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FEATURES OF SPRING ICE PHENOMENA ON BALKASH LAKE IN EXTREMELY WARM MONTHS

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In this paper we are considering the processes of ice destruction on Balkash Lake during extremely warm months. A significant correlation found between the average monthly air temperature of March and the dates of ice destruction beginning, complete freezing ending and water clear of ice. The Bagrov-Tokarev anomaly criterion for March was calculated and the extreme months were determined. The features of ice destruction during the spring season for the years with extremely warm months were analyzed. The number of days with certain types of ice phenomena are calculated, the various types of ice phenomena were analyzed for extremely warm months. The maps of ice thickness distribution were compiled. The deviation of the dates of ice destruction beginning, complete freezing ending and water clear of ice from the averages dates in extremely warm months was found.

The data source were hydrological guides, monthly average air temperature data, and data reanalysis using the CDS Copernicus climate database of the European Center.

Keywords: Extremely warm months, ice destruction beginning, complete freezing ending and water clear of ice, average air temperature, ice thickness.

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INTRODUCTION

Lake ice is being a part of the cryosphere, is influenced by climate change. It is well known that the cryosphere is a very sensitive component of the climate system. Lake ice cover period is decreasing, there is a general change of ice break-up dates in spring and ice freeze-up dates in fall (IPCC. Climate change 2013). For the period 1846-1995 in the lakes and rivers of the Northern Hemisphere, changes in freeze-up dates averaged 5.8 days per 100 years later, and changes in break-up dates averaged 6.5 days per 100 years earlier (Magnuson et al., 2000). The number of annual open-water days increased by 0.63 days per decade across the Northern Hemisphere from 1931-2005 (Andrew et al., 2021).

The role of lake ice is very important for physical, chemical and biological processes. The presence and absence of lake ice cover is important for transportation (usage of ice cover as ice roads and seasonal shipping during open-water season) (Bonsal et al., 2006). Understanding of the processes and interactions of lake ice with climate is essential for climate modelling and weather forecasting (Brown et al., 2010; Eerola et al. 2010). Lake ice phenological events as the freeze up and break up dates, ice cover duration has been shown to be good indicators of climate change and its variability (Magnuson et al., 2000; Duguay et al., 2006; Assel et al., 2003; Latifovich eta al., 2006).

Lake Balkash is a large regional water body, which has its annual ice period. The lake has its peculiarities, that affect the ice regime. The large latitudinal extent and various hydrometeorological conditions of certain areas, different mineralization of the western and eastern parts of lake determine the complex nature of the processes of ice formation and destruction in the water area.

The ice regime in the eastern part is different due to mineralization (Surface water resources of the USSR, 1970). Ice drift, piles of ice, embacles can have destructive effects on the shores, hydraulic constructions and infrastructure (Bogorodsky, 1971). The role of the ice cover is of great importance in the winter regime of the reservoir, since heat exchange between water and air occurs through the layer of ice and snow on it (Odrova, 1979). Lake Balkash is a large water object, to which a huge number of works devoted (Beilinson, 1989; Cherednichenko, Kozhakhmetova, 2009; Shivareva, et.al., 2009; Ivkina, 2015; Vilesov, 2017; Beldeubaev, Dolgikh 2019; Beldeubayev, Salnikov, 2021). It is well known that ice destruction dates observed much earlier than before in recent dates and number of extreme events became more. It is important to consider lake ice phenomena in spring in order to reveal more detailed information about ice destruction in extreme warm months.

DATA

In this work data from meteorological stations for the period 1971…2020 and data from hydrological posts for the period 1972...2020 were used. The location of meteorological stations and hydrological posts are shown on figure1. The data on ice phenomena from hydrological posts, the average monthly air temperature from meteorological stations and data of reanalysis by ice thickness ERA5-Land data (ERA5-Land hourly data from 1950 to present (copernicus.eu)).

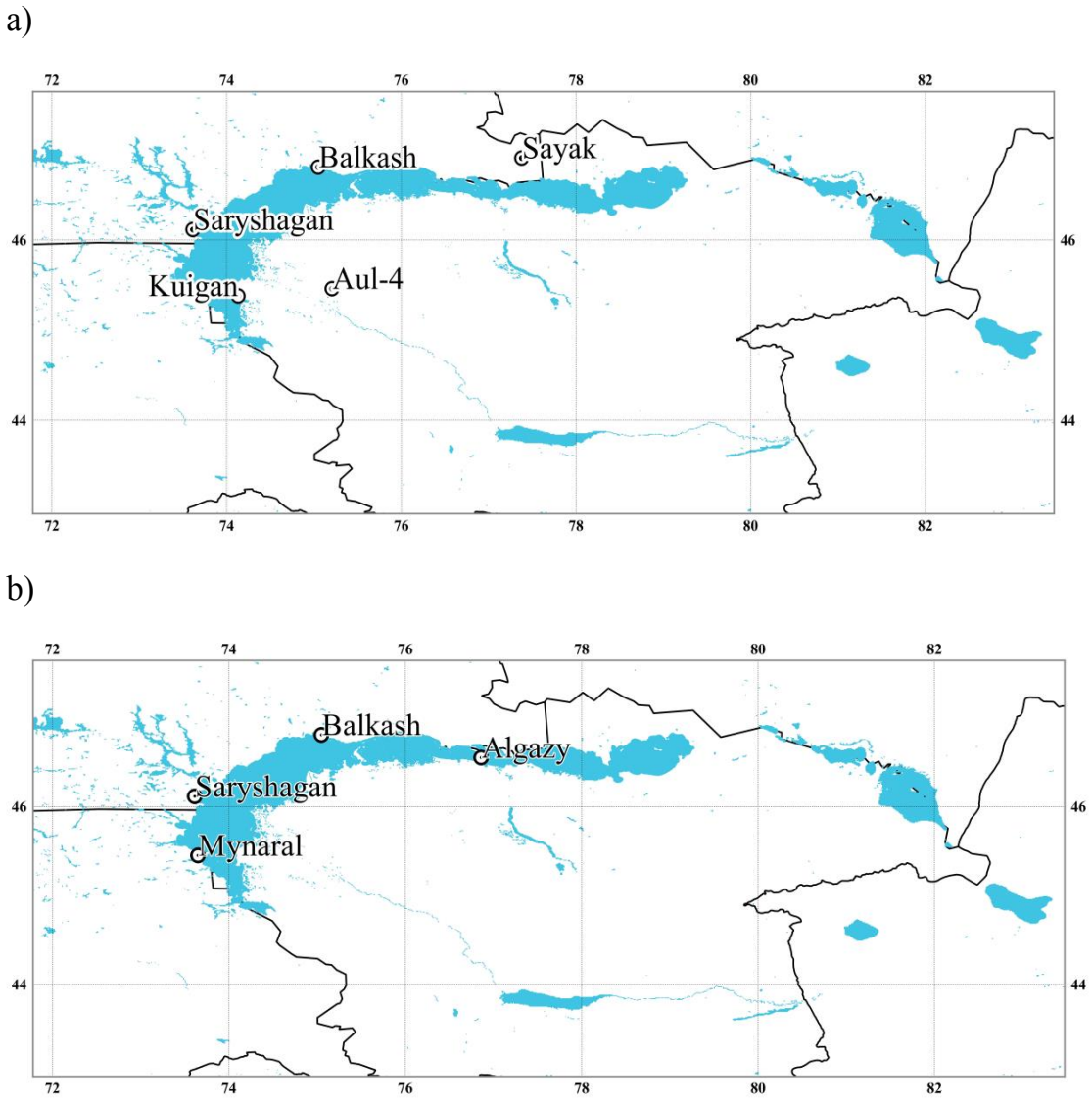


Fig. 1. *Location of a) meteorological stations and b) hydrological posts on Balkash Lake.*

Data on ice phenomena include the dates of ice destruction beginning, complete freezing ending and water clear of ice. The date of the ice destruction beginning is assumed as the date of the appearance of border meltwater, water on ice, areas of clean water (polynya) and other phenomena characterizing the change in the state of ice in the presence of complete freezing. The end of the ice formation corresponds to the date preceding the first date of the appearance of ice fields, broken ice, the beginning of ice drift under the influence of wind or ice drift (in the presence of runoff currents). For the date of clearing from ice, a day was taken from which ice events were no longer observed in this season.

RESULTS

The cold period on the lake Balkash according to 5 meteorological stations (Aul-4, Balkhash, Kurgan, Sary Shagan, Sayak) lasts from November to March (Fig. 2).

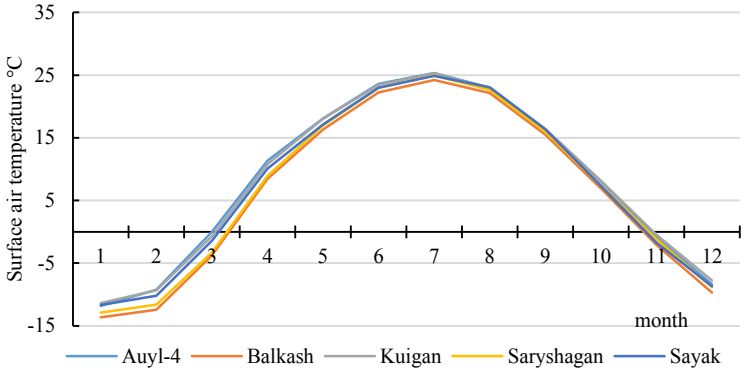


Fig.2. *Annual distribution of the average long-term air temperature for 1971-2020.*

In accordance with Figure 2, it can be seen that the distribution of the average long-term air temperature at all meteorological stations is similar. Air temperature is one of the main factors of ice formation and destruction.

The dates of the opening and the end of the complete freezing are significantly influenced by the air temperature in March. Figure 3 shows the scattering diagrams between the average monthly air temperature in March and the dates of ice destruction beginning, complete freezing ending and water clear of ice.

In accordance with Figure 3, the negative correlation between the air temperature in March and the dates of spring ice phenomena is visible. The correlation coefficient (-0,8) is significant. According to the Bagrov-Tokarev anomaly criterion (Bagrov, 1966), extremely months were calculated.

$$K_T = \frac{1}{N+M}\left[\sum_{n=1}^{N}\left(\frac{\Delta T_i}{\delta_i}\right)^2_n - \sum_{m=1}^{M}\left(\frac{\Delta T_i}{\delta_i}\right)^2_m\right] \quad (1)$$

ΔTi – temperature anomaly at the point i;

δi – mean square deviation of temperature;

N – the number of points with a positive anomaly;

M – the number of points with a negative anomaly;

Threshold values have been established for the Bagrov-Tokarev anomaly index: at K ≥ 1.15, the field anomaly is large, at K ≤ 0.75, a minor anomaly is noted and at 0.75 < K < 1.15, the anomaly has an average intensity.

The table 1 shows the years where March was extremely cold and extremely warm.

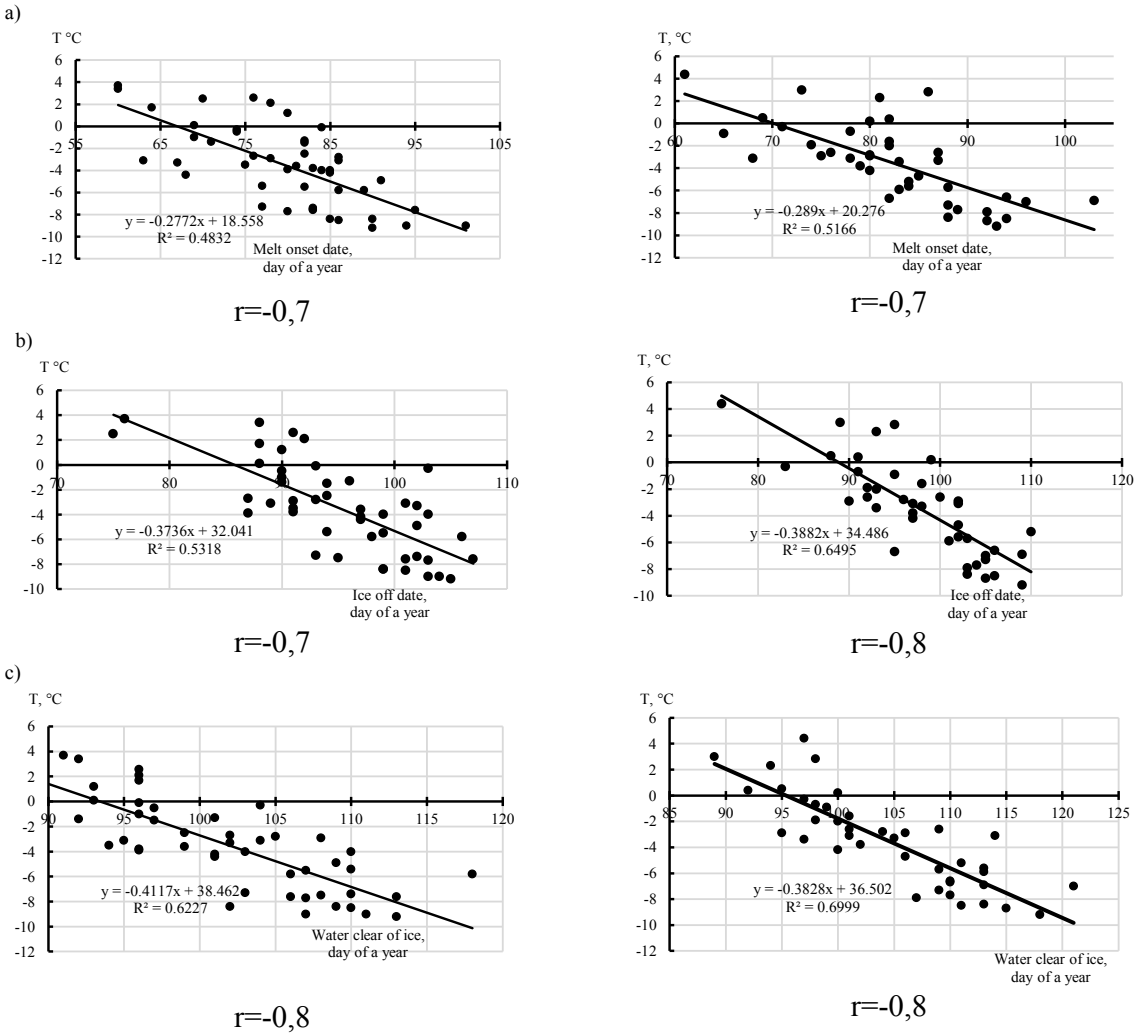


Fig.3. *Scattering diagrams between the average monthly air temperature in March and the dates of a) ice destruction beginning, b) complete freezing ending, c) water clear of ice at the hydrological posts of Balkash (left) and Saryshagan (right).*

Table 1

Extreme cold and extreme warm years for March for period 2000…2020

Extreme cold		Extreme warm	
Year	Index meaning	Year	Index meaning
1976	-2,38	2002	3,59
1979	-2,26	2005	2,27
1982	-1,71	2006	1,78
1985	-2,91	2008	2,97
1991	-1,33	2013	3,95
		2016	2,62
		2018	2,14

March was extremely warm after 2000, and the extremely cold months after 2000 were not observed.

The table 2 shows the average values of the dates of ice destruction beginning, the end of complete freezing ending and water clear of ice.

Table 2

Average dates of ice destruction beginning, complete freezing ending and water clear of ice for the period 1971…2020

Hydrological posts	Dates		
	Ice destruction beginning	Complete freezing ending	Water clear of ice
Balkash	20 March	5 April	12 April
Saryshagan	23 March	8 April	14 April
Mynaral	17 March	31 March	9 April
Algazy	25 March	8 April	17 April

According to Table 2, the average dates of the beginning of ice destruction are in the second half of March. The ice begins to open earlier at the Mynaral post – on March 17, later at the Algazy post – on March 25. The average date of the freezing ending at the Mynaral post is on March 31, and at the other posts – on April 5... 8. Clearing of water from ice begins earlier at the Mynaral post – on April 9, later at the Algazy post – on April 17. In the southwestern and western parts of the lake, the ice breaks and ends earlier than in the eastern part of the lake.

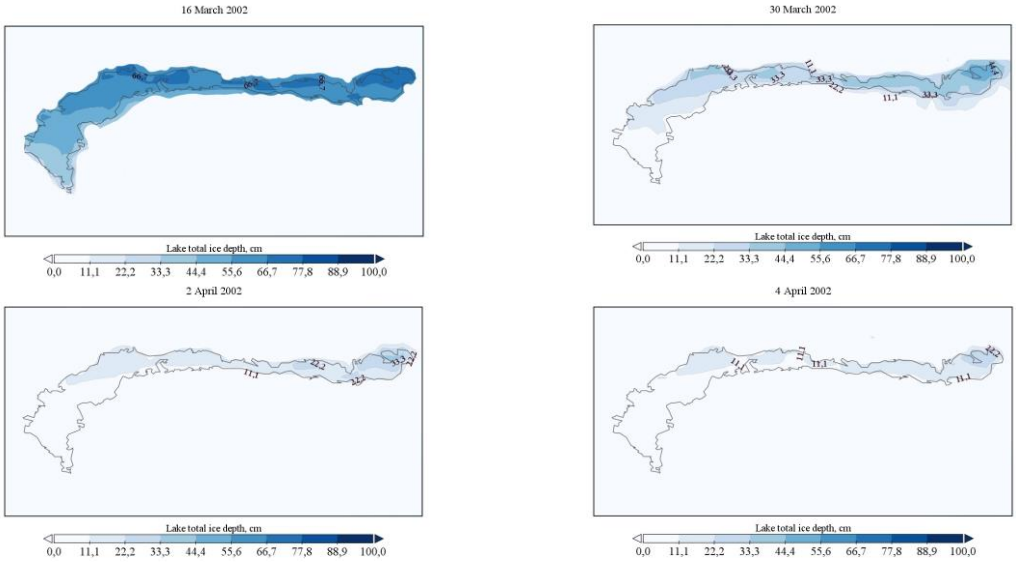
The table 3 shows the dates of spring ice phenomena and their deviations from the average dates at the posts of the lake Balkash in the years with extremely warm March.

Table 3

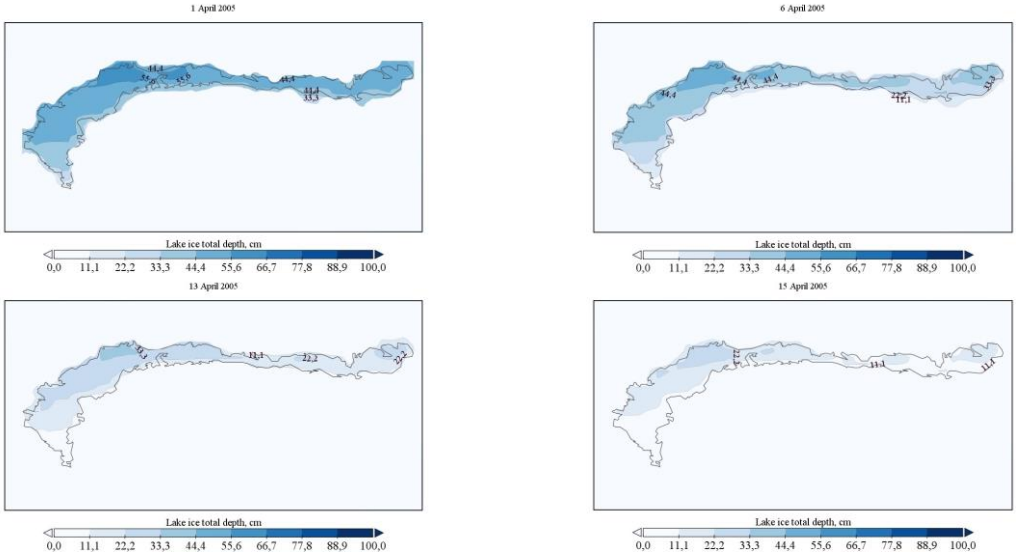
Dates of ice destruction beginning, complete freezing ending and water clear of ice in extreme warm March

Hydrological posts	Years	Dates		
		Ice destruction beginning	Complete freezing ending	Water clear of ice
Balkash	2002	1 March (-19)	29 March (-7)	2 April (-10)
	2005	19 March (-1)	2 April (-3)	6 April (-6)
	2006	5 March (-15)	29 March (-7)	6 April (-6)
	2008	16 March (-4)	31 March (-5)	6 April (-6)
	2013	1 March (-19)	17 March (-19)	1 April (-11)
	2016	10 March (-10)	15 March (-21)	30 March (-13)
	2018	21 March (1)	31 March (-5)	3 April (-9)
Saryshagan	2002	-	-	-
	2005	-	-	-
	2006	-	-	-
	2008	26 March (3)	4 April (-4)	7 April (-7)
	2013	2 March (-21)	17 March (-22)	7 April (-7)
	2016	13 March (-10)	-	29 March (-16)
	2018	22 March (-1)	3 April (-5)	4 April (-10)
Mynaral	2002	24 February (-21)	12 March (-19)	16 March (-24)
	2005	11 March (-6)	25 March (-6)	1 April (-8)
	2006	1 March (-16)	20 March (-11)	24 March (-17)
	2008	8 March (-9)	22 March (-9)	24 March (-16)
	2013	18 March (1)	24 March (-7)	26 March (-15)
	2016	14 March (-3)	24 March (-7)	25 March (-15)
	2018	21 March (4)	26 March (-5)	27 March (-13)
Algazy	2002	4 March (-21)	30 March (-9)	4 April (-13)
	2005	26 March (1)	3 April (-5)	13 April (-4)
	2006	15 March (-10)	2 April (-6)	16 April (-1)
	2008	23 March (-2)	5 April (-3)	10 April (-7)
	2013	28 March (3)	27 March (-12)	9 April (-8)
	2016	-	-	-
	2018	-	-	-

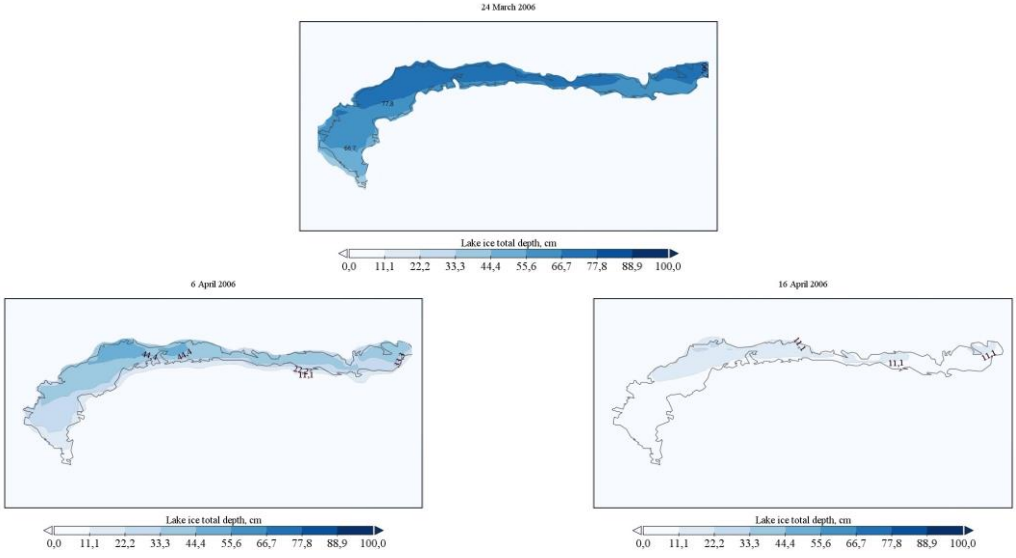
a)


16 March 2002
30 March 2002
Lake total ice depth, cm
0,0 11,1 22,2 33,3 44,4 55,6 66,7 77,8 88,9 100,0
2 April 2002
4 April 2002

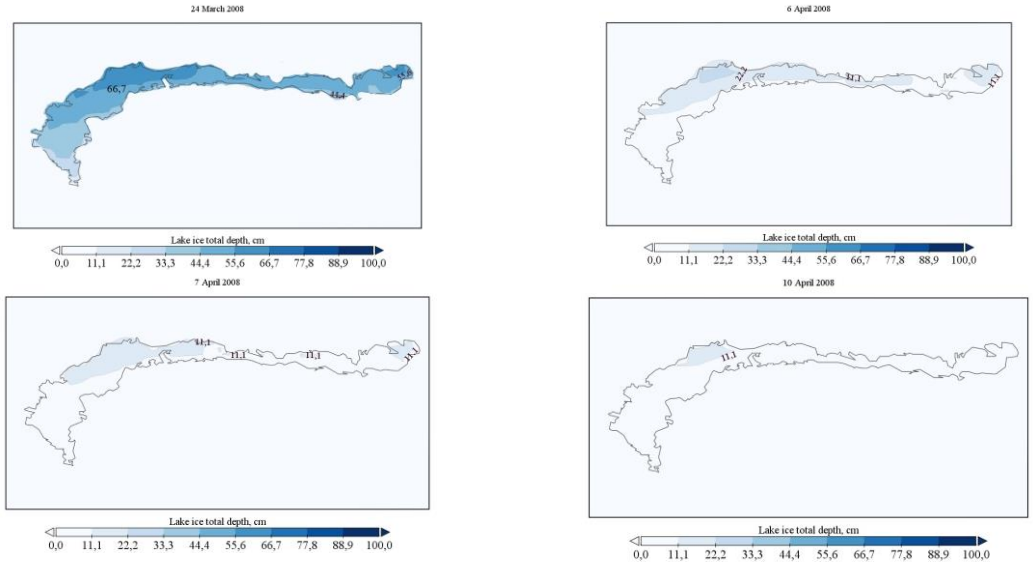
b)


1 April 2005
6 April 2005
Lake ice total depth, cm
0,0 11,1 22,2 33,3 44,4 55,6 66,7 77,8 88,9 100,0
13 April 2005
15 April 2005

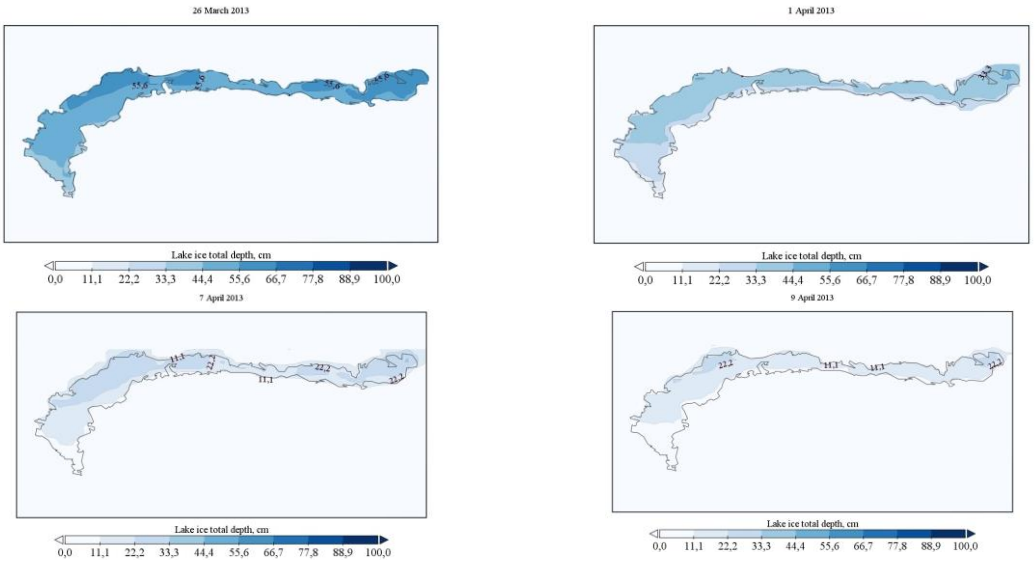
c)


24 March 2006
Lake ice total depth, cm
0,0 11,1 22,2 33,3 44,4 55,6 66,7 77,8 88,9 100,0
6 April 2006
16 April 2006

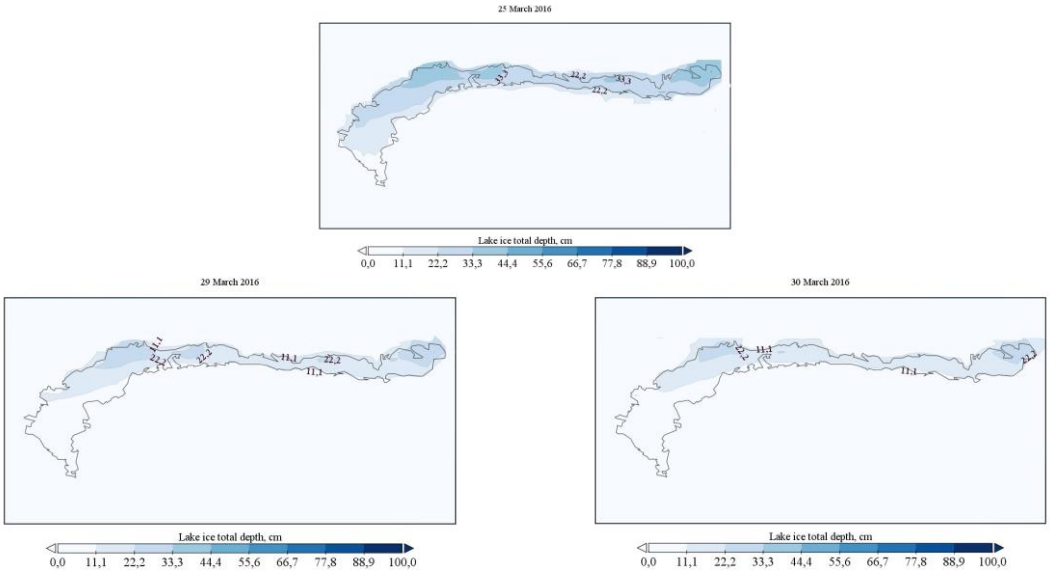
d)


24 March 2008
6 April 2008
Lake ice total depth, cm
0,0 11,1 22,2 33,3 44,4 55,6 66,7 77,8 88,9 100,0
7 April 2008
10 April 2008

e)


26 March 2013
1 April 2013
Lake ice total depth, cm
0,0 11,1 22,2 33,3 44,4 55,6 66,7 77,8 88,9 100,0
7 April 2013
9 April 2013

f)


25 March 2016
Lake ice total depth, cm
0,0 11,1 22,2 33,3 44,4 55,6 66,7 77,8 88,9 100,0
29 March 2016
30 March 2016

g)

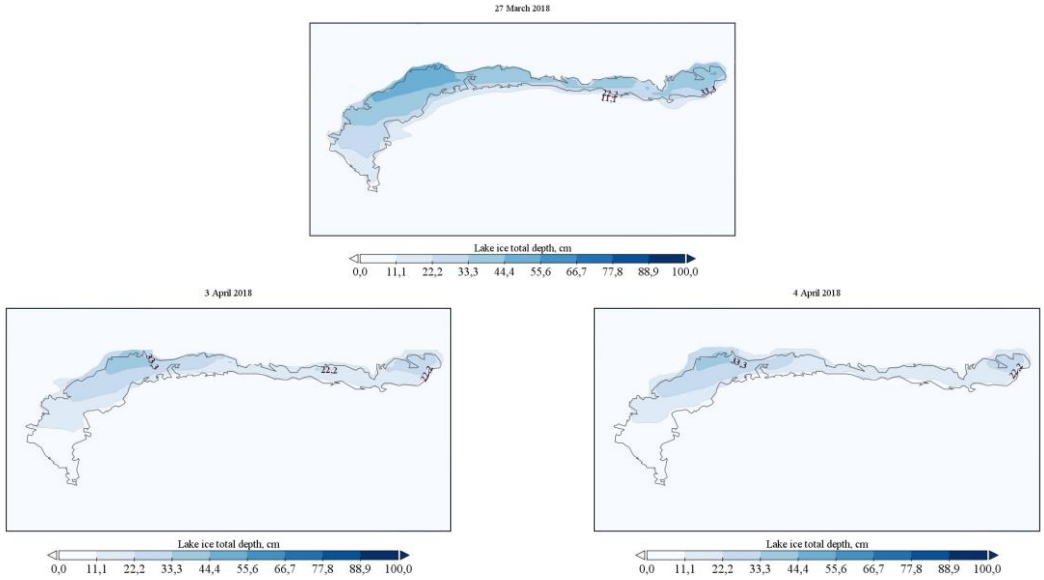


Fig. 4. *Lake ice total depth on Balkash Lake in years with extremely warm months.*

Table 3 shows that in the years with extremely warm March, most dates of spring ice phenomena were earlier than average dates. However, in the dates of the ice destruction beginning destruction there are dates with a later date, despite the fact that March during these years was extremely warm. This indicates that the thermal factor is not the only one that affects the destruction of the ice cover.

Instrumental observation data are conducted at a single point and may not be representative of the entire lake (IPCC. Climate change 2007). Therefore, it becomes necessary to use data from other sources.

Figure 4 shows the ice thickness maps of the Lake Balkash water area according to the reanalysis data from the cds climate data store website.

In 2002, according to three posts, the ice began to break on February 24…March 4. The first ice destruction dates were 19…21 days earlier than average dates (table 3). During the destruction of the ice cover, incomplete freezing (5 days), water on ice (10…12 days), border meltwater (5…9 days), ice movement (2…8 days), polynya (5 days) were observed at the posts. The earliest end of complete freezing was observed at the Mynaral post – on March 12, which was 19 days earlier than the average date. At the posts of Balkash and Algazy, the complete freezing ended on March 29…30, 7…9 days earlier. At the Mynaral post on March 13…15 floating ice was observed and on March 16, 24 days earlier, the water was completely cleared of ice. At the Balkash and Algazy posts, floating ice was observed for 3…4 days, water clear of ice was observed on April 2…4, 10…13 days earlier. According to the figure 4a on lake ice total depth maps from March 16 to April 4, it can be assumed that the ice began to melt form the southwestern part of the lake. From the first destruction to the date of water clearing, maximum ice thickness decreased form 66,7 cm to 22,2 cm.

The dates of the ice destruction beginning in 2005 differ significantly among the posts. At the Mynaral post, the first ice destruction was observed 6 days earlier – on 11 March. At the Balkash post the ice began to destruct on March 19. Deviation towards earlier dates was insignificant – 1 day. On Algazy post, the first ice destruction was observed on March 26, although March in 2005 was extremely warm ice at this post began to destruct 1 day earlier. In the process of ice destruction, border meltwater was observed, at the Balaksh post – 13 days, on Algazy – 9 days

The earliest date for the complete freezing ending in 2005 was at the Mynaral post – on March 25. The complete freezing ended 6 days earlier than average date. At the posts of Balkash and Algazy, freezing ended on April 2…3, deviations from the average dates towards earlier (3…5 days) were insignificant. After the complete freezing ending, floating ice was observed. Complete clearing of water from ice at the posts was observed from April 1 to 13. According to the figure 4 b in 2005, from April 1 to 15, ice decreased from the southwestern part of the lake. The maximum ice thickness in the period of 1…15 April decreased from 55,6 cm to 22.2 cm.

In 2006, the ice began to break in early and mid-March 10…16 days earlier. During the destruction of ice at the Balkash and Algazy posts, border meltwater and embacles were observed. At the Balkash and Algazy posts, ice movement began on March 29. Complete freezing ended 6…11 days earlier. In early April, polynya (5…8 days), floating ice (2…7 days) were observed. At the Mynaral post, water cleared of ice early – on March 24, which was 17 days earlier than the average date. On the total ice depth maps for April 16, it is shown section of ice-free water on both parts of the lake. The maximum ice thickness form March 24 to April 16 decreased from 77,8 cm to 11,1 cm.

In 2008, the earliest date of ice destruction (March 8) was noted at the Mynaral post. The ice breaking occurred 9 days earlier than the average date. The latest date of destruction was at the Saryshagan post – on March 26, later than the average date by 3 days. At the posts of Algazy and Balkash, the ice began to destruct 2…4 days earlier. During the destruction of ice at the posts, water on ice (9…13 days), border meltwater (10…15 days). According to posts from March 22 to April 5, the complete freezing ending observed, which was 3…9 days earlier than the average dates. During the end of complete freezing ending several days of ice movement, polynya and floating ice were observed. At Mynaral post, water cleared of ice on March 24, 16 days earlier. At other posts, clearing was observed from April 6 to 10, 6…7 days earlier. According to the figure 4 d, it can be seen that on the days of the earliest clearing from ice, according to Mynaral post (on March 24), fee areas from ice are not visible on the map. Ice thickness maps from April 6 to 10 show a significant decrease of ice. The maximum ice thickness from March 24 to April 10 decreased from 66,7 cm to 11,1 cm.

In 2013, early ice destruction (March 1…2) was observed at the Balkash and Saryshagan posts. According to these posts, on March 1…17, in the presence of complete freezing, water on ice was observed. The early complete freezing ending was also at the posts of Balkash and Saryshagan – March 17. At the posts on Mynaral and Algazy, the complete freezing ending was noted on March 24 and 27. After the complete freezing ending, ice movement, polynya, ice piles were observed at the posts. Water clear of ice was noted at the end of March and early April, 7…15 days earlier than average dates. Lake ice total depth maps for April 7 and 9 in the southwestern part of the lake show ice-free areas (fig.4e). The maximum ice thickness from March 26 to April 9 decreased from 55,6 cm to 11,1 cm.

According to three posts (Mynaral, Saryshagan, Balkash) in 2016, the first ice destruction was observed on March 10…14, which was 3…10 days earlier than the average dates. The ice destruction began with the appearance of water on ice, border meltwater, polynya. At the posts Balkash and Mynaral, the complete freezing ended on March 15 and 24, 21 and 7 days earlier than the average dates. After the complete freezing ending at the Balkash post, ice piles was observed. The clearing of water from ice at all posts was observed at the end of March, 13…16 days earlier than average dates. According to the reanalysis of the ice thickness, on the maps for 25…30 March, it can be assumed ice is melting from southwest to east. The maximum ice thickness decrease form 33,3 cm to 22,2 cm. In 2018, the ice destruction beginning was on March 21…22. At the posts of Balkash and Mynaral on 21…25 March border meltwater was observed. The earliest complete freezing ending was at Mynaral post – March 26. After the ending of complete freezing at the Balkash post, ice piles was observed. The complete freezing at three posts ended 5 days earlier than average dates.

The clearing of water from ice was on March 27…April 4, which was 9…13 days earlier. According to the maps from figure 4g, the ice disappearing is visible on the lake total ice depth maps on April 3…4. From March 27 to April 4, the maximum ice thickness decreased from 44,4 cm to 33,3 cm.

CONCLUSION

Thus, in this paper, the features of the ice cover's destruction of Balkash lake in extremely warm months were considered and following conclusions can be drown:

- The air temperature of March is determine for the destruction of ice cover on Lake Balaksh:
- According to the criterion of Bagrov Tokarev's anomaly, years with extremely warm March were revealed. The gradation of extremely warm months included the years after 2000;
- In most cases, in years with an extremely warm month, the ice destruction beginning, the complete freezing ending and the water clear of ice were observed earlier than the average dates. The deviation from average dates were found.
- Ice cover in most cases begins to destruct from the southwestern part of the lake.

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ЭСКТРЕМАЛДЫ ЖЫЛЫ АЙЛАРДАҒЫ БАЛҚАШ КӨЛІНІҢ КӨКТЕМ МЕЗГІЛІҢДЕГІ МҰЗ ҚҰБЫЛЫСТАРЫНЫҢ ЕРЕКШЕЛІКТЕРІ

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Бұл мақалада Балқаш көліндегі мұздың өте жылы айларда бұзылу процестері қарастырылды. Наурыздағы орташа айлық ауа температурасы мен мұздың бұзылуының басталу, мұз жамылғысының аяқталуы және судың мұздан тазару күндері арасында айтарлықтай корреляция анықталды. Наурыз айы үшін Багров-Токарев аномалиясының критерийі есептелді және экстремалды айлар анықталды. Көктемгі кезеңде мұздың бұзылу ерекшеліктері экстремалды жылы айлармен талданды. Мұз құбылыстарының белгілі бір түрлерімен күндер саны есептеледі, экстремалды жылы айлар үшін мұз құбылыстарының әртүрлі түрлері талданады. Мұздың қалыңдығының таралу карталары салынды. Экстреалды жылы айларда мұздың бұзылуының басталу күндерінің, мұз жамылғысынң аяқталуының және судың мұздан тазару кундерінің ауытқуы табылды.

Деректер көзі гидрологиялық анықтамалықтар, ауа температурасының орташа айлық мәні және еуропалық орталықтың CDs Copernicus климаттық деректер базасынан алынған реанализ болды.

Түйінді сөздер: экстремалды жылы айлар, мұздың бұзылуының басталуы, мұз жамылғысын аяқталуы және судың мұздан тазауы, ауаның орташа температурасы, мұздың қалыңдығы.

ОСОБЕННОСТИ ВЕСЕННИХ ЛЕДОВЫХ ЯВЛЕНИЙ НА ОЗ. БАЛКАШ В ЭКСТРЕМАЛЬНО ТЕПЛЫЕ МЕСЯЦЫ

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В этой статье рассматриваются процессы разрушения льда на озере Балкаш в экстремально теплые месяцы. Была выявлена значительная корреляция между среднемесячной температурой воздуха в марте и датами начала разрушения льда, окончания ледостава и очищения воды ото льда. Был рассчитан критерий аномалии Багрова-Токарева для марта и определены экстремальные месяцы. Проанализированы особенности разрушения льда в весенний период годы с экстремально теплыми месяцами. Подсчитано количество дней с определенными типами ледовых явлений, проанализированы различные типы ледовых явлений для экстремально теплых месяцев. Были составлены карты распределения толщины льда. Обнаружено отклонение дат начала разрушения льда, окончания ледостава и очищения воды ото льда от средних дат в годы с экстремально теплые месяцами.

Источником данных были гидрологические справочники, данные о среднемесячной температуре воздуха и реанализ данных с климатической базы данных CDs Copernicus Европейского центра.

Ключевые слова: экстремально теплые месяцы, начало разрушения льда, окончание ледостава и очищение воды ото льда, средняя температура воздуха, толщина льда.