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Solar activity related periodicities in sea surface temperature

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Abstract

Sun is a variable star showing a great variety of non-stationary active processes. Such non-stationary and non-equilibrium processes (solar activity) can lead to sporadic acceleration of energetic particles with greatly enhanced flux (solar wind). These processes modify the radiation environment of Earth and cause strong geomagnetic storms through coupling of solar wind and Earth's magnetosphere. This may lead to aurorae and large electric currents that can disrupt communication, power grids and satellite navigation. During active times, Sun's energy output is irregular and highly explosive. Earth's climate is also influenced by solar activity variations. Sea surface temperature is a well known parameter relating to climate change. It can influence air on the near shore atmosphere and its variations can modify Earth's climate in a highly complex way. Present study analyzes sea surface temperature and solar activity variations, in order to find out the presence of solar activity related periodicities in sea surface temperature. Wavelet analysis of global, northern and southern sea surface temperature time series and various solar activity indices were carried out. Major long-term periodicity found common in global, northern and southern sea surface temperature is 17.9 years. Southern hemisphere sea surface temperature variation is shown mainly to follow variations in sunspot activity. However, global sea surface temperature and northern hemisphere sea surface temperature variations are more influenced by asymmetry in the polar magnetic field of the Sun.

Key words: Sea surface temperature, Solar activity, Solar magnetic field, Sunspots

1. Introduction

Solar activity affecting Earth's climate is an active area of research. During past times, it is observed that low sunspot number coincides with cool weather and high sunspot number with warm weather. Also during a long-term decrease in sunspot number known as Maunder minimum that the Little ice age

occurred in Europe. Total Solar Irradiance (TSI) modulated by 11 years cycle of solar activity act as a major source in climate change of Earth². Solar activity is shown to be a major contributor of global climatic variation by Reid¹ too.

Sea Surface Temperature (SST) is an index of measuring average kinetic energy of molecules at the surface of the ocean. Radiometers measure temperature

in IR at a depth of 10µm below the sea surface and in microwave bands at a depth of 1mm below the surface. SST variations influence ocean-climate interactions (eg. El Nino Southern Oscillation). Sea surface measurements are derived by merging satellite and in situ observations. Study of nature of SST variations and factors affecting it are essential for an accurate climate prediction. Folland *et. al.*³ find out that climate in the Sahal region of Africa is influenced by worldwide SST anomalies. A high resolution SST record indicates that climate in the North Atlantic regions follows solar activity variations on multidecadal to centennial scales⁴.

Efforts have been found in the literature to correlate solar activity and sea surface parameters. Benestad⁵ found out a significant correlation between sunspot cycle length and terrestrial global mean temperature by examining relationships between sunspot cycle length and global mean land and sea surface temperatures. Also sea surface temperatures during the period from 1760 to 1994 were reconstructed using sunspot cycle length. A large difference obtained between total radiative forcing on the Earth, measured through ocean parameters such as net heat flux into the oceans, sea level change rate and SST, and TSI variations implies the necessary existence of an amplification mechanism. According to Shajiv⁶, ocean heat content and the sea surface vary in step with ~11 year solar cycle. SST anomalies in the Arabian sea can influence south west monsoon rain fall pattern over Indian subcontinent⁷. Spectral analysis of sea surface temperature (1880-2008) shows a periodicity of 21.3 years⁸ and this correlates well with the reversal of solar magnetic field in every 22 years.

Present study investigates the relationship between SST and various solar activities using wavelet analysis.

2. Data and Method

Monthly averaged SST data for the years 1964-2015 is collected from the NOAA website (<ftp://ftp.ncdc.noaa.gov>). Monthly averaged sunspot number from 1964 to 2015 is obtained from the website <http://www.sidc.be/silso>. Monthly averaged sunspot area and its northern and southern hemispheric parts for the period 1964-2015 are collected from the website

<http://solarscience.msfc.nasa.gov/>.

Monthly averaged solar radio flux data for the period 1964-2012 is taken from the website <http://www.esrl.noaa.gov/>. Monthly averaged flare index data (1966-2008) is obtained from the website <ftp://ftp.ngdc.noaa.gov>. Polar faculae number for the north and south hemispheres are available at the website <http://solarwww.mtk.nao.ac.jp>.

Asymmetry in any solar activity index (SI_{ASY}) is calculated as the ratio of difference of values of solar activity index in northern and southern hemispheres to the sum of values of solar activity index in northern and southern hemispheres.

$$SI_{ASY} = \frac{SI_N - SI_S}{SI_N + SI_S} \quad (1)$$

where

SI_N = Sum of values of solar activity index in the northern hemisphere

SI_S = Sum of values of solar activity index in the southern hemisphere

Wavelet techniques are used for study and analysis of various data. Wavelet analysis is a method of transforming original data to another form so that dynamic movements within the signal can be easily evaluated. It decomposes a non-stationary time series into time-frequency space.

Continuous Wavelet Transform (CWT) is a method of wavelet transform, that applies wavelet as a band pass filter to the time series. Wavelet is stretched in time by varying its scale continuously and Morlet wavelet is selected as the mother wavelet. Being a complex wavelet, Morlet wavelet can return information about both amplitude and phase. Outcome of CWT is the convolution of time series with the scaled and normalized wavelets. Continuous wavelet spectrum gives the variations of amplitude with scale and time.

If ψ is the mother wavelet (satisfying finite energy and admissibility conditions), then CWT of a real signal $x(t)$ is defined as

$$x_{WT}(b, a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} \psi' \frac{t-b}{a} x(t) dt \quad (2)$$

where ψ' denotes complex conjugate of ψ . Parameters b and a corresponds to the dilation and translation of analyzing wavelet⁹.

3. Analysis :

In the present analysis, a comparison of periodicities in SST and that in solar activities are carried out using the method of wavelet analysis.

4. Results and Discussion

4.1 Sea Surface Temperature :

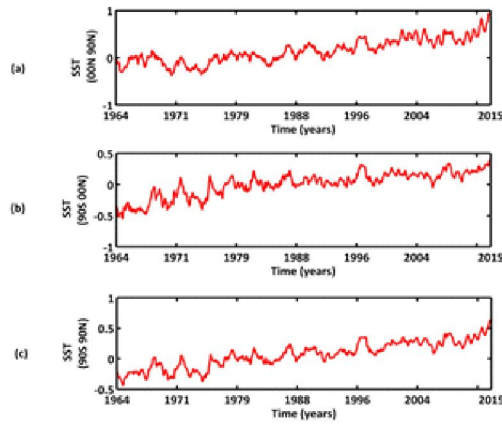
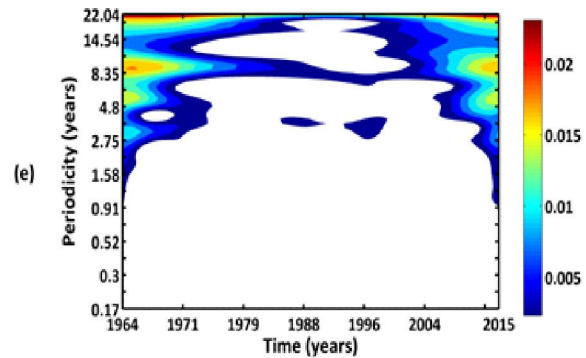
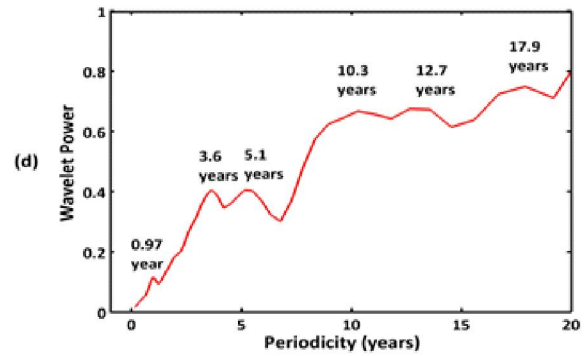
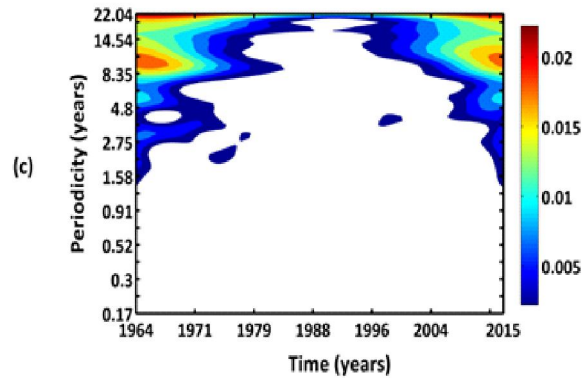
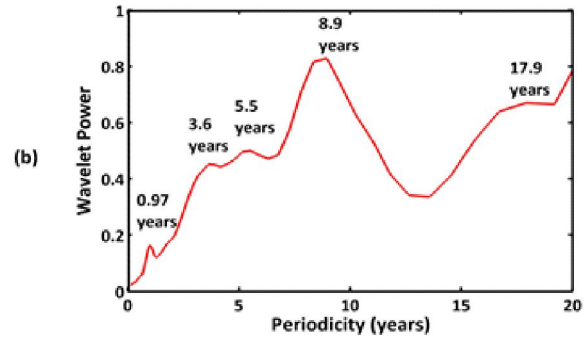
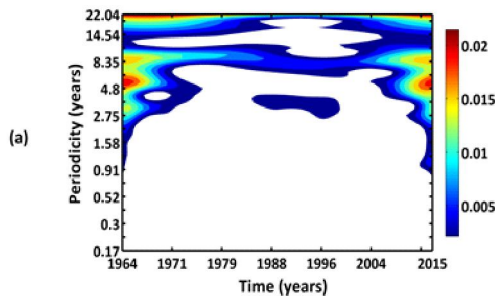


Fig. 1 Time series of monthly averaged SST for the period 1964-2015 in the region (a) 00N to 90N (Northern hemisphere) (b) 90S to 00N (Southern hemisphere) (c) 90S to 90N (Global)

Figs. 1 (a) and (b) show the monthly variation of SST (1964-2015) in the northern and southern hemispheres respectively. Fig. 1 (c) represents the global variation. As is evident from all the three figures, there is an increasing trend for SST, with clear periodic variation. The rise in global mean SST from 1970 onwards was reported earlier by Large and Yaeger¹⁰.



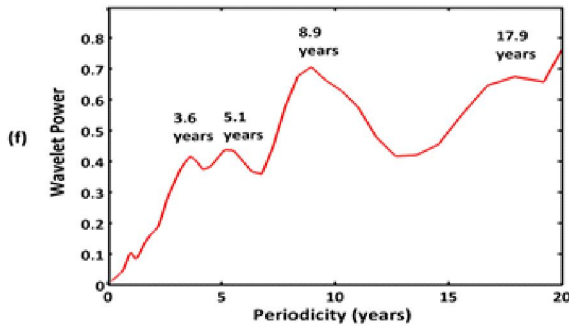


Fig. 2(a) and (b) CWT of monthly averaged SST and the corresponding GWPS in the region 00N to 90N (Northern hemisphere)

(c) and (d) CWT of monthly averaged SST and the corresponding GWPS in the region 90S to 00N (Southern hemisphere)

(e) and (f) CWT of monthly averaged SST and the corresponding GWPS in the region 90S to 90N (Global)

CWT of monthly averaged SST and their corresponding time averaged wavelet spectrum known as global wavelet power spectrum (GWPS) are shown in Fig. 2 (a) to Fig. 2(f). CWT of a non-stationary signal depicts periodicities as well as their time of occurrence. Variation of wavelet power from minimum to maximum is indicated in the CWT using a range of colours, given on the colour bar on the right side of CWT. Minimum wavelet power is indicated by dark blue and maximum wavelet power by dark red. The strength or the power of different periodicities present in SST can be exactly observed from the GWPS. From the GWPS plots in Fig. 2, it is evident that the longer periodicities exhibit stronger power than shorter periodicities.

It is seen that the 17.9 years periodicity is present in both northern and southern hemispheres. Its global presence is also evident. Periodicities nearer to 5 years and 3.6 years are also present in all the three (northern, southern and global) wavelet spectra. But, 8.9 years periodicity with considerable power is present only in the northern and global spectra. Dominant periodicities like 12.7 years and 10.3 years are unique for the southern hemisphere. Less dominant one like 0.97 years is found in northern and southern hemispheres.

Periodicities nearer to 17.9 years, as we observed in SST have also been reported for other climatic parameters like Northern Atlantic Oscillation,

Indian monsoon strength, etc.^{12,14,16} and Silveira and Pezzi (2014) have also observed, periodicities in SST nearer to 8.9 years in various regions, as we have obtained. Periodicities 12.7 years and 10.3 years were earlier obtained for tropical South Atlantic SST and global monthly averaged SST respectively¹⁵.

4.2 Solar activity Indices :

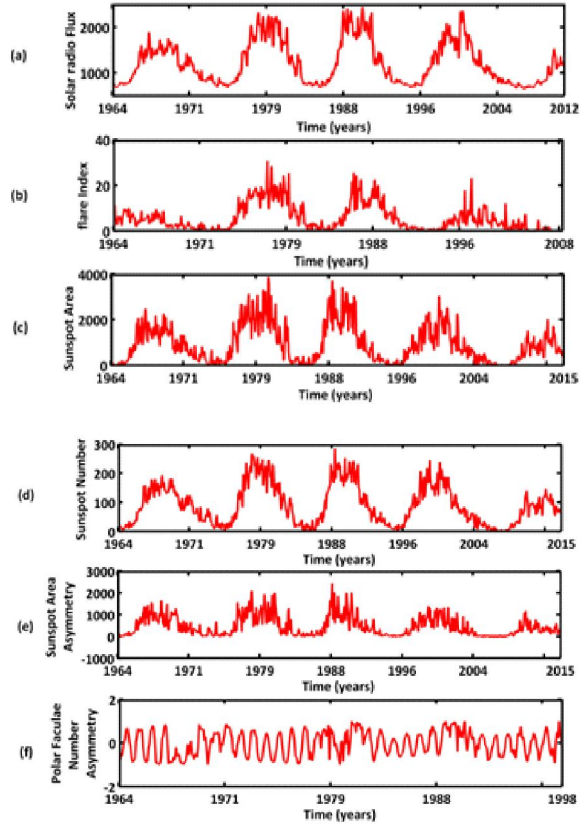
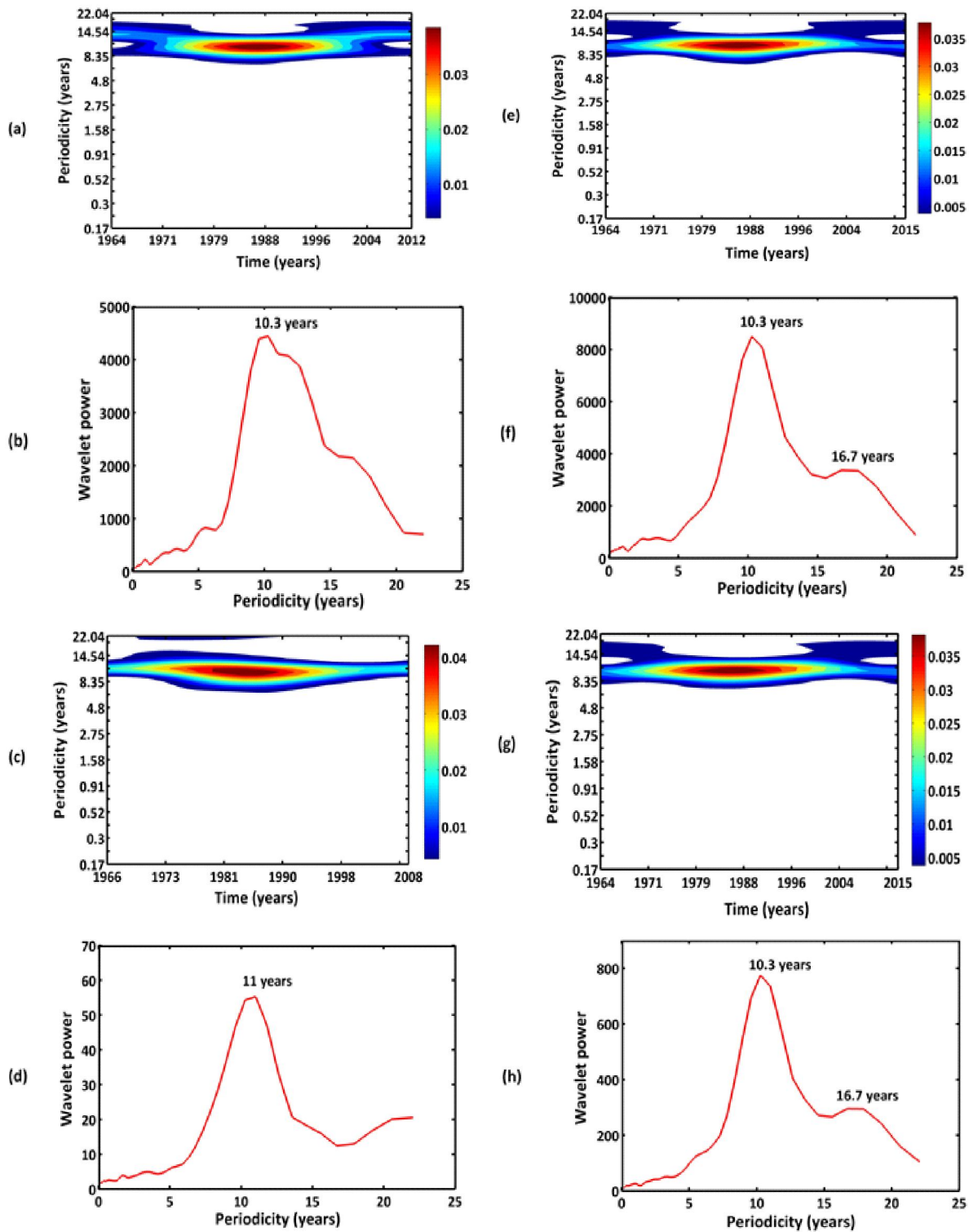


Fig. 3 Time series of monthly averaged

(a) Solar Radio flux (1964-2012) **(b)** Flare Index (1966-2008) **(c)** Sunspot Area (1964-2015) **(d)** Sunspot Number (1964-2015) **(e)** Sunspot Area Asymmetry (1964-2015) **(f)** Polar Faculae Number Asymmetry (1964-1998)

Time series of solar activity indices such as solar radio flux, flare index, sunspot area, sunspot number, sunspot area asymmetry and polar faculae number asymmetry are shown in Fig. 3 (a) to (f). All signals are non-stationary signals having a strong cyclic trend.



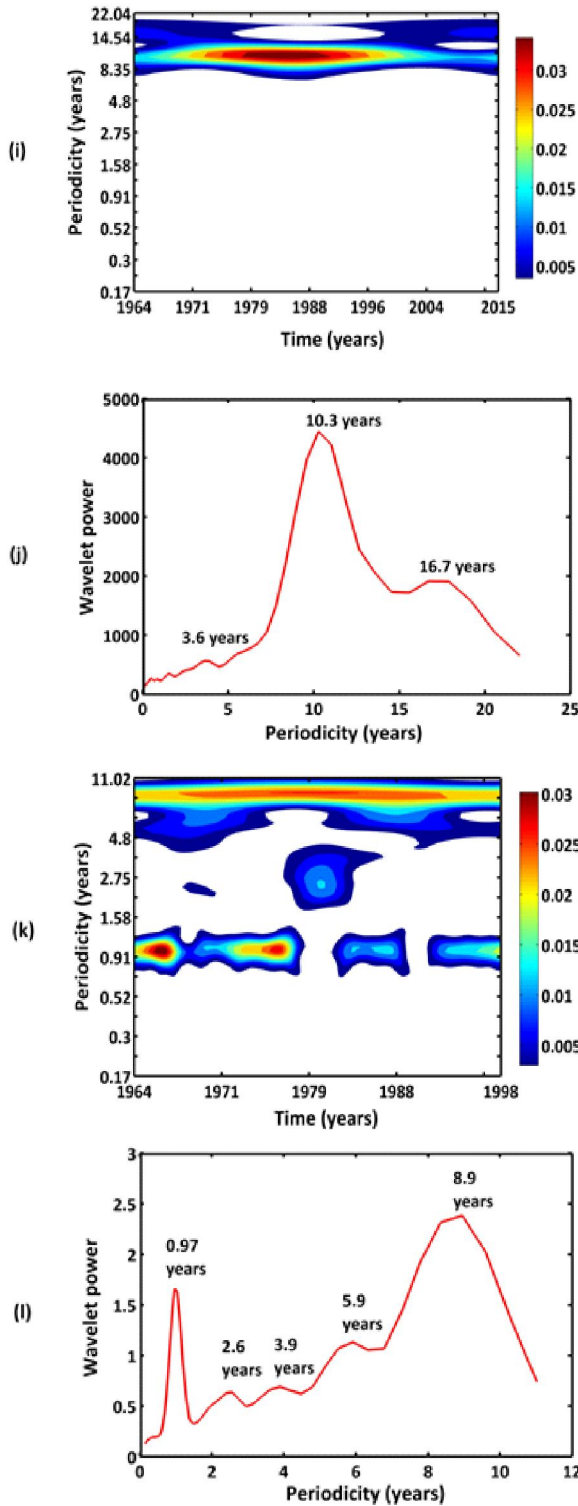


Fig. 4(a) and (b) CWT of monthly averaged Solar Radio Flux and the corresponding GWPS **(c) and (d)** CWT of monthly averaged Flare Index and the corresponding GWPS **(e) and (f)** CWT of monthly averaged Sunspot area and the corresponding GWPS **(g) and (h)** CWT of monthly averaged Sunspot Number and the corresponding GWPS **(i) and (j)** CWT of monthly averaged Sunspot Area Asymmetry and the corresponding GWPS **(k) and (l)** CWT of monthly averaged Polar Faculae Number Asymmetry and the corresponding GWPS

CWT of monthly averaged solar activity indices and the corresponding GWPS are shown in Figs. 4 (a) to 4(l). It is interesting to note that various dominant periodicities obtained for the SST are present in the solar activity indices too. A periodicity of 10.3 years is very strong in solar radio flux, sunspot area, sunspot number and sunspot area asymmetry (Figs. 4 (b), (f), (h) and (j)). Periodicities 8.9 years and 0.97 years are dominant in polar faculae number asymmetry (Fig. 4 (l)). Sunspot area is observed to hold 3.6 years periodicity. Similar periodicities have been obtained in various earlier studies too.

Analysis of north-south asymmetry in the area of sunspot groups in three latitude zones (0° - 10° , 10° - 20° and 20° - 30°) using FFT, Maximum entropy analysis and Morlet analysis shows that 8-9 years are characteristic periodicities of solar activity in the southern hemisphere¹⁷. Periodicities ~ 17 years and 3.5 years were reported for equatorial rotation of the Sun and Zurich sunspot number respectively^{13,18,19}.

Common periodicities observed both in SST and solar activity indices are shown in Table 1.

Most of the major periodicities observed in SST are present in solar activity indices too. Particularly three major periodicities viz. 8.9 years, 3.6 years and 0.97 years are evident in polar faculae number asymmetry. This implies that SST variations are closely connected to asymmetry in the polar faculae number of the Sun. 10.3 years periodicity is dominant in southern hemisphere SST only and is shown by sunspot related indices. Toroidal and poloidal magnetic fields are the two major components of solar dynamo. Sunspots are a very good proxy of toroidal field²⁰ while, polar faculae number is highly correlated with poloidal

Table 1. Common periodicities in SST with Solar activity indices

Sl. No.	Periodicities in SST (years)			Solar activity indices with same Periodicities
	North hemisphere	South hemisphere	Global	
1	-	10.3	-	Sunspot Number, Sunspot Area, Sunspot Area Asymmetry, Solar Radio Flux
2	8.9		8.9	Polar faculae Number Asymmetry
3	3.6	3.6	3.6	Sunspot Area Asymmetry
4	0.97	0.97		Polar faculae Number Asymmetry
5	5.5	-	-	Solar Radio Flux

magnetic fields. Thus there seems to be some correlation between polar magnetic field of the Sun and SST. Same periodicities were observed earlier in SST and solar irradiance²¹, showing a dependence of SST on sunlight. Study reported in this paper tries to establish dependence of SST on solar magnetic field.

5. Conclusion

Most of the periodicities found in SST coincide with periodicities of various solar activity indices linked with solar magnetic field. Hence solar magnetic field shall be considered as one of the factors causing sea surface temperature variations. Major periodicities in sunspot parameters are found only in southern hemisphere SST. And hence southern hemisphere SST variations are influenced by toroidal field of the Sun.

The study can be extended by detailed analysis of wavelet spectrum of SST and solar indices. From this a comparative analysis of amplitude modulation of periodicities in both the indices can be carried out and conclusive results may be obtained.

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