

Dynamics and Thermohaline Structure in the Contact Zones of the Azov Sea

Academician G. G. Matishov^{a,b} and K. S. Grigorenko^{a,*}

Received October 10, 2021; revised October 27, 2021; accepted October 28, 2021

Abstract—The results of instrumental measurements of the thermohaline structure and currents in the areas where fresh river waters (Taganrog Bay and Temryuk Bay) and the Black Sea waters (Kerch Strait) mixed with the waters of the Sea of Azov during the period 2018–2021 are presented. A preliminary classification of the currents of the Taganrog Bay and the Kerch Strait has been constructed on the basis of data on the water exchange. The highest velocities of currents in the Kerch Strait were recorded under north and south winds. During west and east winds, a mosaic hydrodynamic pattern is formed. In the Taganrog Bay, there is a complex system of self-induced oscillations of the water basin, which is swayed by east and west winds and fed by the Don River runoff. The currents of the Sea of Azov have a more complicated structure than has been previously considered. Everywhere, in addition to the drift, there is also a gradient (seiche) component, due to which the observed currents are often directed against the wind cyclically changing direction and velocity to the opposite.

Keywords: Sea of Azov, water scarcity of the Don River, negative and positive surges phenomena, seiche, sea currents

DOI: 10.1134/S1028334X22020118

The problem of classification of currents in the Sea of Azov is still relevant, despite decades of studies. Although a significant amount of contact data is now available, it is rather fragmentary [1–3]. Many estimates are obtained on the basis of mathematical modeling [4–7]; however, calculations often contradict observations [8, 9]. The salinity of the Sea of Azov changes due to the impact of fresh river runoff and waters coming from the Black Sea. Evaporation, precipitation, and inflow of groundwaters have no determining effect on the salinity; however, the river runoff has interannual and seasonal climate-related fluctuations of the water content [10]. The problem of periodic changes in salinity has been considered many times before [11, 12]. In 2020 a decrease in the Don River runoff led to salinization of the Sea of Azov on an incomparably larger scale than in the 1970s. The decreased runoff of the Don River was compensated by increased advection of the Black Sea. Changes in the thermohaline structure are most significant in the Don River estuary, as well as in the Kerch Strait. The influence of the Kuban River is manifested in the wide

Temryuk Bay only in a narrow seaside zone. The general purpose of this work is to study the mechanism of salinization on the basis of new data.

MATERIALS AND METHODS

We used materials of the expeditions of the R/V *Deneb*, which cruised during the periods from November 15, 2018, to December 2, 2018; from November 30, 2020, to December 25, 2020; and from April 15, 2021, to April 29, 2021. Vertical sections of salinity were plotted on the basis of conductivity, temperature, and depth (CTD) measured by SBE-19 and CTD-90m oceanographic probes. The parameters of the currents of the Taganrog Bay and the Kerch Strait were measured by an Aanderaa RCM 9LW Doppler Recording Current Meter, which was successively suspended at several measurement horizons of each station. The meteorological characteristics under marine conditions were obtained with the Vaisala ship weather station of the R/V *Deneb*.

RESULTS OF EXPEDITIONAL STUDIES

Frequent negative surges in the Don River estuary suggest that there must be a compensation current in the deepest parts of the bay, tending to flatten the water surface. In the eastern part of the Taganrog Bay, 10 km west of Taganrog and Chumbur spit, the param-

^a Southern Science Center, Russian Academy of Sciences, Rostov-on-Don, 344006 Russia

^b Murmansk Marine Biological Institute, Kola Science Center, Russian Academy of Sciences, Murmansk, 183010 Russia

*e-mail: Klim_grig@mail.ru

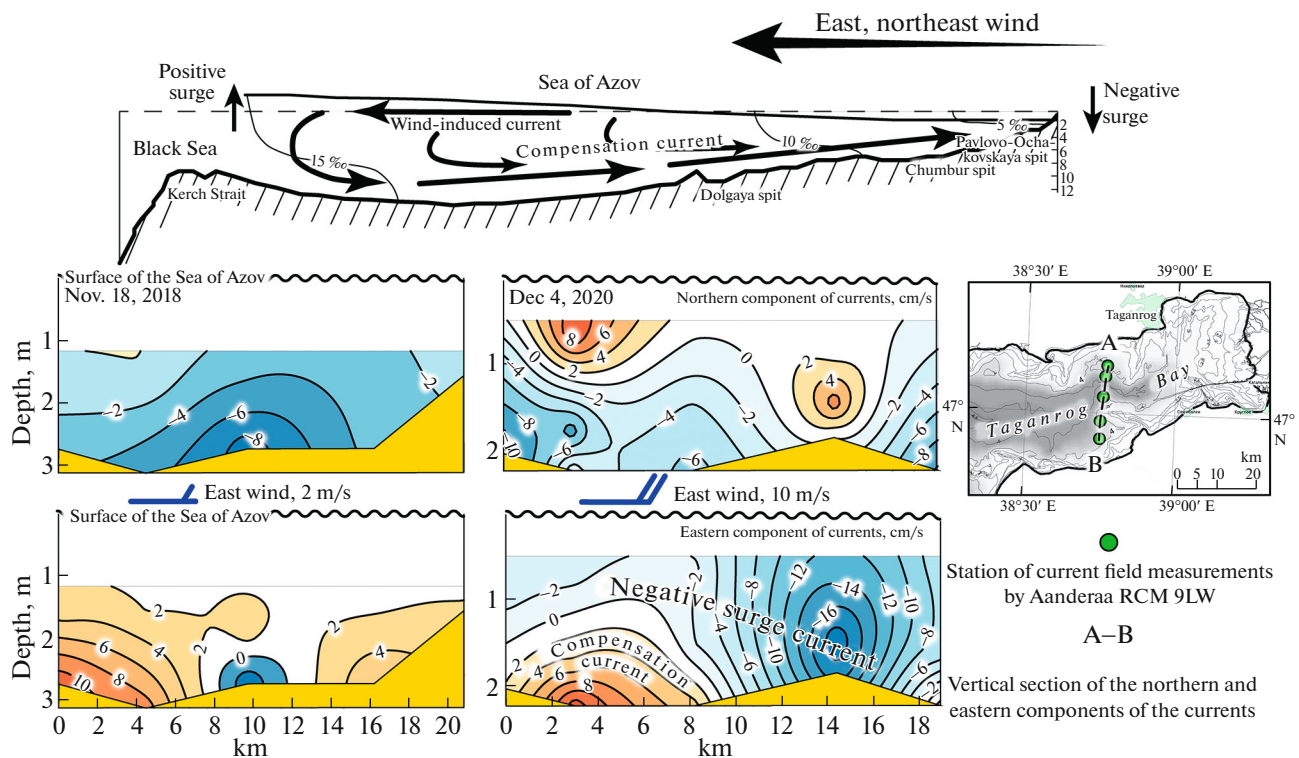


Fig. 1. The section of the currents in the eastern part of Taganrog Bay on November 18–19, 2018 and December 4, 2020.

eters of transport of waters westward and eastward were surveyed in November 2018, December 2020, and April 2021 (Fig. 1). The conditions of measurements during the fall and winter surveys in 2018 and 2020 were quite different; however, significant zonal transport of waters was recorded at both times. On November 18–19, 2018, there was a weak (2 m/s) east wind and the “rollback” of waters in the Taganrog Bay after a “strong verkhovka” from the sea to the river. On December 4, 2020, the measurements were conducted during the active phase of an intensive windy negative surge in the east wind of 10 m/s. This resulted in a fall in the water level by 1 m and in a decrease in the cross-sectional area of the section. The outermost northern and southern stations were conducted slightly closer to the adjacent stations relative to the network of 2018.

The compensation (eastern) current of the Taganrog Bay was instrumentally measured in 2020 under conditions of a strong negative surge (verkhovka) and filled the deepest part of the bay—the flooded channel of the paleo-Don River—with a maximum velocity of 13.3 cm/s.

The core of the negative (western) surge was located closer to the southern shore and was directed to the northwest along the underwater tip of the Chumbur spit. The maximum velocity of its eastern component was 19.2 cm/s. The general direction of the currents corresponds to the bay bathymetry. In the bottom layer, the current is directed along the valley

bends. In the near-surface layer, the negative surge “spreads” over the wider and rather steep shores of the Taganrog Bay, along the underwater spits (Chumbur bank on the southern shore, Petrushino on the northern shore).

During the spring survey in April 2021, the water flow rates in the Don River at the Razdorskaya stanitsa were up to 350–400 m³/s. The measurements were conducted under conditions of a weak (up to 5 m/s) west (positive surge-inducing) wind (Fig. 2) and in the almost complete absence of flooding. The water level in the delta rose by 0.5 m during the period of measurements. In the deepest part of the section, a stream directed to the northeast with a maximum velocity of 21 cm/s was revealed. The flow filled the entire volume from the surface to the bottom. Counter-currents were detected from the north and south of the central stream.

In the area of the Chumbur bank, near the southern boundary of the section, stratification of the eastern component of currents was recorded. The near-surface layer moves eastward, and the bottom layer moves westward, toward the sea. Both flows had a southern component.

The contribution of the Kuban River flood to desalinization and dynamics of the waters of the Sea of Azov in the spring of 2021 was most noticeable. The inflow into the Krasnodar reservoir on April 19, 2021, was 837 m³/s; the discharge was 750 m³/s [13]. The

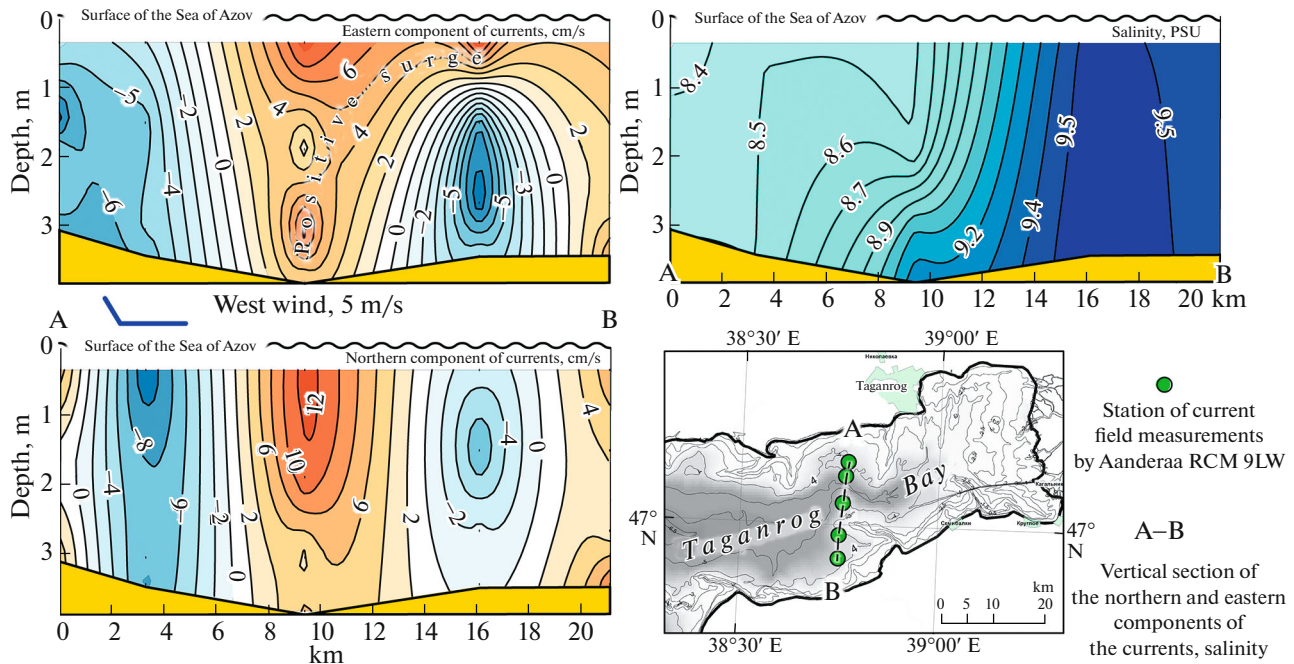


Fig. 2. The section of currents and salinity in the eastern part of the Taganrog Bay on April 17, 2021.

waters of the Kuban River were visually distinguishable at a distance of 10–15 km from the shore. They differed in color and transparency and were characterized by a large amount of removed garbage. Desalination of the surface layer of Temryuk Bay was noticeable at a distance of 25 km from the shore, where waters with salinity of less than 15 PSU were detected. At the surface of the stations closest to the shore, salinity decreased to 8 PSU. The layer where salinity changed abruptly was located at a depth of about 2 m. The bottom layer had salinity of 15–15.5 PSU.

The currents had a disorderly pattern. The Kuban River waters spread in the cyclonic direction with a velocity up to 25 cm/s in the upper two-meter layer at the outermost shore station. The stream of the anticyclonic direction with a maximum velocity of up to 5 cm/s was detected at a distance of 5 km from the shore. Another five kilometers away, there are streams moving counterclockwise and clockwise along the coast, with the transport of waters of up to 8 cm/s for both of them. Water movement of the mostly cyclonic direction with average velocities of 4–6 cm/s and maximum values of 14 cm/s near the surface was observed at the seaward stations, 15 km or further from the shore (Fig. 3).

In the northern part of the Kerch Strait (Fig. 4), an intensive longshore westward current is formed in the east wind. The transport of the Black Sea waters (with salinity over 17 PSU) with maximum velocities of more than 10 cm/s and deviation to the west was recorded instrumentally. Near the Crimean coast, the current induced by the west wind is added to the near-

bottom current. The resulting transport of waters, from the surface to the bottom, is directed to the northwest. The core of the current (up to 27 cm/s) is located at a depth of 7–8 m. The center of transport of waters to the south is located in the near-bottom horizon, five kilometers from the western boundary of the section. The most intense westward current (more than 36 cm/s) is located at a depth of 4 m, 3 km from the eastern boundary of the section.

The survey of the northern part of the Kerch Strait was carried out in April 2021 under conditions of an increasing south–southwest wind. The scheme of flows and salinity (Fig. 5) on the eastern side corresponds to almost calm weather (less than 2 m/s). The end of the works on the western side was accompanied by seven-point winds (14 m/s). Therefore, the recorded scheme of currents has a weakly indicative spatial pattern, but a strongly pronounced temporal pattern.

In the initial period, weak movements (2–4 cm/s) and a change in directions within the entire water column—from north to south or from east to west, were observed. Stratification of salinity was clearly visible, i.e., desalination by the Kuban flood waters at the surface (12.4 PSU) and filling of the depressions at the bottom with waters with a salinity of 15.6 PSU. In the central part of the section, the wind increased to 7–9 m/s, the water column rushed to the northwest with a velocity of up to 19 cm/s. The current became significantly weaker with depth. Below 5-m depth, velocities reached 2–4 cm/s to the north and 0–2 cm/s to the west. The strong south–southwest wind (12–14 m/s)

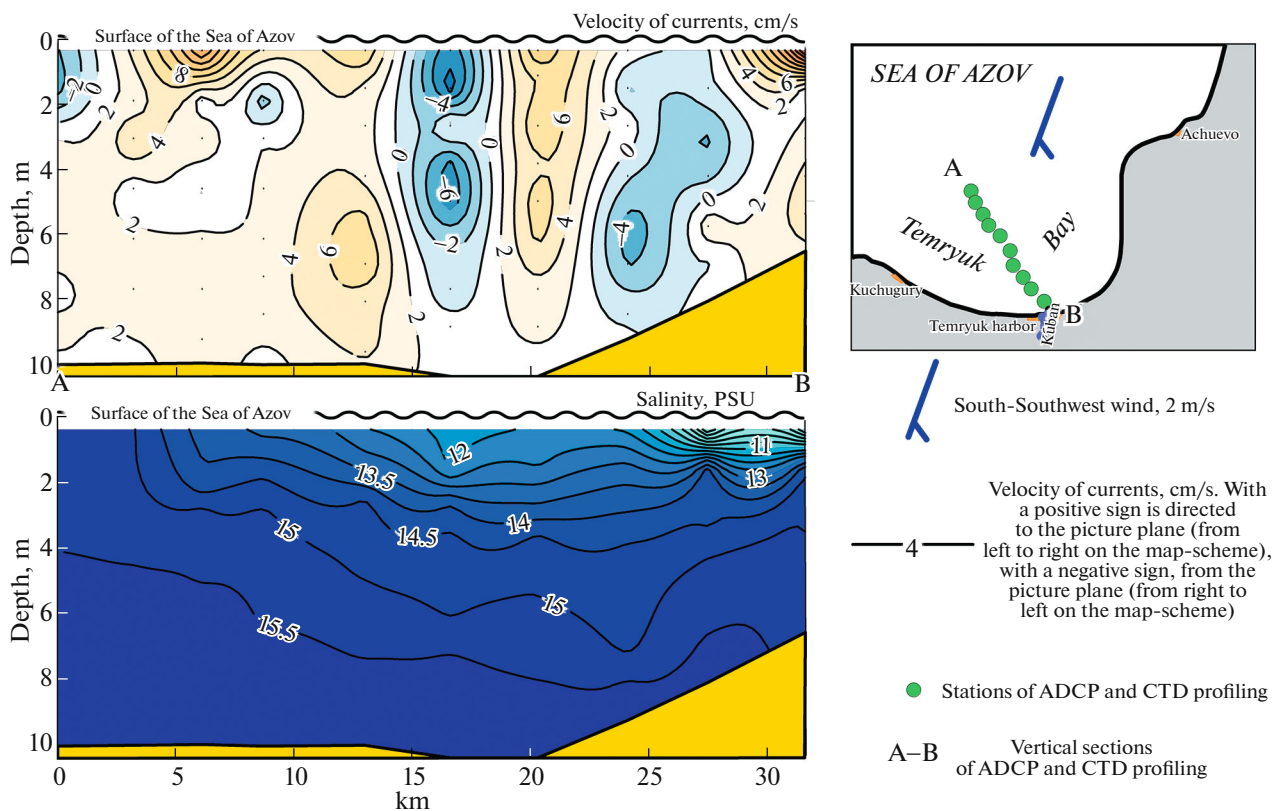


Fig. 3. The section of the currents and salinity in Temryuk Bay of the Sea of Azov April 19, 2021. Current velocities are normalized relative to the plane of the section A–B.

near the Crimean coast intensified the current up to a velocity of 42 cm/s to the west–northwest.

RESULTS AND DISCUSSION

Table 1 summarizes all estimates of the transport of waters in the Kerch Strait and in Taganrog Bay. The data were obtained from the measurements made on board R/V *Deneb* in the years 2018–2021. A north wind of average strength leads to an excess by five times of the transport of waters from the Sea of Azov (3988 m³/s) over the transport of waters from the Black Sea (729 m³/s). The flow rates of the northern current are twice as high as the mean annual flow rates of the Volga River [14] during strong south winds. The flow rate in the southerly direction, meanwhile, is characterized by the minimum value of 70 m³/s, 240 times less than from south to north. Under the east wind, the flow from north to south exceeds by more than two times the flow from south to north (4874 and 1874 m³/s respectively, 519 m³/s for the Black Sea waters).

In general, the measurements conducted allow us to believe that, under the current low fresh runoff into the Sea of Azov, advection (pumping) of the Black Sea

waters can be caused by wind from practically any direction.

The Kuban River desalinates the surface layer of Temryuk Bay of the Sea of Azov. The scale of the desalinated zone changes with runoff variations, whereas no systematic differences compared to previous measurements were detected [9].

Depending on the interannual cyclicality of runoff and the predominant regime of the wind, several types of stratification of currents are distinguished in the zones where the Sea of Azov makes contact with the Don River and the Black Sea.

During the fall–winter low-water period in the Taganrog Bay, under conditions of a wind-induced negative surge, the presence of a negative surge and compensation currents has been established. In spring, in the absence of flooding, during the wind-induced positive surge, the currents of a positive surge and runoff were identified.

During intense flooding, the negative surge coincides in direction with the runoff current and is intensified by the runoff. The superimposition of the positive surge and runoff currents during floods or large releases from the Tsimlyansk hydroelectric complex can lead to a dangerous rise in the water levels

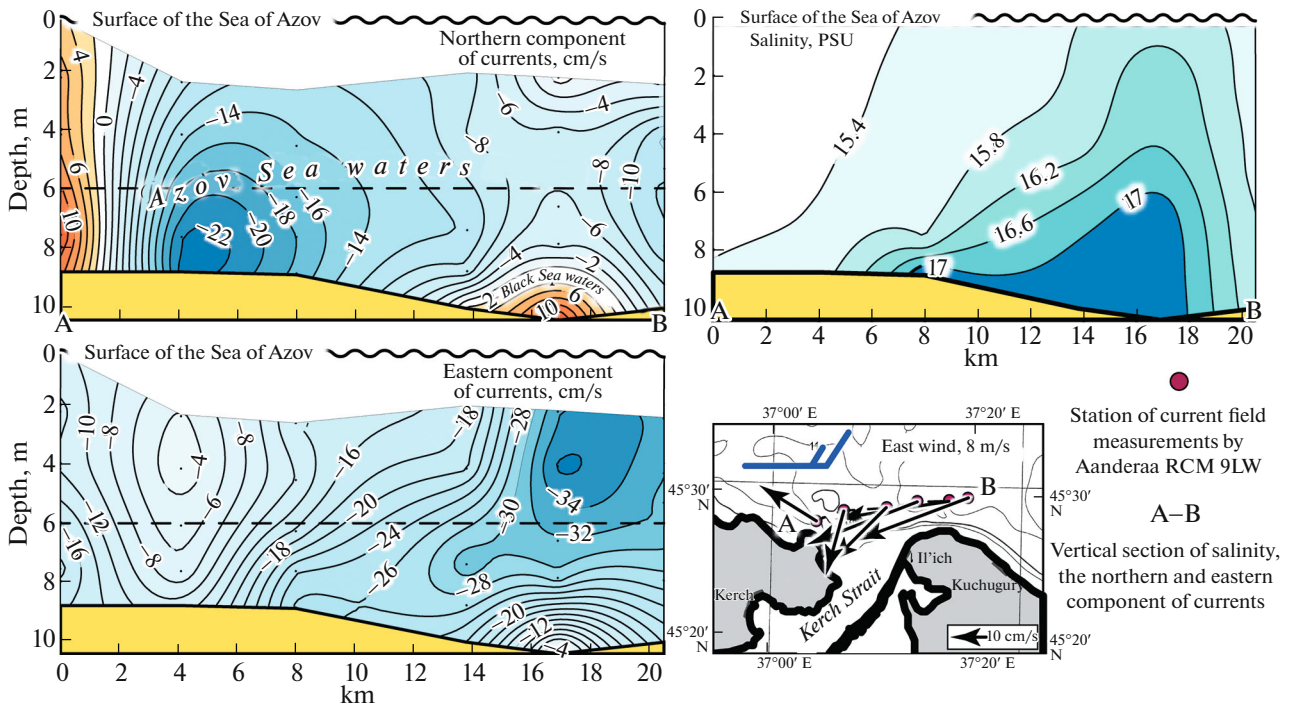


Fig. 4. Currents in the northern part of the Kerch Strait December 12, 2020.

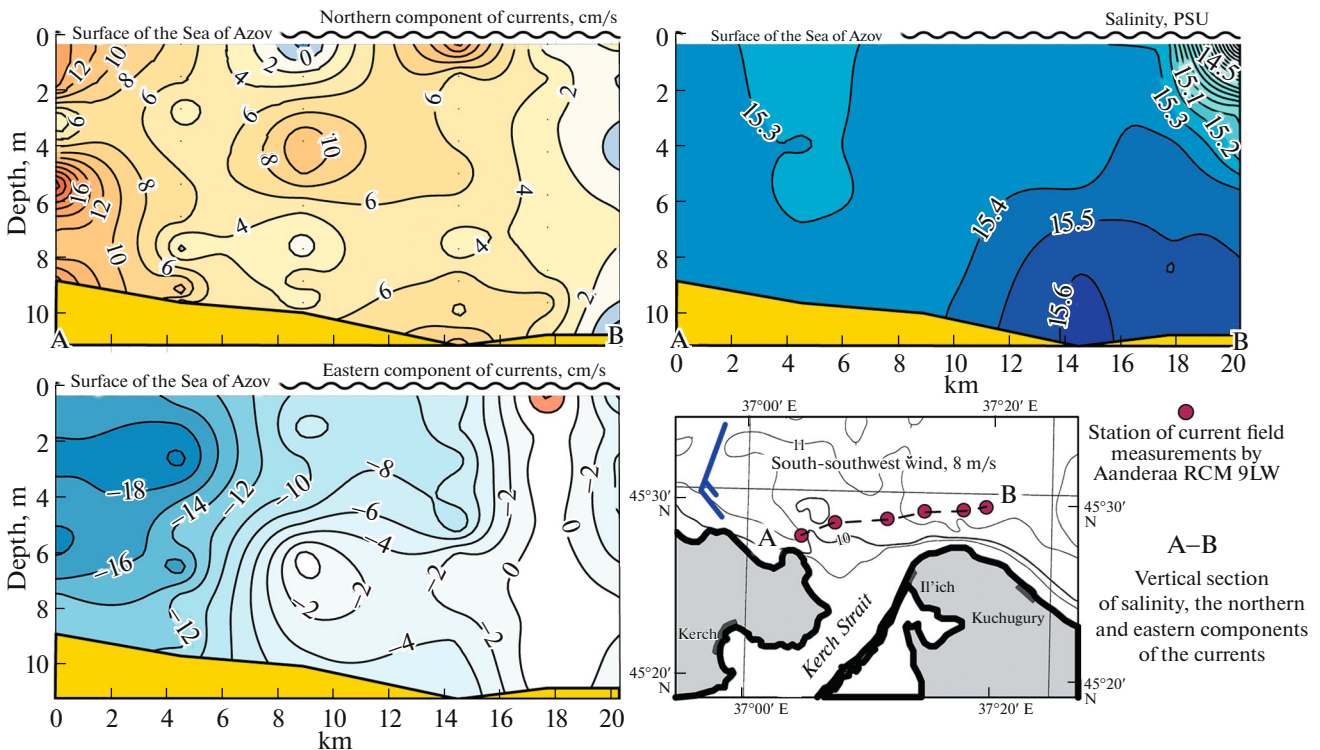


Fig. 5. Currents in the northern part of the Kerch Strait April 20, 2021.

and flooding of the entire estuary area of the Don River [15].

The countercurrents of the Taganrog Bay are characterized by great variability. Two measurements were

made in the late fall–winter period at the minimum flow rates (300–400 m³/s) of the Don River under conditions of an east wind. At the moment when the wind inducing the negative surge began to be weaker,

Table 1. Water transition through the Kerch Strait and the Taganrog Bay under different weather conditions

The northern part of the Kerch Strait			
Date of measurement	Transport of waters, m ³ /s		Direction and velocity of wind
	to the north (to the Sea of Azov)	to the south (to the Black Sea)	
November 25–26, 2018 [8]	1920	150	South–southwest, 3 m/s
April 15, 2019 [8]	17100	70	South–southwest, 12 m/s
July 24, 2019 [9]	729	3988	North, 7 m/s
December 12, 2020	1874 (519 for waters with salinity of more than 17 PSU)	4874	East, 8 m/s
April 20, 2021	11853	48	South–southwest 0–14 m/s
The eastern part of the Taganrog Bay			
	To the east (to the Don River)	To the west (to the Sea of Azov)	
November 18–19, 2018	1250	37	East, 2 m/s
December 4, 2020	380	1590	East, 10 m/s
April 17, 2021	2218	1742	West, 5 m/s

the back current exceeded the runoff current by more than 30 times. At the time of the maximum development of the “strong verkhovka,” the western negative surge current prevailed on the surface of the Taganrog Bay. The eastern compensation current filled the bottom depressions even when the total depth of the section was 2–3 m. The flow rates in it were four times less than in the negative surge current. The Don River runoff at that time was 240–300 m³/s, which was lower than the flow rates of the eastern compensation current of the Taganrog Bay. In the spring of 2021, the transport of the positive surge current exceeded the flow rates of the runoff component by 20%. There were no cases of measurements when a current with a higher salinity (greater than 9 PSU) was not routed from the sea to the river.

This phenomenon is explained in the works [4, 16, 17], which have considered free (seiche) fluctuations of the level of the Sea of Azov after the cessation of the wind impact. In particular, according to the simulation results, it was shown that 9–12 h after the weakening of the strong east wind, the energy of the one-node seiche dissipates, and an amphidromic system is formed in the Taganrog Bay. The strait between the shallow (less than 2 m) tips of the Dolgaya and Belosaray spits is only 20–25 km wide, whereas the western part of the Taganrog Bay is about 60 km wide. Such narrowness contributes to additional isolation of the cyclonic seiche system, the weakening of water exchange, and the circulation of river and sea waters within the bay under continuous negative–positive phenomena.

Direct measurements of the currents in November 2018 confirm the important role of the seiche in the pattern of currents of the Sea of Azov (Fig. 6). During the first two days of measurements, the current was

directed against the east wind; on November 19, the flow turned upwind. On November 20–22, differently directed currents of the amphidromic system of the western part of the Taganrog Bay were recorded. The source of the level drop was the strong east wind on November 14–16. Within 4–5 days after slackening of the wind, the system of wave currents was formed. These currents changed direction already independently of the predominant wind.

In the Sea of Azov, there is a complex superposition of natural oscillations of the water basin, which is swayed by the east and west winds and is fed by the Don River runoff. The water-abundant Don River substantially enhances the runoff current and can lead to an additional slope of the sea surface [18]. Under the current low-water conditions, drops in the level are mostly wind-induced. After ceasing the wind resupplying, the balance of energy of the one-node structure decreases in a cascade of scales and fluctuations of the level of multi-node seiches become less significant; however, the wave currents often remain directed against the observed wind.

CONCLUSIONS

These observations allow us to consider the system of currents of the Sea of Azov not as a drift system, but as a drift-gradient (seiche) one. It is the seiche motions, which are strictly directed counterclockwise, that contribute to the transport of bottom sediments and the formation of spits, regardless of the direction of the forcing wind.

The highest current velocities in the Kerch Strait were recorded during north and south winds. A mosaic hydrodynamic pattern is formed with west and east winds. In particular, on December 12, 2020, the

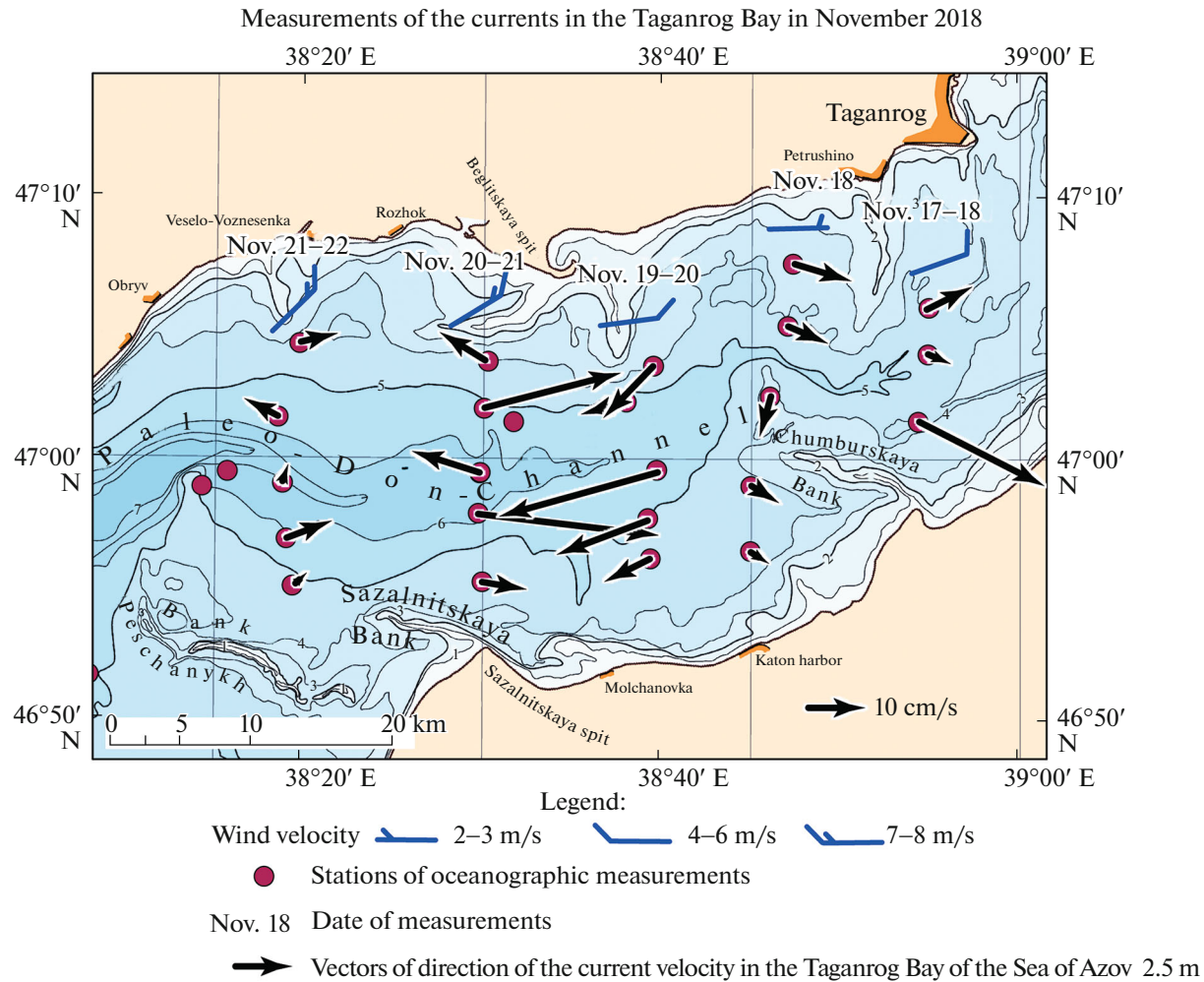


Fig. 6. Daily changes in the current directions in the Taganrog Bay of the Sea of Azov.

southwestward transport of waters prevailed; waters near the Crimean coast moved northward, and saline inflows from the Black Sea entered the sea along the bottom depressions of the

Cis-Kerch coastal waters (Fig. 5).

ACKNOWLEDGMENTS

E.P. Oleynikov, A.Yu. Moskovets, and G.V. Valov participated in the collection of material and analytical work.

FUNDING

This study was supported by Russian Science Foundation, project no. 20-17-00196. The work was carried out on the research vessels and equipment of the Center for Collective Use of the South Scientific Center of the Russian Academy of Sciences no. 501994.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. N. M. Knipovich, *Hydrological Researches in the Azov Sea* (Shestoi Oktyabr', Moscow, 1932) [in Russian].
2. E. M. Lemeshko, A. N. Morozov, and S. V. Fedorov, in *Proc. 3rd All-Russian Conf. Ecology. Economy. Informatics. The Azov Sea, Kerch Strait and near Strait Zones in the Black Sea: Control Problems for Coastal Areas for Ecological Safety Support and Rational Environmental Management* (Southern Federal Univ., Rostov-on-Don, 2016), pp. 213–228 [in Russian].
3. I. B. Zavialov, A. A. Osadchiev, P. O. Zavialov, V. V. Kremenetsky, and I. V. Goncharenko, *Oceanology* **61** (3), 329–338 (2021).
4. *Waves, Flows, Surging, and Pollution Transformations in the Azov Sea*, Ed by L. V. Cherkesov and T. Ya. Shul'ga (Mar. Hydrophys. Inst., Sevastopol, 2017) [in Russian].
5. N. A. Dianskii and V. V. Fomin, *Tr. Gos. Okeanogr. Inst.*, No. 218, 74–104 (2017).
6. Yu. I. Inzhebeikin, *Tr. Gos. Okeanogr. Inst.*, No. 213, 15–102 (2011).

7. A. I. Mizyuk, G. K. Korotaev, A. V. Grigor'ev, O. S. Puzina, and P. N. Lishaev, *Morsk. Gidrofiz. Zh.* **35** (5 (209)), 496–510 (2019).
8. K. S. Grigorenko, E. P. Oleinikov, and E. G. Grigorenko, *Nauka Yuga Ross.* **15** (3), 63–69 (2019).
9. G. G. Matishov and K. S. Grigorenko, *Oceanology* **61** (2), 173–183 (2021).
10. *The Surface Water Resources of the USSR, Vol. 7: Don-skoi Area*, Ed. by Z. M. Kozhina and O. N. Potapova (Gidrometeoizdat, Leningrad, 1973) [in Russian].
11. L. V. Dashkevich, S. V. Berdnikov, and V. V. Kulygin, *Water Resour.* **44** (5), 749–758 (2017).
12. Yu. M. Gargopa and S. V. Sarvilina, *Water Resour.* **38** (6), 765–774 (2011).
13. *Water Environment for the Area of Kuban Basin Water Management Board* (Kuban Basin Water Management Board, 2021).
http://www.kbv-u-fgu.ru/?path=bvu_vho&page_vho=25.
14. *The Surface Water Resources of the USSR, Vol. 12: Lower Volga Region and Western Kazakhstan, Iss. 1: Volga River Basin Below Cheboksary*, Ed. by G. G. Dobroumova, O. N. Potapova, and T. S. Shmidt (Gidrometeoizdat, Leningrad, 1971) [in Russian].
15. G. G. Matishov, A. L. Chikin, S. V. Berdnikov, and I. V. Sheverdyayev, *Dokl. Earth Sci.* **455** (3), 360 (2014).
16. V. A. Ivanov, A. V. Konovalov, and L. V. Cherkosov, *Meteorol. Gidrol.*, No. 4, 73–80 (2003).
17. G. G. Matishov and Yu. I. Inzhebeikin, *Oceanology* **49** (4), 445–453 (2009).
18. *The Seas of the USSR: Hydrometeorology and Hydro-chemistry, Vol. 5: The Sea of Azov*, Ed. by D. E. Gershanovich, N. P. Goptarev, B. M. Zatulnaya, and A. I. Simonov (Gidrometeoizdat, St. Petersburg, 1991) [in Russian].

Translated by V. Krutikova