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Cosmic Ray decreases during 1977-1994

S. K. Pandey[a] and M.P. Yadav[b]
(a) Department of Physics, Govt. Science College, Jabalpur (M.P.), 482001, India
(b) Department of Physics, Govt. Tilak P. G. College, Katni (M.P.), 483501, India
Presenter: M.P. Yadav (mp_yadav 2005@yahoo.com), ind-pandey-sk-abs1-sh2.6-poster

Eight nine solar wind disturbances with cosmic ray (CR) intensity decreases ≥ 4% and planetary index (Ap) ≥ 30 have been identified by using neutron monitor (NM) data and solar geophysical data (SGD) during the period 1977-1994. The 81 of the 89 responsible solar wind disturbances with decrease of CR intensity ≥ 4% have been determined by examining the characteristics of associated low energy particle enhancements in combination with neutron monitor data. The vast majority (91% of the 89 events) are caused by coronal mass ejections (CMEs) and the shocks that they generate. The ejecta is intercepted only when the solar event originates with in 40^0 of the Sun's central meridian. Statistically, it is observed that, in maximum number of solar events (66% of the 89 events) the decreases in the intensity of CR that started few hours after than the occurrence of storm sudden commencement (SSC) at the Earth. Further , it is observed that, it is not always necessary that maximum number of events have occurred during maximum activity period.

1. Introduction

The cosmic ray decreases are divided into four categories bases on the decrease morphology and the behavior of low energy (<200 MeV) particles detected by near Earth space craft. The categories are associated with three different types of solar wind structure. Classes 1 and 2 events are associated with strong, extensive shocks whose source region on the sun can be determined by the rapid onset of solar particles at the time of solar flare event. Such shocks are driven by fast, CMFs (Cane et al., 1987). These shocks leads to produce geomagnetic storms at various locations of Earth. Class 1 events originate in solar events with in about 50^0 of central meridian (Cane et at, 1993). This is consistent with the interception of large ejecta which are directed in the general direction of the Earth (Richardson and Cane,1993). Class 2 events are associated with solar events farther from central meridian so that the ejecta do not encounter the Earth. Class 3 events are similar to class 1 events in appearance, in that the NM and energetic particle data reach a minimum associated in space craft data do not extent above 60 Mev/amu. In these events, the associated shocks are usually, not very energetic and that the CMEs are slower and probably less extended that those associated with more energetic events (Cane et al., 1990). Class 4 events onset more slowly and have longer duration than events associated with the other classes. Class 4 decreases events are associated with complex plasma regions including corotating, high speed streams and ejecta (Cane et al 1993). In this study the classification of solar wind structure associated with cosmic ray decreases (CR>4%) is expanded to include events which are associated geomagnetic SSCs during the year 1977-1994. In principle, these structure can be inferred directly from in situ solar wind plasma (SWP) and magnetic field data. However such data are only sufficient complete to allow the solar wind structures to be classification in less than 60% of the events, whereas the more complete energetic particle data can provide such information for a large majority of the events. We find that where simultaneous data are available, there is excellent agreement between the solar wind structures deduced using the energetic particle data and by consideration of the solar wind data. Furthermore, the particle data allow us to infer which events are likely to be energetic and therefore have identifiable solar source regions. The objectives of this work is to study the energetic solar wind disturbances associated with SSCs with relatively, reliable solar event association. This will aid reserchers making studies that require such information. This paper is intended to unambiguously identify solar sources of geomagnetic storms with CR decreases >4% based on comprehensive set of solar, interplanetary, geomagnetic and cosmic ray decreases observations, CMEs from the sun derive solar wind disturbances in terms of magnetic field, speed and cosmic ray decreases, which in turn cause magnetic disturbances at the Earth.

2. Data Analysis

Eighty nine solar wind disturbances related to SSCs with CR intensity decreases > 4% and Ap≥30 have been identified by using Mount Wellington neutron monitor, SGD, situ SWP particle and magnetic field data during the period 1977-1994. The largest decreases the variation between station can be significant. An example is the events of February 1978, which was 24% at Mount Wellington but 19% at deep river. We use hourly data to determine the sizes and onset times of the decreases. The site is obtained by dividing the minimum rate by the average rate observed for several hours preceding the onset of the decreases. An aim of this works is to improve our understanding of the physical mechanisms responsible for cosmic ray decreases and associated with geomagnetic storms. In this paper, we concentrate on identifying solar sources for geomagnetic storms with cosmic ray decreases ≥ 4% occurring between 1977 and 1994.

3. Results and Discussion :

The class wise distribution of events and corresponding their average size of CR intensity have been performed. Number of events of class 1,2,3 and 4 and their corresponding average CR decrease are 29, 21, 28 and 03 and 9.5, 6.0%, 5.7% and 6.0% respectively. Fig 1 (a,b) shows the distribution of the sizes i.e. magnitudes of CR decrease (%) of class 1 and class 2 events as a function of solar events helio latitude and longitude. The solid circles indicate class 1 events and open cicles indicate class 2 events. Fig 1(a) clearly demonstrates that the ejecta is encountered (class 1, class 2 events), if the CMEs originated within 35^0 helio latitude region. It is apparent from Fig 1(b) that the ejecta is encountered (Class 1 events) of the CMEs originates with in about 50^0 of helio longitude. The distribution in Fig 1(b) suggest that the maximum latitudinal and longitudinal extent of ejecta at 1 AU is about 35^0 and 90^0 respectively. This is similar to the average latitude span of a group of very energetic CMEs (Cane et al , 1987) which occurred close to the limbs, suggesting that, assuming similar extents in latitude and longitude, CMEs/ejecta do not expand in longitude during propagation from the sun. Another indication of the extent of ejecta comes from the fact that two ejecta which caused ≥ 4% CR decrease in February and April 1994 were apparently also seen at Ulysses (Gosling et al., 1994) which at the time was at 60^0 south of ecliptic and at 3.5 AU. Thus one might conclude that ejecta expand at high latitudes in these cases to extend beyond 60^0 from the ecliptic, as suggested by Gosling et al. (1994). On the other hand, preceding the April 1994 decrease, the soft Xray telescope on Yohkoh observed a very long lasting, spatially extended event and a possibility is that there was more than one mass ejection one directed at ulysses and one at Earth. It is also evident from the Fig 1(a,b) that the distribution of class 1 and 2 events sizes as a function of solar event latitude, longitude, has a pronounced peak near central meridian. This is to be expected since shocks are strongest at the nose so that the effect of the shock on the cosmic ray density will be greatest for central meridian events. The effect of the ejecta is also likely to be greatest for these events, since the Earth is more likely to penetrate well inside the ejecta. This expectation has been shown to be correct by a multispace craft study of several large, shock associated decreases (Cane et al, 1996). The asymmetry in the distribution of class 1 events in Fig 1(a,b) (i.e. greater number of northern (18) versus southern (11) events and eastern (20) versus western (9) events has been known for many years (Yoshida and Akasofu, 1965). Since the distribution of class 1,2 events is asymmetric, this means the shock effect is certainly asymmetric. This is to be expected because the draping field lines around the ejecta leads to an asymmetry in the post shock compression region (Cane,1988), where the cosmic rays expression increased scattering. Unequal distribution of class 1 events is suggesting that the ejecta shows asymmetry. This is consistent with expectations, since there is no obvious reason for the ejecta to be asymmetric about the event longitude as well as latitude also. Our conclusions are not consistent with the conclusion of Iucci et al. (1986), that the second steps of Forbus decrease are asymmetric. However, one must question the analysis, since they find second steps for decreases originating at all longitudes, whereas our observations suggest that they should only be present in events originating with in 40^0 of central meridian. Yearly occurrence of number of events ≥ 4% cosmic ray decreases during the period 1977-1994 have been plotted histographically in Fig 2. Occurrence rate of cosmic ray decreases is clearly related to the solar cycle. It is apparent from Fig 2 that there was one year almost near each solar minimum having no ≥ 4% decreases. For example, there were no events in 1987, when the long terms modulation for 22^{nd} sunspot cycle commenced, supporting the proposal (Lopate and Simpson, 1991) that drifts rather than ejecta played a more important role in the modulation process at this time. The absence of events in year 1987 provides evidence of a close association between ≥ 4% cosmic ray decrease events and fast ejecta. Though the CME rate observed by the solar maximum mission (SMM) coronograph (Burkepile and St Cyr, 1993) increased monotonically from 1985 to 1989, there was a lack of fast (>800 Km/sec) CMEs in 1987. It is observable from the fig. 2 that maximum number of events have occurred during the year 1978, 1982, 1989 and 1991 while all these years are not years of maximum activity. From this we conclude that, it is not always necessary that maximum number of events ≥ 4% have occurred during maximum activity years. (Kumar and Yadav, 2003a). The effect at solar can be seen in the CME rate from 1979 to 1981, as observed by the solar wind coronagraph. This showed a maximum in 1980/1981 (Howard et at., 1985) but the highest rate of fast CMEs have been observed in 1982, the year in which the maximum rate of cosmic ray decreases in 21 solar cycle. This result is consistent with Howard et al, 1985. Also, it is remarkable that there was a local minimum in 1980. Thus sunspot cycle dependence of cosmic ray decreases is related not surprisingly to the rate of fast CMEs. Statistical studies found that the CMEs transit time from the sun to the near earth space falls in between 1 and 5 days and coarsely depends on the initial speed of CMEs (Hewish and Bravo, 1986; Gopalswami et al, 2000; Kumar and Yadav, 2002,2003). This study will be more useful in determining the sources of cosmic ray decreases detected in the outer heliosphere in relation with geomagnetic storms (Cliver and Cane, 1996).

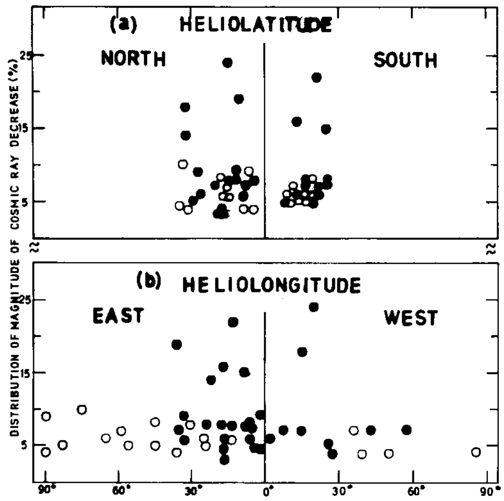

Fig 1 Distribution of the sizes (magnitude of CR each decrease) flare associated decrease as a function solar event helio latitude, longitude.

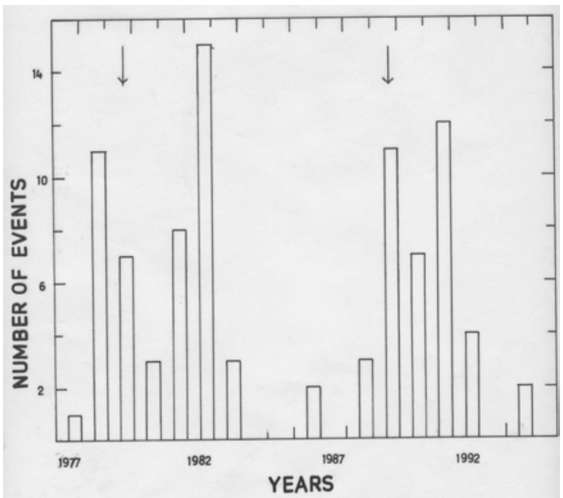

Fig 2 Number of > 4% CR decrease during year of study.

4. Conclusions

1. The 81 of the 89 responsible solar wind disturbances with decrease of CR intensity ≥ 4% have been observed.
2. The vast majority (91% of the 89 events) are caused by coronal mass ejections.
3. The ejecta is intercepted only when the solar event originates within 40^0 of the sun's central meridian.
4. It is not always necessary that maximum number of events have occurred during maximum activity period.
5. Statistically, it is observed that, in maximum number of solar events (66% of the 89 events) the decreases in the intensity of CR that started few hours after than the occurrence of SSC.

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