Physical Science International Journal

24(6): 44-55, 2020; Article no.PSIJ.58988
ISSN: 2348-0130

Heliospheric Modulation of GCR at Mid and High Latitudes

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Authors' contributions

This work was carried out in collaboration among all authors. Author KCO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DFK and NONA managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/PSIJ/2020/v24i630198
Editor(s):
(1) Dr. Lei Zhang, Winston-Salem State University, USA.
(2) Dr. Thomas F. George, USA.
Reviewers:
(1) Roshni Dave, India.
(2) Jan Louis Raath, North-West University, South Africa.
(3) Caio Lagana Fernandes, University of Sao Paulo, Brazil.
(4) Mukesh K. Jothe, Barkatullah University Institute of Technology, India.
(5) Abdelmadjid Maireche, University of M'sila, Algeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/58988

Original Research Article

Received 23 May 2020
Accepted 29 July 2020
Published 07 August 2020

ABSTRACT

The variations of Galactic Cosmic Ray (GCR) as compared with the behaviour of various solar activity indices, heliospheric parameters and the geomagnetic index Ap during 1999-2015, which covers part of cycles 23 and cycle 24 have been studied. Two sets of data were considered, consisting respectively of all days of the month and the five quietest days. Neutron Monitor Stations of Moscow and Rome (mid latitude stations) and Inuvik and Oulu (High latitude stations) were employed. Cosmic Ray (CR) wave characteristics were obtained by the harmonics method. The mean, diurnal amplitude of the first, second, and third harmonics were calculated and profiled. Furthermore, correlation analysis was carried out to determine the association between parameters. Results showed that the total magnetic field B_T and the sunspot number (SSN) showed the strongest association with CR in both quiet conditions and all day conditions considered. The higher harmonics showed a slightly stronger association with CR than lower

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harmonics. A time-lag of about 12-15 months was observed for SSN suggesting a potential for predicting CR flux, while the total magnetic field had a zero lag for all the heliospheric parameters considered.

Keywords: Heliosphere; galactic cosmic ray; neutron monitors; solar activity.

1. INTRODUCTION

CRs play an important role in the solar system, such as in Climate Change [1], and its usefulness in space weather application [2]. A lot of researches have tried to understand the variability of CR because of their possible effects on geophysical processes. The diurnal variation of CR is the result of a complex combination of the effects of the interplanetary magnetic field (IMF) and geomagnetic field in addition to the rigidity and latitudes of the location on the troposphere. Among such researchers include [3-10]. The simple harmonic analysis of the diurnal variation of CR has been applied by authors such as [11,12,9,6,10] and their linear association with different drivers investigated by a few works [13].

GCRs are modulated in the heliosphere because of the variable solar magnetic activity, and this modulation varies in the course of the solar cycle. The level of modulation greatly depends on the energy level of the CR particles. Solar wind dynamics and the IMF play an important role in determining the electrodynamics of the heliosphere, they also determine the convection and adiabatic energy changes that occur in the heliosphere, there is therefore a strong association between IMF and GCR as suggested by Cane et al. and Belov [14,15]. Usoskin et al. also observed that the correlation of the solar and heliospheric parameters is stronger during negative polarity than the positive polarity of the solar magnetic cycle [16].

GCR measured in the earth are affected by the conditions in which they are transported throughout the heliosphere and geosphere. These modulations vary with varying solar activities, however, during shorter time scales, CR are modulated in the heliosphere primarily by the globally merged interaction region with intense magnetic fields. Okpala et al. established that the interplanetary magnetic field was the most dominant modulating parameter especially during quiet conditions, and the solar wind dynamic pressure was more effective during the disturbed conditions [13]. The solar modulation of CR intensity has been extensively investigated in the past by using the data of ground based detectors in association with various solar, interplanetary and geomagnetic parameters [17,18]. The solar terrestrial relationships provide important factor to explain the aspects of 11 and 22 years variation of GCR [19]. Many authors have found common and sometimes conflicting associations between GCR intensity and solar heliospheric parameters [20]. Mitrokotsa et al. reported a time lag of 13 to 16 months between sun spot number (SSN) and GCR flux, whereas recent studies have shown a time lag of 2 to 4 months [21,22]. There is a common consensus that a wide range of processes lead to the modulation of GCR flux on the surface of the earth [23].

CR can enter the heliosphere through the heliospheric neutral sheets, especially during negative polarity minima their intensity at 1 AU is more sensitive to the warpedness of the neutral sheets during the recording phase of odd cycles, this leads to slower recovery of CR flux for $qA < 0$ cycles, and it is therefore observed that odd CR cycles are longer than even CR cycles [16]. There is also a significant difference in the solar modulation of CR during positive and negative magnetic cycles, and the rigidities of the neutron monitors contribute little or no difference to the different modulation of CR during odd and even cycles [24]. Mavromichalaki et al. established that the time lag for solar indices is higher than those of heliospheric indices, when associating these indices with CR [20]. Generally solar and heliospheric indices show an anti-correlation with CR intensities. However, the nature and extent of heliosphere modulation of CRs especially during quiet conditions are not completely known. The objective of this study is to investigate the heliospheric modulation of GCR. Specifically, the study shall identify the nature of- and calculate the extent of- association between GCR (mean, amplitude of harmonics) and key heliospheric features (including time lag) for quiet days and all days in a given month at mid and high latitudes.

2. DATA AND ANALYSIS

2.1 Sources of Data

The following data (see Table 2) were used; i) Ap index obtained from the World data Center for Geomagnetism, Kyoto, Japan (http://wdc.kugi.kyoto-u-ac.jp/), ii) Magnetic field total (B_T) and the Flow Speed (FS) of the solar wind from Omniweb plus (http://omniweb.gsfc.nasa.gov/). ii) Flare Index (FI) from Kandilli Observatory Turkey (http://ngdc.noaa.gov/stp), iv) Number of Coronal Mass Ejections per month (NC) from Solar and Heliospheric Observatory (http://cdaw.gsfc.nasa.gov/) and the sunspot number (SSN) was from National Geophysical Data Center, USA. The CR count rates from two mid latitude stations (Rome and Moscow) and two high latitudes (Oulu and Inuvik) were used. The data set consists of hourly mean count rates and span the years 1999-2015. The data were obtained from the archives of the neutron monitor counts at Inuvik, Moscow, Rome, Oulu. Details of the sources of data are seen in Table 2, while the details of the stations are presented in Table 1.

The details of the four stations used are shown in Table 1.

2.2 Harmonic Analysis

The amplitude and phase of the harmonics of the daily variations of CR Intensity as derived after Chapman and Bartels were computed by the harmonic analysis. The harmonic analysis provides reliable measures of the amplitude and the phase of a reasonably stationary time series provided the amplitudes are sufficiently large [25].

Time dependent harmonic function F(t) with 24 equidistant points in the interval from t = 0 to t = 2π can be expressed in terms of Fourier Series;

$$F(t) = a_o/2 + \sum_{n=1}^{24}\left(a_n cos(nt) + b_n\, sin(nt)\right) \quad (1)$$

$$F(t) = a_o + \sum_{n=1}^{24}(r_n cos(nt) - \varphi_n) \quad (2)$$

Where a_o is the mean value of the F(t) for the time interval from t = 0 to 2π and a_n and b_n are the coefficients of the nth harmonics, which can be expressed as follows;

$$a_o = \frac{1}{12}\sum_{i=1}^{24} n \quad (3)$$

$$a_n = \frac{1}{12}\sum_{i=1}^{24} n\cos nt \quad (4)$$

$$b_n = \frac{1}{12}\sum_{i=1}^{24} n\sin nt \quad (5)$$

The amplitude r_n and phase φ_o of the nth harmonic are obtained from eqns. 4 and 5 as:

$$r_n = (a_n^2 + b_n^2)^{1/2} \quad (6)$$

And

$$\varphi_{n= tan^{-1}}\left[\frac{a_n}{b_n}\right] \quad (7)$$

The diurnal variation of the CR intensity can be adequately represented by the superposition (eqn 8) of the first three harmonics as follows [11];

$$F(t) = a_1\cos t + b_1\, sint + a_2 cos2t + b_2 sin2t + a_3 cos3t + b_3\, sin3t \quad (8)$$

Harmonic analysis for monthly CR counts for solar quiet days as well all days were performed for the four neutron monitor stations. The first three harmonics and the phase of the time series for the period of 1999 – 2015 were thus calculated.

Table 1. CR stations and their details

Station	Latitude (°)	Longitude (°)	Altitude (m)	Cut off rigidity (GV)	Type of neutron monitor
INUVIK (INV)	68.35	226.28	21.00	0.18	18NM64
MOSCOW (MOS)	55.08	37.60	200.00	2.43	24NM64
OULU (OUL)	65.05	25.47	0.00	0.81	9NM64
ROME (ROM)	41.90	12.52	60.00	6.32	20NM64

2.3 Monthly Means

The mean solar Sq amplitude (ΔH_{sq}) is calculated (from eqn. 9) as the mean of the hourly values from the five international quiet days for the month

$$X_i = \frac{1}{5}\sum_{j=1}^{5} C_{ij} \qquad (9)$$

C_{ij} is the CR count rate for a particular hour, i, for a given quiet day, j (j = 1 to 5).

While for the all days we employ equation 10,

$$X_{all} = \frac{1}{n}\sum_{j=1}^{n} C_{ij} \qquad (10)$$

C_{ij} = the CR count rate for a particular hour, i for every day of the month, j = 1 to 30
n = the number of days in a month,
j = 1 to n

Equation 11 is the measure of the fit of equation, which is also the dispersion relation.

$$d = \sum_{i=1}^{n} d^2 = \sum_{i=1}^{n}[Y_i - F(t_i)]^2 = \sum_{i=1}^{n}[Y_i - I_i]^2 = minimum \qquad (11)$$

Where Y_i, is the data point at time i, n = 24(hours),

Table 2. Sources of data

Parameter	Source of data	Website
Ap index	World Data Center, Kyoto	http://wdc.kugi.kyoto-u-ac.jp/
Magnetic field B total (B_T)	Omniweb plus	http://omniweb.gsfc.nasa.gov/
Flare Index (FI)	Kandilli Observatory	http://ngdc.noaa.gov/stp
Flow Speed (FS)	Omniweb plus	http://omniweb.gsfc.nasa.gov/
Number of Coronal Mass Ejections per month (NC)	Solar and Heliospheric Observatory	http://cdaw.gsfc.nasa.gov/
Sunspot Number (SSN)	National Geophysical Data Center	http://ngdc.noaa.gov/
Inuvik Station data (INV)	Bartol Research Institute	http://neutronm.bartol.udel.edu
Moscow Station data (MOS)	Moscow Neutron Monitor	http://cosrays.izmiran.ru
Oulu Station Data (OUL)	Oulu Neutron Monitor	https://cosmicrays.oulu.fi
Rome Station Data (ROM)	Rome Neutron Monitor	http://cr0.izmiran.ru

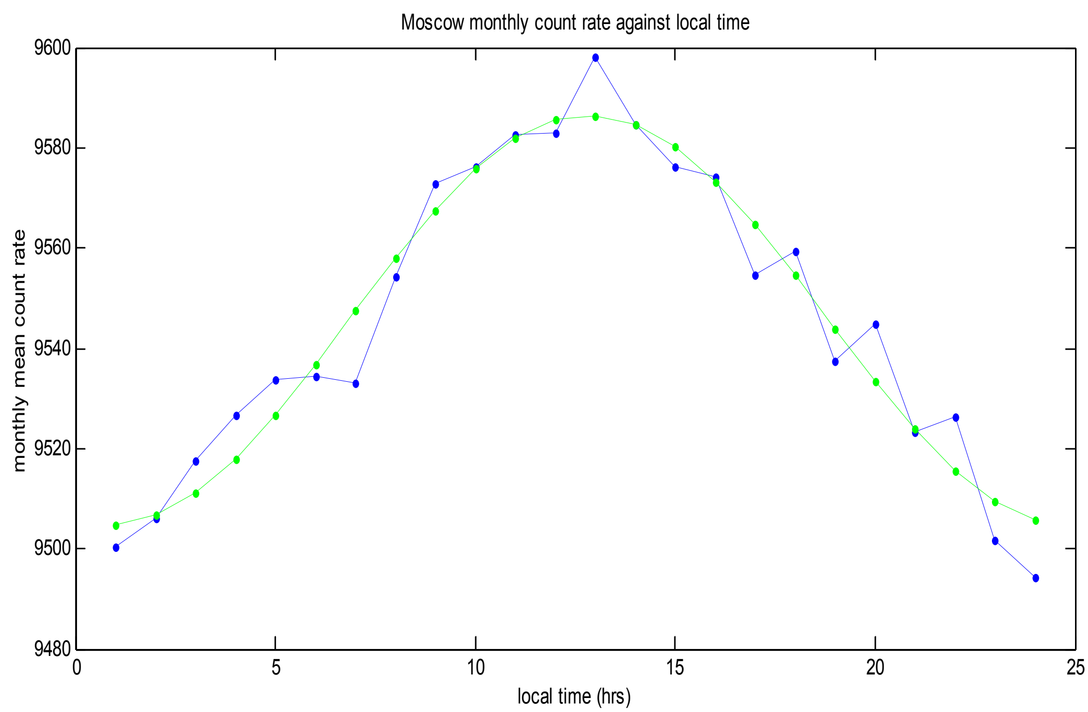

Fig. 1. Illustration of Sq variation on the first Harmonic

2.4 Count Rates

The count rates for all the stations were normalized such that the value of the mean of October 2007 was 100%, this is to reduce the effect of the difference in the instruments from one station to the other. The profile of the monthly mean count rates is shown in Fig (2A) and Fig. (2B), for all days and quiet days conditions respectively.

It is clearly seen that both all days and quiet days conditions have similar profiling, although there is a general reduction in count rates during quiet days.

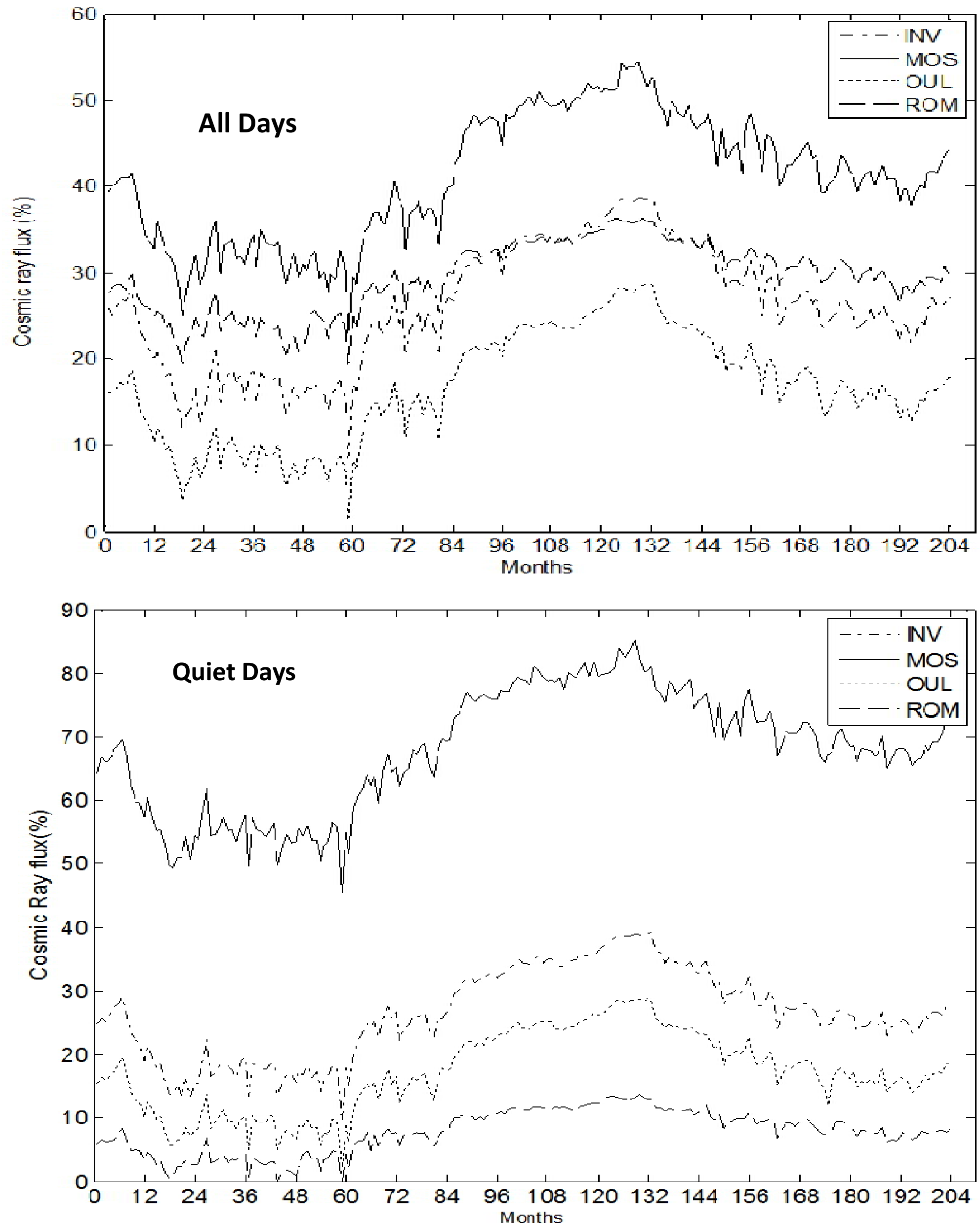

Fig. 2. Time series of the monthly mean for all the stations; All days and Quiet days respectively. 1 in the horizontal axis represents the first month of the time series. The CR flux is in % of the value for Oct, 2007

2.5 CR Time-Series Profiles

The plots for the time series profiles between solar and heliospheric parameters and CR are shown in Fig. 4(A &B) for all days and quiet days respectively. The plots were grouped according to their different functions; the geomagnetic parameters, the magnetic field parameters and the particulate emission parameter. These parameters were plotted together on two horizontal axes with the CR of the two rigidity extremities (Rome and Inuvik), used in the work. The B_T values were generally multiplied by 20.

2.6 Correlation Analysis

Cross correlation analysis was performed with a 95% significance level to calculate the association between each of the parameters and CR intensities, both for the Sq days, and for all the days. The values of the cross correlation analysis are represented in Table 3 and Table 4, along with their different time lags.

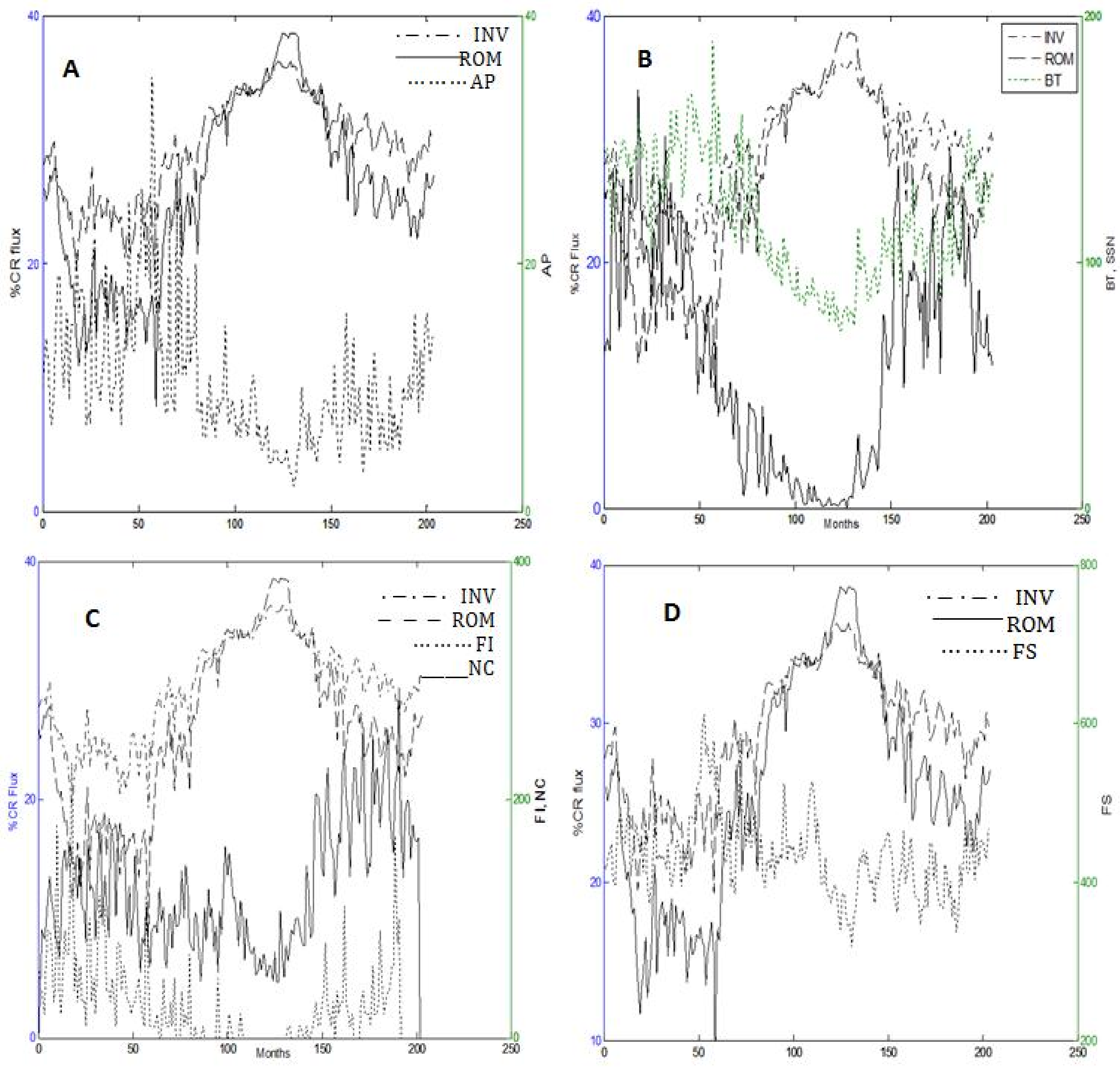

Fig. 3. Profiles of A- AP index, B-Total magnetic field and SSN, C-FI and NC and D-FS monthly variation for all days. Each have been superposed with the ROM and INV CR flux for the same period. The First month on the x-axis is Jan, 1999

Table 3. Correlation and time lag table for quiet days conditions

Station	Parameter	Mean (lag in months)	1st Harmonic (lag in months)	2nd Harmonic (lag in months)	3rd Harmonic (lag in months)
INV	AP	-0.67(0)	0.24(-45)	0.24(-46)	0.20(-46)
	BT	-0.67(0)	0.18(-15)	0.24(0)	0.17(-53)
	FI	-0.53(+12)	0.20(-13)	0.34(-11)	0.13(-11)
	FS	-0.56(0)	0.22(-45)	0.27(-13)	0.19(-24)
	NC	0.29(-71)	0.26(-195)	0.32(-172)	0.34(-196)
	SSN	-0.77(14)	0.16(28)	0.32(-1)	0.19(-11)
MOS	AP	-0.66(1)	0.19(28)	0.24(-43)	0.20(-12)
	BT	-0.71(0)	0.16(16)	-0.22(-27)	0.19(-40)
	FI	-0.54(11)	0.19(53)	0.26(-1)	0.23(13)
	FS	-0.57(0)	0.18(26)	0.22(-53)	0.24(-13)
	NC	0.28(-74)	0.17(-198)	0.21(-196)	0.27(-199)
	SSN	-0.72(15)	0.14(52)	0.30(3)	0.20(14)
OUL	AP	-0.66(1)	0.19(24)	0.20(125)	0.23(20)
	BT	-0.68(0)	0.15(-63)	0.14(130)	0.16(-165)
	FI	-0.53(11)	0.22(132)	0.25(156)	0.29(46)
	FS	-0.57(0)	0.18(24)	0.17(123)	0.24(22)
	NC	0.29(-72)	0.56(-28)	0.56(-28)	0.58(-129)
	SSN	-0.76(12)	0.12(-7)	0.13(-13)	0.14(-18)
ROM	AP	-0.65(1)	0.22(-33)	0.25(12)	-0.26(24)
	BT	-0.72(0)	0.20(-40)	0.16(18)	-0.25(24)
	FI	-0.55(12)	0.22(-13)	0.25(23)	0.30(114)
	FS	-0.56(0)	0.20(-29)	0.27(5)	0.25(24)
	NC	0.28(-73)	0.20(-145)	0.46(-137)	0.32(-71)
	SSN	-0.73(13)	0.27(-13)	0.19(0)	-0.28(-40)

Table 4. Correlation values and time lags for all days condition

Station	Parameter	Mean (lag in months)	1st Harmonic (lag in months)	2nd Harmonic (lag in months)	3rd Harmonic (lag in months)
INV	AP	-0.71(0)	-0.20(-34)	0.4(0)	0.27(-30)
	BT	-0.86(0)	-0.20(-24)	0.3(0)	0.19(0)
	FI	0.41(-72)	-0.16(-38)	0.33(-176)	0.49(27)
	FS	0.55(31)	0.19(-15)	0.34(0)	0.24(-26)
	NC	+0.41(71)	0.16(-38)	0.33(-176)	0.49(27)
	SSN	-0.81(+4)	0.19(51)	0.23(18)	0.19(9)
MOS	AP	-0.71(1)	0.22(0)	0.26(9)	0.47(0)
	BT	-0.87(1)	0.25(0)	0.22(9)	0.36(0)
	FI	0.41(-71)	0.17(27)	0.25(-175)	0.40(-145)
	FS	-0.54(-37)	0.20(-45)	0.20(-45)	0.30(-15)
	NC	0.41(-71)	-0.18(-38)	-0.25(-175)	0.40(-145)
	SSN	-0.73(11)	0.18(38)	015(-4)	0.25(22)
OUL	AP	-0.72(0)	0.17(15)	0.18(0)	0.40(22)
	BT	-0.87(1)	0.11(20)	-0.14(-47)	0.20(22)
	FI	0.42(-72)	0.17(-176)	0.32(-122)	0.53(-123)
	FS	-0.55(-37)	-0.17(70)	0.23(23)	0.35(27)
	NC	0.42(-71)	0.17(72)	0.32(-122)	0.53(-123)
	SSN	-0.80(14)	0.13(54)	0.10(65)	0.22(63)
ROM	AP	-0.70(0)	0.39(8)	0.39(8)	-0.22(35)
	BT	-0.88(1)	0.40(0)	0.36(8)	-0.24(27)
	FI	0.40(-72)	0.18(27)	0.29(-137)	0.31(0)
	FS	-0.55(-36)	0.21(-45)	0.26(-30)	0.23(67)
	NC	0.40(-73)	-0.19(-40)	0.29(-137)	0.31(0)
	SSN	-0.77(13)	0.31(13)	0.24(13)	0.24(-33)

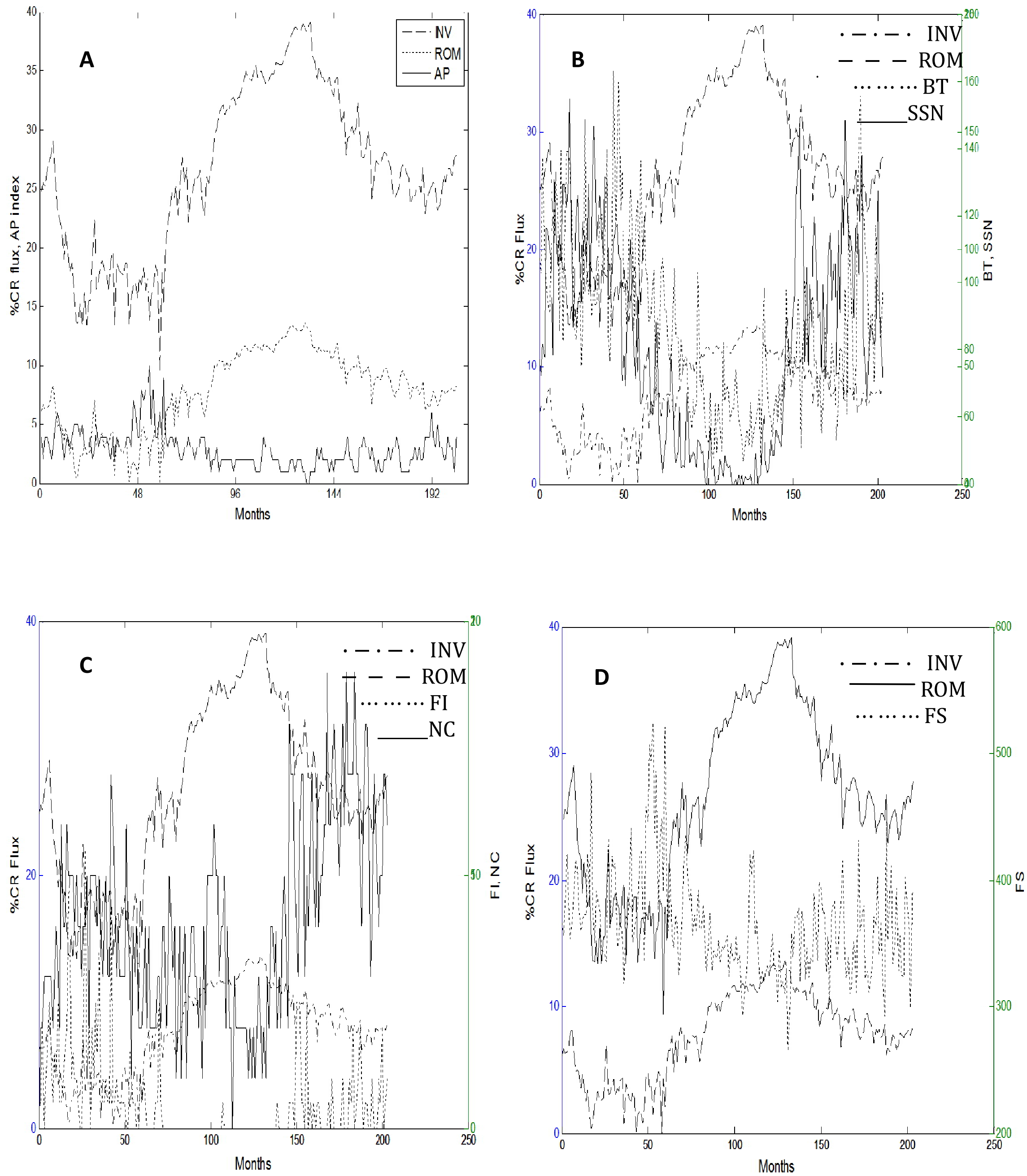

Fig. 4. Profiles of A- AP index, B-Total magnetic field and SSN, C-FI and NC and D-FS monthly variation for quietest days. Each have been superposed with the ROM and INV CR flux for the same period. The First month on the x-axis is Jan, 1999

2.7 Interstation Correlation

Table 5 shows the correlation values of the different stations, and the stations were highly correlated.

Table 5. Interstation correlation

	INV	MOS	OUL	ROM
INV	1.00	0.98	0.97	0.98
MOS		1.00	0.99	0.98
OUL			1.00	0.96
ROM				1.00

3. HELIOSPHERIC MODULATION OF GCR (DURING QUIET DAYS)

Fig. 2B shows the time series of the GCR under quiet conditions for all the stations. The GCR variability under quiet conditions represents changes that are associated with minimal heliospheric disturbances and other transient events. It is important to note that solar transients such as solar flares, and weak coronal mass ejections could occur during designated quiet conditions. Such events may not have significant effects on the geomagnetic field as this depends on the geoeffectiveness of the transient [26]. However, the heliosphere as a whole is expected to be impacted by such transients and consequently, the GCR entering into it. Since the heliosphere consists of magnetic component and particulate component, the heliospheric modulation considered are under magnetic component drivers (ie sunspot number and total magnetic field B_T), and particulate component drivers (Number of coronal mass ejection NC, flare index and Flow Speed).

Fig. 4A is a profile of the GCR variability and the geomagnetic Ap index. Fig. 4B is a profile showing the comparison between the time series of GCRs and the magnetic component drivers SSN and BT. Fig. 4C and D is the same profile with the particulate component, FI, NC and FS respectively. The CRs presented in the Fig. 4 are for Rome and Inuvik. They represent the general trend in the fluctuations of the extremities in the CR rigidity (high rigidity Rome, and low rigidity Inuvik). The rigidities have a much stronger effect on the amount of GCRs reaching the stations.

The geomagnetic field is expected to modulate GCRs since the rigidity of the CRs reaching the earth is expected to alter in response to the change in the magnetic field. The variation of the CR flux in all the stations are expected to be similar. This is reflected in the very strong correlation shown in Table 5 for all stations and is a validation of the results obtained in our analysis of the quiet condition. The Ap index showed a correlation of ≥ 0.65 in all the stations considered in this study (see Table 3). Fig. 4A depicts the inverse association of Ap with CR flux.

There was reduction in the CR flux during solar maximum years 2000 to 2004 and a repeat at the maximum close to 2015. Monthly fluctuations in the Ap index is largest during the declining phase of the solar cycle 23 and the rising phase of the cycle 24. As expected, the Inuvik station has a higher CR flux since its rigidity is lower than the rigidity at the Rome station. This lower rigidity of Inuvik makes it apparently more susceptible to strong fluctuations in its CR flux when compared to other stations of higher rigidity like Rome. It is equally important to note that the difference in the CR flux during weak geomagnetic activity (in Fig. 4) is larger than the difference during the period of strong geomagnetic activity. For instance, it is observed that the largest difference in the CR flux between low rigidity station and high rigidity station occurred during the solar minimum years of 2007-2009. In addition, the large difference during the rising phase of cycle 24 and near its peak is a reflection of the dependence of the flux on the geomagnetic disturbance which may also be related to the solar activity. Solar activity correlates well with geomagnetic activity since they are intricately connected (Okpala *et al*. 2014), hence observation here is an indication of the indirect effect of solar activity on the CR flux especially on the observed association between Ap index and CR flux (see Table 3) [13].

The B_T showed a strong association with the GCR intensity, with a correlation value of ≥ 0.67 across all stations, and showed zero lag with the GCR flux, however, the association is inverse as seen in Fig. 4B. Monthly fluctuations are high during solar maximums and lower during solar minimums, this also applies to the GCR flux. It is however, noticed that there seem to be an overlap between B_T and SSN during the maximum phases. Correlation between SSN and the average of the CR intensity during quiet conditions showed a larger time lag (≥12 months) when compared with the B_T parameter. Mavromichalaki, observed similar time lags during odd cycles [20]. The time lags associated with the harmonics were quite large for both the SSN and B_T parameters, although for the B_T parameter, the harmonics increased as the latitude decreased, while for the SSN, the harmonics increased as the latitude increased.

Considering the particulate emission parameters, the flow speed FS was observed to show an inverse relationship with the GCR flux, as seen in Fig. 4D. The profile of the FS- showed a similar trend with other heliospheric parameters already discussed, that is, during periods of maximum, the fluctuations were higher and lesser during periods of minimum. The correlation was inverse and ≥ 0.56 with zero time lags. The amplitudes of the harmonics generally increased across all stations, as the degree of the harmonics increased. The number of monthly coronal mass ejection NC and flare index FI, were observed to show an inverse relationship with the GCR flux, as seen in Fig. 4C and also showed similar trends with the rest of the heliospheric parameters. The correlation was ≥ 0.28 and ≥ 0.53 respectively for NC and FI, while the correlation of the harmonics increased as the degree of the amplitude increased. The time lag of NC was very high; the reason for these high time lag is unclear, but may be related to solar activity.

Although the means of these parameter showed some correlation and association with GCR intensities, it was observed that the amplitudes of the harmonics of the particulate emission showed more useful association as compared with the amplitudes of the harmonics of the magnetic field parameters. It was also observed that the higher the harmonics, the higher the value of the correlation. Therefore, when dealing with the energetic emission parameters one would get more information from the amplitudes of the harmonics as compared with their means.

4. HELIOSPHERIC MODULATION OF GCR UNDER ALL DAYS CONDITIONS

Fig. 3 (A-D) shows the time series of the GCR under all days conditions. Since the heliosphere consists of magnetic component and particulate component, the heliospheric modulation is discussed under magnetic component drivers (i.e. sunspot number and total magnetic field BT), and particulate component drivers (Number of coronal mass ejection NC, flare index and Flow Speed).

Fig. 3A is a profile of the GCR variability and the geomagnetic Ap index. Fig. 3B is a profile showing the comparison between the time series of GCR and the magnetic component drivers SSN and B_T. Fig. 3C is the same profile with the particulate component, FI, NC, and Fig. 3D shows the profile with FS. The CR presented in Fig. 3 are for Rome and Inuvik. They represent general trend in the fluctuations of the extremities in the CR rigidity (i.e. high rigidity Rome, and low rigidity Inuvik), hence all the stations were not represented. The correlation (Table 4) gives details of stations association with the heliopsheric parameters. The Ap index showed a correlation of ≥ 0.70 in all the stations considered in this study (see Table 4) which is slightly higher than the value of the quiet conditions. Fig. 3A depicts the inverse association of Ap with CR flux.

There is no significant difference between the correlation coefficient for all days and quiet days, since the quiet days are also embedded in the all days conditions. However, the all days tend to have a slightly higher correlation values than quiet days, and generally had a time lag of zero (0) as compared with the quiet days which had a time lag of one (1), across all stations. Monthly fluctuations in the Ap index is largest during the declining phase of the solar cycle 23 and the rising phase of the cycle 24. However, in this case, Oulu had the highest CR flux and its rigidity is lower than the rigidity at the Rome station. It is equally important to note, just like in the quiet conditions that the difference in the CR flux during weak geomagnetic activity (in Fig. 4A) is larger than the difference during the period of strong geomagnetic activity (Fig. 3A)

With respect to the magnetic field parameters, The B_T showed a strong association with the GCR intensity, and had a correlation coefficient of ≥ 0.86 across all stations, and showed one-month time lag with the GCR flux, the association is inverse and strong as seen in Fig. 3B. it was also observed that the peaks of the profiles of the B_T and the SSN coincide with the peaks of the Ap profiles as shown in Fig. 3B and 3A respectively.

The correlation of the SSN with the GCR flux was also inverse and showed a high association (≥0.75) with a time lag ≥ 14 months except for INV. Reason for this departure is unclear. From Table 4, it was observed generally that higher rigidity stations like Moscow and Rome had higher correlation values than low rigidity stations, for the B_T parameter, while for the sunspot number, the reverse is the case. The time lags associated with the harmonics were quite large for both the SSN and BT parameters, For energetic emission parameters, The flow speed FS was observed to show an inverse relationship with the GCR flux, as seen in Fig. 3D. The amplitudes of the harmonics generally increased across all stations, as the degree of the harmonics increased as discussed in the quiet day conditions.

5. CONCLUSION

We studied the modulation of GCR on quiet days and all days, to identify their dependence and association with solar and heliopsheric parameters. Four stations (two high latitudes and two mid latitudes) were used in this study, the data covered 17 years starting from January 1, 1999, to December 31, 2015, which included solar cycles 23 and 24. From the preceding discussions, the following were established; there is a strong disparity between the strength of the CR flux for all days and for quiet days with respect to the rigidity of the stations. This is indicative of the effect of the disturbed heliosphere on the count rate of GCRs. The CR monthly mean counts in the four stations are highly correlated, showing similar temporal variation, whereas the means of the magnetic fields parameters such as the B_T and SSN showed more association with mean CR, in the case of the particulate emission parameters, the harmonics showed more association. The B_T and the SSN which are the two magnetic field parameters showed the strongest association with a CR in both quiet conditions and all days condition. Hence, the implications of the results show that the magnetic field components of the heliosphere are dominant in the modulation of GCR

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/58988