Characteristics of Solar Flare Particle Increases during Recovery of Forbush Decreases with reference to 7 May 1978 Event

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Sudden increase of cosmic ray intensity registered mainly by ground based detectors is due to high energy particles of solar origin. These are generated on rare occasions during intense solar flares. Out of 30 ground level enhancements observed so far, the increase of intensity on 7 May 1978 is the largest in this and earlier solar cycles and has peculiar characteristics which are reported along with similar events observed earlier. It is found that the intensity increase is highly anisotropic with the maximum increase being registered by the European stations. The event occurred during the late recovery phase of a large and long lasting Forbush decrease and hence it is quite likely to have better channeling effect in guiding the particles along the interplanetary magnetic field lines from the sun, producing large anisotropy. The characteristic features of the past events occurring during late recovery of Forbush decreases, but in different phases of solar activity, are not very different from one another. From this it is concluded that the near earth region is not dominant in producing the modulation of cosmic rays.

1. Introduction

The sun occasionally emits relativistic particles which have been observed by ground based detectors since 1942. Even though these energetic solar flare particles have been observed for almost three solar cycles, their intensity or number density varies greatly from flare to flare. It is, therefore, not possible to define a unique measure of solar particles that is independent of the flare configuration or of the time period within the solar cycle. These occur characteristically shortly after the observation of a flare at optical, microwave and X-ray wavelengths. It is now possible to measure particle fluxes directly in space up to energies as low as 1 MeV. However, the measurement of the particle flux at high energies is still within the realm of ground based neutron monitor detectors. The latest highly anisotropic ground level enhancement (GLE) has occurred on 7 May 1978 during the late recovery of a large Forbush decrease. In an earlier study, two identical GLEs have been analyzed to determine their characteristics to derive the propagation conditions of energetic particles near the sun-earth region. These two solar events (22 Nov. 1977 and 25 Feb. 1969) occurred during quiet conditions prior to the increase and showed very similar characteristics, in spite of being in two completely different phases of the solar cycle. Such a comparison was very useful in deriving the modulation effects near earth. In this study we have, therefore, first derived the various characteristics of 7 May 1978 event, which are then compared with other solar particle events occurring in the past having similar characteristics.

2. 7 May 1978 Event

The solar particle event of 7 May 1978, which produced large ground level enhancement, occurred during the late recovery of a large Forbush decrease of about 15% (Fig. 1). After an examination of the available high resolution 5-min data from a number of stations, it is observed that the event is highly anisotropic with maximum amplitude seen by stations in European longitude. Fig. 2 depicts the neutron intensity at 5-min intervals for a typical available European station, Utrecht (52°15'N; 5°11'E; sl. 2.76 GV) where the maximum increase of ≈ 80% is registered. The increase in cosmic ray intensity on 7 May 1978 began at about 0335 hrs UT and reached its maximum at ≈ 0345 hrs UT. This event was most probably associated with the solar flare of importance 2N in McMath plage region 15266 at N24, W68 with $H_a$ maximum at 0336 hrs UT. The increase of intensity probably started before the time of $H_{a,max}$, which is usually less probable. The decay time constant is also quite small for stations recording maximum increase and is ≈ 15 to 20 min, whereas it varies appreciably at other stations. If one considers the European zone to be the zone of maximum increase we derive an
increase of \( \approx 200\% \) in the stations with cut-off rigidity \( \lesssim 1 \text{GV} \) for the rigidity spectral exponent of \( \approx 5 \). From the limited data available for this event for 15 neutron monitors and those for earlier events, it is generally true that the spectral exponent for solar relativistic particles is \( \approx 5 \) (Ref. 7).

Further, based on high resolution data at 5-min intervals, we find that this GLE is highly anisotropic. To determine the zone of maximum impact direction of solar particles, we have obtained the asymptotic direction of viewing for particles of different rigidities. According to the "look" direction of the station for 3GV at 0000 hrs UT, which is expected to be the mean value of the rigidity for the stations with cut-off \( \lesssim 1 \text{GV} \), we show in Fig. 3 the observed increase for 14 stations. Even though it was desirable to have corrected all the increases to sea-level values and for cut-off \( \approx 1 \text{GV} \), it was not attempted due to the availability of only limited data and the ambiguity in finding the rigidity spectral exponent. From Fig. 3 we notice that the event is highly anisotropic with the maximum increase from a direction widely spread in the sunward direction. Nevertheless, the increase is minimal from the anti-sun direction. The anisotropy is also marked in the north-south direction with larger increase from northern hemisphere, as would be expected due to the source location at \( N 24 \). Theoretically, from the location of the solar flare as well as due to the large but simple Forbush decrease prior to this event, we could expect the maximum intensity of solar particles only from the garden hose direction at least in the initial phase of the event.
3. Comparison with Other Events

So far 30 GLEs have been observed in the last four decades. These have been intensively studied and reviewed in literature. These events have been depicted in Fig. 4 specifying their magnitude, source position and the cosmic ray conditions at the time of the GLE.

For the comparative study of 7 May 1978 event with other GLEs having similar characteristics and interplanetary conditions, we have identified four other events under the following similarity conditions.

(i) GLE should be at the late recovery of a Forbush decrease of amplitude ≥ 5%.
(ii) The maximum amplitude of GLE itself should be ≥ 10%.
(iii) The location of source solar flare should be 60 ± 30° west so as to be near the foot of the Archimedean spiral, as is the case of 7 May 1978 event.

Based on these conditions we have been able to select five particle events of similar nature, viz., 4 May 1960, 18 July 1961, 18 Nov. 1968, 7 Aug. 1972 and 7 May 1978. A critical review of the available results for all these events show that they are highly anisotropic in the initial stages, with small rise-time. Even though they occur at different phases of solar cycle, it has not been possible to find any distinctive difference between their characteristics. This could also be due to different interplanetary conditions in the near sun-earth region as the amplitude of the Forbush decrease is highly variable and no two flares producing GLE have occurred which are located at the same position, as was the case in the earlier studies.

4. Discussion and Conclusion

The 11-yr modulation of galactic cosmic ray intensity provides very clear evidence of changes in the conditions in interplanetary space which affect the propagation of cosmic rays. If these changes are taking place in the inner reaches of the modulating region near the earth, they should be noticeable in the principal features of solar flare particle events occurring at different phases of the 11-yr sunspot cycle.

In terms of the convection-diffusion theory, the propagation of solar flare particles should be dominated by the diffusion coefficient and the intensity profiles during the rise and decay phases of the solar flare events. Since these characteristics are not very different from each other in the GLEs considered in this paper, the diffusion coefficient may not be very different. Moreover, the solar wind speed is also not very different from each other during these events occurring in late recovery of Forbush decrease. Therefore, it could be the modulating boundary, which might be changing during different phases of the solar cycle and may be responsible for producing the galactic cosmic ray modulation, as suggested earlier.

From the analysis presented here, we conclude therefore that the GLE observed on 7 May 1978 is by far the largest since 1960 and is highly anisotropic both during rise and decay. Even though the conditions are most favourable, the maximum intensity is observed from a wide angle opening towards the sun, instead of from a narrow angle in the garden-hose direction.

From a preliminary comparison of earlier events, it is speculated that near earth region is not very dominant in producing cosmic ray modulation. However, further high resolution data covering both European and American zone in opposite hemispheres and particularly at low cut-off rigidity, are required to derive the detailed characteristics of 7 May 1978 to compare with earlier events.

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References