Chapter 3. Background hydro-meteorological conditions of the Kerch Strait area

Ovsienko S., Fashchuk D., Zatsepa S., Ivchenko A., Petrenko O., Ilyin Yu., Yurenko Yu., Postnov A., Fomin V., Repetin L., Diakov N., Lavrova O.

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3.1. Atmospheric circulation

In the marine environment, movements and transformations of pollutants are known to be affected by certain hydro-meteorological factors that are primarily wind, the waves, water circulation and temperature, and ice conditions. Therefore, in order to estimate the magnitude of abnormality of the November 11, 2007 storm and to understand the general (background and baseline) pollution dynamics, analysis was conducted of the Kerch Strait hydro-meteorological regime based on its long-time observation.

Data collected in 1945–2009 during observations carried out along the Kerch Strait shores by the Opasnoe HMS, the Kerch AMS in the Zavetnoe village and at the Black Sea by the Anapa HMS give ground to determine two opposite wind flows (transfers) blowing into the North-Eastern-Eastern and South-South-Western directions. Each of them got formed under the influence of a specific type of atmospheric process taking place over the Black Sea area (Chernyakova A. P., 1965, Eremeev V. N. *et al.,* 2003).

On the annual basis, the Northern (N), North-Eastern (NE), and South-Western (SW) types of flow (transfer) have a higher frequency of 11–13 %. The frequency seasonal maximum of the N, NE (25–28 %) and SW (15–25 %) types is observed during the winter months. Frequencies of other flow (transfer) types correspond to the other wind directions and equally spread through the year not exceeding 8 % per month. Northern winds dominate on the Kerch Strait with development of the N and NE types of flow (transfer), while among the Southern winds, those with the SW type of flows (transfer) prevail.

During 11–18 November 2007, a distinct SW wind flow was registered at the time of the atmospheric masses spread-over from the Baltic Sea to the Balkans and development in the Black Sea region of powerful Southern cyclones accompanied by the strong S and SW winds (Anapa, S, 20–35 m/sec; Novorossiysk, SE–SW, 17–22 m/sec). In the North-Eastern part of the Black Sea, the winds have usual maximum velocity exceeding 15 m/sec once a year during the October-April period. Strong winds could last for 10–13 hours in average. For instance, in November 2007, that type of wind was observed by the Kerch AMS during the 8-hour period. However, the probability of the SW type of transfer to be witnessed at the Kerch Strait

Photo: The storm on 11th of November, 2007, http://englishrussia.com/index.php/2007/11/13/storm-hdr/

in October-April does not exceed 12% to be followed by 7–9% for the NW and N flows (Simonov A.I., Altman E.N., 1991). For this time of the year, the most probable would be the NE type of wind with a maximum velocity of 20–25 m/sec. Besides, analysis of the wind gradation distributions has showed that storms with wind velocity exceeding 20 m/sec could be witnessed in 1–3% of the cases observed (in specific situations over the Black Sea and with certain wind directions), (Simonov A.I., Altman E.N., 1991). No information has been present in the bibliography since 1936 about the storms similar to the one observed during the Kerch accident in November 2007, which apparently happened to become a very rare combination of factors with a disastrous aftereffect.

3.2. Stormy winds at the North-Eastern Black Sea

The North-Eastern Black Sea is an energy-generating area of the Black — Azov Seas region and is well known for its higher storm activity as compared to the other areas. Occurrence of stormy winds is summarized in Table 3.2a and at Figure 3.2a.

Table 3.2a. Occurrence (%) of stormy winds (11–30 m/sec) per direction registered by the coastal stations and in the open shelf area of the North-Eastern Black Sea.

Area	N	NE	E	SE	S	SW	W	SE
Feodosia	0.10	0.51	0.26	0.02	0.47	0.46	0.40	0.47
Zavetnoe	0.38	1.50	0.14	0.05	0.29	0.11	0.18	0.13
Opasnoe	0.50	2.35	1.42	0.01	0.34	0.11	0.45	0.11
Taman’	0.98	2.76	2.55	0.09	0.68	0.16	0.52	0.38
Anapa	0.68	2.47	2.36	0.11	3.37	0.61	0.88	0.57
Open Sea	0.60	4.45	1.84	1.01	1.3	0.79	1.25	0.16

The Kerch Strait and the Black Sea open-shelf North-Western wind diagram for the winds exceeding 10 m/sec shows predominance of the North-Eastern, Eastern and Southern winds (Fig. 3.2a).

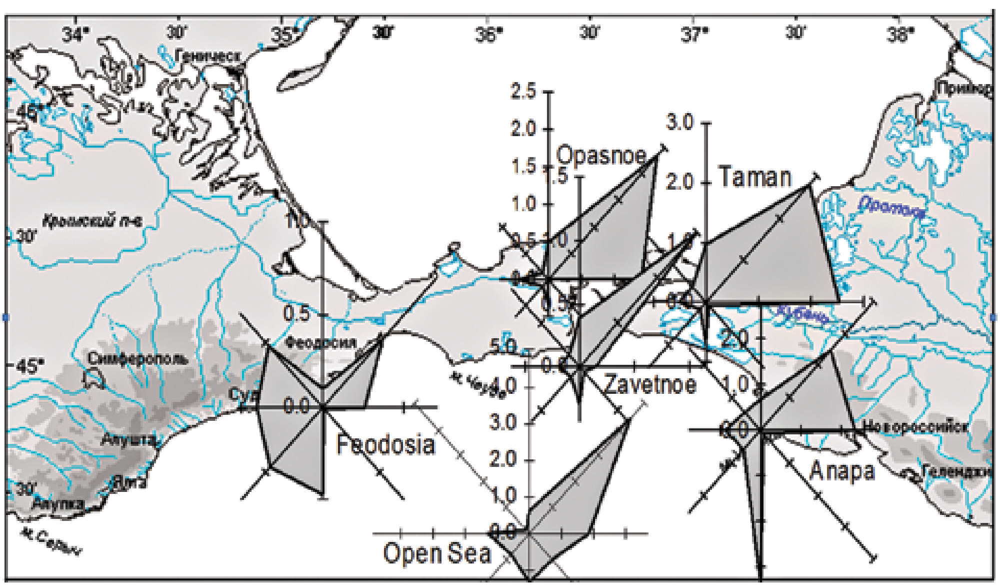


Fig. 3.2a. Wind diagram of the stormy winds (11–30 m/sec) annual observations (%) by the shelf and coastal stations in the North-Eastern Black Sea.

During the year, the Anapa off-shelf area experiences 42 days with winds exceeding 10 m/sec in average, and inter-annually their number varies from 10–15 to 50–70 days. Strong winds are observed through the whole year during all the seasons. In order to avoid the influence of coastal topography on seasonal variability of the stormy winds (11–30 m/sec), their monthly frequency for the near-Kerch open-sea area of the Black Sea was calculated based on the atmospheric pressure data of last 38 years of observations by the Hydrometeorological stations network. While the North-Eastern and Eastern winds prevail during the year with frequency of 19 % and 15 %, respectively (Fig. 3.2b) the period of strong winds (≥15 m/sec) highest frequency

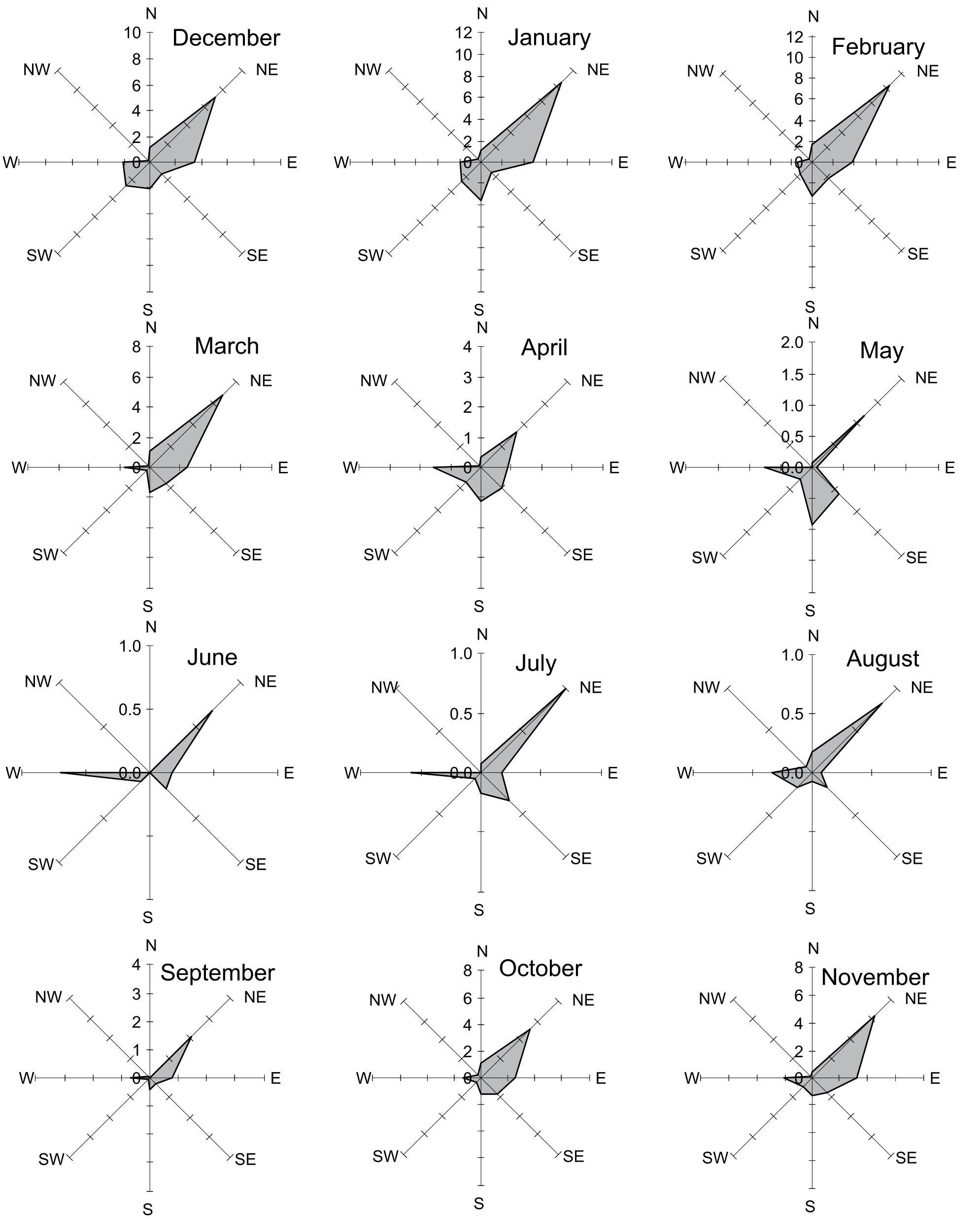


Fig. 3.2b. Monthly wind frequency (%) diagram of the stormy winds (10–30 m/sec) in the near-Kerch area, North-Eastern Black Sea.

(>3 %) continues from December to March reaching its maximum in January–February (6.6 %).

Although the Northern, North-Eastern and Eastern stormy winds (> 10 m/sec) typically come from the coast, their velocity (of up to 35–40 m/sec) and relatively high frequency (up to 7 % in total) can produce a dangerous impact on the hydro-technical facilities and boats to contribute to the build-up of strong wind currents and waves.

However, the most dangerous wind directions in the near-Kerch sea areas and on the Southern Kerch Strait are the South-Western, Southern and South-Eastern. Though their annual average frequency is low (0.14 % for SE, 0.08 % for S and 0.37 % for SW), in February it may increase to 0.82 % for SE, 0.28 % for S and 0.37 % for SW. Despite of an observed relatively low frequency in regard to the Southern strong winds (3 % in this area in total), there could be occasionally observed the exceptionally powerful South-Eastern and Southern stormy winds reaching a hurricane speed and producing extremely high wind waves with a large development distance.

Photo: The storm on 11th of November 2007, http://englishrussia.com/index.php/2007/11/13/storm-hdr/.

3.3. Waves generated by wind

In 1954–2002, the wave height long-term observations were conducted three times a day (two times in the winter period) by the Opasnoe HMS through using a wave recorder (Eremeev V. N. *et al.,* 2003). The annual and monthly wave height average has showed the dominance of the N, NE and SW waves direction (see Tabs. 3.3a, 3.3b, 3.3c). It was also clear that high waves reaching up to 1.2–2.0 m were observed in the Kerch Strait narrowest part rather occasionally, while the N and NE wave directions prevailed. Maximum wave height of 2–3 m was observed nine times in total (six times in April, two — in June, and one — in July) in the Northern part of the strait and under the Northern winds influence. Thus, the four m high waves brought by the impact of the Southern winds, as it was recorded by the Caucasus port in November 2007, had not been observed on the Strait during almost 50 years of observations. The 0.7–1.0 m high waves usually prevail through the whole year round (44–51 % cases) except for March. The wave 1–2 m high frequency varies through the year from 1 to 7.3 % reaching the maximum in October — February (Eremeev V. N. *et al.,* 2003).

Annual average frequencies of waves are given in Table 3.3a based on long-term monthly observations over the wave direction and height gradation registered by the Opasnoe HMS during the period of 1954–2002. The wave subtotal probability and height frequency are given in Table 3.3b.

As the table shows, waves of the Northern, North-Eastern and South-Western directions prevail in the Northern narrowest part of the strait. The maximum observed wave heights are summed up in Table 3.3c. Based on the observation data, it is apparent that the wave 1.8–2.0 m major heights in the Northern narrowest part of the strait are observed occasionally and usually under the Northern and North-Eastern direction disturbance impact that generate the most dangerous waves.

Table 3.3a. Long-term monthly and annual frequency of the wave height gradation (m): number of cases (cases) and percentage for the period of 1954–2002 given by the Opasnoe HMS.

Waves height (m)	Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
≤0.2	cases	1166	426	1272	2178	2428	2416	2450	2228	1819	1490	1355	1392	20620
	%	49.9	49.2	48.6	54.4	53.8	55.2	54.2	49.3	48.0	47.7	47.3	48.7	50.9
0.3–0.7	cases	969	381	1148	1767	1951	1916	1932	2124	1743	1399	1255	1217	17802
	%	41.5	44	5.8	44.2	43.2	43.8	42.7	47.0	46.0	44.8	43.8	42.5	44.0
0.8–1.2	cases	167	59	151	115	114	45	137	161	211	219	208	196	1783
	%	7.2	6.8	5.8	2.9	2.5	1.0	3.0	3.6	5.6	7.0	7.3	6.9	4.4
1.3–1.9	cases	33	0	45	33	21	0	0	9	14	15	48	56	274
	%	1.4	0.0	1.7	0.8	0.5	0.0	0.0	0.2	0.4	0.5	1.7	2.0	0.7
2.0–3.0	cases	0	0	0	6	0	2	1	0	0	0	0	0	9
	%	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.3b. Annual averages of the wave-height gradation frequency (m) per direction, number of cases (cases) and percentage for the period of 1954–2002 given by the Opasnoe HMS. The wave height frequency subtotal and the regime probability.

Gradation	Direction	N	NE	E	SE	S	SW	W	NW	Frequency	Probability
Still	cases									1950	100
	%									4.8	
≤0.2	cases	2980	2393	932	614	2583	3169	3037	2962	18760	92.5
	%	7.4	5.9	2.3	1.5	6.4	7.8	7.5	7.3	46.1	
0.3–0.7	cases	3019	6641	1597	387	2447	1706	883	1122	17802	49.1
	%	7.5	16.4	3.9	1.0	6.0	4.2	2.2	2.8	44.0	
0.8–1.2	cases	77	1228	352	10	74	15	10	17	1783	5.1
	%	0.2	3.0	0.9	0.0	0.2	0.0	0.0	0.0	4.4	
1.3–1.9	cases	6	210	50	1	7	0	0	0	274	0.7
	%	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.7	
2.0–3.0	cases	2	4	3	0	0	0	0	0	9	0.0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total	cases	6084	10476	2934	1012	5111	4890	3930	4101	40488	
	%	15.0	25.9	7.2	2.5	12.6	12.1	9.7	10.1	100.0	

Table 3.3c. The wave height maximum (m) observed on the Kerch Strait by the Opasnoe HMS during the period of 1954–2002 (Eremeev V.N. *et al.*, 2003).

	Month												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Height (m)	1.6	1.6	1.8	2.0	1.8	2.0	2.0	1.3	1.3	1.8	1.4	1.6	2.0
Wind direction	N, NE	NE	NE	NE	E, NE	NE	N	NE	NE	E, NE	N	NE	NE, N

The mathematical modeling results (the numerical model applied is described in (Ilyin Yu. *et al.*, 2009) for the Kerch Strait wave fields are given in Fig. 3.3a. Those simulated were the wind speeds of 15 m/sec on a numerical grid with a horizontal resolution of 150 m for the four prevailing wind directions, i. e., the North-Eastern, Northern, North-Western and the Southern (Fig. 3.3a–3.3d), (Oceanographical Atlas of the Black and Azov Seas, 2009).

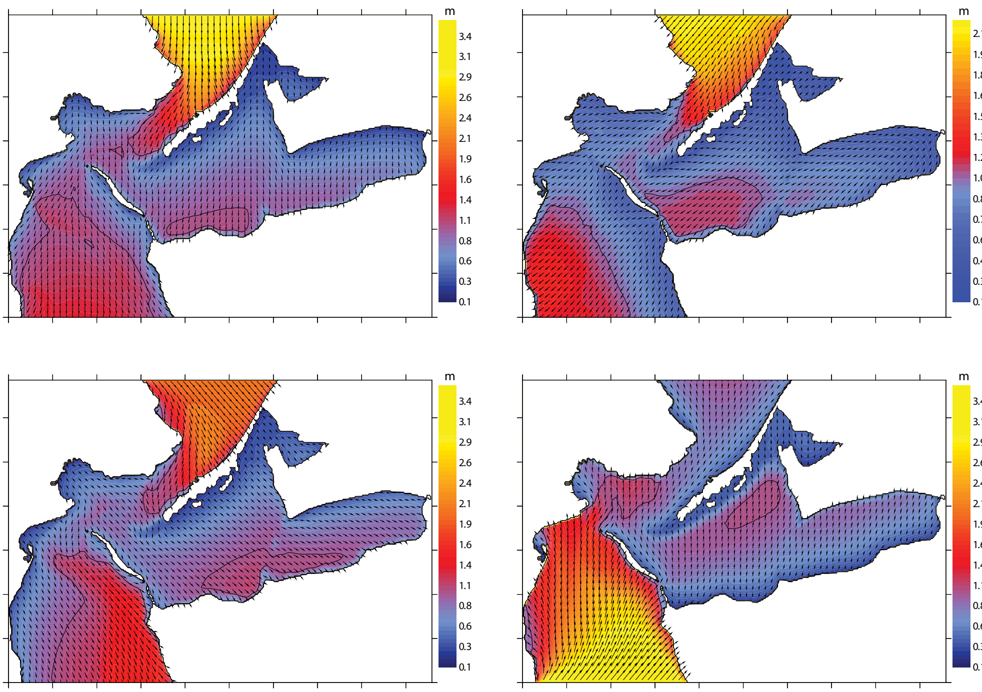


Fig. 3.3a, b, c, d. Significant wave heights (m) and mean wave directions on the Kerch Strait for the Northern (a), North-Eastern (b), North-Western (c) and the Southern winds (d).

3.4. Stormy events at the Black sea

The autumn cyclones to happen once in every seven-ten years differ from the usual cyclones, and produce the most destructive impact on the Black Sea in its North — Eastern parts in particular. Usually, they cross the sea basin in November during the period of the autumn air cooling when the water temperature still remains relatively high. Even a century and a half ago, the navigators considered those cyclones similar to the tropical ones by the origin, characteristic features and aftereffects.

One of those events happened to be «The Balaklava Gale» to brake-out off the Crimean South-Western coast on 14th November (new style calendar) 1854 during the Crimean War. Ivashintsev (1855) wrote in his paper: «It happened so, that there were no traces of the terrible storm along the Western shore… Odessa did not suffer from the hurricane». According to reports of shipmasters and from the shore-based posts, the storm velocity was 30 km per hour. The storm radius equaled to 90 miles. The highest wind velocity was 35 m per second, which equals to 72 Italian miles per hour. Twenty-one English ships were lost, and together with the ships navigating in other parts of the sea, the number of lost ships reached 30 (or 34 in other papers). Some English ships

Photo: Storm in the Black Sea, http://englishrussia.com/index.php/2007/11/13/storm-hdr/.

crushed near the Chersoneses Cape, at the mouth of Kacha River, close to Yevpatoria. Almost 1500 men died and the loss suffered totaled at 60 million Franks. The history has witnessed not too many examples of a simultaneous loss of such number of first-class ships. In the English history the date «14th November 1854» and the name «Balaklava» became synonyms of the word «catastrophe». The Balaklava storm has been memorized by the locals and in the historical chronicles also because of the death of the three-mast propeller steamship *The Black Prince* (Booklet, 2009), which carried a golden treasure.

It is worth mentioning that on the next day a cold, clear weather settled down, which correlated well with the meteorological data about a cold front passage.

Photo: B.F. Timm. Crush of the Turkish-Anglo-French navy near Balaklava, during the storm, November 1854. Lithography. A collection of R.Ya. Shterengarts. Moscow. Taken from the web site http://chekist-07.boom.ru/balaklava/zametki/shtorm.htm.

The storm on 28–29 January 1968 was also considered to be among the strongest on the Eastern Black Sea by its intensity, duration, coverage area and consequences (Ikonnikova L.I. 1977; Zdanov A.M. *et al.*, 1968). That outbreak of cyclonic activity over the Black Sea followed on a build-up of a deep stationary cyclone (985 hPa in the centre) between two anticyclones — a warm one in the South-East (over the Caucasus) and a cold one in the North-West of Europe. The wind over the Black Sea proper was controlled by a secondary cyclone which had formed over the Asia

Minor in the Southern part of the stationary cyclone and was moving to the Black Sea gradually deepening to 990 hPa in the centre. That secondary cyclone crossed the Turkish Anatolia coast at a speed of 50 km/h and reached the Kerch Strait on 28 January 1968. During the night of 27–28 January, the wind velocity had sharply increased and the westerly near the Turkish coast reached 30–34 m/sec with a windy zone exceeding 100 km in radius. Following the cyclone trajectory, the zone jointly with the hurricane winds moved towards the Kerch Strait extending to the whole Black Sea. The winds blew at a speed of 20–30 m/sec in the Black Sea interior and up to 35 m/sec by the Crimean Peninsula. The maximum wind speed (30–34 m/sec) zone reached the Caucasian coast by the evening of 28 January. That storm was unusual due to occurrence of the long waves which caused a 1.5-m sea-level rise at the Caucasian coast, and 9–10 m wind waves that crashed at the Sochi pier producing the 30–40 m high splashes (Zdanov A. M. *et al.*, 1968). In their result, the coastal railway and houses were over flooded.

A similar storm brought by a Southern cyclone, though accompanied by a smaller decrease in the atmospheric pressure, occurred on 12–16 November 1981. During that storm the cyclone centre stayed over the Crimea for three days. The isobars and its followed geotropic wind flow on the Eastern storm periphery rushed to the Kerch Strait in parallel to the Caucasus Mountains. The wind reached its maximum over the North-Eastern Black Sea.

In recent times, a similar storm on 14–16 November 1992 inflicted a heavy material loss to result in destruction of the oil and gas rigs in the North-Western Black Sea, and concrete constructions, while washing away the sand from the beaches in the Odessa City and in the Crimea areas (Fig. 1a).

3.5. Temperature and salinity

The sea surface water temperature (SST) of the Kerch Strait varies from 0ºC to 2–4ºC in winter and from 22ºC to 29ºC in summer. The minimum average SST of the strait is observed in January and of the bottom layers — in March. In March, the water warm-up starts jointly with seasonal formation of a thermocline in which the gradients are maximum in June. The maximal temperature of the water column is registered in August, when the vertical gradients have slowly disappeared and the water keeps its homogeneity until December (Eremeev V. N. *et al.,* 2003). In the Northern part of the strait (the Opasnoe HMS), the minimum SST of 1.0ºC is observed in February and the maximum of 24.1ºC is recorded in July-August (both values are long-term monthly averages, Table 3.5a, Fig. 3.5a). The water seasonal fluctuations are generally typical for shallow water space of the middle-latitude seas.

Table 3.5a. The monthly average water temperature at the surface of the Kerch Strait Northern Part (measured by the Opasnoe HMS), (Eremeev V. N. *et al.*, 2003).

Month												Year
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XI	
1.9	1.0	2.5	8.0	15.3	21.1	24.1	24.1	20.1	14.3	9.0	4.6	12.2

During November 2007 the water temperature stepwise decreased from 14–17ºC to 7–9ºC in the end of the month (Fig. 3.5b). The difference between the three stations of observation in the Ukrainian part of the Kerch Strait (HMS of Opasnoe, port Kerch and Zavetnoe HMS) was not significant. The storm on 10–12 November was not reflected in the water temperature condition. The air temperature variability was much

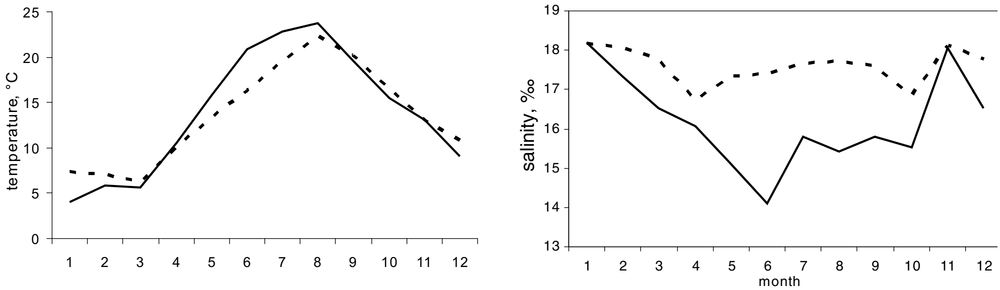
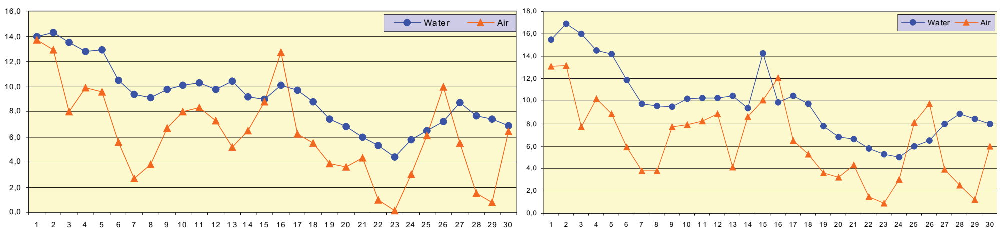


Fig. 3.5a. Seasonal fluctuation of water temperature °C (a) and salinity ‰ (b) averaged for the Kerch Strait water space and shown at the surface (solid line) and the near-bottom (dotted line) layers.

higher with sharp fluctuations in few days. Increase in air temperature was registered during 9–12 November followed by decrease of 1.5–2ºC on 13.11.2007, a situation which is rather typical for cyclone passing periods.



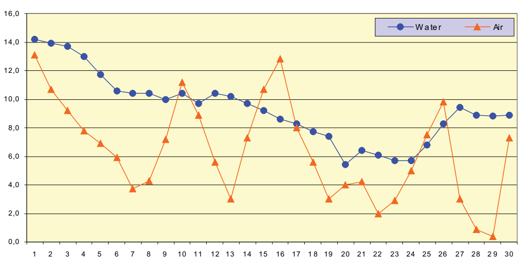


Fig. 3.5b. Diurnal water and air temperatures in different regions of the Kerch Strait during November, 2007: HMS Opasnoe (1), port Kerch (2) and HMS Zavetnoe (3).

An average sea surface salinity (SSS) of the Strait varies from 14‰ in June to 18.2‰ in January and November. However, the minimal salinity level of the bottom layer is observed in April and October. In January and November salinity does not change from the surface to the bottom layers.

In the result of the Azov water outflow, the annual average salinity of the Black Sea coastal waters in the proximity of the Kerch Strait remains the lowest for the whole Black Sea being 13.52‰, which is 1.2‰ lower the average salinity level recorded in the North-Western part of the Black Sea, though the latter is strongly influenced by the Danube river run-off, as well as by the Ukrainian large rivers (Dnieper, Dniester, Southern Bug). In the Kerch Strait Northern part at the entrance to the Azov Sea the water salinity levels could fluctuate in the range of 11.3–18.42‰ within a number of days due to a Black Sea water outflow.

3.6. Water dynamics

The Kerch Strait water exchange with the Black Sea is determined by the wind flows over the strait jointly with the Azov Sea geographical and physical peculiarities. The exchange takes place by means of an effective reciprocal movement through the strait cross-section that results from the water level difference of the Northern (the Azov Sea) and Southern (the Black Sea) parts. The difference in the level depends on the rivers discharge into the Azov Sea and wind flows. The wind flow and stormy winds impact on the sea level is stronger than the rivers influence — on the average 5–6 times and 10–15 times, correspondingly. Thus, winds build-up short-term and the rivers — long-term oscillations of the Azov and Black Seas water exchange.

With the Northern winds prevalence, the strait sea level slopes towards the Black Sea and the so called 'Azov' type flows build-up (Fig.3.6a). The flow velocity increases from 0.1 m/sec to 0.4 m/sec following the waters progressive movement from the Azov Sea to the Northern narrowest part of the Kerch Strait. During those short, high and rapid water flow intrusions, the Northern narrowest part could not release all the accumulating in front of it volumes, and in that case the opposite direction currents build-up in the water bottom layers along the Russian shoreline (back towards the Azov Sea). Simultaneously, the bottom current average velocity may go up to 0.7–0.8 m/sec. Due to the morphological peculiarities of the strait by the Tuzla Island, the water velocity there remains always below 0.4 m/sec. After Tuzla the water flows get wider towards the Black Sea drifting later into the Crimea shoreline direction. The water slows down to 0.1 m/sec before entering the Black Sea.

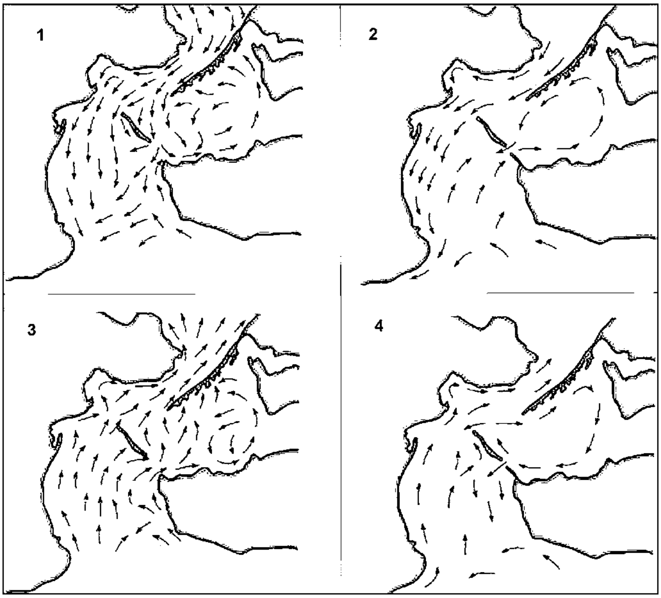


Fig. 3.6a. The Kerch Strait water flows impacted by the Northern wind flow (Azov) are given above, and the Southern wind flow (Black Sea) is given below; before construction of the Tuzla dyke (left) and after the construction (right) as observed in autumn 2003.

The water level slopes from the Black to the Azov Sea under the impact of the winds blowing from the South and the so called 'Black Sea' flow type builds-up (Fig. 3.6a). While the flow progresses towards the central part of the Kerch Strait, the sea current velocity increases from 0.1 m/sec to 0.4 m/sec (no more than 0.4 m/sec at Tuzla).

After leaving the Tuzla gully, the Black Sea waters fill in the central part of the Strait. The main stream heads to the North while partially entering the Kerch Bay. The sea current velocity could exceed 0.4 m/sec in the Northern narrowest part, but slows down after it, when entering the Azov Sea. Small gyres may appear due to the Kerch Strait and its islands geomorphologic complexity, as well as variability of the wind fields. Those gyres could reach 4–6 km in diameter in the Northern part of the strait, while being of a 1–2 km diameter in its Southern part. The currents velocity could be 0.7–0.8 m/sec in the narrow passes and to average of 0.25–0.3 m/sec. A usual currents velocity does not exceed 0.4–0.5 m/sec, while averaging 0.1–0.3 m/sec in the wider sections (Altman E.N., 1987, Panov B.N., Rubinshtein I.G., 1989 Eremeev V.N. *et al.,* 2003).

The recurrence of the 'Azov' flows to the Black Sea average 58 % annually and, consequently, the flows from the Black Sea sustain 42 %. Under the Northern winds impact, duration of the continuous flows from the Azov Sea could reach 300 hours and impacted by the Southern winds flows from the Black Sea could last for up to 200 hours. Mixed flows could be observed for 6–10 hours on the average. Annually, the 'Azov' flows are generated during 208 days in total, the 'Black Sea' — 135 days, and mixed flows — 22 days (all the numbers are long-term averages from 1962 till 2006). On the monthly scale, the numbers are 18, 11, and 2 days, respectively.

Serious changes occurred to the Kerch Strait water circulation after the Tuzla dyke construction in 2003 and the sediment formation and abrasion rate were the first to experience the impact. Results of satellite observations over the Kerch Strait flows and visual surveillance conducted over the shoreline dynamics in 2003–2007 have shown that the water flows velocity along the Crimean sea coast increases significantly under the impact of the Northern and North-Eastern winds, since the waters from the Azov Sea are prevented by the dyke from spreading evenly within the strait area (Borovskaya R.V., 2005). As a result, along the coastline from the city of Kerch to the Takil Cape many sand beaches (going by 10–20 m deep into the mainland) were washed away during three years after the dyke construction (2004–2007).

Satellite pictures provide convincing evidences that the Tuzla dyke construction has generally changed water circulation in the Kerch Strait. Under the impact of the Southern winds, the Black Sea water falls into the Taman Bay having passed through the Pavlov Pass only, i. e., through a pit along the Strait (the Tuzla Island — the Chushka Spit) and not through the Tuzla gully. As a result and under the Southern winds impact, a typical cyclone-type circulation (counterclockwise) for the bay area changes into its opposite — an anti-cyclonic, which contributes to accumulation of suspended particles in the bay to eventually result in its silting. In addition, the dyke unfinished construction presents an obstacle for the Black Sea flows and triggers Southern development of reverse flows along the Taman coastline under the Southern winds impact, as well as a local anti-cyclonic gyre build-up in the strait Southern part (from the Black Sea side of the dyke).

3.7. Water exchange between the Black and Azov Seas

According to the annual average long-term data from 1923 till 1985, the water flow from the Azov to the Black Sea through the Kerch Strait is 49.8 km^3/year having a maximum of 71.2 km^3/year (142 % of the average were observed in 1979) and a minimum of 35.2 km^3/year (71 % of the average were observed in 1973). The water flow from the Black Sea averages 33.4 km^3 and varies from 20.6 km^3 registered in 1923 to 46.3 km^3/year reached in 1949, i. e., from 63 % to 138 % of the long-term annual average, respectively. The produced water exchange is directed from the Azov to the Black Sea and averagely sustains 16.4 km^3/year, while its maximum of 48.8 km^3

was reached in 1932 and the minimum of 2.0 km^3 was registered in 1973. The reached maximum sustained 299% of the annual average (Altman E.N., 1987, Ilyin Yu. P, Lipchenko M.M., Dyakov N.N., 2003).

The water volumes discharged from the Black to the Azov Sea are most often larger (Simonov A.I., Altman E.N., 1991), except for spring (March-May) when the situation becomes different: discharges from the Azov to the Black Sea become prevalent (340–860 m^3/sec). This phenomenon is caused by regime of the two main rivers falling into the Azov Sea, being the Don and the Cuban. Jointly with the winds they play an important role in generating sea currents during the spring time, while the rivers high waters increase velocity of the currents from the Azov to the Black Sea. Furthermore, due to the flows higher frequency from the Azov to the Black Sea, the annually prevailing currents direction is from the Azov Sea bringing, as a result, 12–14 km^3/year of Azov water to the Black Sea on the yearly basis, calculated on data from 1923 till 1999 (Eremeev V.N. *et al.,* 2003).

A stable slowdown of the outflow from the Azov to the Black Sea was observed from 1912 to 1975, when the Azov Sea water balance sustained 28.6; 22.3; 10.6 and 5.5 km^3/year for the periods of 1912–1922; 1941–1945; 1966–1975; and 1971–1975, accordingly (Remizova S.S., 1984). Based on the recent field observations available (data collected by the Opasnoe HMS), an annual average discharge from the Black Sea registered in the Northern part of the Kerch Strait sustains 3900 m^3/sec, while the Azov Sea discharge sustains 3500 m^3/sec.

Still, the resulting flow is directed from the Azov to the Black Sea to sustain around 12 km3/year considering the flow annual average frequency. The resulting flow estimation deriving from the Azov sea water balance equation for the period after the rivers overregulation gives a slightly higher number of about 14 km3/year, while its fluctuations mainly depend upon the Don and Cuban rivers decreased water discharge (Table 3.7a), (Eremeev V.N. *et al.,* 2003).

Table 3.7a. The Azov Sea fresh-water balance and the resulting flow through the Kerch Strait (Eremeev V.N. *et al.*, 2003).

Period of averaging	1923–1998	1923–1950	1951–1998	Changes
Rivers discharge, km^3	36.5	40.5	34.7	–5.8
Precipitation, km^3	15.2	15.0	15.3	+0.3
Evaporation, km^3	33.0	33.3	32.9	–0.4
Resulting flow through the Kerch Strait, km^3	16.2	20.5	14.2	–6.3

3.8. Fluctuations of the sea level

The Kerch Strait sea level fluctuations vary by nature. The most significant in terms of their impact are the wind driven downward and upward fluctuations, while the seasonal and climatic-scope fluctuations produce the reasonably smaller amplitudes. Annually the sea level fluctuations in the Kerch Strait demonstrate a well expressed seasonal variability to reach the maximum in June and the minimum — in October. The span of those seasonal fluctuations roughly reaches 25 cm. The biggest through the year sea level changes could be registered in January-February in the Northern part of the Strait, while in its Southern part — in February-March and they are triggered by a strong sea storm activity in those places during the mentioned months. The smallest sea level changes in the Kerch Strait could be observed in August–September (Eremeev V.N. *et al.,* 2003).

The sea level long-term fluctuations are largely related to the changes in discharge from the rivers of the Azov-Black Sea basin and substantially exceed their seasonal parameters to reach 35–40 cm. Generally, the year-to-year fluctuations experienced by the Azov-Black Sea basin show a stable tendency of increase (1.4–1.7 mm/year).

Winds are the main reason for the Kerch Strait sea level meso-scale fluctuations. Their produced downward and upward fluctuations affect the sea level smooth seasonal changes through exceeding their average amplitude by 5–6 times, while reaching 8–10 times when the storm is very strong. Downward and upward fluctuations are the most often observed in the Kerch Strait Northern part under the impact of the North-Eastern wind having the highest frequency, strength and duration. On the Strait, the most dangerous conditions for the catastrophic sea level rises in such synoptic situations are those, when the Northern winds blow at the Azov Sea Northern coast, the North-Western winds — at the North-Western coast and the Western winds — at the South of the sea. The Northern narrowest part of the Kerch Strait is the border for expansion of the sea level disturbance produced by the Azov Sea downward and upward fluctuations. The Strait part to the South is affected by the Black Sea level changes. It's worth mentioning that under the impact of extreme upward fluctuations — that happen nearly once in 50 years — large parts of the Tuzla Spit could be over flooded. Energy generated by high waves in the course of the upward fluctuations is well known to be crucial for erosion of the Kerch Strait accumulative formations (Eremeev V.N. *et al.,* 2003).

3.9. Ice coverage

The Kerch strait freezes every year. However, the ice cover appears late and it is thinner on the Strait than at the Azov Sea due to the influence of the warmer waters coming from the Black Sea.

A standard practice for the winter type classification (mild, moderate and severe) is applied for the ice conditions analysis through taking into consideration the total sum of the daily air temperatures above the sea level during the icy seasons. The ice-condition main characteristics including specific dates and the ice coverage duration in the Kerch Strait Northern part (counted dependant on the winter type) are given in Table 3.9a (Eremeev V.N. *et al.,* 2003).

Statistically, based on the Opasnoe HMS long-term observations that have an 80% probability, the ice cover formation starts on the Kerch Strait on 11 January. This ice formation date could vary from 1 to 30 January depending upon a severe or mild winter, accordingly. During the moderate and mild winters, complete ice cover on the strait does not occur, while it may happen by 20 January during severe winters. Still, solid and continuous ice cover appears in the strait Northern part up to the Tuzla

Photo: The Kerch Strait in winter 2006, by *Michael Khmelkov*.

Island only, and the thickness of the fast shore ice could be of 10 cm in the Kerch inlet. Ice is usually more solid on the Taman Bay and could be 30 cm thick reaching up to 65 cm during severe winters. Ice there is mainly of local origin. It occurs in mid- or late December and forms a fixed solid stable cover during the first decade of January. The Taman Bay is not covered with ice all-over. Complete ice melting with probability of 80 % happens around 8 March. It may happen three weeks later (29 March) during a severe winter or two weeks earlier (23 February), if the winter is mild.

Table 3.9a. Average dates and probability (P, %) of ice phenomena on the Kerch Strait for the period of 1944–2003 (the Opasnoe HMS), (Eremeev V. N. *et al*., 2003).

Ice phenomena	Winter type						Average	
	Severe		Moderate		Mild			
	Date	P	Date	P	Date	P	Date	P
First ice formation	01.01	100	03.01	100	30.01	57	11.01	80
Stable ice formation	12.01	100	13.01	65	23.01	18	14.01	49
Beginning of a fast-shore ice formation	15.01	82	09.01	40	17.01	11	12.01	34
First complete freezing	13.01	91	20.01	80	27.01	14	18.01	51
Final freezing	20.01	27	–	5	–	0	28.01	7
Beginning of the fast-shore ice breaking	25.02	73	06.02	35	2.02	7	14.02	29
End of the fast-shore ice breaking	10.03	100	24.02	95	18.02	29	27.02	64
Final ice free	29.03	100	07.03	100	23.02	57	08.03	80

Sometimes in winter the Strait recurrent re-opening and freezing could happen. For example, with the North-Eastern winds and severe frosts arriving, the Strait starts acquiring relatively solid ice coverage, while with the Southern winds blowing it could become free from solid ice quite fast.

Strong Northern and North-Eastern winds build-up large accumulations of cohesive and hummocky ice (up to 4 points by the 5-point scale) at the strait Northern entrance that impede the navigation. Due to the ice potential sliding, the most dangerous for the strait navigation in winter is the turn from the Chushka to the Camush-Burun ranges, the Zerkovnaya bank area, and the North-Eastern end of the Tuzla Island (Eremeev V. N. *et al.,* 2003).

The winter 2008 was abnormally cold, similar to 2006, and the Azov Sea got covered by ice with thickness of 35–45 cm. In port Caucasus the ice was 5–10 cm. In January 2008 the air temperatures were among the lowest observed since 1891 in the area — below –23°C and often the weather was stormy with low visibility in the sea. Presently, there are no technologies of oil spill response in waters covered with ice.

Photo: The entrance to the Port of Crimea in winter 2006, by *Michael Khmelkov*.

3.10. Evolution and movement of the Tuzla Island sediment

Two main streams of sediments could be determined at the Kerch Strait that feed accumulative bodies being the stream in the North by the Chushka Spit and the Southern stream by the Tuzla Island (Fig. 3.10a).

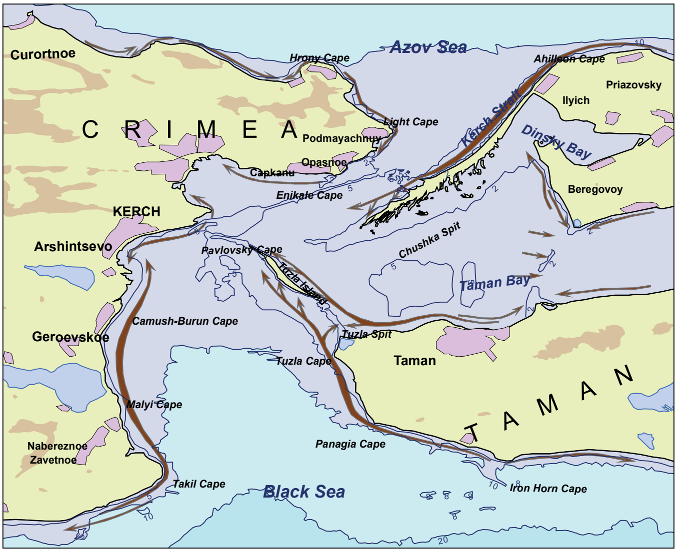


Fig. 3.10a. The main flow of sediments in the Kerch Strait (Boldyrev V. L., 1958). The thickness of arrow corresponds with the power of soil flow.

The Tuzla Spit erosion process to eventually turn the spit into an island has been protracted having started about 300 years ago. Initially, that erosion process seized a radical part of the spit to result in its thinning with a complete outbreak to follow during the Black Sea strong storm on 29 November 1925. The spit erosion material started moving towards its distant end to cause the spit growth and extension in length. After the scour formation, that material was disbursed by the both sides of the spit and the scour seabed, while being partially moved towards the spit distant end. With the scour getting wider and the current within it getting slower, as well as due to the depth reduction by the both sides of the spit resulting from the wash material silt, the spit wash-away rate went substantially down. Due to the high-bed profile by the both sides of the scour, a system of the sand banks fluctuations has emerged (Eremeev V. N. *et al.,* 2003).

Photo: The Tuzla Island, Ukraine (left) & Russia (right). Sea of Azov (top) & the Black Sea bottom), http://www.picsearch.com/info.

3.11. Conclusions

The Northern, North-Eastern, Eastern and Southern winds prevail in the near-Kerch area of the Black Sea. Dangerous for navigation, coastal and off-shore hydro-technical constructions, the North-Eastern and Eastern hurricane winds have an average velocity of 30 m/sec, while their gusts exceed 35 m/sec. However, the Southern, South-Western and South-Eastern winds could generate extreme waves provided a larger distance for their formation is available. These winds do not happen often, but possess a stronger destructive potential notorious for bringing natural disasters resulting from the atmospheric circulation in the Kerch area.

Photo: Stormy waves on 11 November 2007, Novorossiysk, Black Sea, photo by *Alexander Kuznetsov*, and ice coverage of the Kerch Strait during cold winter period in January and February, from KERCH.COM.UA.