Cosmic ray variations during density extremes in solar wind

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A comparison of the variations of the cosmic ray neutron monitor intensities with variations of geomagnetic disturbance \( D_a \) and (number) densities \( N \) of interplanetary plasma observed near the Earth during June-August, 1979 and May 1999 (intervals when \( N \) was abnormally low) has been presented. It showed that cosmic ray variations were very loosely related to \( D_a \) variations (variations often out-of-phase by several days, and magnitudes not proportional) and had no relationship with plasma densities \( N \) (low or high).

**Keywords:** Cosmic ray intensity, Solar wind, Geomagnetic indices, Interplanetary plasma density

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1 Introduction

Cosmic rays are energetic particles that are found in space and filter through our atmosphere. These are generally termed as Galactic Cosmic Rays (GCR). Ground-based neutron monitors at several locations on the Earth, for the last several decades, are regularly monitoring cosmic rays. Observations so far indicate a long-term solar cycle effect, with cosmic ray neutron monitor intensity anti-correlated with sunspot numbers.\(^1\)\(^2\) For short-term effects, the relationship between solar variations with interplanetary plasma parameters and further with cosmic ray Forbush decreases and geomagnetic storms is also discussed in detail in various publications.\(^3\)\(^4\)

Solar wind parameters vary considerably on different time scales. At the largest scale, the variations reflect the solar origin of the wind, where low densities are found in the fast flow from coronal holes and high densities in the slow flow from the vicinity of the streamer belt.\(^5\) The largest amplitude density variations occur on shortest time scales and are primarily associated with the slow flow. Those of interplanetary origin are high-density regions formed by compression\(^6\) and have corresponding low-density regions of rarefaction following them.

For geomagnetic indices like \( D_a \) or \( A_p \), the relevant interplanetary parameter is the \( B_z \) component (north-south component of the interplanetary magnetic field, IMF). If \( B_z \) is negative, geomagnetic storms occur, because a connection (entry through the neutral point) gets established between solar wind and the plasma in the geomagnetic tail, leading to auroral precipitation and equatorial ring currents (which cause \( D_a \)). The number densities in the interplanetary space and the solar wind velocity have a combined effect (solar wind pressure) on \( D_a \) or \( A_p \) magnitudes. For cosmic rays, effects on two time scales are envisaged. When an interplanetary feature near the Earth is affecting \( D_a \), the cosmic rays also suffer modulations called Forbush decreases, in a matter of hours and almost coinciding with the \( D_a \) variations (decreases), and show a recovery in a matter of tens of hours. Thus, \( D_a \) storm main phases are reasonably well related qualitatively with cosmic ray Forbush decreases. On a longer time scale, Burlaga et al.\(^6\)\(^7\) proposed that fast CMEs (solar Coronal Mass Ejections) contribute to form a propagating diffusion region (heliocentric barrier) further out in the heliosphere, so that CR intensity never quite recovers at the earth’s orbit. The structures of the recovery in the 11-year cycle of CR in relation to the state of interplanetary magnetic field have been studied in detail.\(^8\)

Recently (May 11, 1999), an unusually extended depression in the plasma density \( (N) \) of the solar wind occurred in the vicinity of the Earth. The density fell to 0.1-0.2 protons cm\(^{-3}\), compared with average solar wind densities of \(-5\) cm\(^{-3}\). Several aspects of this event have been described in papers in a special section in *Geophys Res Lett.,* 27 (23) (2000) December 1. In this communication, variations of interplanetary plasma parameters and cosmic ray neutron monitor intensities are compared for a few selected events when \( N \) values were abnormally low.
2 Data source and type
Data used are for neutron monitors at Climax (39°N, 106°W, cut-off rigidity 2.99 GV) for three recurrent events in 1979 and at Jungfraujoch (47°N, 8°E, cut-off rigidity 4.48 GV) for the 11 May, 1999 event, and for Interplanetary plasma number density $N$ and geomagnetic disturbance index $D_{st}$. All data were obtained from NOAA websites.

3 Plots of hourly values
Figure 1 shows plots [hourly values (UT)] of CR intensity, $N$, and $D_{st}$ for five continuous days, for three recurrent events (27-day recurrences) during June-August 1979. These events have also been mentioned by Ipavich et al. Their values were discussed by Crooker et al., for (a) 5-9 June 1979, (b) 2-6 July 1979, (c) 29 July – 2 Aug. 1979, and (d) the recent event 9-13 May 1999. In each, the top plot is for cosmic ray neutron monitor intensity [Climax in (a), (b), (c); Jungfraujoch in (d)], the second plot for interplanetary number density $N$, and the third plot for geomagnetic disturbance index $D_{st}$. The days are chosen not for any storm indications in cosmic rays or $D_{st}$ but for intervals when $N$ was very low (extreme low density events). The following may be noted:

(i) In (a) 5-9 June 1979, $N$ values were high (touching 50) on 6 June, but were very low (~2 or less) on 7, 8 and 9 June. However, during 7-9 June, there was a medium-sized $D_{st}$ storm ($D_{st} = 50$ nT) and a large cosmic ray storm (Forbush decrease, $\sim -7\%$). Thus, the low value of $N$ made no difference and a storm still occurred. It was checked and found that $B_z$ component of IMF was negative (southward) when $D_{st}$ decrease occurred. Also, the large value of $N$ on June 6 did not produce any striking changes either in cosmic ray intensity or in $D_{st}$. The $B_z$ component was not negative during this interval. This can be considered as a good example of how $B_z$ has an overwhelming influence on geomagnetic storm variations, and interplanetary $N$ and $V$ (in any combination) have a much lesser relevance. The cosmic ray storm of substantial magnitude coinciding with $D_{st}$ is surprising, because with $N$ almost zero, the interplanetary structure could not be very strong. The cosmic ray effect was substantial probably because the structure may have large dimensions with total magnetic field $B$ anomalies extended over a large volume.
(ii) In (b) 2-6 July 1979, \( N \) values were high (touching 50) on 3 July, but very low on 4-6 July 1979. During 4-6 July, \( D_a \) hardly exceeded 15 nT and cosmic rays had small fluctuations. It may be noted that cosmic rays have a regular diurnal variation of an amplitude of \( \sim 1\% \), with a maximum after local noon. Thus, the low values of \( N \) did not have any implication. The small fluctuations in cosmic rays should be due to a small accumulation of previous interplanetary events in the heliosphere (a small barrier).

(iii) In (c) 29 July - 2 Aug. 1979, \( N \) values were very large (exceeding 75) on 29 July, moderate (-10) on 30 July, and very low on 31 July - 2 Aug. 1979. On 29 July, cosmic rays did not show any strong variation and \( D_a \) was not negative, indicating that conditions were not appropriate for storms (\( B_z \) was not negative). On the other hand, on 1 August, cosmic rays had a substantial Forbush decrease (\( \sim 5\% \)), with no \( D_a \) storm. Thus, cosmic ray storm could occur even when \( N \) was very low and there was no terrestrial magnetic disturbance. This should be again because of a heliospheric barrier caused by the accumulation of earlier events.

(iv) In (d) 9-13 May 1999, \( N \) was very low on 9-12 May 1999. The cosmic rays showed normal (diurnal type) fluctuations and \( D_a \) was quiet. However, on 13 August, when \( N \) was large (\( \sim 25 \text{ nT} \)) and \( D_a \) had a moderate storm (\( \sim 50 \text{ nT} \)), cosmic rays showed no Forbush decrease at all and showed instead, a 4% increase. Thus, cosmic rays and other indices had very different behaviours, because cosmic rays were interacting with heliospheric anomalies unrelated to the present event as such.

It would thus seem that cosmic ray variations have their own characteristics, not necessarily related to the terrestrial parameters or to the interplanetary parameters in the vicinity of the Earth.

4 Plots of daily values

The events of June-August 1979 have been mentioned by Ipavich et al.\(^{10}\) as recurrent. Recurrences can be seen conveniently on a 27-day calendar (like the Bartels diagram for geomagnetic \( K_p \) index). Figure 2 shows the plots of daily values of cosmic ray intensity, \( N \), and \( D_a \) for intervals of 27 days: (a) 1-27 June 1979, (b) 28 June-24 July 1979, (c) 25 July-20 Aug. 1979, during which there were stretches of abnormally low values of plasma density \( N \) [Positive \( N \) values and negative \( D_a \) values are shown black.]

On 4 July (28 days after 7 June) in (b), cosmic rays had a large Forbush decrease and there was another Forbush decrease 27 days later on 31 July in (c). Thus, the 27-day pattern was followed, but the \( D_a \) did not have strong storms on these dates. The cosmic ray decrease on June 6 and a small, slow Forbush decrease on 19 June. For both, the \( N \) values were low or moderate, and \( D_a \) had a small storm and a large storm, respectively. Thus, \( N \) value was probably irrelevant and \( D_a \) values were not proportional to cosmic ray decreases, indicating that cosmic rays were responding to more extensive interplanetary structures, whose effect near the Earth was rather small.

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storm of 19 June in (a) was followed by cosmic ray storms on 16 July in (b) (27-day spacing from 19 June) and 17 August in (c) (32-day spacing from 16 July). Thus, the 27-day pattern was not followed. The $D_s$ values were moderate and often out of phase with cosmic ray variations by several days, again indicating that $D_s$ responded to interplanetary structures near the Earth and cosmic rays responded to the large-scale heliospheric properties of these structures.

5 Conclusions

A comparison was made of the variations of the cosmic ray neutron monitor intensities with variations of geomagnetic disturbance $D_s$ and (number) densities $N$ of interplanetary plasma observed near the Earth during June-August, 1979 and May 1999, when some very low $N$ values occurred. It was noticed that cosmic ray variations were very loosely related to $D_s$ variations (variations often out of phase by several days, and magnitudes not proportional) and had no relationship with plasma densities $N$ (low or high).

The reason for such a poor relationship should be that $N$ and $D_s$ extremes relate to a very restricted region (magnetic blobs) of interplanetary space in the vicinity of the Earth, while cosmic rays are affected over large spaces. The long-term changes of cosmic rays occur mainly near the heliospheric barrier (termination shock) several tens of AU away, and the short-term changes occur due to blobs, but extended over a wide region of space.

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