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Long-term forecasting of appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs by teleconnection indicators

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Long-term forecasting of the ice regime of water bodies is a difficult task and is still unresolved in the part of improving the accuracy of forecasts. The objective of this paper is the development of the long-term forecasting methods of appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs by teleconnection indicators. The research was carried out based on the observation data of 38 water gauges, which are located on 6 reservoirs of the Dnipro Cascade. The appearance dates of ice phenomena and freeze-up for the period from the observation beginning at each water gauges to 2020, inclusive, were used. In addition, in the research were also used the information about the teleconnection indicators, namely 34 atmospheric indices, sea surface temperature indices, teleconnection indices and patterns, that are determined by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration of United States of America (NOAA USA). The long-term forecasting methods of the appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs were developed by searching for the best correlation or regression relationship between dates and teleconnection indicators. The probabilities of acceptable error of the developed methods are in the range of 61–72%, which corresponds to the category of "satisfactory" assessment of the method quality. It makes it possible to recommend them for use in operational forecasting.

KEY WORDS: ice phenomena, freeze-up, Dnipro reservoirs, teleconnection indices and patterns, forecasting equations

Introduction

Reliable and early forecasts of the appearance timing of ice phenomena and freeze-up at the Dnipro Cascade reservoirs are very necessary for the rational use of water resources of the Dnipro River, for establishing the operating regimes of reservoirs taking into account the requirements and interests of various sectors of the economy: hydropower, shipping, fisheries, utilities, etc. (Kaganer, 1976; Scherbak et al. 2007; Khrystiuk and Gorbachova, 2022). Long-term forecasts of the appearance dates of floating ice and freeze-up with forecast lead time at least 1 month are necessary, first of all, to determine the timing and depth of the autumn triggering of the Dnipro reservoirs.

The scientific and methodological base, which is still used by the Ukrainian Hydrometeorological Center for creating of the long-term forecasts and consultations of the ice regime characteristics of water bodies of Ukraine, is represented by developments 30-70 years ago (Guseva, 1947, 1963; Eremenko, 1962). Note that it needs to be fundamentally revised on new scientific and methodological bases and modern approaches. Along with this, there are no methods for the long-term forecasting of the appearance dates of ice phenomena and freeze-up at the reservoirs of the Dnipro Cascade, therefore, such methods need to be developed.

The development problem of the reliable long-term forecasts of the water bodies ice regime is one of the most difficult in hydrometeorology and has not yet received a fully satisfactory solution (WMO, 1975; 1979; 2009; Sutyrina, 2017). The widespread approaches in the long-term forecasting of the ice regime of water bodies are statistical, discriminant, correlation, regression analyses, orthogonal functions for determining optimal predictors of atmospheric processes (WMO, 1979; GOH, 2012; Das et al., 2022). Along with this, two main approaches are used in the long-term forecasting. The first approach is based on finding relationships between the quantitative indicators of atmospheric circulation over the forecasting object or over separate adjacent (large in area) synoptic areas or zones and the terms (dates) of the ice phenomena appearances (more often their deviations from the norm). The second approach is based on physical and statistical methods that use multiple linear regression equations with the representation of hydrometeorological fields when decomposing them by natural orthogonal components or Chebyshev polynomials (WMO, 1979). In recent decades, methods of satellite sensing, teleconnection indices and patterns, and methods of machine learning are intensively developed and used (Massie et al., 2002; Lindenschmidt et al., 2010;

Sutyrina, 2017; Vyshnevskyi and Shevchuk, 2020; Graf et al., 2022).

In papers (Shimaraev, 2007; Sizova et al., 2013; Sutyrina, 2017; Khrystiuk and Gorbachova, 2022) the teleconnection indices were used for the long-term forecasting of the water bodies ice regime and acceptable results were obtained. In the world, the use of the teleconnection indices and patterns is a well-known methodological approach in the hydroclimatic forecasting, which allows forecasting weeks to months in advance (van den Dool, 2007; Chen and Georgakakos, 2014; Chen and Lee, 2017). For the first time, the concept of using teleconnections was proposed by Ångström (1935) who described the correlations between remote oscillations of the atmospheric circulation and anomalies. Later, this approach was widely used for the long-term forecasting of meteorological parameters. Teleconnection indices and patterns are becoming increasingly popular in the hydrological research. So, the teleconnection indicators are used to forecast and analyze the flow of rivers (Peters et al., 2013; Wang et al., 2020), precipitation (He and Guan, 2013; Mekanik et al., 2015), water equivalent of snow cover on the river catchments (Sobolowski and Frei, 2007), droughts (Chiew et al., 1998; Chen and Lee, 2017), ice phenomena (Shimaraev, 2007; Sizova et al, 2013; Sutyrina, 2017; Khrystiuk and Gorbachova, 2022).

The main objective of this research is to develop the long-term forecasting methods of the appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs using the teleconnection indicators.

Materials and methods

The cascade of the Dnipro reservoirs was created from the end of the 20s to the beginning of the 70s of the 20th century. So, in 1927–1932, the Dnipro Hydro Power Plant (HPP) was built at the Dnipro River. During the Second World War, this station was partially destroyed, but by 1950 it was restored. The construction of Kakhovka HPP lasted from 1950 to 1956, Kremenchuk HPP – during 1954–1960, Kamianske HPP – from 1956 to 1964, Kyiv HPP – during 1960–1964, Kaniv HPP – from 1963 to 1975 (Kaganer, 1976; Khilchevskyi, 2014). So, a total of 6 reservoirs were built on the Dnipro River, which are located in three physiographic zones: forest (Kyiv reservoir), forest-steppe (Kaniv, Kremenchuk, and partially Kamianske Reservoirs) and steppe (Dnipro and Kakhovka and partially Kamianske reservoirs) (Fig. 1) (Kaganer, 1976). The regulation of the Dnipro River by the reservoirs changed the river ice regime compared to its natural regime. Ice phenomena influence the operation of hydrotechnical structures and hydroelectric power plants, duration of navigation, fisheries, etc. Each of the Dnipro reservoirs has own morphometric features, which determine the freezing conditions in its individual sections. The first ice phenomena at the reservoirs appear primarily in the shallow waters, at the mouths of rivers that flow into reservoirs, at the lake areas, where water masses cool earlier due to the shallow depths (Kaganer, 1976; Vyshnevskyi and Shevchuk, 2020). In severe frosts and low wind speed, the ice formation occurs intensively and simultaneously at the all water area of reservoirs. With weak frosts and strong wind speed, when cooling is replaced by warming, the ice formation occurs slowly and extends over a long period of time (Kaganer, 1976).

Systematic observations of the reservoirs ice regime are carried out at coastal water gauges. At the same time, there are no the systematic observations on the water area of reservoirs, sometimes the episodic observations are carried out in the form of expedition surveys, aerial reconnaissance and satellite images. Note that although this information is useful, it cannot replace the systematic observations. The absence of the observations on the water areas of reservoirs makes it difficult to understand the formation conditions of ice phenomena in a spatial section.

Observations of the reservoirs ice regime of the Dnipro Cascade are carried out at 38 coastal water gauges. There are 5 to 8 water gauges on each of the reservoirs (Fig. 1, Table 1). The research used the materials of observations of the hydrological regime of the lakes and reservoirs of the Dnipro River basin contained in various published reference materials prepared by the Central Geophysical Observatory named after Borys Sreznevsky (Kyiv).

An electronic database is created in MS Excel tables, which includes the information about the appearance dates of ice phenomena and freeze-up for the period from the beginning of observations at each water gauge to 2020, inclusive. At the Dnipro Cascade reservoirs the dates of their first appearance in the current winter period were taken for the appearance dates of ice phenomena and freeze-up.

National Weather Service (NWS) of the National Oceanic and Atmospheric Administration of United States of America (NOAA USA) defines the following teleconnection indicators: atmospheric indices, sea surface temperature indices, teleconnection indices and patterns. The NOAA determined the atmospheric indices and sea surface temperature indices for the Pacific region and, partially, the Atlantic region. Teleconnection indices and patterns are calculated for different areas of the Earth. Mean monthly values of all these teleconnection indicators are listed on the website: https://www.cpc.cep.noaa.gov/products/MD_index.php.

In our research 34 teleconnection indicators and their standardized values were used.

Usually, at the Dnipro Cascade reservoirs the processes of ice formation are considered from the point of view of the influence of weather conditions (air temperature, speed and direction of wind, etc.), heat supplies in the reservoirs and intensity of their return to the atmosphere, as well as wind waves and flows that mix water masses (Kaganer, 1976). At the Dnipro Cascade reservoirs, the first ice phenomena are usually observed during the invasion of cold arctic air masses on the territory of Ukraine in the autumn-winter period. From year to year the calendar dates of such incursions vary widely and depend on the general atmospheric circulation in the Northern Hemisphere (Guseva, 1947, 1963; Eremenko, 1962; Kaganer, 1976). At the same time, according to modern ideas, the formation of hydrological, including ice, regime of water bodies is the result of complex

Fig. 1. Scheme of the Dnipro Cascade reservoirs and location of the water gauges on the them (numbering of reservoirs corresponds to Table 1).

processes of climatic and hydrological interactions, which are caused by the circulation of the atmosphere and ocean on the Earth (Wang et al., 2020). So, the basis of the forecasting concept by the teleconnection indicators is the idea of the influence of remote atmospheric circulation fluctuations on the formation of ice phenomena. At the same time, the state of atmospheric circulation is characterized by the various quantitative indices and patterns both in space and time (Sutyrina, 2017). At the Dnipro Cascade reservoirs, the methods of long-term forecasting of the appearance timing of ice phenomena and freeze-up are developed by searching for the best correlation or regression relationship between their dates and teleconnection indicators of the NOAA USA. Along with this, one water gauge-indicator was selected for each reservoir for which a forecasting method was developed. These water gauge-indicators were chosen from among others as those at which the ice phenomena appear annually first. The delay of the ice phenomena appearance at other water gauges is determined by the location of these gauges near the deep-water parts of the reservoir, where significant masses of heat are concentrated; near hydrotechnical structures that violate the natural regime of the reservoir; near the mouths of rivers that flow into the reservoir; in areas with significant water flow, which prevents ice formation.

The assessment of the regression equations quality and accuracy of the long-term forecasting of the appearance timing of ice phenomena and freeze-up at the Dnipro Cascade reservoirs was carried out by the dependent data in accordance to (GOH, 2012). So, the method quality of hydrological forecasting is determined by indicators according to Table 2.

Table 1. List of water gauges at the Dnipro Cascade reservoirs

№	The reservoir name	The year of reservoir filling	The water gauges number	The water gauges name
1	Kyiv reservoir	1966	6	Dniprovske village, Chernobyl town, Green Cape village, Tolokun village, Lebedivka village, Vyshhorod town
2	Kaniv reservoir	1976	6	Vyshhorod town, Kyiv city, Ukrainka town, Rzhyshchiv urban-type settlement, Pereiaslav town, Kaniv town
3	Kremenchuk reservoir	1961	7	Kaniv town, Sokyrna village, Cherkasy city, Topylivka village, Adamivka port, Hradyzk urban-type settlement, Svitlovodsk town
4	Kamianske reservoir	1964	5	Svitlovodsk town, Kremenchuk town, Myshuryn Rih village, Verkhnodniprovsk town, Kamianske town
5	Dnipro reservoir	(1932) 1948	6	Kamianske town, Dnipro city, Sukhachivka urban-type settlement, Locsmano-Kamianka urban-type settlement, Mykilske-na-Dnipri village, Zaporizhzhia city
6	Kakhovka reservoir	1958	8	Rozumivka village, z.st. Plavni, Blahovishchenka village, Vyshchetarasivka village, Nikopol town, Hrushivska Damba, Velyka Lepetykha urban-type settlement, Nova Kakhovka town

Table 2. Indicators of quality of the hydrological forecasting method for the series population $n \geq 25$ (GOH, 2012)

Category	Indicators of quality		
	$\bar{S}/\bar{\sigma}$	coefficient of determination *(R)*	probability of acceptable forecast error (δ_a, %)
good	≤ 0.50	≥ 0.87	≥ 82
satisfactory	0.51 – 0.80	0.86 – 0.60	81–60

The mean square deviation of the forecast value ($\bar{\sigma}$) and mean square error of the verification forecasts ($\bar{S}$) were determined by the formulas:

$$\bar{\sigma} = \sqrt{\left(\sum_1^n \Delta D_i^2\right)/(n-1)} \quad (1)$$

$$\bar{S} = \sqrt{\left(\sum_1^n (D - D')^2\right)/n} \quad (2)$$

where:
ΔD_i – is the deviation of the appearance dates of ice phenomena/freeze-up (D_i) from mean date for multi-year observation period ($\bar{D}$);
n – is the population of the series;
D – is the historical date;
D' – is the forecast date.

Acceptable forecast error was determined by the formula:

$$\delta_a = \pm 0.674\bar{\sigma} \quad (3)$$

Probability of acceptable forecast error was determined by the formula:

$$\delta_p = (N'/N)\ 100\% \quad (4)$$

where:
N' – is the number of forecasts, the error of which did not exceed the acceptable forecast error;
N – is the total number of forecasts.

The numerical expression of the appearance dates of ice phenomena and freeze-up was carried out by determining their deviations from November 30 (a conventional date that is adopted for all reservoirs of the Dnipro Cascade for the convenience of calculations).

Results and discussion

The analysis of the observation series of the appearance dates of ice phenomena and freeze-up at 38 water gauges of the Dnipro Cascade reservoirs made it possible to determine the water gauge-indicators for which the long-term forecasting methods were developed. The Kremenchuk reservoir is divided into two parts – the upper (channel) and the lower (lake) according to morphometric characteristics. So, the methods of the long-term forecasting of the appearance timing of ice phenomena and freeze-up were developed separately for the upper and lower parts of this reservoir.
At the Dnipro Cascade reservoirs, the mean values, early and late of the appearance dates of ice phenomena and

freeze-up naturally change from north to south in accordance with the physical and geographical conditions of their formation and the individual characteristics of the locations of the water gauge-indicators. The appearance dates of ice phenomena and freeze-up are characterized by significant fluctuations. So, the differences between the late and early dates of the appearance of ice phenomena and freeze-up are about 3 months. The calculated acceptable forecast errors have the range from 10 to 13 days (Table 3).

Analysis of correlation and regression relationships of 34 atmospheric indices, sea surface temperature indices, teleconnection indices and patterns of NOAA USA with the appearance dates of ice phenomena and freeze-up at the water gauge-indicators made it possible to find the best such relationships and to determine predictors (indices and patterns) for forecasting. It turned out that the appearance dates of ice phenomena and freeze-up are determined by the values of 15 teleconnection indices and patterns for different months (Table 4, 5). So, at the Dnipro Cascade reservoirs the formation of ice phenomena and freeze-up is caused by the atmospheric circulation processes at the North and the East Atlantic (NATL, EA, SCAND, EATL/WRUS), the Arctic (AO), the Pacific Ocean (Niño 1+2, Niño 3, PNA, TAHITI, SOI, Darwin), and also near the equator (Z500t, EqSOI, repac_slpa, TROPaн). The diversity of the atmospheric circulation processes also determines the instability of the ice regime and significant variability of the timing of its main phases at the Dnipro Cascade reservoirs.

The results of the checking of forecast regression equations (Table 4) according to the dependent data show that these dependencies quite satisfactorily reproduce the historical dates of the appearance of ice phenomena and freeze-up at the Dnipro Cascade reservoirs (an example is shown in Fig. 2). Forecast values in most cases do not exceed the acceptable forecast errors. The value of the extreme dates of the appearance of ice

Table 3. Statistical characteristics of the observation series of the appearance dates of ice phenomena and freeze-up at the water gauges- indicators of the Dnipro Cascade reservoirs

The water gauges name	Period and duration of observations years	The mean date	The early date	The late date	ΔA day	δ_a day	P_m
		the appearance of ice phenomena					
Kyiv reservoir – Green Cape village	1966–1974, 1978–2020 / 52	November 27	30.10.1979	28.01.2007	90	11	38
Kaniv reservoir – Kyiv city	1977–2020 / 43	December 13	17.11.1993	10.02.2020	85	12	54
Kremenchuk reservoir – Cherkasy city	1976–2020 / 45	December 15	14.11.1993	08.02.2020	86	13	56
Kremenchuk reservoir – Adamivka port	1976–2020 / 45	December 10	13.11.1993	30.01.2007	78	10	51
Kamianske reservoir – Myshuryn Rih village	1954–2020 / 57	December 10	01.11.2000	09.02.2020	100	11	51
Dnipro reservoir – Kamianske town	1963–1986, 1989–2020 / 55	December 21	18.11.1993	09.02.2020	83	13	62
Kakhovka reservoir – Blahovishchenka village	1958–2020 / 63	December 20	12.11.1993	08.02.2020	87	13	61
		the appearance date of freeze-up					
Kyiv reservoir – Green Cape village	1966–1974, 1978–2020 / 52	December 1	01.11.1979	28.01.2007	88	12	30
Kaniv reservoir – Pereiaslav town	1977–2020 / 44	December 14	14.11.1993	31.01.2007	78	10	43
Kremenchuk reservoir – Cherkasy city	1976–2020 / 45	December 20	20.11.1993	05.02.2001	77	13	49
Kremenchuk reservoir – Topylivka village	1976–2020 / 45	December 16	13.11.1993	31.01.2007	79	11	45
Kamianske reservoir – Myshuryn Rih village	1954–2020 / 57	December 19	03.11.2014	04.02.2001	93	12	48
Dnipro reservoir – Locsmano-Kamianka urban-type settlement	1964–2020 / 56	December 23	15.11.1993	03.02.2007	80	13	52
Kakhovka reservoir – z.st. Plavni	1968–2020 / 53	December 22	15.11.1993	17.02.2004	91	13	51

Note: ΔA – the difference between the late and the early dates of the appearance of ice phenomena/freeze-up; δ_a – acceptable forecast error; P_m – mean forecast lead time (the forecasts are released October 20 (the appearance dates of ice phenomena) and on November 1 (the appearance dates of freeze-up)).

Table 4. Dependencies for the long-term forecasting of the appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs

The water gauges name	The forecasting equation	$\overline{S}/\overline{\sigma}$	δ_p [%]
	the appearance of ice phenomena		
Kyiv reservoir – Green Cape village	$\Delta I = -408.63 + 14.48 \cdot NATL_{IX} + 1.13 \cdot Z500t_{IX}$	0.92	67
Kaniv reservoir – Kyiv city	$\Delta I = 12.20 - 12.81 \cdot AO_{VII\text{-}IX} + 2.29 \cdot EqSOI_{II}$	0.96	72
Kremenchuk reservoir – Cherkasy city	$\Delta I = 14.46 + 6.56 \cdot EA_{VI} - 5.14 \cdot AO_{VII\text{-}IX}$	0.92	69
Kremenchuk reservoir – Adamivka port	$\Delta I = 102.21 - 4.21 \cdot SCAND_{VI} - 3.76 \cdot Niño\ 1{+}2_{I}$	0.94	71
Kamianske reservoir – Myshuryn Rih village	$\Delta I = 10.18 - 4.50 \cdot PNA_{II} - 2.50 \cdot repac\_slpa_{IX}$	0.95	67
Dnipro reservoir – Kamianske town	$\Delta I = 20.39 + 7.81 \cdot TAHITI_{IV} - 0.57 \cdot SOI_{IV}$	0.95	64
Kakhovka reservoir – Blahovishchenka village	$\Delta I = 20.70 - 5.71 \cdot EATL/WRUS_{VII\text{-}IX} + 2.82 \cdot SOI_{I}$	0.95	61
	the appearance date of freeze-up		
Kyiv reservoir – Green Cape village	$\Delta F = -947.80 + 13.07 \cdot NATL_{IX} + 21.55 \cdot TPOR_{VIII\text{-}IX}$	0.88	66
Kaniv reservoir – Pereiaslav town	$\Delta F = 14.66 - 4.88 \cdot EA_{I} - 4.53 \cdot PNA_{II}$	0.89	70
Kremenchuk reservoir – Cherkasy city	$\Delta F = 20.72 - 5.30 \cdot SCAND_{V} + 3.38 \cdot EAWR_{I\text{-}II}$	0.94	70
Kremenchuk reservoir – Topylivka village	$\Delta F = -48.85 + 16.96 \cdot TROPan_{IX} + 2.61 \cdot Niño\ 3_{IX}$	0.93	68
Kamianske reservoir – Myshuryn Rih village	$\Delta F = 17.18 - 6.08 \cdot Darwin_{III} - 4.32 \cdot SCAND_{V}$	0.89	69
Dnipro reservoir – Locsmano-Kamianka urban-type settlement	$\Delta F = 22.77 + 4.93 \cdot TAHITI_{IV} + 2.25 \cdot SOI_{IV}$	0.96	64
Kakhovka reservoir – z.st. Plavni	$\Delta F = 21.24 - 4.20 \cdot EATL/WRUS_{VIII} + 6.18 \cdot TAHITI_{IV}$	0.93	67

Note: $\overline{S}$ – mean square error of the verification forecasts; $\overline{\sigma}$ – mean square deviation of the forecast value; δ_p [%] – probability of acceptable forecast error; ΔI, ΔF – the forecast deviations of the appearance dates of the ice phenomena and the freeze-up from the conditional date November 30, days.

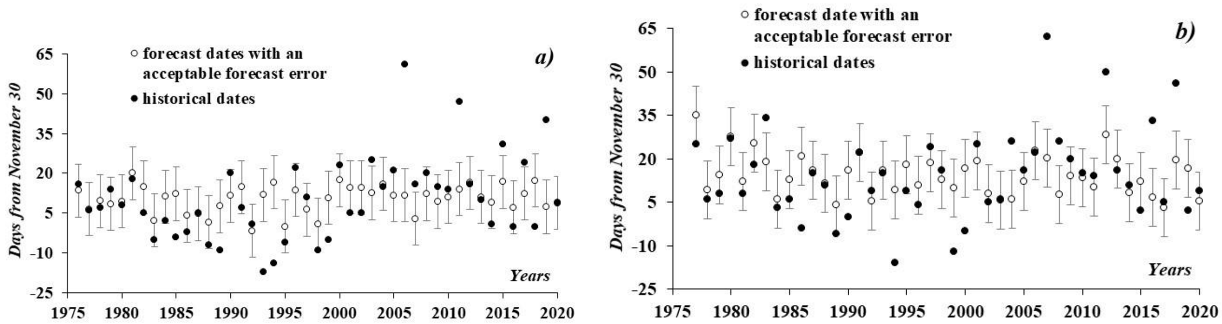

Fig. 2. Historical and forecasted (with an acceptable forecast error) appearance dates of ice phenomena at the Kremenchuk Reservoir near Adamivka port (a) and the appearance dates of freeze-up at the Kaniv Reservoir near Pereyaslav city (b).

phenomena and freeze-up are the exception. It is determining the high values of the ratio of the mean square error of the verification forecasts ($\overline{S}$) to the mean square deviation of the forecast value ($\overline{\sigma}$) (Table 4). At the same time, the probabilities of acceptable errors of the hydrological forecasting methods of the appearance dates of ice phenomena and freeze-up at all water gauge-indicators correspond to the quality assessment "satisfactory" according to (Table 1). This makes it possible to recommend the developed methods for the forecasting of the appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs.

In the papers (Shimaraev, 2007; Sizova et al, 2013; Sutyrina, 2017) for the long-term forecasting of the ice regime of water bodies using the teleconnection indices, the quality assessments of the developed methods were obtained, which have the "good" category according to (Table 1). The lower quality category of methods for the long-term forecasting of the appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs is obviously due to the significant variability of atmospheric processes over the territory of Ukraine in the autumn-winter period. Nevertheless, the use of teleconnection indicators as predictors, although it does not fully solve the problem of the long-term forecasting of the appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs, however, expands its possibilities.

Table 5. Description of teleconnection indicators, which are used as predictors in the forecast dependencies in the Table 4

№	The name of the teleconnection indicator	Short description of the teleconnection indicator	The beginning year of the indicator calculation
1	North Atlantic (5–20°North, 60–30°West), NATL	It is determined for the water surface temperature in the North Atlantic, a rectangle of 5–20°N, 60–30°W	1982
2	Zonally Average 500 MB Temperature Anomalies (Z500t)	It is determined on air temperature anomalies averaged in the 20°N band.–20°S, on the isobaric surface of 500 mb	1979
3	Arctic oscillation (AO) index	It is determined on the values of air pressure anomalies in northern latitudes (norther than 20°N)	1950
4	Equatorial SOI, (EqSOI)	It is determined on atmospheric pressure indicators at sea level in rectangles 80°–130°W, 5°S–5°N and 5°S–5°N, 90°–140°E	1949
5	East Atlantic (EA) pattern	Similar to the North Atlantic Oscillation (NAO) pattern, but the centers of its anomalies are shifted to the southeast	1950
6	Scandinavia pattern (SCAND)	It is determined on the atmospheric circulation nature over Scandinavia, Western Europe and the eastern part of the Russian Federation/western part of Mongolia	1950
7	Niño 1+2 (0–10°South) (90°West–80°West)	It is determined on the temperature of the water surface of the Pacific Ocean in the rectangle 0–10°S, 90–80°W	1950
8	Pacific - North American (PNA) index	It is determined on the atmospheric circulation nature over the northern part of the Pacific Ocean and the North American continent	1950
9	repac_slpa	It is determined on the atmospheric pressure at sea level in the eastern equatorial region of the Pacific Ocean in the rectangle 5°S–5°N, 80°–130°W	1949
10	Tahiti Sea Level Pressure	It is determined on atmospheric pressure at sea level at the Tahiti station (an island in the Pacific Ocean)	1951
11	Southern Oscillation Index (SOI)	It is determined on atmospheric pressure at sea level at Darwin and Tahiti stations	1951
12	East Atlantic/ West Russia (EATL/WRUS) pattern	It is determined on the atmospheric circulation nature over Europe, the northern part of China, the center of the North Atlantic and the northern part of the Caspian Sea	1950
13	Global Tropics (10°South-10 North, 0-360), TROPта TROPан	It is determined on the temperature of the water surface of the Pacific and Atlantic oceans in the band of 10°S–10°N, 0–360°	1982
14	Niño 3 (5°North–South) (150°West–90°West)	It is determined on the surface temperature of the Pacific Ocean in the rectangle 5°N–5°S, 150–90°W	1950
15	Darwin Sea Level Pressure	It is determined on atmospheric pressure at sea level at the Darwin station (Australia)	1951

Conclusion

For the first time, for the Dnipro Cascade reservoirs the methods for the long-term forecasting of the appearance dates of ice phenomena and freeze-up using 34 teleconnection indicators, namely atmospheric indices, sea surface temperature indices, teleconnection indices and patterns were developed. The forecast equations contain 15 teleconnection indicators for different months which is describe the atmospheric circulation processes in the North and the East Atlantic, the Arctic, the Pacific Ocean, and also near the equator. The verification of the developed methods based on dependent data showed that the probabilities of acceptable errors is within 61–72%, which corresponds to the assessment of the method quality as "satisfactory". This makes it possible to recommend them for use in the operational forecasting. Forecasts can create for the ice phenomena appearance at October 20 and for the freeze-up appearance at November 1, provided that the values of the teleconnection indicators are published on the website of the NOAA USA. The mean forecasts lead time ranges from 38 to 62 days for the appearance dates of ice phenomena and from 64 to 70 days for the appearance dates of freeze-up.

At the Dnipro Cascade reservoirs, the development of the long-term forecasting methods of the appearance dates of ice phenomena and freeze-up is complicated by their significant fluctuations, due to the significant variability of atmospheric processes over the territory of Ukraine in the autumn-winter period.

The use of the teleconnection indicators for the long-term forecasting of the appearance dates of ice phenomena and freeze-up at the Dnipro Cascade reservoirs provides the acceptable results. Therefore, a similar approach can be used to develop the methods of the long-term forecasting of other characteristics of the ice regime, for example, the timing of freeze-up break-up and ice phenomena disappearances at the reservoirs and rivers of Ukraine.

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