DRAFT 15.11.2022

Russian sector

ANNUAL BULLETIN OF MONITORING THE CLIMATE STATE AND CHANGE IN THE CASPIAN SEA REGION

2021

1. DATA DESCRIPTION

1.1 For the preparation of the Bulletin, the data observed at the coastal and estuarine hydrometeorological stations/posts were used on the following characteristics (parameters):

Observation post	Air temperature	Precipitation	River inflow	Sea level	Seawater temperature
Russian Federation					
Debent	+	+		-	+
Izberg	+	+		-	+
Makhachkala	+	+		+	+
Tyuleniy Isl.	+	–		+	+
Lagan' (Kaspiisky)	–	–		+	+
Verkhnelebyazh'e village, the Volga River			+		
Kargalinsky hydrosystem, the Terek River			+		
Sulak village, the Sulak River			+		

1.2. The Bulletin uses the data from Roshydromet to characterize ice conditions in the Northern Caspian.

2. METEOROLOGICAL CONDITIONS

2.1. AIR TEMPERATURE

2.1.1 Air temperature in 2021

According to data of the meteorological stations on the Russian coast of the Caspian Sea, 2021 was unusually warm. Average annual air temperature values varied from +13,5 to +14,8°C, that exceeded the norm by 1,3…2,0°C, anomalies were 2-3 times higher than the standard deviation.

The air temperatures of the winter, spring and summer significantly exceeded the norm: in the winter – by 1.2-1.6°C; in the spring – by 1.6-2.0°C. In the spring, anomalies exceeded the values of the standard deviation by two times at the Izberg and Derbent weather stations; positive anomalies of summer temperatures amounted to 2.3-3.3°C, which 2.3-4.7 times higher than the standard deviation. In Derbent, the summer of 2021 was the hottest in the hundred-year history

of meteorological observations. The average air temperature was +26.8°C, which is 3.3°C higher than normal. 2021 went ahead there the summer of 2010 with its average temperature of +26.5°C. For Izberg, Makhachkala and Tyuleniy Island, the summer of 2010 still remains the hottest. The temperature anomalies of the autumn season ranged from -0.3 to +0.6 °C and did not exceed the values of the standard deviation (Table. 2.1.1).

Table 2.1.1 - Characteristics of the average annual and seasonal air temperature according to the data of observation posts of the Caspian region in 2021: ***T*** *– the current value of air temperature;* ***vT*** *– deviations from the long-term average for 1961-1990, ℃;* ***s*** *– the average square deviation in °C for the period 1961-1990*

The observation post	Year			Winter			Spring			Summer			Autumn		
	T	vT	s	T	vT	s	T	vT	s	T	vT	s	T	vT	s
Russian sector															
Debent	14,8	2,0	±0,7	4,4	1,5	±1,3	12,3	2,0	±0,9	26,8	3,3	±0,7	14,9	0,6	±0,9
Izberg	13,7	1,5	±0,6	3,5	1,2	±1,0	11,3	1,8	±0,9	25,6	2,3	±1,0	14,0	0,2	±0,8
Makhachkala	13,5	1,3	±0,7	2,8	1,3	±1,7	11,9	1,6	±1,1	25,7	2,3	±0,7	13,3	-0,3	±0,9
Tyuleniy Isl.	13,6	1,8	±0,9	1,2	1,6	±1,7	12,1	1,7	±1,2	27,2	3,0	±0,8	12,8	-0,3	±1,0

Ranks of the warmest years in the Russian sector of the Caspian Sea and related anomalies of the average annual air temperature are given in the table 2.1.2.

Table 2.1.2 – Ranks of the warmest /or coldest / years in the Russian sector of the Caspian Sea and related anomalies of the annual average air temperature: ***R*** *- the rank of the current values in a series ordered in descending order for positive anomalies and in ascending order for negative ones (only the first 5 ranks are shown); the period for calculating the ranks: whole observation period*

R	Year	Average annual temperature	Anomaly	Year	Average annual temperature	Anomaly	Year	Average annual temperature	Anomaly	Year	Average annual temperature	Anomaly
Russain sector												
Derbent				Izberg			Makhachkala			Tyuleniy Isl.		
1	2019	15,0	2,3	2010	14,1	1,9	1966	13,9	1,7	2010 2020	13,8	2,0
2	2021 2020 2018	14,8	2,1	2019	13,8	1,6	2010	13,8	1,6	2019	13,7	1,9
3	2010	14,7	2,0	2021 2020 2018	13,7	1,5	2020 2019	13,7	1,5	2021	13,6	1,8
4	2015	14,5	1,8	2015 2005	13,5	1,3	2018	13,6	1,4	2004 1966	13,4	1,6
5	2017	14,4	1,7	2012	13,4	1,2	2021 1981	13,5	1,3	2007 2005	13,3	1,5

In Derbent, 2021 along with 2020 и 2018 (+14,8°C) takes the second place among the ranks, while 2019 remains the warmest year since the beginning of the regular instrumental observations for the air temperature (in 1922) with the average value of +15°C, which is by 2,3 °C higher than the norm. In Izberg, 2010 remains the warmest year with the average annual temperature of +14,1°C, while 2021 together with 2020 и 2018 in the ranged series (from the warmest year to the coldest) gained the third place. The warmest years at Tyleniy Isl. stattion were 2020 и 2010 with the similar average value of +13,8°C, while 2021 (+13,6°C) took the third place. According data in Makhachkala, 2021 along with 1981 in the ranged series gained the fifths place.

Table 2.1.3 shows the records of the maximum average monthly air temperature (°C) recorded at the weather stations on the Russian coast in 2021. At Makhachkala station, the average monthly temperature in April repeated the April monthly records of 2016, 2012 and 1983 (+12.7°C), the previous record was observed in 2000 (+12.6°C). At all stations, the records of the average monthly temperature in August, observed earlier, were updated: in 2014 at stations on the western coast of the Middle Caspian Sea and in 2010, 2014 at the Tyleniy Isl. station.

Table 2.1.3 – Absolute maximum/minimum of the monthly average air temperature (°C) recorded in the Caspian Sea region in 2021

The observation post	Month	Absolute maximum of 2021	Previous maximum and a year of its occurrence	Absolute minimum of 2021	Previous minimum and a year of its occurrence
Russian sector					
Derbent	August	28,5	28,1 (2014)		
Izberg	August	27,4	27,1 (2014)		
Makhachkala	August	12,7	12,6 (2000)		
	August	27,9	27,1 (2014)		
Tyuleniy Isl.	August	28,5	27,8 (2014, 2010)		

Table 2.1.4 shows the records of the maximum monthly air temperature (°C) recorded at weather stations on the Russian coast in 2021. In May 2021, the maximum air temperature was exceeded in Derbent. On May 22nd, the maximum air temperature was + 32.5° C there, the previous maximum was recorded on May 30th in 2019 (+ 31.6°C). In June 2021, the maximum monthly air temperature was recorded at the Tyuleniy Isl. station. The maximum temperature in June was + 35.8°C, the previous maximum was recorded on June 23rd in 2015 (+35.4°C).

Table 2.1.4 – Records of monthly maximum air temperature (°C) in the Caspian Sea in 2021

The observation post	Date	Month	Air temperature, °C	Previous maximum, °C	Date of the previous maximum
Russian sector					
Derbent	22	May	32,5	31,6	30 May 2019
Tyuleniy Isl.	28	June	35,8	35,4	23 June 2015

Table 2.1.5 shows the records of the minimum monthly air temperature (°C) observed at the weather stations on the Russian coast of the Caspian Sea in 2021. On March 13th, the minimum monthly air temperature was exceeded in Izberg. The minimum temperature was -7.3°C, the previous minimum was recorded on March 12th in 2012 (-7.2°C).

Table 2.1.5 – Records of monthly minimum air temperature (°C) in the Caspian Sea in 2021

The observation post	Date	Month	Air temperature, °C	Previous minimum, °C	Date of the previous minimum
Russian sector					
Izberg	13	March	-7,3	-7,2	12 March 2012

2.1.2 Trends in the air temperature run

Table 2.1.6 presents estimates of the linear trend of average annual and seasonal air temperatures at the weather stations in the Caspian region for the period 1976-2021. According to the data observed at all weather stations on the Russian coast, there is an increase in average seasonal temperatures.

Table 2.1.6 – Estimates of the linear trend of average annual and seasonal air temperatures in the Caspian Sea region for the period 1976-2021: ***a*** *– the coefficient of the linear trend;* ***D*** *– the coefficient of determination. The trend values that are insignificant at the level of 5% are highlighted*

The observation post	Year		Winter		Spring		Summer		Autumn	
	a	D	a	D	a	D	a	D	a	D
Russian sector										
Derbent	**0,54**	0,66	**0,44**	0,24	**0,52**	0,49	**0,70**	0,63	**0,55**	0,34
Izberg	**0,39**	0,44	**0,32**	0,11	**0,49**	0,44	**0,48**	0,36	**0,35**	0,15
Makhachkala	**0,28**	0,20	**0,31**	0,08	**0,34**	0,21	**0,41**	0,28	**0,30**	0,10
Tyuleniy Isl.	**0,36**	0,40	0,28	0,06	**0,46**	0,31	**0,56**	0,50	**0,38**	0,20

The rate of the increase varies from 0.28 to 0.70°C/10 years. The increase in temperature both over the year and in particular seasons is statistically significant at all stations, with the exception of winter temperatures at Tyuleniy Isl. station. The average annual temperatures rose by an average of 0.28-0.54°C every 10 years, the trend is statistically significant.

2.2 PRECIPITATION

2.2.1 Precipitation in 2021

Table 2.2.1 presents the characteristics of annual and seasonal precipitation in 2021. Humidity showed significant variations at the stations on the Russian coast of the Caspian Sea in 2021.

Table 2.2.1 – Characteristics of annual and seasonal precipitation in 2021: *R* – *the amount of precipitation, mm;* ***RR*** **–** *the ratio of the current value to the norm for 1961-1990, %*

The observation post	Year		Winter		Spring		Summer		Autumn	
	R	RR	R	RR	R	RR	R	RR	R	RR
Russian sector										
Derbent	485,6	130,0	165,5	156,4	99,5	130,5	40,4	65,3	243,4	183,0
Izberg	363,2	132,9	100,1	163,4	59,7	108,8	33,3	54,6	221,0	228,0
Makhachkala	343,8	101,4	123,4	151,6	64,1	93,0	39,0	51,1	177,2	158,4
Tyuleniy Isl.	167,2	86,2	61,6	152,2	23,5	38,3	37,5	91,6	59,8	116,0

In Izberg and Derbent, precipitation was more than normal. The annual precipitation reached up to 363.2 mm (133% of the norm) in Izberg and to 485.6 mm (130%) in Derbent. In Makhachkala, the annual precipitation amounted to 343.8 mm, which is about the norm (101%). At the Tyuleniy Isl. station, the annual precipitation amounted to 167.2 mm (86% of the norm).

In the winter of 2021, the amount of precipitation was higher than in the other seasons and reached up to 152-163% of the norm. December 2021 was exceptionally rainy, the monthly amount of precipitation varied at different stations from 24.5 (167%) to 112.3 mm (328% of the norm). In January and February, there was a decrease in precipitation with the monthly amount of 5.2-30.7 mm (24-86% of the norm).

In spring, its amount consisted to 93-130 % of the norm on the western coast of the Middle Caspian and only 38% at Tyuleniy Isl. station. Monthly precipitation significantly exceeded the norm in March: 159% of the norm was observed in Izberg and 276% in Derbent. In April, precipitation values went down at all stations (15-35% of the norm),

Low amounts of precipitation were observed in June and August as well. The monthly precipitation was 70-74% of the norm in June, and August was exceptionally dry (only 3-14% of the norm). There was no precipitation at all on the Tyuleniy Island in August. As a result, the

seasonal amount of precipitation in the summer was: 51.1% of the norm in Makhachkala; 54.6% in Izberg; 65.3% in Derbent; 91.6% at Tyuleniy Island.

In autumn, monthly precipitation was growing over the norm and reached up to 126-196% of the norm in September and 150-449% of the norm in October. November was again significantly dry with average monthly amounts 9-45% of the norm. Seasonal precipitation amounted to 116-228% of the norm.

Table 2.2.2 shows the absolute minimal monthly precipitation (mm) recorded at the Tyuleniy Isl. weather station in 2021. According to this station data, August 2021 along with August 1983 and 1979, gained the first place in the list of the driest months during the observation period of 1959-2021. The second place with the monthly precipitation of 0.1 mm is occupied by August in 2002, 2005 and 2006.

Table 2.2.2 – Absolute maximum/minimum of precipitation (mm) recorded in the Caspian Sea region in 2021

The observation post	Absolute maximum of 2021		Previous maximum		Absolute minimum of 2021		Previous minimum	
	value	date	value	date	value	date	value	date
Russian sector								
Tyuleniy Isl.					0,0	August	0,1	August (2006, 2005, 2002)

2.2.2 Trends in precipitation

Table 2.2.3 presents estimates of the linear trend of annual and seasonal precipitation amounts at weather stations in the Russian sector of the Caspian Sea for the period of 1976-2021. On the Russian territory, there is both a decrease and an increase in seasonal precipitation amounts, but statistically insignificant.

The rate of change in precipitation amounts varies from -7.4 to 17.2 mm /10 years. In winter, there is an increase in precipitation amounts, in summer – a decrease. At the same time, the increase in precipitation amounts is much more pronounced than the decrease.

Table 2.2.3 – Estimates of the linear trend of annual and seasonal precipitation in the Caspian Sea region for the period 1976-2021: ***a*** **–** *linear trend coefficient;* ***D*** **–** *determination coefficient. The trend values that are insignificant at the level of 5% are highlighted*

The observation post	Year		Winter		Spring		Summer		Autumn	
	a	D	a	D	a	D	a	D	a	D
Russian sector										
Derbent	17,2	0,06	8,4	0,06	-1,9	0,01	-1,1	0,00	12,4	0,05
Izberg	13,1	0,08	4,4	0,02	0,3	0,00	-0,8	0,00	9,8	0,04
Makhachkala	9,1	0,02	8,2	0,07	-0,3	0,00	-3,8	0,02	5,7	0,01
Tyuleniy Isl.	-7,4	0,04	2,6	0,06	-4,2	0,04	-0,9	0,00	-4,4	0,04

3. HYDROLOGICAL CONDITIONS

3.1. RIVER INFLOW TO THE CASPIAN SEA

3.1.1 The Volga River runoff

The Volga is a river in the European part of Russia, one of the largest rivers of the globe and the largest in Europe. Its length is 3530 km (3690 km before the construction of reservoirs). The outlet of the Volga is in the Valdai Upland at an altitude of 228 m, the river flows into the Caspian Sea. The mouth lies 28 m below the ocean level. The Volga River is mainly fed by snow (60% of annual runoff), groundwater (30%) and rain (10%).

Several periods are distinguished in the long–term fluctuations of the Volga runoff: 1942-1955 - the period of relatively natural runoff of the Volga; 1956-1960 – the period of filling of large reservoirs of the Volga-Kama Reservoirs cascade; from 1962 to the present – the period of regulated runoff. At the top of the Volga delta, the average multiyear runoff of the river during the period of relatively natural runoff was 240 km^3, during the period of filling of large reservoirs – 234 km^3, during the period of regulated runoff – 242 km^3. Four periods with the different Volga runoff are distinguished within the regulated flow regime: 1) 1961-1970, water flow below the average (W=228 km^3), 2) a low-water phase in 1971-1977 (W=202 km^3), 3) a high-water phase in 1978-1995 (W=267 km^3), and 4) a phase with the water flow close to the average in 1996-2021 (W=239 km^3).

During the instrumental observation period, the maximum annual runoff volume was 333 km^3 (1994), the minimum was 166 km^3 (1975).

The main part of the river runoff falls into the spring flood season.

In conditions of natural runoff, the share of spring flood runoff was 60% of the annual runoff, today – 37%. The regulation of the Volga runoff has led not only to the reduction in the volume of spring flooding, but also to the increase in winter water discharge. The main characteristics of the spring-summer flood have changed: the maximum flood discharge has decreased, the peak of the flood in regulated conditions is observed 20 days earlier than in the natural conditions. The duration of the flood decreased from 109 days in the natural regime to 74 days in regulated conditions, the main reduction occurred at the phase of the flood rise – its duration decreased by 22 days. In 2021, the annual flow of the Volga according to the data of the Verkhnelebyazh'e was 208 km^3, which is less than the average value (242 km^3).

A characteristic feature of the water regime in 2021 was low water discharge throughout the year, and the average monthly water runoff was around the average multiyear value only in May. The largest negative deviation occurred in February (K=0.7) (Table 3.1.1).

Table 3.1.1 – Water discharge at the top of the Volga Delta (m^3/s) and modular coefficients (K) in January-December 2021

Parameter	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
Q av. in 2021	5280	4510	5230	6620	17700	10900	5120	5100	4840	4630	4640	4700	6605
Q av. multiyear in 1962-2020	5693	6061	6619	7921	17781	12144	6665	5904	5583	5495	5732	6135	7683
K in 2021	0,9	0,7	0,8	0,8	1,0	0,9	0,8	0,9	0,9	0,8	0,8	0,8	0,9
Q max in 2021	5960	5020	5610	15600	19700	16700	5330	5290	5080	4690	4690	4770	19700
Q min in 2021	4590	3910	4800	4800	16000	5370	4970	4920	4620	4580	4600	4660	3910

Note: modular coefficient is a ratio between the parameter in a single year and its multiyear average

3.1.2 The Terek River runoff

The Terek River is one of the major rivers in the Northern Caucasus. Its outlet is located on the slope of the Main Caucasian Ridge in the Trusovsky gorge, from the glacier of Mount Zilga-Khokh. The height of the outlet is 2,713 meters above the ocean level, the total length of the river along the dug and straightened channel through the Agrakhan peninsula is 586 km, the catchment area is 37400 km^2. The Terek River is fed by mixed water from the melted glaciers and snow, as well as groundwater and rainfall.

The flow of the Terek is almost unregulated. Therefore, the Kargalinsky hydrosystem is referred to as having a natural flow regime. The average multiyear water discharge is 215 m^3/s as calculated for the period of 1965-2020 based on the data of the Kargalinsky hydrosystem station, and the average annual flow is 6.776 km^3.

Over the entire observation period, the maximum annual runoff was 11.4 km^3 as observed in 2005, and the minimum was 2.6 km^3 in 1976.

The average annual water discharge in 2021 was 277 m^3/s, and the annual flow was 8,733 km^3. The maximum discharge was observed in June in 2021, the lowest in April (Table 3.1.2).

Table 3.1.2 – Water discharge of the Terek River (the New Terek branch) at the Kargalinsky hydrosystem station (m^3/s) modular coefficients (K) in January-December 2021

Parameter	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
Q av. in 2021	207	200	175	124	273	453	390	309	236	410	298	249	277
Q av. multiyear: 1965-1967, 1971-1998, 2001-2020	175	179	186	147	194	349	396	275	178	152	165	184	215
K in 2021	1,2	1,1	0,9	0,8	1,4	1,3	1,0	1,1	1,3	2,7	1,8	1,4	1,3
Q max in 2021	217	214	207	532	777	922	930	669	527	687	311	308	930
Q min in 2021	200	189	108	60,1	103	198	174	115	128	304	277	202	60.1

Long-term fluctuations of the Terek flow

The flow of the Terek is determined by the climatic conditions prevailing in its watershed. The analysis of multiyear data on its average annual water discharge based on difference-integral curves allows us to distinguish two periods:

– 1965-1996 – period with its relatively low runoff;

– 1997-2021 – period with its increased runoff.

The average amount of precipitation had a positive anomaly of 34.6 mm in reference to the norm (1961-1990) in the period 1997-2021, which corresponded to the period of increased water flow of the Terek River. In the phase of reduced water flow of 1965-1996, the anomaly of the average annual precipitation calculated for this period was only 0.3 mm in reference to the norm.

The general warming of the climate and the increase in humidity resulted in growing flow of the Terek River (Figure 1).

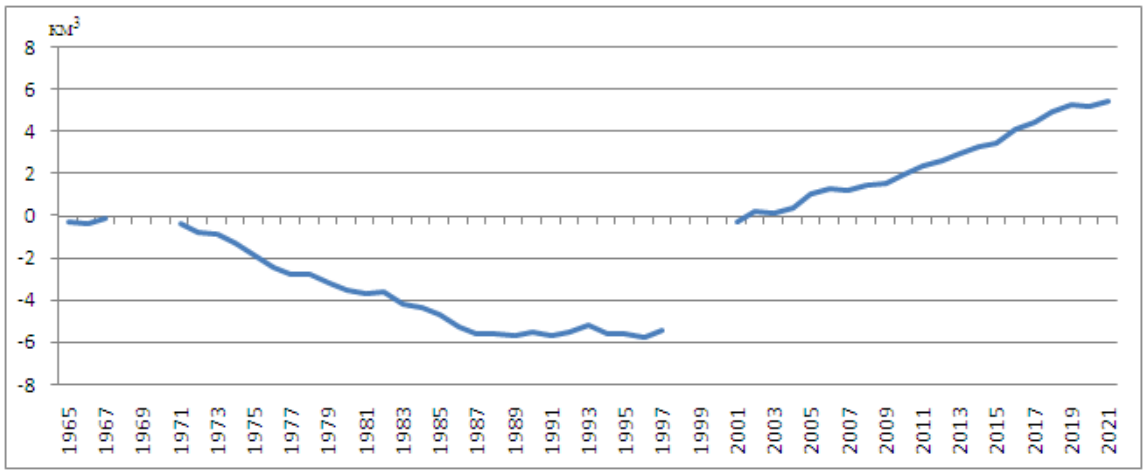


Fig. 1. Difference-integral curves of the Terek runoff at the Kargalinsky hydrosystem station for the period of 1965-2021

3.1.3 The Sulak River runoff

The Sulak is a river in Dagestan. Length – 169 km, catchment area – 16620 km^2. It is formed by merging the Avar Koysu River and Andian Koysu River. It flows to the Caspian Sea and forms a delta. The river feeds in a mixed way with a predominance of snow.

The flow of the Sulak River is regulated by a cascade of reservoirs. The largest of them is the Chirkei reservoir, which determines the entire flow regime of the river. Therefore, the intra-annual distribution of its runoff is disrupted and depends on human economic activity. The average annual water discharge of the Sulak River as calculated for the period 1976-2020 is 151 m^3/s, and its average annual water runoff is 4,762 km^3. The maximum annual runoff was 7,761 km^3 as observed in 2002, the minimum of 2,680 km^3 was observed in 1996.

In 2021, the average annual water discharge was 134 m^3/s, and the annual flow was 4,226 km^3. The maximum discharge was observed in September, the lowest in May (Table 3.1.3).

Table 3.1.3 – Water discharge of the Sulak River at the Sulak village station (m^3/s) and modular coefficients (K) in January-December 2021

Parameter	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
Qav. in 2021	119	146	144	134	118	128	125	125	129	206	118	116	134
Qav. multiyear: 1976-1985, 1988-1993, 1995-1997, 2000-2005, 2009, 2010, 2012-2020	143	153	139	129	166	204	187	150	118	120	140	156	151
K in 2021	0,83	0,95	1,04	1,04	0,71	0,63	0,67	0,83	1,09	1,72	0,84	0,74	0,89
Qmax in 2021	136	153	147	141	135	134	130	130	352	339	124	122	136
Qmin in 2021	108	137	141	128	77,3	117	122	115	96,3	127	111	114	108

3.2. THE LEVEL OF THE CASPIAN SEA

3.2.1 The sea level in the Russian sector in 2021

The water level sharply fell down by 22...27 cm in the north-western part of the Caspian Sea in 2021 compared to the previous year (Table 3.2.1). The main reason for this decrease was the low inflow of the Volga River in 2021 (208 km^3), which was significantly lower than the multiyear norm (242 km^3) and its inflow in 2020 (280 km^3).

Table 3.2.1 – Average monthly and yearly sea level (cm) in the Russian sector in 2020 and 2021

Period	Month												Yearly average
	1	2	3	4	5	6	7	8	9	10	11	12	
Russian sector													
Makhachkala													
2020	-22	-16	-14	10	-5	11	8	-6	-6	-12	-18	-18	-7
2021	-25	-31	-28	-27	-23	-18	-20	-24	-36	-37	-42	-42	-29
Tyuleniy Isl.													
2020	-33	-26	-8	-19	-9	6	4	-11	-6	-2	-11	-13	-11
2021	-23	-38	-34	-30	-26	-21	-28	-28	-43	-42	-51	-46	-34
Lagan’													
2020	-12	0	32	11	21	45	33	16	28	38	14	15	20
2021	5	-22	-12	-3	16	14	-6	5	-27	-11	-25	-19	-7

The shallow western part of the Northern Caspian is characterized by severe upsurges induced by prevailing, especially in the cold season, storm winds of eastern and south-eastern directions. In 2021, the maximum annual water levels were caused by these storm winds, and

the minimum annual levels were caused by downsurge induced by winds of western directions (W, NW, SW).

Wind-driven sea level fluctuations in the Northern part of the Caspian Sea

6 upsurges with 34...62 cm rise in sea level, which though did not exceed the dangerous limit were observed at Tyuleniy Isl. station in the period from January to December of 2021. 63 cases of wind-driven surges were registered at Lagan' station: 28 upsurges and 35 downsurges that did not exceed the dangerous mark. The most significant surge phenomena:

- March 14-17, there was an increase in the water level by 88...110 cm in the north-western part of the Caspian Sea. On March 16, annual highest levels were recorded at Tyuleniy Island and Lagan stations (35 and 107 cm, respectively);

- March 23, 24, there was an increase in the water level by 41...72 cm caused by the eastern direction of the wind (gusts up to 15-16 m/s);

- March 25-29, a drop in the water level by 54...82 cm was recorded, caused by the western and southwestern winds, the maximum wind speed reached up to 15-18 m/s. On March 26, the minimum annual level (-99 cm) was recorded in Lagan'.

- October 19-21 and 26, 27, the water level fell down due to the steady north-western wind (up to 16-18 m/s) by 42...68 cm in the first case and by 34...61 cm in the second case;

- November 4-7, there the water level rose up due to the steady wind of the eastern quarter (E, NE, SE). On November 6, gusts reached up to 18 m/s, and the average daily wind speed was 12.3 m/s. The magnitude of the surge reached 44...87 cm cm;

- December 8-9 and 13-16, there was an increase in the east and south-east winds with gusts up to 16-18 m/s. The level rose up to 52...82 cm and 44 ... 115 cm, respectively.

On October 25, the level reached a dangerous limit on the western coast of the Middle Caspian Sea at Makhachkala station, this downsurge was induced by the north-western wind with speed of 20 m/s. This was the minimum annual level (-63 cm, which is 13 cm below the dangerous mark). The mark of -50 cm is referred to as the "Dangerous phenomenon" criterion for Makhachkala station. In January, February, March, September, November of 2021, the minimum monthly levels (-45...-49 cm) approached this criterion in Makhachkala.

3.2.2 Long-term sea level fluctuations

Long-term fluctuations in the Caspian Sea level are mainly explained by climatic changes in the water balance of the sea, primarily river inflow to the sea. Comparison of runoff data (Verkhnelebyazh'e station) with the run of the average annual sea levels (Tyuleniy Isl. station) shows a general relationship between them: sea level rises in high-water periods and falls in low-

water ones. There are three periods in the long-term fluctuations of the level: the period of sharp level fall (1941-1977), the period of sharp level rise (1978-1995) and the third one – from 1996 to the present.

In 1977, the level fell to the lowest mark for the entire time of instrumental observations (-29.0 m abs) decreasing by 1.7 m compared to the previous period. In 1995, the level increased to the highest mark -26.63 m abs, the rise reached up about 2.26 m by 1995. After 1995, there were periods of falling, rising and stabilization of the level. In general, the level decrease was 148 cm compared to 1995, reaching in 2020 and 2021 -28.11 and -28.34 m abs, respectively (Figure 2).

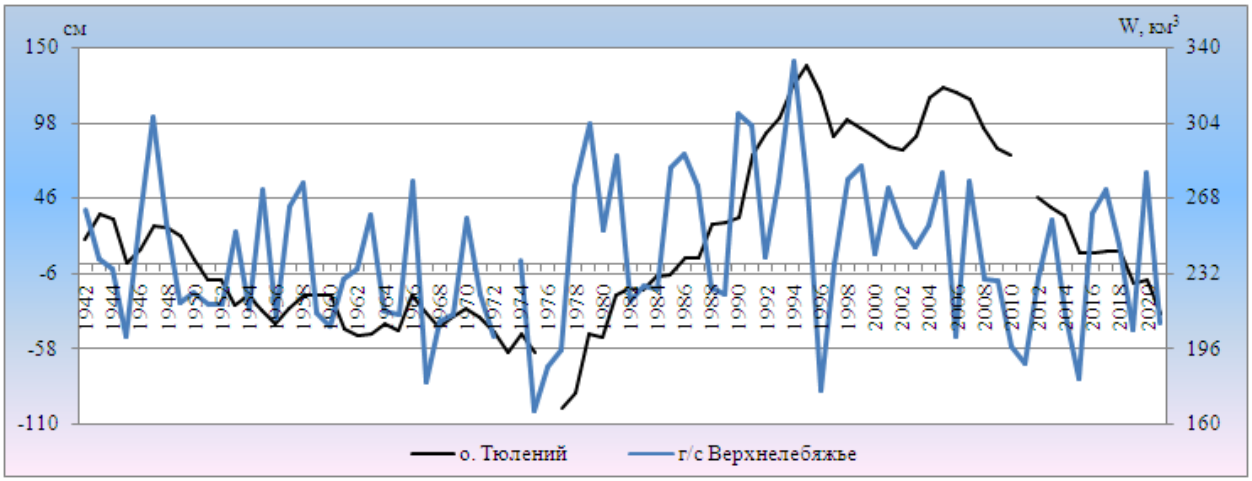


Figure 2. Average annual values of the Volga River discharge at Verkhnelebyazh'e station and the sea level at Tyuleniy Island station

3.3. SEAWATER TEMPERATURE

3.3.1 Seawater temperature in the Russian sector of the Caspian Sea in 2021

In 2021, the average annual seawater temperature at marine stations in the Russian sector of the Caspian Sea varied from +14.2 to +14.7°C, which is 1.1...2.1°C higher than normal, the values of anomalies were 1.6-2.6 times higher than the standard deviation. The water temperature in the spring and summer significantly exceeded the norm. In the spring, they were 1.6-2.4°C higher, and anomalies exceeded the standard deviation by 1.3-1.8 times. Positive anomalies of summer temperatures amounted to 2.2…3.3°C, which is 3-4 times higher than the standard deviation.

The seawater temperature shows noticeable seasonal fluctuations and has a well-defined annual run. The average water temperature varied from 1.4…2.3°C in the cold season to 27.0…27.8°C in the summer months in the northwestern part of the sea. The average water

temperature varied from 4.1-4.6°C in the cold season to 25.4-25.7°C in the summer on the western coast of the Middle Caspian (table 3.3.1).

Table 3.3.1 – Characteristics of the average annual and seasonal seawater temperature according to the data of observation points of the Caspian region in 2021: ***T*** **–** *the current seawater temperature;* ***vT*** **–** *deviations from the multiyear average for 1961-1990, ℃;* ***s*** **–** *the standard deviation in °C for the period 1961-1990*

The observation post	Year			Winter			Spring			Summer			Autumn		
	T	vT	*s*	T	vT	*s*	T	vT	*s*	T	vT	*s*	T	vT	*s*
Russian sector															
Derbent	14,5	1,2	±0,7	4,6	0,3	±1,3	11,2	1,8	±1,0	25,7	2,4	±0,7	16,0	-0,1	±0,9
Izberg	14,2	1,1	±0,7	4,2	0,3	±1,1	11,1	1,9	±1,1	25,5	2,4	±0,6	15,4	-0,8	±0,9
Makhachkala	14,7	2,1	±0,8	4,1	0,9	±1,2	11,6	2,4	±1,3	25,4	3,3	±0,8	16,3	1,0	±0,9
Tyuleniy Isl.	14,3	1,4	±0,6	2,3	0,8	±1,0	13,6	1,7	±1,2	27,0	2,2	±0,6	13,2	0,0	±1,0
Lagan’	14,3	1,5	±0,8	1,4	0,2	±0,6	13,7	1,6	±1,2	27,8	2,8	±0,8	13,4	0,8	±1,1

Table 3.3.2 shows the ranks of the warmest years in the Russian sector of the Caspian Sea and the corresponding anomalies of the average annual seawater temperature.

An average annual record of seawater temperature has been set in Makhachkala. The annual temperature was +14.7°C, the previous record was observed in 1966, 2018 and 2019 (+14.1°C). The annual water temperature at Tyuleniy Isl. station was +14.3°S in 2021, which takes the second place in the list of records after the value in 2019 (+ 14.4S). In Derbent and Lagan, 2021 took the third place in the ranked series of observations (from the warmest year to the coldest), positive anomalies amounted to 1.2 and 1.5° C, respectively.

Table 3.3.3 shows the records of the maximum average monthly water temperature (°C) recorded at observation posts in the Russian sector in 2021.

In Derbent, the maximum of monthly average water temperature was updated in April 2021 (+12.5°C), the previous record was observed in April 2000 (+11.9°C). At the Makhachkala station, the average monthly water temperature in April repeated the highest average temperature observed in April 1962 (+12.2°C), which is 0.2°C higher than the record of 2000 (+ 12.0°C). At Izberg, Makhachkala and Tyuleniy Isl. stations were updated records of the average monthly temperature in August 2021.

Table 3.3.2 – Ranks of the warmest /or coldest / years on the Russian coast of the Caspian Sea and related anomalies of the annual average seawater temperature: *R* - *the rank of the current values in a series ordered in descending order for positive anomalies and in ascending order for negative ones (only the first 5 ranks are shown); the period for calculating the ranks: whole observation period*

R	**Year**	**Average annual temperature**	**Anomaly**	**Year**	**Average annual temperature**	**Anomaly**	**Year**	**Average annual temperature**	**Anomaly**	**Year**	**Average annual temperature**	**Anomaly**	**Year**	**Average annual temperature**	**Anomaly**
Russian sector															
	Derbent			Izberg			Makhachkala			Tyuleniy Isl.			Lagan’		
1	2018, 1981	14,7	1,4	2002, 1966	14,5	1,4	2021	14,7	2,1	2019	14,4	1,5	1989	14,5	1,7
2	2002	14,6	1,3	2004, 1981	14,3	1,2	2019, 2018, 1966	14,1	1,6	2021	14,3	1,4	2012	14,4	1,6
3	2021, 2019, 2010, 2001	14,5	1,2	2021, 2010, 2005, 2001	14,2	1,1	2002	14,0	1,5	2012	14,2	1,3	2021, 2005	14,3	1,5
4	2005, 1995	14,4	1,1	2019, 2018, 1995	14,1	1,0	2010, 2005	13,9	1,4	2020	14,1	1,2	2019, 2015, 1974	14,2	1,4
5	2020	14,3	1,0	2000, 1990	14,0	0,9	2004	13,8	1,3	2010, 1966	14,0	1,1	2016, 2017	14,1	1,3

Table 3.3.3 – Absolute maximum/minimum of the monthly average seawater temperature (°C) recorded in the Caspian Sea region in 2021

The observation post	Month	Absolute maximum of 2021	Previous maximum and a year of its occurrence	Month	Absolute minimum of 2021	Previous minimum and a year of its occurrence
Russian sector						
Derbent	April	12,5	11,9 (2000)			
Izberg	August	27,2	26,4 (2005, 2006)			
Makhachkala	April	12,2	12,0 (2000)			
	August	27,5	27,1 (1999)			
Tyuleniy Isl.	August	28,4	27,3 (2010)			

Table 3.3.4 shows the records of the maximum monthly water temperature (°C) recorded at observation posts in the Russian sector of the Caspian Sea in 2021. In Izberg, the maximum monthly water temperature reached up to +29.0°C in September and exceeded the previous maximum recorded in September 2003 (+28.6°C). In Makhachkala, three records of the maximum monthly water temperature were set: in April, in June and in August 2021.

Table 3.3.4 – Records of monthly maximum seawater temperature (°C) in the Caspian Sea region in 2021

The observation post	Date	Month	Seawater temperature, °C	Previous maximum, °C	Date of the previous maximum
Russian sector					
Izberg	1	September	29,0	28,6	4 September 2003
Makhachkala	30	April	17,1	16,6	April 1976*
	28	June	29,4	28,6	30 June 2018, 25 June 2019
	11	August	30,9	30,2	22 August 1999

*State Water Cadastre of the USSR 1976. Marine Yearbook, vol. I. Baku 1977 (Table 2.1 shows only the average weekly and monthly values)

Table 3.3.5 – Records of monthly minimum seawater temperature (°C) in the Caspian Sea region in 2021

Not observed in 2021

The observation post	Date	Month	Seawater temperature, °C	Previous maximum, °C	Date of the previous maximum
Russian sector					

3.3.2 Trends in seawater temperature run

Table 3.3.2 presents estimates of the linear trend in average annual and seasonal water temperatures at the observation posts in the Russian sector of the Caspian Sea for the period of 1961-2021 (for Izberg, Makhachkala and Tyuleniy Isl. stations), 1975-2021 (Lagan'), 1977-2021 (Derbent).

According to all weather stations in the Russian sector, the average seasonal temperatures were rising over those periods. The rate of the increase varies from 0.08 to 0.56°C/10 years. The trends both over the year and in particular seasons are statistically significant at all stations, with the exception of winter temperatures at Derbent station, spring temperatures at Tyuleniy Isl. station and autumn temperatures at the Izberg station. The average annual temperatures have been increasing by an average of 0.16-0.42°C every 10 years, which is statistically significant.

Table 3.3.2 – Estimates of the linear trend of annual and seasonal seawater temperature in the Caspian Sea region for the period of 1976-2021: ***a*** **–** *linear trend coefficient;* ***D*** **–** *determination coefficient. The trend values that are insignificant at the level of 5% are highlighted*

The observation post	Year		Winter		Spring		Summer		Autumn	
	a	D	a	D	a	D	a	D	a	D
Russian sector										
Derbent	**0,27**	0,29	0,14	0,03	**0,34**	0,18	**0,31**	0,15	**0,26**	0,11
Izberg	**0,16**	0,20	**0,12**	0,04	**0,33**	0,25	**0,22**	0,24	0,00	0,00
Makhachkala	**0,23**	0,25	**0,20**	0,09	**0,20**	0,08	**0,31**	0,21	**0,23**	0,15
Tyuleniy Isl.	**0,17**	0,21	**0,10**	0,04	0,08	0,04	**0,21**	0,23	**0,29**	0,21
Lagan'	**0,42**	0,60	**0,22**	0,23	0,35	0,21	**0,55**	0,47	**0,56**	0,39

4. ICE CONDITIONS

The Caspian Sea annually freezes only in its shallow northern part. According to the maps of the ice cover of the Hydrometeorological Center of Russia, primary ice was observed in the area of the Volga delta on 30 November 2020. Ice fringe, 8-10 cm thick, was seen to the east of the Volga delta near the sea coast, there was also gray drifting ice and light nilas after the fringe seawards.

According to the monitoring data, ice formation in the Lagan' area began on November 28, in the area of Iscusstvenny Isl. post on December 4 (Fig. 3).

Lagan' area was completely frozen on December 5, while the area around Iscusstvenny Isl. on December 11. The minimum temperature at night dropped to -5.0...-8.7 °C on December 24, 25, and then ice cover started to develop actively in the Northern Caspian (Fig. 4).

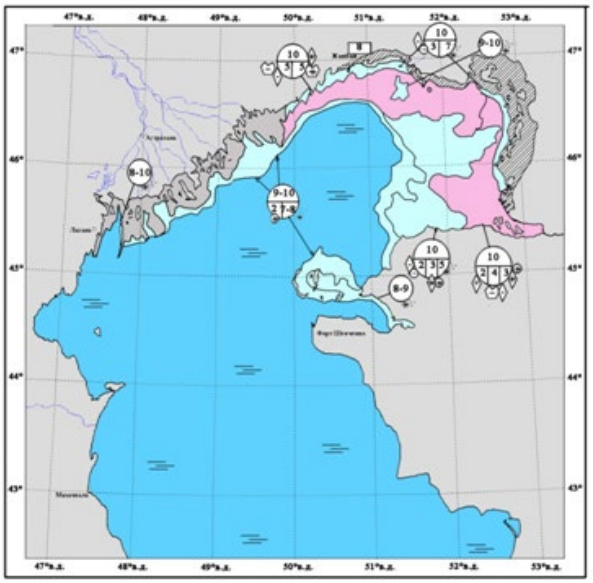


Fig. 3. Map of the ice cover on 30 November 2020

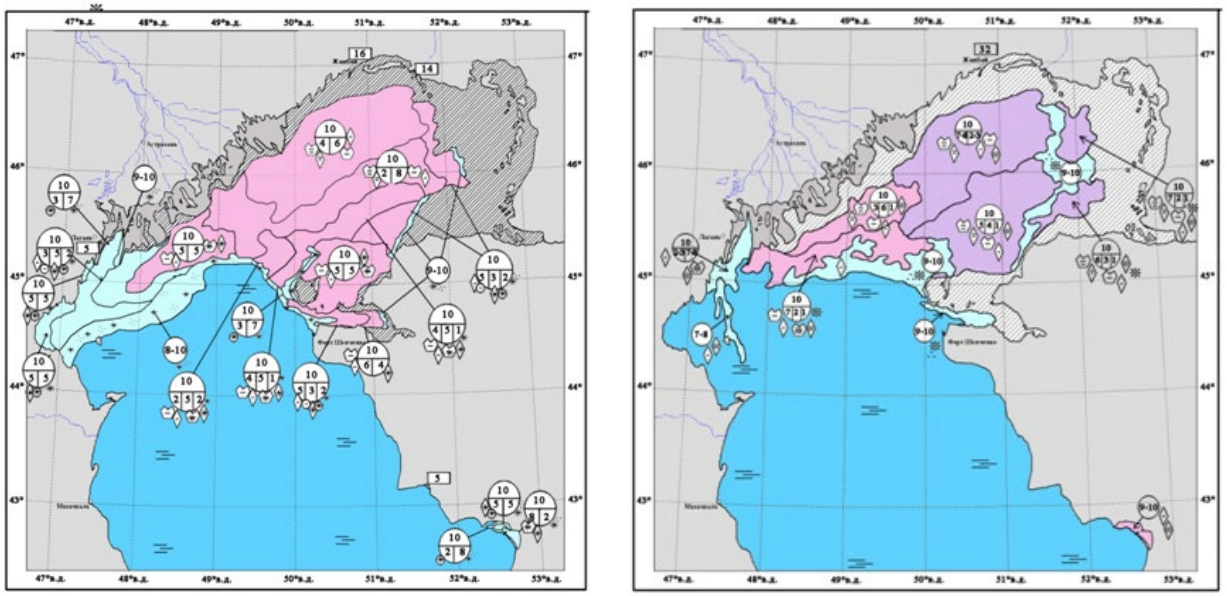


Fig. 4. Map of ice cover on 7 and 23 December 2020

The largest area of ice cover was observed in the first decade of December 2020, when the ice spread to the entire pre-estuary area, partially covering the south-western area and the central shallow part of the Northern Caspian. The maximum thickness of ice at Iscusstvenny Isl. reached 13 cm as observed on 24-26 December 2020.

In the second and third decades of January, ice was spread over more than 60% of the area of the Northern Caspian. Ice foot, 3-5 cm thick, was observed in the north-west of the sea, in the area of Lagan', dark and light nilas were seen further seaward and in the area of the Volga-Caspian Shipping Channel. The ice edge was observed to the north of Tyuleniy Island. In the

area of Iscusstvenny Island, the ice foot was 10-12 cm thick (Fig. 5).

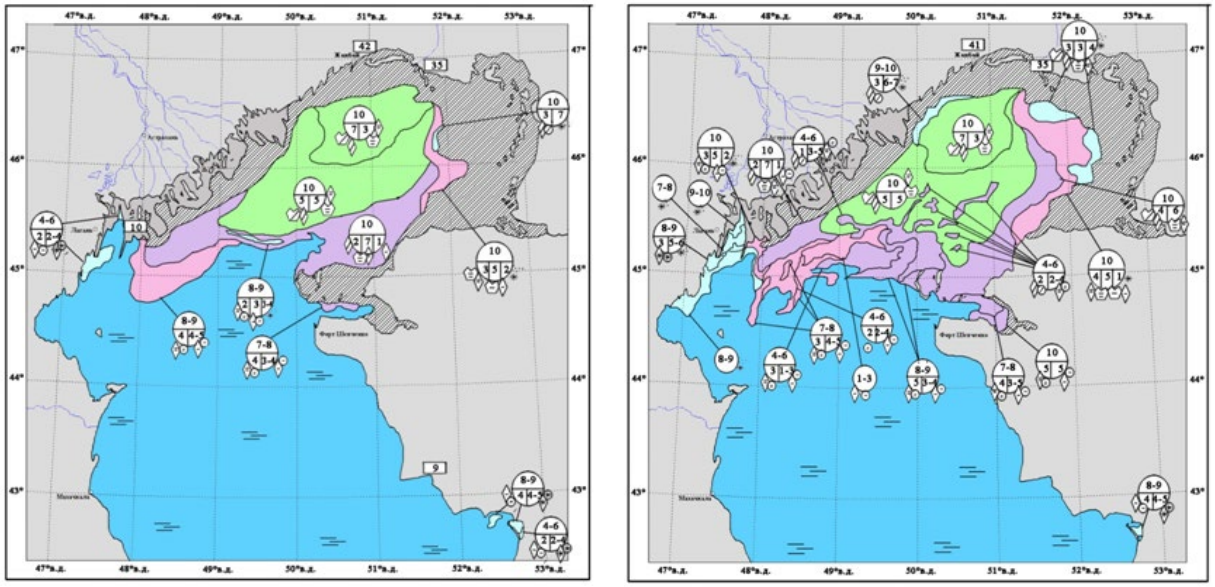
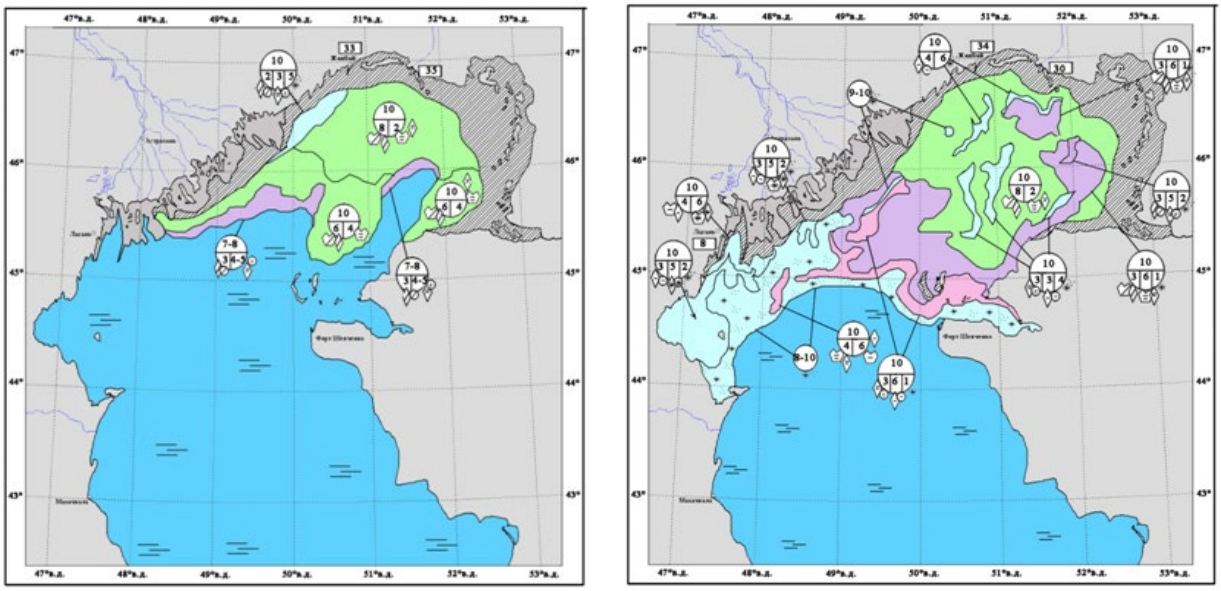


Fig. 5. Maps of the ice cover on 11 and 19 January 2021

The first decade of February has unusually warm weather; ice intensely melted, and its cover area shrank. In the south-western part of the Northern Caspian, "clean water" was observed. In the middle of the third decade of February, the northern part of the sea was affected by an Arctic anticyclone, which brought frosty weather. The minimum air temperature dropped to -11.9... -17.7°C. This resulted in resumption of intense ice formation, which spanned the entire northern part of the Caspian Sea. The ice coverage in the third decade of February became the maximum in the ice season of 2020/2021 in the Caspian Sea. The maximal ice thickness in the Lagan' area was recorded on 26 February 2021 (14 cm) (Fig. 6).

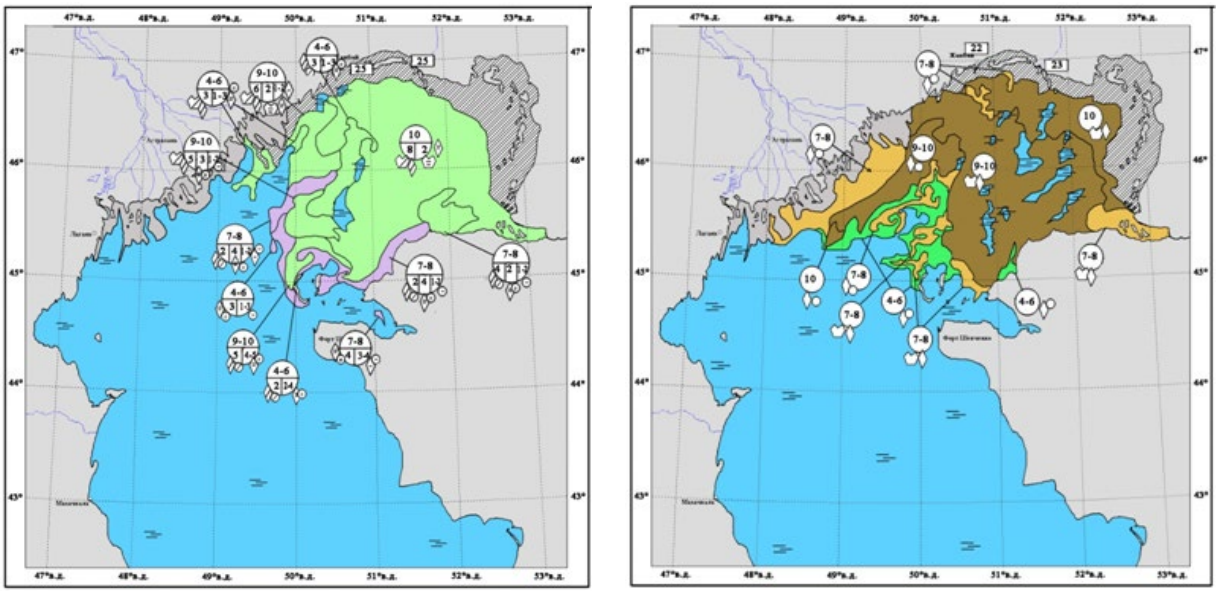


9 February 2021 **23 February 2021**

Fig. 6. Maps of ice cover in February 2021

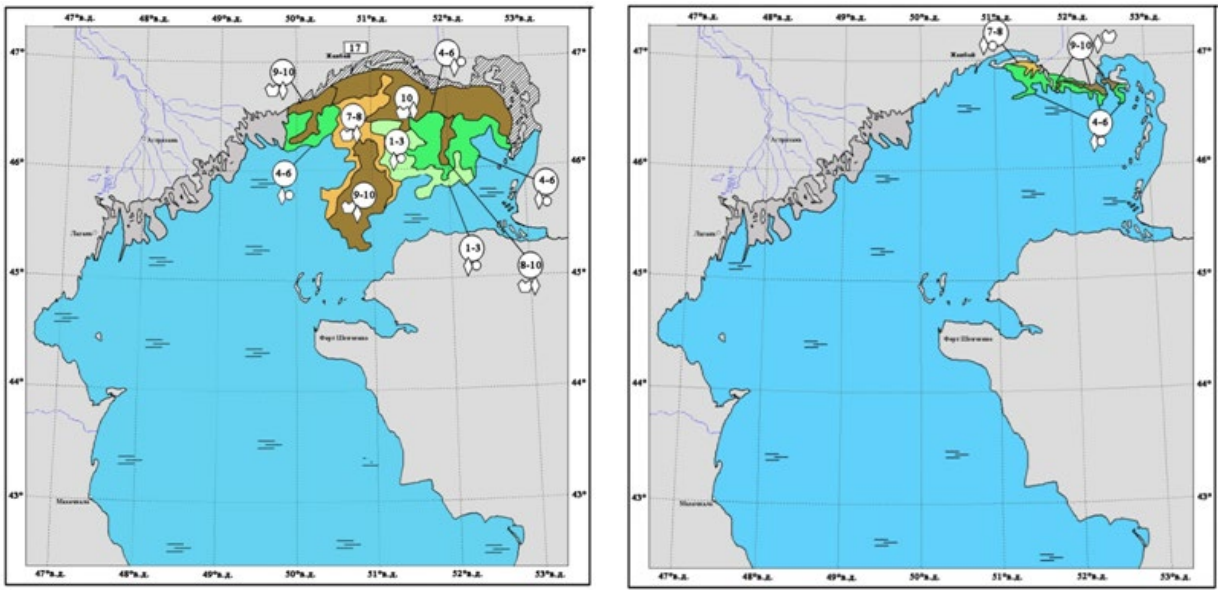
The invasion of cold arctic air in the second decade of March caused a sharp drop in air temperature. Though intense melting and destruction of ice cover was observed in the first decade of March, the processes of ice formation intensified again in the middle of the month (Fig. 7 and 8).

The Northern Caspian was practically cleared of ice at the end of March, only a narrow zone of drifting ice with a compaction of 4-6 to 9-10 balls remained near the north-eastern coast of the sea. According to the monitoring data, the final clearing of ice was observed at Lagan' on March 7, at Iscusstvenny Isl. on March 16 (fig. 8).



8 March 2021 **15 March 2021**

Fig. 7. Maps of ice cover in the first half of March 2021



23 March 2021 **31 March 2021**

Fig. 8. Maps of ice cover in the last decade of March 2021

CONCLUSION

The year 2021 was among the five warmest years in the history of meteorological observations of air and seawater temperature.

Humidity of the Russian coastal area varied in a wide range in 2021. Precipitation exceeded normal in Izberg and Derbent, while it remained within normal limits in Makhachkala. The year of 2021 can be referred to as “dry” at Tyuleniy Isl. station as the annual value of precipitation was below normal.

In 2021, Caspian Sea level was further decreasing as observed at all posts in the Russian sector that was resulted from the low inflow of the Volga River. According to the data of its annual runoff, 2021 is among the seven most low-water years over the last quarter of a century: 1996 (176 km^3); 2006 (201,9 km^3); 2010 (196,7 km^3); 2011 (189 km^3); 2015 (181,7 km^3), 2019 (205 km^3), 2021 (208 km^3).

The winter of 2020/2021 was mild in the northwestern part of the Caspian Sea. The sum of the negative average daily temperatures for the winter season at Astrakhan station was -385.5°C, at Tyleniy station -93.0°C. Duration of the ice period at Iscusstvenny Isl. was 75 days (norm 84 days), at Lagan’ post 67 days, that did not exceed the norm. There was no ice cover on Tyuleniy Island during the entire winter period due to the unusual warm weather. In cold winters, the maximum duration of the ice period is 125 days (1984/1985) at Iscusstvenny Isl., 143 days (1997/1998) at Lagan’, 132 days (1993/1994) at Tyuleniy Isl.