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MARINE PHYSICS

Field Measurements of Sea Currents on the Mangistau Shelf of the Caspian Sea

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Abstract—The pilot Kazakhstan–Russia project provided the first systematic data in a long time on coastal currents in one of the least studied areas of the Caspian Sea, namely the Mangistau Shelf. Moored autonomous buoy stations equipped with inclinometric meters for the velocity and direction of the current in the bottom layer, as well as water temperature sensors, operating at two points on the shelf for 69 days from June 2 to August 9, 2021. CTD-probing of the vertical structure was performed as well.

Keywords: Caspian Sea, Mangistau Shelf, coastal currents, thermohaline structure

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INTRODUCTION

The Mangistau Shelf (red rectangle in Fig. 1) refers to the area off the coast of the Mangyshlak (Mangistau) Peninsula in the Kazakhstan sector of the Caspian Sea. In this area there is the largest port of Kazakhstan and the city of Aktau with a population of 200000 people, a number of mining and chemical industries; extraction and transportation of raw hydrocarbon materials are carried out as well. The annual volume of oil production exceeds 20 million tons there. The fishing industry is quite well developed as well: commercial fish catches amounted to 2.3 thousand tons in 2020. It is obvious that information on sea currents, mainly shelf ones, is necessary for predicting pollution transport, ensuring the activities of maritime transport, fishing, and solving many other practical problems. Meanwhile, the "freshest" field data on currents (as well as on other oceanological characteristics of the sea) for the Mangistau Shelf date back to 1988, and even at that time such measurements in this area were only single measurements (e.g., [2, 5]). Over the past few decades, the climate in the Caspian region has changed significantly [3], and the level of the sea itself first rose by more than 1 m, and then dropped again by 2.1 m [3, 7]. It may be assumed that the regime of shelf currents has undergone changes as well. In 2010, sounding of currents was performed with the ADCP onboard profiler [1] was performed in the 35th voyage of R/V *Rift* of the Institute of Oceanology, Russian Academy of Sciences, near the area of interest to us, but this was only a single measurement.

In this regard, a joint Kazakhstan–Russian project "Pilot Study of Sea Currents on the Mangistau Shelf of the Caspian Sea" was implemented in order to study the modern coastal circulation on the Mangistau Shelf in 2021. The project was supported by the Ministry of Education and Science of the Republic of Kazakhstan and initiated by the Esenov Caspian University of Technology and Engineering (Aktau, Kazakhstan) and Shirshov Institute of Oceanology, Russian Academy of Sciences (Moscow, Russia).

MEASUREMENTS

The studied area and the location of the measuring equipment installation points are shown in Fig. 1. At these points, autonomous buoy stations (ABSs) equipped with SeaHorse inclinometers of the velocity and direction of the current in the bottom layer [6, 8], as well as water temperature sensors near the bottom, for a period of 69 days were moored. The exact coordinates of Station 1 are 43°37′23.9″ N, 51°08′17.8″ E (the depth of the place is 14 m); Station 2, 43°46′26.1″ N, 51°00′07.0″ E (the depth of the place is 13 m). Each of

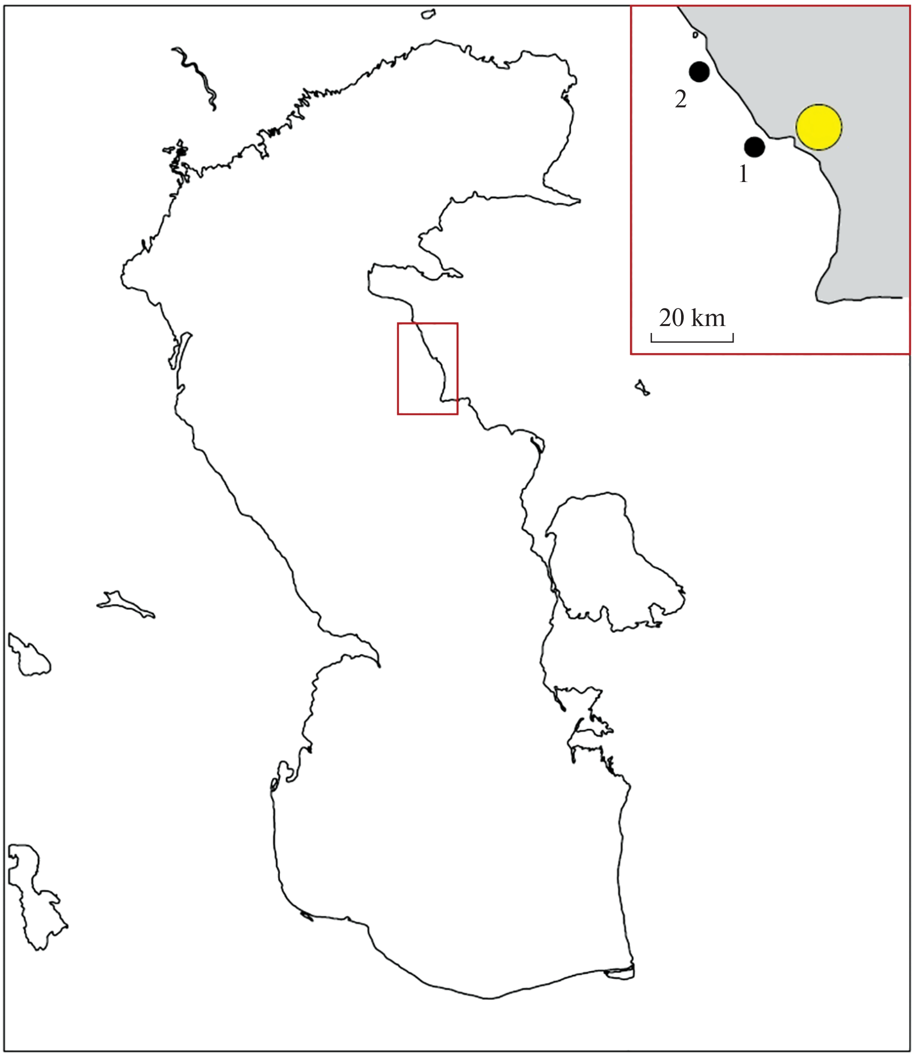

Fig. 1. Studied area and location of moored autonomous buoy stations 1 and 2. The yellow circle shows the location of Aktau and the meteorological station.

the stations was located at a distance of ~3 km from the nearest point on the coast, and the distance between the two stations was 12 nautical miles (22 km). Both stations were set up from a coaster on June 2 and raised on August 9, 2021. The measurements during the entire monitoring period were carried out with a discreteness of 20 min. Semi-daily data on wind velocity and direction, as well as on air temperature, obtained at the meteorological station of Aktau of Kazhydromet and available on the website https://www.gismeteo.ru/diary/5320/2021/, were applied for interpretation of the results of measurements as well. The wind velocity vectors were recalculated into wind friction stress using standard formulae [9]. In addition, satellite images of the infrared and visible ranges of the spectrum of the MODIS Aqua radiometer (https://oceancolor.gsfc.nasa.gov/, a total of 39 images for the period of field measurements) were analyzed. A CTD survey of the thermohaline structure from the surface to the bottom was performed at each of the stations using the CastAway CTD probe at the beginning of the ABS operation period on June 2, 2021.

DATA

The results of 69-day measurements of the current velocity at two stations combined with meteorological data are shown in Fig. 2.

Throughout the entire period of measurements, winds of variable intensity (from 0 to 12 m/s) were registered almost exclusively from NW directions, generally predominating in the summer in this region [2]. At the same time, the values of the zonal and meridional components of the velocity of shelf currents at both stations

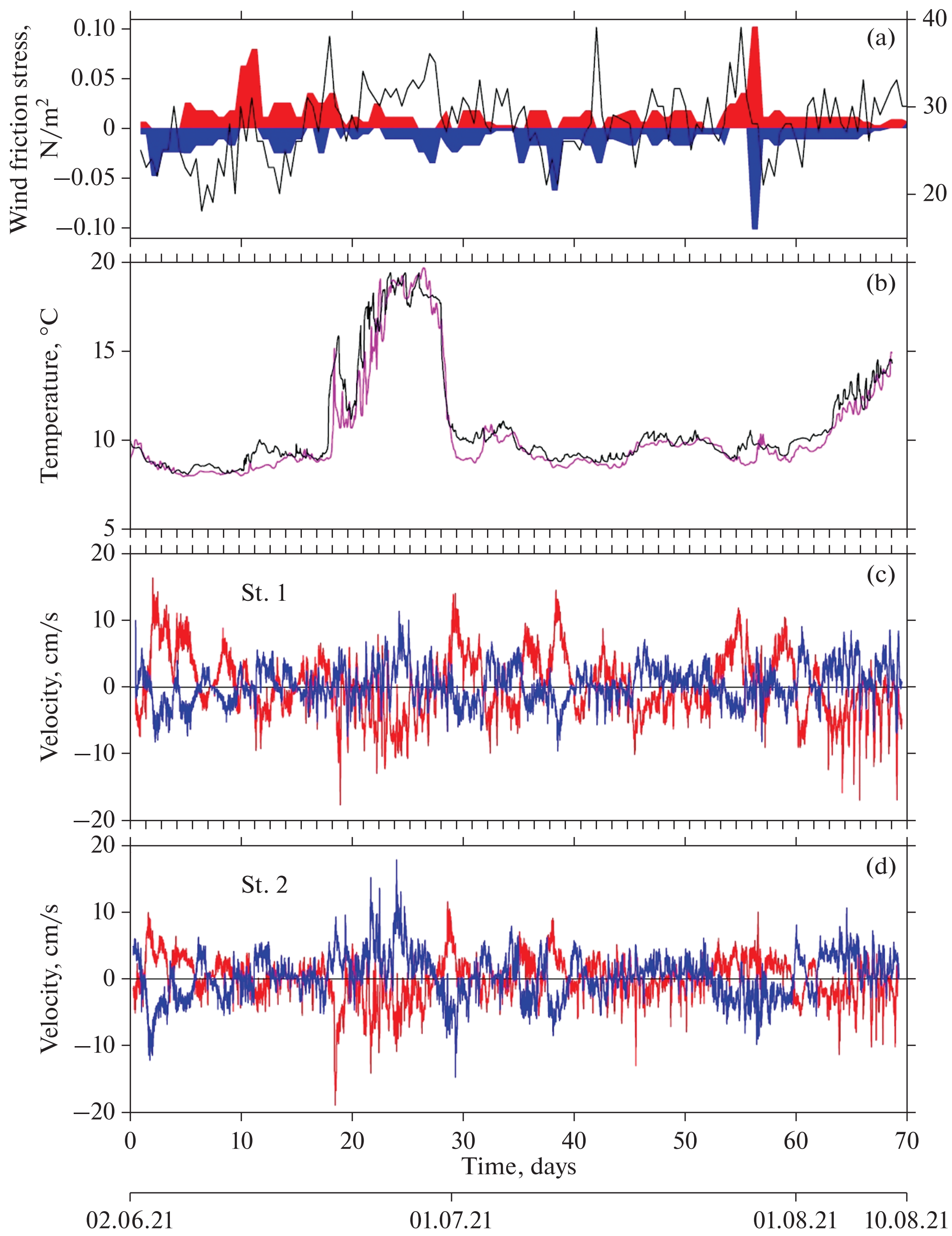

Fig. 2. Variability in hydrophysical parameters during the entire measurement period from June 2 to August 9, 2021. From top to bottom: (a) transverse to the coast (red shading) and alongshore (blue shading) wind stress components and air temperature (black curve). The positive sign of the wind stress component transverse to the coast corresponds to the direction from the sea to the land, parallel to the coast (the direction from southeast to northwest); (b) water temperature in the bottom layer at moored stations 1 (black curve) and 2 (violet curve); zonal (red curve) and meridional (blue curve) current velocity components in the bottom layer at stations 1 (c) and 2 (d).

were in the range of 0–20 cm/s and had both positive and negative signs, i.e., the flow was sign-alternating. The characteristic periods of changes in the direction of the current velocity, as well as the wind strength, correspond to the synoptic period (5–8 days). The higher-frequency inertial oscillations with periods of 16–18 h were noted against this background as well. The average values of the current velocity over the entire monitoring period are close to zero, but correspond to a weak current to the NW, i.e., against the predominant wind.

The zonal and meridional components of the current velocity had different signs and changed in antiphase almost always at both stations. Such anticorrelation indicates that currents predominated in the

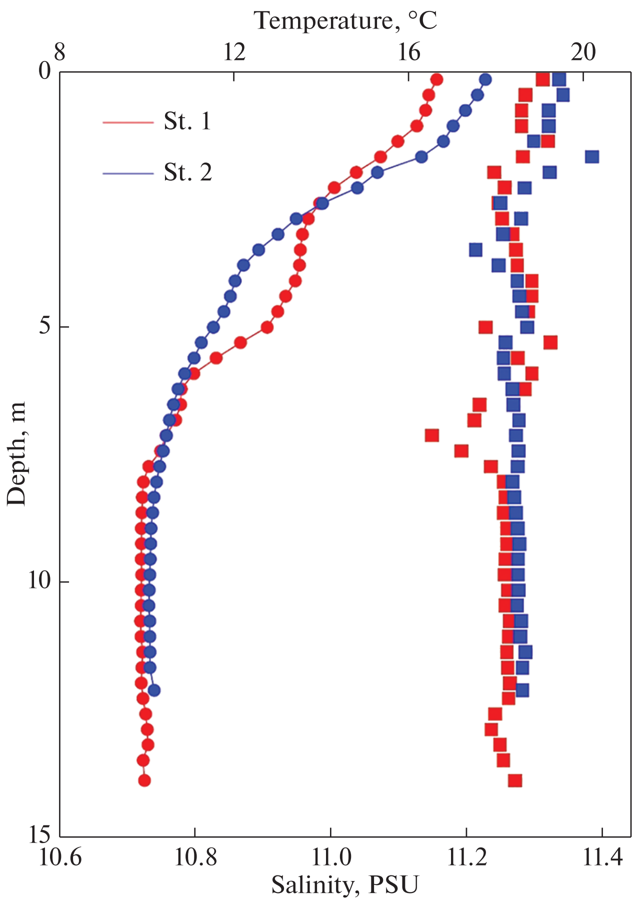

Fig. 3. Vertical profiles of temperature (circles) and salinity (squares) at stations 1 (red) and 2 (blue), according to measurements on June 2, 2021.

alongshore direction along the isobath from SW to NE, and vice versa. The corresponding components of the currents at stations 1 and 2 were highly correlated (r ~ 0.8). This means that the characteristic spatial scales of the predominant circulation structures exceeded the distance between the stations (~30 km).

The thermal state of the bottom layer was characterized by almost constant temperatures of ~10°C at both stations during most of the monitoring period, with the exception of the time interval from June 22 to 30, when there was a rapid temperature increase up to ~19°C (according to the available satellite data, this was close to the sea surface temperature at that moment) and then an even faster return to the previous value, as well as the last decade of measurements, when a gradual temperature increase up to 15°C was registered. In both cases, an increase in near-bottom temperature accompanied the intensification of currents in the NW direction.

Such low water temperature at a shallow depth, which persisted throughout the hot summer, when the air temperature reached ~40°C on some days (Fig. 2a), allows us to suggest the occurrence of upwelling confidently.

Indeed, the vertical temperature profiles recorded in June (Fig. 3) showed a strong thermal stratification and almost complete absence of the upper quasi-homogeneous layer, as the temperature decreased almost linearly from 18–19°C at the surface to 10.8°C at a depth of 8 m. According to the CTD probe data, without corrections for the ion–brine composition different from the oceanic one, the salinity varied in a rather narrow range from 11.2 to 11.4 PSU.

Upwelling in the form of filaments of relatively cold (18–24°C) water in a narrow coastal area against the background of surrounding waters heated to 27–33°C were noted on 31 of 39 considered satellite images during the measurement period, i.e., in 80% of cases. Based on the satellite data, we suggest that the most intense upwellings are typical of the area located to the south from Cape Peschanyi and for the Kazakh Bay, however, they propagate in the form of a strip with a width of 10–30 km narrowing to the north over the entire studied area and to the north from it, up to Cape Tyub-Karagan at a latitude of 44.6° N. This is consistent with the results of the analysis of longer-term archives of satellite images published in the literature [4] as well. In addition, a number of satellite images for the period of our field measurements show mesoscale eddy structures of a presumably shear nature at the boundary of the upwelling zone and surrounding waters. At the same time, these eddies were cyclonic in about 80% of cases and anticyclonic, in only 20%.

CONCLUSIONS

The interpretation of the newly obtained data of field and satellite monitoring allows us to draw the following conclusions about the nature of the coastal marine circulation on the Mangistau Shelf during the studied period. According to our assumption, this circulation is formed under the influence of two competing mechanisms: (1) the direct local activity of the NW winds predominant in this region, which contribute to the development of currents in the SE direction, and (2) the influence of larger-scale factors (vorticity of wind fields, heterogeneity of thermohaline fields), as is known, leading to the formation of a cyclonic circulation in the Middle Caspian [2, 5] and, consequently, currents of the NW direction near the eastern coast of the sea. The first mechanism is strong enough in the periods when the NW wind and an alongshore current to the southeast is formed, as well as coastal wind upwelling, which is clearly expressed in powerful thermal stratification and localization of very cold waters at shallow depths. This situation is less favorable in terms of environmental conditions in the studied area,

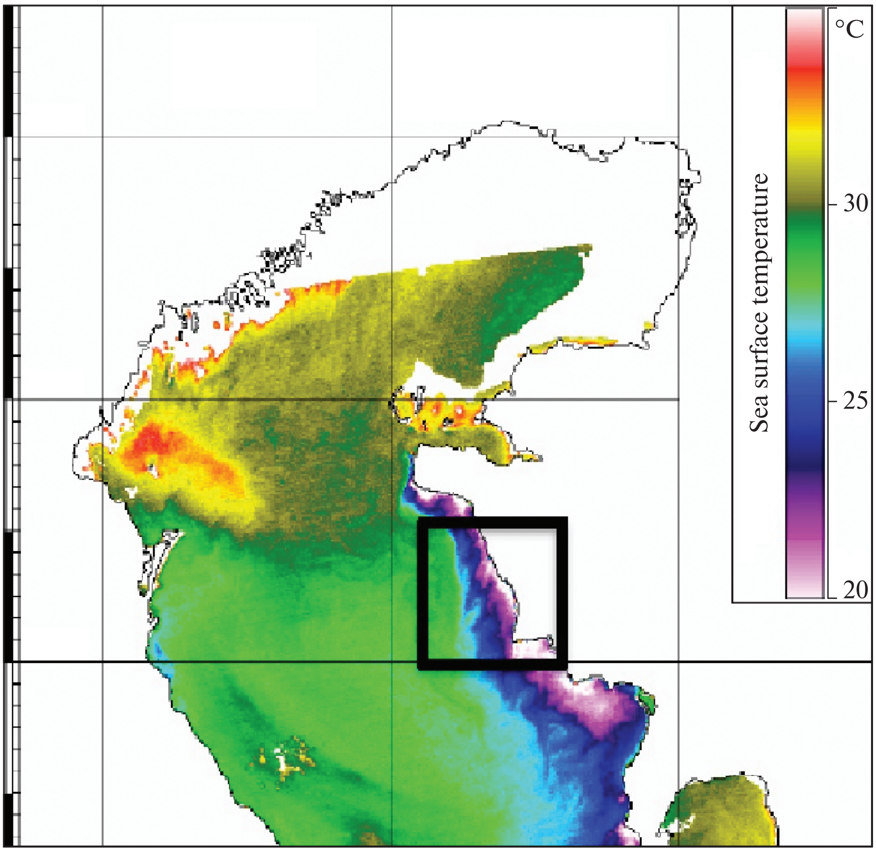

Fig. 4. Average sea surface temperature of the Caspian Sea on July 20, 2021, according to satellite data of the infrared range of the MODIS Aqua radiometer. An occurrence of upwelling at the eastern coast is clearly visible. The area of field research is marked with a square.

since the main sources of pollution are located to the north of it, and stratification can contribute to the accumulation of pollutants in the surface layer and, in some cases, the development of hypoxia. However, the balance of forces controlling the circulation changes in favor of the second mechanism during periods of weakening of the local wind, and a current of a cyclonic sign was formed in the NW direction, and upwelling stops or weakens, which leads to an increase in temperature in the bottom layer and a gradual relaxation of stratification. This conceptual scheme, however, is still only hypothetical, and its confirmation requires further, longer-term studies.

The successfully completed pilot Kazakhstan–Russian project allowed us to obtain the first systematic data on shelf currents in one of the least explored areas of the Caspian Sea in a long time. In addition, this provided an opportunity to organize effective cooperation between Russian and Kazakhstan scientists in the field of Caspian Sea research, which, in our opinion, has great potential for further development in the medium and long term.

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CONFLICT OF INTEREST

The authors declare that they do not have a conflict of interest.

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