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Activity cycles and properties of sunspot bipoles

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A comparison of the properties of bipoles with the strength of activity cycles in the period of cycles 15–24 according to digitized sunspot drawings from Mount Wilson Observatory is performed. It is shown that the previously found relationship between the average tilt angle of bipoles normalized to the average latitude of the cycle (Dasi-Espuig et al., 2010) is possibly due to the dependence of the average latitude of sunspots $< \lambda >$ on the amplitude of the activity cycle. The tilt angle of the bipoles $< tilt >$ itself is weakly related to the strength of the current activity cycle. A modified averaging index for the tilt angles in the solar cycle is proposed, $< tilt/\lambda >$, in which averaging is performed for the ratio. It is shown that there is a weak relationship between the magnitude of this index in the current cycle and the amplitude of the next cycle activity.

Keywords: Sun, solar activity, long-term variations: general

1 Introduction

It is known that the position of the magnetic axis of solar bipoles, connecting the leading and tail parts, has an angle with the direction of the line east–west. As a rule, the tail parts of the groups of spots lie closer to the poles and the angle of inclination increases with latitude. This pattern found by Joy (Hale and Nicholson, 1925), together with the Hale law (Hale et al., 1919) on the polarity reversal of the leading and tail spots in the 22-year cycle is perhaps one of the main causes of the existence of the solar magnetic cycle. Later, Joy's law was confirmed in many works (Howard, 1991; Sivaraman et al., 1993; Kosovichev and Stenflo, 2008). At present, it is believed that the Joy law is caused by the action of the Coriolis force, which unfolds the pop-up magnetic fields that form the sunspots (Fisher et al., 2000). In this paper it is established that the Coriolis force leads to the reverse flow along the top of the tube, which leads to a relatively larger extension of the magnetic field lines and, consequently, to a stronger field strength in the front of the tube. With a

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greater field strength, the leading leg is more floating with a higher rate of build-up and remains more cohesive than the next leg.

In the same time Tlatov et al. (2013) found that for bipoles with area < 300 mhs. The difference with the results of Stenflo and Kosovichev (2012) is attributed to a bias owing to inclusion of smaller bipoles in their sample. The higher the latitude, the more dominant the small bipoles and their effect on the average tilt angle becomes.

There is a wide variation in the angle of inclination of the bipoles, which can have a contribution from the following components. The lifetime of the active region. The orientation of bipoles is almost random, but after 1–3 days it becomes more organized, reaching a final orientation (Harvey, 1993; Kosovichev and Stenflo, 2008).

The size factor. For the first time Harvey (1993) showed that the scatter depends strongly on the size of the bipoles, which is the smallest for the largest bipoles and increases with decreasing size of the area. Nevertheless, the largest AR again seems to deviate statistically from Joy's law (see Tlatov et al., 2010). Length of bipoles. Fisher et al. (1995) showed that the average angle of inclination of bipoles (*tilt*) increases with increasing bipole axis length (d). Distance from the center of gravity of butterflies sunspots. Harvey (1993) found that the preferred orientation of active regions and ephemerical regions is the strongest at the mid-latitude ARs (λ_0). The deviation from this orientation increases with the help of the differential latitude $\triangle\lambda_0$.

Based on observational data in the white light of Observations of Mount Wilson and observations of Kodaikanal (Howard et al., 1999; Sivaraman et al., 1999; Dasi-Espuig et al., 2010) found that the average scale angles normalized in latitude for cycles 16–21 correlate with the intensity of the cycle. In McClintock and Norton (2013) a significant difference was found in the tilt angles of the northern and southern hemispheres, the average angles of the Northern Hemisphere turned out to be larger than those of the angles of the Southern Hemisphere. In this case, the average angles of inclination of the northern hemisphere do not show dependence on the cycle.

We performed the digitization of measurements of the magnetic fields of sunspots of Mount Wilson observatory during the period 1917–2016. In this paper, we want to test the dependence of the angles on the tilt from observations of sunspot umbra magnetic fields for cycles 15–24.

2 Data

For the digitization (tabulation) of data from sketches of Mount Wilson Observatory (MWO), we have developed special software. The details of digitization and the first results of analysis of a series of data were described in Tlatova et al. (2015). For each spot, we measured heliographic coordinates, area in pixels, area in physical units, corrected for heliographic projection, configuration of sunspot umbra in vector format, observation time and magnetic field strength. The total number of days (from the number of observations processed by us) in which measurements of magnetic fields were measured was 20318 during the period 1917 to October 2016. The number of magnetic field measurements of individual umbra and pores was about $5 \cdot 10^5$, the number of bipoles extracted was $\sim 5 \cdot 10^4$.

Figure 1 shows the average monthly number of selected bipoles. The total number of allocated bipoles was 51413. The diagram shows that the largest number of bipoles

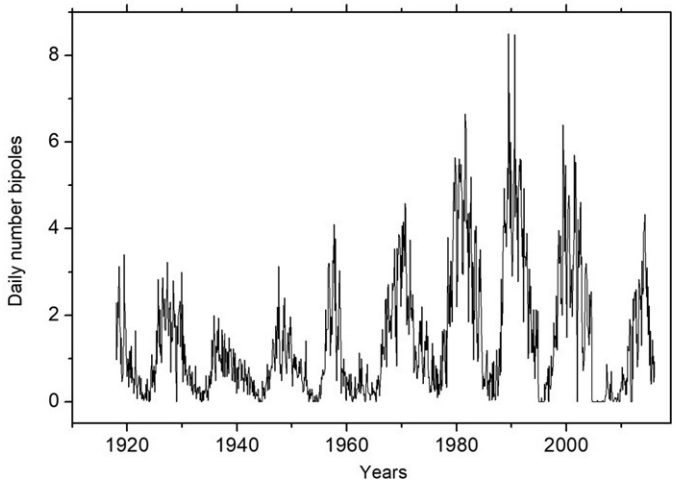


Figure 1 Variation of the number of bipoles per day, averaged over the month according by the MWO data.

corresponds to ∼1990 or to the 23-rd activity cycle. Obviously, this is due not to the actual number of bipoles, but to the number of bipoles drawn on the maps of MWO observatory.

Figure 2 shows the time-scale diagram of the number of selected bipoles. As expected, the distribution of the selected bipoles corresponds to the "butterfly" of Maunder. Also, the heterogeneity of the data is associated with the unevenness of the series. The size is proportional to the area of the largest sunspot umbra, but is limited to 3 pixels.

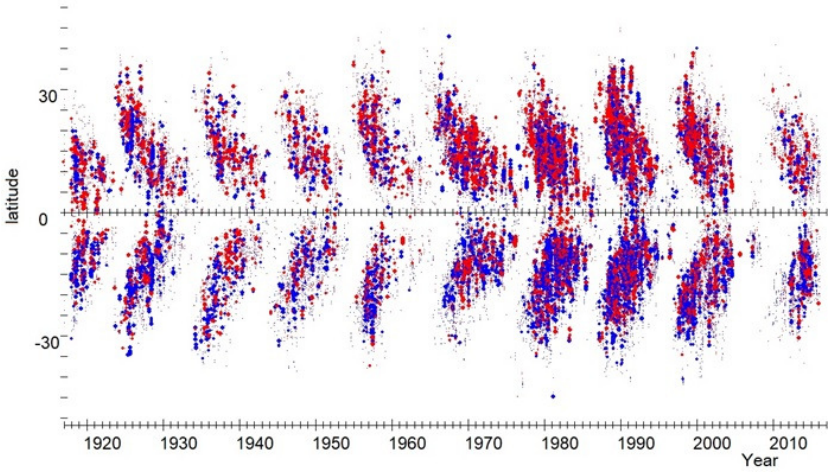


Figure 2 The latitude–time distribution of the allocated sunspot bipoles. The blue color corresponds to the position of the tail part of the bipoles closer to the north pole than the leading ones, the red color-tail is closer to the south pole.

The main result obtained in Tlatova et al. (2018) is to establish differences in the properties of bipoles in the even and odd cycles of activity. Most significantly, these differences are observed in the low-latitude zone.

3 Relationship between the tilt angle and the amplitude of solar cycles

The articles Dasi-Espuig et al. 2010; McClintock and Norton, 2013, discuss the relationship between the angle of inclination and the amplitude of activity cycles over a period of the 15–21 cycles of activity. Data of sunspots in the white light of Mount Wilson and Kodaikanal observatories were used. In Ivanov (2012) the data of the "Catalog of Solar Activity" were also added.

The main conclusions of these studies are based on a comparison of the amplitude of the cycle, expressed in the total area of sunspots, and the functional, where λ is the latitude of the spots. However, the use of this functionality to establish a connection may not be correct. Figure 3 shows the ratio between the cycle strength expressed as the sum of the areas $S = \sum_n S_{\rm spot}$ where n is the number of spots per cycle from the data (https://solarscience.msfc.nasa.gov).

There is a high correlation ($R = 0.9$) between parameter S and $< \lambda >$: $\lambda = 11.2 \pm 0.53 + 1.1 \cdot 10^{-6}(\pm 1.1 \cdot 10^{-7})$. Thus, the established relationship between the angle of tilt and the amplitude of cycles in Dasi-Espuig et al. (2010), McClintock and Norton (2013), Ivanov (2012) is, possibly, a consequence of the connection between S and $< \lambda >$ in which the role of bipoles proper is negligible.

To study the connection between the tilt angle and the amplitude of the cycle, another functional can be used. Here, the ratio for each bipole is calculated, and only then the average value in the cycle is calculated. Indeed, in Fig. 4 are graphs of the dependence of tilt angle on latitude for cycles 15–24. To exclude large values

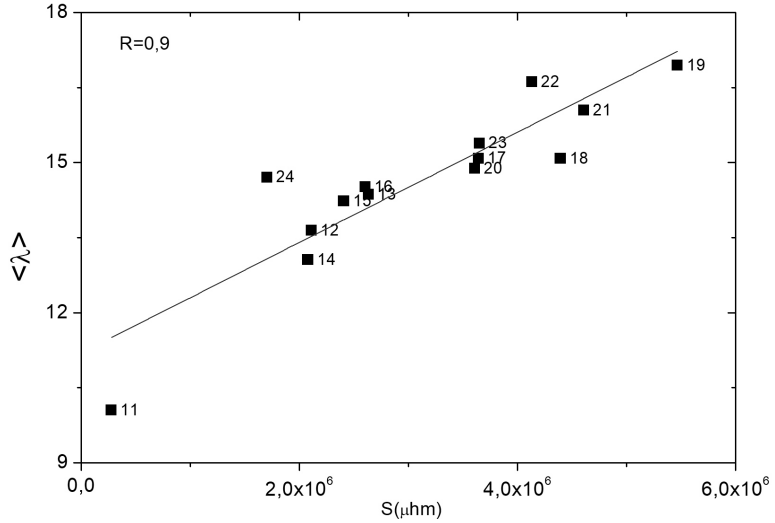


Figure 3 Relationship between the strength of the solar cycle S_n and the average latitude of the sunspots in the cycle $< \lambda >_n$.

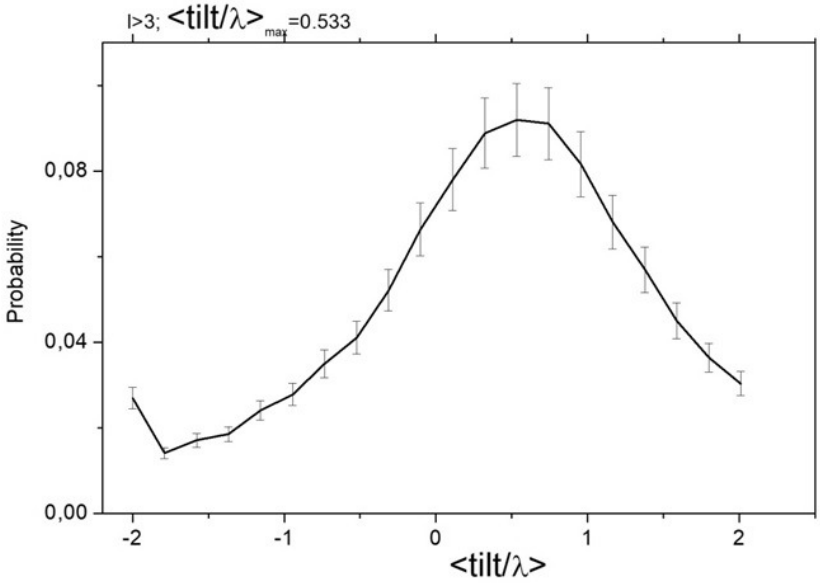


Figure 4 Distribution of the parameter $< tilt/\lambda >$ over the entire observation period.

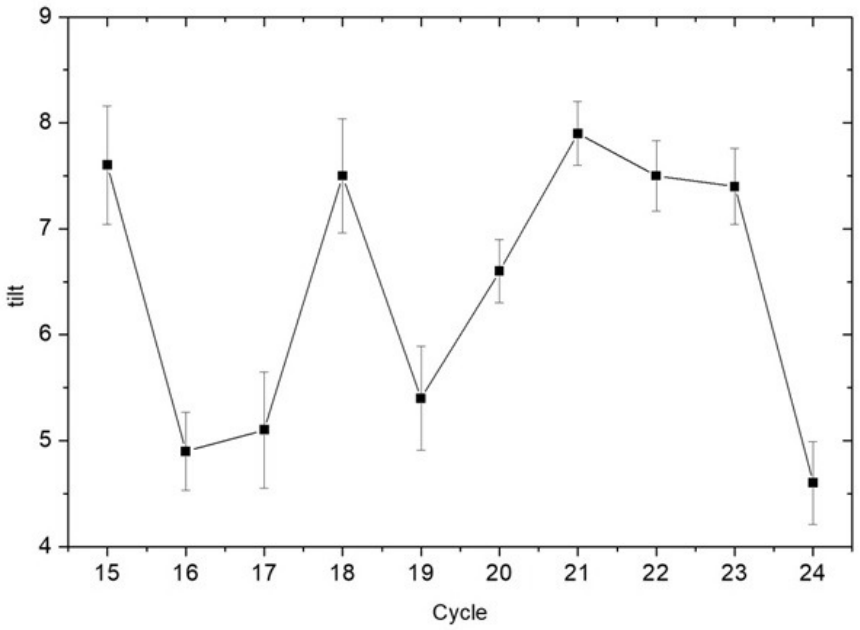


Figure 5 Values of the tilt angle averaged for activity cycles.

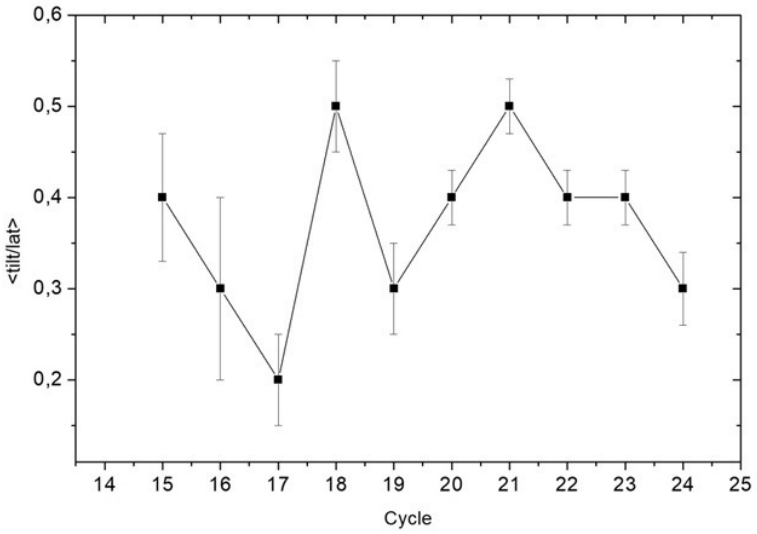


Figure 6 Distribution of the parameter $< tilt/\lambda >$ in the activity cycles.

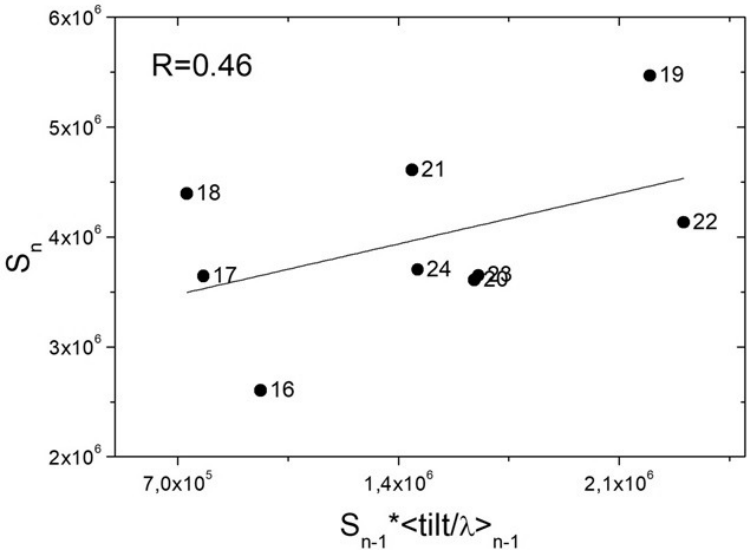


Figure 7 Relationship of the parameter in the cycle $n-1$ and the strength of the next activity cycle n.

near the equator, we assumed that $\lambda = 1°$ if $\lambda < 1°$. In the first approximation, this dependence can be represented as linear, so we can expect that the functional, where the brackets denote the averaging over a period, is a characteristic of the angle of inclination of bipoles, with the elimination of the dependence on latitude (dependence on Joy's law).

Figure 5 shows the values of the angle tilt for activity cycles 15–24. Values were obtained when searching for a normal distribution in the distribution of bipoles along the tilt angle.

Figures 5 and 6 show that the ratio between the mean angle or the parameter *tilt* and the strength of the current activity cycle is practically absent (correlation coefficient $R \sim 0.2$). Thus, we found that when the latitude factor is eliminated, which depends on the cycle strength, the findings established in Dasi-Espuig et al. (2010), McClintock and Norton (2013), Ivanov (2012) are not significant.

Figure 7 shows the relationship between the parameter $< tilt/\lambda >$ in the current cycle n and the strength of the next activity cycle, expressed as the sum of the areas of the spots. The connection is not strong, the correlation coefficient is $R \sim 0.46$.

Conclusions

In this paper, the characteristics of magnetic bipoles of sunspot fields over a period of about 100 years are examined from the data of digitization of maps with sketches of solar sunspots with the measured magnetic field intensities of Mount Wilson Observatory.

We found: 1) It is shown that the relationship between the mean angle $< tilt >$ and the strength of the solar activity cycle is weak or absent. The previously found relationship between the parameter $< tilt > / < \lambda >$ (Dasi-Espuig et al., 2010) is most likely due to the connection of the mid-latitude spots in the cycle and the strength of the activity cycle. 2) There is a weak relationship between the parameter $S_n \cdot < tilt/\lambda >$ in the current cycle and the strength of the next activity cycle.

Acknowledgements

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