Ocean Sci. Discuss., 10, 539–553, 2013
www.ocean-sci-discuss.net/10/539/2013/
doi:10.5194/osd-10-539-2013

Ocean Science
Discussions
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Transport of AABW through the Kane Gap, tropical NE Atlantic

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Received: 18 January 2013 – Accepted: 18 February 2013 – Published: 11 March 2013

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

We study low-frequency flow of Antarctic Bottom Water through the Kane Gap (9° N) in the Atlantic. The measurements in the Kane Gap include five visits with CTD sections in 2009–2012 and a year-long record of currents using three AquaDopp current-meters. We found an alternating regime of flow, which changes direction several times during a year. The velocities reach $0.21\,\mathrm{m\,s^{-1}}$. The transport of Antarctic Bottom Water ($<1.9\,^{\circ}\mathrm{C}$) based on the mooring and LADCP data varies by ±0.3 Sv.

1 Introduction

In the Atlantic Ocean, Antarctic Bottom Water (AABW) is formed mainly in the Weddell Sea near the Antarctic slope as a result of cascading and mixing of cold and dense Antarctic Shelf Water through the layer of warmer and more saline Circumpolar Deep Water. The pathways of AABW northward propagation between the basins of the Atlantic are confined to the depressions in the bottom topography. Antarctic Bottom Water propagates from the Weddell Sea to the Scotia Sea through several passages in the South Orkney Ridge and then this water penetrates to the Argentine Basin while merging with the AABW transported from the Weddell Sea through the South Sandwich Trench. The waters are later transported to the Brazil Basin along three pathways: the Vema Channel, the Hunter Channel, and over the Santos Plateau. Figure 1 shows a scheme of AABW propagation in the bottom layer (Morozov et al., 2010a).

After propagating to the north of the Brazil Basin, part of Antarctic waters is transported to the East Atlantic through the Romanche and Chain fracture zones. Another part flows to the Equatorial Channel and Guyana Basin and later splits propagating to the east through the Vema Fracture Zone and to the northwest to the North American Basin (Morozov et al., 2010a).

Transform fracture zones Vema, Romanche, and Chain are the main pathways for bottom water propagation to the eastern Atlantic basin. Before the bottom water enters the Romanche and Vema fracture zones the potential temperatures are $\Theta = 0.51\,^{\circ}\mathrm{C}$ and $\Theta = 1.33\,^{\circ}\mathrm{C}$, respectively (Mantyla and Reid, 1983). The lowest potential temperatures after the exit from the fracture zones are $\Theta = 1.66\,^{\circ}\mathrm{C}$ (Romanche) and $\Theta = 1.69\,^{\circ}\mathrm{C}$ (Vema) (Mantyla and Reid, 1983). The values are very close owing to stronger mixing in the Romanche FZ.

Measurements of velocities using current meters in the Romanche and Chain fracture zones revealed comparable easterly transports of Antarctic waters equal to 0.66 and 0.56 Sv, respectively (Mercier and Speer, 1998). These results are close to independent estimates of bottom water transport through the Romanche Fracture Zone 0.5 Sv obtained using LADCP current measurements in 2005 (Morozov et al., 2010a). In addition, the results of measurements in 2006 (Morozov et al., 2010a) recorded the transports of 0.4 Sv over the main sill of the Vema Fracture Zone (11° N). All values were calculated for the transport below the 1.9 °C isotherm. The authors of (Mantyla and Reid, 1983) conclude that the waters that propagate through the Romanche Fracture Zone influence only the regions of the Guinea, Sierra Leone, and partly Angola basins, whereas the waters that flow through the Vema Fracture Zone influence the Gambia Abyssal Plain, Canary, and possibly Iberian basins (van Aken, 2000). They actually fill the entire bottom layer in the Northeast Atlantic. A scheme of AABW propagation in the Gambia Abyssal Plain was suggested in (McCartney et al., 1991) and supported in (Morozov et al., 2010a) based on the distribution of potential temperature near the bottom.

Antarctic Bottom water that propagates to the East Atlantic through the Vema Fracture Zone and Romanche and Chain Fracture Zones reaches the Kane Gap near the coast of Guinea. At the same time, the waters from these two sources in the East Atlantic with $\Theta < 1.85\,^{\circ}\mathrm{C}$ cannot propagate through the Kane Gap because they are separated by the sill in the Kane Gap (Fig. 2), whereas isothermal surface $\Theta = 2\,^{\circ}\mathrm{C}$ over the Kane Gap is not separated. Hence, exchange over the sill of the Kane Gap is possible in the AABW layer with temperatures $1.85\,^{\circ}\mathrm{C} < \Theta < 2.0\,^{\circ}\mathrm{C}$.

The degree of the influence of abyssal water flows on the regions north and south of the Kane Gap required additional long-term measurements at the sill of the gap. This was done by a series of CTD casts in 2009–2012 and deployment of a year long mooring with current meters and temperature sensors in the bottom layer. Only the data of measurements in May 2009 were previously published (Morozov et al., 2010a,b). The publications in 2011–2012 are cruise reports only with the information of the activities in the cruises without data analysis. In this paper we focus our attention mostly on the velocities and transports measured using LADCP and moored instruments.

2 Measurements to investigate the bottom flow in the Kane Gap

The values of potential temperature at the bottom in the region of the Kane Gap are shown in Fig. 2. The data of water samples and Conductivity-Temperature-Depth profilers (CTD) from the WOD09 were supplemented with the results of our expeditions in 2009–2012 and (Hobart et al., 1975). Before 2009, no current measurements were made in the Kane Gap. Even the direction of bottom water through this passage was not clear. In 2009, we started the program of measurements of the bottom water flow through the Kane Gap in the region of the sill at 9° 20′ N, 19° 51′ W (approximate depth 4560 m) During this period, we carried out five series of CTD (SBE-19) and Lowered Acoustic Doppler Profiler (LADCP) (RDI WHS 300 kHz) measurements (Fig. 3) In October 2010, we deployed a mooring with three current-meters and a line of temperature sensors (Fig. 3). The mooring was recovered in October 2011. The instruments measured currents at 15 m from the head at the operation frequency 2 MHz. The instruments were fixed at 4352, 4477, and 4562 m. The deepest instrument was 7 m above the bottom. The sampling period was 600 s (10 min). The sections in 2010 and 2011 were occupied immediately before and after the deployment and recovery of the mooring.

All instruments used in the cruises were calibrated before each cruise. The accuracies of SBE-19 sensors are 0.003 °C, 0.0005 S m^{-1}, and 7 m. The accuracy of current measurements is 0.01 m s^{-1} and 5° of direction. The raw CTD and LADCP data were processed using the standard software. Velocity profiles were calculated using the method described in (Visbeck, 2002), version 7b.

Figure 4 shows the distributions of potential temperature and velocity (northwest to southeast direction, positive to the northwest) in the bottom layer measured in October 2012. The bottom topography in Fig. 4 is based on the results of the echo-sounding in 2012. Figure 5 shows graphs of the currents measured by the near-bottom current-meter whose components were projected on the northwest-southeast axis (along the passage), and potential temperature at 7 m above the bottom

In May 2009, during a Russian expedition onboard the R/V "*Akademik Ioffe*", cruise 27 (AI-27) measurements of currents were performed for the first time near the main sill of the Kane Gap (Fig. 3) using a LADCP combined with CTD-profiling (Morozov et al., 2010b,c). The bottom flow in the passage was directed to the southeast from the Gambia Abyssal Plain to the Sierra Leone Basin (velocities were approximately 0.1 m s^{-1}), while the transport was 0.16 Sv ($\Theta < 1.9$ °C) The transport below 1.9 °C isotherm was estimated by interpolating the LADCP velocities onto a grid over the section across the channel using 20-m layers. In May 2009, only one station was occupied. Later, 4–5 stations with vertical velocity profiles were made. We estimate the error of transport calculation in May 2009 at 20 % and in the later cruises at 10–15 % of the given value. The transport in the Kane Gap in May 2009 is three times smaller than the transport of bottom waters through the Vema Fracture Zone the source of bottom waters in the Northeast Atlantic.

The values of potential temperature 1.857 °C recorded in May 2009 at the main sill near the bottom and at the nearest stations occupied in the previous years are very close to each other (Fig. 2). Lower values of potential temperature at the bottom ($\Theta =$ 1.8 °C) recorded at a distance of 200 km to the south were not found at the sill. It is likely that the bottom waters that propagated to the region of the Kane Gap from the north and south through different fractures in the Mid-Atlantic Ridge are subject to strong mixing with the overlying layers due to internal waves and they merge near the Kane Gap.

In October 2009 (cruise AI-29) (Morozov et al., 2010d) we repeated the measurements in the Kane Gap (Fig. 3). A CTD-section was occupied combined with LADCP profiling. The measurements clearly demonstrated a flow directed to the northwest. The velocities did not exceed 0.1 m s^{-1} and the transport below the 1.9 °C isotherm was estimated at 0.11 Sv. Near the bottom, the minimum bottom potential temperature was $\Theta = 1.846$ °C. The jet of the coldest water was displaced to the western slope, which is explained by the Ekman frictional boundary layer (Northern Hemisphere) during the northward water flow.

In October 2010 (cruise AI-32), another CTD-section with LADCP measurements was occupied in the Kane Gap (Fig. 3). The maximum velocities reached 0.13 m s^{-1} and the transport was estimated at 0.19 Sv. The minimum potential temperature was as low as $\Theta = 1.838$ °C. The flow was directed to the northwest similarly to the situation in October 2009. The measurements in October 2011 (Fig. 3) (cruise 32 of R/V "*Akademik Sergey Vavilov*", ASV-32) (Morozov et al., 2012) revealed a flow with almost zero velocities, and in October 2012 (Fig. 3) (cruise ASV-36) we recorded a northwesterly flow with the maximum velocities reaching 0.08 m s^{-1} and a transport of 0.12 Sv

The year-long record of moored current measurements that started in October 2010 revealed that the currents were alternating in speed and direction with sub-inertial frequencies in addition to a strong tidal signal. The graphs of daily average data are shown in Fig. 5. During the first six months of the mooring operation a period of 180 days is clearly seen in the record (Fig, 5). However, the duration of the record did not allow us to resolve such long period and the dominant sub-inertial period is estimated at 90 days based on the spectral analysis (Fig. 6). During the first three months (November-January) the currents were directed to the northwest. Then the direction of the currents turned to the opposite and from February to the beginning of April the currents were directed to the southeast. This periodicity can be related to the seasonal variability of transport in the Romanche Fracture Zone found in (Mercier et al., 1998). In May, the regime of the currents changed to predominant oscillations with a higher (sub-inertial) frequency. We estimate the average period of these fluctuations of shorter period at 44 days (Fig. 6).

The velocity of bottom water transport through the Kane Gap averaged over 350 days is 0.01 m s^{-1}, and it is directed to the southeast. The mean transport is 0.016 Sv. The maximum value of the southeastern velocity is 0.21 m s^{-1}, while the maximum northwestern velocity was as high as 0.16 m s^{-1}. The mean southeastern velocity during the longest period of the permanent flow to the southeast (February–April, 2011) is 0.1 m s^{-1}, and the mean transport is 0.16 Sv. During this period 1250 km^3 of AABW was transported to the south of the Kane Gap. If we assume that the mean depth south of the Kane Gap is 4650 m and the layer of AABW is located below 4300 m we estimate that the region filled with the bottom water transported from the north is limited by a distance of approximately 50 km from the sill of the Kane Gap. This estimate is valid also to the north of the Kane Gap.

As seen from Fig. 5 during the period when the currents were directed to the northwest, the temperature of the transported bottom water was slightly cooler ($\Theta = 1.84\,^{\circ}$C) than during the period of the southeastern direction of the currents ($\Theta = 1.86\,^{\circ}$C). This suggests that the bottom waters from the southern source (Romanche FZ) are cooler than those from the northwestern source (Vema FZ). One can also judge this from Fig. 2. Generally the bottom temperatures in the gap based on the mooring data vary in the range between 1.80–1.92 °C. In October 2012 the minimum temperature recorded by CTD measurements was $\Theta = 1.832\,^{\circ}$C (Fig. 4).

3 Conclusions

We analyzed data of field measurements in the Kane Gap (9° N), a deep passage between the Gambia Abyssal Plain and Sierra Leone Basin in the Atlantic to study low frequency flow of Antarctic Bottom Water through this channel. The measurements in the Kane Gap included five visits in 2009–2012 with CTD sections and a year-long record of bottom currents by three current-meters. We found an alternating regime of flow, which changes direction several times during a year. The velocities reached 0.21 $\mathrm{m\,s^{-1}}$. The transport of Antarctic Bottom Water ($< 1.9\,^{\circ}\mathrm{C}$) varied by ±0.3 Sv based on the LADCP and moored measurements, while the long-term mean is almost zero. The AABW transported through the Kane Gap to the north and south will not propagate over a distance exceeding 50 km.

Acknowledgement. The mooring with current meters was supplied by the Royal Netherlands Institute for Sea Research. It was financially supported in part by the Netherlands Organization for the advancement of scientific research (NWO) in the Russian–Dutch exchange program. The work was supported by the Russian Foundation for Basic Research (grants 09-08-10000-k, 12-05-00277, 11-08-00076), the NWO-RFBR program (project no. 047.017.2006.003).

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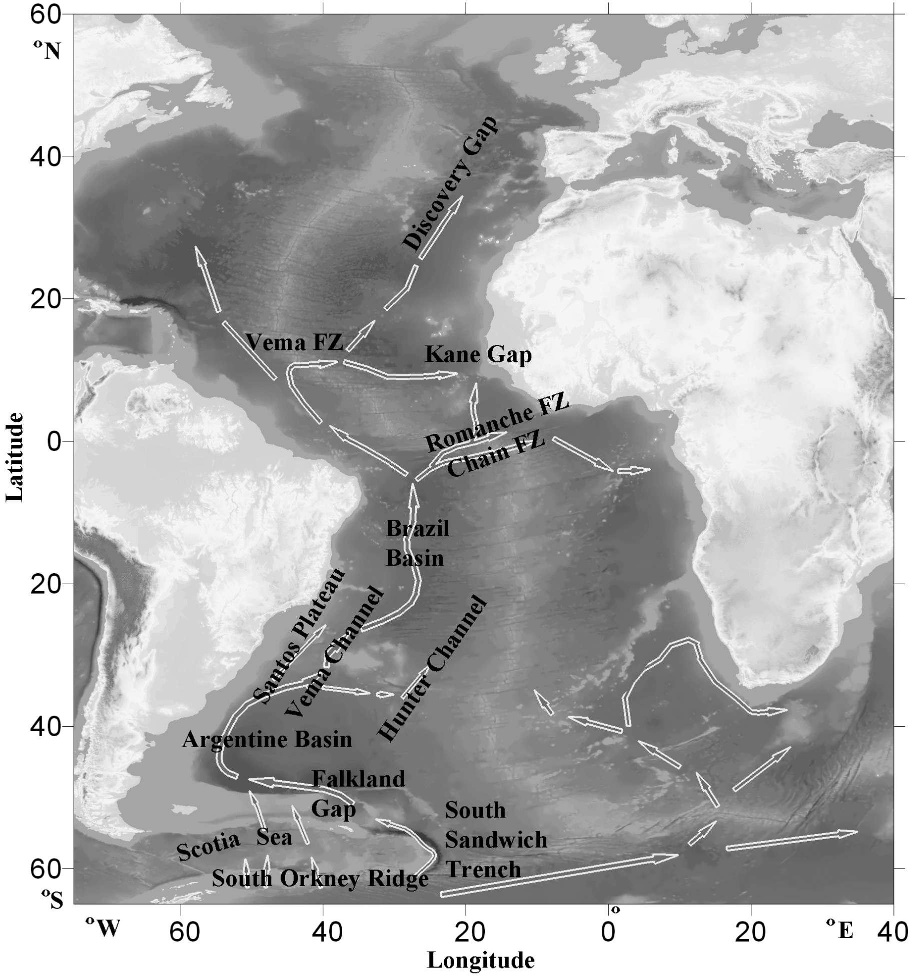

Fig. 1. Scheme of AABW propagation in the Atlantic Ocean.

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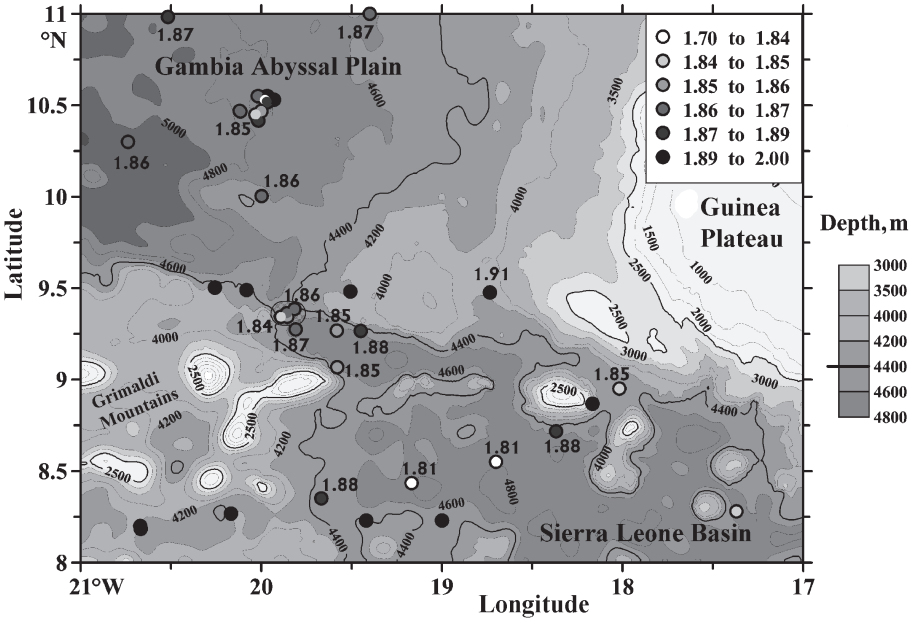

Fig. 2. Bathymetry of the Kane Gap region with observations of near-bottom potential temperature (in °C). Historical stations are shown with dots of different color depending on the temperature (see notations in the inset; our study region is shown with an oval).

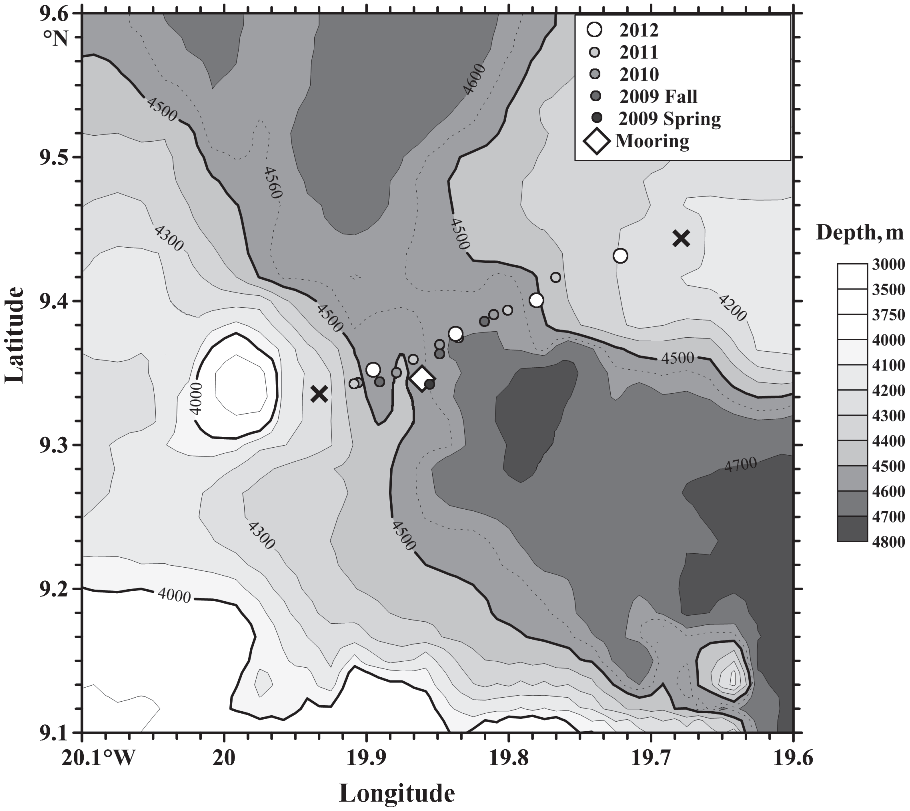

Fig. 3. Bottom topography in the Kane Gap region based on (Smith, Sandwell, 1997) and echo-sounding measurements during cruises. Locations of CTD and LADCP stations in 2009–2012 and the mooring are shown. The crosses indicate the beginning and end of the bathymetry section in 2012.

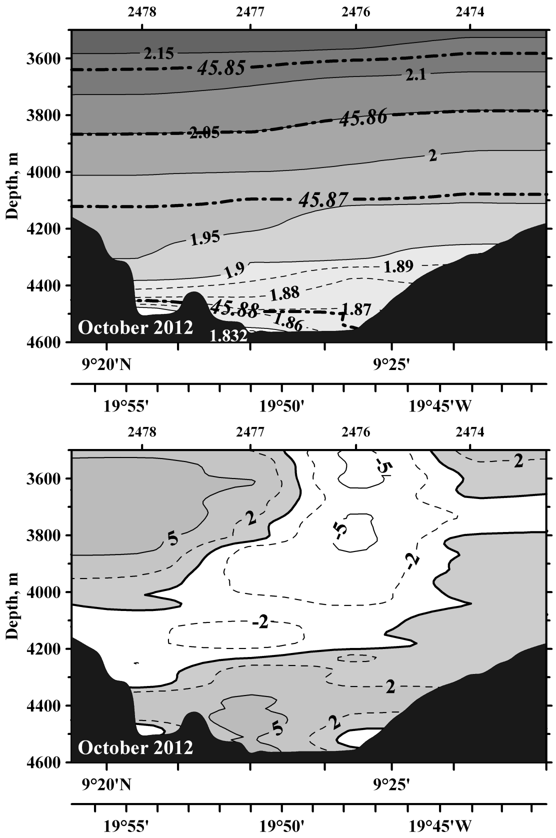

Fig. 4. Sections of potential temperature (°C), and potential density σ_4 (above) and velocity (northwest to southeast direction, positive to the northwest) (cm s^{-1}) (below) across the Kane Gap in 2012. Contour lines of potential density are shown with thick dash-and-dot lines. Numbers of stations are shown above and coordinates are below.

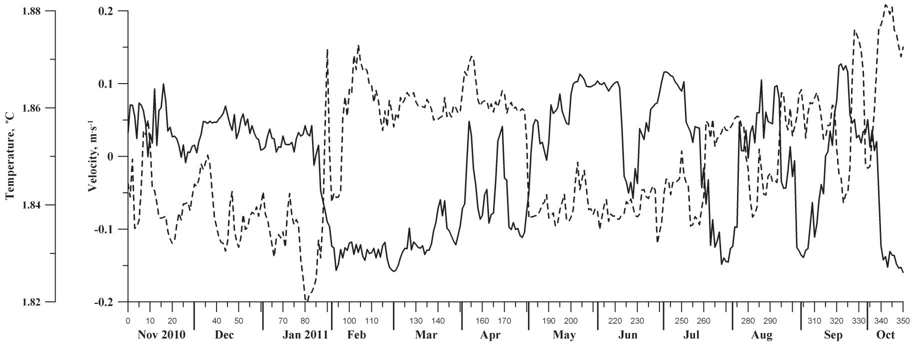

Fig. 5. Graph of the current component along the main axis of the Kane Gap (northwest to southeast direction, positive to the northwest) (solid line) and temperature (dashed line) measured at the lowest current meter (7 m above the bottom). The bottom axis shows the sequential days and months of measurements.

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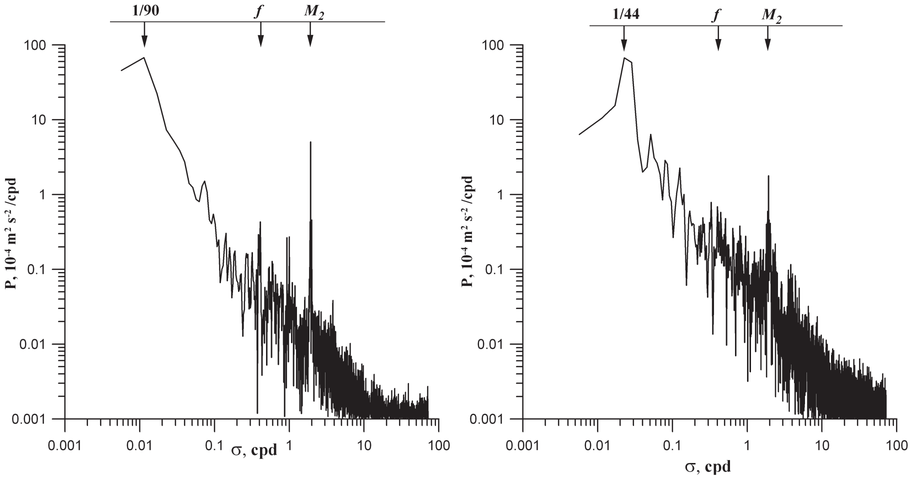

Fig. 6. Nearly raw spectra of kinetic energy from currents at 7 m above the bottom for the periods between November 2010 and May 2011 (left) and between May and October 2011 (right).