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Raj Kumar
Department of Physics, D S B
Campus, Kumaun University,
Nainital, Almora, Uttarakhand,
India

Study of periodicity in sunspot numbers during solar cycle 23-24 using fast Fourier transform technique

Raj Kumar

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Abstract

We present here a study of long term periodicities and hemispheric periodicities in sunspot numbers (SSNs) during solar cycle 23 and 24. We have utilized Fast Fourier Transform (FFT) technique for the determination of periodicities. We found a long term periodicities of 3, 4, 6 and 12 years for SSNs when examined for cycle 23 and 24 combindly. We found short term periodicities corresponding to the solar rotational periods in the range of 25 to 36 days. We found mainly 26, 27, 28 and 36 days periodicities in this category. Other short term periods of 45 and 83 days were exhibited by SSNs. Rieger type periodicities of 112, 131, 133 and 182 days were observed for SSNs when studied for long term periodicities by taking the monthly time series. Annual period of 1 year and quasi Biennial periods of 1.5, 2 and 2.4 years were observed in this study of SSNs.

Keywords: Solar cycle 23-24, sunspot numbers, periodicity, fast Fourier transform technique

1. Introduction

In this study, we have examined the periodicity in sunspot numbers (SSNs) for the solar cycles 23 and 24. This property of solar activity is correlated with periodic variations in the solar magnetic field generated by the solar dynamo (Pesnell, 2015) ^[42]. Magnetic field polarity activity follows a 22-year cycle of periodic change, however the most well-known periodicity is the 11-year solar cycle, commonly known as the Schwabe cycle (Schwabe, 1843) ^[45]. Every solar activity feature, from days to years, is impacted by these periodic variations (Nayar 2006; Kilcik *et al.* 2010; Mendoza & Velasco-Herrera 2011; Du, 2012; Zou & Li 2014; Li *et al.* 2016, 2017) ^[33, 23, 32, 18, 50, 50, 30]. Regarding the short-term data, the most notable periodicity is 27 days, which is associated with the change of solar flux at earth by solar rotation. Midrange periodicities are defined as those with periods longer than 27 days to 11 years (Bai, 2003) ^[3]. Bai (2003) ^[3] examined SXR flares for the midrange periodicities during solar cycles 19-23. Over this span of solar cycles, several periodicities were discovered like 33.5, 51, 85 and 129 days periodicity. The Sun's characteristics can be inferred from the periodicities of various classes of SXR flares (Bai 2003) ^[3]. In their study of midrange periodicity, Choudhary, D. P. *et al.* (2014) ^[13] used sunspot area, flare occurrence, and coronal mass ejections. They discovered that while flux emergence, which is represented by sunspot area, has multiple periodicities, the periodicities of CME and flare occurrences differ from flux emergence's. In a recent study, Oloketuyi *et al.* (2019) ^[38] examined solar X-ray flares and sunspot numbers during solar cycles 23 and 24, finding that different periodicities are obtained for different SXR flare classes. Kilcik *et al.* (2020) ^[24] observed a 546-day periodicity in the maximum CME speed index after examining the temporal and periodic change of the index together with several classes of solar X-ray flares. They also discovered that C and M-class flares had a frequency of 1024-1170 days.

Examining the sunspot number periodicities is crucial for forecasting space weather conditions. Here we present the study of periodicity in sunspot numbers during the solar cycle 23 and 24. Section 2 presents the Observations and methodology. In section 3, analysis and results are described. Section 4 contains the discussion and conclusion.

Corresponding Author:
Raj Kumar
Department of Physics, D S B
Campus, Kumaun University,
Nainital, Almora, Uttarakhand,
India

2. Observations and Methodology

In this study, we have used the time series data of daily sunspot numbers (SSN) during solar cycle 23 and 24. The data for the period of 1996 to 2019 is provided by the Brussels World Data Center for sunspot numbers (SIDC) <http://www.sidc.be/silso/datafiles>.

We have used Fast Fourier Transform (FFT) method for the determination of periodicities in daily sunspot numbers. In order to evaluate the power spectrum analysis of daily and monthly SSN, Fast Fourier Transform technique is very useful tool for the periodic analysis of time series. However, this method was firstly employed by Kiliç (2008) [25]. The power density spectrum of the signal shows how the power of the periodic signal is distributed among various frequency components. We have used an autoregressive modeling process to estimate the statistically significant peaks and we have used 95% confidence level to define the prominent periods present in the data series. Since the FFT analysis uses an algorithm that allows us to scan a part of the power spectrum with any desired resolution in frequency (or period) that's why we have analysed the data for different frequency

domains and then we have drawn the power spectrum of frequency domain ($f=1/T$) for each solar cycle. Thus, in power spectrum of FFT, the spectrum is plotted between peak power and frequency.

3. Analysis and Results

We have examined the total sunspot numbers for various periodicities while accounting for the 23rd and 24th solar cycles. The ensuing subsections provide the detailed study.

3.1 Periodicities in Sunspot Numbers

In Figure 1, the FFT periodogram is displayed for SSN during cycle 23 and 24. We have taken the monthly data of SSN during solar cycle 23 and 24 for finding the higher mid-term or long term periodicities. The famous periodicity in sunspots is 11 year solar cycle. Here we got the highest periodicity of 12 years. We found that periodicities of 3 and 2.4 years are most prominent. Other periodicities with periods 2, 4 and 1 years are also detected as prominent periods. We have found also Rieger type (mid-term) periodicity of 131 day and intermediate period of 313 days.

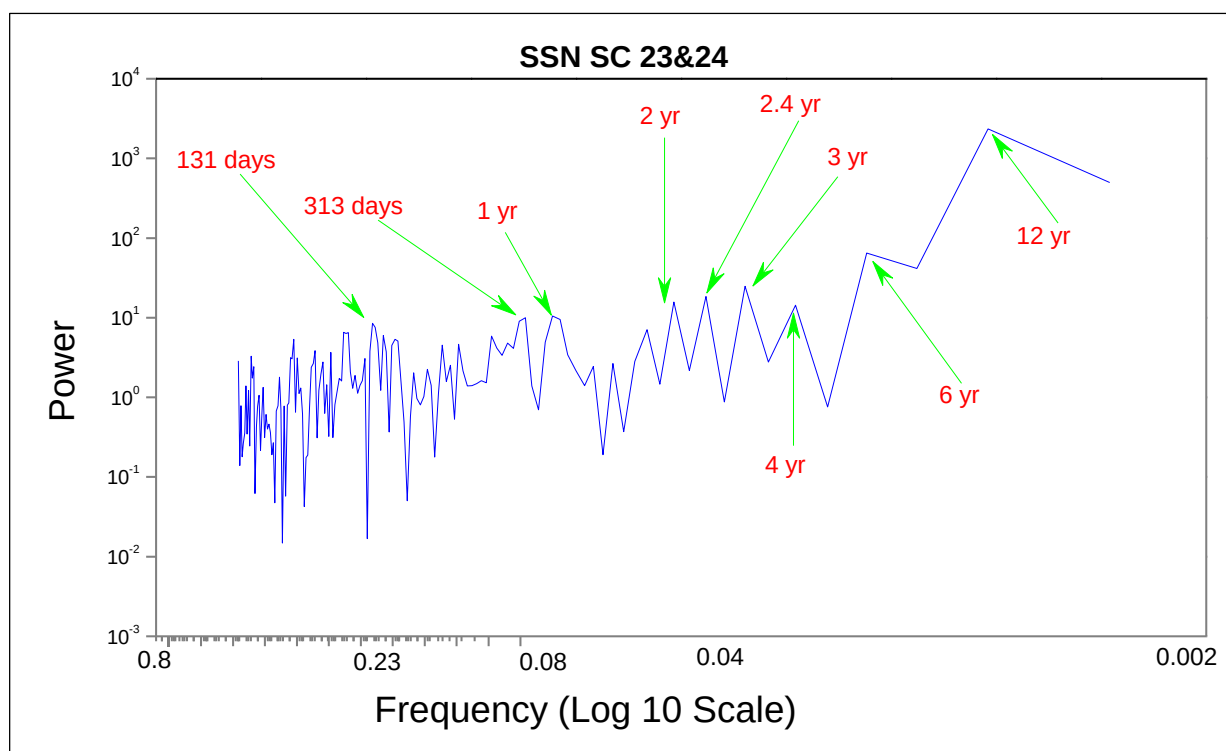


Fig 1: Fast Fourier transform periodogram for SSNs during solar cycle 23 and 24.

In Figure 2, we have plotted the FFT power spectrum of SSN for solar cycle 23. We found number of resolved peaks of different periods, which contain the periods of 27, 36, 83,

112, 133 and 365 days. Much more peaks are obtained in this periodogram with some lower amplitude.

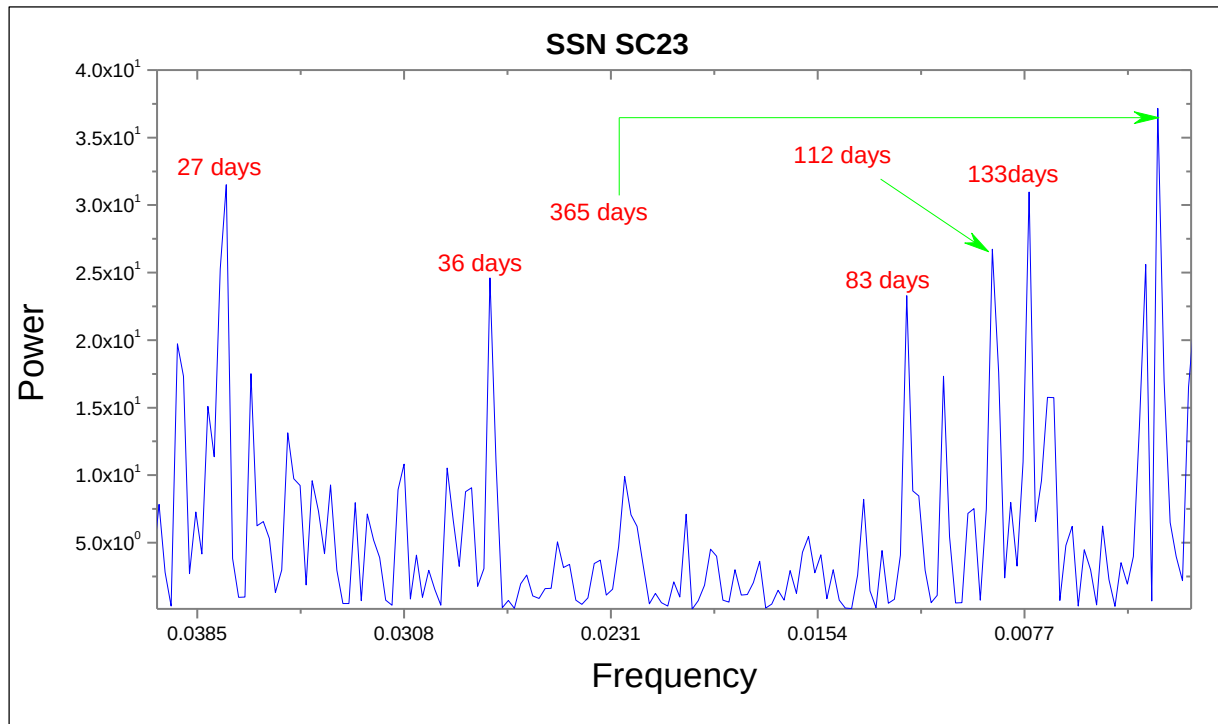


Fig 2: Fast Fourier transform periodogram for SSN during solar cycle 23.

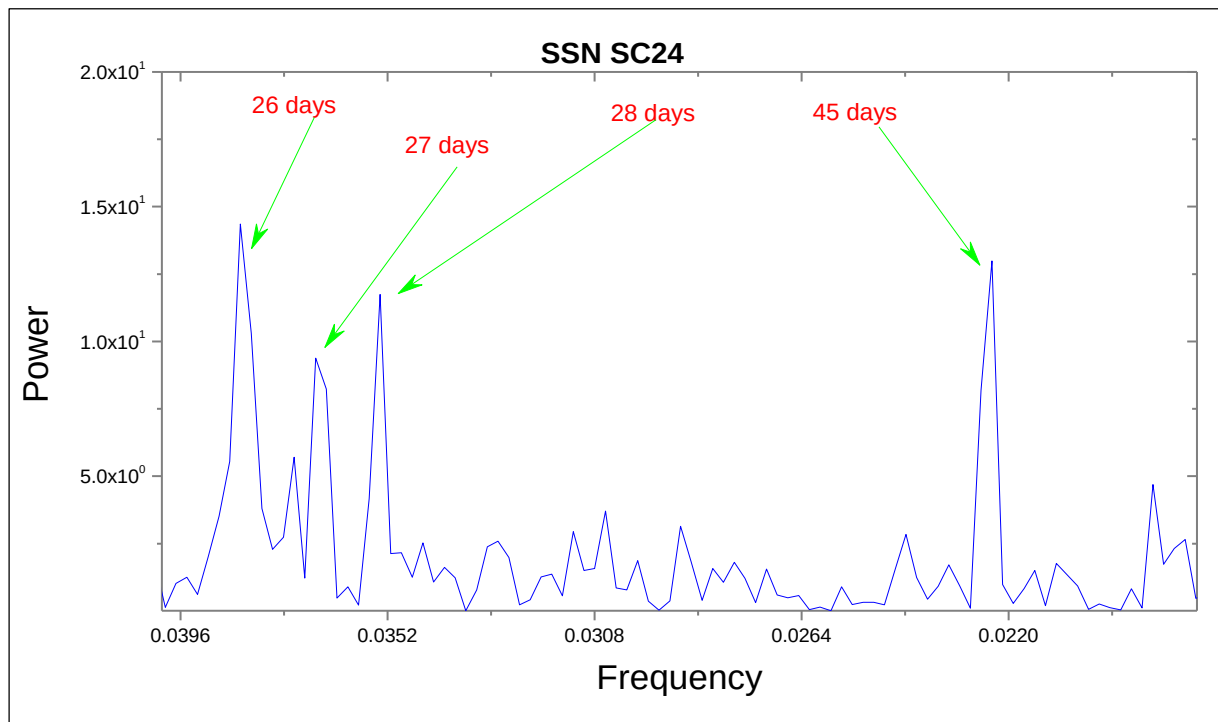


Fig 3: Fast Fourier transform power spectrum plotted with frequency for SSN during solar cycle 24.

We took the cycle 24 separately to study the periodicity of SSNs in this cycle. The power spectrum obtained using FFT method is shown in Figure 3. We have obtained mainly four periods for this cycle of SSN which are 26, 27, 28 and 45 days. First three periods are approximately similar to each other. On an average we can take 27 day periodicity as prominent one.

3.2 Periodicities in Northern and Southern Hemispheres of Sunspot Numbers

Many solar activity features show the hemispheric asymmetry in northern and southern hemisphere. The sunspot numbers also show this hemispheric asymmetry. The different

periodicities of these solar parameters in opposite hemispheres lead to the north-south asymmetry (Carbonell *et al.*, 1993; Oliver and Ballester, 1994; Ballester *et al.*, 2005; Temmer *et al.*, 2006; Chowdhury *et al.*, 2019 etc) [12, 35, 8, 46, 16]. So we plan to investigate the periodicity in different hemispheres for sunspot numbers during solar cycle 24.

In Figure 4, a power-frequency spectrum of sunspot numbers during solar cycle 24 (located in northern hemisphere) is plotted using FFT method. We found that 546 days and 28 days periodicity is most prominent periodicity indicated in FFT power spectrum. The SSNs in the northern hemisphere show periodicity of 28, 45, 182, 219 and 546 days.

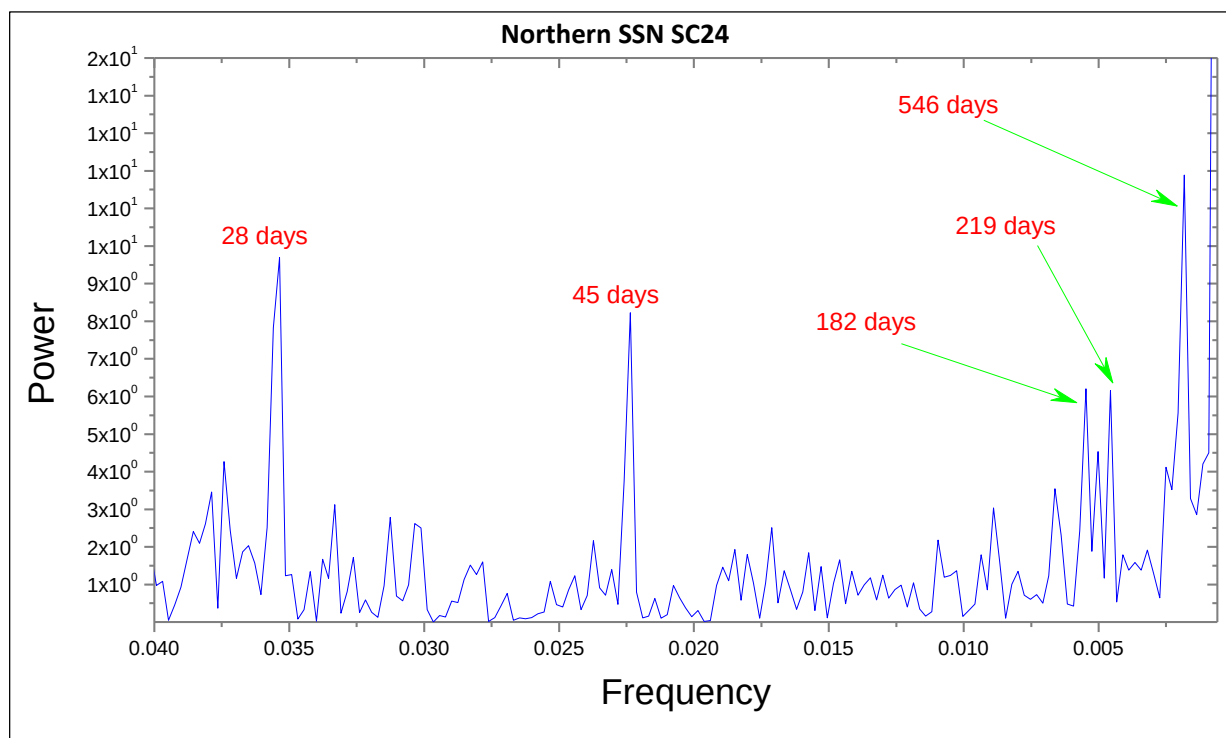


Fig 4: Fast Fourier transform power spectrum plotted with frequency for SSNs located in northern hemisphere during solar cycle 24. Confidence level of 95% is used to detect the prominent periods.

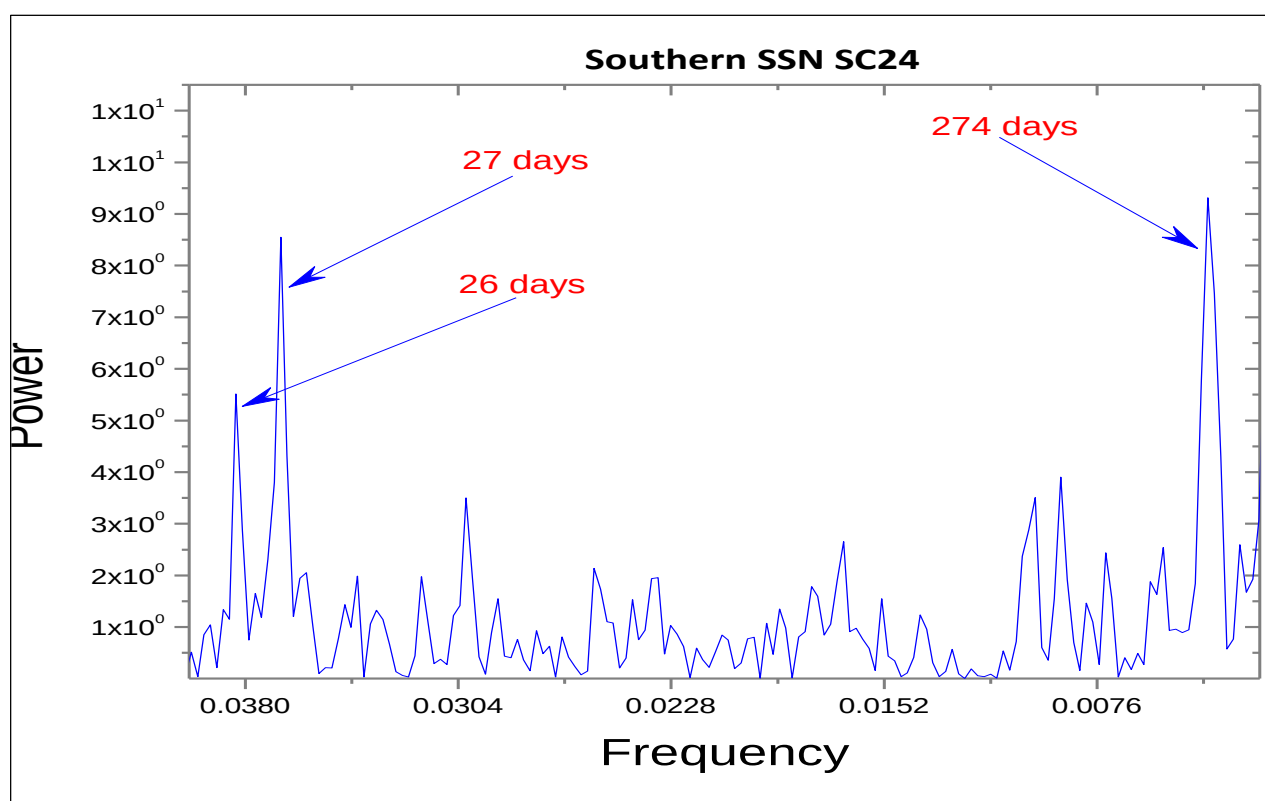


Fig 5: Fast Fourier transform power spectrum plotted with frequency for SSNs located in southern hemisphere during solar cycle 24.

In the FFT periodogram of sunspot numbers located in southern hemisphere for the same cycle (Figure 5), we found that periodicity of 28 days in northern hemisphere is shifted to 27 days and 26 days. A highly significant periodicity of 274 days was found in southern hemisphere.

4. Discussion and Conclusion

The FFT periodogram method was employed to determine the short term and midrange periodicities in SSNs for two solar cycles 23 and 24. We have divided the periodicities in

different classes (Table 1). Periodicities within the range of 25 to 36 days—centered around 27 days—are generally consistent with the solar rotation period. This has been confirmed by numerous studies focusing on various solar features (Özgüç *et al.*, 2004; Yin *et al.*, 2007; Kilcik *et al.*, 2010; Chowdhury *et al.*, 2009, 2011)^[40, 49, 23, 15]. Additionally, Bai (2003)^[3] identified a periodicity of 33.5 days during solar cycle 23. We found the solar rotation periods of 26, 27, 28 and 36 days in different categories of SSNs. For instance, periodicity of 28 days was found in SSNs located in northern

hemisphere of the solar disc, but for SSNs located in southern hemisphere, two periods of 26 and 27 days were observed. A mid-range periodicity ranging from 37 to 100 days was also detected in our study and designated as other short term periods. These periodicities are consistent with findings from previous studies. For example, Atac and Özgüç (2006) [2] identified periodicities of 64 and 83 days while analyzing total soft X-ray (SXR) emissions and their north-south hemispheric distribution during cycle 23. Similarly, Kilcik *et al.* (2010) [23] reported a 62-day periodicity for solar cycle 23 and a 73-day periodicity for cycle 22. In our analysis, we also observed periodicities of 45 and 83 days. Our study also revealed a set of periodicities ranging from 100 to 200 days, which corresponds to the well-known Rieger or Rieger-type periodicities first reported by Rieger *et al.* (1984). In our analysis, we detected Rieger-type periodicities

of 112, 131, 133, and 182 days. Similar periodicities have been identified in various solar cycles by other researchers (Bogart and Bai, 1985; Bai and Cliver, 1990; Droge *et al.*, 1990; Kile and Cliver, 1991; Joshi and Joshi, 2004; Kilcik *et al.*, 2010) [9, 4, 17, 22, 20, 23]. Bai and Sturrock (1991) [5] identified a periodicity of 129 days in their study. Similarly, Oloketuyi *et al.* (2019) [38] reported a 128-day periodicity while analyzing soft X-ray (SXR) flares. Aroori *et al.* (2021) [1] also detected several periodicities within this range—such as 112, 131, 148, 164, and 192 days—during their investigation of sunspot numbers (SSNs) and solar radio emissions for solar cycle 23. Choudhary *et al.* (2014) [13] observed periodicities between 158 and 182 days in sunspot area data. A near six-month periodicity was further confirmed by Vourlidas *et al.* (2010, 2011) [47, 48] and Choudhary *et al.* (2014) [13].

Table 1 List of periods obtained for sunspot numbers during solar cycle 23 and 24.

Time series data	25-36 days ^a	37-100 days ^b	101-199 days ^c	200-330 days ^d	≈ 365 days (≈1 year) ^e	~ 500 to 900 days (~1.5 to 2.5 year) ^f	> 900 days (> 2.5 years) ^g (Year)
SSN (23&24)		-	131	313	365	730, 877	3, 4, 6, 12
SSN 23	27, 36	83	112, 133	-	365		-
SSN 24	26, 27, 28	45	-		-	-	
SSN NH 24	28	45	182	219	-	546	
SSN SH 24	26, 27	-		274	-	-	

^a solar rotation period, ^b other short term periods, ^c Rieger and Rieger type periods, ^d intermediate periods, ^e annual period, ^f quasi-biennial periods, ^g other long term periods

We observed the periodicities of 219, 274 and 313 days designated as intermediate periods. Aroori *et al.* (2021) [1] found the periodicities having periods of 239, 263, 269, 281, 316 and 317 etc, while investigating the same for SSNs and solar radio emissions. The category of annual period of 365 days was also detected in our study for both SSNs considered collectively for solar cycles 23-24 and when taken for cycle 23 only. Several researchers have identified these periodicities across different solar cycles and parameters (Pap *et al.*, 1990; Oliver *et al.*, 1992; Howe *et al.*, 2000; Lou *et al.*, 2003; Knaack and Stenflo, 2005; Aroori *et al.*, 2021) [41, 37, 14, 31, 21, 1]. Oscillations with periods of 28 to 29 months are referred to as biennial oscillations, while those occurring near this range are known as quasi-biennial oscillations (QBOs). In our study, we defined QBOs as periodicities between 1.5 and 2.5 years (approximately 500 to 900 days). Within this range, we identified periodicities of 730 and 877 days in sunspot numbers during solar cycles 23 and 24, based on monthly data used to detect long-term trends. A 546-day periodicity was found in northern hemisphere sunspot number data during cycle 24. Additionally, we detected longer-term periodicities of 3, 3.15, 3.4, 4, 6 and 12 years in sunspot numbers. These findings are consistent with earlier studies (Nayar *et al.*, 2002; Özgüç *et al.*, 2002; Knaack *et al.*, 2004; Lara *et al.*, 2008; Katsavrias *et al.*, 2012; Aroori *et al.*, 2021) [34, 39, 25, 28, 21, 1]. Since we have taken the data for two solar cycles from 1996 to 2020, the highest period found was 12 years (and 6 year, a factor of 12) corresponding to Schwabe cycle of 11 year. It is proposed by several studies (Carbonell and Ballester, 1990, 1992; Oliver, Ballester, and Baudin, 1998; Ballester, Oliver, and Baudin, 1999; Ballester, Oliver, and Carbonell, 2002) [10, 11, 36, 6, 7] that periodicity is associated with the periodic emergence of the magnetic flux linked to the regions of strong magnetic field. Sunspots are also the areas of strong magnetic activity where the Sun's magnetic field is concentrated. Emergence of magnetic flux periodically constitutes the periodic change in sunspot numbers. These periodicities of sunspot numbers are natural solar phenomena

which might be the results of variation in the solar magnetic activity.

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