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Manifestation of the Solar Cycle in the Circulation Characteristics of the Lower Atmosphere in the Northern Hemisphere

A. A. Kukoleva[a], *, N. K. Kononova[b], and A. A. Krivolutskii[a], **

[a]*Central Aerological Observatory, ROSHYDROMET, Dolgoprudny, Moscow oblast, Russia*
[b]*Institute of Geography, Russian Academy of Sciences, Moscow, Russia*
**e-mail: kuan-2012@yandex.ru*
***e-mail: alexei.krivolutsky@rambler.ru*

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Abstract—The relationships between circulation characteristics in the lower atmosphere of the Northern Hemisphere and the sunspot cycle are analyzed with the use of the superposed epoch method and elements of correlation analysis on the basis of data on the length of elementary circulation processes of different types (according to Dzerdzeevsky classification) and the time series of Wolf numbers for 1899–2016. It is ascertained that a general intensification of solar activity promotes an increase in the length of meridional forms of circulation, but its effect on different subtypes of elementary circulation mechanisms is different. Seasonal differences in the solar effect on the lower atmosphere are also revealed.

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1. INTRODUCTION

The problem of the influence of solar activity (SA) on weather and climate is more than 100 years old. The accumulated results for this time are described in detail in Russian (Eigenson et al., 1948; Rubashev, 1964; Mustel, 1966; Witels, 1977; Sazonov, 1964; Kulieva, 1975; Avdyushin and Danilov, 2000; Mokhov and Smirnov, 2008; Krivolutsky and Repnev, 2009; Zherebtsov et al., 2017) and international (King, 1973; Dickinson, 1975; Hines and Halevy, 1977; Wilcox, 1975; Gerety et al., 1977; Marsh and Svensmark, 2003; Haigh et al., 2010; Gray et al., 2010; Ermolli et al., 2012; Krivolutsky et al., 2015) literature.

SA variations imply a complex of phenomena: changes in the number of sunspots (Wolf numbers), variations in corpuscular fluxes (solar cosmic rays) and radiation intensity in different spectral regions, etc. According to observation data (Lean and De Land, 2012), the variability of the spectral intensity of solar radiation increases as the wavelength decreases in a sunspot cycle (SC). Thus, it is small (~0.1% during a solar cycle) in the visible and near-infrared regions. The variations in the near-UV and shorter wavelengths (240–320 nm) attain 6%. Below 200 nm, they reach several tens of percent or more; at wavelengths of <100 nm and in the X-ray range (<10 nm), they reach more than 100%. These shortwave spectral regions have the strongest effect on the degree of ionization and the gas composition of the atmosphere.

Calculations in up-to-date numerical models (Krivolutsky and Repnev, 2009; Krivolutsky et al., 2016) show that the ozone content in the atmosphere is sensitive to variations in UV radiation and the effect of corpuscular solar fluxes, which is confirmed by observation data.

In this work, we analyze data on the length of atmospheric circulation patterns in the classification (Dzerdzeevsky, 1968) versus SA. In that time, B.L. Dzerdzeevsky, together with the researchers of the Pulkovo Astronomical Observatory A.Ya. Bezrukovoy and B.M. Rubashev, received results that provided evidence of the correlation of the solar activity and geomagnetic storminess with the general atmospheric circulation. The correlation between the frequency of change in circulation types over the Northern Hemisphere (hereinafter, elementary circulation mechanisms (ECMs)) and the level of geomagnetic storminess was later analyzed (Val'chuk et al., 2002; Chernavskaya et al., 2006). It turned out that ECMs change more often in years with low geomagnetic storminess. The strongest correlation (with coefficient $r = -0.58$) was revealed for the period 1972–1991. Intensification of interlatitude air exchange after outbursts of ECM was also revealed.

Despite the constant interest in the problem (only a few related works are listed above), the question about the influence of solar radiation variations on the Earth's lower atmosphere is still relevant.

Table 1. Results of ECM series processing for circulation groups (1899–2016)

Circulation group	Z	ZD	NM	SM
Mean ECM length, days per year	25.4	88.2	197.4	48.6
Standard deviation of the mean σ, days	1.5	3.4	3.2	4.6
Coefficient *R* of correlation between the series of annual mean ECM lengths and the series of Wolf numbers (for 1899–2016, *N* = 118 years)	0.12	–0.13	–0.15	0.19
Coefficient *R** of correlation between the superposed series of ECMs and Wolf numbers in a SC (by data for 10 SC, *N* = 11 years)	–0.53	–0.62	0.39	–0.30

Table 2. Correlation between ECM and SC for different seasons (superposed epoch analysis for 1899–2016)

Circulation group	ZD	NM
Winter	– (7aw, 5b, 5d)	+ (11a, 11b)
Summer	+ (4b, 7bs)	+ (10b, 8bs, 8 cs, 8ds, 9a)
Spring–Autumn		– (12a, 12bs, 12cs)
Prespring–prewinter	+ (4a)**	– (8bw, 12d)**

** The result is within 1.5σ limits.

In this work, an attempt is made to isolate the SA signal from long-term series of the circulation characteristics of the lower air layers. Elements of correlation analysis and superposed epoch analysis are used to solve this problem.

2. SOURCE DATA

In our study, we use a series of the lengths of different of ECM types according to the Dzerdzeevsky classification (Kononova, 2009, www.atmospheric-circulation.ru) in the Northern Hemisphere in the period from 1899 to 2016 and data on solar activity (Ishkov, 2013). The length of ECM of different types is known in days per month and per each year in total.

According to the Dzerdzeevsky classification, four groups of atmospheric circulation over the Northern Hemisphere (on the sea level) are singled out; they include 13 ECM types and 41 subtypes.

(1) Zonal group (Z): high-pressure region on the North Pole, no blocking processes in the Northern Hemisphere, and a ring of circumpolar cyclones (ECM types 1 and 2).

(2) Zonal disturbance (ZD): one blocking process in any sector of the hemisphere under high pressure on the North Pole (EMC types 3–7).

(3) Northern meridional (NM): 2–4 blocking processes and 2–4 southern cyclone outlets under high pressure in the Arctic region (ECM types 8–12).

(4) Southern meridional (SM): low pressure on the Pole, no blocking processes, southern cyclone outlets in 3-4 sectors of the hemisphere (ECM 13).

ECMs are united in seasonal circulation groups (Dzerdzeevsky, 1957): winter, summer, spring–autumn, and prespring—prewinter (early and late winter).

Each ECM has an alphanumeric index (e.g., 7bw). The first digit indicates the type number, the first letter gives the subtype (geographic position of the blocking anticyclone and other peculiarities), and the second letter (can be absent) denotes the season ("s" for summer and "w" for winter, since the circulation types are mainly formed in these seasons).

Time series of ECM length have been primarily processed: the long-term average length (days per year) and the standard error of the mean σ (Table 1) were calculated for each series. The series of deviations from the average length (for circulation groups (Z, NM, NM, and SM) and individual types within these groups) have been calculated for the superposed epoch analysis.

The time series of the total annual lengths of individual ECMs and of circulation groups were analyzed.

The correlation coefficients *R* between the ECM length series (for each circulation group and for individual ECMs) and the corresponding series of Wolf numbers were calculated over 118 years. The *R* values turned out to be small (up to 0.2) and thus insignificant, with a probability of 0.95. Table 1 (fourth row) also gives these results for the circulation groups (Z, NM, NM, and SM).

3. SUPERPOSED EPOCH ANALYSIS OF CORRELATION BETWEEN ECM LENGTH AND SC

The superposed epoch method has been applied to SCs in the period from 1899 to 2016 (ten complete cycles, from 14 to 23). The mean ECM lengths have

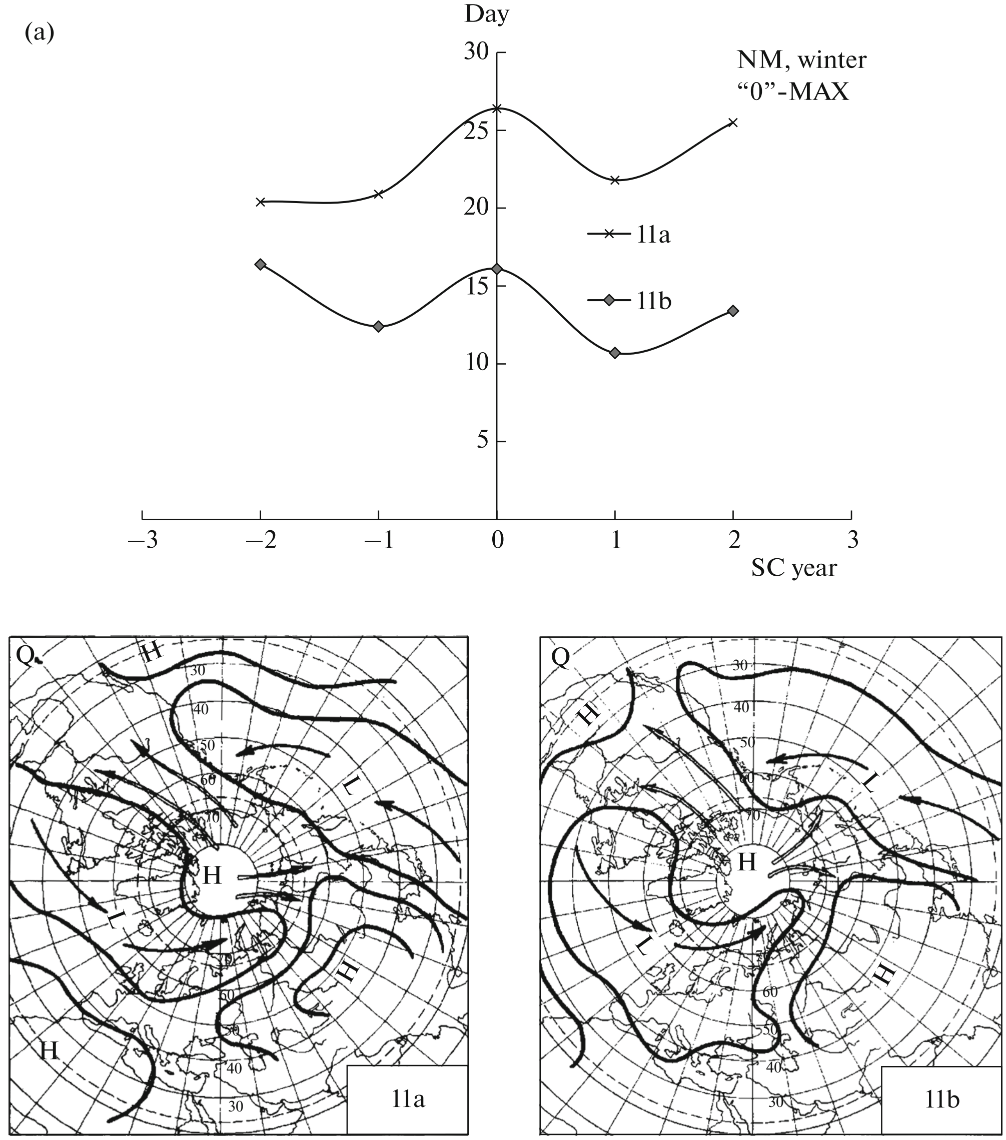

Fig. 1. Superposed epoch method in SC for series of MN and ZD circulation group lengths for different seasons (1899–2016) and corresponding circulations patterns: (a) NM group, winter.

been calculated for each cycle phase for the circulation groups (Z, NM, NM, and SM) and individual ECM types inside the groups (on the ±second and ±first days from the zero point, which is taken at (a) ECM maximum and (b) ECM minimum). These superimposed series of mean ECM lengths in certain years of SC are analyzed.

The correlation between circulation type length and SC is considered significant if the deviations of the length from the long-term average for the superimposed series exceeds $\pm 2\sigma$ within ±2 days from the SA maximum (minimum); the σ values do not exceed 1–2 days for individual subtypes.

The analysis shows that changes in the total circulation time (over all types within a circulation group) in a circulation group are within the limits specified. Thus, there is no significant correlation.

However, when individual ECM types are considered, this correlation is revealed by the chosen criterion in several cases. Table 2 shows the indices of these ECMs, with indication of their circulation and seasonal groups (Dzerdzeevsky, 1957). The “+” sign in the corresponding cell means that the ECM length (conventionally “positive” correlation) increases at the activity maximum, and “–” means that the ECM length decreases with an increase in SA (“negative” correlation).

The results for Z and SM groups are not shown in Table 2, because they turned out to be insignificant.

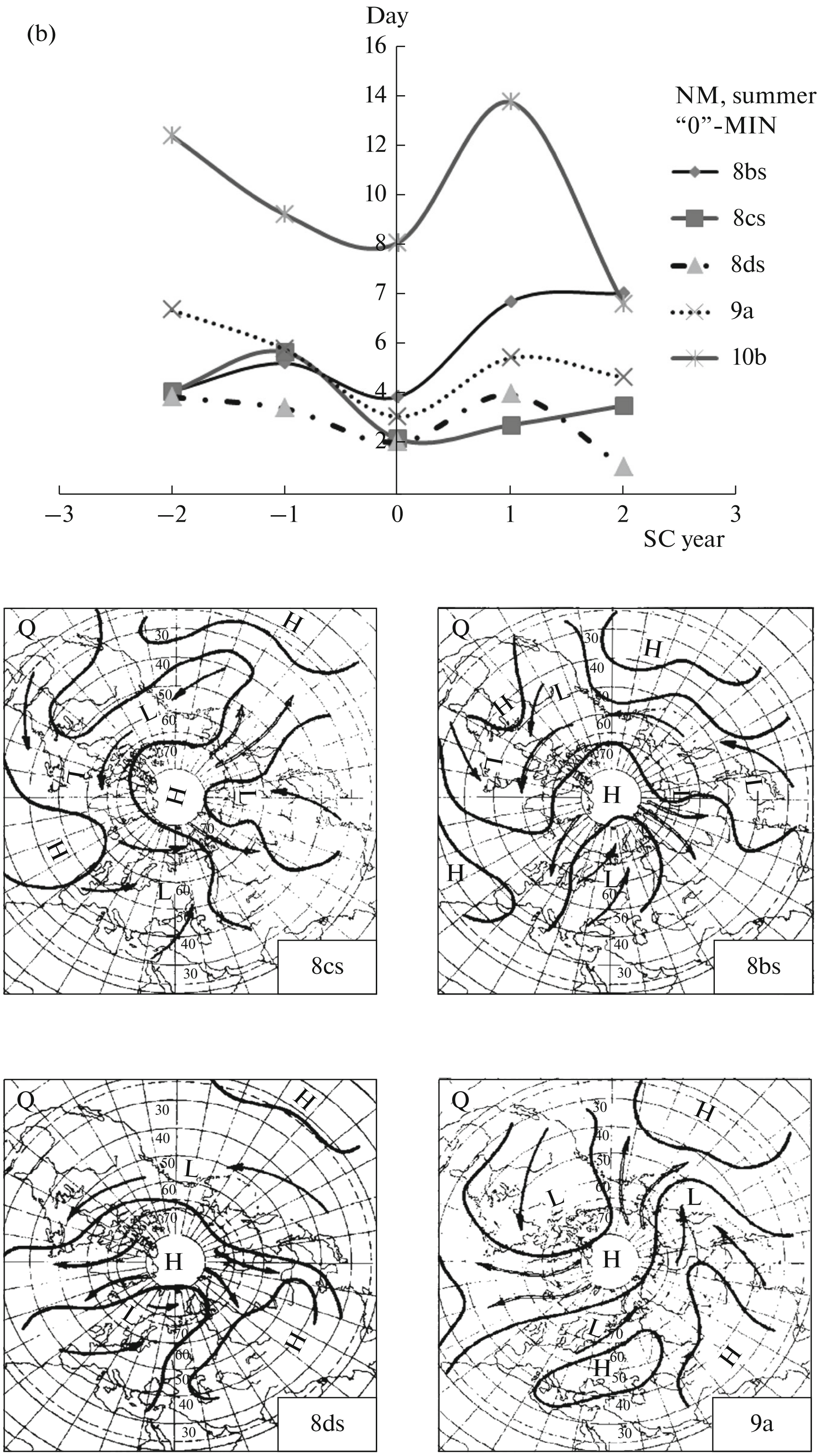

Fig. 1b. NM group, summer.

Figure 1 shows reliable results (curves of variations in the lengths of individual subtypes in the superposed SC) and surface pressure maps for the corresponding ECM, which illustrate the circulation scheme. The arrows show the cyclone and anticyclone trajectories. A positive correlation is clearly pronounced for NM group in all main seasons. For example, the deviation for subtype 11b of this group attains + 47% of the long-term average at the SA

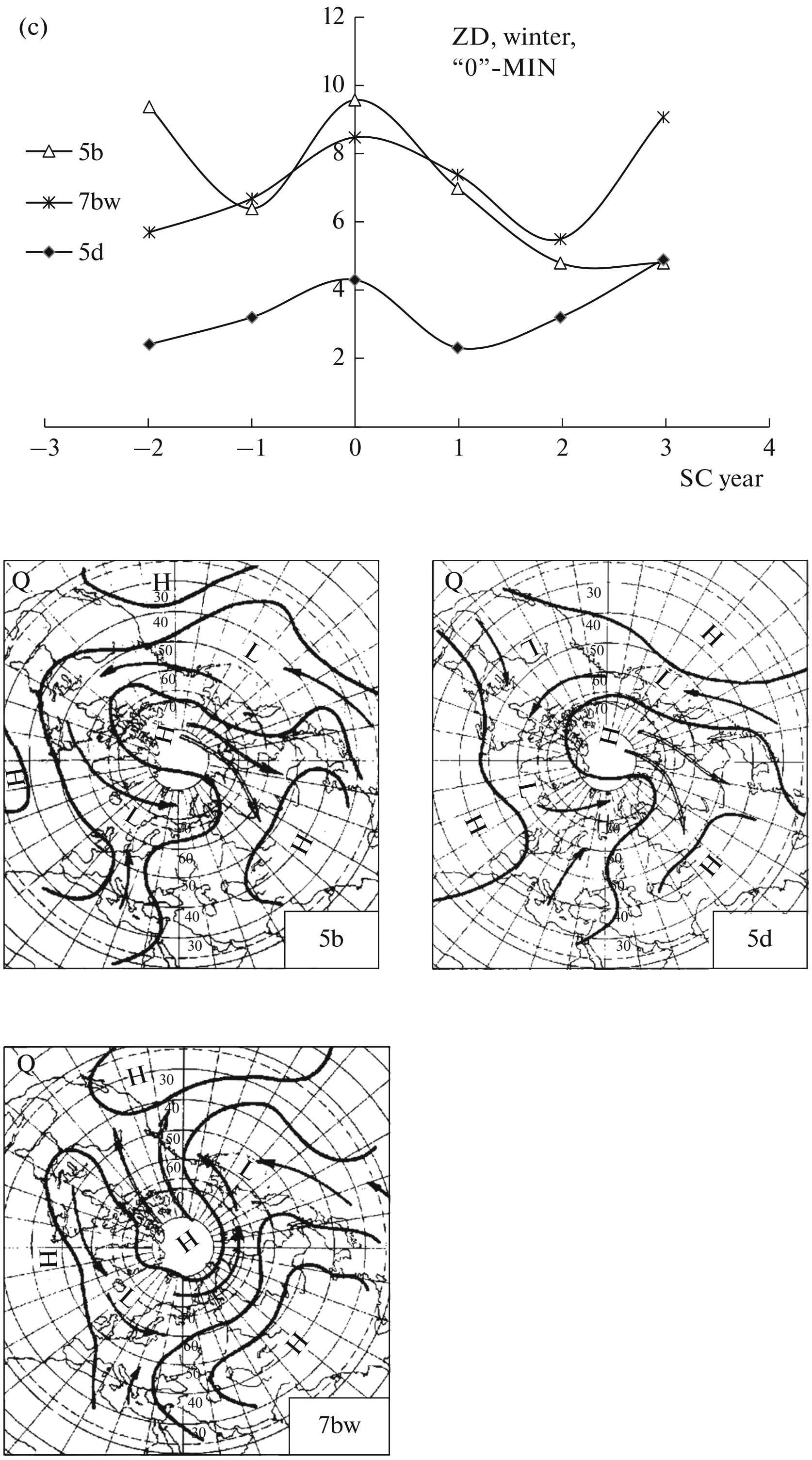

Fig. 1c. ZD group, winter.

maximum in winter and–39% at the minimum. Thus, we can preliminarily conclude that an increase in SA elongates ECMs in the NM circulation group.

For several subtypes of ZD group, solar activity decreases the length in winter and increases in summer (see examples in p.779 and p. 780). For other ECMs in

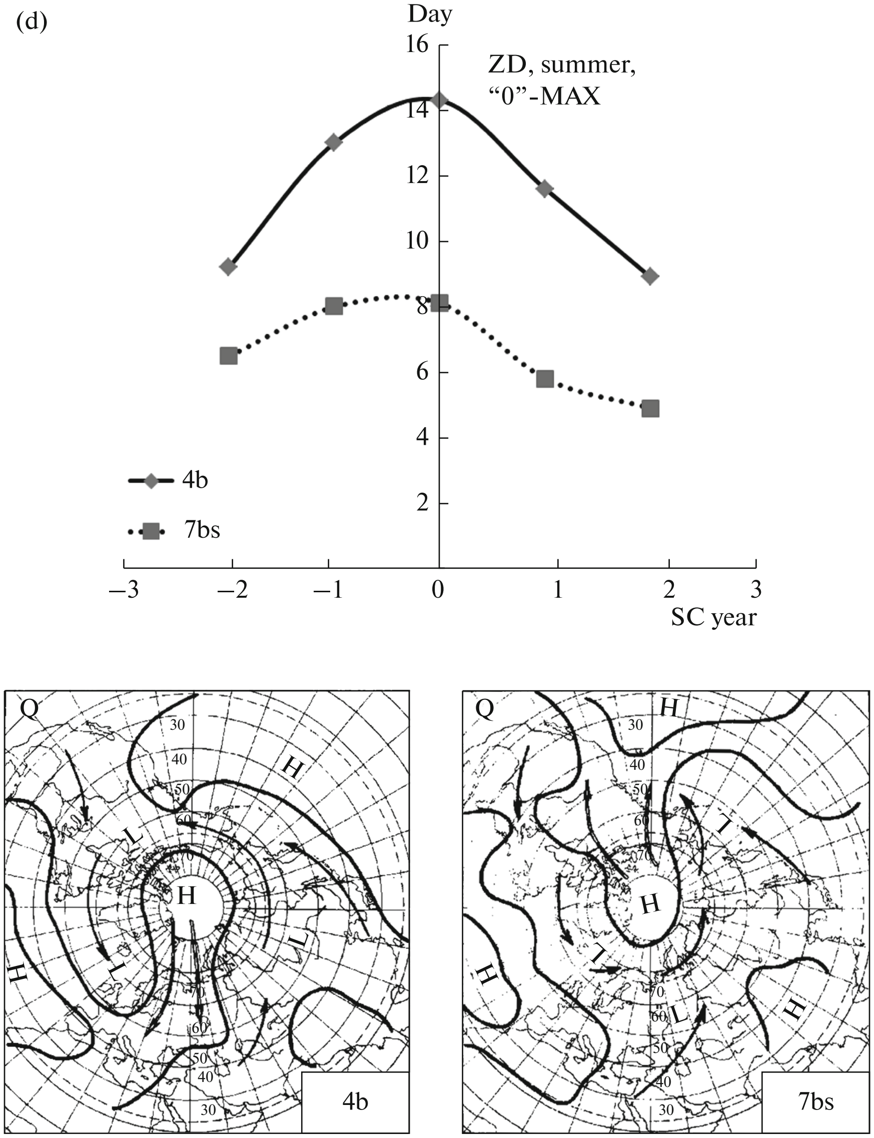

Fig. 1d. ZD group, summer.

this group, the correlation with SC is not pronounced or reliable.

Type 12 (NM group) shows a reliable negative correlation in spring and autumn. This circulation type is the most disturbed: three to four outlets of blocking anticyclones to high latitudes are observed in the hemisphere.

The dependence on CA for most circulation types is not expressed in early or late winter (prespring–prewinter), and only three of them (4a, 8bw, 12d) show a weak correlation (Table 2).

The correlation coefficient R^* between the number of total ECM lengths and the corresponding superposed series of mean Wolf numbers was also calculated from the superposed series. Let us recall that the superposition was carried out for ten SA cycles (from 1899 to 2016); each series consists of 11 points (years of SCs imposed). The coefficient is calculated for the circulation groups and is given in the last row of Table 1. It is interesting that the correlation coefficient R^* is several tiems higher than coefficient R (between the corresponding series of annual mean values, see Table 1) and is negative for Z (–0.53) and ZD (–0.62) groups. The latter does not completely correspond to Table 2. This apparently proves the complex character of the studied correlation.

The positive correlation ($R^* = 0.39$) for NM group agrees well with the superposed epoch calculation results, which are significant with a probability of 0.95.

In addition, when 11-year superposed series in a SC are considered, variations in NM and SM groups show a significant negative mutual correlation ($R =$

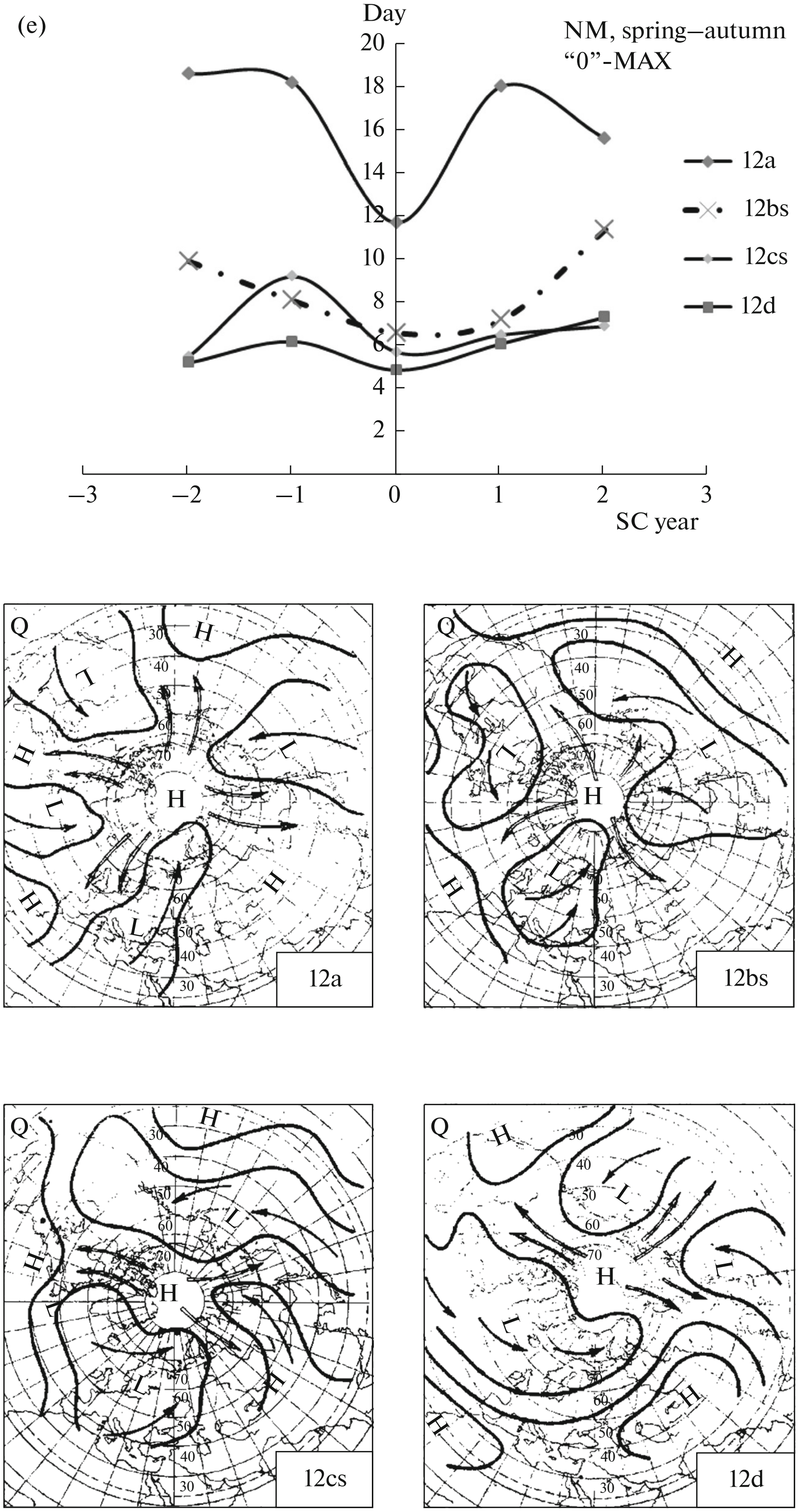

Fig. 1e. NM group, spring–autumn.

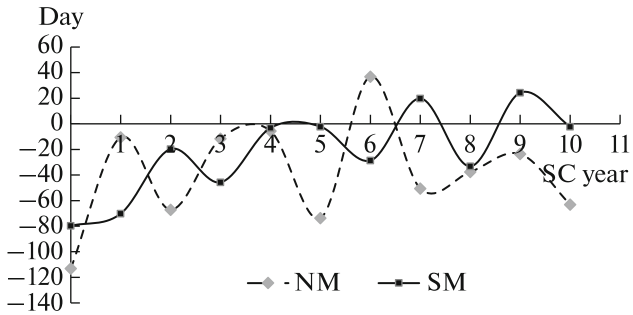

Fig. 2. Time variations in the annual mean length of NM and SM circulation groups in a SC calculated by the superposed epoch method for 1899–2016 (the beginning and end points correspond to SC minima).

−0.9) (curves in Fig. 2). The complex, quasi–two-year character of these variations is evidently caused by other factors (not only variations in SA).

Thus, our study indicates the possible positive effect of SA on the length of ECM types of the NM group in winter and summer. During transitional seasons, the SA exhibits a significant negative correlation with the most complex forms of circulation of type 12, which are characterized by the occurrence of three to four blocking events in the hemisphere.

4. CONCLUSIONS

Seasonal differences in the SC effect on certain types of circulation in the Northern Hemisphere were found for the first time:

—solar activity promotes an increase in the length of ECM of the **northern meridional circulation group** (two to three blocking processes over the hemisphere) in winter and spring, and a decrease in transitional seasons;

—a negative correlation with SA in winter and positive in summer was revealed for the **zonal disturbance group** (with one blocking process in the hemisphere).

In general, the results partly confirm the previous conclusion about the enhancement of meridional circulation forms with an increase in SA. However, new quantitative estimates of the correlation between the circulation characteristics and SC were calculated in this work, a new, data-processing method was applied, and seasonal peculiarities were revealed.

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