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Impact of Solar Wind and Earth's Magnetic Field on the Intensity of Cosmic Rays

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Galactic cosmic rays (gcr$_s$) are high energy particles mainly protons that are found in space and spread through our atmosphere. They come from all directions in space and the origin of some of them is unknown. Variations in gcr intensity observed at earth are due to irregularity of solar wind. Cosmic rays which travel towards the solar system are faced with outward flow of magnetized plasma known as solar wind and also heliospheric magnetic field (hmf). As cosmic rays travel; they interact with the solar wind and magnetic field which leads to changes in their energy and spectra. Short term variations of cosmic ray intensity were analysed in this work by using data obtained from a single neutron monitor (nm) for a period of two consecutive years. And the result shows that solar wind and earth's magnetic field contribute immensely to the variation in the intensity of cosmic rays.

Keywords: Cosmic rays; neutron monitors; solar wind; variation.

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1. INTRODUCTION

"Galactic cosmic rays (GCR_S) are very high energy particles which consist mainly of charged particles and some nuclei. The charged particles are chiefly protons (hydrogen nuclei), about 90%, helium nuclei about 9% and 1% traces of heavier elements" [1]. "These charged particles contribute an average density in the galaxy of about $1eVcm^{-3}$" [2]. "The charged particles and the nuclei have life time of order of 10^6years or more and carry energy of order of about 1MeV to 10^{20}eV; and have been accelerated by supernovae and other energetic sources in the Milky way galaxy" [3-4]. "The main flux is in the energy of a few GeV. The primary cosmic rays interact in the atmosphere at a height of about 30km where they produce showers of secondary particles mainly muons which penetrate the troposphere; below 7km" [5]. "Even though, there is much lower fluxes of electrons and positrons, these particles give us vital information on the sources of CR_s and the transport of these particles through the galactic magnetic field" [6]. "The secondary particles are detected on earth with ground-based detectors, such as neutron monitors. Neutron monitors are used to study cosmic radiation; because their large active volumes provide enough precision even for a low fluence of cosmic radiation" [7]. "These neutron monitors have been used for precise monitoring of time variations in the cosmic ray flux, which some routinely achieve 0.1% accuracy in hourly rates" [8].

"A star upon reaching supernova will leave behind remnants that are capable of lasting up to thousands of years. According to supernova remnants cosmic ray hypothesis; particles are accelerated by shock front of the supernova, a process known Fermi acceleration, and then further accelerated by the magnetic field" [9-10].

"Cosmic rays are considered to have energies above 1MeV and emanates from the outside the heliosphere with the exception of anomalous cosmic rays (ACR_s) which come from the heliosphere" [11]. "The galactic cosmic ray modulation in the heliosphere is produced by magnetic irregularities of Interplanetary Magnetic field (IMF)" [12]. "The magnitude of IMF and its irregularity density are defined by solar activity; and the density of these irregularities increases with the growth of IMF strength" [13]. "In the heliosphere, they interact with the solar magnetic field that is being carried by the solar wind. Galactic Cosmic Rays (GCR_S) encounter a turbulent solar wind within an enclosed heliospheric magnetic field (HMF) when entering the heliosphere. Because of this, their energy and directions are faced with temporal variations" [14]. "Also solar activity makes the heliosphere to undergo both short and long-term changes which manifest as temporal variations on the cosmic ray flux. This process is called solar modulation of cosmic rays (CR_S)" [10,14]. Along with calculations of CR propagations in the galaxies, the interpretation of the data requires intensive modeling of solar modulation effect. Solar modulation is experienced by all CR_s that enter the heliosphere to reach our detectors near the earth, [15].

2. METHODS

2.1 Data, Analyses

Two sets of data obtained from Mexican City Observatory (http://132.248.105.25/index.php) at aniezijoseph@gmail.com were used in this work. The intensity of the mean monthly count rates for each month was obtained from this equation:

$$I_i=\frac{1}{n}\sum_i^n R_i$$

Here I is the intensity of the monthly mean count rate, n is the number of days in each month and R is the raw cosmic ray count rate on daily basis.

2.2 Plots of Monthly Mean Count Rate

Figs. 1 and 2 are the plots of the monthly mean count rate against each month for 2016 and 2017 respectively.

2.3 Deriving the Relation between the Particle Speed and Speed of Light with Earth's Magnetic Field

The force acting on a low energy electron in a uniform magnetic field is giving as

$$F = \mathrm{Bqv} \quad (1)$$

B is the earth's magnetic field, q is the electron charge and v is its

This force makes the electron to undergo circular motion giving by

$$F = \frac{mv^2}{r} \quad (2)$$

Here, m is the mass of the particle, r is the radius of the circular part and v is its velocity. Equating equations 1 and 2, we have $\mathrm{Bqv} = \frac{mv^2}{r}$

$\frac{mv}{qB} = r$=or $q = \frac{mv}{rB}$, (3)

Again, the particle rigidity is defined as:

$\rho = \frac{pc}{q}$, i.e. $q = \frac{pc}{\rho}$ (4)

Where p is the particle's relativistic momentum, q is its charge and c is the speed of light in outer space.

Equating equations 3 and 4,we have

$\frac{mv}{rB} = \frac{pc}{\rho} \rightarrow mv\rho = rBpc$ (5)

Dividing through by rpc, we have

$\frac{mv\rho}{rpc}$ = B (6)

If we define $\frac{v}{c}$ asβ , we have that B=$\frac{\beta m\rho}{rp}$ (7)

3. RESULTS AND DISCUSSION

Figs.1 and 2 are the plots of the mean cosmic-rays count rate for 2016 and 2017 respectively. The idea here is to study the diurnal variations of cosmic ray flux and how they are influenced by solar wind and earth's magnetic field. This was analyzed by plots of average monthly count rate against each month for two consecutive years: 2016 and 2017.Comparing the two figures, one can see a good correlation between them. Fig. 1 and 2 show almost the same trend of variations with both normalized on December. Also the two graphs peaked on almost the same month, which depicts that a common parameter is responsible for their variations. If $N_{max}$and N_{min} represent the maximum and minimum cosmic ray fluxes respectively, then in Fig. 1, N_{max} occurred on March, July, October while N_{min} occurred on January, April, May,. In Fig. 2, N_{max}occurred on March, July, and September while N_{min} occurred on February, June, August, and October. According to [16], the peaks observed are due to radioactivity from the nuclear explosions in the atmosphere. The neutron rate was higher in some months than others, which according to [17], that this increase in intensity signifies a large increase in some particular component of the cosmic rays arriving at the top of the atmosphere, and this component is efficient at producing neutrons at sea level. The peaks observed can further be clarified based on the following observations according to [18]: on 12-14 April 1993, a radioactive cloud in the atmosphere over Moscow was recorded and the cloud was seen at altitude h=10-30km with maximum activity ~ 10^{-4} Bq/cm^3, but the source of the cloud was unknown. Also, a powerful surface nuclear explosion was produced on 14th October in 1970 near lake Lobnor in China. Again, in the atmosphere radioactive clouds were observed near Murmansk on 25-26 October and on November 11-12, near Moscow all in 1970. These observations were made in polar region at the altitude range h=15-25km, and charged particle flux increased about 7-8 times in comparison with the cosmic ray background. The source of the cloud was also unknown. The count rate on October 2016 and October 2017 are seen to anti-correlate with 2016 having maximum count and 2017 having minimal count. This strong decrease in the count rate is attributed to strong Forbush effect, [19]. This

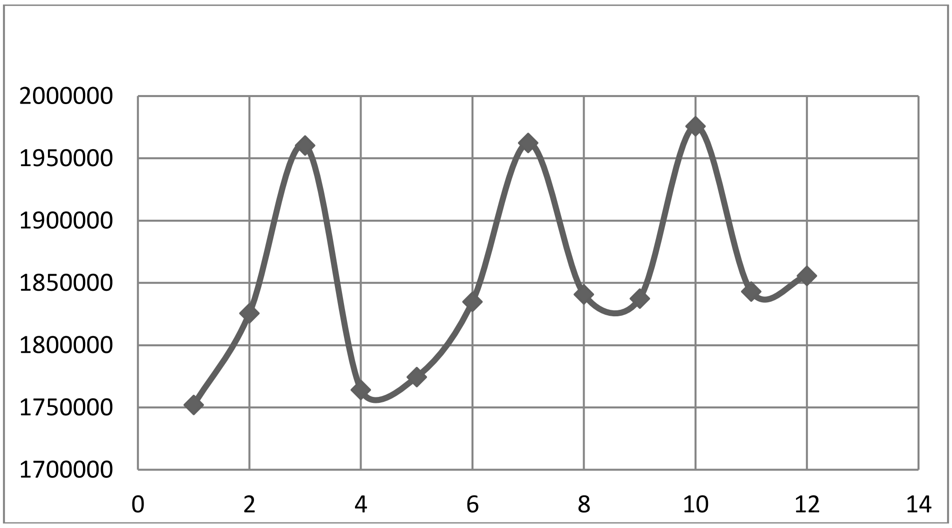

Fig. 1. Plot of neutron monthly mean count rate for 2016

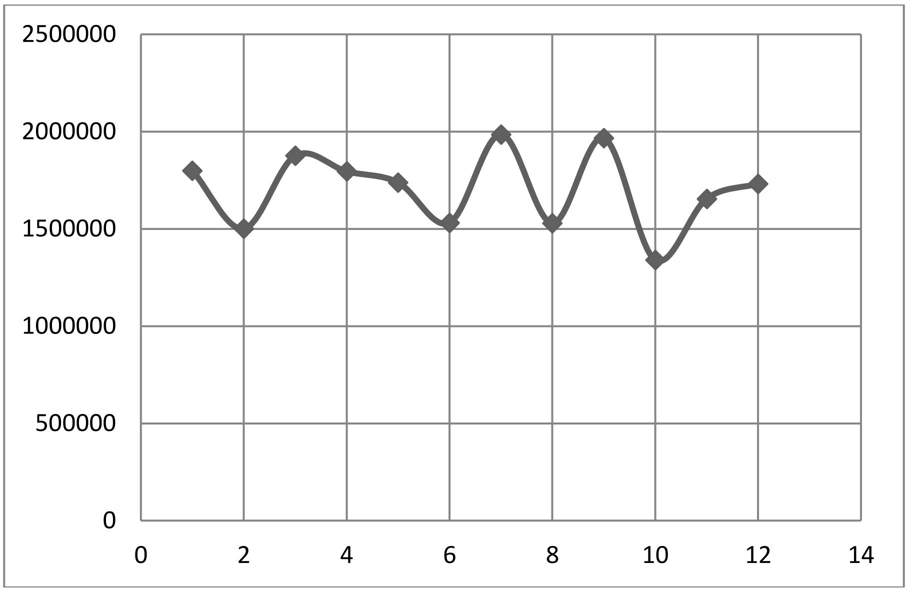

Fig. 2. Plot of Neutron monthly mean count rate for 2017

Forbush effect also suggests that solar activity also anti correlate with the intensity of cosmic rays at low energies as well. According to, [18], with the increase in solar activity and magnetic field instability, prominences and their rupture become more frequent. These ruptures originate Coronal Mass Ejection (CME) which in turn will give rise to a decrease in the observed galactic cosmic rays.

4. CONCLUSION

Solar wind and earth's magnetic field contribute immensely to the variation in the intensity of cosmic rays. Variations in cosmic rays intensity are as a result of deflection of the galactic cosmic rays by the magnetic field which is being carried away from the sun by the solar wind. Solar wind decelerates some of the incoming particles, while the earth's magnetic field deflects them, which leads to variations in the intensity of the cosmic rays. Almost all particles that reach earth's upper atmosphere come from outer space and are modulated by the expanding magnetized plasma from the sun.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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