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RESEARCH ARTICLE

Various Solar Activity Parameters and their Interrelationship from Solar cycles 20 to 24

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ABSTRACT

In the present paper we have studied the long term variation of various solar parameters with 11-year cyclic solar activity behavior. A detailed correlative study has been performed using the monthly data among the variety of solar activity (SA) parameters for example Sunspot Numbers (SSN), Solar Flux(SF, 10.7cm flux), Grouped Solar Flare (GSF), Solar Flare Index (SFI) and Coronal Index (CI) for last five 11-year solar cycle 20 to 24 (the present solar cycle). The SSN is the prime SA parameter that shows higher degree of correlation with the other solar parameters; however the correlation coefficient and running cross correlation are concerned. The correlation analysis shows that the solar active parameters (or indices) exhibit a strong correlation between SSN-SF and distinct characteristic behavior of SSN for Group solar flare and solar flare indices (GSF and SFI). Presently, the slop of regression lines between SSN and GSF and those between SSN and SFI is found to decrease continuously with the progression of cycles (from solar cycle 20 to 24). It is also verify from the peak values of SSN and SFI. As well as, the significant peak differences on SSN-CI for even and odd cycles is clearly apparent.

KEYWORDS: Sunspot number, Solar Flux, Grouped Solar Flare, Solar Flare Index, Coronal Index.

INTRODUCTION

All the observed time-dependent phenomena are called solar activity and are seen in different wavelengths as a changing appearance of the sun [1].The most important index of solar activity has been the Zurich or wolf sunspot number was introduced in 1848 by Rudolf wolf, which help to explain the physical mechanism and provides the longest continuous measure of changes in solar activity over time, begin with Wolf classical formula for the relative number of sunspots, is given by R_z = k(10g + n), where k is a correlation factor the observer, g is the number of identified sunspot group and n is the number of individual sunspots. Today, the monthly and yearly updates available online by the different observatories like Sunspot Index Data Center in Brussels, Belgium [2]. The solar activity expressed through many solar indices such as Sunsopt Number (SSN), Solar Radio Flux (10.7 cm) and other solar indices covering the whole electromagnetic phenomena [3], underlying the convection zone and rise electromagnetic spectrum from high energy X-ray and ultraviolet data, each of them reflects different physical condition in solar atmosphere [4].

Solar activities have been understood in the term of behavior and characterization of the magnetized solar plasma. Solar flare are the complex magnetic phenomena seen as sudden and intense increases in brightness on the solar disk .They occur when the coronal loops (magnetic field loops) increase and twisted in magnetic field loops undergo reorganization, store massive amount of energy, releasing energy into the solar corona and chromospheric plasma. It is widely accepted that they are the result of the rapid conversion of a large amount of magnetic energy (stored into the corona) dissipated through magnetic reconnection. The release of energy takes place in a matter of minutes to hours, and can amount to value up to 10^{26} J (10^{33} erg) [5]. The first solar flare as a local short-duration brightening on the white-light observations was reported by R. C. Carrington and R. Hodgson on 1 September 1859 [5-7]. However the important flare index called group solar flare (GSF). The term "grouped" means all observations made in different location to the same flare event by different solar observatory were lumped together and count as one. The flare parameters including its heliographic coordinates, the start, maximum and end time of the flare, duration, apparent and correlated areas, optical importance, are deduced using the data of all observation [6, 8]. GSF are not the total energy emanated by the solar flare but it's a relative numbers on a given month.

Many studies in the Solar Terrestrial Field classified solar flare as one of the important solar events affecting the earth, where as the calculation of the solar flare index (SFI) take care of these two factors. The solar flare index Q defined by Kleczek in 1952 for describing the Hα flare over a 24-hour periods as Q= i × t, where i represent the intensity scale of importance of a flare in Hα and t the duration of the flare in minutes. It is assumed that this relationship gives roughly the total energy emitted by the flares. The flare index is an essential parameter to measure the value of the short-lived activity on the sun atmosphere [9-10].

The number of sunspots can be seen on the surface of the sun increases and decreases in a regular pattern, known as the solar cycle, with a maximum number of sunspots occurring every 11 years. The Solar cycle is a magnetic cycle of 11 year in which the average number of sunspot visible over the surface varies from a minimum near zero to a maximum of about a hundred. Every 11 years, the sun moves through a period of fewer, smaller sunspot, prominences and flare called a solar minimum and a period of more, large sunspots, prominences and flare called a solar maximum. After 11 year the magnetic field poles are reversed.

The number of SA indices as solar flare, coronal holes and electromagnetic radiation in various bands (10.7 radio flux, green coronal etc.) and sunspot number on the solar disk, showing the level of sunspot activity, are widely used index of SA. The sunspot numbers (SSN) are taken as the most famous and popular index for study the sun atmosphere. SSN series is most analyzed time series in the solar physics [11-13]. Among these, The 10.7 cm radio flux has been measured in daily basis since 1947 and monthly data available from Feb 1947. The Zurich sunspot number R_z monthly value available from 1749 onward. But beginning in 1981 and present, the international sunspot number has been provided by the Royal Observatory of Belgium, with Solar Influences Data analysis Center [2].

The 10.7 cm solar radio flux (SF-10.7cm) is one of the most widely used indices of solar activity. Its applications include use as a simple activity level indicator, as a proxy for other solar emissions or quantities which are more difficult to obtain. A 10.7 cm solar flux measurement is a determination of the strength of solar radio emission in a 100 MHz-wide band centered on 2800 MHz (a wavelength of 10.7 cm), averaged over an hour. It is expressed in solar flux units (sfu), where 1 sfu = 10^{-22}W $m^{-2}Hz^{-1}$[14].

Initially, almost investigators have generally used the SSN as an essentially solar index for various study between the sun and the earth for examine the complicated and associating phenomena. Later on the other important solar indices (i.e. Solar radio flux 10.7cm, Group solar flare, Green corona line index , Sunspot area etc.), are also used to describe the phenomenon of solar activity . In the light of large database and correlation studies, it has been recognized that SSN and SF (10.7cm) are highly correlated even on a monthly average basis [2]. Nevertheless, many investigators still prefer to use both of these solar indices (monthly or yearly averages) for their correlative studies of the solar terrestrial phenomenon [2, 15].

There is growing evidence that solar variability influence the heliosphere, biosphere and Earth's Climate- The solar variability finds its representation via a large number of phenomena and structures observed in the solar atmosphere changes in the green coronal irradiance over solar cycle are very pronounced and their long term temporal behavior is in a good agreement with the corresponding variation of the solar magnetic flux. Rybansky (1975) was first introduced green line coronal index of solar activity. The coronal green line index (coronal index) is a general indicator, which characterizes the presence of long-lived coronal structure and represents the daily irradiance emitted by the green corona (Fe XIV, 530.3 nm) line into one steradian towards the earth [16-18]. The green coronal index exhibits a very good correlation with other solar indices (sunspot number, 10.7 cm radio flux, the X-ray flux and the total solar magnetic flux). It was found that the green corona intensity vary with solar cycle, we have been used green coronal line index data set based in the Lomnicky site photometric scale and it is routinely measured at several station across the world [17,19].

Altrock R.C. et al. [4] have been reported that the CI is one of the index to study the STR, is based on the irradiance of the green corona (Fe XIV, 530.3 nm) as observed by ground base coronagraphs on the basis of daily observation. They found that the maxima of CI cycle have monotonically increased by the factor of two. Recently the many investigator have been performed a correlative study between solar activity (SA) with cosmic ray intensity (CRI) by the "running cross-correlation method" [12, 20]. The majority of investigators have generally used SSN as a representative solar index for various studies associated with Solar-terrestrial relationship (STR) or Sun-Earth connection [21-24]. Later, with the availability of variety of solar indices, various authors have used arbitrarily one index or a combination of some solar indices for their investigation [25-30].

Earlier, Badruddin et al. [11] have reported a different trend of regression lines, dealing with the solar cycle relationship between SSN and the frequency of major flare occurrence by considering flares of higher importance only on a yearly basis. Recently, the long-term variation of several solar, interplanetary, and geomagnetic parameters during the last many solar cycles has been reported and it is found that SSN and SF shows similar 11-year fluctuation of varying amplitude. In fact the correlation coefficient is ≥ 0.95 between SSN and SF, it would be sufficient to use either of the two solar indices. Nevertheless many investigators prefer to use both of these solar indices (monthly and yearly basis) for their correlation studies of the terrestrial phenomena under investigation, though the results expected are bound to be the same [7, 15, 31-32].

Earlier, it had found that the slope of regression lines between SSN and SFI, GSF continuously decreased from solar cycle 20 to 23 though their correlation were quite significant [8, 32-33]. In the present paper, we have made an attempt to study the relative merits of various solar indices (SF, GSF, SFI and CI) in relation to SSN and their interrelationship for solar cycles 20 to 24 (present solar cycle).

COLLECTION OF DATA

Most of the solar indices data (SSN , SF-10.7 cm , GSF, SFI and CI) have been taken from the website of NOAA (ftp;//ftp.ngdc.noaa.gov/STP/SOLAR_DATA/….html) available in public domain, Which have been available for a long period of time through the "Solar Geophysical Data", the monthly publication of NOAA, Boulder Colorado, USA.

METHOD OF ANALYSIS

***Running cross correlation*:**

In the present paper a ''running'' cross-correlation method has been used to study the momentary relationship between SSN and flare activity parameters GSF and SFI [28, 31]. In this method, we have used a time window of width T centered at time t: [t - T / 2, t + T / 2]. The cross-correlation coefficient r(t) is calculated for the data within this window. Then the window is shifted in time by a small time step Δt < T, and the new value of the cross correlation coefficient is calculated. Here the time shifting of 1 month has been taken into account to calculate the correlation coefficient for each month between SSN and flare activity parameters (GSF and SFI), for the entire period of investigation. The time window covers 50-month period. This value was chosen to match two contradictory requirements: (1) the uncertainty of the calculated r(t) are smaller for large T and (2) T should be small in order to reveal the fine temporal structure of the cross correlation function. The selection of period for the time window in the present analysis has been made after testing the several time periods (for example, 40, 50, 60, and 70 months) and it is found that 50-month period for the time-window is appropriate, as it satisfies both contradictory requirements mentioned above [8,12].

30-month moving average:

We have studied the long term relationship among various solar activity parameters (SSN, SFI, and GSF). Therefore to comparing the behavior and characteristic feature of various parameters, the 30-month moving average has been used, which has been calculated to filter out the fluctuations of data series The 30-month moving average of data series has been considered, as it is close to the first zero of the autocorrelation function and roughly one-fourth of the main period (11 years) [8]. The 30-month moving average method merely smooths the fluctuations in the data. This is accomplished by "moving" the arithmetic mean values through the time series. To apply the moving-average method to a time series, the data should follow a fairly linear trend and have a definite rhythmic pattern of fluctuations.

RESULT AND DISCUSSION

Sun spot number is reliable parameter of long term solar activity for the most studies in the field of Solar Terrestrial Relationship (STR). Moreover, many other solar indices such as GSF, SF (2800MHz, 10.7cm), coronal index also has been used to evaluate calculated value and characteristic feature of long term variation of 11-year solar cycles, particularly form ionosphere studies. More over the coronal green line intensity index (Fe XIV, 5303A°line has been sporadically since 1939 and more regular since 1947 at many coronal station in the world) of solar activity explain the photosphere and coronal phenomena of the solar atmosphere, which have been routinely published in the Solar Geophysical Data. With the availability of solar data through many open access web sites and it is appropriate to investigate the interrelationship among various solar indices and to evaluate the proper parameter for STR studies. For these purpose, we have been used the monthly average values of the solar indices for investigation that explained in earlier section.

SSN and SF Relationship:

In the present paper, the cross-correlation between SSN and SF shows a high degree of correlation, which has been found to be ≥ 0.96 for the solar cycles 20 to 23 and for SC-24 is 0.92. These result shows that for STR studies, either SSN or SF can be used, both are relatively good parameter or will yield show the similar results. Evaluating the correlation coefficient to be (≥0.96) as high as with progression of solar cycles 20 to 23 and except solar cycle 24 depicted in table-1.

***Sunspot and solar flare indices*:**

The 30-month moving average has been calculated to filter out the short-term fluctuation of the data series, to compare the qualitative behavior and variation of various solar indices. The 30-month moving average of SSN, GSF and SFI is depicted in the Figure-1. The differences in the peak value is clearly seen which is continuously decrease from solar cycle 20 to 22 (the peak of GSF is upward in solar cycle 20 and 21) while the previous condition reversed for solar cycle 22 and 23 (the peak of SSN dominates in solar cycle 22 and 23). The peak difference between SSN and SFI are found to decrease for solar cycle 21 to 23, while the difference is large and opposite for the solar cycle 20 (the peak of SSN is upward). Thus in comparison to other solar cycle with the large peak difference shown between GSF and SFI during solar cycle 20 could be due to lack of flare with higher importance or the large duration of flares during the said cycle showing abnormal relationship between SSN and SFI.

Table 1. The Correlation coefficient for solar cycles 19 to 24.

solar cycle	CORRELATION COEFFICIENT (r)			
	SSN-SF	SSN-GSF	SSN-SFI	SSN-CI
SC 19	NA	NA	NA	0.959
SC 20	0.971	0.899	0.676	0.921
SC 21	0.979	0.964	0.905	0.852
SC 22	0.978	0.946	0.919	0.954
SC 23	0.963	0.902	0.778	0.900
SC 24	0.929	NA	0.571	NA

NA : data not available.

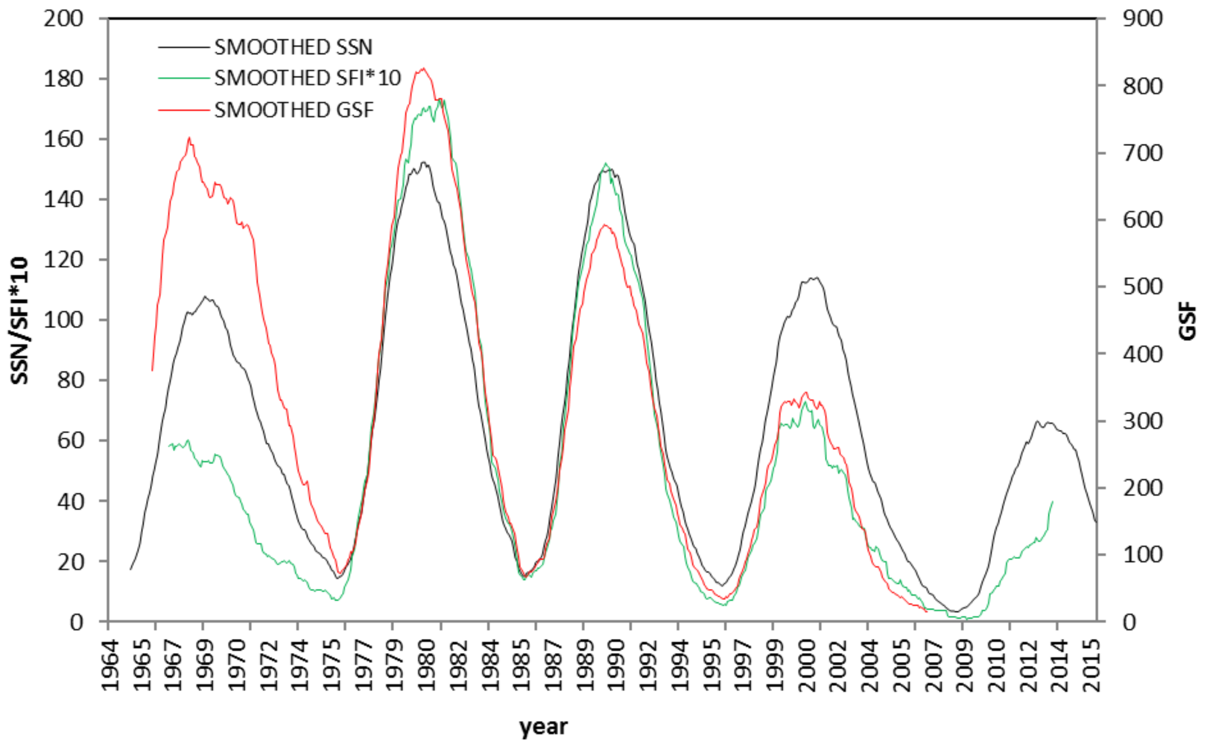

Figure 1. The 30-month smoothed series of SSN, GSF, and SFI from 1964 to 2016. The difference in the peak value of SSN, SFI and GSF are clearly seen.

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In general, the GSF series follows the SSN series except during the maxima, and the correlation is stronger during the ascending and descending phase and is weaker during the maxima and minima from figure-5. We have plotted the crossplot between SSN and GSF for solar cycles 20 to 23 illustrated in figure-2. Here the correlation coefficient is not as high as found in the case of SSN and SF. It is noticed that the correlation coefficient between SSN and SF is ~0.89 (lower) or more with the highest value being ~0.96 for solar cycle 21. The correlation coefficient is almost similar for solar cycles 21 and 22 (~0.96 and ~0.94) and ~0.90 for corresponding solar cycle 23 depicted in table-1. However, it is observed using with statistical/numerical value of SSN-GSF regression line are significantly different from each other, the slop of regression line is continuously decreasing (the value of m in the straight line equation $y = m x + c$) and tend to the x-axis (figure-2). The regression line for solar cycle 20 signifies that for SSN (≈100), GSF is high (≈643) whereas for solar cycle 23 at the same SSN the GSF is significantly low (≈208) also evident for the above result from the figure-2

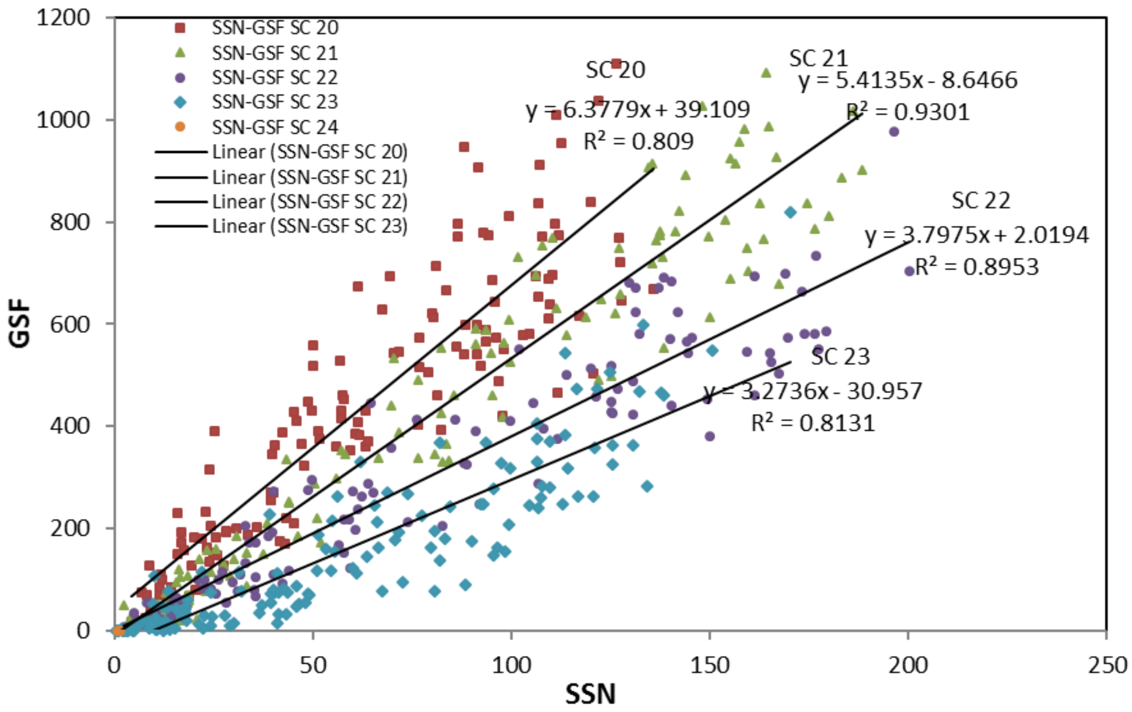

Figure 2. The crossplot SSN and between GSF for the solar cycles 20 to 23 the different trend of regression lines (continuously tending toward x axis) is clearly seen.

Tabel 2. Total and average value of GSF, SFI and SF for sloar cycles 20-24.

Solar cycle	Total value of GSF	Avg value of GSF	Total value of SFI	Avg.value of SFI	Total value of SF	Avg.value of SF
SC-20	58714	434.92	446.06	3.626	15700.5	113.771
SC-21	53190	422.14	1149.17	9.120	16853.1	133.754
SC-22	35902	301.58	846.13	7.051	15928.9	133.856
SC-23	21957	148.36	461.18	3.116	17600.9	118.925
SC-24	NA	NA	167.43	2.325	10531.1	106.374

Furthermore we have also calculated the total/average value of GSF for solar cycle 20 to 23 shows continuously decreasing pattern and hence verifies the above result depicted in table-2, perhaps same evaluation are simplifies by the value of GSF in relation SSN (the ratio of GSF and SSN), appeared to decrease continuously from solar cycle 20 to 23, as it appear in the form of slope of the trend line illustrate in figure-3. During the year 1986 (the minima of solar cycle 22) the value of GSF was exceptionally high (=51) in comparison to SSN (=2.5), this has not been shown in the minima of other solar cycles. Further need such investigation why during minimum activity period such high value of GSF obtained.

Occurrences of energetic flare outcome over sun atmosphere through center of the core are better defined through SFI and GSF. We have potted the scattered graph between SSN and SFI for solar cycles 20 to 24 (SFI data available up to Dec. 2014). The regression line continuously decease and tends toward the x-axis for solar cycles 21 to 24 except for the solar cycle 20 (data available since 1966) illustrated in figure 4; the value of c of the regression line for cycle 20 is higher than the other one. Later on the correlation coefficients between them are found to be SC-20 is ~0.675 (lowest), SC-21 is ~0.905, SC-22 is ~0.919 (highest), and SC-23 is ~0.778 and SC-24 is ~0.570. In short the correlation coefficients are high during the period of solar cycles 21 and 22 (≥0.90) and

~0.778 for solar cycle 23, yields the lowest correlation coefficient ~0.571 for solar cycle 24 (data available up to Dec. 2014) depicted table-1. Some another aspects caught our attention that the total /average value of SFI continuously decrease from Solar cycles 21 to 24 except for cycle 20 (data available since 1966), this observation appraisal continuously decease the flare activity in relation to SSN depicted in table 2. Here, again we have noticed for the value of SSN (≈100), SFI is the largest for the solar cycle 21(≈12.51) and is lowest for solar cycle 23(≈7.54) as apparent in figure-4.

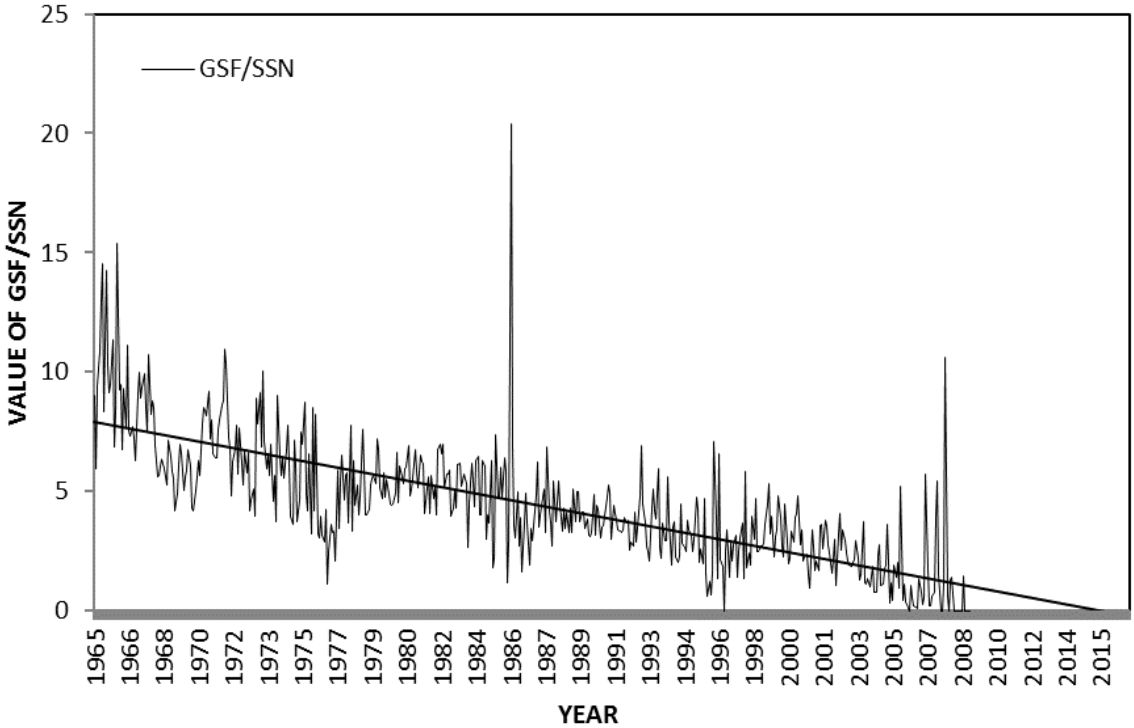

Figure 3. Decreasing trend of GSF/SSN ratio with respect to time is observed throughout the investigating period since 1965 to 2008.

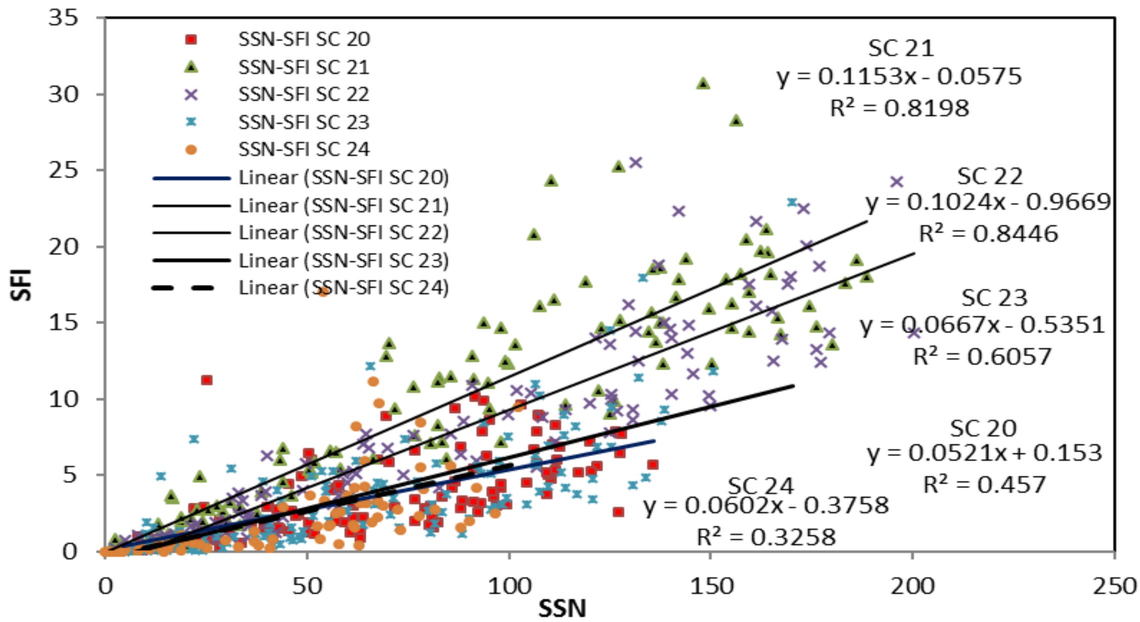

Figure 4. The crossplot between SSN-SFI for the solar cycles 20 to 24.The different trend of regression lines continuously tending toward x axis form solar cycle 21 to 24 is clearly seen.

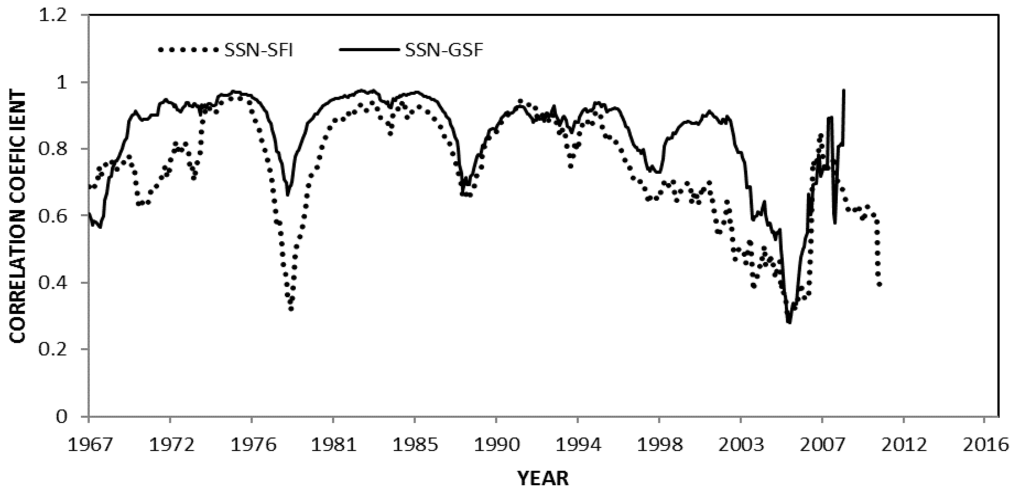

Figure 5. The 50-month running cross-correlation functions between SSN and GSF as well as SFI for the period 1967-2010.

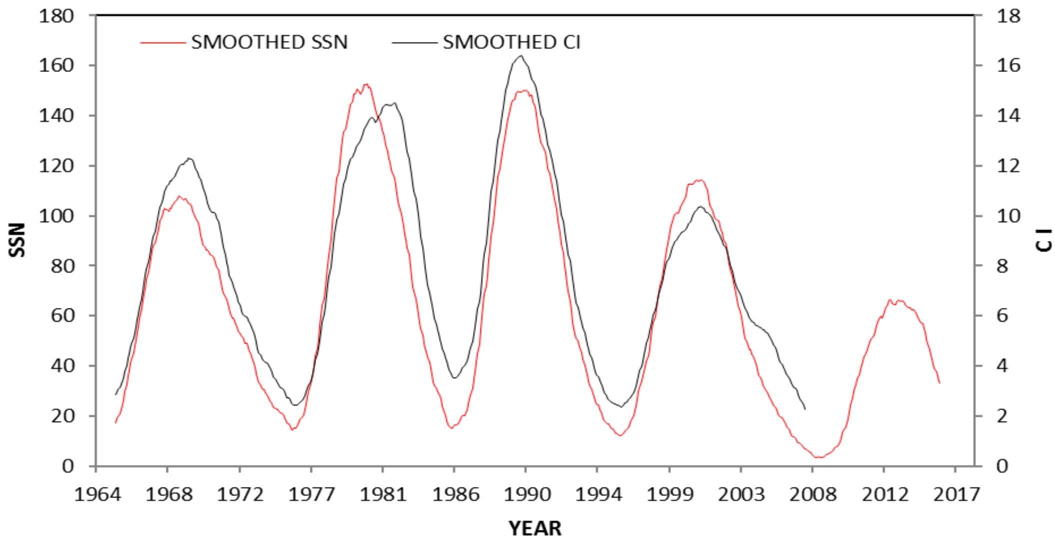

Figure 6. The 30-month smoothed series of SSN-CI since 1964-2016. The close correspondence between SSN and CI is clearly apparent.

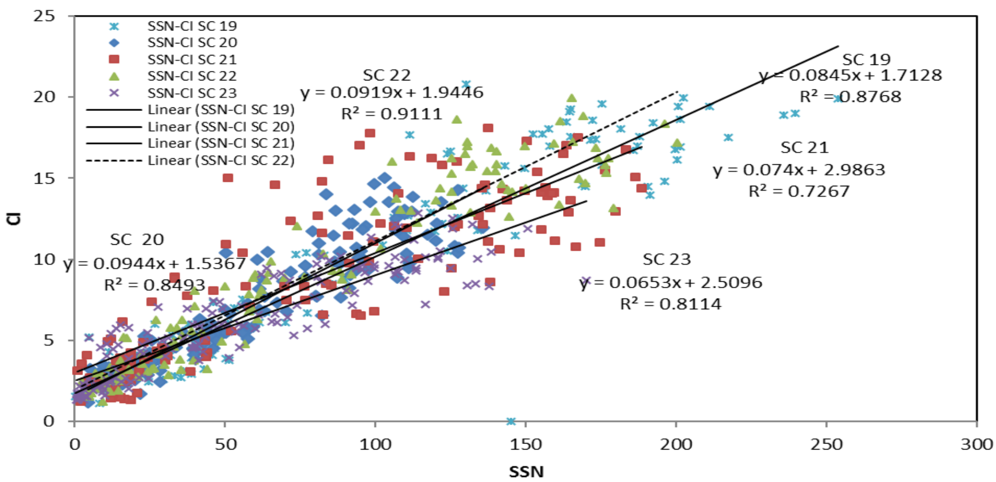

Figure 7. The crossplot has between SSN and CI for the solar cycles 19 to 23. Almost the similar trend of regression lines for odd and even cycle is clearly seen.

Furthermore, we have calculated the 50 month running cross-correlation between SSN and GSF as well as for SSN and SFI throughout the total investigate period and found that the correlation is better (high) between SSN and GSF during ascending and descending phase (figure 5). Moreover the lowest value of cross-correlation coefficient has been obtained during the maxima of solar cycle and just after it (i.e. during 1968, 1978, 1988, and 1998 sequentially for SC-20 to 23). This result verified the various observations regarding the solar disturbance during the investigation of maximum activity period. During the maxima, the peak differences continuously decreased (figure-1). Almost the similar result has been obtained with respect to the correlation between SSN and SFI with progression of solar cycles 20 to 23 which is clearly apparent, thus the correlation plot between SSN and flare activity parameters (GSF and SFI) is good, over the long term period of solar cycles.

SSN and CI Relationship:

Furthermore, we have used another solar activity parameter CI for the total investigation period. The solar corona is the outermost – very hot and diluted – layer of the solar atmosphere; its temperature is about 2 million degrees and electron density of 108 cm^{-3}. The green line intensity is visible during a complete 11-year solar cycle activity and around the entire solar limb [19].

The green line intensity is the best indicator of the solar variability in the emission corona. Now we have plotted a graph between the monthly mean value of SSN and CI considering 30-month moving average of both series figure 6. We have found that there is a close relationship in the long term variation of SSN and CI, where CI closely tracks the SSN throughout the total investigation period. The significantly difference in amplitude and behavior of odd-even CI cycles are observed in accordance with the SSN and we have found that the odd solar cycles (21 and 23) are of the similar behavior and even solar cycles (20 and 22) shows the similar behavior on the basis of peak difference, which verifies the even-odd asymmetry of solar cycles in figure 6. The correlation coefficient between SSN and CI for solar cycles 19 to 23 are depicted in table 1. The regression lines for odd solar cycles (19 and 21) and for even solar cycles (20 and 22) are of similar trends is clearly apparent from figure 7. The regression line for solar cycle 23 is differ from all of them, crosses the regression lines of solar cycles 19, 21 and 22 and appears at the lowest position on cross plot.

CONCLUSION

The significance differences in the amplitude and behavior of odd and even solar cycles have been reported time to time [34-35]. The observed difference between odd and even cycles are the outcome of the nonlinear interaction that provide the stabilizing mechanism for the cycles amplitude [36-37]. The odd cycle have larger amplitude in comparison to the even solar cycle.

The 22-year solar magnetic cycle is presently identified by alternating magnetic fields polarities of the bipolar sunspot groups in the neighboring 11-year cycles and by the solar corona magnetic field topology as well, when extrapolated from the direct field, measurement at the level of the solar photosphere [8]. Our observation focused on the behavior of long term variability depends on the solar output and flare activity in relation with the local sunspot active region are in continuously decreasing with progression of solar cycles 20 to 24. For study of solar terrestrial interrelationship between various solar active parameters can be used as monthly average basis. SSN-SF is highly correlated until and unless the GSF and SFI are also highly correlated with SSN for photosperic and chromospheric phenomena.

Generally the solar flare appear when the magnetic field loop has been reconstructed where as the flare index is the indicator to releasing the energy in the chromospheres as well as green line coronal index reflecting the physical condition across the coronal as well as defined the all photospheric phenomenon [18]. Here the most investigators and researchers are explore the physical mechanism for finding the relationship among the variability of solar indices in the different phase of 22-year of magnetic cycle recognized by the alternating magnetic field polarity which altered after 11-year cyclic period of investigation. These results provide an idea for understanding the local solar disturbance in relation to the general level activity.

Based on the statistical and numerical calculated value and discussion presented the following conclusion is drawn as:

1. It is implies that the SSN and SF is highly correlated and the correlation coefficient is high (≥0.96) for solar cycles 20 to 23 and is ~0.92 for solar cycle 24. Therefore for any correlative study if correlation coefficient is ≥

0.95 thus any one can be used for finding the solar terrestrial relationship shows better and same result.

2. The correlation coefficient between SSN and GSF is not as high as found between the SSN and SF. The correlation coefficient is ~0.89 (lowest) for solar cycle 20 and the high (~0.96) for solar cycle 21. SSN and GSF are almost similar for solar cycles 21 and 22 (~0.96 and ~0.94) and ~0.90 for solar cycle 23. Moreover the regression line are significantly vary with each other, the slop of regression line tend to lower side on crossplots shows the continuously decreasing trend with progression of cycles 20 to 23. For the verification of the result we have calculated the total and average value of GSF is continuously decreasing for solar cycles 20 to 23. The continuously decreasing trend is also appear of GSF in relation to SSN (GSF/SSN) throughout the total investigating period , which further verified our results mention in above.

3. The correlation coefficients between SSN and SFI are high during the period of solar cycles 21 and 22 (≥0.90) and ~0.778 for solar cycle 23, yields the lowest correlation coefficient ~0.57 for solar cycle 24. However it is again notice that the regression lines are significantly differ and slop of regression line is continuously decreased with progression of cycles 20 to 24.

4. The different characteristics behavior of even-odd solar cycles on the basis of peak differences between smoothed SSN and CI are clearly apparent, which verifies asymmetry of even-odd solar cycle. We have found that the peak value is large for even cycles in comparison to odd cycle. The correlation coefficient between SSN and CI are maximum for solar cycle 19 and 22 (≈0.95). Moreover it is also verifies the same result from the regression line trends between SSN and CI for even cycles (20and 22) and odd cycles (19 and 21) but solar cycle 23 shows the peculiar behavior from the above solar cycles because of low activity and need to further study.

On the basis of statistical analysis and discussion presented above, we have concluded that the flare activity is continuously decreased from the solar cycle 20 to 24.

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