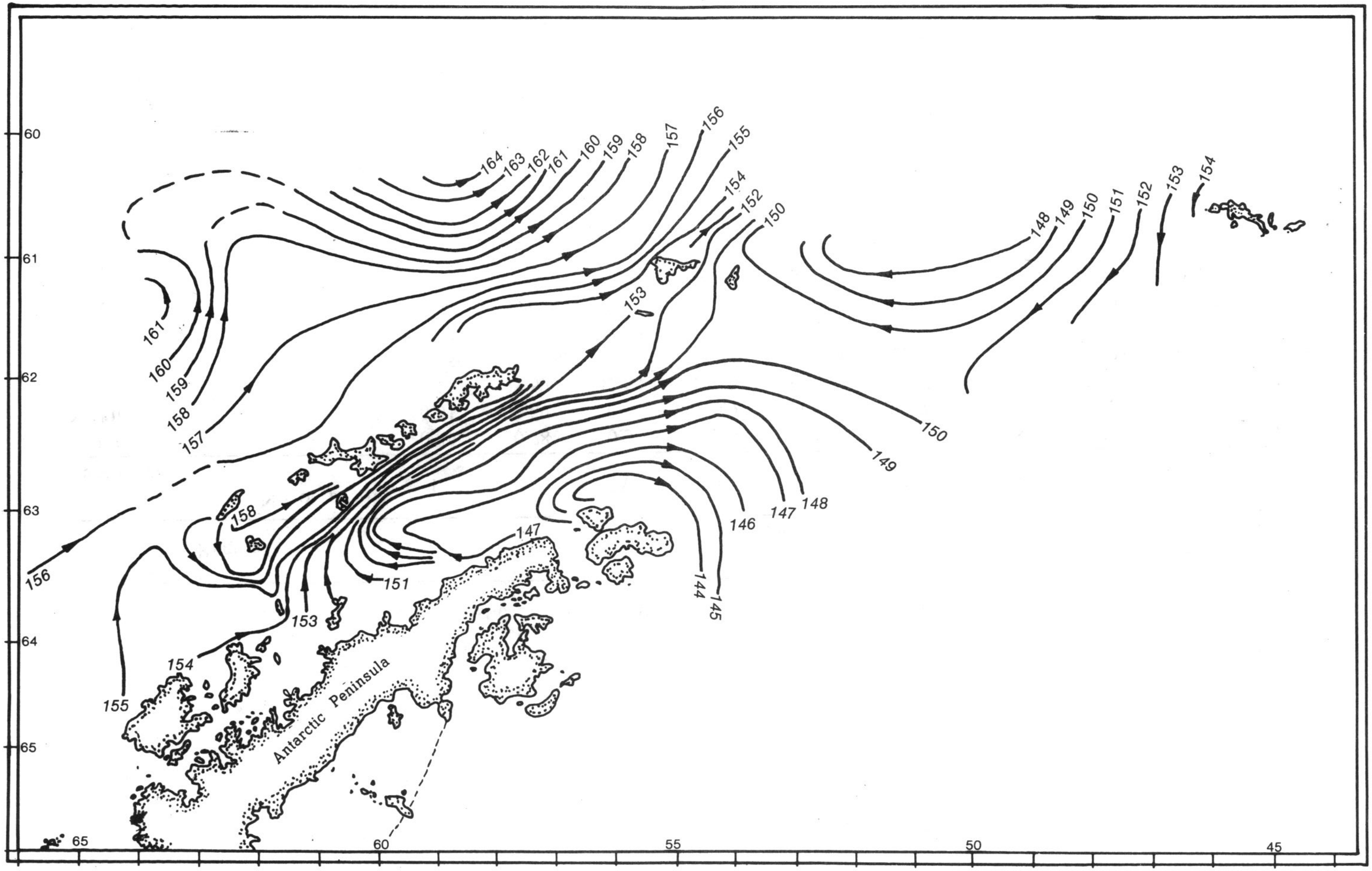

Fig. 6. The surface dynamic topography referred to 500 dbar (cm dyn)

Table I

Characteristic dynamic parameters of waters in investigated regions

Region	Drake Passage			Palmer Archipelago		Bransfield Strait			Elephant — Joinville	
Parameters / No of profile	I	II	IV	VII	VIII	IX	X	XI	XII	XIII
R_o*10^{-2}	0,39	0,78	0,55	5,80	1,62	6,48	2,95	3,20	2,21	1,51
N_E*10^{-2}	0,31	0,89	0,51	5,49	1,80	11,97	1,83	2,96	2,86	1,58
r (km)	112,50	92,69	42,64	17,70	37,41	30,75	47,09	53,66	32,20	33,26
V_{max} $(m \cdot s^{-1})$	0,056	0,091	0,030	0,134	0,079	0,260	0,181	0,223	0,092	0,065
R_d (km)	4,74	4,58	1,68	1,36	2,68	4,50	4,12	5,15	3,31	1,06
R_d/r	0,043	0,049	0,039	0,077	0,082	0,146	0,087	0,098	0,103	0,032
R_d/r_o	0,036	0,050	0,043	0,135	0,073	0,142	0,98	0,096	0,085	0,070

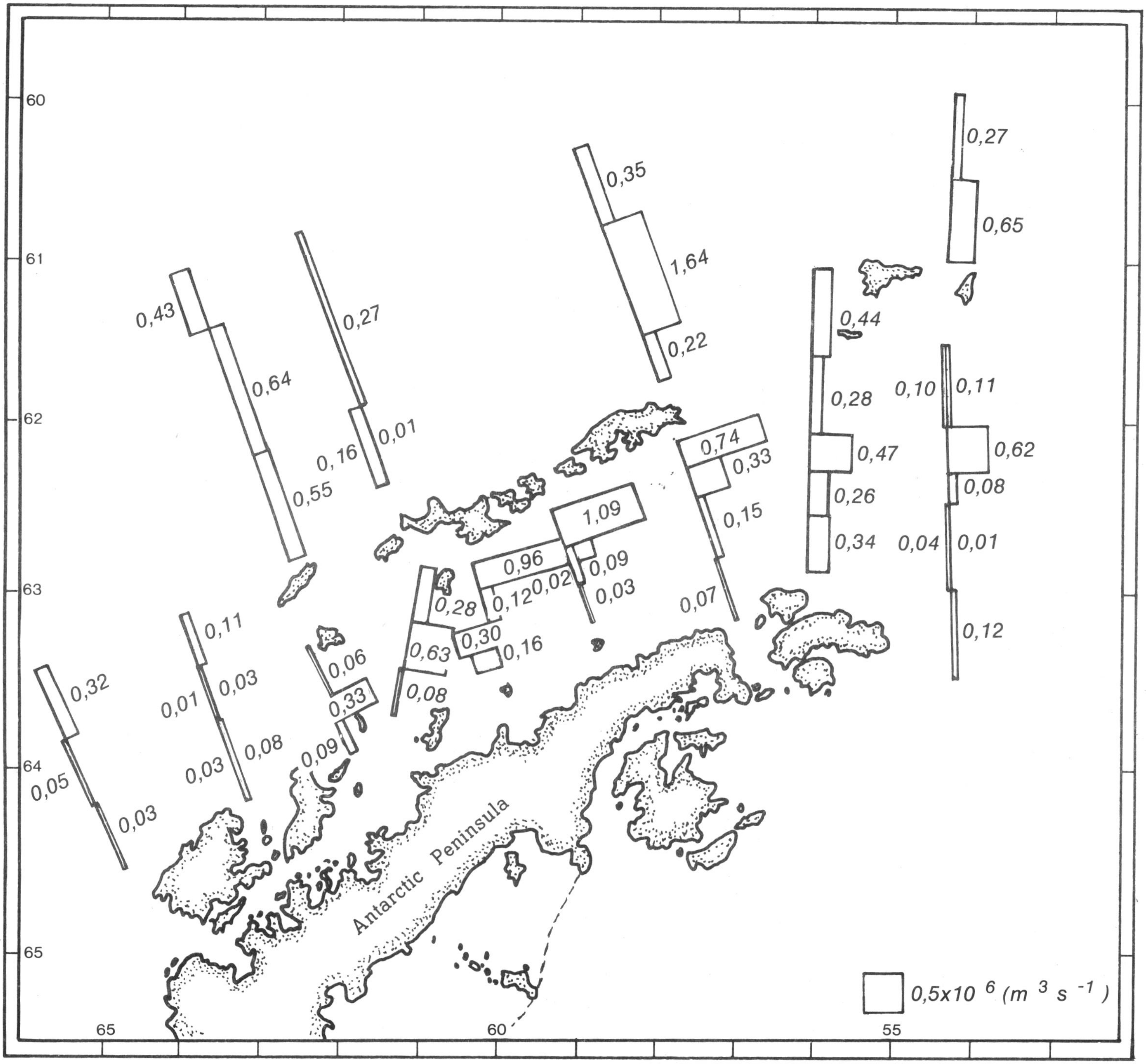

Fig. 7. Transport of water masses (10^6 m^3 s^{-1}) in the layer 0—500 dbar at particular thirteen profiles.

weak counter-current (at section X only subsurface one) with the flow values ranging from 0.02 to 0.07×10^6 m^3 s^{-1} was found.

In Table I the following parameters characterizing the dynamic peculiarities of waters are presented:

R_o — Rossby number,
N — eddy number,
r — whirl radius,
V_{max} — maximum velocity of geostrophic current,
R_d — deformation of Rossby radius,
R_d/r — ratio calculated from above numbers
R_d/r_o — ratio calculated from the empirical Nof's formula.

Two values: N_E and R_o differ insignificantly for oceanic eddies as was proved by Wilkinson (1972). This statement has its confirmation in the results obtained in this work as it can be seen in Table I. The most diversified parameter was the whirl radius which showed values from 18 up to 113 km.

In the Drake Passage, the low values of V_{max} go together with big whirl radiuses, which most probably excludes formation of whirl. The low values of N_E, much lower than the critical ones (1.47×10^{-2}) confirm the above statement.

The highest velocities of geostrophic flow (0.26 ms^{-1}) were found in the Bransfield Strait. The mean values of whirl radius were 31—54 km. In that region the biggest differences between whirl number and Rossby number were observed which caused great difficulties in proper interpretation of the phenomenon. However, high values of whirl number, higher than the critical one suggest the existence of a hydrological front. It has its confirmation in the results calculated for the frontal zone of Brazil and Falkland Currents.

The whirl numbers approximating the critical one and corresponding to the geographical latitude of the Bransfield Strait occurred at section VIII — in the vicinity of the Palmer Archipelago and at section XIII — between Elephant and Joinville Islands. In the places of these whirls the velocity of current was low, below 0,1 ms^{-1}, and the whirl radius was 35 km. The values of quotient R_d/r, calculated with the two above described methods, show the significant concurrence of results for the most numbers of profiles.

4. Discussion

The hydrological situation of the described regions is under influence of the seasonality and dynamics of two main water masses originating from the Weddell and Bellingshausen Seas. The pace of seasonal changes has its reflection in temperature changes in the surface layer. The positive temperatures were not observed in the first half of December in the eastern part of the

Bransfield Strait, while at the beginning of January the temperatures, in that region, were of about 1°C. It was impossible to draw the map of surface temperature on the basis of the surface thermograph readings, because the readings were higher on every return of the ship to the investigated region.

The analysis of maps showing the depths of occurrence of isotherm −0.8°C (Fig. 3), the isopycne $\sigma_\theta = 27.5$ (Fig. 5) and surface distribution of salinity (Fig. 4) — allows to delimit the range of waters originating from the Weddell Sea. The cold waters with highest salinity, thus having highest density, were present on the shelf of Joinville Island and also occupied a considerable part, mostly the southern one, of the Bransfield Strait. They were sinking in northern part of the Bransfield Strait and the well pronounced process was visible along the South Shetlands Archipelago.

Circulation is the most interesting element of water dynamics; it is shown on the map of dynamic topography (Fig. 6). The flux of water of the Bellingshausen Sea origin inflowing into the Bransfield Strait from the east can be seen from diagrams of profiles V, VI, VII and VIII (Fig. 7). The maximum heights of diagrams show the highest flow intensity. In the region of Deception and Tower Islands there was observed quasi-front between inflowing waters from the Bellingshausen Sea and waters of the Weddell Sea origin already present there. That quasi-front showed the reversible meander, being, most probably, forced by bottom topography in that region. The next quasi-front was noticed in the Bransfield Strait and it can be seen in condensed distribution of the depth of occurrence of isopycne ($\sigma_\theta = 27.5$) and isotherm (−0.8°C; Figs 3,5). Between the last quasi-front and the South Shetlands Archipelago the main flux of eastwards flowing waters was detected; it occurred in the layer from 0 to 500 dbar. The counter-current with low flow values was pronounced at the surface of the Antarctic Sound and occurred as a subsurface one, between 200 and 500 dbar, in the central part of section X (Fig. 7).

In the eastwards water flow in the Bransfield Strait, a permanent transformation of hydrological parameters of water masses originating from two seas, takes place. Much faster transformation concerns the temperature and much slower — salinity. The surface distribution of isohalines 34,0 and 34.1×10^{-3} (Fig. 4) showed that waters in the Bransfield Strait had not only eastward flow but they also penetrated the northern shelf, getting in there between the islands of the South Shetlands Archipelago. According to Clowes (1934), surface waters of the Bellingshausen Sea do not have such high salinity values.

The main flux of waters, after leaving the Bransfield Strait, was detected south from 62°S occurring in the 30 km wide zone. As can be seen from Fig. 6, it next changed its direction towards the south-east. This fact and the cyclonic deflection of isolines of dynamic topography observed between Elephant and South Orkney Islands, plus additionally the occurrences taking place within the Bransfield Strait — suggest the exceptionally low activity of waters of the Weddell Sea origin during the performed investigation. The confirmation of this statement was found from a comparison of the results from BIOMASS — SIBEX with the previous ones obtained during BIOMASS — FIBEX (Stein and Rakusa-Suszczewski 1983). The bigger activity of waters of the Weddell Sea origin occurring in the Bransfield Strait in 1981 was accompanied by a distinct counter-current. The limit of Weddell — Scotia Confluence towards the east of Elephant Island reached 58°S and in the region 61—62°S — an anticyclonic whirl was than observed.

In the entire region of investigations, the low values of deformation of Rossby radius were found (Table 1); they resulted from the small differences of density in the water column. The differences are of order of magnitude 10^{-1} kgm^{-3} while in other regions of the world ocean their order of magnitude is 100 kgm^{-3}. This fact suggests that the vertical and horizontal movements of water masses are interrelated and thus make one system in the investigated layer of 0—500 dbar. This process is most intensive at the border of interaction of water originating from the Weddell Sea with surrounding waters, especially in the Bransfield Strait.

Waters of the Belligshausen Sea had their flow in the Drake Passage towards north-east, however several dynamic phenomena accompanied that flow. In the northern part of profile IV, an anticyclonic whirl with small radius of 42 km causing downward movement of waters, was observed.

At section III, in the vicinity of Livingston Island, a subsurface counter-current was noted (Fig. 7). Too big distances between stations did not allow to describe in details and classify univocally this phenomenon.

Northwards from King George Island, the flux with the geostrophic velocity in an anticyclonic whirl of about 0.09 ms^{-1}, was detected. Most probably, it was the border of Continental Waters, separating, in that region, the Coastal Zone from Antarctic Zone.

At section I, northwards from Clarence Island, the increased flow of water was recorded and this fact should be related to the presence of northern limit of the Weddell-Scotia Confluence (Fig. 7). The fact of the existence of WSC limit in that region can be supported by denser distribution of density ($\sigma_\theta = 27.5$) isobaths. Additionally, the analyses of θ — S diagrams and surface gradient of silicates content, which is not presented in this paper, are evidence of the WSC presence.

In the entire investigated region of the Bransfield Strait and the Drake Passage there were low geostrophic velocities — they were on the average of 0.22 ms^{-1} and 0.66 ms^{-1}, respectively. These numbers allow to make further calculations. Waters flowing along the South Shetland Islands from

Deception Island to the eastern coast of King George Island, would need 9,5 days to pass this distance in the main flux. The same distance, in the Drake Passage, would be covered within 35 days.

The used method of nonlinear coefficients such as: Rossby number, eddy number — allowed to regionalize the dynamic phenomena but could not be fully used for their classification. The assumptions such as: reference plane, estimation of whirl radius and value of vertical disturbance of density stratification seem to be correct; this is supported by the results presented in Table 1.

5. Резюме

Предметом работы является анализ циркуляции вод в проливе Брансфилд и окружающих его акваториях, а также проба выяснения генезиса этих явлений на основании результатов океанографических исследований, проведенных на борту НИС „Профессор Седлецки" во время экспедиции BIOMASS-SIBEX.

С целью изображения явлений перемещения вод подсчитано динамическую высоту 500 dbar, после этого была выполнена карта геострофических течений на поверхности, а также расходы течений на выделенных профилях. При определении масштаба динамических явлений использовался анализ значения числа Россби и числа вращения, а также радиуса деформации Россби. Использование этого метода для конкретной гидрологической ситуации разрешило районизировать динамические явления, но не позволило на их полную классификацию.

Сравнение полученных результатов с динамической ситуацией во время экспедиции BIOMASS-FIBEX приводит к выводу, что в сезоне 1983/1984 г. активность вод моря Уэдделла была значительно меньшей.

6. Streszczenie

Przedmiotem pracy jest analiza zjawisk mezoskalowych w cyrkulacji wód Cieśniny Bransfielda oraz otaczających ją akwenów, a także próba wyjaśnienia ich genez na podstawie wyników badań oceanograficznych wykonanych na R/v "Profesor Siedlecki" podczas ekspedycji BIOMASS — SIBEX.

W celu zobrazowania zjawisk przemieszczania się wód obliczono wysokości dynamiczne względem poziomu odniesienia 500 dbar, a następnie sporządzono mapę prądów geostroficznych na powierzchni oraz wydatków przepływów na wydzielonych profilach. Przy określaniu skali zjawisk dynamicznych posłużono się analizą wartości liczby Rossby'ego i liczby wirowej oraz promienia deformacji Rossby'ego. Zastosowanie tej metody do danej sytuacji hydrologicznej pozwoliło na rejonizację zjawisk dynamicznych, natomiast nie w pełni na ich klasyfikację.

Porównanie uzyskanych wyników z sytuacją dynamiczną w okresie ekspedycji BIOMASS — FIBEX prowadzi do wniosku, że na przełomie 1983/84 roku aktywność wód Morza Weddella była znacznie mniejsza.

7. References

1. Atlas Antarktiki, 1969 — Geometeorologičeskoie izdatelstvo, 403—448.
2. Clowes A. I. 1934 — Hydrology of the Bransfield Strait — Discovery Rep., 9; 1—64.
3. First Post FIBEX Hydrographic Data Interpretation Workshop — Hamburg 20—26, September 1983 — Pol. Polar Res., 4 (1983): 155—162.
4. Gordon A. L., Georgi D. T., Taylor H. W. 1977 — Antarctic Polar Front Zone in the Western Scotia Sea — Summer 1975 — J. Phys. Oceanogr., 7: 309—328.
5. Gordon A. L., Nowlin W. D. 1978 — The Basin Waters of the Bransfield Strait — J. Phys. Oceanogr., 8: 258—264.
6. Nof D. 1983 — The Transport of isolated cold Eddies on a Sloping Bottom — Deep-Sea Res., 2A: 171—182.
7. Nowlin W. D., Whitworth T., Pillsbury R. D. 1977 — Structure and Transport of the Antarctic Circumpolar Current at Drake Passage from short-term measurements — J. Phys. Oceangr., 7: 788—802.
8. Nowlin W. D., Clifford M. 1982 — The kinematic and thermohaline zonation of the Antarctic Circumpolar Current at Drake Passage — J. Mar. Res., 40: 481—507 (suppl.).
9. Patterson S. L., Sievers A. H. 1980 — The Weddel-Scotia Confluence — J. Phys. Oceanogr., 10: 1584—1610.
10. Pedlovsjy J. 1979 — Geophysical Fluid Dynamics — Springer-Verlang New York, 2—21.
11. Sievers H. A., Emery W. J. 1978 — Variability of the Antarctic Polar Frontal Zone in Drake Passage — Summer 1976/77 — J. Geophys. Res., 83: 3010—3022.
12. Stavn R. H. 1971 — The horizontal-vertical distribution hypothesis: Langmuir circulation and *Daphnia* distribution — Limnol. Oceanogr., 16: 453—466.
13. Stein M., Rakusa-Suszczewski S. 1983 — Geostrophic Current in the South Shetland Islands during FIBEX — Mem. of National Inst. of Polar Res., 27: 24—34.
14. Wilkinson D. L. 1972 — An Apparent similarity among Ocean Eddies — Deep-Sea Res., 19: 895—898.
15. Witek Z., Kalinowski J., Grelowski A., Wolnomiejscki N. 1981 — Studies of aggregations of krill (*Euphausia superba*) — Meeresforsh. 28(4): 228—243.
16. Wyrtki K., Magaard L., Hager J. 1976 — Eddy Energy in the Oceans — J. Geophys. Res., 81, 15: 2641—2646.
17. Zubov N. N., Mamaev O. J. 1956 — Dinamičeskij metod vyčislenija elementov morskich tečenij — Leningrad pp.

Paper received: 23 January 1986.