

Postprint of Rieger-type Periodic Phase Analysis of Solar North-South Hemisphere Sunspot Areas Based on Empirical Mode Decomposition

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Abstract

This study employs the Empirical Mode Decomposition technique to investigate Rieger-type periods in sunspot area data from solar cycles 12 to 24, as well as their phase relationships in the northern and southern hemispheres. The findings reveal that: (1) the periodicity scales and temporal scales of Rieger-type periods differ between the two hemispheres, resulting in hemispheric asymmetry; (2) the average Rieger-type period length in the northern hemisphere is slightly greater than that in the southern hemisphere; (3) the phase of Rieger-type periods in the dominant hemisphere is not necessarily leading, and hemispheres with similar Rieger-type periodicity scales are not necessarily strongly correlated.

Full Text

Rieger-type Periodic Phase Analysis of Sunspot Areas in the Northern and Southern Hemispheres Using Empirical Mode Decomposition

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Abstract

This paper employs Empirical Mode Decomposition (EMD) technique to investigate the Rieger-type periodicity present in sunspot area data from solar cycles 12 to 24 and examines the phase relationships between the northern and southern hemispheres. The study reveals three key findings: (1) both the Rieger-type cycle scale and temporal scale differ between the two hemispheres, leading to

hemispheric distribution asymmetry; (2) the average Rieger-type cycle length in the northern hemisphere is slightly longer than that in the southern hemisphere; and (3) the phase of the dominant hemisphere is not necessarily 超前, and hemispheres with similar Rieger-type cycle scales do not necessarily exhibit strong correlations.

Keywords: Asymmetrical solar hemispheres; Rieger-type cycle; Phase

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The 154-day periodicity in solar activity, known as the Rieger-type cycle, is widely observed across various solar activity indices. First discovered in solar flares by the Solar Maximum Mission (SMM) satellite, this periodicity was subsequently identified in sunspot numbers and areas. Rieger-type cycles typically range from 130 to 185 days and appear near the maxima of solar cycles. This periodicity exhibits an exceptionally long temporal distribution with a certain degree of intermittency, represents a global rather than localized solar feature, and shows stronger periodicity during solar maxima than minima. Current physical interpretations of the Rieger-type cycle include: generation by differential rotation and toroidal magnetic fields in the solar interior dynamo layer [1]; and production through instabilities of magnetic Rossby waves, where quasi-biennial oscillations emerge when magnetic Rossby wave intensity exceeds 10 G, while Rieger-type cycles arise when intensity is below 10% G [2]. Consequently, investigating solar Rieger-type periodicity holds significant scientific value for understanding the spatiotemporal evolution of solar cycles and their physical relationship with internal solar wave effects.

Numerous statistical and theoretical studies have addressed hemispheric asymmetry in solar activity phenomena, with the research team led by Li Kejun at Yunnan Observatories achieving particularly systematic results [3][4]. The north-south asymmetry in sunspot activity arises from phase asynchronization between the hemispheres. Studies of solar activity indices reveal that the northern hemisphere dominated during cycles 19 and 20, while the southern hemisphere became dominant during cycle 21 [5]. Furthermore, the hemisphere that produces the first X-class flare typically exhibits more intense solar activity than the opposite hemisphere [6]. However, research on hemispheric asymmetry of Rieger-type periodic signals remains relatively scarce, though evidence suggests such asymmetry exists [7]. This paper investigates and analyzes the Rieger-type periodicity present from cycles 12 to 24 and its north-south asymmetry.

Empirical Mode Decomposition (EMD) [8] represents an excellent time-frequency analysis method proposed in recent years. Compared with traditional frequency analysis techniques, EMD is more suitable for extracting nonlinear and non-stationary signals and has been widely applied in solar physics research [3][4]. Therefore, this study also employs this method to extract and analyze Rieger-type periodic characteristics of sunspot area data in both hemispheres. The paper is organized as follows: Section 1 introduces the data sources, Section 2 presents our analysis procedures and discussion, and

Section 3 provides a summary of our research.

1. Observation Data

This study utilizes sunspot area data for the northern and southern hemispheres from the National Aeronautics and Space Administration Solar Physics Marshall Space Flight Center, collected from May 1, 1874 to October 31, 2016 (<https://solarscience.msfc.nasa.gov/greenwch.shtml>). Sunspot number and area exhibit nonlinear relationships [9], with sunspot area possessing greater physical significance than sunspot number alone. To investigate phase relationships of Rieger-type periodicity across different solar cycles, we divided the data according to the start and end times of each solar cycle, obtaining sunspot area data from cycles 12 through 24. We applied 30-day smoothing to eliminate signal components with smaller periodicities (solar rotation), with the smoothed northern and southern hemisphere sunspot areas shown in Figure 1 [Figure 1: see original paper]. The data clearly demonstrate noticeable differences between the two hemispheres, with each cycle exhibiting distinct sunspot area distributions. We subsequently analyze the Rieger-type periodicity present within these 13 solar cycles and the phase relationships of this periodicity within each cycle.

2.1 Extraction of Rieger-type Periodic Signals from Sunspot Data

We applied EMD analysis to separately decompose the northern and southern hemisphere sunspot area data from cycles 12 to 24 into Intrinsic Mode Functions (IMFs). The extracted Rieger-type periodic components are displayed in Figure 2 [Figure 2: see original paper], where the blue line represents the southern hemisphere and the red line represents the northern hemisphere. Rieger-type periodicity typically appears in the maximum phase region of each cycle.

We then performed probability distribution statistics on the average periods of the decomposed Rieger-type components, applied Gaussian fitting to obtain their mean and standard deviation, and compiled the statistical results. The Rieger-type periodic components for cycles 12 to 24 in the northern and southern hemispheres are shown in Figures 3 and 4, respectively. The X-axis represents period in days, while the Y-axis shows normalized probability distribution. Blue dots represent the frequency probability distribution, red curves indicate Gaussian fitting of the frequency distribution, upward triangles mark the peak points of fitted curves (with X-coordinate representing average frequency and Y-coordinate representing occurrence probability), dotted lines indicate average frequency, dash-dotted lines show one standard deviation confidence intervals, and dashed lines represent two standard deviation confidence intervals. Figures 3 [Figure 3: see original paper] and 4 [Figure 4: see original paper] clearly reveal substantially different frequency distributions between hemispheres within the same cycle, demonstrating hemispheric asymmetry.

Based on the fitting functions from Figures 3 and 4, we obtained the average

periods of Rieger-type components for cycles 12 through 24, presented in Table 1. The results show that both hemispheres exhibit Rieger-type periodicity with distinctly different cycle lengths. Specifically, cycles 16, 17, and 22 in the northern hemisphere and cycles 12 and 20 in the southern hemisphere show periods slightly above or below the typical Rieger-type range of 130-185 days, indicating that this range is not constant but varies with solar cycles [7]. Cycles 13, 14, and 19 show similar average periods between hemispheres. Averaging across all 13 cycles yields mean Rieger-type periods of approximately 170 days for the northern hemisphere and 160 days for the southern hemisphere. This aligns with findings that monthly sunspot group numbers also exhibit different Schwabe cycle lengths between hemispheres, with the northern hemisphere's average slightly longer.

Rieger-type periodicity typically appears near cycle maxima spanning 1-3 years. We identified each cycle's maximum phase by applying 185-day smoothing to the original data, selecting the midpoint of the smoothed data's maximum value, drawing a horizontal line intersecting the data curve, and using the intersection points' X-coordinates to define the cycle's maximum period. The intersection of northern and southern hemisphere maxima defined each cycle's maximum phase. The extracted IMF maxima are shown in Figure 5 [Figure 5: see original paper], with blue representing the southern hemisphere and red representing the northern hemisphere. Figure 5 reveals clear differences between hemispheres during cycles 17, 18, and 19. Since Rieger-type periodicity correlates inversely with solar cycle intensity, and cycles 17, 18, and 19 represent stronger solar cycles (as shown in Figure 1), substantial differences in Rieger-type periodicity between hemispheres emerge during these cycles.

2.2 Phase Correlation Analysis of Rieger-type Periodic Components

Rieger-type periodicity occurs at different times in the two hemispheres (varying by approximately 1-2 years), indicating temporal (phase) differences [8]. To clarify the phase relationship between Rieger-type components of northern and southern hemisphere sunspot area data, we employed cross-correlation function analysis. The correlation coefficients and phase differences during maximum periods for different cycles are summarized in Table 2.

In Table 2, positive phase differences indicate the northern hemisphere leads the southern hemisphere, while negative values indicate the northern hemisphere lags. Across the 13 solar cycles, the mean correlation coefficient between hemispheric Rieger-type components is 0.44, with a mean phase difference of approximately 51 days (northern hemisphere lagging). This phase asynchrony represents one cause of north-south asymmetry. Comparing hemispheric phase differences reveals that the northern hemisphere leads in 7 cycles and lags in 6 cycles, with neither relationship persisting for more than two consecutive cycles. Notably, cycles 13, 14, and 19, which showed similar periods in Table 1, exhibit correlation coefficients of 0.50, 0.46, and 0.39 respectively—not the highest cor-

relations. Cycle 15 shows the strongest correlation at 0.61, while cycle 12 shows the weakest at 0.31. This demonstrates that similar hemispheric cycle scales do not necessarily produce strong correlations.

3. Summary

While sunspot spatiotemporal distributions in the northern and southern hemispheres appear roughly symmetric—forming the familiar “butterfly diagram” — significant differences persist. Statistical analysis of hemispheric sunspot areas reveals that the Rieger-type period represents an intrinsic cycle present in both solar hemispheres. In each solar cycle, the Rieger-type cycle scale and temporal scale differ between hemispheres, producing asymmetry consistent with reference [7]. The average Rieger-type period is slightly longer in the northern hemisphere, aligning with results from reference [5]. Although the northern hemisphere dominated during cycles 19-20 and the southern hemisphere dominated during cycles 21-23 [7], our results in Table 2 show that the dominant hemisphere does not necessarily exhibit a more advanced Rieger-type phase. This may occur because hemispheric activity levels relate to the complex solar interior dynamo, while Rieger-type periodicity connects to magnetic Rossby waves. The finding that similar hemispheric cycle scales do not guarantee strong correlations further demonstrates north-south asymmetry, possibly reflecting differences in magnetic field strength between hemispheres, though the generation mechanism remains unclear.

Originally discovered in hard X-ray radiation from solar flares, the 154-day Rieger-type period has been confirmed through studies of soft X-ray, microwave, and $H\alpha$ flares. Its physical origin lies in complex solar interior dynamics. Investigating this periodicity provides valuable information not only for flare occurrence rates but also for spatiotemporal evolution of sub-photospheric magnetic phenomena. Since solar flares occur far more frequently in active regions than in quiet regions, and since sunspot area (and number) contributions primarily originate from active regions, this study’s examination of Rieger-type periodicity’s hemispheric distribution in sunspot area holds significant scientific value for flare research. First, determining whether flares exhibit the same hemispheric statistical characteristics as sunspot area will aid understanding of long-term flare evolution and potential driving mechanisms. Second, investigating whether magnetic energy origin, accumulation, and release processes during flare eruptions correlate with solar cycle characteristics and hemispheric activity intensity will provide statistical information for clarifying flare driving and eruption mechanisms.

References

- [1] Gurgenchashvili E, Zaqarashvili T, Kukhianidze V, et al. Rieger-type periodicity during solar cycles 14-24: estimation of dynamo magnetic field strength in the solar interior[J]. *Astrophysical Journal*, 2016, 826(1):55.

- [2] Teimuraz V.Zaqarashvili, Marc Carbonell, Ramón Oliver, Quasi-biennial oscillations in the solar tachocline caused by magnetic Rossby wave instabilities [J].The Astrophysical Journal Letters,2010,724:L95-L98.
- [3] Li K J, Feng W, Xu J C, et al. Why is the Solar Constant Not a Constant?[J]. Astrophysical Journal, 2012, 747(2):1112-1112.
- [4] Li K J, Shi X J, Feng W, et al. Long-term variations of the coronal rotation and solar activity [J]. Monthly Notices of the Royal Astronomical Society, 2012, 423(4):3584-3588.
- [5] Verma V K, Joshi G C, Paliwal D C. Study of periodicities of solar nuclear gamma ray flares and sunspots[J]. Solar Physics, 1992, 138(1):205-208.
- [6] Lu Yangping, Le Guiming, Zhao Haofeng, et al. The Relationship between First X-Class Flare, First High Latitude Sunspot Hemisphere Features and the Asymmetry of Solar Activity during Solar Cycles 21-24[J]. Astronomical Research and Technology, 2016, 13(2):150-152.
- [7] Lu Yangping, Le Guiming, Zhao Haofeng, et al. The Relationship between First X-Class Flare, First High Latitude Sunspot Hemisphere Features and the Asymmetry of Solar Activity during Solar Cycle 21-24 [J]. Astronomical research and technology, 2016, 13(2):150-152.
- [8] Eka Gurgenashvili, Teimuraz V.Zaqarashvili, Vasil Kukhianidze, North-south asymmetry in Rieger-type periodicity during solar cycles 19-23 [J],The Astrophysical Journal,2017,845:137 (11pp),
- [9] Norden E.Huang, Zheng Shen, Steven R.Long, The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis[J],The Royal Society,1998,454: 903-995.
- [10] Feng Wen, Xie Jinglan, Li Kejun. A Statistical Study on Sunspot Area Varying with Sunspot Number[J]. Astronomical Research and Technology, 2016, 13(2):153-159.
- [11] Feng Wen, Xie Jinglan, Li Kejun. A Statistical Study on Sunspot Area Varying with Sunspot Number [J]. Astronomical research and technology, 2016, 13(2):153-159.

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