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PECULIARITIES OF GLACIERS FLUCTUATIONS OF ATLANTIC ARCTIC (END OF XIX - BEGINNING OF XXI CENTURIES)

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Abstract. A long-term series of the evolution of glaciers in Greenland, Iceland, Spitsbergen and Novaya Zemlya in 1890-1980 were continued on glaciological data 1980-2000's. It is shown that during the XX-th century in the fluctuations of glaciers Atlantic Arctic (just like in Antarctic) periodicity was manifested equal on the average of 18.6 years variability of luni-solar tidal forces. The most significant retreat of glaciers in the Arctic occurred during zonal circulation epoch of the Northern Hemisphere (1916-1956). In the 1980s - 1990s years of the meridional southern epoch of atmospheric circulation the surges of Greenland, Iceland and Spitsbergen glaciers were resumed, and on Novaya Zemlya and Zemlya Frantsa - Iosifa the slowdown in the rate of reduction of glaciations was observed. These events occurred against the background of a sharp increase in cyclonic activity in the North Atlantic and the Arctic basin during the winter and summer seasons.

Keywords: glacier, edge fluctuation, surge, retreat, luni-solar tide, circulation epoch.

INTRODUCTION

According to zoning of Arctic Ocean [3] the North-European basin includes the archipelagos: Greenland (1 802 400 km2 of ice), Iceland (11 048 km2), Spitsbergen (35 100 km2), Novaya Zemlya (24 400 km2), Zemlya Frantsa – Iosifa (13 700 km2).

Because west coast of Greenland washed by waters of Baffin and Labrador seas, these archipelagos can be attributed to the larger geographic region - Atlantic Arctic. In the East its boundary is the New Earth, and in the West its boundary lies on the east coast of Canada and the Islands of Canadian Arctic archipelago [3].

In this article the data on glaciers fluctuations of considered archipelagos (except Zemlya Frantsa - Iosifa due to the lack of data on fluctuations) from 1870-1890 up to 1970s - 1980s [10] are used. The dynamics of the fronts of the investigated glaciers has been received by period (in average about 18-20 years), selected on the basis of joint analysis of fluctuations Arctic and Antarctic glaciers [13].

DYNAMICS OF POLAR GLACIERS AND LUNI-SOLAR TIDES

Peculiarities of Spitsbergen and Greenland glaciation (counterphase of glaciers edges fluctuations) and their relationship with blocking circulation processes in the North Atlantic and luni-solar tides are reflected in the works [8, 4]. This was preceded by data on the effect of lunar-solar tidal forces on the dynamics of Antarctic glaciers, as well as the atmospheric circulation and changes in the level of the sea surface [6, 7]. In the analysis of time series of Antarctic iceberg runoff and the dispersion *D* of tidal fluctuations of Earth velocity rotation in the speed of rotation of the Earth was set high correlation. The periodicity of considered processes variability was on average equal to 18.6. Further analysis of the fluctuations of Spitsbergen, Iceland, Greenland and Novaya Zemlya glaciers also showed the presence the periodicity in the 18.6 year, due to variations of the lunar tidal forces. It should be noted that the Arctic glaciation centers (unlike Antarctic) not be located near the pole. In this regard, the direction of their fluctuations also depends on change of circulation epochs on hemispheres and prevailing of air mass transfers in this time [4].

THE MAIN TENDENCIES OF GLACIERS FLUCTUATIONS OF ATLANTIC ARCTIC

In accordance with the classification of circulation mechanisms in the Northern Hemisphere by B.L. Dzerdzeevskii [9] the area under consideration presents the polar regions of the Atlantic (60^0 W - 0^0) and European (0^0 – 60^0 E) sectors. Consideration of glaciers dynamics within each of the sectors (in Atlantic - Greenland and Iceland in European - Spitsbergen and Novaya Zemlya) is showed consistent of tendencies in their fluctuations. However, when comparing of glaciers dynamics of one sector with the dynamics of other pairs were identified periods of manifestation counterphase of fluctuations fronts of glaciers.

The only exception was the time intervals when the change of circulation epochs (mainly in the second half of the XX century) with the manifestation of synchronicity in changes in locations of glaciers edge (fig. 1, 2, 3).

Spitsbergen

The longest series of observations of glacier fronts position have to Spitsbergen. By means studies of glaciologists IGAN USSR since the second half of the 1960s are revealed more than 500 cases of advance (surges) for 250 pulsating glaciers [10, 11, 12].

Fig. 1 shows the fluctuations of glaciers edge of Spitsbergen (1) according to Koryakin V. S. (1988), the dispersion *D* of tidal fluctuations of Earth rotation velocity in 10^{-20} (2) according to Sidorenkov N.S. (2008), the circulation epochs of Northern Hemisphere by classification B. L. Dzerdzeevskii [9]. Changes of glaciers in the 1980s-2000s (4) made according to [2, 17, 18, 19, 11, 12].

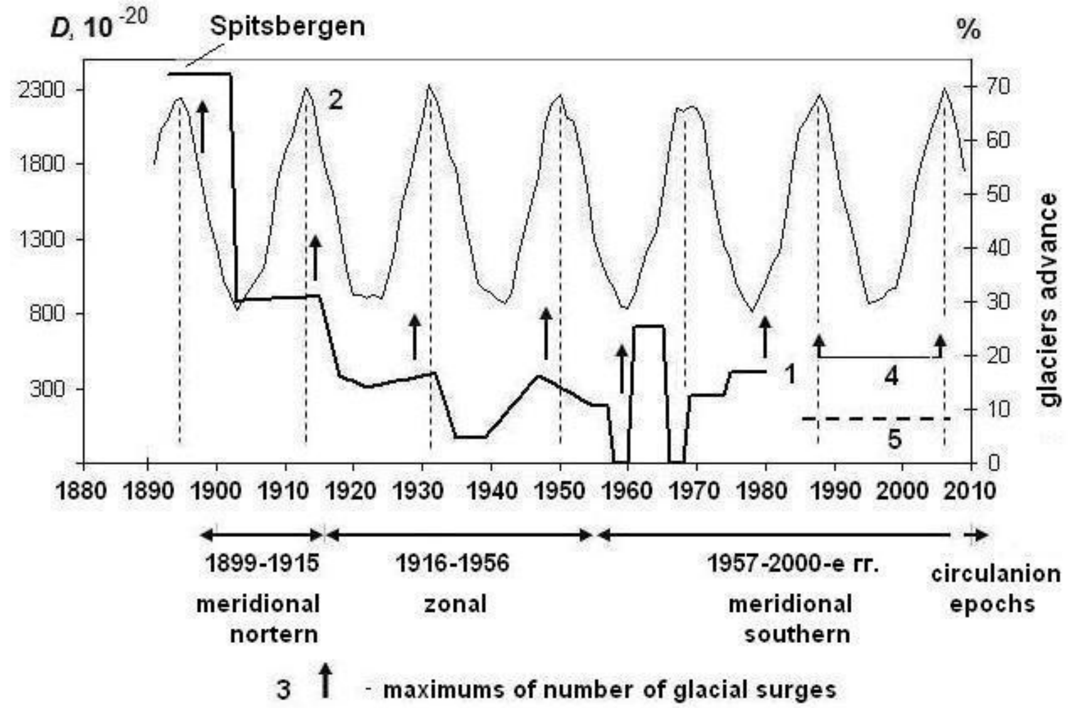

Fig. 1. *Dynamics of Spitsbergen glaciers, the luni-solar tides and circulation epochs of the Northern Hemisphere. 1 - fluctuations of Spitsbergen glaciers edge (number of advancing glaciers in %) from 1893 to 1980 [10]; 2 - variations of dispersion D tidal oscillations of the Earth's rotation velocity (in* 10^{-20}*) from 1891 to 2009 [15]; 3 - maximums of number of Spitsbergen glaciers surges [10]; 4 - surges of Spitsbergen glaciers in the 1980s - 2000s [2, 17, 18, 19]; 5 - period of growth rate of Spitsbergen glaciation [12]. Boundaries of circulation epochs in the Northern Hemisphere are shown in accordance with classification by B. L. Dzerdzeevskii [9].*

From fig. 1 follows that from 1890 to 1957/1958, all maximums of surges of Spitsbergen glaciers fairly well defined and adjusted with the maximums of extremums dispersion *D* of Earth rotation angular velocity. In 1930s - 1950s this tendency was also observed, despite the significant retreat of glaciers at this time.

In the period of new growth of glaciers surges at the turn of 1960 and 1969-1980, their maximums were on the minimums of dispersion of lunar tidal forces. Characteristically, that with a further reduction of Spitsbergen glaciation in 1980s - 2000s, there were new manifestations of surges in different parts of archipelago.

The activity of glaciers - Usherbreen in 1978-1985, Arebreen in 1985, Osbornbreen in 1987 [17], Kongsvegen in 1987-1994 [18], Paula and Bakaninbreen in 1985-1995 (with the wave in 1985-1989) [17, 19], Fridtiof in 1988-1994 with surge in 1995/1996, Paula, Scobreen with surge in 2005 [2] was marked. Selected maximums of glacier surges (about 1985-1989 and 2004/2005) again are coincided with maximums of dispersion of luni-solar tides.

To confirm of maximums surges in fluctuations of Spitsbergen glaciers the analysis of these data and duration action of groups circulation for sectors in Northern Hemisphere (classification by B.L. Dzerdzeevskii) [9] was carry out. In the result it was found good accordance of glaciers dynamics and group of latitudinal western and longitudinal northern circulation (Lat. west – Long. north). In the best way this relationship is manifested in 1904-1980. Correlation coefficient of variability of curves was 0.55.

Greenland and Iceland

On fig. 2 shows fluctuations of the glaciers edge of Greenland (1), Iceland (2) [10] and variations of dispersion *D* of tidal fluctuations of Earth rotation velocity (3) [15]. Information about changes of Greenland and Icelandic glaciers (4, 5) taken from [16, 12]. Boundaries of circulation epochs in the Northern Hemisphere are shown in accordance with classification B. L. Dzerdzeevskii [9].

Consider the centers of glaciation are located in the Atlantic sector in close proximity to each other. In this regard despite on lack of coincidence of periodicity of studies and frequency of maps surveying of Greenland and Iceland glaciers, in general, there is good consistency of tendencies in their fluctuations. Thus, the correlation of the considered series (9-year moving averages) from 1891 to 1940 was equal to 0,69. Due to the large difference in size of glaciations in Greenland and Iceland the reaction of glaciers to the same climate change may manifest itself with different velocity.

The retreat of Greenland and Iceland glaciers in the 1890s-1900s was resumed in the mid- 1920s. Greenland glaciers continued to retreat until the 1940s, and only since 1952, next to 1958-1960, and then to 1968-1970 began their appreciable advance. Glacial complexes of Iceland are almost restored by the end of the 1940s.

From fig. 2 it follows that until the mid-1930's and then from the late 1950s to 1961, the curves of fluctuations of Greenland glaciers edge (1) and variations of dispersion of Earth rotation angular velocity (3) mainly reflected counterphase in their many-years changes. The same character of fluctuations edge, but until the mid-1940s, was observed on glaciers of Iceland (2).

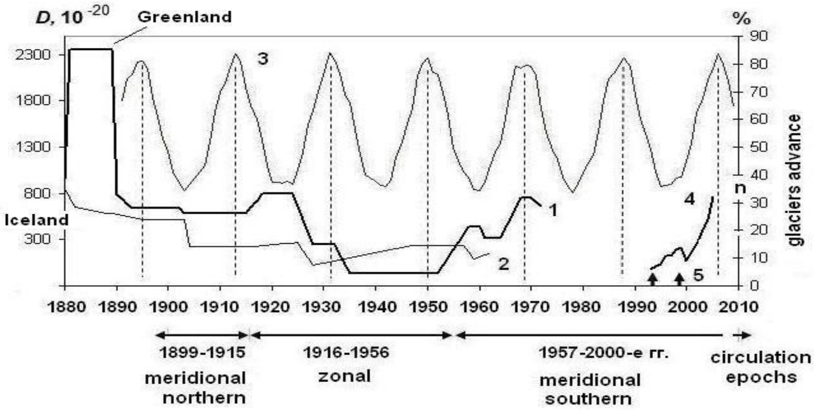

Fig. 2. *Dynamics of Greenland and Iceland glaciers, luni-solar tides and circulation epochs of the Northern Hemisphere. 1 - fluctuations of edge of Greenland glaciers from 1890 to 1972; 2 - - fluctuations of edge of Iceland glaciers from 1890 to 1963 (the number of advancing glaciers in %) [10]; 3 - variations of dispersion D of tidal oscillations of the Earth rotation velocity (in* 10^{-20}*) from 1891 to 2009 [15]; 4 – surges of Greenland glaciers (n is the number of cases) [16]; 5 - surges of Iceland glaciers [12]. Boundaries of circulation epochs in the Northern Hemisphere are shown in accordance with classification by B. L. Dzerdzeevskii [9].*

From 1960 to the early 1970s, with the change of zonal circulation epoch of Northern Hemisphere (1916-1956) on meridional southern epoch was observed synchrony in changes of curves fluctuations Greenland (1) and Iceland (2) glaciers with curve of luni-solar tidal forces (3).

For the time period from 1972 to 1992, we don't have any information about dynamics of Greenland glaciers. However, the monitoring of seismic waves in Greenland has revealed a new class of earthquakes associated with glaciers. On the main outlet glaciers of ice sheet it was found that from 1993 to 2005 the number of earthquakes and therefore glacial movements sharply increased. Over the last 5 years, the rate of manifestation of earthquakes doubled. The most active of these processes manifested in the dynamics of north-western glaciers of Greenland. This type of earthquakes associated with increasing sliding velocity of outlet glaciers on bed as the response of glaciers to changes in climatic conditions [16].

In Iceland in the 1990s on the largest ice cap Vatnajokull of island were recorded rapid surges of outlet tongues Tungnar (1994) and Ding (1999) [12].

Novaya Zemlya

The archipelago is located in the east of European sector of the Atlantic Arctic region on the boundary with the Arctic basin.

Fig. 3 shows fluctuations of edge of Novaya Zemlya of (1) and Iceland (2) glaciers [10] and variations of the dispersion *D* of tidal fluctuations of Earth rotation velocity in 10^{-20} (3) [15]. Data about changes of Novaya Zemlya and Iceland glaciers in the 1980s - 2000s (5, 6, 7) are taken from [10, 11, 12]. Boundaries of circulation epochs in the Northern Hemisphere are shown in accordance with classification by B. L. Dzerdzeevskii [9].

Curves of fluctuations of Novaya Zemlya (1) and Iceland (2) glaciers are listed together in order to emphasize the differences in their dynamics which connected with differences in the character of atmospheric circulation and nourishment regime of glaciers of these archipelagos. Despite the proximity, the same groups circulation of these sectors (latitudinal, longitudinal, and others) may differ from each other by a set of elementary circulation mechanisms (ECM) [9]. Thus, at one and the same time in the dynamics of edge glaciers of considered sectors asynchronicity is may manifest (advances fronts in one sector and retreat in other).

According fig. 3 the most significant retreat of glaciers of Novaya Zemlya occurred in 1907-1911. One of stage of maximum of this retreat, most likely, had at the end of the 1920s. The greatest reduction of glaciation area occurred during retreat Novaya Zemlya glaciers in 1933 -1952. Then at the turn of the 40s -50s, there has been a slowdown in reduction of glaciation. This tendency continued in the second half of XX and early XXI centuries. On mountain glaciers of Novaya Zemlya the surges was not observed at this time [10, 11].

On fig. 3 arrows indicate direction of movement of Novaya Zemlya and Iceland glaciers edge (8 – glaciers advances, up arrow; 9 - retreat, down arrow). As can be seen, during periods of minimum of dispersion of lunar tidal forces (3) in fluctuations of glaciers edges of the Novaya Zemlya (1) and Iceland (2) the counterphase is observed. This was manifested in the epoch of meridional northern circulation (1899-1915) and epoch zonal circulation (1916-1956) (see fig. 3).

Then after 1957 (the beginning of epoch of the meridional southern circulation) the tendencies in the fluctuations of glaciers of archipelagos acquire the same direction. However, the surges of Icelandic glaciers in 1994 and 1999 (5) now fall to a minimum variations of dispersion of lunar tidal forces (3). On the Novaya Zemlya from second half of XX century to the 2000s has seen a slowdown in the process of reduction of glaciation area. This is also shows about some improvements in conditions for the existence of glaciers of concerned archipelagos.

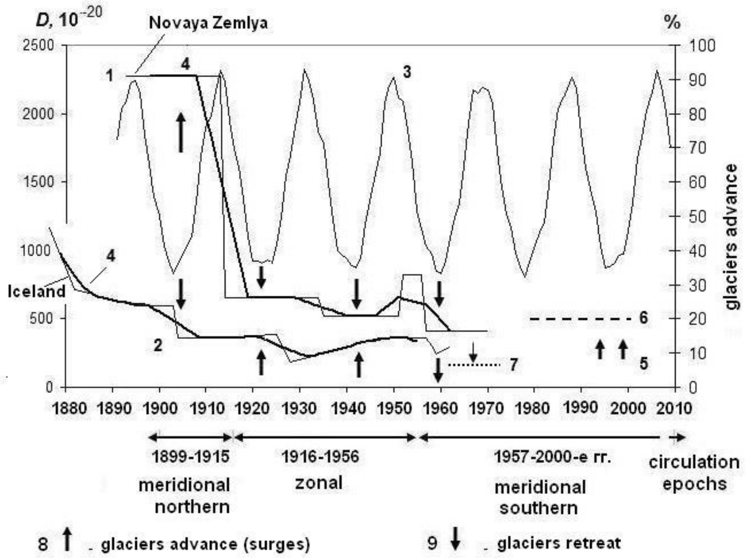

Fig. 3. *Dynamics of Novaya Zemlya glaciers (in comparison with Iceland), luni-solar tides and circulation epochs of the Northern Hemisphere. 1 - fluctuations of edge of Novaya Zemlya glaciers from 1893 to 1970; 2 - - fluctuations of Iceland glaciers edge from 1890 to 1963 (the number of advancing glaciers in %) [10]; 3 - variations of dispersion D of tidal oscillations of the Earth's rotation velocity (in 10^{-20}) from 1891 to 2009 [15]; 4 - 11-year moving averages of fluctuations of Novaya Zemlya and Iceland glaciers; 5 – surges of Iceland glaciers [12]; 6 - period of decrease of area reduction rate of Novaya Zemlya glaciers of [11]; 7 - period of the maximum area reduction glacier Vatnajokull in Iceland [10, 12]. Boundaries of circulation epochs in the Northern Hemisphere are shown in accordance with classification by B. L. Dzerdzeevskii [9].*

Zemlya Frantsa - Iosifa

The glaciers of archipelago are located in the higher latitudes of the North-European basin of Atlantic Arctic. The intensity of mass and energy transfer of glaciation and hence the velocity of change of its sizes is significantly less than on other Arctic islands. It is associated with lower nourishment when removing glaciers from the major trajectories of cyclones, as well as a decrease in the melting of ice due to position in high latitudes. About surges of Zemlya Frantsa – Iosifa glaciers we don't have information. However, in accordance with the data of [12], reduction of glaciation of archipelago from 1953 to 1978 amounted to 9,3 km^2 /year, and from 1978 to 2001 – 6,3 km^2 /year. As you can see, the last annual decrease of ice area indicates a slowing of reduction velocity of glaciation of Zemlya Frantsa – Iosifa in the last 20 years of the past century.

It should be noted that the above periods and dates activate the surges of Greenland, Iceland, Spitsbergen glaciers and slow the rate of reduction of Novaya Zemlya and Zemlya Frantsa – Iosifa glaciations in 1980-1990, was preceded by the most significant for XX century the wave of annual duration of the circulation forms that define the epoch of meridional southern circulation (1957-2000-s). At this time prevailed elementary circulation mechanisms (ECM) 13s (summer type) and 13w (winter type). Dynamics schemes of these ECM shown in fig. 4.

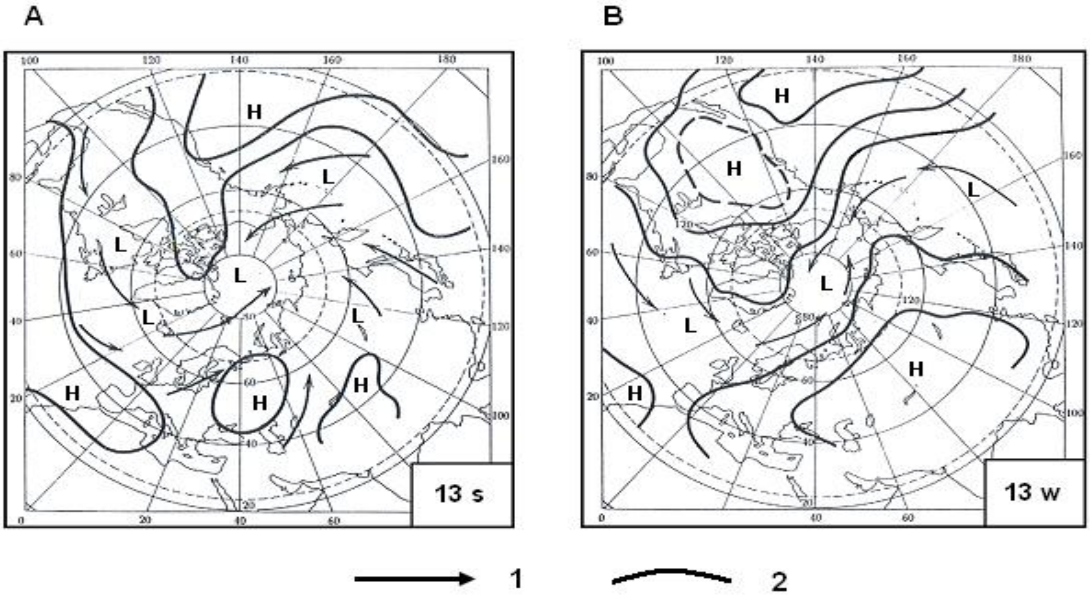

Fig. 4. *Dynamic schemes of elementary circulation mechanisms (ECM) of meridional southern circulation (classification by B. L. Dzerdzeevskii) [9]: A. ECM 13s (summer): B. ECM 13w (winter). 1 - general trajectory of cyclones; 2 - demarcation line separating the fields of cyclonic and anticyclonic activities.*

According to the data from [9], as reflected in fig. 5 A, B, the total duration of these macro-processes in 1983-2008, exceed 100-150 days per year with maximum of 200 days in 1989. It's typical that during action of ECM 13 over the Arctic basin in winter and summer the cyclonic circulation is accomplished with center near pole. Drift fields of Arctic sea ice at this time also is cyclonic character. Series of Atlantic cyclones in these macro-processes transfer of air masses for all considered centers of Atlantic Arctic glaciation and provide favorable conditions of nourishment regime of glaciers [5]. Fig. 5 B illustrates the period of the maximum duration of meridional southern circulation and activation of surges Spitsbergen glaciers in 1980-2005.

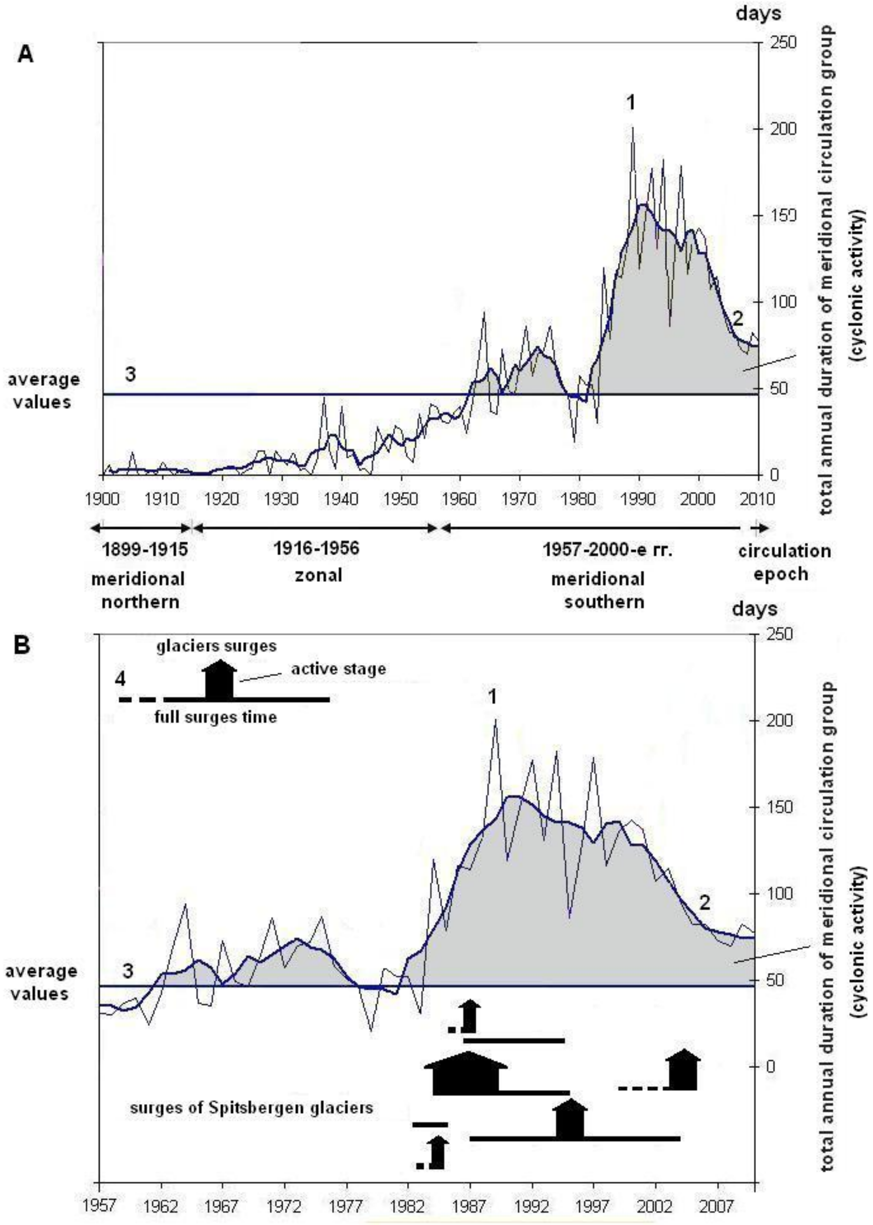

Fig. 5. *Dynamics of the duration of meridional southern circulation [9] and fluctuations of Spitsbergen glaciers of [2, 17, 18, 19]: A. 1 - long-term fluctuations of the total annual duration of the meridional southern group circulation in days for 1900-2010; 2 - 5-year moving averages of duration of meridional southern group of circulation; 3 - average duration of circulation group; B. 1 - long-term fluctuations of the total annual duration of the meridional southern group of circulation in days for 1957-2010,; 2 - 5-year moving averages of duration of meridional southern group of circulation; 3 - average duration of group; 4 – surges of Spitsbergen glaciers. Boundaries of circulation epochs in the Northern Hemisphere are shown in accordance with classification by B. L. Dzerdzeevskii [9].*

The analysis also showed that the maximum wave of duration of meridional southern circulation in 1989 almost coincided with the maximum of dispersion of the luni-solar tides in 1988 (between minimums in 1978 and 1996). It is possible that the imposition of these two processes lead to a sharp intensification of cyclonic activity in the Atlantic and the Arctic basin and consequently the activation of ice processes in the 1980s-1990s.

Previously it was shown that the dynamics of Spitsbergen and Greenland glaciers is closely connected with the main Centers of Action of Atmosphere (CAA) of the Northern Hemisphere [4]. During the period from 1890 to 1970, the CAA has repeatedly shifted from its long-standing position in latitude and longitude. When the largest their displacement in 1931-1940, the trajectories of the cyclones are shifted by 20^0 of longitude to the East in relation to their position in 1906-1915. In this time the intensive circulation activity has shifted to $5\text{-}10^0$ of latitude from North of Europe to the Barents and Kara seas [14]. In 1928-1942, besides mutual offset of Icelandic minimum and the Azores maximum were observed minima values of momentary pole of Earth rotation. The convergence of both pairs of CAA has contributed strengthening of zonal circulation and intense warming in all regions of Northern Hemisphere [1].

CONCLUSION

Peculiarities of dynamics of these natural factors and connected with them global realignment of circulation processes, characterize zonal epoch of atmospheric circulation of Northern hemisphere (1916-1956 [9]). Maximum of summary duration of groups of elementary circulation mechanisms (ECM) of this epoch is observed to the second half of 1920s-1940s. It was at this time there was most significant for the XX century retreat of glaciers and reduction of glaciation area on all the archipelagoes of Atlantic Arctic and in other Arctic regions.

In the first two decades of the meridional southern epoch of atmospheric circulation (1957-2000s, [9]) the fluctuations of Atlantic Arctic glaciers had were significantly different character. This period marked a notable advance of Greenland glaciers and increase in the number of surges of Spitsbergen glaciers. However, in the 1980s and the 2000s, the area of Spitsbergen glaciation continued to decrease but in Iceland the period of maximum of reduction area of largest ice complex Vatnajokull was in 1960 and the first half of 1970s. At the same time were retreating of Novaya Zemlya glaciers. This was reflected in the surges of glaciers of Greenland, Iceland, Spitsbergen and the slowdown in reduction of glaciations of Novaya Zemlya and Zemlya Frantsa – Iosifa in the 1980s-1990s.

The overall picture of glaciers dynamics of considered archipelagos dynamically changed in the 1980s - 1990s. In these years was resumed surges of Greenland, Iceland, Spitsbergen glaciers and there has been a slowdown in reduction of Novaya Zemlya and Zemlya Frantsa – Iosifa glaciations.

During the XX century in the fluctuations of glaciers edge of the largest island glacier complexes of Atlantic Arctic and the Arctic basin (as in the fluctuations of edge and Antarctic iceberg runoff) was shown relationships with variations of dispersion *D* of tidal fluctuations Earth rotation velocity. Periodicity in the dynamics of considered glaciations were on average equal to 18.6 year of variability of luni-solar tidal forces. Thus, we can conclude that the luni-solar tides influence on regime, fluctuations of edge and iceberg runoff of glaciers, both the Southern and Northern polar regions.

It is established that the maximum duration of meridional southern circulation of the XX century (1989) almost coincided with maximum of dispersion of luni-solar tides in 1988 (between minimums in 1978 and 1996). It is possible that the overlap of the two peaks of natural processes contributed to such an abrupt intensification of cyclonic activity and more intensive entrance of precipitation in the North Atlantic and the Arctic basin.

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