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Correlative Study of Cosmic Ray Intensity with Sunspot Number and Grouped Solar Flare during 1954 to 2021

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CORRELATIVE STUDY OF COSMIC RAY INTENSITY WITH SUNSPOT NUMBER AND GROUPED SOLAR FLARE DURING 1954 TO 2021. Ashok Kumar Jyoti, Assistant Professor Physics, Govt. B. P. Deo PG College Kanker, CG Dr. Meera Gupta, Professor Physics, Govt. Dr. V.V. Patankar Girls PG College Durg, CG Dr. Jagjeet Kaur Saluja, Professor Physics, Govt. VYT PG College Durg, CG ABSTRACT-Entire world is facing with very serious global climatic situation and tremendous (rapid) environmental changes problem in the last 200 to 300 years. Matter and energy both are the main constituents of the supergiant

ABSTRACT

Entire world is facing with very serious global climatic situation and tremendous (rapid) environmental changes problem in the last 200 to 300 years. Matter and energy both are the main constituents of the supergiant Universe. Our planetary system including Earth is controlled by super energetic Sun and also by Galactic world. Tremendous amount of energy in the various forms is releasing from galaxies, including Sun, impowers our Earth in very fascinating way. Most abundant highly energetic and penetrating (galactic origin) cosmic radiation which is, perhaps assuming to be responsible for life on Earth by various researchers; how these cosmic radiations play a major role in climatic changes in our solar system including environment of our Earth. Sunspot formation, Solar radio flux emissions, Solar radio bursts (Solar flares), Coronal mass ejections (CMEs), Solar wind plasma (SWP) emissions and Solar proton ejections (SPEs) etc. are most important phenomena occur in the Sun. 1954 to 2021. The mean time-lag observed between cosmic ray intensity and SSN Total is estimated to be about 0 to 15 month for Oulu, Moscow & Rome NM stations during SC 19 to SC 24. Same way the mean time-lag observed between cosmic ray intensity and GSF is estimated to be about 0 to 8 month for all these NM stations during SC 20 to SC 23. It is found that the SSN are highly negatively or anti-correlated (~ -0.7978 to -0.9211) with cosmic ray intensity for Oulu, Moscow & Rome. Same way it

is found that GSF is also highly negatively or anti-correlated (~ -0.7750 to -0.8878) with cosmic ray intensity for all these stations. SSN Total (SIDC-SILSO) shows high negative correlation $C(t) H'' - 0.807$ with CRI count rates for both Oulu and Moscow Cosmic ray neutron monitor stations. Moderate correlation $C(t) H'' - 0.433$ observed for Rome CRI counts with SSN Total (SIDC-SILSO).

KEY WORDS

Sunspot number, Grouped solar flares, Solar activity cycle & parameters, Cosmic Ray Intensity (CRI), Magnetic polarity, Solar indices.

INTRODUCTION

In our solar system Sun is a very strong (tremendous) energy source, provide us light, heat radiation due to thermonuclear fusion reactions in which hydrogen, deuterium, helium and many other low atomic number nuclei participate in this process. We are shielded in a very strong gravitational and magnetic field cage of our Sun Earth system. Sun, which is a spectral class G2 type star, has its very strong magnetic and very-very strong gravitational field (gravity) bind our solar system. We are also in a cage of Earth's magnetic and gravitational shielding (magnetosphere and gravitational field). Earth's magnetosphere protect us from out-coming radiation i.e., cosmic radiations, originating from Galactic Centre, novae or supernovae explosions and also emerging from big sized star (hyper giants, blue super giants star etc.). We can say that we are strongly affected by a combined magnetic and gravitational shielding of the universe. There is a very momentarily changing magnetic and gravitational shielding situated around us. These means we are affected by strong magnetic and very high gravitational environment. Natural environment (space weather climate) changes every time and affected by radiation and gravity. Worldwide cosmic ray neutron monitor stations, pressure corrected data taken from Oulu (low cut off rigidity, 0.81 GV, Lat. 65.05° N, Longitude 25.47° E and Alt. 15m), Moscow (middle cut off rigidity, 2.43 GV, 55.47° N 37.32° E data from NM 12IGY, 18NM64 and from 24NM64, <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. Data taken from NGDC (NOAA), OMNIWEB, WDC and SGD for correlative statistical graphical analysis.

Methods of Analysis and Data Detection Techniques

The monthly means of cosmic ray neutron monitor count rates as CRI (Oulu, Moscow & Rome) data taken from <https://cr0.izmiran.ru> have been used. Solar parameters such as monthly means of International Sunspot numbers SSN Total (SIDC-SILSO) from <https://www.bis.sidc.be> and Grouped Solar flares GSF data has been used. 30 Month running average (smoothed) data of various solar parameters with CRI have been used for correlative study. Data have been normalized by using the formula $(X/X_{avg}) * 100$. A detailed correlative study has been performed between CRI with solar activity parameters. 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 solar parameters. Solar data have been taken from the website of NOAA (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA.html). Monthly mean grouped solar flare data from <https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/h-alpha/tables/documentation/number-of-solar-flare>, January 1965 to March 2009. Cross and multiple correlation study done by using 30 month average data for different solar parameters (SSN & GSF) and pressure corrected cosmic ray intensity data from different neutron monitor stations.

RESULTS AND DISCUSSION

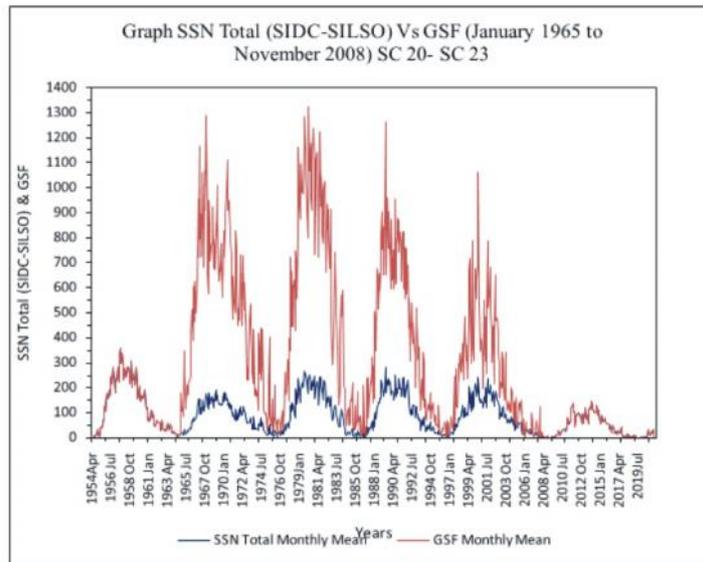


Fig.1: shows the graph between International SSN Total (SILSO) and GSF during SC 20 to SC 23 (January 1965 to November 2008).

The maximum monthly mean GSF value is found to be 1109 , in the year December 1967. GSF value is found to be minimum in the year October 1996, and the value is 0 .The cross correlation between SSN Total (SIDC-SILSO) and GSF is found to be CC H” 0.843 high positive correlation during SC 20 to SC 23.

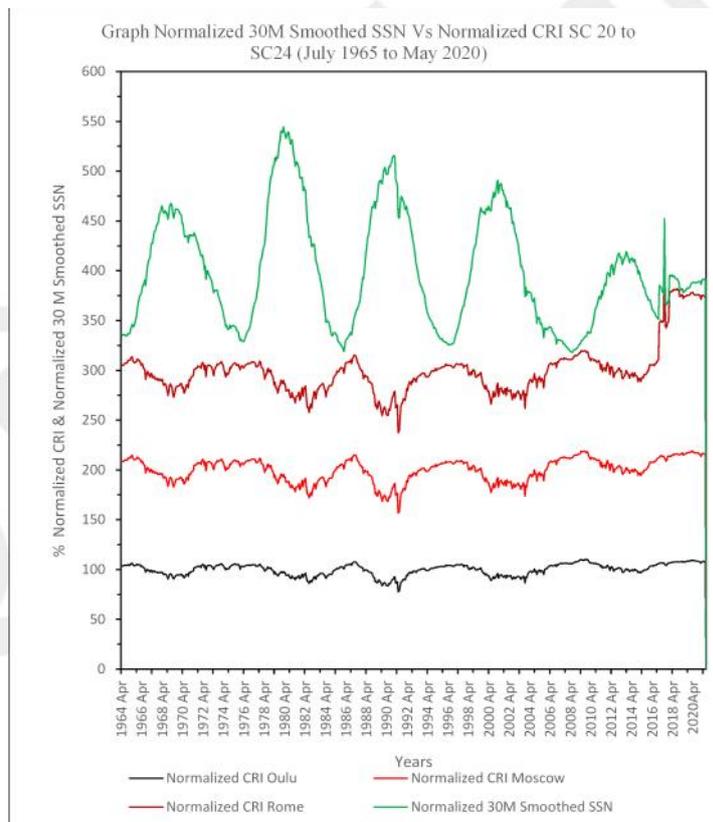


Fig.2 : shows the Graph between Normalized 30 month smoothed SSN Vs Normalized cosmic ray intensity (Oulu, Moscow & Rome) during solar cycle 20 to solar cycle 24 (July 1965 to May 2020).

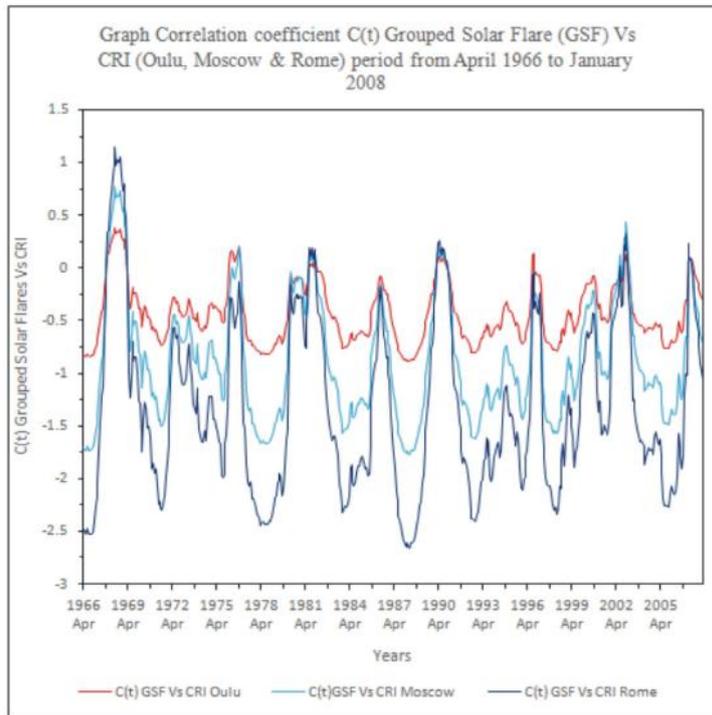


Fig.3 : shows the graph between cross correlation coefficient $C(t)$ GSF Vs CRI (Oulu, Moscow & Rome) with years during April 1966 to January 2008.

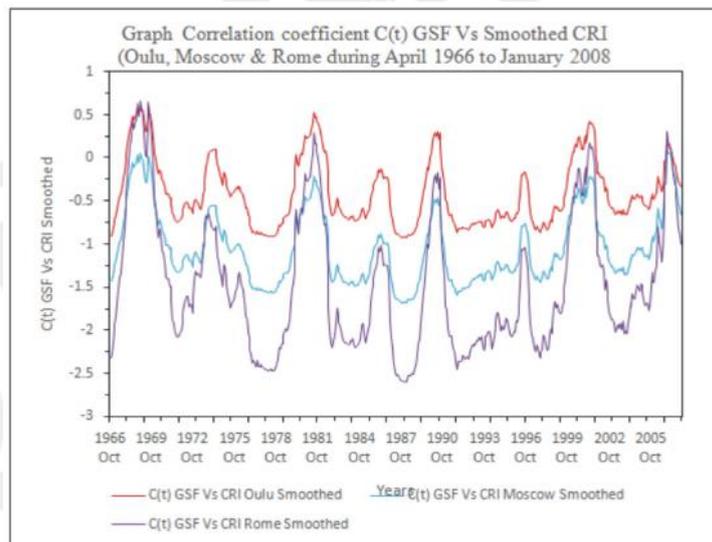


Fig.4 : shows the Cross correlation between GSF and Cosmic ray intensity (Smoothed) of Oulu, Moscow and Rome neutron monitor count rates from April 1966 to January 2008.

Table-1: Cycle-wise Correlation Coefficient C(t) between CRI (Oulu, Moscow & Rome) and monthly mean SSN Total (SIDC-SILSO) for SC 19 to SC 24.

Solar Cycles (SC)	Correlation coefficient C(t)		
	Oulu	Moscow	Rome
SC-19 (1954.3-1964.8) (Apr1954-Oct 1964)	-0.656	-0.916	-0.915
SC-20 (1964.8-1976.5) (Oct 1964-June 1976)	-0.836	-0.812	-0.799
SC-21 (1976.5-1986.7) (June1976-Sep 1986)	-0.588	-0.631	-0.628
SC-22 (1986.7-1996.9) (Sep1986-Oct 1996)	-0.913	-0.915	-0.885
SC-23 (1996.9-2008.9) (Oct 1996-Dec 2008)	-0.787	-0.769	-0.821
SC-24 (2008.9-2019.9) (Dec 2008-Dec 2019)	-0.861	-0.862	-0.590
April 1954 to December 2019 (SC19 to SC 24)	-0.807	-0.807	-0.433

It is well known that 11-year modulation of cosmic rays is anti-correlated with different solar parameters during the 11-year solar activity cycle. We have found the correlation coefficient $[C(t)H'' - 0.656]$ for CRI Oulu-SSN Total, $[C(t)H'' - 0.916]$ for CRI Moscow- SSN Total and $[C(t)H'' - 0.915]$ for CRI Rome-SSN Total for solar cycle19. Similarly we have calculated correlation coefficient between SSN Total and CRI (Oulu, Moscow & Rome) for the solar cycles 20 $[C(t)H'' - 0.836, -0.812$ and $- 0.799]$, for the SC21 $[C(t)H'' - 0.588, -0.631$ and $-0.628]$, for SC 22 $[C(t)H'' - 0.913, -0.915$ and $-0.885]$, for SC 23 $[C(t)H'' - 0.787, -0.769$ and $-0.821]$ and for SC 24 $[C(t)H'' - 0.861, -0.862$ and $-0.590]$ alternately. It has been found that the correlation coefficient between CRI-SSN is low, $C(t)H'' - 0.453$ for Rome, and correlation coefficient between CRI-SSN is high , $C(t)H'' - 0.807$ for both Oulu and MoscowNM stations during SC 19 to SC 24.

Table-2: Cycle-wise Correlation Coefficient between CRI (Oulu, Moscow & Rome) and GSF for different phases of the solar cycle 19 to 24.

Solar Cycle(SC)		Correlation CoefficientC(t)		
		Oulu	Moscow	Rome
SC-20 (1964.8-1976.5)(Oct 1964-June 1976)	SC20	-0.741	-0.684	-0.681
	ASC	-0.758	-0.781	-0.710
	DESC	-0.753	-0.709	-0.738
SC-21 (1976.5-1986.7)(June1976-Sep 1986)	SC21	-0.628	-0.668	-0.674
	ASC	-0.878	-0.863	-0.859
	DESC	-0.654	-0.717	-0.675
SC-22 (1986.7-1996.9)(Sep1986-Oct 1996)	SC22	-0.847	-0.850	-0.814
	ASC	-0.888	-0.883	-0.886
	DESC	-0.898	-0.893	-0.861
SC-23 (1996.9-2008.9)(Oct 1996-Dec 2008)	SC23	-0.590	-0.579	-0.655
	ASC	-0.659	-0.680	-0.635
	DESC	-0.704	-0.666	-0.743
Period January 1965 to March 2009	C(t)	-0.582	-0.542	-0.583

Correlation coefficient between Cosmic ray intensity and GSF has been calculated for both ascending and descending phase of SC 20 to SC 23 for Oulu, Moscow and Rome (Table-2). For entire period January 1965 to March 2009 Correlation coefficient C(t) is found to be -0.582, -0.542 and -0.583 alternately for all these three stations .

The correlation coefficient between CRI and different solar activity parameters with time-lag has also been calculated for the SC 20 to SC 23 using the method of “Minimizing correlation coefficient

method “. Here we have selected both the series cosmic ray intensity and solar activity parameters for the same period with 0 time -lag and then shifted one series by a step of one months and calculated the cross correlation coefficient C(t) between both the series. Similarly, the other series has also been shifted by one months and the value of cross correlation coefficient C(t) is calculated. As much, the time (number of shifted months) is obtained, when the anti-correlation (negative) coefficient value is maximum. This is the time-lag between both the series CRI and Solar activity parameter. Moreover, probable error (P.E.) for each value of correlation coefficients has been calculated by the formula: P.E. = $0.6745(1-r^2) / \sqrt{N}$.

Table-3 Cycle-wise Maximum correlation coefficient between CRI (Oulu, Moscow & Rome) and SSN Total (SIDC-SILSO) for solar cycles 19 to 24 with Probable Error and Time -Lag.

Solar Cycles (SC)	Correlation coefficient (r) & Probable Error			Time-Lag		
	Oulu	Moscow	Rome	Oulu	Moscow	Rome
SC19	NA	-0.9084 ±0.0144	-0.9094 ±0.0136	NA	15 Month	0Month
SC20	-0.8664 ± 0.01463	-0.9029 ±0.01049	-0.8250 ±0.01814	6 Month	3 Month	0 Month
SC21	-0.8078 ±0.02104	-0.8280 ±0.019044	-0.7978 ±0.02201	1 Month	1 Month	15Month
SC22	-0.9211 ±0.009256	-0.9052 ±0.011029	-0.9095 ±0.01055	4Month	4 Month	4 Month
SC23	-0.8061 ±0.0194	-0.8018 ±0.01986	-0.8020 ±0.01984	6 Month	6 Month	12Month
SC24	-0.9168 ±0.009327	-0.9134 ±0.0096912	-0.8384 ±0.0173	4 Month	0 Month	4 Month

The mean time-lag observed between cosmic ray intensity and SSN Total is estimated to be about 0 to 15 month for Oulu , Moscow & Rome NM stations during SC 19 to SC 24. It is found that the SSN are highly negatively or anti-correlated (~ -0.7978 to -0.9211) with cosmic ray intensity for Oulu, Moscow & Rome.

Table-4: Cycle-wise Maximum correlation coefficient between CRI (Oulu, Moscow & Rome) and GSF for solar cycles 20 to 23 with Probable error (P.E.) and Time-Lag.

Solar Cycles (SC)	Correlation coefficient (r) & Probable Error			Time-Lag		
	Oulu	Moscow	Rome	Oulu	Moscow	Rome
SC20(1964.8-1976.5) (Oct 1964-June 1976)	-0.8433 ± 0.01756	-0.8870 ± 0.01296	-0.7999 ± 0.021904	1 Month	3 Month	1Month
SC21(1976.5-1986.7) (June 1976-Sep 1986)	-0.8229 ± 0.019554	-0.8475 ± 0.01706	-0.7750 ± 0.02604	1 Month	6 Month	5 Month
SC22(1986.7-1996.9) (Sep 1986-Oct 1996)	-0.8878 ± 0.01293	-0.88027 ± 0.01374	-0.8862 ±0.01312	0 Month	0 Month	0 Month
SC23(1996.9-2008.9) (Oct 1996-Dec 2008)	-0.7971 ± 0.02109 (P.E.)	-0.7761 ±0.0230 (P.E.)	-0.7836 ±0.02232 (P.E.)	1 Month	8 Month	1Month

The mean time-lag observed between cosmic ray intensity and GSF is estimated to be about 0 to 8 month for all these NM stations (Oulu, Moscow & Rome) during SC 20 to SC 23. It is found that GSF is also highly negatively or anti-correlated (~ -0.7750 to -0.8878) with cosmic ray intensity for all these stations.

CONCLUSION

1. There is a strong inverse correlation between cosmic ray intensity with sunspot numbers. With cosmic rays being minimum during period of high solar activity and maximum during low solar activity. The correlation is generally stronger on a cycle by cycle basis.
2. During the period 1954 to 2021 the average time-lag observed between cosmic ray intensity and SSN Total (SIDC-SILSO) is estimated to be approximately 0 to 8 month for Oulu, Moscow & Rome NM stations.
3. The mean time-lag observed between cosmic ray intensity and SSN Total is estimated to be about 0 to 15 month for Oulu, Moscow & Rome NM stations during SC 19 to SC 24. It is found that the SSN are highly negatively or anti-correlated (~ -0.7978 to -0.9211) with cosmic ray intensity for Oulu, Moscow & Rome.
4. The mean time-lag observed between cosmic ray intensity and GSF is estimated to be about 0 to 8 month for all these NM stations during SC 20 to SC 23. Same way it is found that GSF is also highly negatively or anti-correlated (~ -0.7750 to -0.8878) with cosmic ray intensity for all these stations.
5. SSN Total (SIDC-SILSO) shows high negative correlation $C(t) \text{ vs } H^+$ -0.807 with CRI count rates for both Oulu and Moscow Cosmic ray neutron monitor stations. Moderate correlation $C(t) \text{ vs } H^+$ -0.433 observed for Rome CRI counts with SSN Total (SIDC-SILSO).
6. When correlation coefficient between CRI and SSN for different solar cycles (19 to 24) is considered with time-lag, it is found that the time-lag is larger for odd solar cycles and it is smaller for even solar cycles for all the three stations (Oulu, Moscow & Rome), which supports the odd-even hypothesis of cosmic ray modulations.

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