Green coronal index is a better parameter for the solar terrestrial studies

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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 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. It is evident the fact that solar variability influence the heliosphere, chromospheres, ionosphere and the Earth climate. As such we have investigated the appropriateness of various solar indices, on the basis of cross-correlative study for SSN-SFI and SSN-CI, where SSN is prime parameter. We find that the CI may also have the best parameter for the said variability. Recently the green coronal index (CI) has been reported to be the best parameter for long-term variation studies for said solar cycle.

Key words: Sunspot number, Solar Flux, Grouped Solar Flare, Solar Flare Index, Coronal Index.

1. Introduction

The sun is magnetically variable star with an average period of about 11 years, known as solar cycle. All the observed time-dependent phenomena are called solar activity and are seen in different wavelengths as a changing appearance of the sun (1). Sunspots are the general indicator of SA is directly affecting terrestrial ionospheres (2). Solar activity can be expressed with many solar indices such as sunspot numbers (SSN), 2800 MHz radio flux, solar flare index, green coronal line (Fe XIV, 530.3 nm) etc. Each of them reflects different physical condition in the solar atmosphere (3). The SSN are available for a long period of time from 1964 to 2017. The standard way of representing the solar activity is through the variation of sunspot numbers. Almost all the investigators have generally used the sunspot number as a representative solar index for various studies in their investigations association phenomena between the sun and the earth (4-8). 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 $Rz = k(10g + n)$, 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 data are available online by the different observatories like Sunspot Index Data Center in Brussels, Belgium (9).

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 (10). Solar flare index is one of the best indicators of activity variations on the chromosphere. This feature makes the flare index a suitable full-disk solar index for comparison with similar solar indices which reflect different physical conditions from the different layers of the solar atmosphere. Kleczek (1952) first introduced the quantity "$Q = i \times t$" to quantify the daily flare activity over 24 hours per day. He assumed that this relationship gives roughly the total energy emitted by the flares. In this relation, "i" represents the intensity scale of importance and "t" the duration (in minutes) of the flare. The flare index is an essential parameter to measure the value of the short-lived activity on the sun atmosphere (11-12).

Coronal index (CI), one of the index of solar activity which is used for the study of solar terrestrial relations. 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 (13-15). 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 (15-16). Coronal index represent the full disk solar index is easily compared to solar indices that arise under different physical condition (17). 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. Therefore, the green corona intensity can easily be compared with similar solar indices inferred from both ground-based and space-borne experiments within the past few decades (16).

2. 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.

3. Method of analysis

Running cross correlation: In the present paper ‘‘running cross-correlation” method has been used to study the momentary relationship between SSN and flare activity parameters GSF and SFI (Usoskin et al., 2001; Mishra and Tiwari et al., 2003). 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 $\Delta t < T$, 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 (Gupta M., Mishra V.K. and Mishra A. P. et al., 2006; 2007).

30-month moving average: We have studied the long term relationship among various solar activity parameters. 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) (Gupta et. al., 2007). The 30-month moving average methods merely smooth 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 Solar flux (SF) (2800MHz, 10.7cm), coronal index (CI) and solar flare index (SFI) 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 CI (Fe XIV, 5303Aº 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 to evaluate the proper parameter for STR studies. For this purpose, we have been used the monthly average values of the solar indices for investigation, mentioned in earlier section.

4. SSN and SFI relationship

Occurrence of energetic flares are better defined through SFI, give the amount of energy released from the corona. 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 (1); 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 (1). It was further verified that the peak value from solar cycle 21 to 24 are of decreasing trend table (3).

Table-1 Tabulate the correlation coefficient for solar cycles 20 to 24.

CORRELATION COEFFICIENT r	
solar cycle	SSN-SFI
SC 20	0.676
SC 21	0.905
SC 22	0.919
SC 23	0.778
SC 24	0.571

Tabel 2. Total and average value of SFI for solar cycles 20 to 24.

Solar cycle	Total value of SFI	Avg.value of SFI
SC-20	446.06	3.626
SC-21	1149.17	9.120
SC-22	846.13	7.051
SC-23	461.18	3.116

SC-24	167.43	2.325

Table 3.Tabulate the cycle maxima of SFI with progression of solar cycle 20 to 24 and clearly apparent the continuously decreased peak point except for SC-20.

Solar cycle	Cycle maxima (year)	R_{max} (peak point)
SC-20	1968	6
SC-21	1981	16.9
SC-22	1989	14.84
SC-23	2000	7.03
SC-24	2013	3.75

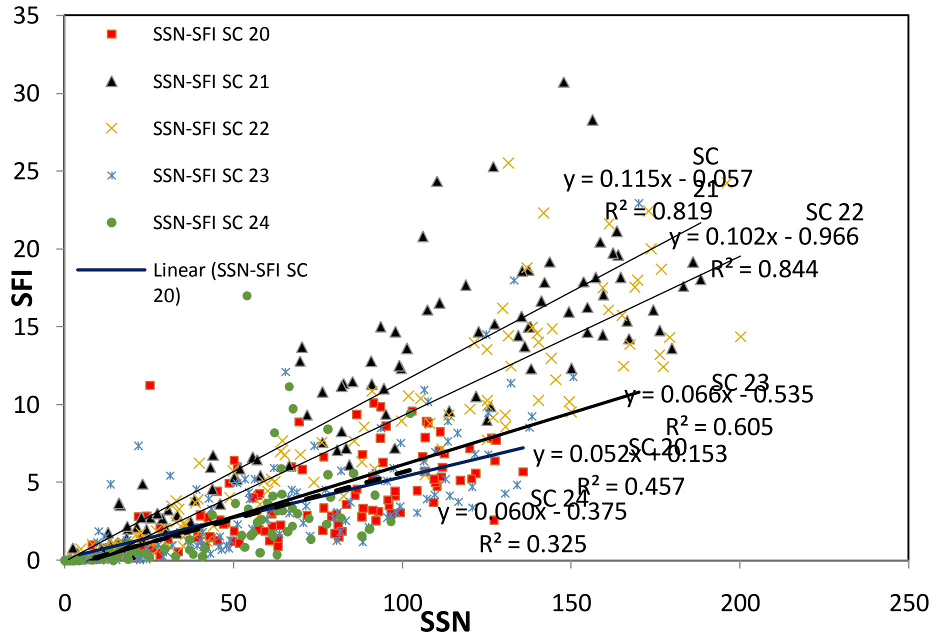

Figure 1. The crossplot between SSN-SFI for the solar cycles 20 to 24.The different trend of regression lines continuously tending toward x axis form solar cycle 21 to 24 is clearly seen.

5. Relationship between SSN and CI

The green line coronal intensity CI 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 2. 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 year). 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 (figure 2).

6. Correlation between Coronal index (CI) and Sunspot numbers (SSN)

Now a crossplot have been plotted between SSN and CI for the solar cycle 19 and 23, the data for solar cycle 24 was not available. 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 3. 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.

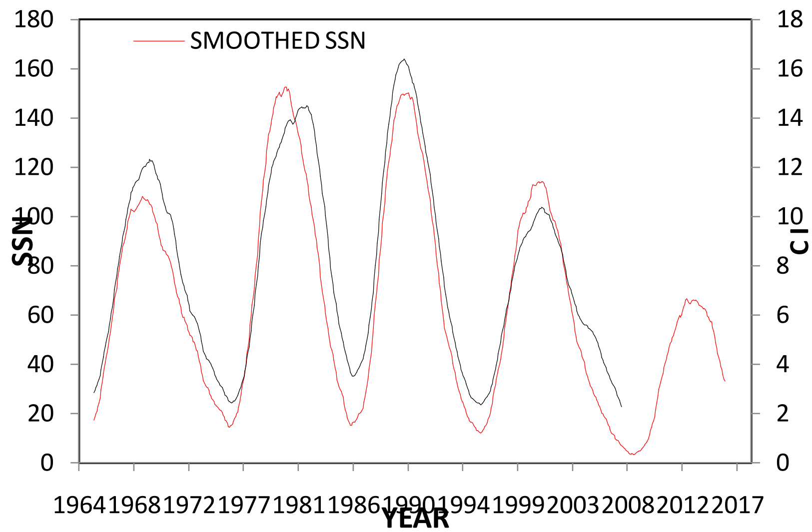

Figure 2. The 30-month smoothed series of SSN-CI since 1964-2016. The close correspondence between SSN and CI is clearly apparent.

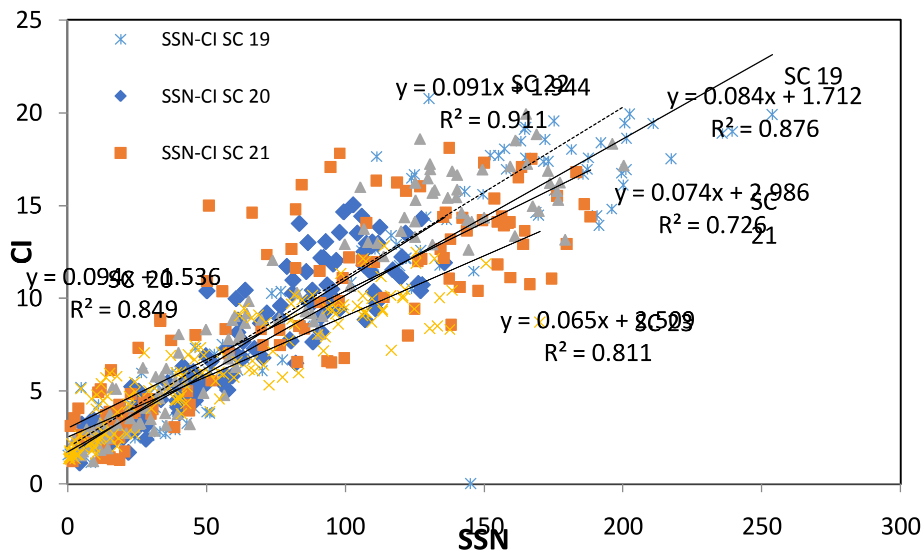

Figure3. The cross plot has between SSN and CI for the solar cycles 19 to 23. Almost the similar trend of regression lines for odd and even cycle is clearly seen.

7. Correlation coefficient between Sunspot numbers SSN and Coronal index (CI)

The correlation coefficient between SSN and CI for solar cycles 19 to 23 are depicted in table 4. The correlation coefficient SSN-CI have been highest form solar cycles 19 to 23 ($\geq$0.90), except solar cycle 21. The correlation coefficient was high for solar cycle 19 (~0.959) are of small for solar cycle 21

(~0.852). In fact the correlation coefficient between SSN and CI is ≥0.90; as a basic parameter one can use either of the two solar indices.

Table 4. Tabulate the correlation coefficient of SSN-CI for solar cycle 19 to 23.

CORRELATION COEFFICIENT (r)	
solar cycle	SSN-CI
SC 19	0.959
SC 20	0.921
SC 21	0.852
SC 22	0.954
SC 23	0.900
SC 24	NA

Conclusion

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 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-SFI is highly correlated until and unless the CI is also highly correlated with SSN for photosperic and chromospheric phenomena. It is well known fact that the local magnetic fields are responsible for all the major manifestation of solar activity. The significance differences in the amplitude and behavior of odd and even solar cycles have been reported time to time (18-19). The observed differences between odd and even cycles are the outcome of the nonlinear interaction that provides the stabilizing mechanism for the cycle amplitude. The odd cycles have larger amplitude in comparison to the even solar cycles.

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 (19-22). 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. 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.
2. The correlation coefficients between SSN and SFI are high during the period of solar cycles 20, 22 and 23 (≥0.90), yields the lowest correlation coefficient ~0.85 for solar cycle 21.
3. 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.

4. SFI serve as an important factor for solar-terrestrial relationship, it could be regarded as a proxy data set, until and unless CI could be serve as a best parameter for the long-term STR study on the basis of correlation coefficients for solar cycle 20- 24 as mentioned on point 1,2.

Acknowledgments

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References:

1. Atac T, and Ozguc A. Flare index of solar cycle 22, Sol. Phys., 1998; 180: 397-407.
2. Gupta M, Mishra VK and Mishra AP. Study of cosmic ray intensity variation in relation to solar activity for sunspot cycles 19 to 23, Indian Journal of Radio and Space Physics,2006 (a) ; 35: 167-173.
3. Altrock RC, Rybansky M, Minarovjech M, and Rusin V. Coronal index of solar activity for 1998, Contrib. Astron. Obs. SkalnatePleso, 1999 ; 29 :105-110.
4. Dorman IV, and Dorman LI. Solar winds properties obtained from the study of 11- year cosmic ray cycle., J. Gepphys. Res., 1967; 72: 1513.
5. Pomerantz MA, and Duggal SP. Cosmic ray solar diurnal anisotropy, Space Sci.Rev., 1971;12: 75.
6. Rao UR. Solar modulation of galactic cosmic radiation, Space sci. Rev., 1972 ;12: 719.
7. Webber WR and. Lockwood JA. Characteristic of the 22- year modulation of cosmic rays as seen by neutron monitors, *J. Geophys. Res.*, 1988 ;93 : 8735.
8. Chattopadhyay R, Midya SK, and De UK. Statistical study on the temporal correlation of different solar parameters with OI 6300 A line intensity over Calcutta and its implications, Indian Journal Radio space Physics, 2003; 32:135.
9. Hathaway DH, Wilson RM, and Reichmann EJ. Grpuped sunspot numbers: Sunspot cycle characteristic, Sol. Phys., 2002; 211 : 357-370..
10. Kane RP. Solar cycle variation of coronal green line index, Indian Journal of Radio and Space Physics, 2015 ;44: 122-125.
11. Kleczek J. Catalouge of activity of chromoshperic flare, Publ. Inst, Centr. Astron. (Prague), 1952 ; NO. 22.
12. . Atac T, and OzgucA. Flare index during the rising phase of solar cycle 23, Sol. Phys.,2001; 198: 399-407.
13. Rybansky M, Rusin V, minarovjech M and Gaspar P, Coronal index of solar activity; years 1939-1963, Sol. Phys. 1994; 152: 153-159.
14. Kane RP. Solar cycle variation of coronal green line index, *Indian* Journal of Radio and Space Physics, 2015 ;44: 122-125.
15. Minarivjech M. Rusin V, and Saniga M. The green corona database and the coronal index of solar activity, Contrib. Astro. Obs. SkalnatePleso, 2011; 41: 137-141.
16. Rusian V, Minarovjech M, Saniga M and Klocok L. Longterm variation of the green corona (530.3 nm) irradiance, ILWS workshop Goa, 2006; PP-19-24.
17. Gupta M., Mishra VK, and Mishra AP. Solar activity parameters and their interrelationship: Continuous decrease in flare activity from solar cycle 20 to 23, *J. Geophys. Res.*, 2007;112: A05105, doi:10.1029/2006JA012076
18. Wilson RM. Bimodality and Hale cycle *Sol. Phys*., 1988; 117: 269.
19. Mursula K, Usoskin IG and Kovaltsov GA. Persistent 22- year cycle in sunspot activity: Evidence for a realic solar magnetic field, *Sol. Phys*., 2001; 198: 51.
20. Hathaway DH, The solar cycle, Living Reviews in solar physics, 2015; 12(2015): 4.
21. Mishra VK and Tiwari DP. Long-term association of solar activity and Cosmic ray intensity for solar cycles 21 and 22, *Indian J. Radio Space Phys*., 2003; 32 :65.
22. . Mishra VK, Tiwari, DP, Tiwari CM and Agrawal SP. Comparative study of different solar parameters with sunspot numbers, *Indian J. Radio Space Phys*.,2005; 34 : 13- 16.