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Correlation of Interplanetary magnetic field IMF with Cosmic ray intensity,Kp,Ap and Dst

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Abstract- TheUniverse is very large having billions of billion stars, several billions of galaxies and severalthousands of Quasars are there. Universe is attracted through invisible huge supernatural gravitational attraction force. Entire Universe is made up of matter and energy. Matterexists in various forms, inthe Universe. We find matter in very tiny elementary particles (bosons & Fermions), in nebulae, in celestial bodies i.e., asteroids, satellites, comets, planets, stars, galaxies, quasars also.Energies exists in various forms, such as electromagnetic waves (gamma rays, x-rays, ultraviolet rays, visible light, infrared rays, micro waves, radio waves etc.), cosmic rays, etc. Earth's magnetic field is widely affected by the Sun's magnetic field and the various phenomenon occur on Earth's mental and core region. Various phenomena occur in the Sun i.e., CMEs, SWP ejections, SPEs, Solar radio bursts, formation of Sunspot, Solar flare eruptions and solar radio Flux emission. These solar happening events change the Earth-Sun climate (environment) effectively. Cosmic radiations are very energetic, coming from outside (or beyond) the solar system. These radiations originate from various sources such as from Quasars, from centre of galaxies, from Supernovae explosions and from big sized stars etc.Middle or average degree of anti-correlation [C(t) ≈ -0.591](for CRI Oulu – Ap), [C(t) ≈ -0.604] (for CRI Moscow – Ap) and low degree negative correlation [C(t) ≈ -0.369] (for CRI Rome – Ap) observed during April 1954 to February 2023.High degree of negative correlation [C(t) ≈ -0.755] (for CRI Oulu –IMF), [C(t) ≈ -0.7375] (for CRI Moscow-IMF) observed during April 1954 to February 2023.The correlation between Ap and Dstobserved, [C(t) ≈ -0.74 for SC 21],[C(t) ≈ -0.91 for SC 22], [C(t) ≈ -0.77 for SC 23] and [C(t) ≈ -0.79 for SC 24]. The correlation between IMF-Kp, CC ≈ 0.77 and Standard Deviation SD is, 2.83 observed for solar cycle 24. The correlation coefficient between geomagnetic Ap index and interplanetary magnetic field observed as 0.68, 0.70, 0.73 and 0.74 continuously for SC 21, SC 22, SC 23 & for SC 24.

Keywords- Cosmic ray intensity, Interplanetary magnetic field, Disturbance time index, Geomagnetic index

1.Introduction- Aslam O.P.M. and Badruddin (2012) have studied the solar modulation of cosmic rays during the declining and minimum phases of solar cycle 23:comparison with past three solar cycles [1].Belov A.V.

and their research group (2005) have analyzed the relation of global magnetic solar field indices and solar wind characteristics with long –term variations of galactic cosmic rays [2].Gupta Meera et.al. (2005) have studied the correlative study of solar activity and cosmic ray intensity for solar cycles 20 to 23 [3]. Gupta Meera, Mishra V.K. & Mishra A.P. (2006) have analysed the cosmic ray intensity variations in relation to solar activity for sunspot cycles 19to23 [4].Gupta Meera and his collaborates (2014) have examined the correlative study of solar activity and cosmic ray intensity variations during present solar cycle 24 in comparison to previous solar cycles [5].Mavromichalaki, H., Paouris E. &Karalidi T. (2007) have studied the Cosmic ray modulation: An empirical relation with solar and heliospheric parameters [6].Rathod, M. and their group (2017) have analysed the long-term variation of solar flareindices in relation to sunspot numbers from solar cycle 20 to 24 [7].Rathore, B.S. et al. (2011) have studied the Cosmic rays during intensegeomagnetic conditions and their solar /interplanetary causes [8].Tiwari, B. K. & his research collaborates (2014) have analyzed the Modulation incosmic ray during the declining and minimum solar activity period of solar cycle 23 [9].10. Tiwari, B.K. et al. (2014) have studied the variation in cosmic ray intensity due to solar-interplanetary activity between 1996-2013 [10].

2.Methods of Analysis and Data Detection Techniques-The ground based neutron monitors world-wide network provides very stable and variable records of intensity of cosmic ray particles of different rigidity for more than 70 years of period. Thus,the monthly means of cosmic ray neutron monitor count rates as CRI (Oulu, Moscow & Rome) data taken from https://cr0.izmiran.ruhave been used. A detailed correlative study has been performed between CRI with solar activity parameters. Cross and linear graphhas been plotted for IMF-F10.7, IMF-Ap, IMF-CRI, Dst-Ap. Our investigation focused on solar heliospheric and cosmological variable and interrelationship between them. In this paper we have focused our study on cosmic ray modulation and their correlative association with Interplanetary magnetic field.Most of the data have been taken from the website of NOAA (fttp://fttp.ngdc.noaa.gov/STP/SOLAR DATA.html).Worldwide cosmic ray neutron monitor stations,pressure corrected data taken from Oulu (low cut off rigidity, 0.81 GV,Lat. 65.05 ^{0} N, Longitude 25.47 ^{0} E and Alt. 15m), Moscow (middle cut off rigidity, 2.43 GV, 55.47 ^{0}N 37.32 ^{0}E data from NM 12IGY, 18NM64 and from24NM64,http: //cro. izmiran.ru/scripts/nm64queryD.dll/mosc) and Rome (high cutoff rigidity,6.27GV,data from 20NM64, through website cro.izmiran.ru/rome/main.htm, Italy) have been used for correlation study and for graphical analysis.In this analysis, we have taken the Cosmic ray intensity of various cut-off rigidity stations i.e., Oulu, Moscow & Rome for various solar cycles 19 to 24 and Pre SC 25(period from July 1957 to February 2023).

3. Results and Discussions-

3.1 Correlation between IMF and Cosmic ray intensity

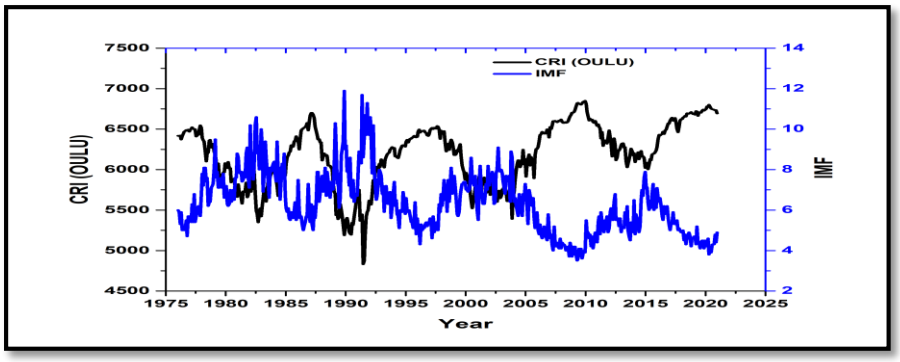

Figure-1 Linear relationship between IMF and Cosmic Ray Intensity CRI (Oulu) for the interval 1975 to 2021.

The correlation between IMF &Cosmic ray intensity (Oulu)has been calculated as CC≈ -0.74, -0.74, -0.81& -0.73for SC 21, 22, 23 & 24 correspondingly. A negative correlation with average degree has been found during SC 21, 22, and 24 for these parameters. In the same way, a negative correlation with a high degree has been recorded for both of these indices for SC 23. IMF and CRI (Oulu) are highly anti-correlated with each other

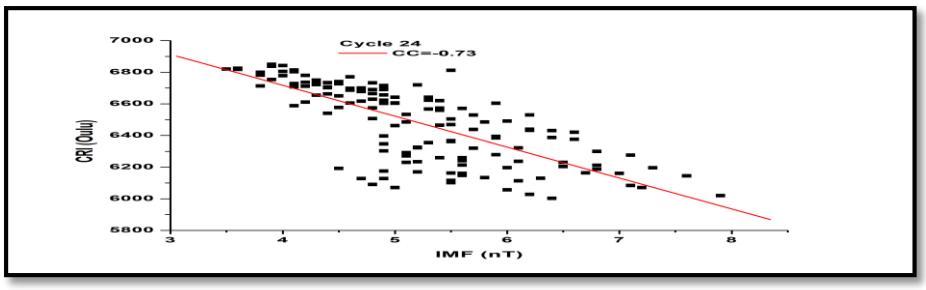

Figure-2 Cross plot between IMF and CRI (Oulu) for SC 24.

Cross-correlation between IMF (nT) and CRI (Oulu) has been calculated asCC ≈ -0.73 for solar cycle 24. A negative correlation with a middle or average degree has been calculated for this period. We have observed that cosmic ray intensity decreases with the increase of the interplanetary magnetic field.

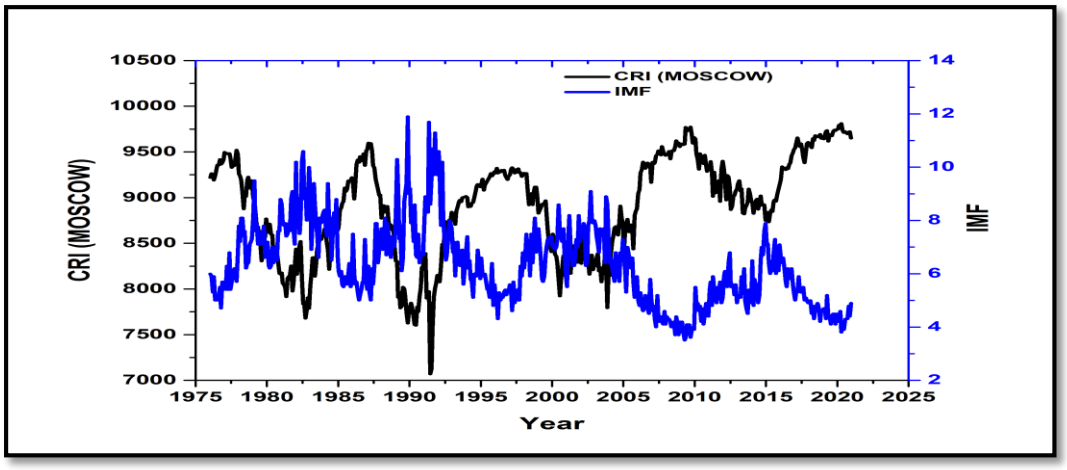

Figure-3 Linear relationship between IMF and Cosmic Ray Intensity (Moscow) for the interval 1975 to 2021.

The correlation between IMF &Cosmic ray intensity (Moscow)has been recorded as CC ≈ -0.71, -0.74, -0.81& -0.69for SC 21, 22, 23 & 24 respectively. A negative correlation with a middle or average degree has beenrecorded during SC 21, 22, and 24 for these parameters. In the same way, a negative correlation with a high degree has been recorded for both of these parameters for SC 23.

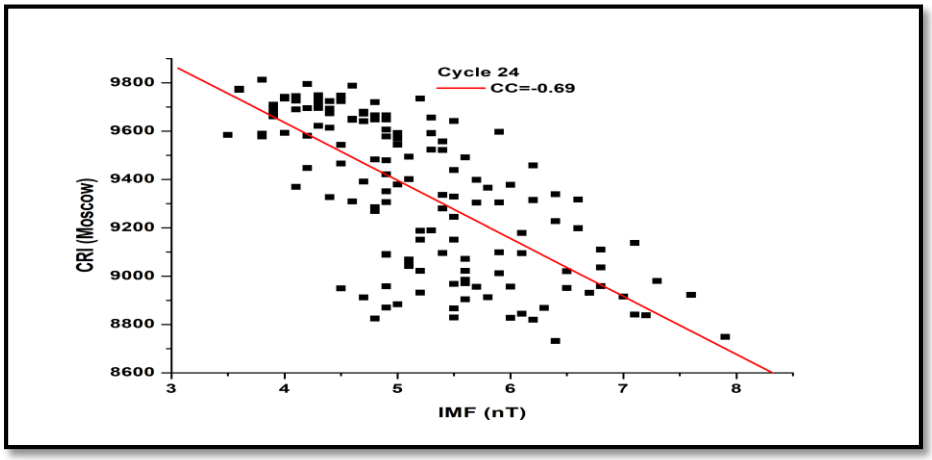

Figure-4 Cross plot between IMF (nT) and CRI (Moscow) for SC 24.

The Cross-correlation between IMF (nT) and CRI (Moscow) has been determinedfor solar cycle 24. CC ≈ -0.69. The negative correlation of middle or average degree has been recorded during this period. The strength of the interplanetary magnetic field characterized the quantitative effect on the cosmic ray intensity. Stronger IMF reduces the cosmic ray intensity.

3.2 Correlation betweenAp and Dst

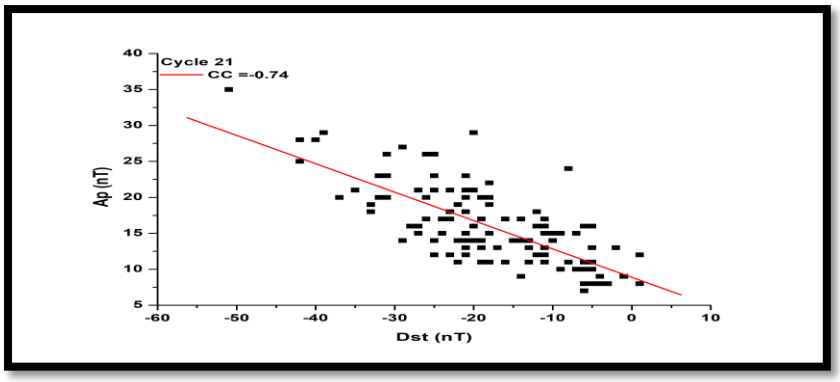

Figure-5 Cross plot between Ap (nT) and Dst (nT) for the solar cycle 21.

This figure depicts a negative correlation between Ap and Dst index with correlation coefficient CC ≈ -0.74.

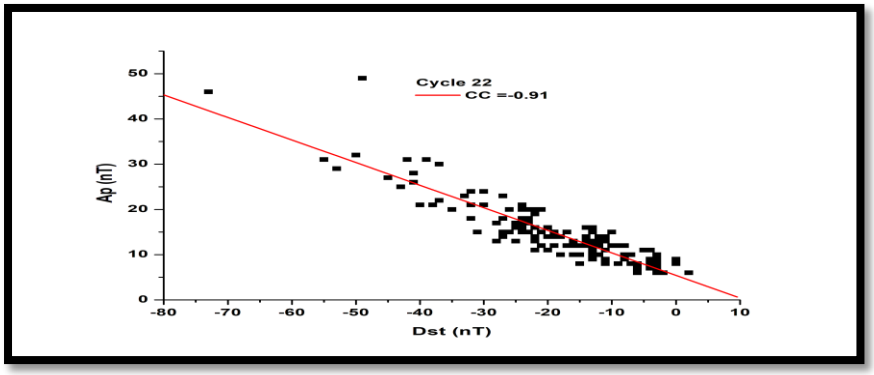

Figure-6 Cross plot between Ap (nT) and Dst (nT) for the solar cycle 22.

The correlation coefficient between Ap and Dst is, CC ≈ -0.91.

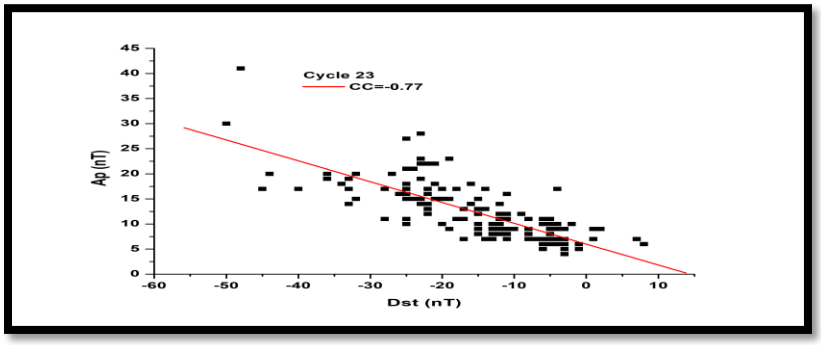

Figure-7 Cross plot between Ap (nT) and Dst for the solar cycle 23.

We have observed the negative correlation CC ≈ -0.77, between Ap and Dst for SC 23.

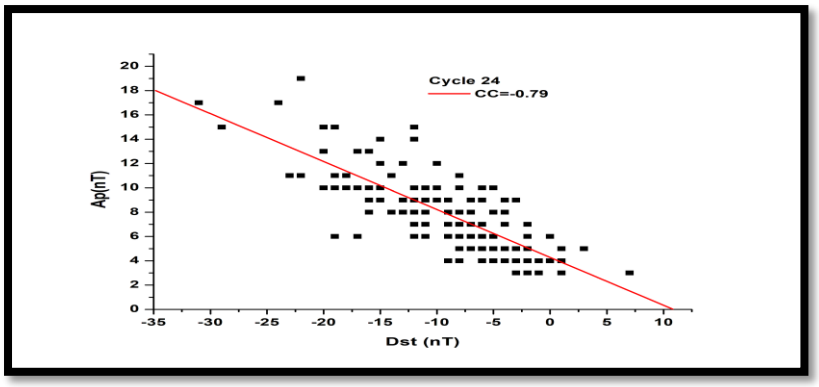

Figure-8 Cross plot between Ap and Dst (nT) for SC 24.

Negative correlation, CC ≈ -0.79.

3.3 Correlation betweenAp and IMF

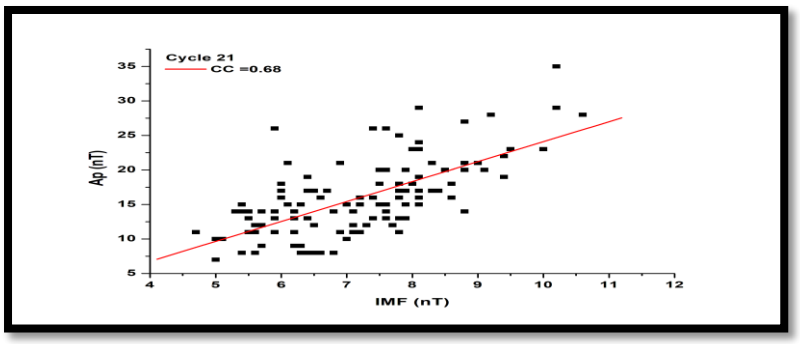

Figure-9 Cross plot between Ap and IMF for the solar cycle 21.

This figure depicts a positive correlation between Ap and IMF index with correlation coefficient CC ≈ 0.68.

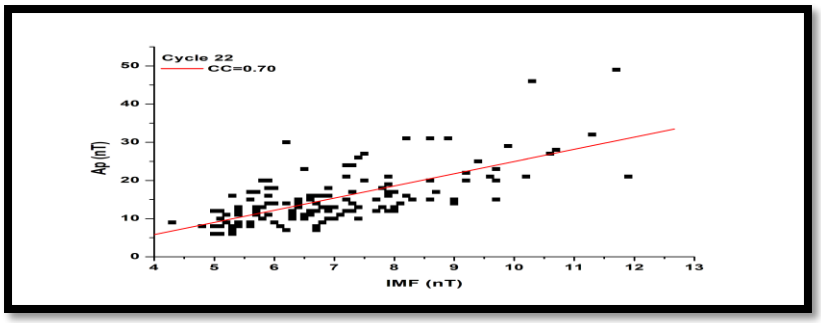

Figure-10 Cross plot between Ap (nT) and IMF (nT) for the solar cycle 22.

We have found positive correlation between them. CC ≈ 0.70.

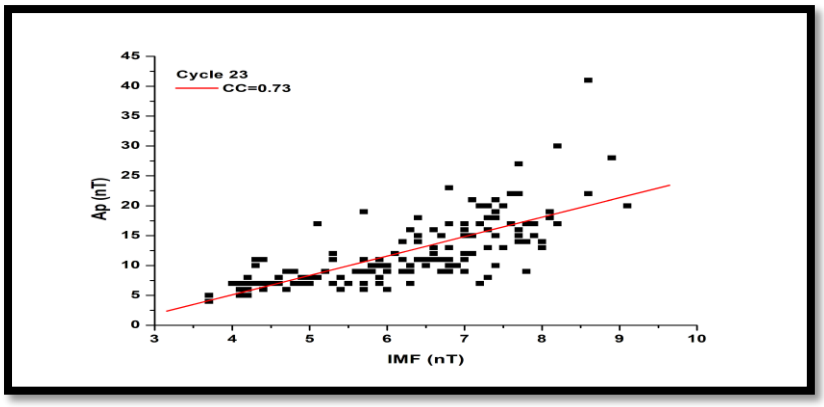

Figure-11 Cross plot between Ap (nT) and IMF (nT) for the solar cycle 23.

We found strong positive correlation between Ap and IMF, CC ≈ 0.73.

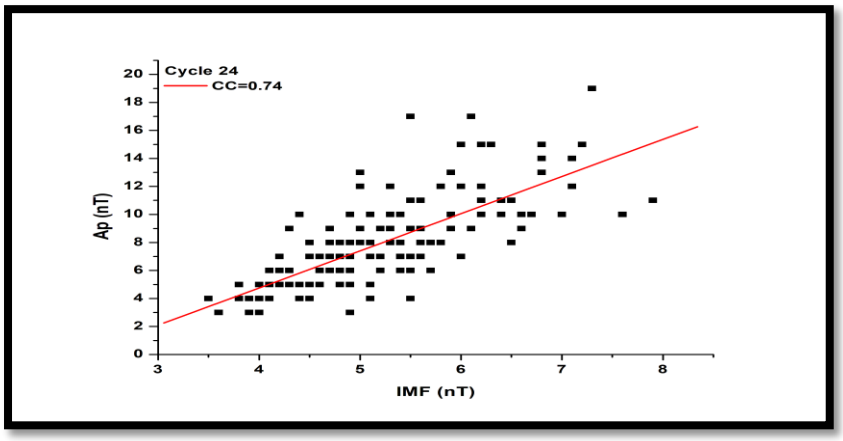

Figure-12 Cross plot between Ap and IMF (nT) for the SC 24.

Positive correlation, CC ≈ 0.74The geomagnetic index Ap is observed as the long-term variation for the changes in the geomagnetic field.

3.4 Correlation between Kp and IMF

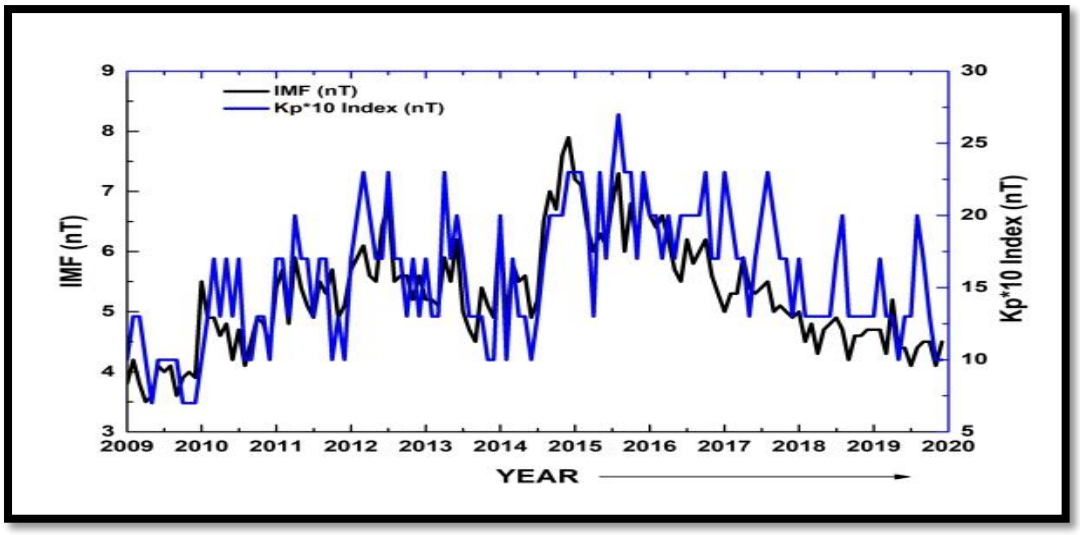

Figure-13 Shows comparison (Linear plot) between Kp*10 index and yearly averaged IMF (Bz) for the Solar Cycle 24 (2009 to 2020).

Figure reveals that there is good time variation between the two parameters i.e., when IMF is at its peak value at the same time Kp*10 index is minimum and vice versa.

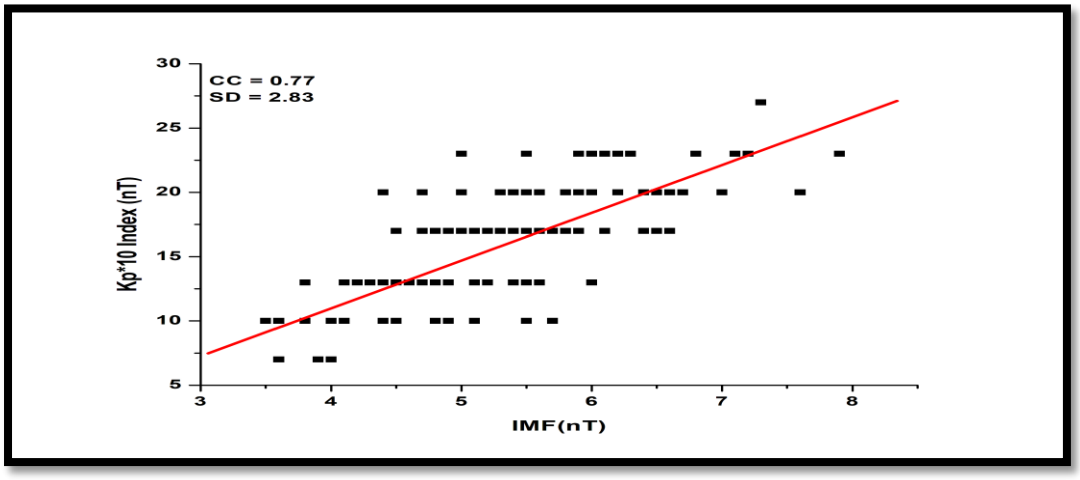

Figure-14 Cross plot between yearly average values Kp*10 index and IMF for the SC 24 (period 2009 to 2020).

In the rising phase of the cycle, Kp*10 index decreases initially, then start increasing in the year 2010. The value decreases unevenly in the declining phase as well. The IMF increases in the ascending phase of the cycle and shows positive peak value in the year 2012 while as its minimum value observed in 2014. CC ≈ 0.77 and Standard Deviation SD is, 2.83.

3.5 Correlation between IMF and F10.7

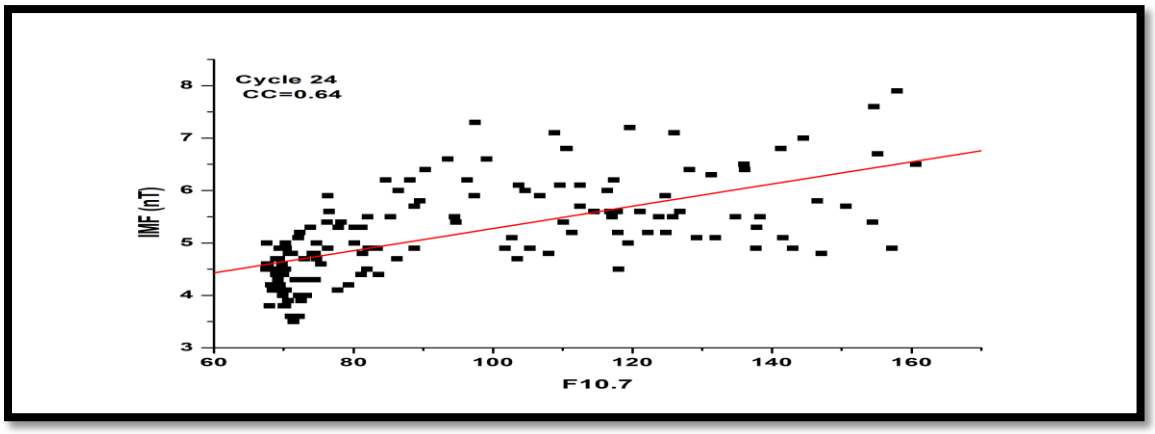

Figure-15 Cross plot between IMF (nT) and F10.7 for the SC 24.

Positive correlation, CC ≈ 0.64.

Table-1 Correlation Coefficient C(t), Cosmic Ray Intensity (Oulu, Moscow, and Rome) Vs Solar, Geomagnetic, and Interplanetary Parameters (Period from April 1954 to February 2023).

S. No.	CRI Vs Solar, Geomagnetic, and Interplanetary Parameters	Correlation Coefficient C(t)		
		Oulu	Moscow	Rome
1	Solar Flux 10.7 cm (Penticton /Ottawa) – CRI	-0.880	-0.880	-0.576
2	Ap Index – CRI	-0.591	-0.604	-0.369
3	IMF (OMNI Web) – CRI	-0.755	-0.7375	NA
4	F 10.7 (OMNI Web) – CRI	-0.7875	-0.795	-0.731

Table-2 Correlation between Interplanetary magnetic field with Solar parameter, Geomagnetic parameter, and CRI

Parameters	Correlation C(t) between IMF with solar parameter, Geomagnetic parameter, and CRI			
	SC21	SC22	SC23	SC24
IMF-F10.7	0.56	0.77	0.77	0.64
IMF-Ap	0.68	0.70	0.73	0.74
IMF-CRI (Oulu)	-0.74	-0.74	-0.81	-0.73
IMF-CRI (Moscow)	-0.71	-0.74	-0.81	-0.69

4.Conclusions-Strong inverse correlation observed between CRI-IMF& CRI-Ap. It has been found that geomagneticApindices shows anti-correlation with Cosmic Ray Intensity (CRI). It is found that solar activity indices show decreasing trend with CRI and also shows negative correlation.IMF positively correlated with Ap and Kp for SC 21 to SC 24.Ap and Dst index negatively correlated with each other during the investigation period 1975 to 2021.

Acknowledgement-

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