Oceanographic conditions over the Kashevarov Bank

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The abnormal distribution of the oceanographic parameters over the Kashevarov Bank has attracted the attention of many researchers. In warm seasons, the surface waters here keep lower temperature and higher salinity, than those of the surrounding environment. On the contrary, in the subsurface layer, the destruction of the northern Okhotsk "cold core" is observed. All year round, the deep waters over the bank remain unusually homogeneous in temperature, salinity, concentration of dissolved oxygen, and nutrients. Even in the winter, thin ice areas (*polynyas)* are often found in the vicinity of the Kashevarov Bank.

There exist several assumptions today about the mechanism that forms specific hydrological and hydrochemical characteristics of this area. Moroshkin (1966), and Kitani and Shimazaki (1971) noted the abnormal conditions of the water parameters in this region. Akiba et al. (1959) and Kitani (1973) mentioned vertical water mixing as the reason, but did not specify its specific force. Chernyavsky (1970), Veselova (1972), Kovshov and Sinyurin (1982), (Markina and Chernyavsky (1984), and Zhigalov and Matveev (1992), explained the situation by cyclonic water circulation alone, in conjunction with up-welling. Alfultis and Martin (1987), speculated on a dominating role of up-welling over the bank. Some authors, Zhabin and Zuenko (1993), and Kuzmina and Sklyarov (1984), considered tidal mixing and up-welling to be the contributing mechanism.

A theoretical model has been worked out by Karpushin et al. (1996), assuming that the abnormal distribution may be formed by the influence of the anti-cyclonic eddy (a Taylor–Hogg column), with a very small radius and a large cyclonic eddy. Such a circulation may cause intensive up-welling. Rogachev and Kosolapkin (1995) considered that homogeneous structures are formed as a result of summary influence of tidal and non-periodic currents. These authors confirm that mixing together the surface, dichothermal and mesothermal water masses is accompanied by an increase of water density and by the decline in sea level, as well as by causing the cyclonic circulation.

All the explanations listed above are hypothetical, as it is difficult to differentiate one forcing component from another due to lack of oceanographic data to confirm the assumptions. The largest problem, apparently, is the absence of direct current measurement records, which does not allow researchers to examine the real water circulation and mixing intensity in this area of the sea.

The goal of this work is to analyze all accessible data and to assess the mechanisms that form abnormal conditions over the Kashevarov Bank.

The Kashevarov Bank at the 200 m isobath is located between parallels 55°15′ and 55°57′ N., and meridians 144°45′ and 146°42′ E (Fig. 1). Two tops of the bank are at minimal depths of about 110 and 130 m. The area surrounding the bank has a varied relief. Besides the bank, there are two canyons here. One canyon, with the depths varying from 1300 to 300 m, lies between Kashevarov Bank and Saint Iona Island. The second canyon is located to the east of the bank and its depths vary from 500 to 300 m.

For the analysis, we used all oceanographic stations that lie within parallels 55°00′ and 56°30′ N and meridians 144°00′ and 147°30′ E. In this area, 315 deep-water stations have been occupied since 1937. As a rule, during an expedition 5 to 10 stations were occupied at a distance of 20–30 miles. The section probes that crossed the Kashevarov Bank and its immediate surroundings were purposely carried out only in recent years (1994, 1995 and 1996, Fig. 1). Half of all observations were performed last August (about 90 stations) and September (about 60 stations). During the cold season (from December through April) only individual observations took place there.

In early spring, water temperature around the Kashevarov Bank, taken in the layer of winter convection, is below zero and never exceeds –1.0° to 1.55°C (section A-A, Fig. 2). The salinity varies from 32.9 to 33.2 psu. Below the layer of winter cooling, the water temperature goes up to +1.5°C and the salinity reaches 33.5 to 33.6 psu. Above the top of the Kashevarov Bank, there was noted the homogeneous distribution of hydrological and hydrochemical characteristics was noted. This can be seen in the vertical direction on the lines. Colder temperature water spreads on the slope off the bank, rather than in surrounding waters. At the stations off the bank, the dissolved oxygen concentration at the top of the 50-m layer was 8.5 to 9.2 ml/l, and in shallow waters over the bank it dropped to 7.2 ml/l.

Figure 3 presents a synthetic chart made as a result of 7 expeditions carried out during May from 1983 through to 1996, in which there areas with cyclonic and anti-cyclonic types of water circulation have been observed. Studies have proved that an extensive cyclonic circulation over the Bank and to the north from the 500 m isobath usually predominates in cold periods. Over the deep-water sites of the Deryugin Basin two zones were marked by predominately anticyclonic water circulation. At times, the anticyclonic circulation was observed west of the Kashevarov Bank, over the canyon. This may be caused by the spreading of warm water from the Deryugin Basin.

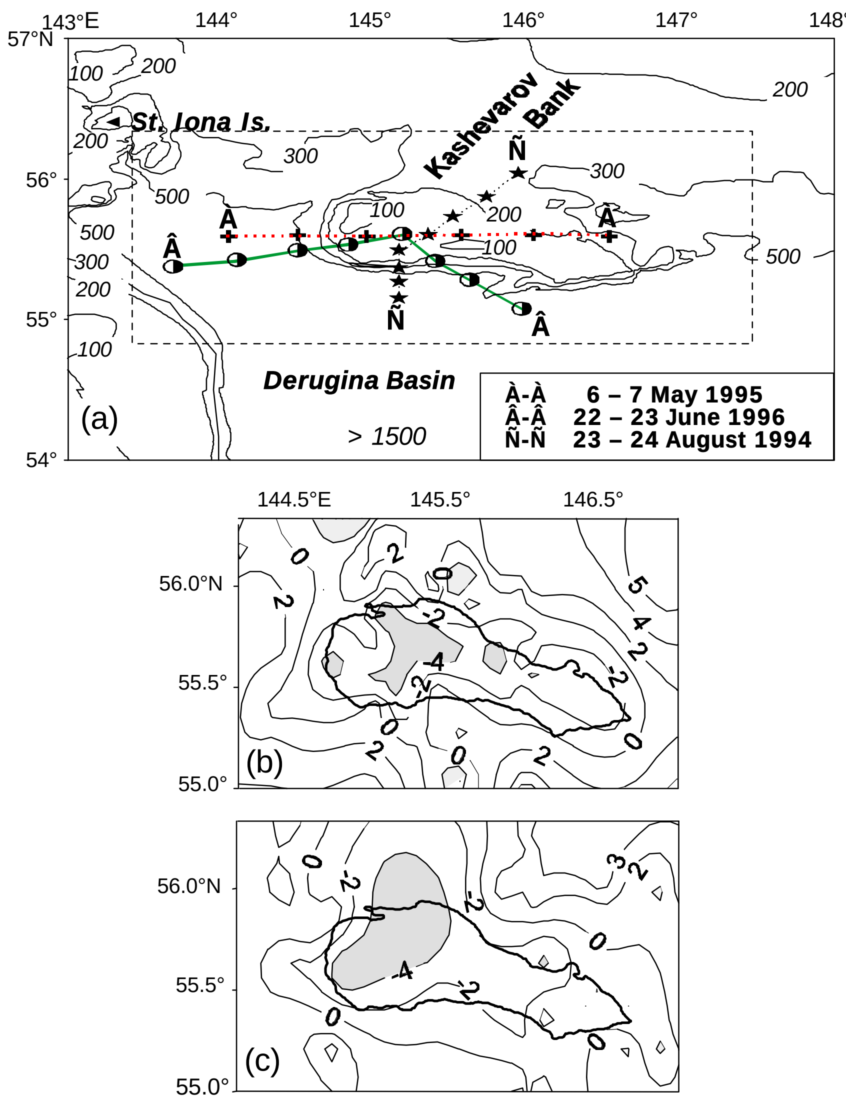

Fig. 1 (a) Bathymetric chart (m) of the Kashevarov Bank area and location of the sections. Averaged spatial surface temperature anomaly (°C) in (b) August and in (c) September.

In late spring, around the Kashevarov Bank (see: section B-B, Fig. 2) an intensive freshening influence was observed (water salinity decreased to 27.0–32.0 psu), caused by both ice melting and mainly by the Amur River outflow. The thin upper fresh layer quickly warmed to 7°–10° C, and the temperature was maintained by a bottom strong vertical density gradient. The lowest salinity and highest water temperature were marked southwest of the Kashevarov Bank. The dissolved oxygen concentrations in these waters did not exceed 8.3 ml/l. Dichothermal waters maintained negative temperatures of about –0.3° to –0.7°C. In late spring, over the Kashevarov Bank, the surface water temperature was about 1.0° to 1.6°C, and temperature over the top of the bank reached –0.5° -0.8°C. Thus, the basic part of incoming solar heat was redistributed in the water column from the surface through to the bottom. The surface water salinity was nearly same as near the bottom of the Bank (33.16 to 33.2 psu). The range of oxygen concentration between the surface and bottom layers did not exceed 0.1 ml/l.

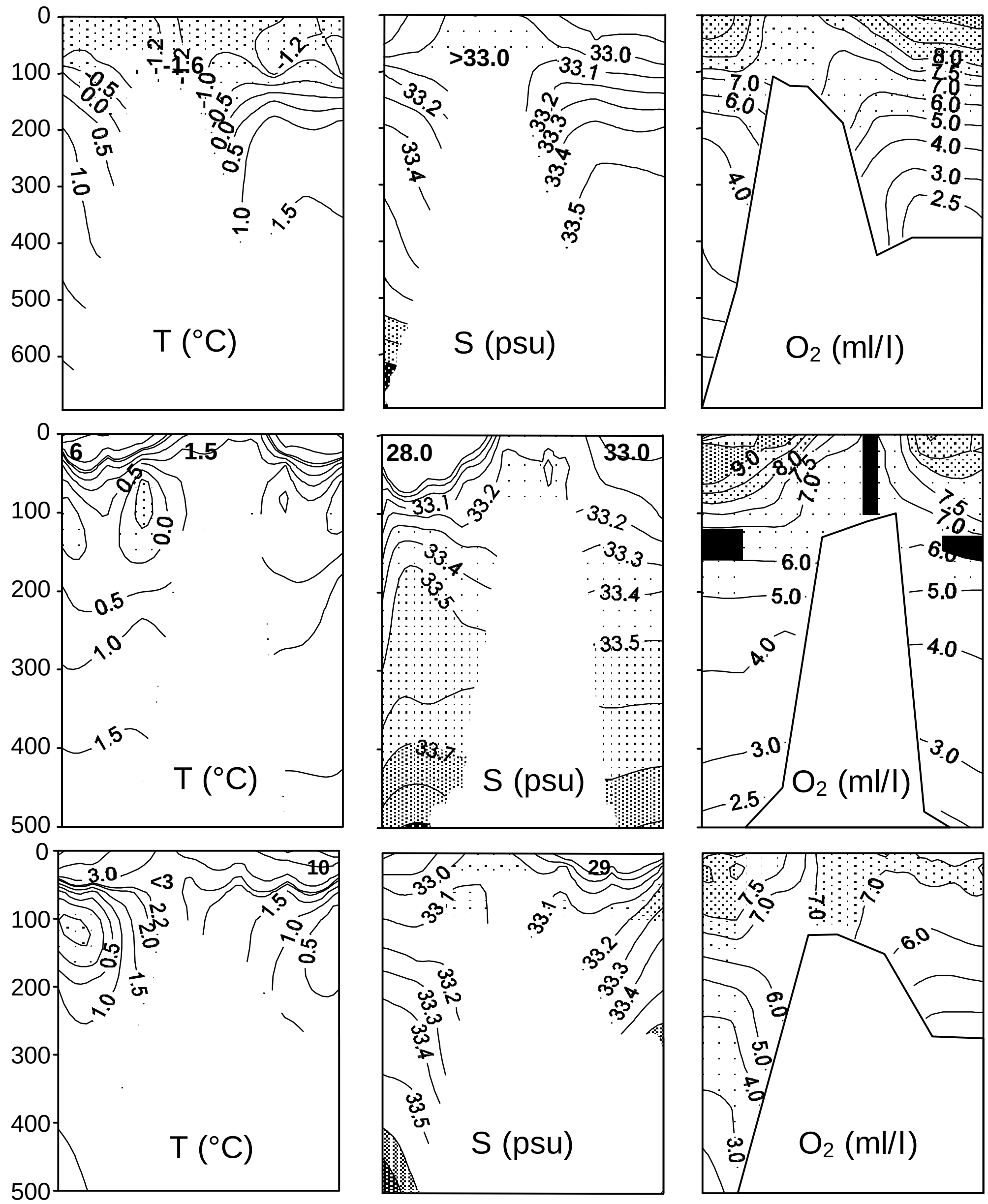

Fig. 2 Distribution of water properties at (top) section A-A for 6–7 May, 1995, (middle) section B-B for 22–23 June, 1996, and (bottom) section C-C for 23–24 August, 1994.

In August (section C-C, Fig. 2), the surface waters around the Kashevarov Bank warmed to 7° to 12°C, while the dichothermal water still maintained negative temperatures. Over the Kashevarov Bank, a thin surface layer with temperature 2.5°–3.0°C and salinity 32.9 up to 33.0 psu was marked. The depth of this layer did not exceed 20–25 m. Below the surface layer, nearly homogeneous waters were found, with temperature ranging from 2.0° to 2.3°C, salinity from 33.05 to 33.2 psu, and oxygen concentration from about 6.5 to 7.2 ml/l. In some years, there was no sign of any thin warm surface layer over the Bank. During these periods, completely homogeneous water was observed over the Bank in all seasons.

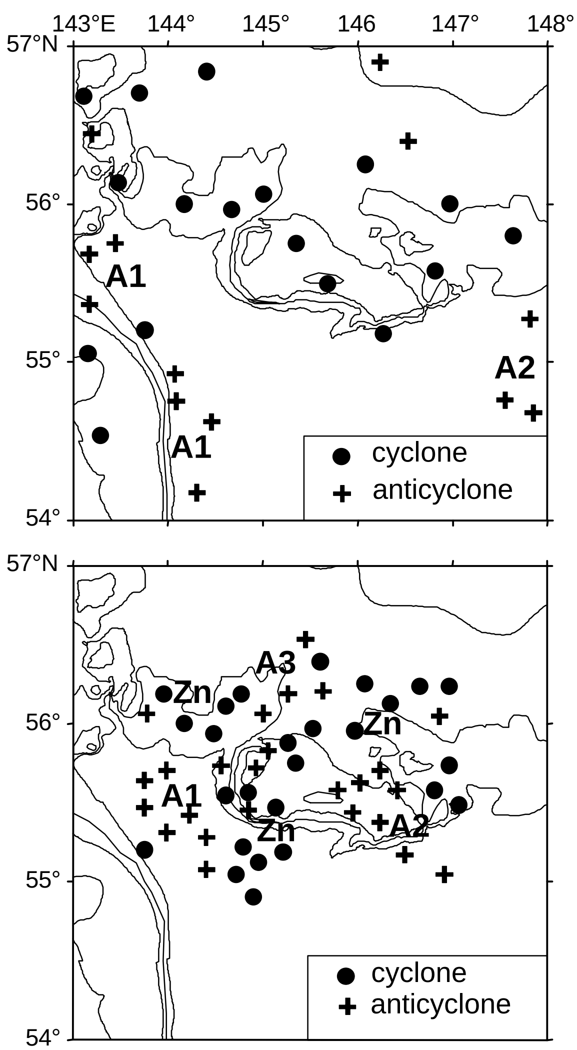

Fig 3 Combined charts of cyclone and anticyclone locations in (top) early spring and (bottom) summer over the Kashevarov Bank.

Figure 4 characterizes the distribution of water temperature at depths 0, 100 and 200 m in August. The temperature was averaged for the period from 1937 to 1996. The points of the highest surface temperature, 11°–13°C are located at some distance in the southwest and north directions from the Kashevarov Bank. As a rule, the locations with the highest temperature overlap the locations with the lowest water salinity. Over the Bank, the surface water temperature drops to 3.5°–5.0°C. The waters over the Bank are colder than surrounding ones, up to a depth of 20 m. At a depth of 30 m this pattern is not observed. From a depth of 50 m, the picture of water temperature distribution is quite the opposite to that of the surface layer: the highest water temperatures (about 1.5°–2.5°C) were observed over the Bank, and the lowest ones (about 0.5°–1.0°C) were marked at some distance from the Bank. A similar distribution of the highest and lowest temperatures was defined at depths from 50 to 200 m. At layer of 300–500 m the temperature conditions are not that clearly determined due to lack of data for accurate averaging. This area is also separated by the Bank slope, which plays a role as well. However, available data show that the August temperature of water in the layer 300–500 m is also higher on the slopes of the Bank, than at a distance away from it.

The September distribution of average water temperatures taken in the course of years is generally similar to the basic August characteristics. However, in September, the depth of the surface layer grows from 20 to 30 m, in which the water temperature over the bank is lower, than that in the surrounding waters.

In August the highest values of water salinity at surface layer (up to 32.90–33.05 psu) are observed over the Kashevarov Bank. The salinity declines with distance from the Bank, and its lowest values (up to 26–28 psu) are observed to the southwest of the Bank. The volume with the highest salinity over the Bank is maintained in the layer from 0 to 75 m. From a depth of 150 m, the salinity over the Bank, compared to surrounding waters, decreases.

The salinity in September is reduced due to the influence of Amur River. The lowest salinity at the surface, 31.14 psu, was marked only to the west of the Kashevarov Bank.

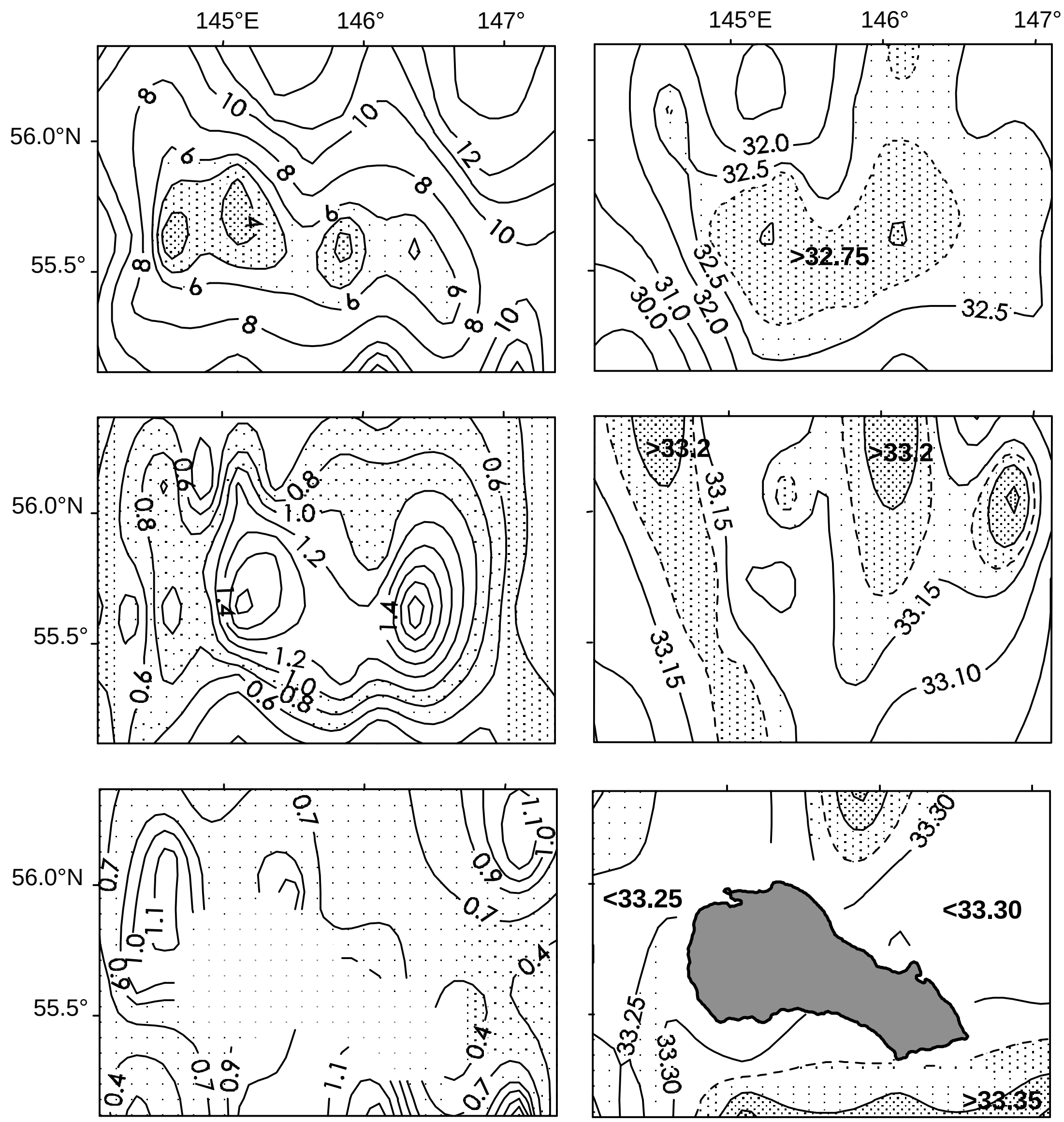

Fig. 4 Distribution of (left column) water temperature (°C) and (right column) salinity (psu) in August (averaged data) at different depths: (top) 0 m, (middle) 100 m, and (bottom) 200 m.

The charts of geostrophic circulation have shown that in warm seasons of the year the top layer (0–30 m) contributes to the dominant cyclonic circulation over the Bank. It is natural, as this is the layer where the highest values of temperature and salinity have been marked. Figure 5 shows two dynamic topography charts for August 1983. On the left-hand charts, the dynamic topography was calculated for the layer from the surface down to 300 m, and an extensive area with cyclonic water circulation was observed. On the right-hand charts, the dynamic topography was calculated for the layer from 30 down to 300 m, and it is evident that the cyclonic circulation area has broken up into a pair of cyclonic and a pair of anti-cyclonic areas. A similar phenomenon was observed when we analyzed the data from the other expeditions, as well as the averaged data for August and September (Fig. 5). Thus, when we take into account the distribution of density in the top layer 0–30 m, we see the prevalence of a cyclonic-type circulation over the Kashevarov Bank. In the other case, the area of cyclonic circulation decreases considerably, and the chart of currents does not look as simple.

Three areas with a prevalence of cyclonic circulation and three areas with a prevalence of anti-cyclonic circulation in the layer from 30 to 300 m depth were observed as typical for warm seasons

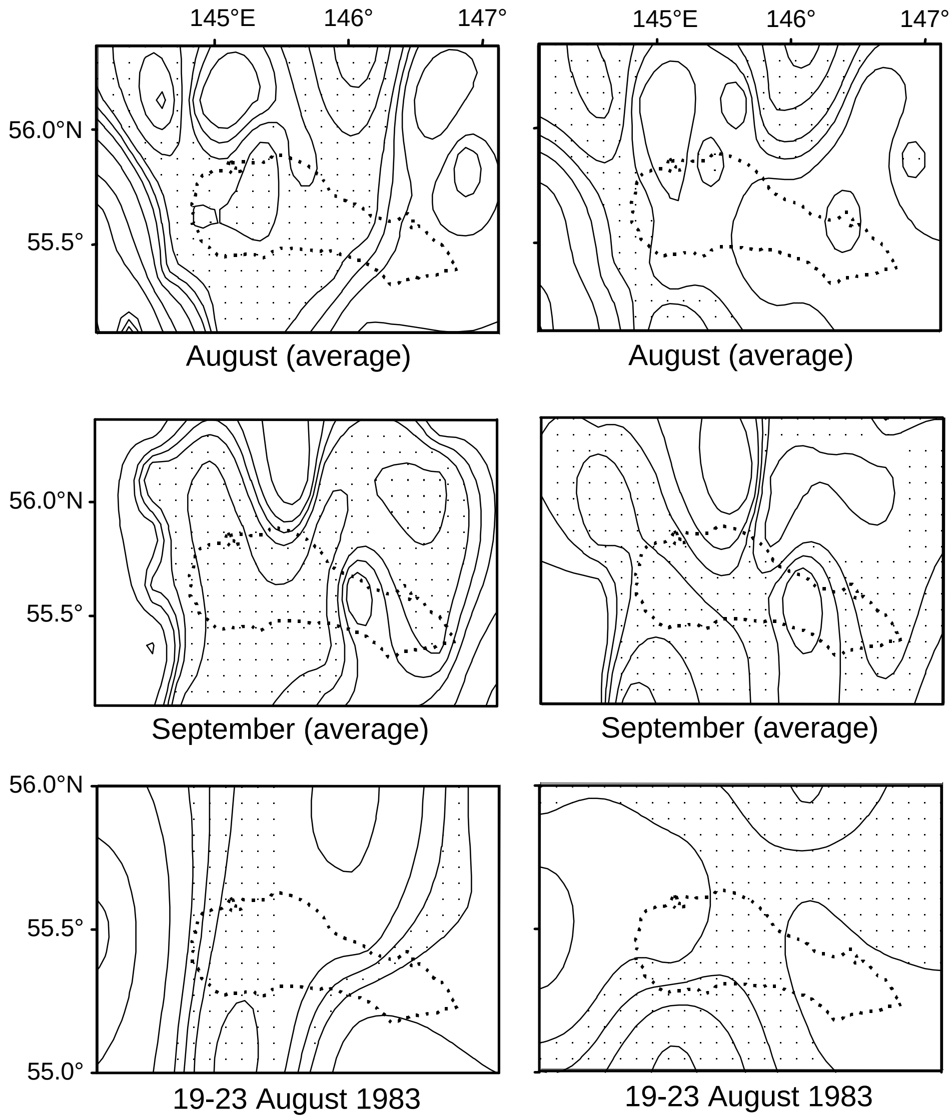

Fig. 5 An example of dynamic topography charts in the Kashevarov Bank area. (Left column) isopleths calculated with surface layer and (right column) calculated without surface layer. Dashed line indicates the area of cyclonic circulation.

(Fig. 3, bottom panel). Areas of cyclonic circulation were marked (Z) and anti-cyclonic circulation were marked (A), and were conditionally numbered. Compared to the similar chart for spring, the area with cyclonic water circulation has noticeably decreased, and the warm waters of the Deryugin Basin (marked as A1 and A2) have moved to the north. It is interesting to note that in summer the anti-cyclonic type of water circulation is usually registered in the eastern part of the Kashevarov Bank (A2). Warmed waters with anti-cyclonic circulation (A3) are often found to the north of the Bank, where they reach by spreading along the deepest curves of the canyon bottom.

Apparently, the real charting of currents over the Kashevarov Bank is more complicated than it is usually thought and its parameters may vary, depending on the season. During warm seasons, the density distribution in the surface layer plays active role in the formation of cyclonic circulation.

Regarding the reasons for anomalic formations found over the Kashevarov Bank, a number of authors consider up-welling and tidal mixing as the basic mechanisms capable of producing a nearly homogeneous water structure which is typical of the Bank.

As for the arguments for or against the up-welling, there are several factors to consider. In the case of up-welling, during the cold period of the year, temperature is expected to be higher over the Bank than in adjacent waters. However, during these periods, as a rule, the water temperature over the Bank is colder than that of the surrounding waters. It is also difficult to explain why winter convection is not restrained by the up-welling but penetrates deeper than that in waters surrounding the Bank. These facts testify that, in addition to the convection, some other processes intensify vertical exchange (for example, tidal mixing).

Up-welling can hardy explain why water salinity is lower in the layer between 150 m and the top of the Bank than that in surrounding waters.

In Figure1b and c, the spatial anomalies of the surface temperature in August and September are shown. It is clearly shown here that, as a rule, the location of the maximal anomalies zone maintains within the limits of the 200 m isobath. In case of up-welling along the Bank slope, the maximal anomalies are assumed to lie under some slope of the Bank rather than over the Bank.

In the case of up-welling at intermediate depths, the convexity of isolines in upward direction is assumed in the section over the Bank. It is interesting to note that, in this case, we see two opposite directions of isolines – up to the surface and down to the bottom. A similar picture with isolines over the Bank was observed by Zuenko and Zhabin (1993). They explained this phenomenon by intensive tidal water mixing over the Bank. This conclusion was confirmed by the results obtained from Bowden's investigations. Bowden (1988) has shown that the same type of isolines is typical of the range between stratified and well-mixed water. The depth of the mixed layer correlates with the parameter that is supposed to be equal or less than P, giving $P = H/U^3$, where H is the depth of a site (m) and U is the current speed (m/s).

Bowden has calculated that the parameter P varies from 70 to 100. The parameter P is proportional to H and is back proportional to U^3. Thus, by knowing the actual thickness of a homogeneous layer over the Kashevarov Bank, it is possible to assume the speeds of tidal currents in this area to be not less than 110 cm/s. Although we have no actual records of tidal currents, we still can borrow facts obtained by Kanari and Suzuki (1986). They calculated that the model tidal speed was about 40–50 cm/s and actual only for daily harmonics (K_1 and O_1). Thus, we can estimate that the total speed equals or is greater than 110 cm/s in the Kashevarov Bank area, which seems quite possible.

We have calculated weighted average values of temperature, salinity, concentration of dissolved oxygen and nutrientss at the stations that were carried out off the Bank (i.e. in the zone with significant stratification). In the first approximation, the weighted average value is equal to the value of complete mixing in the tested layer. The probes were taken from the surface and down to a depth where the weighted average values were equal to the values of mixed waters over the Kashevarov Bank. It appeared that the values of all parameters (temperature, salinity, oxygen and biogenes) over the Kashevarov Bank could be equal to those of weighted average values, in case where the waters outside the Bank were mixed from the surface down to a depth of 170–220 m.

The arguments listed above allows us to conclude that tidal mixing effects serve as a more realistic reason for a nearly homogeneous water structure over the Kashevarov Bank, rather than up-welling. Water mixing results in the lowering of a surface level and in causing cyclonic circulation, at least over a significant part of the Bank. The cyclonic circulation causes divergence of the surface waters outside the bank area, which explains the phenomena of polynyas over the Bank.

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