Received Date: 29/01/2020 Acceptance Date: 10/02/2020 Publication Date: 29/02/2020

# Cosmic ray Intensity variations in relation to solar activity parameters for solar cycle 21-24.

[1] Sarver Ahmad khan, [2] Niyaz Ahmad, [3] A. K. Saxena, [4] G. N. Singh, [5] K .L. Jaiswal, [6] C. M. tiwari
[1, 2, 3 & 6] Department of physics, A P S University Rewa 486003 (M.P), India
[4] Sudarshan College Lalgawan, Rewa
[5] Department of physics, Govt. Model Science College Rewa.
E.mail: [1] sarverahmadkhan@gmail.com

***Abstract:*** *Based on the monthly of many solar parameters [e.g.; sunspot number (SSN), solar flux (SF) and interplanetary magnetic field (IMF)]. The correlation study of solar parameters (e.g.; SSN, SF and IMF) and cosmic ray intensity (CRI, monthly/ yearly of neutron monitor of Moscow) has been carried out by the "cross correlation method" whole behavior of the cross correlation coefficient between cosmic ray intensity (CRI) and solar activity parameters (SA) is almost same instead of highest peaks of solar cycles. However the correlation analysis have been carried out by the process of " minimizing correlation coefficient" and it is establish that observed time lag between cosmic ray intensity (CRI) and many solar activity parameters is identical except the interplanetary parameters. The time lag is found is to be greater for odd solar cycles (21, 23) in comparison to even solar cycles (22, 24), indicating the odd- even asymmetry of solar cycles. The correlation between cosmic ray intensity and different solar activity indices taking time lag factor during the whole period of calculation has been presented. The dissimilarity observed in the time lag between cosmic ray intensity and different solar activity indices, especially for IMF, have also been explained.*

***Key Words:*** *Cosmic rays, sunspots, solar flux and interplanetary magnetic field.*

## 1. INTRODUCTION:

Cosmic rays are of galactic and extragalactic originate outside the solar system and also small parts of cosmic rays (CR) are originated from sun as protons, alpha particles and heavier elements. The cosmic ray intensity is changeless outside the heliosphere but modulation come about during their approach through the heliosphere by the effect of interplanetary magnetic field [Mavromichalaki et al., 1988; Agarwal et al; 1993]. The data is captured from the ground based neutron monitors [Moscow 2.43GV]. Solar indices are the identification of solar activity along with solar flare index (SFI), solar flux (SF) and Grouped solar flare (GSF). Comparable to earth the sun has a cycle of about 11-years. Forbush first mentioned the inverse connection with solar wind velocity and cosmic ray intensity [Forbush, 1988; Rao, 1972; Moraal, 1976; King, 1979; Biber et al, 1983; Singh et al., 2013]. However the many researchers are going for further authentication. The massive zone of the heliosphere and diffusive propagation of cosmic ray particles, there is a time-Lag in correlation between the solar activity parameters and cosmic ray intensity which shows the amplitude of modulation varies from cycle to cycle [Dorman et al., 1967; Nagashima et al 1979]. The 11-year changes in cosmic ray intensity seen on the earth is negative correlated with solar activity parameters also with some time-Lag [Forbush et al 1954]. Due to the time-Lag between cosmic ray intensity and sunspot number, shows a kind of hysteresis effect between long-term perturbation in cosmic ray intensity and solar activity parameters have been performed by various researchers. [Neher et al., 1954; Moraal et al, 1976; Mavromichalaki et al., 1990]. The cosmic ray intensity curve also appear to follow a 22- year cycle with alternate maxima being flat-topped and peaked, as predicted by models of cosmic ray modulation based on the observed reversal of the sun's magnetic field polarity after every 11- year solar cycle, curvature and gradient drift in the large scale magnetic field of heliosphere[Jokipi et al 1977; 1981].

The anomalous behavior in the solar modulation of cosmic rays in addition to perturbation in time-Lag for the odd-even solar cycles have been studied [Lockwood et al 1979]. The anomalous behavior observed in rigidity spectra of cosmic ray intensities are explicate as the result of reversal of polar magnetic field of the sun [kota et al, 1997]. Such phenomena in the cosmic ray intensity have also been seen after solar maximum and also in the decreasing phases of the earlier solar cycles.[Nagashima et al 1980]. The value of correlation varies from one cycle to another. However only one parameter is inadequate to describe cosmic ray modulation. It is an integrated factor which play noteworthy role in cosmic ray modulation. In this paper solar activity determinants of cosmic ray perturbations are scrutinize. [Bhattacharya et al, 2010; Bhattacharya and Roy, 2014]. We have scrutinized the correlation between cosmic ray intensity and many solar activity parameters (SSN, SFI, SF, Solar

INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 6, Issue - 2, Feb – 2020
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Impact Factor: 6.497
Received Date: 29/01/2020 Acceptance Date: 10/02/2020 Publication Date: 29/02/2020

wind velocity, IMF and GSF) in view of time-Lag (minimizing correlation coefficient) and without time-Lag (cross correlation method) from the Neutron monitor stations located at Moscow (Rc = 2.43GV) and Thule (Rc = 1.24GV).

## 2. DATA AND METHOD OF ANALYSIS:

In order to study the long-term cosmic ray modulation during the years 1976-2018 monthly values of cosmic rays of 2GV at the top of the atmosphere were used. These data were kindly provided by the IZMIRAN group using the global survey method (GSM). This method uses data from various ground based detectors (e.g. NMs) are possible and provides useful reliable information on the conditions of the space environment [Krymsky et al, 1966; Dvornikov and sdobnov, 1997; Belov, Gushchina and yanke, 1999]. It is a conceptually a method of analysis and different versions of this method have been evolved and upgraded at various stages of the data processing (Baisultanova, Belov, and yanke, 1995; Belov et al., 2005). The perturbations of 2.43GV cosmic rays with respect to the level of the year 1976 were calculated. For the purpose of this study the time series of cosmic ray variations was normalized, taking the cosmic ray intensity maximum (October, 2009) equal to 1.00 and the cosmic ray intensity minimum (November, 2003) equal to 0.00.

We note that the cosmic ray intensity in the period of Oct-Nov 2003 during the declining phase of the solar cycle has been used only for normalization reasons and does not coincide with the activity maximum of the of the solar cycle during the years 2000-2002 (Kane, 2006).

In this method we have considered the CRI monthly mean data of Moscow (Rc = 2.43GV) and Thule ( Rc = 1.2 GV) Neutron monitors, along with many parameters such as SSN, SF, SFI, Sw velocity, IMF and GSF. Most of the data have been taken from the Website:of NOAA (fttp:/fttp.ngdc.noaa.gov/STP/SOLAR DATA/html) available through solar geographical data for a long period of time (monthly publication of NOAA).

The hysteresis curve between cosmic ray intensity and solar indices (SSN, SF, SFI and GSF) has been drawn by taking full cycle moving average of both the data series.

## 3. RESULTS AND DISCUSSION:

It is well known that the 11-year modulation of the cosmic ray intensity shows some time-Lag behind the solar activity which is the type of hysteresis effect. [Moraal, 1978; Usokin et al 2002; Kane 2011]. Keeping this in view, we have estimated the correlation between the monthly values of the cosmic ray variation at 2.43GV and many solar and heliospheric activity parameters (SSN, SF, SFI, IMF, Solar wind velocity and GSF) for the period of 1976-2018.

In this study, we have taken the cosmic ray intensity data seen by Moscow (2.43GV) and Thule (1.2GV) Neutron monitor stations. Subjective behavior of normalized CC of CRI (Moscow and Thule) with sunspot number, SF, SFI and GSF is illustrated in figures. The solar parameters SF, SFI and GSF have identical variational pattern with cosmic ray intensity and therefore all these parameters have been illustrated in the figure. The time-Lag between cosmic ray intensity and solar parameters (SSN, SF, SFI and GSF) for different solar cycles is clearly seen from figures.

The running cross-correlation function between cosmic ray intensity (Moscow, yearly data) and different solar activity parameters (SSN, SF, SFI and GSF) is illustrated in figures for the overall period of investigation. This type of calculation is helpful to understand the ephemerally behavior of cross correlation function with respect to time. The value of correlation coefficient is non-identical for the different phases of a particular solar cycle and it changes with time. It is seen that general behavior of running cross-correlation function between cosmic ray intensity and various solar activity parameters is almost identical, excluding for the maximum phases of many solar cycles. It is also perceptible from the figure the correlation is stronger during the increasing and decreasing phases of solar cycles and is poor during the maxima and minima of solar cycles. Actually, the highest phase of solar cycle is the largest perturbed period of the cycle and the change in either of the indices is very small during this period. Therefore, dissimilarities in cross- correlation method between cosmic ray intensity and solar activity parameters are predicted during the maximum phase of solar cycles. Furthermore, the dissimilar behavior of normalized correlation coefficient between cosmic ray intensity and sunspot number during the decreasing phase of cycle 1981-1984 and during 1989-1994.

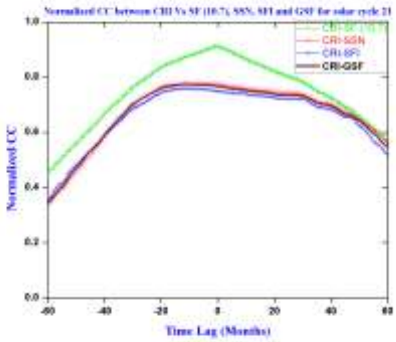


Fig.1 shows the cross correlation as a function of time for solar cycle 21 between CRI-SSN, CRI- SFI, CRI-SF(10.7) and CRI-GSF.

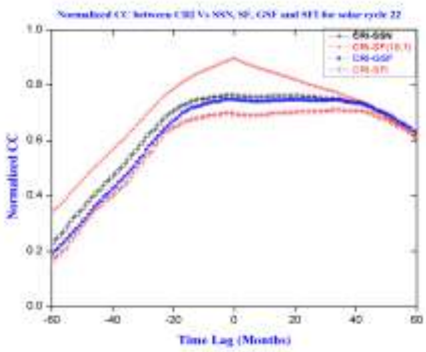


Fig.2 shows the cross correlation as a function of time for solar cycle 22 between CRI-SSN, CRI- SFI, CRI-SF(10.7) and CRI-GSF.

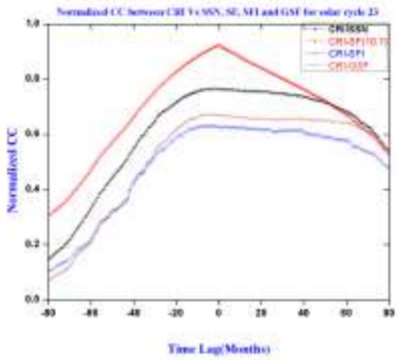


Fig.3 shows the cross correlation as a function of time for solar cycle 23 between CRI-SSN, CRI- SFI, CRI-SF(10.7) and CRI-GSF.

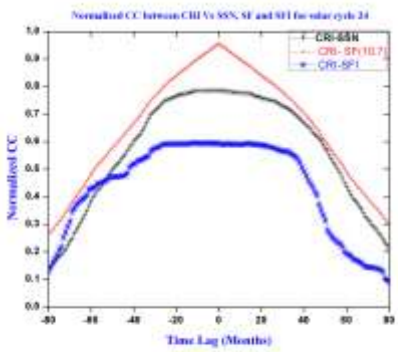


Fig.4 shows the cross correlation as a function of time for solar cycle 24 between CRI-SSN, CRI- SFI, CRI-SF(10.7) and CRI-GSF.

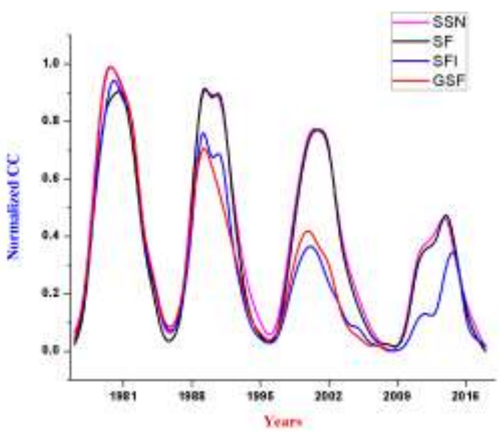


Fig.5 shows the normalization CC as a function of time between the parameters SSN, SF, SFI and GSF for the period 1976 to 2018.

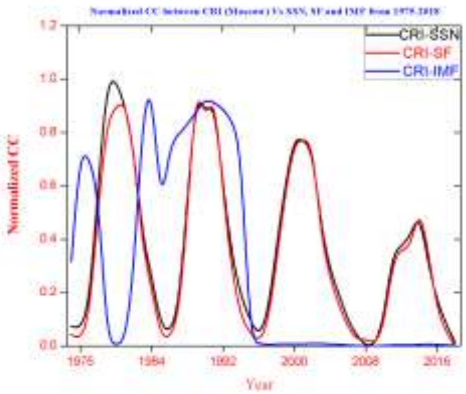


Fig.6 shows the cross-correlation coefficients between CRI-SSN, CRI-SF and CRI-IMF for the period 1976 to 2018.

The maximum anti-cross correlation coefficient between cosmic ray intensity and sunspot number with time-Lags is shown in figures for each solar cycle (21-24) separately one can observe that time-Lag between cosmic ray intensity and sunspot number is remarkably large (13-17 months) for the solar cycles 21 and 23 whereas it is small for the 22 and 24 solar cycles, being 5 months and 9 months for both the stations respectively. At the time of maximum opposite correlation coefficient between cosmic ray intensity and IMF, the time-Lag is zero for odd solar cycles and large for even solar cycles 22 (~25 months) for both the stations. Thus the results guide us to conclude that the time-Lag between cosmic ray intensity and sunspot number is large for odd solar cycles in juxtaposition (comparison) to even solar cycles. This clearly indicates the distinctive behavior between the odd and even solar cycles in relation to time-Lag.

Now, we have analyzed the cross-correlation coefficient between cosmic ray intensity and solar activity parameters with time-Lag from (0-120) months and probable error for each value of correlation coefficient for the period of 1976-2018. The maximum normalized correlation with corresponding time-Lags for the said period. The changes of correlation coefficient (between CRI and SA indices) with relation to time-Lag along with statistical error bars for Moscow neutron monitoring station is shown in figure 6. From figure 6 it is obvious that the high anti-cross correlation between the cosmic ray intensity and solar activity parameters (SSN, SF, SFI, IMF and GSF) is seen with the time-Lag for SC-21 between CRI-SSN is ~13 months, for SC-22 between CRI-SSN is ~5 months, for SC-23 between CRI-SSN is ~ 17 months and for SC-24 between CRI-SSN is ~ 9 months. Identical results have been found for the Thule neutron monitor station, as clearly seen from figure 7.

INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD ISSN: 2455-0620 Volume - 6, Issue - 2, Feb – 2020
Monthly, Peer-Reviewed, Refereed, Indexed Journal with IC Value: 86.87 Impact Factor: 6.497
Received Date: 29/01/2020 Acceptance Date: 10/02/2020 Publication Date: 29/02/2020

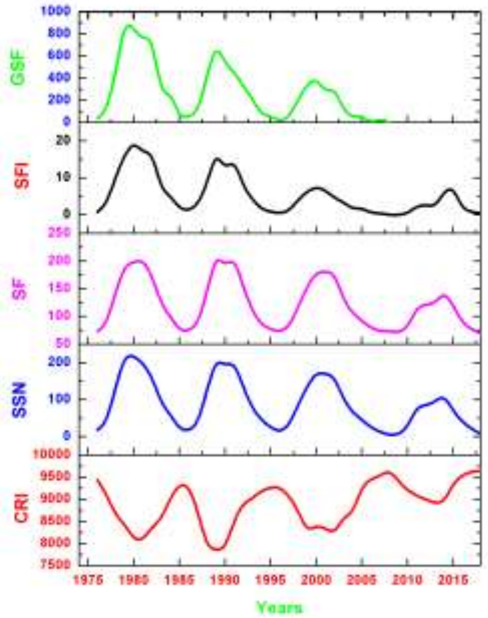


Fig.7. shows the relation between CRI and solar activity parameters (SSN, SF, SFI and GSF).

To help the time-Lag findings, we have further drawn the hysteresis curves between cosmic ray intensity and SF, SFI, IMF and GSF as well as hysteresis curves between cosmic ray intensity and sunspot number are shown respectively, in figure 5 and 6 for the solar cycles 21 to 24. It has been seen that the hysteresis loops for CRI-SSN, CRI- SF, CRI-SFI and CRI-GSF are wide for odd cycles and narrow for even cycles, which further helps the odd-even asymmetry of the cycles and also seen that the hysteresis loops for CRI-SF are narrower than those seen in case of CRI-SSN, CRI-SF,CRI-IMF which helps to find out the time-Lag between CRI-SF and CRI-IMF is less than that between CRI and other solar parameters. Odd cycles have broad area compared to even cycles. The differences may be due to change in magnetic polarity. The open end for solar cycle 24 is still not closed so it indicates that its cycle is in duration.

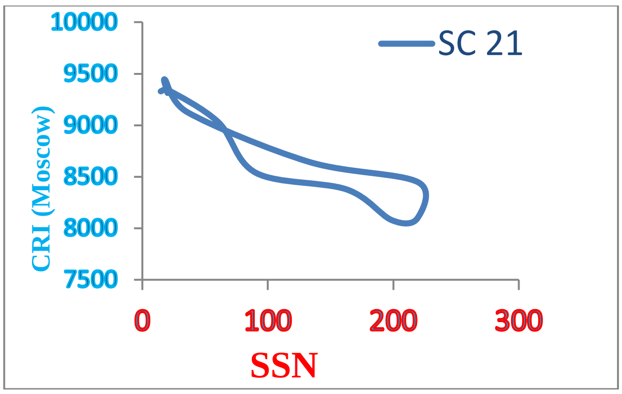


Fig.8 shows the hysteresis loop between CRI and SSN for SC-21.

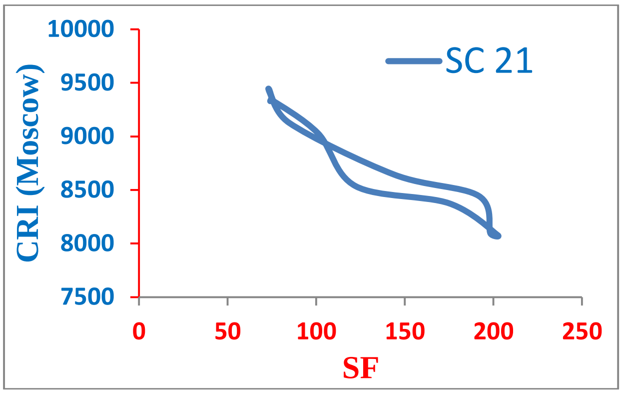


Fig. 9 shows the hysteresis loop between CRI and SF for SC-21.

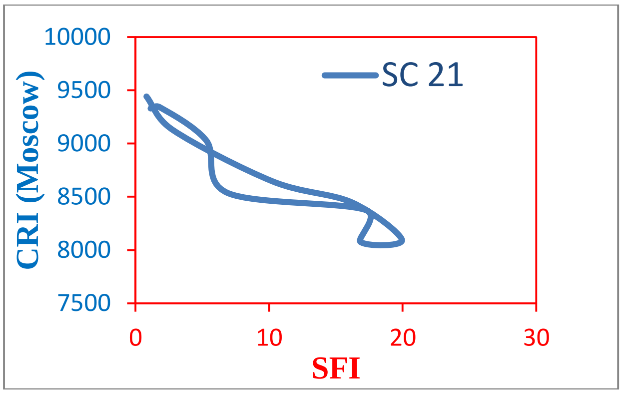


Fig.10 shows the hysteresis loop between CRI and SFI for SC-21.

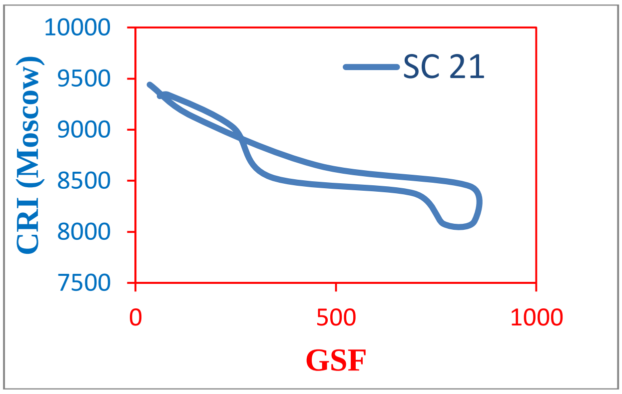


Fig.11 shows the hysteresis loop between CRI and GSF for SC-21.

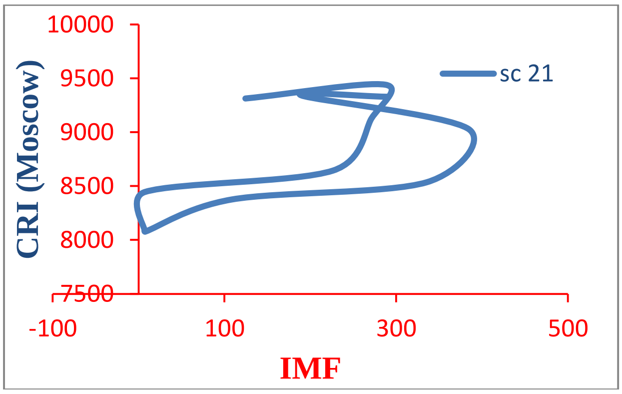


Fig.12 shows the hysteresis loop between CRI and IMF for SC-21.

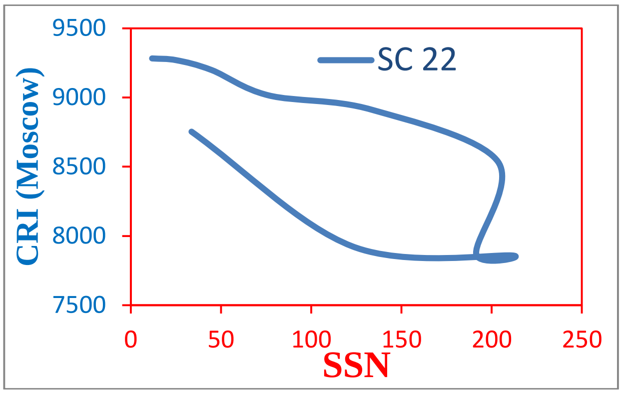


Fig.13 shows the hysteresis loop between CRI and SSN for SC-22.

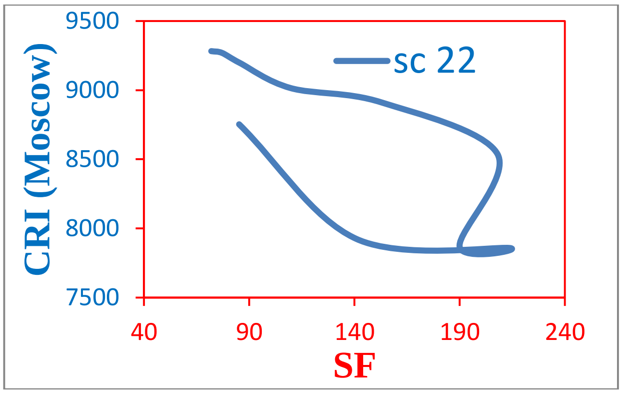


Fig. 14 shows the hysteresis loop between CRI and SF for SC-22.

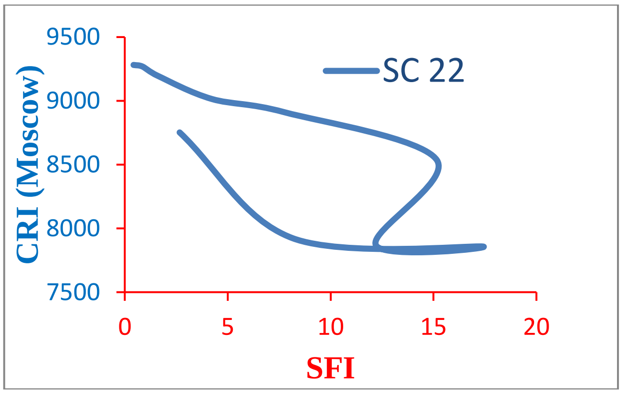


Fig.15 shows the hysteresis loop between CRI and SFI for SC-22.

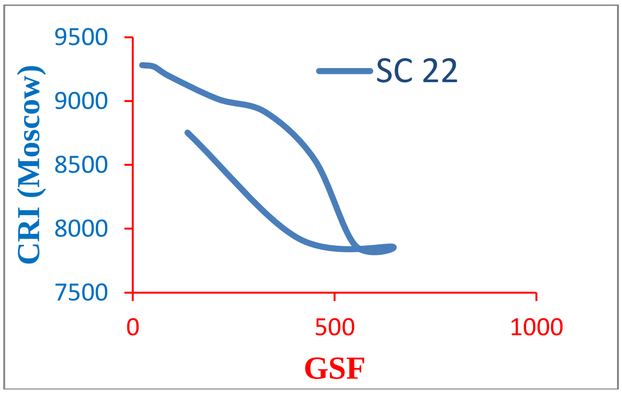


Fig.16 shows the hysteresis loop between CRI and GSF for SC-22.

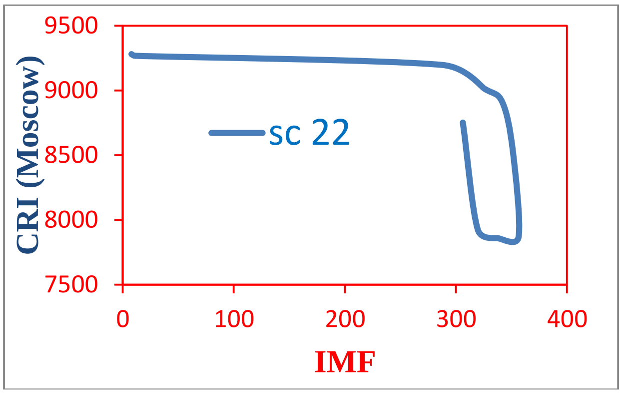


Fig.16 shows the hysteresis loop between CRI and IMF for SC-22.

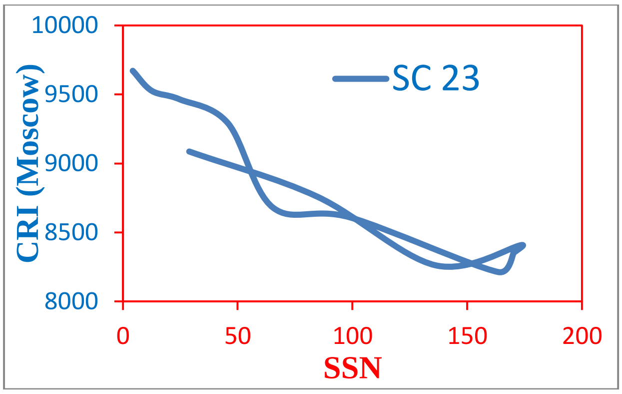


Fig.17 shows the hysteresis loop between CRI and SSN for SC-23.

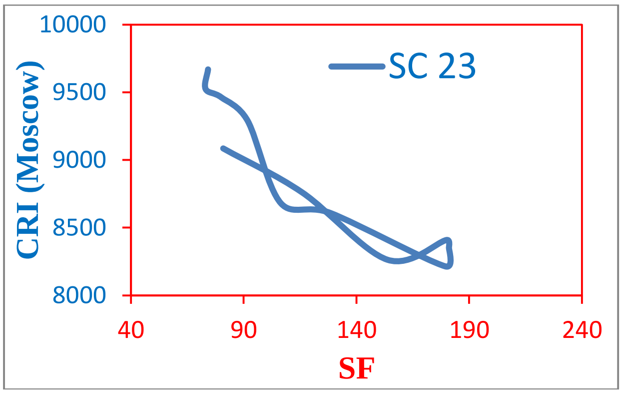


Fig. 18 shows the hysteresis loop between CRI and SF for SC-23.

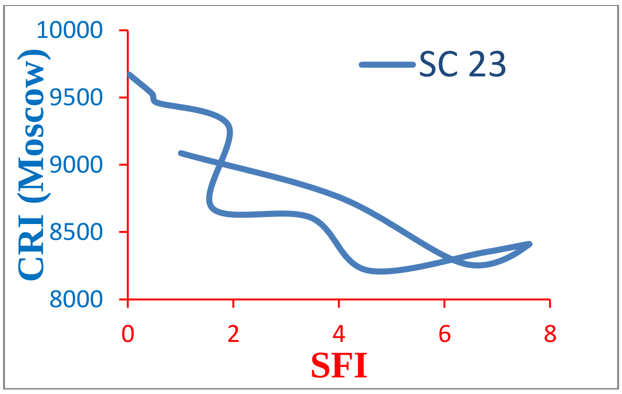


Fig.19 shows the hysteresis loop between CRI and SFI for SC-23.

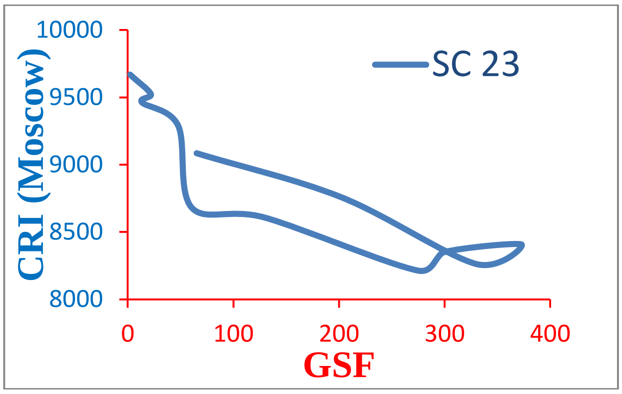


Fig.20 shows the hysteresis loop between CRI and GSF for SC-23.

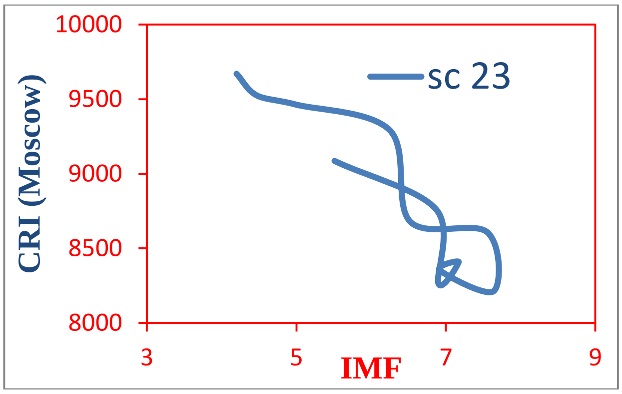


Fig.21 shows the hysteresis loop between CRI and IMF for SC-23.

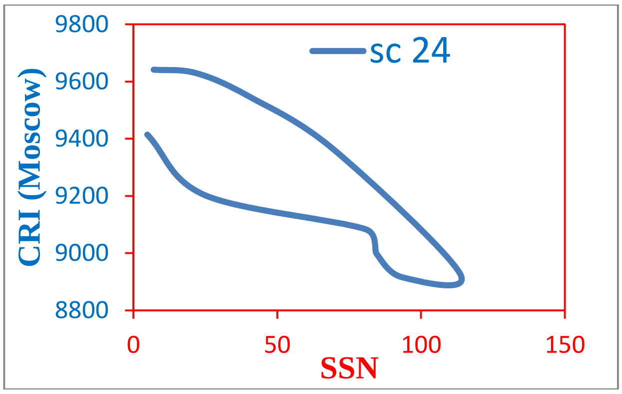


Fig.22 shows the hysteresis loop between CRI and SSN for SC-24.

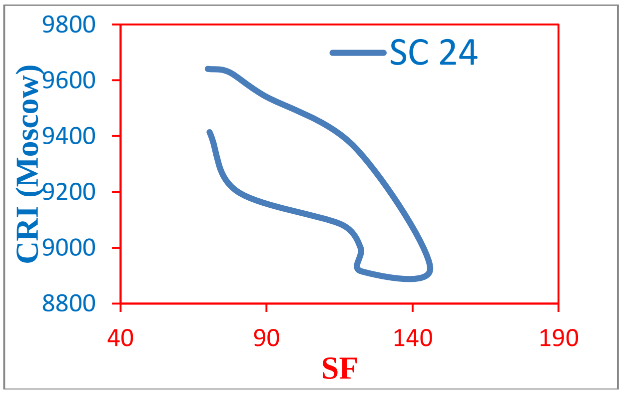


Fig. 23 shows the hysteresis loop between CRI and SF for SC-24.

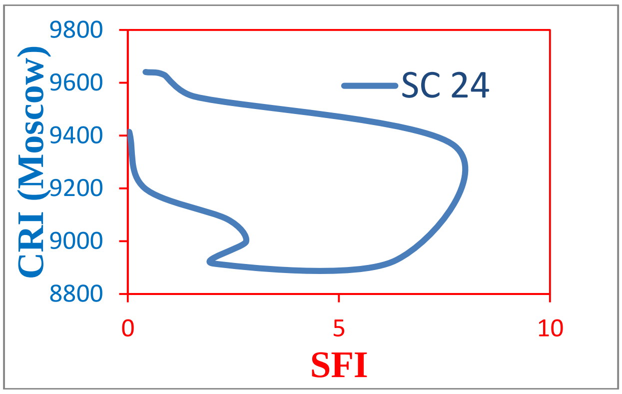


Fig.24 shows the hysteresis loop between CRI and SFI for SC-24.

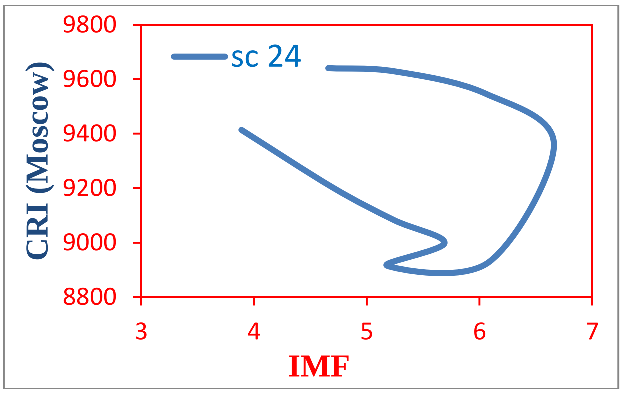


Fig.25 shows the hysteresis loop between CRI and IMF for SC-24.

We noted that individual indices represent particularly physical conditions on the sun (temperature, density, magnetic field etc), where these parameters have begin. Thus small differences arise when we contrast these parameters because of the varying consequences of magnetic fields, the main source of solar activity at different layers of sun's atmosphere. Furthermore, outstanding differences in time-Lag between CRI-SF, CRI-SFI, CRI-IMF and CRI-SSN have been observed, which is of great attentiveness. These dissimilarities arise due to the following differences between SSN, SF, SFI and IMF.

- The peak value of solar flux decreased monotonically during maximum solar cycle 21-24. This is the principal difference between solar flux and other solar indices.
- A time shift between solar flux and SSN has been seen almost the maximum peaks. Furthermore, it has been shown that the increased intensities of solar flux should occur after the appearance of sunspots. While IMF is opposite to the sunspots.

## 4. CONCLUSIONS:

Based on the results and discussion bestowed in this paper, following conclusions are drawn.

- The overall behavior of cross-correlation function between cosmic ray intensity and different solar activity parameters is almost identical for all the phases of different solar cycles 21-24, apart from the maximum phase of cycles. The correlation is powerful during increasing and decreasing phases of solar cycles and it is feeble during maxima and minima of the solar cycles.
- The average time-Lag seen between CRI and many solar activity parameters (SF, SFI) is calculated to be about 5 months apart from the IMF. Where the time-Lag is high (25 months) for the SC-22. Here, it is seen that SSN and SF have a better phase similarity with cosmic ray modulation. Being associated with the outermost part of the solar atmosphere, with time-Lag between CRI and SF is zero as compared to other solar activity indices.
- The time-Lag between CRI-SSN is large (~13 to 17 months) for odd solar cycles and small (~5 to 9 months) for even solar cycles, whereas it is ~ 25 months in solar cycle 22 and is less in other three cycles (i.e. 21, 22 and 24) in case of CRI-IMF relationship. It is obvious that the normalized CC between the cosmic ray intensity and solar activity parameters (SSN, SF, SFI, GSF and IMF) is seen with the time-Lag of SC-21 between CRI-SSN is ~13 months, SC-22 between CRI-SSN is ~5 months, SC-23 between CRI-SSN is ~17 months and SC-24 between CRI-SSN is~ 9 months.

## REFERENCES:

1. Dorman I V & Dorman L I, Solar wind properties obtained from the study of the 11-year cosmic ray cycle, J Geophys Res (USA), 72 (1967) 1513.
2. Nagashima K & Morishita I, Twenty-two year modulation of polar magnetic field of the Sun, Proc of 16th ICRC, held at Tokyo, Japan, Vol. 3, 1979, p. 325.
3. Forbush S E, World-wide cosmic ray variations 1937-1952, J Geophys Res (USA), 59 (1954) 525.
4. Neher H V & Anderson H R, Cosmic rays at balloon altitudes and the solar cycle, J Geophys Res (USA), 67 (1962) 1309.
5. Moraal H, Observations of the eleven-year cosmic-ray modulation cycle, Space Sci Rev (Netherlands), 19 (1976) 845.
6. Mavromichalaki H, Marmatsouri E & Vassilaki A, Simulation of long-term cosmic-ray intensity variation, Sol Phys (Netherland), 125 (1990) 409.
7. Kota J & Jokipii J R, The role of corotating interaction regions in cosmic-ray modulation, Geophys Res Lett (USA), 18 (1991) 1797.
8. Van Allen J A, On the modulation of galactic cosmic rays intensity during solar activity cycles 19, 20, 21, 22 and early 23, Geophys Res Lett (USA), 27 (2000) 2453.
9. Ahluwalia H S, Repetitive patterns in the recovery phase of cosmic ray 11-year modulation, J Geophys Res (USA), 99 (1994) 11561.
10. Dorman L I, Cosmic ray long-term variation: Even-odd cycle effect, role of drift and the onset of cycle 23, Adv Space Res (USA), 27(3) (2001) 589.
11. Usoskin I G, Mursula K, Kananen H & Kavaltsov G A, Dependence of cosmic rays on solar activity for odd and even solar cycles, Adv Space Res (USA), 27 (2001) 571.
12. Kane R P, Comparison of the variations of solar indices, interplanetary plasma parameters and cosmic ray neutron monitor intensities during 1991-2001, J Geophys Res (USA), 108 (2003) 1379.
13. Mavromichalaki H, Marmatsouri E & Vassilaki A, Solar- cycle phenomena in cosmic-ray intensity-Difference between even and odd cycles, Earth, Moon & Planets (Netherlands), 42 (1988) 233.
14. Singh M, Badruddin & Ananth A G, Study of time-lags and hysteresis between solar indices and cosmic rays; implications for drifts and modulation theories, SH34, Proc 29th ICRC, held at Pune (India), Vol. 2, 2005, p. 139.
15. Jokipii J R, Levy E H & Hubbard W B, Effect of particle drift on cosmic-ray transport, I-General properties, application to solar modulation, Ap J (USA), 213 (1977) 861.
16. Jokipii J R & Thomas B, Effect of drift on the transport of cosmic rays, IV, Modulation by a wavy interplanetary current sheet, Astrophys J (USA), 243 (1981) 1115.
17. Lockwood J A & Webber W R, Cosmic-ray modulation during solar activity cycle 20, J Geophys Res (USA), 84 (1979) 120.
18. Nagashima K & Morishita I, Long-term modulation of cosmic rays and inferable electromagnetic state in solar modulating region, Planet Space Sci (UK), 28 (1980) 177.
19. Webber W R & Lockwood J A, Characteristics of the 22- year modulation of Cosmic rays as seen by neutron monitors, J Geophys Res (USA), 93 (1988) 8735.

20. Hatton C J, Solar flares and the cosmic-ray intensity, Sol Phys (Netherlands), 66 (1980) 159.
21. Mavromichalaki H & Petropoulos B, An empirical model for the 11-year cosmic-ray modulation, Earth, Moon & Planets (Netherlands), 37 (1987) 79.
22. Mavromichalaki H, Belehaki A & Rafios X, Simulated effects at neutron monitor energies; evidence for a 22-year cosmic-ray variations, Astron Astrophys (France), 330 (1998) 764.
23. Chattopadhaya R, Midhya S K & De U K, Statistical study on the temporal correlation of different solar parameters with OI 6300 Å line intensity over Calcutta and its implications, Indian J Radio Space Phys, 32 (2003) 135.
24. David H Hathway, Robert M Wilson & Edvin J Reichmann, Grouped sunspot numbers, sunspot cycle characteristics, Sol Phys (Netherlands), 211 (2002) 357.
25. Mishra V K & Tiwari D P, Long-term association of solar activity and CRI for solar cycles 21 and 22, Indian J Radio Space Phys, 32 (2003) 65.
26. Usoskin I G, Kananen H, Mursula K & Tanskanen P, Correlation study of solar activity and cosmic ray intensity, J Geophys Res (USA), 103 (1998) 9563.
27. Rybansky M, Rusin V & Minarovzech M, Coronal index of solar activity, Space Sci Rev (Netherlands), 495 (2000) 227.
28. Agrawal, S. P., Shrivastava, P. K., Shukla, R. P. (1993): Time depending solar cycle, cosmic ray modulation of 23 rd neutron monitor energies. Proc. 23 Int. Cos. Ray. Conf., 3, 590.
29. Belov, A. (2000): Large scale modulation: View from the Earth. Space Sci. Rev., 93, 79-105.
30. Bhattacharya, R., Roy, M. (2014): Correlative analysis of cosmic ray intensity and solar activity parameters. Int. J. Eng., Sc.,Tech.,6, 24-31.
31. Bhattacharya, R., Roy, M., Biswas, M. (2010): On the relation of geomagnetic and solar activity with the secondary cosmic ray flux.Proc. Biodiversity, Water Resource and Climate Change Issues.166-170.
32. Biber, Pomerantz, Taso. (1983): C. M. Proc. 18th Int. Cos. Ray Conf., (Bangalore), 8, 289.
33. Forbush, S. E. (1958): Cosmic ray intensity variations during two solar cycles. J. Geophys Res., 63, 651.
34. King, J. H. (1979): Solar cycle variations in IMF intensity. J. Geophys. Res., 84, 5938-5940.
35. Moraal, H. (1976): Observation of theeleven year cosmic ray modulation cycle. Space Sci. Rev., 19, 845-920.
36. Rao, U. R. (1972): Solar modulation of galactic cosmic radiation. Space Sci. Rev., 12, 719-809.
37. Singh, S. G., Saxena, A. K., Singh, R.P., Singh, Y. K. (2013): Correlative study of solar wind streams velocity and cosmic ray intensity variations during2002-2007.Int.J.Sci.Env.Tech.,2,56.