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Research Paper

Analysis of Cosmic Ray modulation by Solar wind

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ABSTRACT:*Cosmic rays are high-energy particles originating from outer space, primarily composed of protons, electrons, and heavier atomic nuclei. These cosmic particles constantly bombard Earth's atmosphere, leading to various interactions and secondary effects, one of which is the modulation of the ionospheric Total Electron Content (TEC). Solar wind is a continuous stream of charged particles, mainly electrons and protons, flowing outward from the Sun into the vast expanse of space. This phenomenon is a fundamental aspect of our solar system and has a profound influence on the space environment surrounding our planet and beyond. The solar wind, consisting mainly of electrons and protons, creates a protective magnetic shield that extends into space, known as the heliosphere. This magnetic shield, driven by the solar wind, deflects many cosmic rays away from the inner solar system. This study investigated the effect of Solar wind in modulating the cosmic ray fall on the earth's upper atmosphere. The interrelation between cosmic ray activities and solar wind dynamics becomes evident when studying long-term cosmic ray flux records. Observations show an inverse relationship between solar activity and cosmic ray flux. This inverse correlation between solar activity and cosmic ray flux underscores the role of the solar wind as a cosmic ray modulator.*

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I. INTRODUCTION

Cosmic rays

Cosmic rays are high-energy particles originating from outer space, primarily composed of protons, electrons, and heavier atomic nuclei. These cosmic particles constantly bombard Earth's atmosphere, leading to various interactions and secondary effects, one of which is the modulation of the ionospheric Total Electron Content (TEC). TEC, represents the density of free electrons in the Earth's ionosphere and plays a significant role in global navigation systems and ionospheric research. Cosmic rays penetrate the Earth's atmosphere and collide with atoms and molecules, leading to ionization. These high-energy particles can strip electrons from neutral atoms and create positively charged ions and free electrons. The ionization process is particularly significant in the ionospheric region of the Earth's upper atmosphere, where free electrons are abundant. As a result, cosmic rays contribute to the ionization of the ionosphere, directly affecting TEC. The intensity of cosmic rays reaching the Earth's atmosphere is not constant and varies with solar activity, Earth's magnetic field, and other factors[1]-[5].

Total Electron Content

Total Electron Content (TEC) is a critical parameter in the field of ionospheric science and global navigation systems. It refers to the total number of free electrons present in a unit area along a specific line of sight between a transmitter and receiver on the Earth's surface as they traverse the ionosphere. TEC is typically measured in TEC units (TECU), where 1 TECU represents 10^16 electrons per square meter. The ionosphere is a region of the Earth's upper atmosphere that contains ionized gases and free electrons, and it plays a crucial role in the propagation of radio waves, especially those used in global navigation and communication systems like GPS.[6],[7]

Solar Wind

Solar wind is a continuous stream of charged particles, mainly electrons and protons, flowing outward from the Sun into the vast expanse of space. This phenomenon is a fundamental aspect of our solar system and has a profound influence on the space environment surrounding our planet and beyond. The solar wind begins its journey in the Sun's outermost layer, the solar corona, where the Sun's intense heat and magnetic activity cause particles to reach escape velocities, propelling them outwards. This high-speed solar wind can travel at speeds ranging from 300 to 800 kilometers per second (about 186 to 500 miles per second), and it carries with it the Sun's magnetic field, forming what is known as the interplanetary magnetic field (IMF).

Solar wind plays a critical role in shaping the dynamics of our solar system. It interacts with the magnetic fields of planets, including Earth, and can have significant effects on their atmospheres and magnetospheres. When the solar wind encounters the Earth's magnetosphere, it can cause phenomena such as the Northern and Southern Lights, also known as the auroras, by exciting particles in the Earth's atmosphere. Furthermore, solar wind disturbances, like solar flares and coronal mass ejections (CMEs), can disrupt satellite communications, power grids, and even impact the functioning of spacecraft in orbit. Studying the solar wind and its variations is essential for understanding space weather and its potential impacts on technology and the Earth's environment.[8],[9]

The Solar Wind's Role in Modulating Cosmic Rays

The Sun serves as a primary factor in regulating the influx of cosmic rays into our solar system. The solar wind, consisting mainly of electrons and protons, creates a protective magnetic shield that extends into space, known as the heliosphere. This magnetic shield, driven by the solar wind, deflects many cosmic rays away from the inner solar system. During periods of high solar activity, characterized by increased sunspot activity and solar flares, the solar wind's magnetic field becomes stronger and more efficient at repelling cosmic rays. Consequently, cosmic ray intensity decreases during these solar maxima. Conversely, during periods of low solar activity, such as solar minima, the solar wind's protective magnetic shield weakens, allowing more cosmic rays to penetrate the heliosphere and reach the vicinity of Earth.[6],[10]

Variations in Cosmic Ray Flux and Solar Activity

The interrelation between cosmic ray activities and solar wind dynamics becomes evident when studying long-term cosmic ray flux records. Observations show an inverse relationship between solar activity and cosmic ray flux. During solar maxima, when the Sun is most active, cosmic ray flux is at its lowest, as the solar wind effectively reduces the influx of cosmic rays. Conversely, during solar minima, cosmic ray flux is at its highest, as the weakened solar wind permits more cosmic rays to enter the solar system. This inverse correlation between solar activity and cosmic ray flux underscores the role of the solar wind as a cosmic ray modulator.[3],[4],[11]

Solar wind are primarily influenced by the Sun's natural cycle, known as the solar cycle, which lasts approximately 11 years. The solar cycle is characterized by periods of high and low solar activity, with the number of sunspots and solar flares serving as indicators of its phases. These variations in solar activity directly impact the properties of the solar wind.

Solar wind activities vary over the course of a year due to the Earth's orbit, the Sun's solar cycle, seasonal factors, and inherent solar wind variability. These variations can have important implications for space weather, affecting satellite communications, navigation systems, and the behaviour of the Earth's magnetosphere.

The annual variation in solar wind speed closely follows the Earth's heliographic latitude, reaching peak values in March and September, and minima in June and November. It is most clearly seen at solar minimum, as expected (Owens et al., 2019, 2020), but is still also present at solar maximumTop of Form

he alignment of the solar wind with Earth's magnetic field varies throughout the year due to the tilt of Earth's magnetic axis and its orbit around the Sun. This variation leads to different interactions between the solar wind and Earth's magnetic field during different months. Here's a simplified overview of how this alignment changes over the course of a year:

Summer Months (June to August - Northern Hemisphere):

During the summer months in the Northern Hemisphere, Earth's magnetic field is more aligned with the solar wind because the North Magnetic Pole is tilted toward the Sun. This means that the solar wind has a more direct path to interact with Earth's magnetosphere in the Northern Hemisphere.
The South Magnetic Pole is tilted away from the Sun during this time, which reduces the interaction between the solar wind and the Southern Hemisphere's magnetosphere.

Winter Months (December to February - Northern Hemisphere):

In the winter months in the Northern Hemisphere, the North Magnetic Pole is tilted away from the Sun. As a result, the interaction between the solar wind and Earth's magnetosphere is less direct in the Northern Hemisphere during this period.
Conversely, the South Magnetic Pole is tilted toward the Sun during these months, making the interaction between the solar wind and the Southern Hemisphere's magnetosphere more significant.

Spring and Autumn Equinoxes (March and September):

During the spring and autumn equinoxes, which occur in March and September, Earth's magnetic field is more aligned with the solar wind because the North Magnetic Pole is roughly perpendicular to the Sun-Earth line. This alignment allows for more direct interactions between the solar wind and both hemispheres' magnetospheres.

Transition Months (April, May, October, November):

In the transitional months between the seasons, the alignment of Earth's magnetic field with the solar wind gradually changes. As a result, the intensity of interactions between the solar wind and Earth's magnetosphere can vary during these months.

It's important to note that the actual alignment is influenced by the dynamic nature of the solar wind and Earth's magnetic field, and it may not precisely follow the patterns described above. Additionally, the Sun's activity, such as solar flares and coronal mass ejections, can disrupt the normal alignment patterns and lead to increased solar wind activity at any time of the year.

II. METHODOLOGY

In this paper I have studied the effects of solar wind in modulating the cosmic activities during the calendar year 2022. The data for analysing solar wind activities were taken from Omni Web Explorer of NASA. The ionospheric total electron content were taken from CDDIS of NASA. The data for cosmic ray analysis were taken from Inter magnet.org.

Data Cleaning

Cleaned the collected data by removing any outliers, missing values, or noise. Ensured that the data is in a consistent and usable format.

Time Synchronization

Ensured that both the solar wind data and cosmic ray data are synchronized in time. This may require time-shifting one dataset to match the time intervals of the other.The data set used were from Swarthmore, Pennsylvania 39.9N, 75.4W and Boulder 40.02°N

Exclusion of sun flares

The data during short term sun flares are excluded for maintaining a significant relation between the solar wind and cosmic ray data sets.

III. Result and Discussion

Solar wind variations

Figure (1) shows the average solar wind variations for twelve months in 2022 as monthly average. The data were collected at Boulder 40.02°N magnetometer station. Solar activities were found to be gradually increasing from January to March. When the Earth is closer to the Sun (perihelion), typically around early January, the solar wind particles have a shorter distance to travel to reach our planet. This can lead to slightly higher solar wind speeds and densities during this time. The tilt in the magnetic field is gradually more oriented in parallel to solar wing magnetic fields. This allows to strengthen the solar wind to penetrate more in to the earth’s atmosphere. From March to June, it is found to be decreasing due to the large elliptical orbital distances. FromJune to November, the activities were gradually rise to the peek due to the magnetic alignment and the decreasing elliptical distances.

Cosmic Ray variations

Figure (2) shows the cosmic variations for different months in 2022 with monthly average. Swarthmore, Pennsylvania 39.9N.

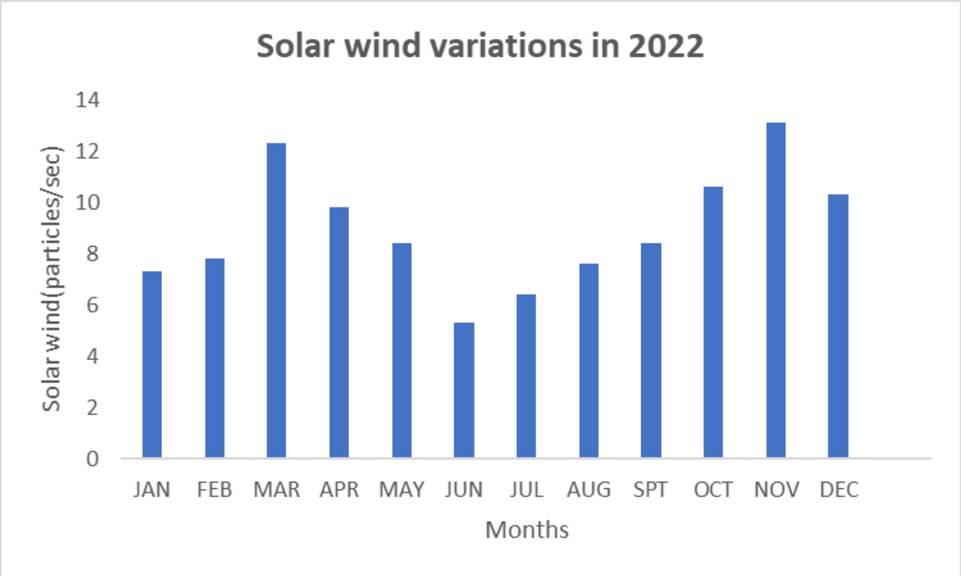

Figure (1). The solar wind variations for the year 2022 Boulder 40.02°N magnetometer station.

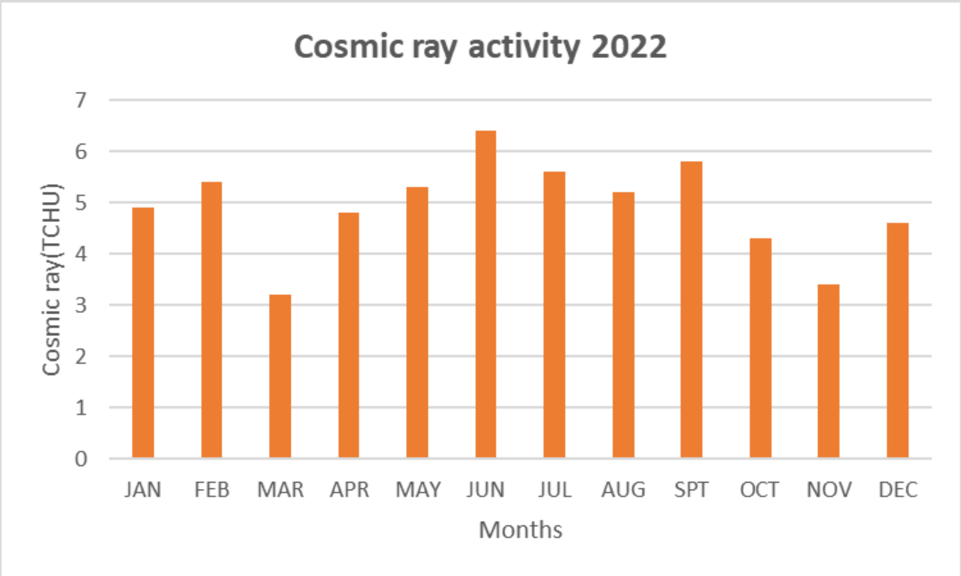

Figure (2). The cosmic ray variations for different months in 2022 with monthly average. Swarthmore, Pennsylvania 39.9N.

Modulation of cosmic activities by Solar wind variations

Figure (3) shows the correlation between cosmic ray activities and solar wind. From figure it is clear that the solar wind truly modulates the cosmic fall to the upper atmosphere. The cosmic fall is low at the rise of solar wind effects and vice versa.

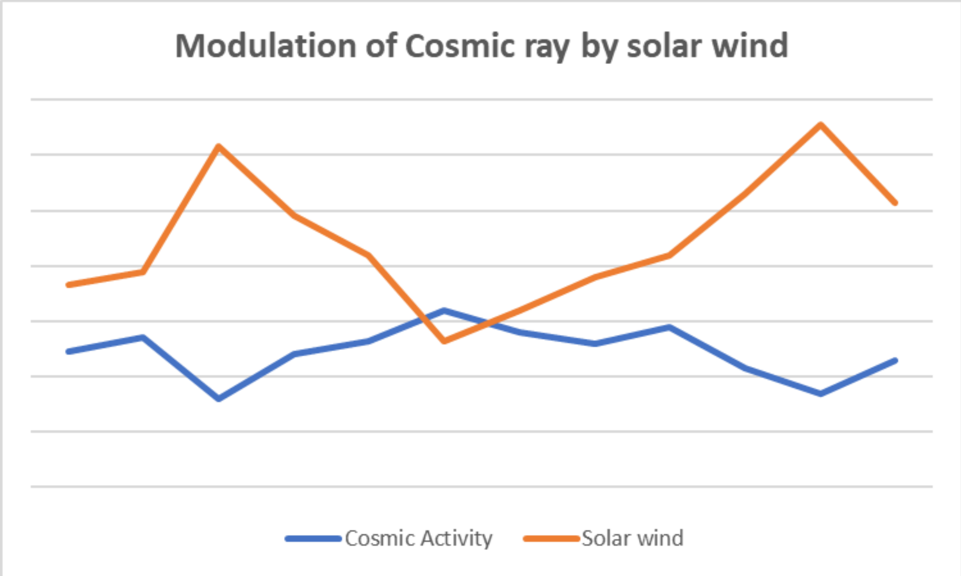

Figure (3). Modulation of cosmic ray by solar wind from Jan-Dec 2022

IV. Conclusion

The interrelation between cosmic ray activities and solar wind dynamics becomes evident when studying long-term cosmic ray flux records. Observations show an inverse relationship between solar activity and cosmic ray flux. During solar maxima, when the Sun is most active, cosmic ray flux is at its lowest, as the solar wind effectively reduces the influx of cosmic rays. Conversely, during solar minima, cosmic ray flux is at its highest, as the weakened solar wind permits more cosmic rays to enter the solar system. This inverse correlation between solar activity and cosmic ray flux underscores the role of the solar wind as a cosmic ray modulator.

REFERENCES

[1]. J Giacalone, H Fahr, H Fichtner, V Florinski, Quantitatively relating cosmic rays intensities from solar activity parameters based on structural equation modelingAdvances in Space ResearchVolume 72, Issue 2, 15 July 2023, Pages 638-648

[2]. J Vencloviene, M Beresnevaite, S Cerkauskaite, Anomalous cosmic rays and heliospheric energetic particles, Space science during a Storm on May 15, 2005. Geomagn. Aeron. 63, 434–440 (2023)

[3]. G. Ptitsyna a, O.A. Danilova a, M.I. Tyasto a, V.E. Sdobnov, Cosmic ray cutoff rigidity governing by solar wind and magnetosphere parameters during the 2017 Sep 6–9 solar-terrestrial event, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 246, May 2023, 106067 Reviews,April 2022

[4]. Ilias Cholis and Ian McKinnon, Constraining the charge-, time-, and rigidity-dependence of cosmic-ray solar modulation with AMS-02 observations during Solar Cycle 24, Phys. Rev. D 106, 063021 – Published 26 September 2022

[5]. X Guo, Y Zhou, V Florinski, C Wang , Dynamical Coupling between Anomalous Cosmic Rays and Solar Wind in Outer Heliosphere, The Astrophysical Journal, 2022 – iopscience.iop.org

[6]. M Kornbleuth, M Opher, GP Zank, An Anomalous Cosmic-Ray Mediated Termination Shock: Implications for Energetic Neutral Atoms, The Astrophysical Journal, 2023 –iopscience.iop.org

[7]. OA Danilova, NG Ptitsyna, MI Tyasto, Hysteresis Phenomena in the Relationship between the Cosmic Ray Cutoff Rigidity and Parameters of the Magnetosphere during a Storm on May 15, 2005, - Geomagnetism and Aeronomy, 2023 – Springer

[8]. Danilova, O.A., Ptitsyna, N.G. & Tyasto, M.I. Hysteresis Phenomena in the Relationship between the Cosmic Ray Cutoff Rigidity and Parameters of the Magnetosphere

[9]. Chali Idosa Uga & Binod Adhikari, Study of Cosmic Ray Intensity (CRI) along with Solar Wind Parameters and Geomagnetic Indices from Different Stations, Cosmic Research, Sept 2023

[10]. N.G. Ptitsyna a, O.A. Danilova a, M.I. Tyasto a, V.E. Sdobnov, Cosmic ray cutoff rigidity governing by solar wind and magnetosphere parameters during the 2017 Sep 6–9 solar-terrestrial event, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 246, May 2023, 106067

[11]. Yuming Wang et al, Variation in Cosmic-Ray Intensity Lags Sunspot Number: Implications of Late Opening of Solar Magnetic Field, The Astrophysical Journal, April 2022