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Research Paper

The cause of the appearance or disappearance of the Rieger-type periodicity in the northern and southern hemispheres of the sun

N. B. Xiang[1,2,3], X. H. Zhao[3] and F. Y. Li[4,3]

[1]Yunnan Observatories, Chinese Academy of Sciences, Kunming 650011, China, [2]Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Nanjing 210008, China, [3]State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing 100190, China and [4]School of Earth and Space Sciences, Peking University, Beijing 100871, China

Abstract

We use a continuous wavelet transform to analyse the daily hemispheric sunspot area data from the Greenwich Royal Observatory during cycles 12–24 and then study the cause of the appearance or disappearance of the Rieger-type periodicity in the northern and southern hemispheres during a certain cycle. The Rieger-type periodicity in the northern and southern hemispheres should be developed independently in the two hemispheres. This periodicity in the northern hemisphere is generally anti-correlated with the long-term variations in the mean solar cycle strength of hemispheric activity, but the correlation of the two parameters in the southern hemisphere shows a weak correlation. The appearance or disappearance of Rieger-type periodicity in the northern and southern hemispheres during a certain solar cycle is not directly correlated with their corresponding hemispheric mean activity strength but should be related to the strength of the hemispheric activity during sunspot maximum times, which hints the Rieger-type periodicity is more related to temporal evolution of toroidal magnetic field. The Rieger-type periodicity in the two hemispheres disappears in those solar cycles with relatively weak hemispheric activity during sunspot maximum times. The reason for the disappearance of this periodicity may be due to the combined influence of relatively weak toroidal magnetic fields and torsional oscillations, the differential rotation parameters vary through the solar cycle and may not remain more or less unchanged during some time, which does not permit the strong growth of magnetic Rossby waves.

Keywords: sun: general – sun: activity – sun: magnetic fields

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1. Introduction

A short periodicity of 154 d was first detected by Rieger et al. (1984) in gamma-ray flares observed by the gamma-ray spectrometer aboard the Solar Maximum Mission during solar cycle 21. Then, the Rieger-type periodicity of 152–160 d was proved to exist in almost all solar activity indicators, such as in X-ray flares (Rieger et al. 1984; Dennis 1985; Bai 1987; Kile & Cliver 1991; Dimitropoulou, Moussas, & Strintzi 2008), in sunspot number or area (Lean & Brueckner 1989; Lean 1990; Carbonell & Ballester 1992; Oliver, Ballester, & Baudin 1998; Krivova & Solanki 2002; Zaqarashvili et al. 2010; Gurgenashvili et al. 2016, 2017), in solar diameter (Delache, Laclare, & Sadsaoud 1985), in 10.7 cm radio flux (Lean & Brueckner 1989), in total solar irradiance (Pap, Tobiska, & Bouwer 1990), in type II and IV radio bursts (Verma et al. 1991), in daily counts of CME events (Lou et al. 2003), in type III radio bursts (Lobzin, Cairns, & Robinson 2012), etc. These studies indicated that the Rieter-type periodicity is not only a feature of flare activity but also associated with strong magnetic field activity. It is also a global phenomenon, and so the cause of this periodicity must be a mechanism involving the whole Sun. On the other hand, the Rieger-type periodicity is not always present in all solar cycles. Carbonell & Ballester (1992) found that the Rieger-type periodicity was absent in records of the sunspot area during solar cycles 12–15. Ballester, Oliver, & Carbonell (2002) analysed the data set of photospheric magnetic flux and revealed that the Rieger-type periodicity disappeared after cycle 21. However, Gurgenashvili et al. (2016) analysed the records of sunspot area and number and showed that the Rieger-type periodicity was present in solar cycles 14–24, with varying from 155 to 200 d. The authors suggested that the Rieger-type periodicity was 190–195 d in records of sunspot area during cycles 14–15, while it was absent in the study reported by Ballester et al. (2002) because they only searched a periodicity of 155–160 d. Gurgenashvili et al. (2017) also gave evidence that the Rieger-type periodicity was about 180–190 d in the weaker southern hemisphere during the north-dominated cycles 19–20. Furthermore, Zaqarashvili et al. (2010) hinted that the frequency of symmetric unstable modes in the tachocline may yield the Rieger-type periodicity of about 280 d in the case of strong differential rotation; the wavelet analysis of sunspot area and number given in Figure 1 of Gurgenashvili et al. (2016) and the result of theoretical analysis shown in Figure 4 of Gurgenashvili et al. (2017) indicated that the Rieger-type periodicity should be longer than 200 d, which may correspond to the higher harmonic of magnetic Rossby waves. Consequently, when we investigate the Rieger-type periodicity of the solar activity indicators, the periodicity of 150–200 d, even long than 200 d, should

Author for correspondence: N. B. Xiang, E-mail: nanbin@ynao.ac.cn
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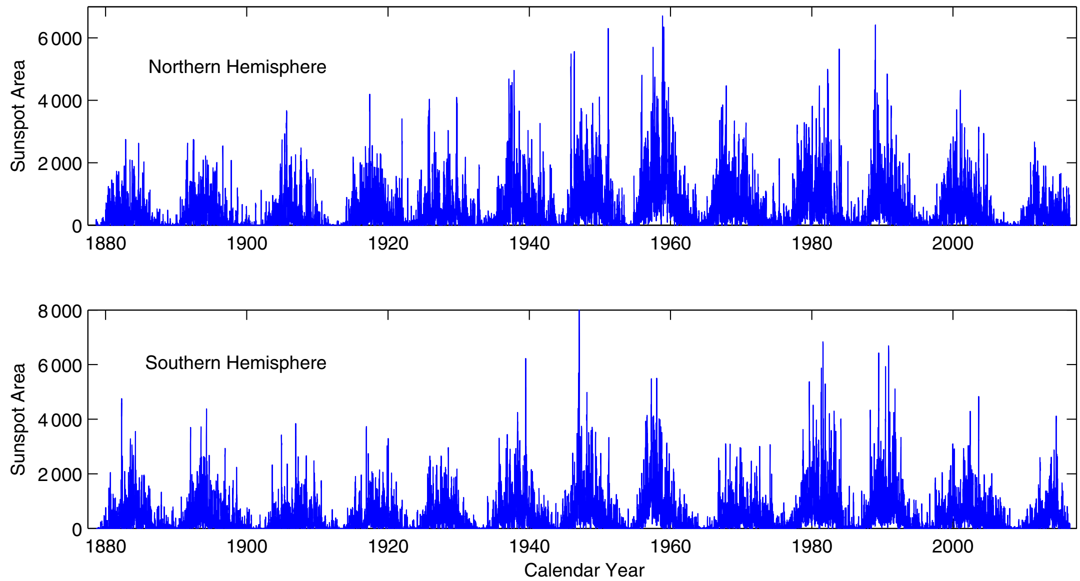

Figure 1. Daily sunspot area, respectively, in the northern (top panel) and southern (bottom panel) hemispheres from 1878 September 1 to 2016 October 31.

be checked carefully, but the periodicity longer than 200 d should be cautiously confirmed that it is a really Rieger-type periodicity, rather than a quasi-annual oscillation.

The early studies verified that the Rieger-type periodicity is not a permanent feature of solar activity; conversely, it has an enigmatic and elusive character. It was shown that the periodicity usually can be detected only during epochs of the solar cycle maximum times and it appears in episodes of 1–3 yr (Lean 1990; Oliver et al. 1998; Krivova & Solanki 2002; Zaqarashvili et al. 2010). However, the recent study by Gurgenashvili et al. (2016) demonstrated that the Rieger-type periodicity is cycle-dependent: shorter periods are detected during stronger solar cycles, and so the authors inferred that the enigmatic character of this periodicity is related to the variation of the dynamo field strength. Moreover, Gurgenashvili et al. (2017) further indicated that the Rieger-type periodicity correlating with hemispheric activity levels is the same as it correlates with solar cycle strength. The shorter Rieger-type periodicity occurs in the stronger hemisphere, and so it also has the north–south asymmetry during solar cycles with strong hemispheric asymmetry.

Several different mechanisms have been advised to explain the existence and enigmatic features of the Rieger-type periodicity, but the physical reason for this periodicity is still not completely clear. Ichimoto et al. (1985) advised that the 155-d periodicity detected in flare activity may be related to the timescale for the storage and/or the escape of the magnetic field in the solar convection zone. A similar periodicity of 153 d in flares was found by Bai (1987), and the author suggested that this periodicity should be attributable to a mechanism that causes active regions to be more productive. Bai & Sturrock (1991) advised that a fundamental period could cause the excitation of subharmonic oscillations, and so the Rieger-type periodicity should be a subharmonic of fundamental 25.8-d period. However, this hypothesis would be seriously constrained by helioseismological data (Goode & Thompson 1992). Lou (2000), Sturrock (2004), and Knaack, Stenflo, & Berdyugina (2005) advised that the ‘Rieger-type’ periodicity can be due to large-scale equatorially trapped hydrodynamic Rossby-type waves, which may exhibit detectable features of surface elevations in the photosphere. Moreover, the surface manifestation of Rossby-type waves was reported by Kuhn et al. (2000) that 100m high ‘hills’ in the surface layer were spaced uniformly over the solar surface with a characteristic separation of approximately 90 000 km. However, these authors did not consider the solar magnetic field activity in the Rossby wave theory, and so the relation of waves to solar magnetic activity is still unclear. On the other hand, a series of studies indicated that the joint effect of the differential rotation and the toroidal magnetic field can trigger the tachocline instabilities (Gilman & Fox 1997; Cally 2003; Dikpati & Gilman 2005; Gilman, Dikpati, & Miesch 2007). Based on these studies, Zaqarashvili et al. (2010) gave a more plausible explanation that the Rieger-type periodicity is related to the destabilisation of magnetic Rossby waves in the solar tachocline owing to the joint effect of the latitudinal differential rotation and the toroidal magnetic field. Unstable harmonics of magnetic Rossby waves in this layer cause the periodic surges of magnetic flux on the solar surface, and so the periodicity is detected in the magnetic activity. Gurgenashvili et al. (2016, 2017) further verified this explanation. Furthermore, a recent study performed by Gachechiladze et al. (2019) further showed that several periodicities in the range of 200–400 d detected in sunspot areas during solar cycle 23 can also be explained by different harmonics of global fast magnetic Rossby waves. Additionally, Zaqarashvili & Gurgenashvili (2018) showed that the Rieger-type periodicity can also be related to the equatorially trapped inertia-gravity waves in the solar tachocline. Recently, a comprehensive review of astrophysical Rossby waves introduced in detail the theory of Rossby waves and its study prospect in astrophysics (Zaqarashvili et al. 2021).

Many studies related to Rieger-type periodicity explain why this periodicity is present. However, we analyse the sunspot area data for northern and southern hemispheres during solar cycles 12–24 and find that the Rieger-type periodicity is alone absent in northern or southern hemispheres during some solar cycles. At present, these theories related to Rieger periodicity did not well explain why this periodicity is absent. So, the reason for the of the Rieger-type periodicity in a certain solar cycle is still an open topic,

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and further investigations on this topic are of significance and needed. In this study, we use the records of the daily hemispheric sunspot area during solar cycles 12–24 to detect the Rieger-type periodicities in northern and southern hemispheres separately during these cycles and then combine these detected Rieger-type periodicities and the records of the hemispheric sunspot area as well as the early studies related to this topic try to explaining why the Rieger-type periodicity is present or absent in northern and southern hemispheres during a certain solar cycle.

2. Rieger-type periodicity in the northern and southern hemispheres

2.1. Data and method

In order to detect the Rieger-type periodicity in the northern and southern hemispheres separately during solar cycles 12–24, we use the Greenwich Royal Observatory (GRO) USAF/NOAA daily hemispheric sunspot area data (https://solarscience.msfc.nasa.gov/greenwch.shtml). The available hemispheric sunspot area data set starts from 1874 May (which corresponds to declining phases of solar cycle 11) and runs until 2016 October. In this study, we select the hemispheric sunspot area data from 1878 September 1 until 2016 October 31, which corresponds to the minimum time of solar cycle 12 until the declining phases of solar cycle 24. Figure 1 shows the daily sunspot area in units of millionths of a hemisphere (μHem), respectively, in the northern and southern hemispheres during this time interval. The activity maxima during some cycles are shifted by 1–2 yr in the northern and southern hemispheres, which are shown in this figure, such as during cycles 14, 17, and 20. The phase asynchrony between the two time series is a common phenomenon, and the north–south phase shift of activity maxima is more pronounced than the phase shift of activity minima (Dikpati et al. 2007; Li, Gao, & Zhan 2009). Another feature of the daily sunspot area in the northern and southern hemispheres can be found that the peak values of the two time series not only appear near the maximum times of hemispheric solar activity. Sometimes, the peak values of hemispheric sunspot area higher than that near the maximum time of hemispheric activity and only lasting several days are present during the ascending or declining phases. For instance, the peak value of sunspot area in southern hemisphere during cycle 12 is present in its ascending phase, while the peak value in northern hemisphere during cycle 18 appears in its declining phase.

In a variety of periodicity analysis methods, wavelet analysis is a classical and useful tool which is widely used to detect the periods of time series and the localised oscillatory feature in time-frequency space (Torrence & Compo 1998; Grinsted, Moore, & Jevrejeva 2004; Li, Gao, & Su 2005; Deng et al. 2013; Xie, Shi, & Xu 2017a). Hence, the wavelet analysis is very suitable for detecting the Rieger-type periodicity of the daily sunspot area in the northern and souther hemispheres separately and finding the localised oscillatory feature of this periodicity. Here, we use a continuous wavelet transform (CWT), which is briefly introduced as follows. For a time series $X_n, n = 1, ..., N$, the CWT is defined as Grinsted et al. (2004)

$$W_n^X(s) = \sqrt{\frac{\delta t}{s}} \sum_{n'=1}^{N} X_{n'} \Psi_0 \left[(n' - n) \frac{\delta t}{s} \right] \tag{1}$$

where δt indicates the uniform time step and s shows the variational scale of wavelet, which causes the wavelet to stretch in time. Ψ_0 in this function represents the wavelet basis selected in CWT. When the wavelet is used for feature extraction purposes, the Morlet wavelet is a good choice, which can provide a good balance between time and frequency localisation (Torrence & Compo 1998; Grinsted et al. 2004). Thus, we select the Morlet wavelet, which can be defined as

$$\Psi_0(\eta) = \pi^{-1/4} e^{i\omega_0\eta} e^{-\frac{1}{2}\eta^2} \tag{2}$$

where ω_0 and η are dimensionless frequency and dimensionless time, respectively. Early study indicated that the value of ω_0 effects on the time and frequency resolution of the wavelet transform (De Moortel & McAteer 2004; Xie, Shi, & Zhang 2017b) and a better time resolution is obtained for smaller values of ω_0, but a higher frequency resolution that corresponds to a more accurate periodic value requires larger values of ω_0 (Grinsted et al. 2004; Chowdhury, Khan, & Ray 2010). In this study, the more significant results of the wavelet analysis are the periods while not their temporal locations; thus, we try different and relatively larger values of ω_0 in the process of the wavelet analysis to find the more accurate periodic values and appropriate spatial resolution. On the other hand, the wavelet cannot be completely localised in time, and thus the CWT suffers from edge artefacts. A good solution is to introduce a cone of influence (COI) in which the wavelet transform suffers from these edge effects and the wavelet power is caused by a discontinuity at the edges, which decreases by a factor e^{-2} (Torrence & Compo 1998; Grinsted et al. 2004; Xie, Shi, & Xu 2012; Li et al. 2009). The statistical significance of wavelet power can be assessed by assuming that the noise has a distinctive red spectrum.

2.2. Rieger-type periodicity in northern and southern hemispheres

The hemispheric sunspot area data set used in this study is from 1878 September 1 to 2016 October 31, but some days do not have observations. Especially, there are relatively long gaps in solar cycles 12–13. In order to use the CWT, the linear interpolation is used to interpolate the value when the sunspot area is absent on a certain day. The continuous wavelet power spectra of the daily sunspot area in northern and southern hemispheres during solar cycles 12–15 are given in Figures 2 and 3, respectively. The global wavelet results are also shown in each corresponding panel, when the Rieger-type periodicity is detected. For the confidence level, the thick black contours in these panels where the Rieger-type periodicity is detected show the 95% confidence level, and thus the wavelet power spectra can be considered as true period oscillation. For these panels with no Rieger-type periodicity (in the period range of 150–200 d) found, the statistical significance of the wavelet power is at 90% confidence level and the results are also shown by the thick black contours. Thus, the disappearance of the Riger-type periodicity at relatively lower confidence level indicates that this periodicity should really disappear during some solar cycles. The Figures 4 and 5 show the same as Figure 2, but for CWT of the daily sunspot area in northern and southern hemispheres during solar cycles 16–18 and 24, respectively. The confidence level is also shown as the thick black contours, which indicate the 95% confidence level in the northern hemisphere for cycles 16–18 and 24, the 92% confidence level in the southern hemisphere for cycles 17–18, and 90% confidence level

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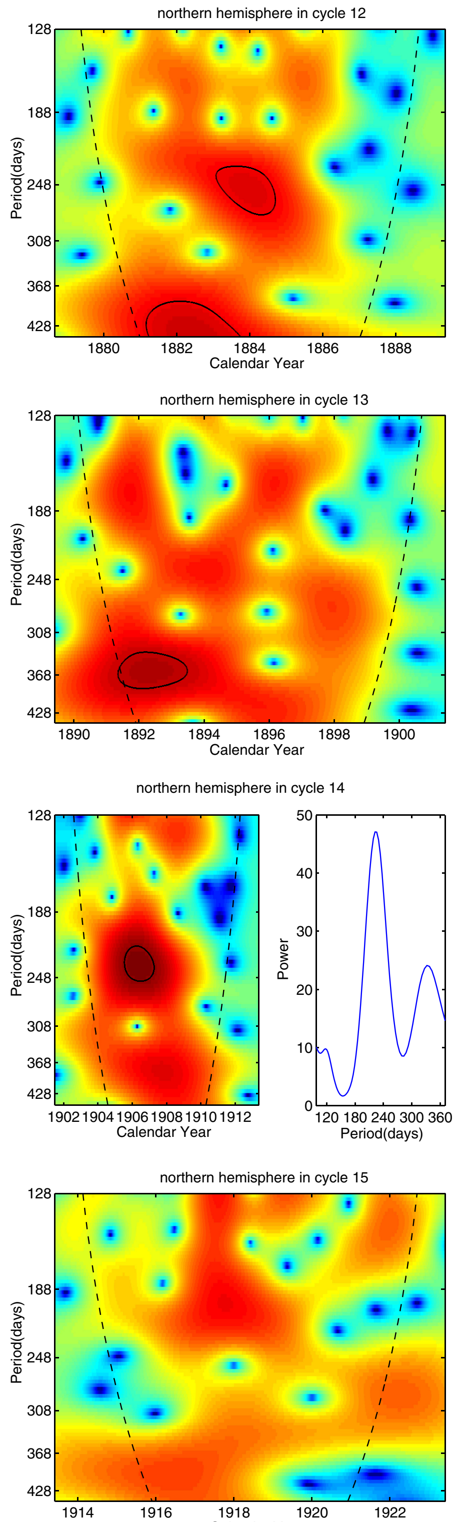

Figure 2. Continuous wavelet power spectra of the daily sunspot area in the northern hemisphere for cycles 12–15 ranking from the top one to the bottom, respectively. The confidence level is shown as the thick black contours, and the black dashed line indicates the COI where edge effects might distort the picture. Global wavelet results are plotted in each corresponding panel, when the Rieger-type periodicity is detected.

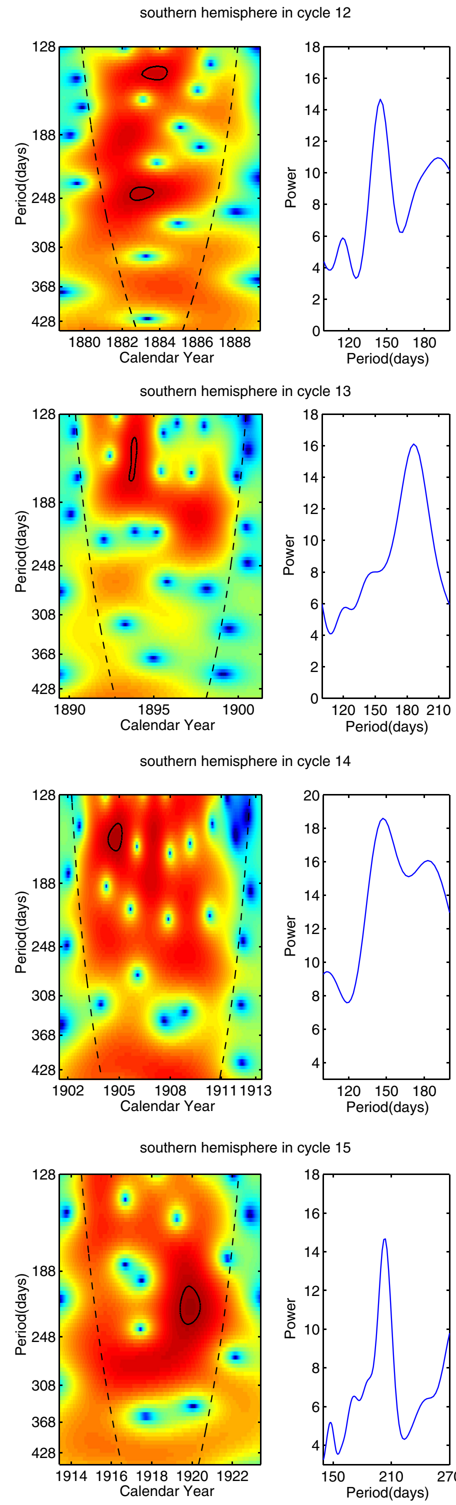

Figure 3. Same as Figure 2 but for the daily sunspot area in the southern hemisphere for cycles 12–15.

in southern hemisphere for cycles 16 and 24, respectively. We do not show the continuous wavelet power spectra of daily sunspot area in northern and southern hemispheres during solar cycles 18–23, since Gurgenashvili et al. (2017) had used the wavelet analysis to detect the Rieger-type periodicity of the two time series in this time interval, and our findings in this study are quiet similar to the results obtained by these authors.

The Rieger-type periodicities in northern and southern hemispheres during solar cycles 12–24, which are shown in

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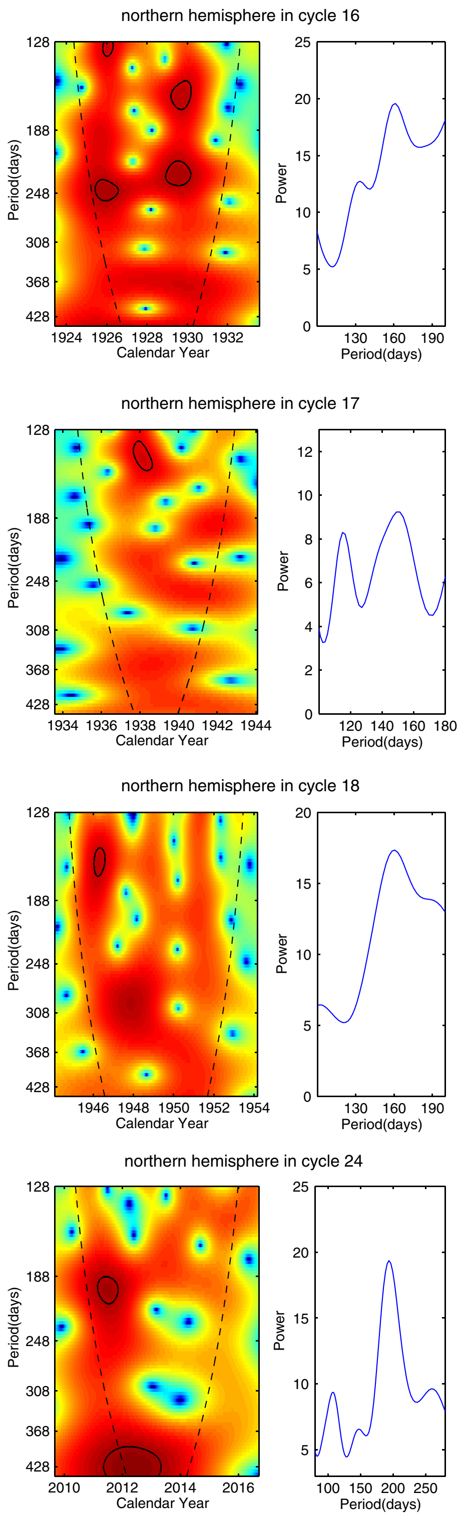

Figure 4. Same as Figure 2 but for the daily sunspot area in the northern hemisphere for cycles 16–18 and 24.

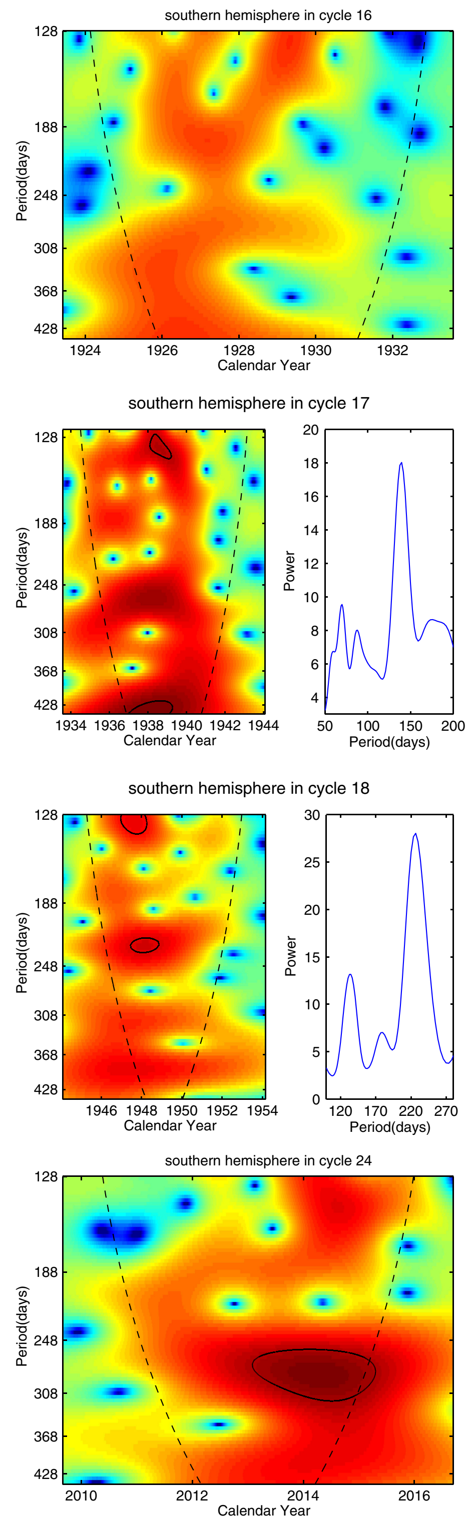

Figure 5. Same as Figure 2 but for the daily sunspot area in the southern hemisphere for cycles 16–18 and 24.

Figures 2, 3, 4 and 5, and are obtained from Table 2 of Gurgenashvili et al. (2017), are also given in Table 1. In this table, these Rieger-type periodicities obtained from Gurgenashvili et al. (2017) are marked in bold.

3. Discussion

The Rieger-type periodicity was discovered more than 30 yr ago, and then it was proved to exist in almost all solar activity indicators, but its appearance/disappearance still keeps mysterious

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Table 1. Estimated Rieger periodicities (days) for both hemispheres in solar cycles 12–24.

Cycle number	12	13	14	15	16	17	18	19	20	21	22	23	24
Northern hemisphere	–	–	225	–	161	153	160	**158**	**165**	**183**	**180**	**175**	194
Southern hemisphere	145	186	147	205	–	140	226	**177**	**190**	**158**	**160**	**160**	–

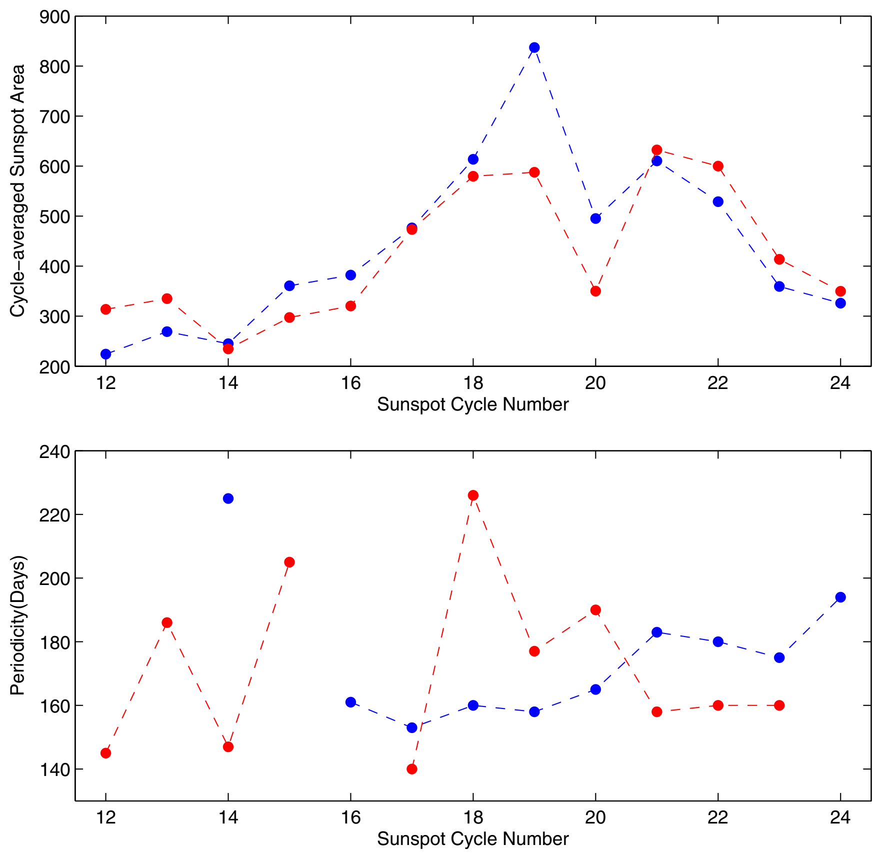

Figure 6. Top panel: cycle-averaged sunspot area in the northern (blue circles) and southern (red circles) hemispheres for solar cycles 12–24. Bottom panel: Rieger-type periodicities in the northern (blue circles) and southern (red circles) hemispheres for solar cycles 12–24.

nature. Recent study demonstrates that shorter Rieger-type periodicities are detected during strong solar cycles (Gurgenashvili et al. 2016); similarly, the shorter period also occurs in the stronger hemisphere derived from the analysis in the sunspot data in cycles 19–23 (Gurgenashvili et al. 2017). In order to further investigate relation of Rieger-type periodicity in the northern and southern hemispheres with hemispheric activity levels, a comparison of Rieger-type periodicities and cycle-averaged sunspot area is shown in Figure 6.

Figure 6 clearly shows the results found in Gurgenashvili et al. (2017), which found that the shorter Rieger-type periodicity is detected in the stronger hemisphere in cycles 19–23, and it has the north–south asymmetry in these corresponding cycles. However, this result is not observed in cycles 12–18, since the Rieger-type periodicity appears alone in the northern or southern hemispheres during some solar cycles. Moreover, the cycle-averaged sunspot area (hemispheric activity level) in the northern hemisphere is almost the same as that in the southern hemisphere in cycle 14, while the periodicity in the northern hemisphere is 225 d, which is much longer than that in the southern hemisphere. The periodicity of 225 d may correspond to the higher harmonic of magnetic Rossby waves, if the Rieger-type periodicity is really due to magnetic Rossby waves in the internal dynamo layer as some authors advised (Zaqarashvili, Oliver, & Ballester 2009; Zaqarashvili et al. 2010; Gurgenashvili et al. 2016). The similar scenario can also be found in cycle 21. Hence, Figure 6 gives the following three scenarios: (1) Rieger-type periodicity has the north–south asymmetry during some solar cycles; (2) Rieger-type periodicity can appear alone in the northern or southern hemispheres during some cycles; and (3) sometimes, the values of Rieger-type periodicity in the norther and southern hemispheres are quite different, though the hemispheric activity levels in the northern and southern hemispheres are almost identical. These scenarios indicate that the Rieger-type periodicity should be developed independently in the northern and southern hemispheres. This result is similar to the findings in Badalyan & Obridko (2011), in which the authors studied the north–south asymmetry of the sunspot indices and its quasi-biennial oscillations and suggested that a great extent solar activity is generated independently in the two hemispheres. However, some studies advised that the periods

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shorter than 1 year (Rieger periodicity) and longer than 1 yr (in the range of 1–3 yr) have different origins (Boberg et al. 2002; Vecchio et al. 2012; Li et al. 2012; Xiang & Qu 2018; Xiang 2019).

Recent study related to investigation on the Rieger-type periodicity in sunspots of the full Sun during cycles 14–24 found that it is cycle-dependent: shorter periods are present during stronger cycles (Gurgenashvili et al. 2016). A similar result may be only found in the northern hemisphere (see Figure 6), which shows the Rieger-type periodicity in the northern hemisphere should be correlated with the long-term variations (e.g., Gleissberg period of about 100 yr, Gleissberg 1939; Hathaway 2010; Zaqarashvili et al. 2015) in the solar cycle strength of this hemisphere. The correlation coefficient between Rieger-type periodicity in the northern hemisphere and the cycle-averaged sunspot area in this hemisphere is −0.60, and the critical value of correlation coefficient test indicates that the statistical significance is above the 93% confidence level. Thus, this should show a strong correlation. Zaqarashvili et al. (2010) and Gurgenashvili et al. (2016) advised that the Rieger periodicity is connected to the deeper regions where the dynamo magnetic is generated. The strong correlation found in this study further gives evidence that the Rieger-type periodicity is derived from the dynamo layer in the solar interior, since the emergence of strong magnetic flux at the solar surface is connected to the dynamo layer. However, in the southern hemisphere, the Rieger-type periodicity appears to be independent of the long-term variations in the solar cycle strength of hemisphere. The correlation coefficient between the Riger-type periodicity and the cycle-averaged sunspot area in the southern hemisphere is only 0.09, which shows a weak correlation. This weak correlation may further validate that the Rieger-type periodicity should be developed independently in the northern and southern hemispheres.

Table 1 also shows that the Rieger-type periodicity in the northern hemisphere is absent in cycles 12–13 and 15; and it is absent in the southern hemisphere for cycles 16 and 24. A careful look at these panels that show the disappearance of Rieger-type periodicity in the northern or southern hemisphere in Figures 2–5, the power spectra look for the periodicity of about 128–230 d that completely covers the oscillation range of Rieger-type periodicity. Moreover, in these solar cycles with missing Rieger-type periodicity, the statistical significance of the wave power is only at 90% confidence level. Thus, it can infer that the Rieger-type periodicity in the northern or southern hemisphere really disappears during these aforementioned solar cycles. Figure 1 shows the daily sunspot area in the northern and southern hemispheres during cycles 12–24, and it indicates that these cycles with missing Rieger-type periodicity in the northern and southern hemispheres show the relatively weak hemispheric activity during sunspot maximum times comparing to that during other solar cycles. It seems that the appearance or disappearance of Rieger-type periodicity in northern and southern hemispheres during a certain solar cycle may be related to the strength of the hemispheric activity during sunspot maximum times. On the other hand, the cycle-averaged sunspot area in the northern (blue circles) and southern (red circles) hemispheres for solar cycles 12–24, which can reflect the mean solar cycle strength of their corresponding hemispheric activity, has also been shown in Figure 6. As it shows, for the northern hemisphere, the cycles 12–13 and 15 show the weak mean solar cycle strength of hemispheric activity. However, the mean hemispheric activity levels of the northern hemisphere in the cycles 13 and 15 are still stronger than that in the cycle 14, while the Rieger-type periodicity appears in cycle 14 but disappears in cycles 13 and 15. For the southern hemisphere, the mean solar cycle strength of hemispheric activity in the cycles 16 and 24 is also stronger than that in cycle 14, but the Rieger-type periodicity is present in cycles 14 and is absent in cycles 16 and 24. It looks like that the appearance or disappearance of Rieger-type periodicity in northern and southern hemispheres during a certain solar cycle is not directly correlated with the mean solar cycle strength of their corresponding hemispheric activity. Because the emergence of strong magnetic flux at the solar surface is connected to dynamo layer, the mean solar cycle strength of hemispheric activity probably reflects the mean strength of dynamo magnetic filed. Thus, the appearance or disappearance of Rieger-type periodicity in northern and southern hemispheres during a certain solar cycle is not directly related to the mean strength of toroidal magnetic field.

Early studies found that the Rieger-type periodicity is usually present during 1–3 yr near the maximum times of solar activity cycle (Lean 1990; Oliver et al. 1998; Zaqarashvili et al. 2010; Gurgenashvili et al. 2016), the similar scenario can also be found in the Rieger-type periodicity in the northern and southern hemispheres. Moreover, we closely scan Figures 1–5 and further find that the Rieger-type periodicity can appear near the maximum time of hemispheric activity, in its ascending phase, or in its declining phase. The more exact spatial distribution of Rieger-type periodicity in the northern and southern hemispheres is that it always appears near the peak value of corresponding hemispheric sunspot area, which hints that the appearance of Rieger-type periodicity may be related to the temporal evolution of toroidal magnetic field.

The instabilities of magnetic Rossby waves commonly exist in the tachocline, and they can happen for very weak toroidal magnetic fields (Márquez-Artavia, Jones, & Tobias 2017; Gachechiladze et al. 2019). Thus, the appearance of Rieger-type periodicity found in the sunspot area only during at particular times or disappearance of this periodicity should be due to the growth rate of magnetic Rossby waves. Zaqarashvili et al. (2010) found that the growth rate of the harmonics on timescales of Rieger-type periodicity is strongly dependent on the differential rotation parameters. When the parameters are increased, the growth rate becomes stronger. The authors considered that the variation of the differential rotation parameters through the solar cycle in the tachocline only permits the strong growth of the magnetic Rossby waves only during the solar maximum, and which can interpret the appearance of Rieger-type periodicity only during the solar maximum. It is difficult to study the temporal evolution of differential rotation parameters in the tachocline, but the studies on solar-cycle-related variation of differential rotation parameters based on investigation sunspots on the solar surface show that strong magnetic fields repress differential rotation, while weak magnetic fields more reflect differentiation of rotation rates; the differential rotation parameters are smaller near the maximum times of solar activity cycle (about the fourth to the seventh year after the minimum of a solar cycle) than that in the other solar activity phases (Brajša, Ruždjak, & Wöhl 2006; Li, Xie, & Shi, 2013b). Though the variation of differential rotation parameters in the tachocline which is due to torsional oscillations (LaBonte & Howard 1982; Howe et al. 2000a, 2005; Howe 2009) is different from that on the solar surface, the relation of the parameters on the solar surface and that in the tachocline (Howe et al. 2000b; Howe 2009) indicates that the results obtained from the early studies of sunspots on the solar surface may reflect the variation of differential rotation parameters in the tachocline to some extent. When solar activity is located in relatively low solar activity, the relatively weak magnetic field in the tachocline may correspond to relatively high values of differential rotation parameters, but the variation of parameters is more obvious and frequent. Thus, such obvious and frequent variation of differential rotation parameters may not be suitable for growth of magnetic Rossby waves. At the same time, the active regions represented by sunspot area in this phase can be found only a few on the solar surface, even the sunspot area continues to approach 0 in relatively low solar activity. Thus, the eruption of magnetic flux from solar interior towards the solar surface shows relatively little. For these reasons, the Reiger-type periodicity detected in sunspot is disappearance in the relatively low solar activity. When solar activity is located near the maximum times of solar activity cycle, the stronger magnetic field in the tachocline indicates the smaller differential rotation parameters, which may affect the growth of the magnetic Rossby wave amplitude. However, the higher values of sunspot can be found on the solar surface; thus, the more magnetic flux erupts from solar interior towards the solar surface, which provides favourable conditions for the appearance of Rieger-type periodicity. Moreover, the variation of differential rotation parameters on the solar surface does not show high amplitude near the maximum times of solar activity cycle (Brajša et al. 2006; Li et al. 2013a, 2013b). According to relation of the parameters on the solar surface and that in the tachocline (Howe et al. 2000b; Howe 2009), the variation of differential rotation parameters in the tachocline is also small. If the parameters remain more or less unchanged during this solar activity phase, the combination of strong magnetic field and relatively small differential rotation parameters can favour a particular harmonic with strong growth of magnetic Rossby waves. Thus, the Rieger-type period is detected in sunspot near the maximum times of solar activity cycle.

The northern hemisphere shows the weak hemispheric activity in solar cycles 12–13 and 15 comparing to the hemispheric activity in other solar cycle, and the Rieger-type periodicity in this hemisphere is absent during the same time. Similarly, the weak hemispheric activity in the southern hemisphere can be found in solar cycles 16 and 24, the Reiger-type periodicity in this hemisphere is also absent in the two solar cycles. Because the eruption of magnetic flux from solar interior towards the solar surface is connected to tachocline, the weak hemispheric activity in northern and southern hemispheres indicates that the weak magnetic activity in the tachocline during these solar cycles. The strong magnetic fields repress differential rotation, while weak magnetic fields more reflect differentiation of rotation rates (Zaatri et al. 2009; Wöhl et al. 2010 ; Jurdana-šepić et al. 2011; Li et al. 2013a, 2013b). Thus, the relatively weak magnetic activity in the tachocline may indicate the higher values of differential rotation parameters in this layer, but the variation of the parameters through the solar cycle may be more complex. On the other hand, early studies had proved that the instabilities of magnetic Rossby waves can still happen for very weak toroidal magnetic fields (Márquez-Artavia et al. 2017; Gachechiladze et al. 2019). But, a particular unstable harmonic of the magnetic Rossby wave with strong growth rate needs combination of toroidal magnetic field and differential rotation parameters that remain more or less unchanged during some time (Zaqarashvili et al. 2010). Consequently, the disappearance of the Rieger-type periodicity may be related to the variation of differential rotation parameters through the solar cycle in the tachocline which is also influenced by torsional oscillations (Labonte & Howard 1982; Howe et al. 2000a, 2005; Howe 2009). It is due to the combined influence of relatively weak toroidal magnetic fields and torsional oscillations, the differential rotation parameters vary through the solar cycle and may not remain more or less unchanged during some time, which does not permit the strong growth of magnetic Rossby waves. Additionally, it was recently shown that the multiple periodicities of 370–380, 310–320, 240–270, and 150–175 d detected in sunspot area are related to the different harmonics of global fast magnetic Rossby waves (Gachechiladze et al. 2019). Correspondingly, the periodicities in the range of 240–300 d are detected in the northern hemisphere during cycles 12 and 16, and in the southern hemisphere during cycles 12 and 24; the periodicity of about 370 d is also found in the northern hemisphere for cycle 13 (see Figures 2–5). Thus, these multiple periodicities can be explained by different harmonics of global fast magnetic Rossby waves.

Finally, the statistical significance of Rieger-type periodicity in the southern hemisphere for cycles 17–18 is not above 95% confidence level but is still up to 92% confidence level. The early studies also found that the Rieger periodicity appears during cycles 17–18 (Gurgenashvili et al. 2016; Zaqarashvili et al. 2021). Moreover, our finding in this study indicates that the disappearance of Rieger-type periodicity in the northern and southern hemispheres occurs only in those solar cycles with weaker hemispheric activity during sunspot maximum times. However, Figure 1 shows that the hemispheric activity in the southern hemisphere for cycles 17–18 is stronger than those solar cycles with missing Rieger-type periodicity. Consequently, the Rieger-type periodicity found in the southern hemisphere for cycles 17–18 is the real oscillation signal; the relatively low confidence level (at 92% confidence level) should be due to the bad data in old cycles.

4. Conclusions

The data used in this study are of the Greenwich Royal Observatory (GRO) USAF/NOAA daily hemispheric sunspot area during solar cycles 12–24. We use the method of CWT to detect the Rieger-type periodicity in northern and southern hemispheres separately during these activity cycles and then try to explain why the Rieger-type periodicity is present or absent in northern and southern hemispheres during a certain cycle. The main conclusions are obtained as follows.

The Rieger-type periodicity in the northern and southern hemispheres should be developed independently in the two hemispheres. This periodicity in the northern hemisphere is generally anti-correlated with the long-term variations in the mean solar cycle strength of hemispheric activity, but the correlation of Rieger-type periodicity in the southern hemisphere with the mean solar cycle strength of this hemispheric activity shows a weak correlation. The appearance or disappearance of Rieger-type periodicity in the northern and southern hemispheres during a certain solar cycle is not directly correlated with their corresponding hemispheric mean activity strength but should be related to the strength of the hemispheric activity during sunspot maximum times. This finding hints that the Rieger-type periodicity is more related to temporal evolution of toroidal magnetic filed. The Rieger-type periodicity in the two hemispheres disappears in those solar cycles with relatively weak hemispheric activity during sunspot maximum times. The reason for the appearance of Rieger-type periodicity in two hemispheres during some solar cycles with relatively strong hemispheric activity is the same as advised in Zaqarashvili et al. (2010), which is related to the combination of relatively strong magnetic field and differential rotation parameters that remain more or less unchanged during some time. The disappearance of Rieger-type periodicity in two hemispheres during those solar cycles with the relatively weak hemispheric activity is due to the combined influence of relatively weak toroidal magnetic fields and torsional oscillations, the differential rotation parameters vary through the solar cycle and may not remain more or less unchanged during some time, which does not permit the strong growth of magnetic Rossby waves.

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