

Latitude-Longitude Characteristics of the North–South Asymmetry of Solar Activity

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Abstract—The characteristics of the latitude-longitude distribution of the north–south (NS) asymmetry of the number of sunspots for the period of 1874–2013 are studied. It is shown that there is an NS asymmetry of the sunspot number in all latitude-longitude ranges in which solar activity is manifested. Longitude ranges that exist for quite a long time in which the activity of the northern or southern hemisphere predominates are selected. It is found that the NS asymmetry of the sunspot number for the Sun as a whole is determined to a greater extent by the asynchronous development of activity in the northern and southern hemispheres.

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1. INTRODUCTION

Solar activity is equally manifested in both hemispheres of the Sun only in the first approximation. A more detailed study of the cycle curves of solar activity by hemispheres shows they differ in phase, amplitude, and duration. For over a hundred years, researchers have shown that the NS asymmetry is not accidental and have found a number of patterns of its manifestation (Vitinskii et al., 1986).

Since the solar cycle is a spatiotemporal phenomenon and not just a temporal one, it would be desirable to study the characteristics of the dynamics of latitude-longitude asymmetry in the activity of the northern and southern solar hemispheres in order to analyze the influence of different factors on this phenomenon. The longitude distribution of solar activity is known to show NS asymmetry. In the northern and southern solar hemispheres, active longitudes are displaced relative to one another (Vitinskii, 1966). The active longitudes of the northern and southern hemispheres are antipodal. The active longitudes of one hemisphere predominate in the ascending phase, and those of the other predominate in the descending phase (Plyusnina, 2003).

The examination of weather maps of the asymmetry index of the brightness of the green coronal line in the northern and southern hemispheres in successive Carrington rotations shows that the latitude and longitude regions dominated by the northern or southern hemispheres form regions oriented either vertically along the latitude or horizontally along the Carrington longitude (Badalyan, 2013). Spectral analysis reveals 11-year quasi-periodicity in the formation of these oriented structures (Badalyan 2013).

2. PROCESSING AND DISCUSSION OF MATERIALS

In this paper, we studied the characteristics of the latitude-longitude distribution of the NS asymmetry of the sunspot number over the period 1874–2013. Observations of sunspot groups of the following observatories were used: Greenwich for 1874–1982 (www.ngdc.noaa.gov), Pulkovo for 1954–2013 (www.solarstation.ru), and Ussuriysk Observatory for 1954–2013. The difference $N_n - N_s$ was used as the NS asymmetry index for a specific latitude-longitude range, where N_n is the sunspot number in the corresponding latitude-longitude range of the northern hemisphere and N_s is that of the southern hemisphere. The NS asymmetry index was calculated in the latitude-longitude range of 30° in longitude and 10° in latitude sliding along the Carrington longitude with a shift of 10° and 5° in latitude. The calculation period is one year. Two-dimensional latitude-longitude annual diagrams of the distribution of the $N_n - N_s$ NS asymmetry index were plotted based on the calculation results. Latitude–time diagrams were plotted with a latitude resolution of 10° and a time resolution of one year by averaging the asymmetry index over all longitude ranges based on the latitude-longitude annual diagrams. By averaging the latitude-longitude annual diagrams of the NS asymmetry index over all latitudes, we obtain a longitude–time diagram with a longitude resolution of 30° and a time resolution of one year. Averaging of the latitude-longitude annual diagrams makes it possible to study the behavior of the index of NS asymmetry of solar activity in any time period of interest, for example, in years near the minimum or

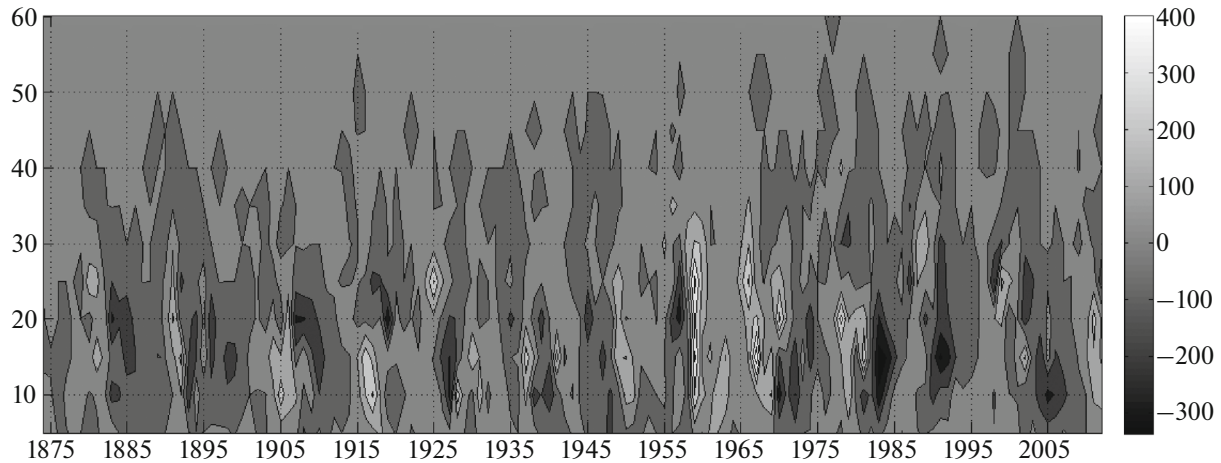


Fig. 1. Latitude–time distribution of NS asymmetry of the sunspot number for 1874–2012.

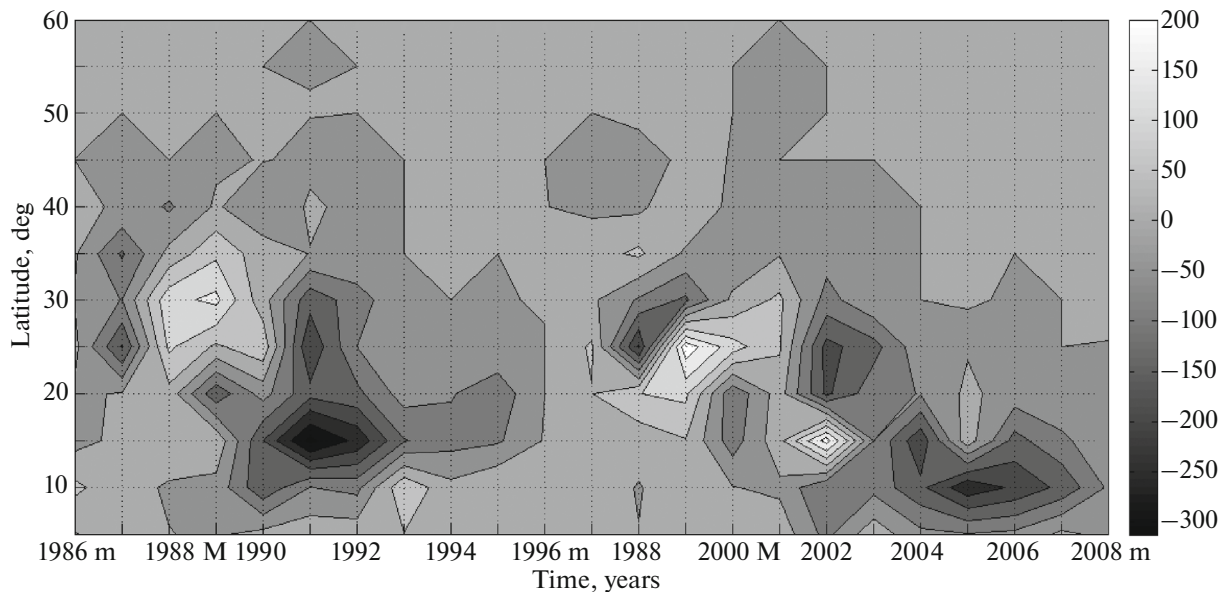


Fig. 2. Latitude–time distribution of NS asymmetry of the sunspot number for 1986–2008. M is the maximum and m is the minimum of the cycle.

maximum of the solar cycle, for the whole cycle, or for another time range.

In Fig. 1, on the diagram of the latitude–time distribution of the NS asymmetry of the sunspot number for the entire studied period of 1874–2013, the periodicity associated with the 11-year cycle can be well defined by the structures extending along the latitude, but it is difficult to distinguish the characteristics of these structures within the cycle solar activity.

The latitude–time diagrams with a higher time resolution in Fig. 2 show that the latitude–time distribution of the NS asymmetry of the sunspot number over the 11-year cycle resembles the Maunder’s butterfly wing. It is most often distinguished along the bound-

ary of small negative values of the $N_n - N_s$ asymmetry index with the inclusion of areas with large absolute negative and positive values of the asymmetry index that exist for quite a long time and migrate from high to low latitudes.

Latitude–time diagrams averaged by the method of superimposed epochs over the corresponding time ranges show near the minima of the cycles (Fig. 3) in which the southern hemisphere predominates in the descending branch of the 11-year cycle and those in which the northern hemisphere predominates in the ascending branch. This can be explained by the fact that, during the considered period of 1874–2013, most cases in the northern hemisphere the cycle began ear-

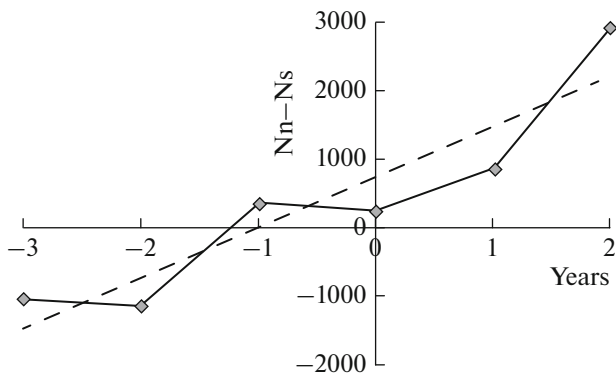


Fig. 3. Latitude–time diagrams averaged for the period 1874–2012 by the method of superimposed epochs. The reference point of the minimum of cycles on the abscissa corresponds to 0.

lier. This is confirmed when we use the maxima of 11-year cycles as reference points and by the fact that the sunspots of the new cycle appear earlier in the northern hemisphere than in the southern hemisphere in 9 of 13 cases. This is apparently associated with 88-year quasi-periodicity (the northern hemisphere leads for four cycles, and then the southern lead for four). It also can be seen in Fig. 4, which shows the variation curves of NS asymmetry $(N_n - N_s) / (N_n + N_s)$ for the ascending phase and the descending phase of cycles 12–23.

The periodicity associated with the 11-year cycle is also found by the type of the longitude–time distribution of the $N_n - N_s$ asymmetry index in Fig. 5. This is due to the fact that, in years near cycle maxima, the absolute value of the $N_n - N_s$ index is larger in magnitude than in years close to the cycle minimum. The diagram also shows fairly stable (lasting for at least two

11-year cycles) longitude ranges in which the northern or southern hemisphere are more active. It can be seen that the NS asymmetry index has the opposite sign on both sides of the cycle maximum. This can be explained by the shift of cycle curves of the northern and southern hemispheres relative to each other. The longitude distribution of the $N_n - N_s$ asymmetry index in the years near the minima and maxima of the solar activity cycles differs. Near the minima, activity usually predominates in the southern hemisphere, and near the maxima, it usually predominates in the northern hemisphere.

Let us apply the method of expansion into natural orthogonal functions (Vertlib et al., 1971) to the longitude–time diagram as follows:

$$\delta N_{ij} = \sum_{k=1}^n T_{ik} L_{kj},$$

where δN_{ij} is the $N_n - N_s$ difference in i th year in the j th longitude range, L_{kj} is k th coordinate function that, in our case, describes the longitude distribution of the NS asymmetry in i th year, and T_{ik} is the time function conjugate with L_{kj} that describes the behavior of this parameter over time. The interorthogonality of time functions makes it possible to assume the linear independence of physical causes, the contributions of which to the studied phenomenon are described by different coordinate functions, and to estimate the contribution of each coordinate function to the considered phenomenon.

As a result of the expansion of the longitude–time diagram for 1879–2012, we obtained 36 coordinate functions and 36 time functions associated with them that describe the longitude distribution of the $N_n - N_s$ index for the year and the change in this distribution from year to year. The contribution of individual coor-

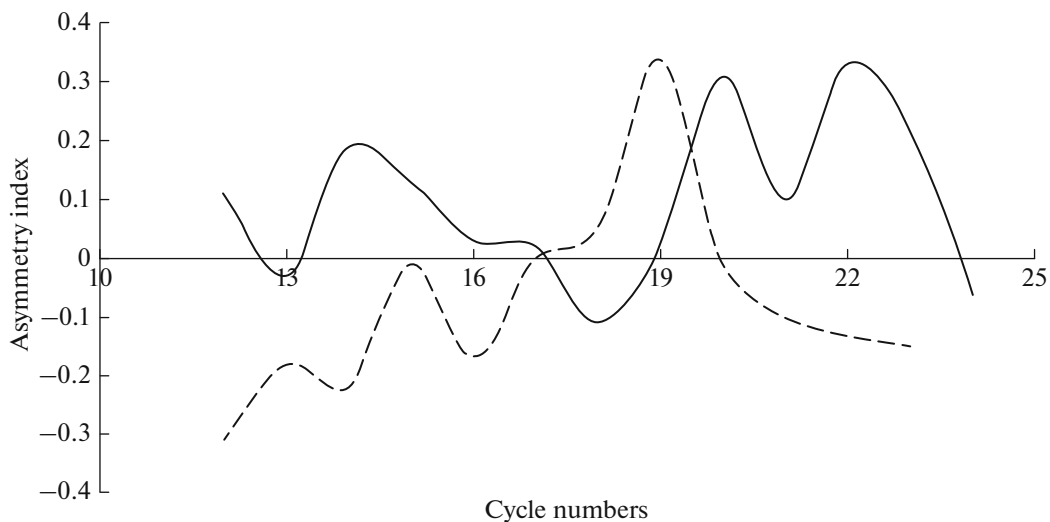


Fig. 4. North–south asymmetry $(N_n - N_s) / (N_n + N_s)$ during the ascending (solid line) and descending (dashed) phases of the cycle.

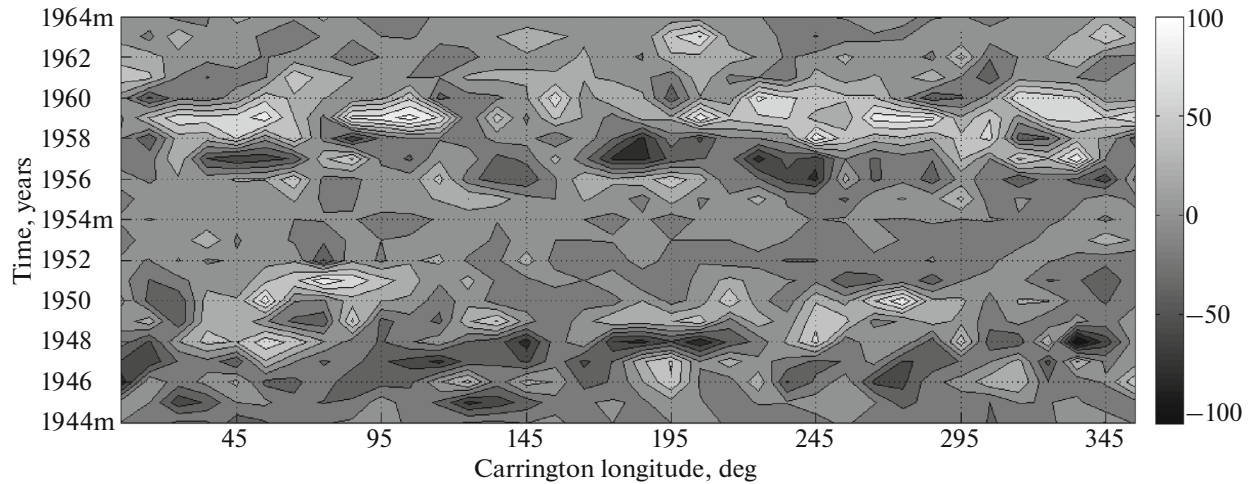


Fig. 5. Long-time distribution of the N_n – N_s asymmetry index for 1944–1964. m is the cycle minimum; maxima are at 1947, 1957.

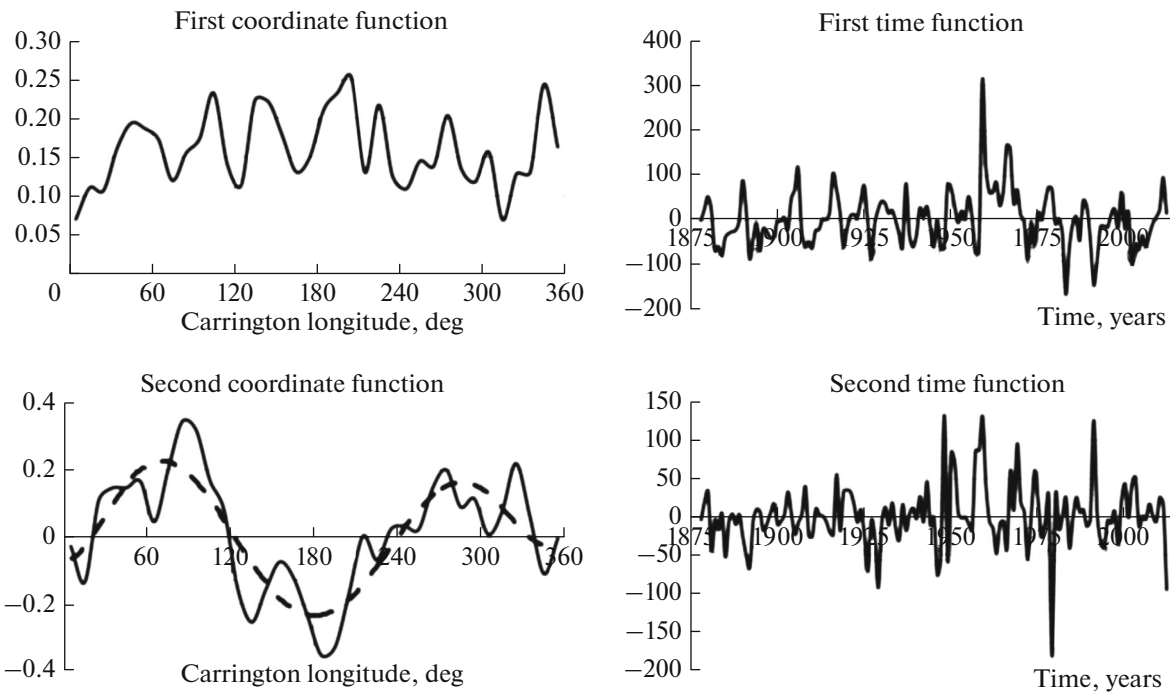
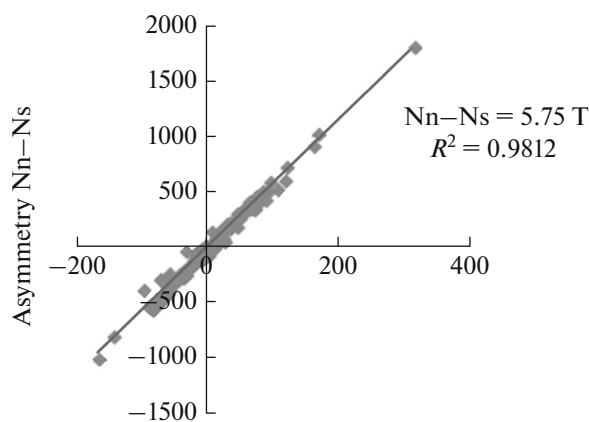


Fig. 6. First two terms of the expansion in natural orthogonal functions of the longitude-time diagram for 1974–2013.

dinate functions was estimated from their eigenvalues, which coincide with the variance of time functions. The contribution of the first six coordinate functions is more than 50%.

Figure 6 shows the graphs of the first two coordinate functions and two corresponding time functions. The first coordinate function contributes 17.5% and describes the longitude distribution of the asymmetry index with longitude structures with a longitudinal extent of about 60° , in which the asymmetry sign reverses, in the ascending and descending branches of

the cycle (see the sign of the time function). By the form of the first coordinate function, it is also possible to assume the presence of a structure with a longitudinal extent of 180° , in which the asymmetry sign also reverses when passing from the ascending branch to the descending branch. In addition, the variation of the first time function describes the variation of annual values of the N_n – N_s NS asymmetry index obtained for the Sun as a whole with high reliability (the square of the correlation coefficient of 98%) (Fig. 7). The corresponding linear regression equation is N_n – $N_s = 5.75T$, where T is the value of the first time function.



Linear approximation
of the dependence $N_n - N_s = F(T)$

Fig. 7. Dependence of the annual values of the $N_n - N_s$ NS asymmetry on the corresponding values of the first time function T .

The second coordinate function describes the differences in the longitude distribution of solar activity in the northern and southern hemispheres. It shows the contribution of different longitude ranges to changes in the NS asymmetry index calculated for the Sun as a whole. It also indicates that there are active longitude ranges in which solar activity is systematically higher or lower in one of the hemispheres of the Sun, northern or southern. For the second coordinate function, there are three such longitude ranges; for the third, there are also three, but they are shifted relative to the second coordinate function. There are two for the fourth coordinate function and four for the fifth. The asymmetry sign in these longitude ranges varies according to the sign of the corresponding coordinate function for a given year. In the spectra of all time functions, there are peaks to some extent around the periods of 88, 44, 21, 11, and 5–6 years.

3. CONCLUSIONS

There is an NS asymmetry of the sunspot number in all latitude-longitude ranges in which solar activity is manifested.

The latitude–time distribution of the NS asymmetry of the sunspot number over the 11-year cycle resembles Maunder’s butterfly wing, which most often is distinguished along the boundary of small negative values of the $N_n - N_s$ asymmetry index with the inclusion in this region of areas with large absolute negative and positive values of the asymmetry index that exist

for quite a long time and migrate from high to low latitudes.

Latitude–time diagrams averaged by the method of superimposed epochs show that, near the cycle minima, the southern hemisphere predominates in the descending branch of the 11-year cycle and that the northern hemisphere predominates in the ascending branch. This can be explained by the fact that the cycle began earlier in most cases in the northern hemisphere (in 9 of 13 cases) during the considered period of 1874–2013. This is also confirmed by the fact that the northern hemisphere of the Sun almost always predominates in the ascending phase of the solar cycle and the southern hemisphere almost always predominates in the descending branch.

Fairly stable longitude ranges in which the northern or southern hemispheres are more active were identified. The contribution of these longitude ranges to the NS asymmetry index for the Sun as a whole is greater.

The NS asymmetry of the sunspot number for the Sun as a whole is associated to a greater extent with the asynchronous development of activity in the solar hemispheres, namely, with a shift of the cycle curves of the northern and southern hemispheres relative to each other.

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