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International Journal of Current Research
Vol. 7, Issue, 09, pp.20045-20048, September, 2015

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

VARIABILITY OF SOLAR CYCLES 22-24 IN RELATION TO COSMIC RAY INTENSITY AND GEOMAGNETIC PARAMETERS

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ARTICLE INFO

Article History:
Received 20th June, 2015
Received in revised form
05th July, 2015
Accepted 23rd August, 2015
Published online 16th September, 2015

Key words:
Solar Activity,
Cosmic Ray Intensity,
Geomagnetic Activityand IMF.

ABSTRACT

In the present work, the study of length of solar cycle 22-24 has been presented in relation to the solar activity, cosmic ray intensity, interplanetary magnetic field and geomagnetic activity. We have studied the solar activity trends of sunspot number (SSN), geomagnetic activity amplitude planetary A-index (Ap), cosmic ray intensity (CRI) and interplanetary magnetic field (IMF) during solar cycles 22, 23 and 24 (till Dec.2014). We have studied the relation among simultaneous variations in cosmic ray intensity (Moscow NM), SSN, Ap and IMF during solar cycles 22, 23 & 24, and found the correlation coefficient. We then compared the relations between those obtained for the two previous solar cycles. We have observed certain peculiar features in cosmic ray modulation during the solar cycles 22-24. The focus of our study was to investigate whether this range is associated with a secular pattern in the length of the solar cycles 22,23 and 24 (SSN, CRI, gamogenetic activity and IMF) in the analysis of the long-term behaviour of the Sun. We have analysed archival data of SIG parameters from 1986 - 2014.

Citation: Prithvi Raj Singh, A.K. Saxena and C.M. Tiwari, 2015. "Variability of solar cycles 22-24 in relation to cosmic ray intensity and geomagnetic parameters", *International Journal of Current Research*, 7, (9), 20045-20048.

INTRODUCTION

The observations and research on the continuously varying the Sun have been made by observing sunspots as an index of solar activity. The source of solar activity is variation in the solar magnetic field, which is visually manifested by sunspots on the solar surface. The so -called 11-year cyclic variation of sunspot number (SSN) was first recognized by (Schwabe, 1843). The most obvious indicators of the activity of cycles are sunspots, flares, plages, and so on (Coles *et al*.1980). All such phenomena are intimately linked to the solar magnetic fields, which exhibit complex but systematic variations from the solar surface to interplanetary space. The link between solar activity and cosmic ray intensity is generally needed to understand the long - term modulation of Cosmic Ray Intensity (CRI), solar activity may be expressed by different parameters. viz. Planetary equivalent amplitude (Ap), Sunspot numbers (SSN) and interplanetary magnetic field (IMF). The long - term cosmic ray variation can be computed by using data of global network of neutron monitor stations having different cut - off rigidities. In the influence of solar activity on cosmic ray began with sunspot number and after that search for appropriate solar index is going on till date (Heber *et al*, 2007).

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The inverse correlation between SSN and galactic cosmic ray intensity is well known (Mavromicalaki *et al.,* 1988; Cliver, 1993; Kane, 2005). The intensity of galactic cosmic rays varies inversely with sunspot numbers, having their maximum intensity at the minimum of the 11-year sunspot cycle (Forbush, 1954, 1958).

More recently, an effort has begun to find a relation between the CRI modulation and the interplanetary magnetic field (IMF), planatery equivalent amplitude (Ap), which it has been suggested to be highly associated (Belov, 2000). A relationship between cosmic-ray intensity variations and IMF intensity exists for short time intervals during Forbush effects (Cane, 1993) and in the distant heliosphere (Burlaga, McDonald, and Ness, 1993, Kudela *et al.,* 2000) distinguish the IMF configurations that can produce Forbush decreases and show that we cannot ignore the importance of the IMF, as it is also strongly related to Cosmic-ray fluctuations. From this point of view we can use the IMF instead of coexisting with, geomagnetic index values (Belov *et al*., 2001) have shown that the tilt of the heliospheric current sheet and other solar heliospheric parameters successfully describe the long-term variations of cosmic rays in the past two solar cycles, especially in the epochs of solar maximum. Recent studies (McDonald *et al*., 2010, Nielsen & Kjeldsen 2011) have reported that the solar cycle 23/24 minimum is different from any other solar minima seen in the past. It has been marked by a prolonged period of very low solar activity that began in 2006.

The recorded SSN of about 400 years is a key parameter in producing the proxy data of parameters with only observations since the 1970s. Thus, we present the status of SIG parameters observed by ground observatories and satellites during approximately 29 years, including SSN, IMF, Ap index, and cosmic ray intensity (CRI). Then, we make some predictions on the effects that the trend will bring to the space environment surrounding the Earth in view of the past events. In the past a lot of work has been done to correlate the solar parameters with cosmic ray intensity on long-term basis.

DATA ANALYSIS

In this paper, we have studied the variation of SIG parameters and correlation between Cosmic ray intensity, geomagnetic activity and solar activity (sunspot number) for the solar cycles 22, 23 and 24 (till Dec.2014), and also make comparative study of solar cycles 22, 23 and 24. For this purpose the yearly mean values of sunspot number (Rz) are taken from the (http://www.ngdc.noaa.gov.in). The pressure corrected yearly mean value of cosmic ray data of Moscow (Cut-off Rigidity=2.43 GV) neutron monitor station have been taken from (www.ngdc.noaa.gov.in). The solar cyclic variation of solar magnetic fields arises from the solar surface to interplanetary space, such as IMF is taken form, NASA Data Centre (http://omniweb.gsfc.nasa.gov.in). We have collected the yearly data of the Ap index during the period 1986 - 2014 from NGDC (ftp://ftp.ngdc.noaa.gov.in).

RESULTS AND DISCUSSION

To assess level of the correlation between sunspot number and cosmic ray intensity for the solar cycles 22 - 24, the correlation coefficient between yearly mean values of these two parameters CRI and SSN has been observed, during the solar cycle 22 is the maximum SSN observed was 200.3 on august 1990 and minimum 1.1 on June 1987. In solar cycle 23, maximum SSN was 150.7 on Sept.2001 and minimum 0.9 on Oct.2007. We have presented the relationship between solar activity (Sunspot Number) and Cosmic Ray Intensity (CRI) in the solar cycles 22, 23 and 24 till Dec.2014. From figure (1) we have calculated correlation analysis of average yearly value of Cosmic Ray Intensity (CRI) with SSN is (R= -0.88) and also found SSN with CRI is inversely correlated for the period 1986-2014. The cosmic ray intensity and sunspot numbers are anti-phase in solar cycles 22, 23 and 24. From figure (1) the CRI is maximum in the year 2009 and minimum in the year 1991 for the period 1986-2014.

We have considered the geomagnetic activity, planetary equivalent amplitude (Ap) and cosmic ray intensity (CRI) Moscow NM is cut-off rigidity (2.43GV), to observe the long – term variation in the solar cycles 22, 23 and 24. From figure (2) we have observed yearly average value of Ap index is inversely correlated with CRI in solar cycles 22, 23 and 24. The Ap is maximum in the year 1991 and Ap is minimum in the year 2009. We have calculated correlation coefficient between yearly average value of cosmic ray intensity (CRI) with geomagnetic activity (Ap) is (R= -0.69) in the period 1986-2014. It is clear that CRI and Ap are anti-phase in solar cycles 22, 23 and 24.

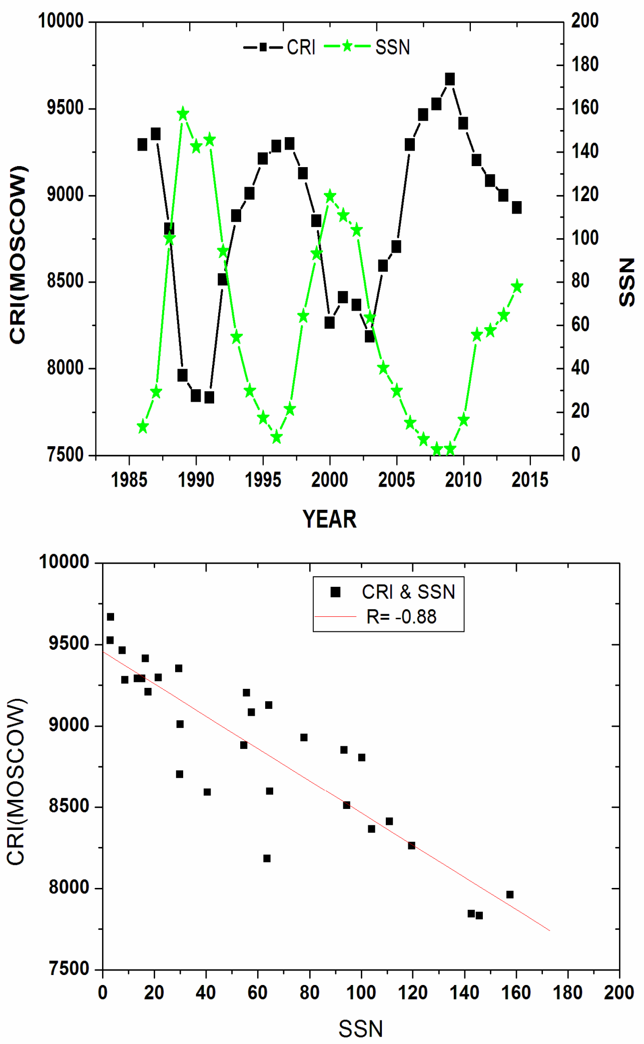
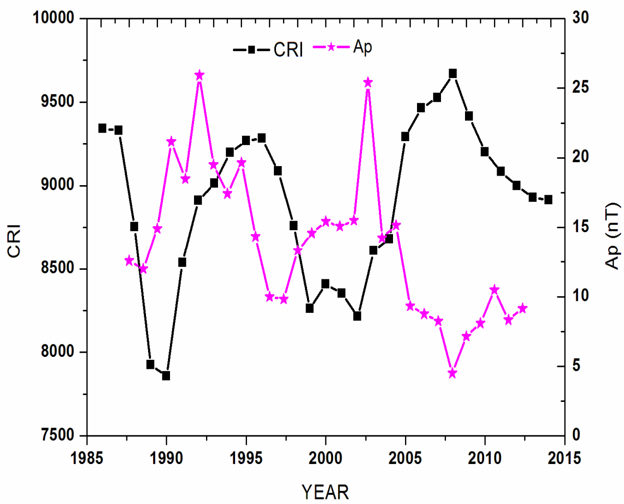


Figure 1. The yearly mean cosmic ray intensity (Moscow) with sunspot numbers for the period 1986-2014



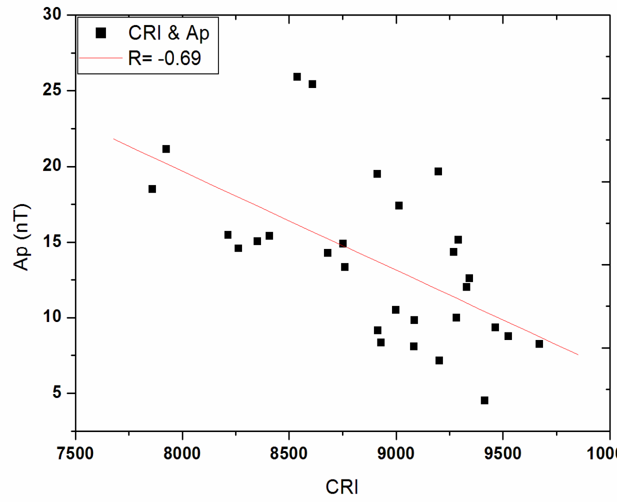


Figure 2. The yearly mean cosmic ray intensity (Moscow) with Ap for the period 1986-2014

We have presented the geomagnetic activity, planetary equivalent amplitude (Ap) index to observe the long- term variations of geomagnetic field disturbances. It is well known that the geomagnetic disturbances are associated with solar outputs emanating from the surface of the Sun in solar cycles 22, 23 and 24.

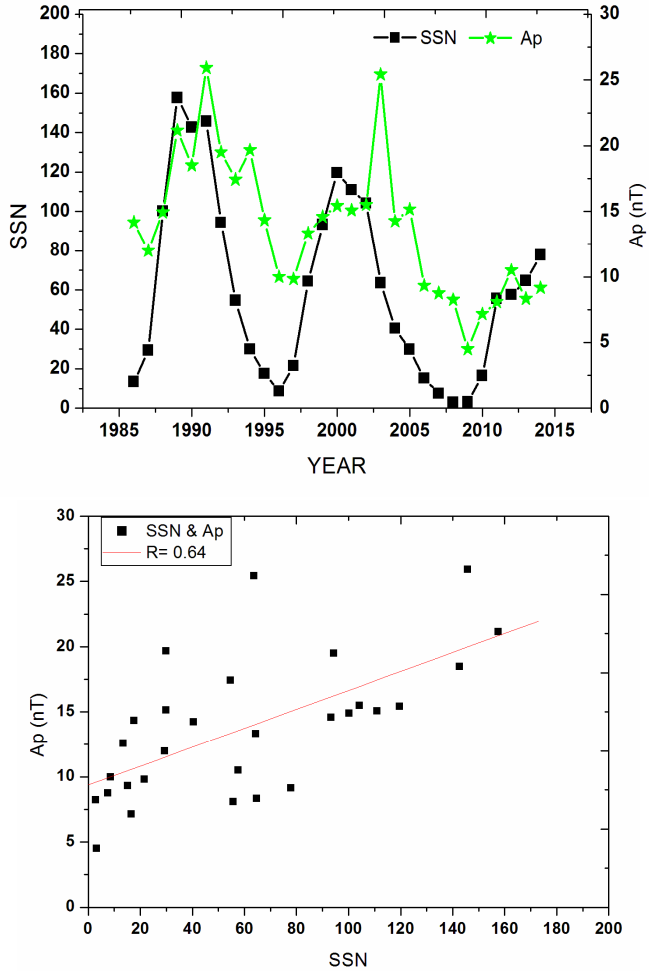


Figure 3. The yearly mean sunspot number with Ap for the period 1986-2014

From Figure (3) we have found the positive correlation coefficient SSN with Ap is (R= 0.63) for the period 1986 to 2014. Fairly systematic increase is Ap in association with SSN has been seen for all the three solar cycles 22, 23 and 24. We have studied the variations of interplanetary magnetic field (IMF) and sunspot number (SSN) in the solar cycles 22, 23 and 24 (till dec.2014). From figure (4) we have found the similar variations in SSN with IMF in solar cycles 22, 23 & 24, and observed large positive correlation coefficient SSN with IMF (R= 0.82) for the period 1986 to 2014.

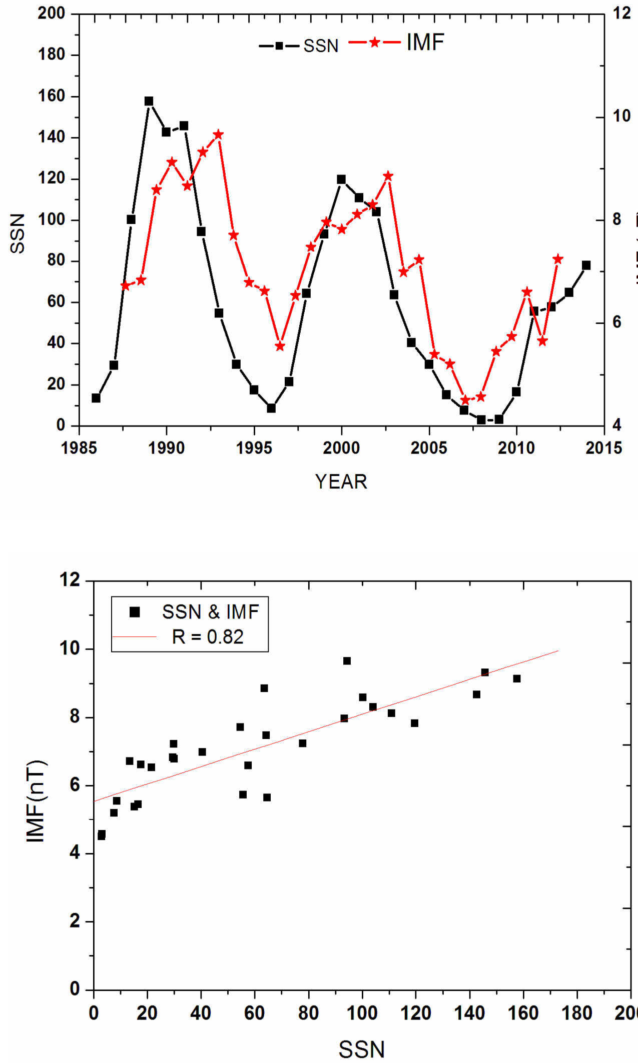
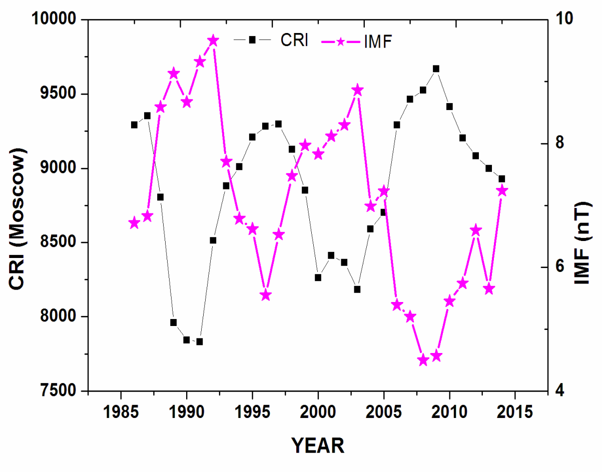


Figure 4. The yearly mean sunspot number with IMF for the period 1986-2014

It is clear that SSN and IMF are same phase in solar cycles 22, 23 and 24. In the Figure (4) IMF is maximum in the year 1992 and minimum in the year 2008.We have compared interplanetary magnetic field (IMF) with cosmic ray intensity in three solar cycles 22, 23 and 24 in Figure (5), the interplanetary magnetic field (IMF) shows a decline trend at least during solar cycle 22, 23 and 24, somewhat similar to sunspot number further the magnetic field (B) is weakest during the solar cycle 23 and is minimum.



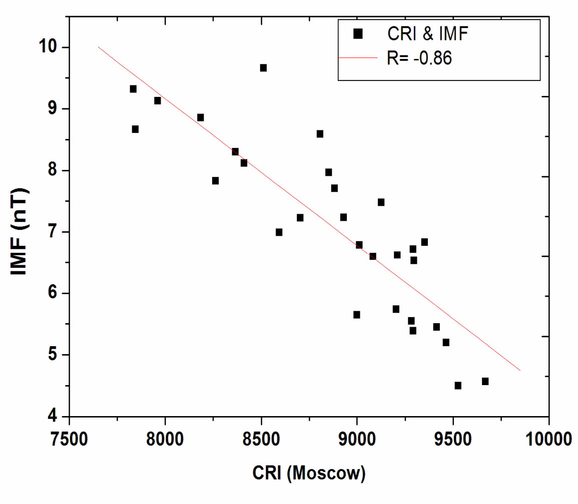


Figure 5. The yearly mean cosmic ray intensity (CRI) (MOSCOW) with IMF for the period 1986-2014

We have studied the variations of interplanetary magnetic field (IMF) and cosmic ray intensity (CRI) in the solar cycle 22, 23 and 24 (till dec.2014). From figure (5) we have found the inverse variations in CRI with IMF, and observed large negative correlation coefficient CRI with IMF is (R= - 0.86) in the period 1986 to 2014. It is clear that cosmic ray intensity and IMF are anti-phase in solar cycles 22, 23 and 24.

Conclusion

A detailed variations and correlative analysis is done between solar activity, geomagnetic activity, IMF and cosmic ray intensity in the period 1986-2014. From the above scattered diagrams it is evident from the analysis that the modulation of cosmic ray intensity under different solar activity (SSN), IMF and geomagnetic activity (Ap) has been distinct correlation coefficients. The solar activities play the significant role in modulating cosmic ray intensity in solar cycles 22, 23 and 24 for the period 1986-2014. The large negative correlation coefficient has been found yearly average value of cosmic ray intensity (CRI) with SSN (R= -0.88), cosmic ray intensity (CRI) with IMF(R= -0.86) for the period of 1986-2014 and also SSN and IMF is inversely correlated (anti-phase) with CRI in the solar cycles 22, 23 and 24. The negative correlation coefficient between yearly values of cosmic ray intensity (CRI) with geomagnetic activity planetary equivalent amplitude (Ap) index (R= -0.69) for the period of 1986-2014 and CRI is anti-phase with Ap in solar cycles 22, 23 and 24. The significant of positive correlation SSN with Ap (*Rz* and *Ap*) is (R= 0.63) for the period 1986-2014. The systematic increases planetary equivalent amplitude (Ap) is association with SSN in solar cycles 22, 23 and 24. The large positive correlation coefficient SSN with IMF (R = 0.82) for the period of 1986-2014 and SSN has similar variation (same phase) with IMF in solar cycles 22, 23 and 24.

Acknowledgement

We thank the NGDC and OMNI Web for providing data solar interplanetary geomagnetic (SIG) parameters and also thank Moscow (Neutron Monitor) data Station for CRI.

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