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JETS AND TRANSPORT OF THE ANTARCTIC CIRCUMPOLAR CURRENT IN THE DRAKE PASSAGE

In December 2003, a hydrographic section across the Drake Passage was carried out by R/V Akademik Sergei Vavilov from King George Island to Tierra del Fuego with a Seabird 911 and lowered Doppler current (ADCP) profilers. A total of 25 stations were occupied across the passage from the surface to the bottom. The geostrophic water transport by the Antarctic Circumpolar Current (ACC) above the bottom reference level is estimated at 111 Sv (1 Sv = 10^6 m^3/s), while the transport above the 3000 dbar reference level is equal to 97 Sv. These values are close to the smallest ones in the record of measurements of water transport through the Drake Passage since 1975. The geostrophic velocities are compared with the LADCP and shipborne ADCP measurements.

Key words: Antarctic Circumpolar Current, Drake Passage, CTD-measurements, measurements of currents, water transport.

The studies of water transport, heat, and salt by the Antarctic Circumpolar Current and their variations are important for the understanding of the oceanic circulation and its influence on the Earth’s climate. The Drake Passage is probably the best place to study the properties of Antarctic Circumpolar Current (ACC) in the sense that here, the current is limited from the north and south by the coasts. The model calculations carried out with virtual «closing» of the Drake Passage [1, 2] demonstrate that cold water transport through the Drake Passage decreases water temperature in the South and Central Atlantic by a few degrees. Fluctuations in this transport influence the thermal regime of the ocean. Another important study in the Drake Passage is related to the variability in the locations and parameters of water masses and oceanic fronts that divide them, as well as generation of eddies at the fronts with the estimates of eddy contribution to the meridional transport of salt and heat in the ACC zone.

The estimates of water and heat transport from the Pacific Ocean to the Atlantic require the data on the CTD-casts and variability of hydrological water structure in the passage. These data are needed for correct modeling of short-period climatic variability of the ocean. Investigation of water, heat, and salt transport by the ACC and studies on the variability of these values are needed to understand the physical nature of oceanic circulation and its influence on the climate variability of the Earth. The ACC connects the circulation systems of waters of the Atlantic, Indian, and Pacific oceans. The ACC in the Drake Passage is bounded by the coasts of South America and Antarctica, which makes it possible to make more precise estimates of water transported by the current.

Experiment. In December 2003, a hydrographic section across the Drake Passage was carried out by R/V Akademik Sergei Vavilov from King George Island to Tierra del Fuego with a Seabird 911 and lowered Doppler current (ADCP) profilers. The measurements were accompanied by current measurements by shipborne ADCP with records to a depth of approximately 400 m. A total of 25 stations were occupied across the passage from the surface to the bottom (Fig. 1).

Analysis and comparison with the previous studies. During the period from 1975 to 1980, sections across the Drake Passage were made in a direction from Cape Horn to Livingston Island. In recent years (especially after 1983), sections across the ACC in this region have been made by UK ships in a direction from the Antarctic Peninsula to the Falkland Islands (Burdwood Bank). Thus, the analysis of water transport by currents through the Drake Passage and their variability has been carried out by different authors primarily on the basis of data from sections located to the east of our section in 2003.

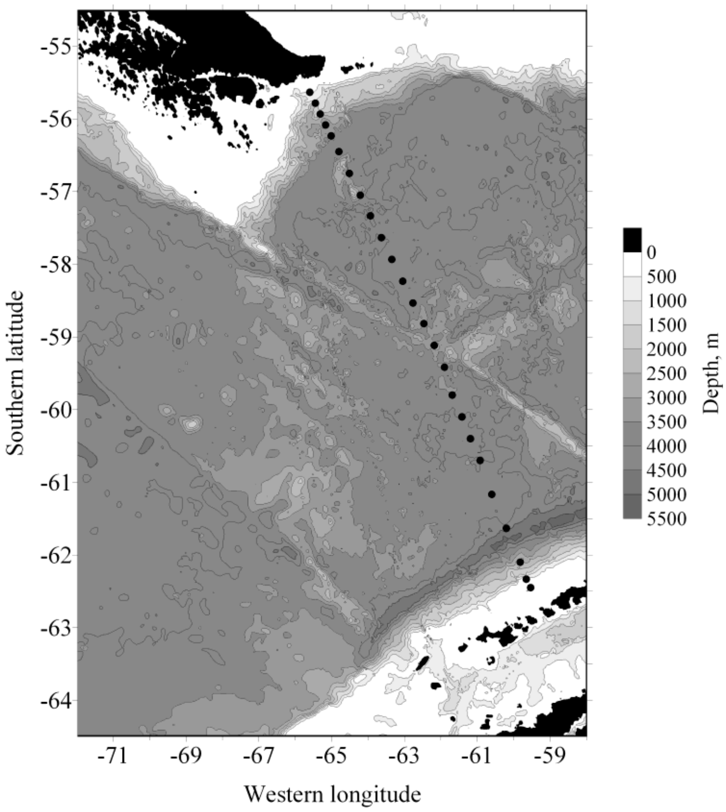

Fig. 1. Bottom topography of the Drake Passage and locations of CTD-stations in 2003.

For comparing our measurements with the previous sections across Drake Passage, we used the data of 17 CTD sections as well as data from the literature. The available data are presented in the table 1. Code of the section SR1a is related to the direction to Tierra del Fuego and SR1b is related to the direction to the Falkland Islands.

The flow through the Drake Passage is limited from below by depths of 3000—3500 m, which correspond to the crest of the Shackleton Ridge. Currents shallower than 400 m can pass round the continental part of South America and flow between the continent and the Falkland Islands. A southerly return flow is also possible here. A section in the direction of Tierra del Fuego from coast to coast would make it possible to estimate the precise value of ACC transport without losses; however, information about such sections is not available. The transport through the Drake Passage in the direction of the Falkland Islands was calculated by different authors. Garcia et al. [3] estimated the ACC transport from the bottom as 131—144 Sv in 1995, 1996, and 1998. Meredith et al. [4] estimated the variability of the transport within 5.3—8.9 Sv on the basis of bottom pressure measurements in 1990—1993. Whitworth and Peterson [5] estimated the transport from the bottom as 134 ± 11 Sv. A close value is given by Petersen and Stramma [6]. The authors of [7] reviewed the measurements and presented data on the ACC transport from the bottom (minimal common depth, MCD) and the 3000 dbar level. These data indicate that the transport by geostrophic currents relative to the 3000 dbar reference level is equal to 107.3 ± 10.4 Sv, while the total transport relative to the bottom is 136.7 ± 7.8 Sv. The mean transport from the 3000 dbar reference level across the section directed to Cape Horn in 1975–1980 is 102.7 ± 12.6 Sv (the minimum transport is 75 Sv), while the mean transport across the section directed to the Falkland Islands in 1993—2000 is equal to 111.9 ± 5.2 Sv. The authors of [7] considered that the estimate of ACC transport based on 14 sections carried out over 25 years demonstrates the relative stability of the transport. Whitworth [8] showed on the basis of long-term moored measurements that the transport changes from 70 to 100 Sv. Cunningham et al. [7] used the statistical Student criterion (*T*-distribution) and concluded that the transports during 1975—1980 and 1990—2000 are the same in terms of mean values with

95 % confidence limits. Hence, mean values with account for the root-mean-square deviations significantly overlap. However, the transport was in the range of 75 ± 111 Sv in 1975—1980 and 105—118 Sv in 1993—2000. Statistical estimates were made on the basis of only 7—8 measurements, and the transport in 1997 (75 Sv) is assumed to have been underestimated.

Table 1

Data of ACC transport measurements across Drake Passage

Dates of the section	Code of the section	Geostrophic transport relative to the 3000 dbar reference level, Sv.	
		Literature data from [1]	Our calculations based on the same data
Feb 27 – Mar 7, 1975	SR1a	111	
Mar 16–22, 1975	SR1a	106	
Feb 26 – Mar 3, 1976	SR1a	110	
Jan 19–24, 1977	SR1a	75	
Jan 20–27, 1979	SR1a	110	
Apr 15–20, 1979	SR1a	102	
Jan 8 – Feb 13, 1980	SR1a	105	
Jan 23–29, 1990	SR1a	107	106
Nov 21–26, 1993	SR1b	110	108
Nov 15–21, 1994	SR1b	115	114
Nov 19–22, 1994	SR1a		106
Dec 5–8, 1995	SR1a		103
Nov 15–20, 1996	SR1b	105	103
Dec 29, 1997 – Jan 7, 1998	SR1b	118	
Feb 11–16, 2000	SR1b	118	
Nov 23–28, 2000	SR1b	110	
Dec 11–15, 2003	SR1a		97

However, this estimate increases the root-mean-square deviation for the whole group of measurements. We think that the transports in the period from 1975 to 1980 made in the western part of the passage are lower than the transports measured in 1990—2000 in the eastern part of the passage. However, the causes of this difference are not clear.

The geostrophic transport of currents was calculated using the same method from the available data of sections in the western part of Drake Passage and the data of sections directed to the Falkland Islands. The values given in [7] appeared similar to our calculations. Therefore, we can reliably compare the estimates of the water transport. In addition to the data given in [3, 4, 6—8], we calculated the transport in 1994 and 1995 on the basis of Chilean WOCE data, which are not presented in [7]. A comparison of the UK and Chilean sections made simultaneously on November 15—21 and November 19—22, 1994 and the calculation made using the same method indicate that the transport across the western section (directed to Cape Horn) is equal to 106 Sv, while the transport across the eastern section (directed to the Falkland Islands) is 114 Sv. Thus, analysis of the literature data and calculations of the ACC geostrophic transports indicate that the ACC transport across the section directed to the Falkland Islands is always greater by a few Sverdrups than the transport across the western sections.

Water transport between the continent and the Falkland Islands is poorly studied. Part of the current flows around Tierra del Fuego and turns to the north. Subsequently, the flow may propagate along the meander, partly turn back, and merge with the main ACC branch passing south of the Falkland Islands. Another hypothesis suggests the presence of an anticyclonic (counterclockwise) circulation around the Falkland Islands. This flow can additionally contribute to the transport across the section in a direction from Antarctica to the Falkland Islands.

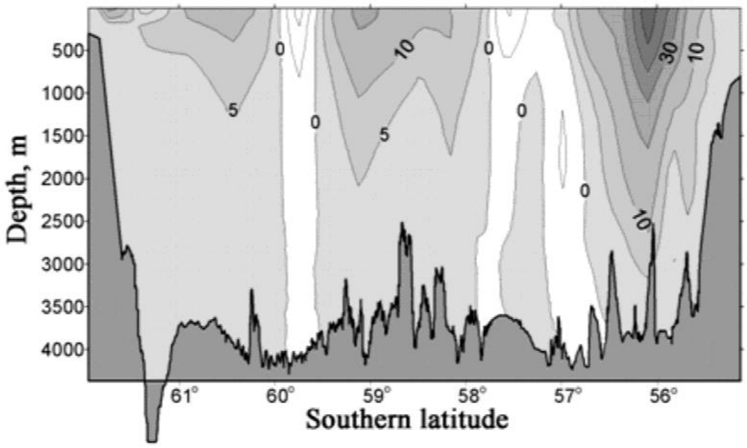

Fig. 2. Section of geostrophic velocities to the bottom. Easterly currents are shown in gray. Contour lines of velocity 0, 5, 10, 20, 30, 40, and 50 cm/s are shown.

Indications of the existence of such circulation and another flow of a scale of a few Sverdrups around the Falkland Islands are given in [9], with numerical calculations made on the basis of one-degree squares. This fact confirms the known scheme for the ACC jet that flows around the continental slope of Tierra del Fuego from the south, adjusting to the bottom topography [10].

A section of geostrophic velocities through the Drake Passage based on our measurements to the bottom in December 2003 is shown in Fig. 2.

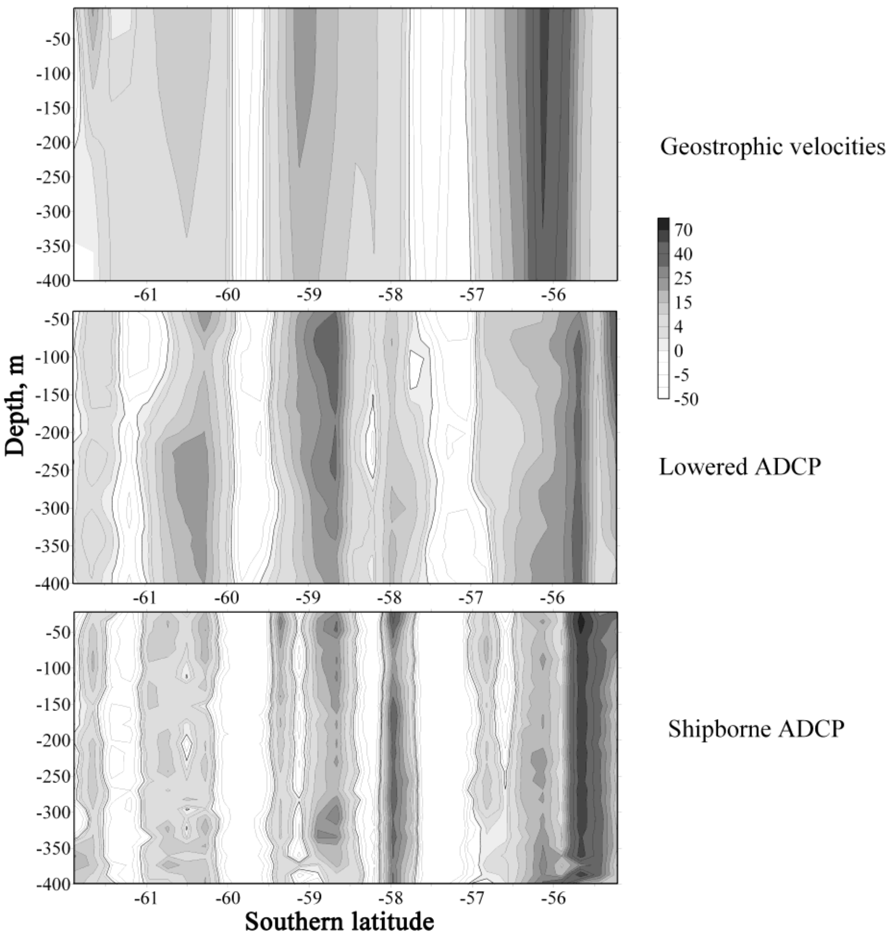

Fig. 3. Sections of geostrophic velocity to a depth of 400 relative to the bottom surface of zero velocity; velocities measured by LADCP; and velocities measured by shipborne ADCP.

The bottom topography is based on the ETOPO2 data. The maximum velocity at the surface is almost 60 cm/s and the velocity in the layer down to 400 m exceeds 50 cm/s. In December 2003, our estimates of the geostrophic transport through Drake Passage were equal to

111 Sv (above the bottom), while the transport above the 3000 dbar reference level was equal to 97 Sv. These values are close to the lower limit of the long-term observations. Westerly transport due to meandering in individual parts of the section is equal to 7.9 Sv. The total transport in the Drake Passage estimated from the LADCP measurements is equal to 156 Sv. The low transport in 2003 can be explained by synoptic processes [8] when strong eddies partly prevent propagation of ACC through the passage.

Conclusion. The CTD and LADCP sections made in 2003 (Fig. 3) demonstrate the presence of at least three clearly pronounced easterly directed jets of ACC in the Drake Passage.

The CTD section consisting of 25 stations (25—30 miles between the stations) cannot resolve more jets of ACC. The shipborne continuous record of currents in the upper 400 m provides a better resolution. This allows one to distinguish more ACC jets. The more recent measurements in the Drake Passage with a resolution of 10 miles between the stations resolve up to 8 jets of the current [11].

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СТРУИ АНТАРКТИЧЕСКОГО ЦИРКУМПОЛЯРНОГО ТЕЧЕНИЯ В ПРОЛИВЕ ДРЕЙКА И ПЕРЕНОС ВОД

В декабре 2003 г. с борта НИС «Академик Сергей Вавилов» был выполнен гидрологический разрез через пролив Дрейка от острова Кинг Джордж до Огненной Земли с помощью CTD-профилографа SBE 911 и погружаемого доплеровского измерителя течений (LADCP). Всего было выполнено 25 станций с измерениями от поверхности до дна. Геострофический перенос вод Антарктическим циркумполярным течением от поверхности до дна составил 111 Св (1 Св = 10^6 $м^3/с$). Перенос до отсчетной поверхности 3000 дбар составил 97 Св. Эти величины близки к наименьшим значениям переноса через пролив Дрейка по данным с 1975 г. Произведено сопоставление геострофический скоростей течений со скоростями по измерениям LADCP и судового ADCP.

Ключевые слова: Антарктическое циркумполярное течение, пролив Дрейка, CTD-измерения, измерения течений, перенос вод.