Interplanetary Transient flows and Associated Forbush Decrease

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Abstract: In this study we discuss the behavior of cosmic rays during the phase of highly intense or ultra intense geomagnetic storms, as shocks driven by energetic coronal mass ejections (CME’s) and other interplanetary (IP) transients are mainly responsible for initiating large and intense geomagnetic storms. Observational results indicate that galactic cosmic rays (CR) coming from deep surface interact with these abnormal solar and IP conditions and suffer modulation effects. In this paper a systematic study has been performed to analyze the CRI variation during super storms i.e. very intense geomagnetic storms with Dst index ≥ −100 nT. The neutron monitor data of three stations Oulu (Re = 0.77 GV), Climax (Re = 2.97 GV) and Huancayo (Re = 13.01 GV) well distributed over different latitudes and hourly values of IMF parameters derived from satellite observations near Earth IP medium from OMNI Data base is used for the period spanning over solar cycles 20, 21, 22 and 23. It is found that AP and AE indices show rise before the forward turnings of IMF, while the Dst index shows a classic storm time decrease. The analysis indicates that the magnitude of all the responses depends on BZ component of IMF being well correlated with solar maximum and minimum periods. Transient decrease in CRI with slow recovery is observed during the storm phase duration.

Keywords: Coronal mass ejection, magnetic cloud, Forbush decrease.

1 Introduction

The kind of interaction between solar wind and terrestrial magnetosphere depends up on the structures present in the solar wind. The magnetic cloud is a kind of large scale interplanetary structure resulted as a transient ejection of the solar plasma in the solar wind. Its characteristics were first time reported in 1981 by a group of scientists[1]. According to their studies performed on the basis of the systematic variation of interplanetary magnetic field component (IMF B) in a flow behind an interplanetary shock using the spacecraft data between 1 and 2 AU, it was reported that the magnetic field strength in the cloud was high while the intensity and the temperature were low. To investigate the relationship of these magnetic clouds with other parameters of the interplanetary medium, a number of classification schemes have been introduced. According to first classification scheme given in 1982 (a) clouds following shocks, (b) clouds preceding interaction regions and (c) clouds associated with cold magnetic enhancements [2]. During 1988 some investigators have given another classification considering the magnetic field direction as a primary discrimination, according to which a magnetic cloud is termed as a 'positive magnetic cloud' if at spacecraft onset, the magnetic field vector is rotating in a direction directed northward. If this direction of rotation is directed towards the south than such type of magnetic cloud are 'negative magnetic cloud'[3].

Magnetic clouds are ideal objects for solar-terrestrial studies because of their simplicity and extended intervals of southward and northward magnetic fields [4]. On the solar side the rope-like field configuration of the cloud generated interest to ascertain whether it would be the manifestation of a coronal mass ejection (CME) [5,6] or of a disappearing filament [7]. On the terrestrial side, the immersion of the Earth in to the cloud may provide a long lasting period with a southward interplanetary magnetic field that is favorable for the formation a strong geomagnetic storm [8]. As a magnetic cloud is a transient ejection of solar plasma in the solar wind defined by relatively strong and rotating magnetic field associated with them, where a large and smooth rotation of the magnetic field direction takes place over the distances of approximately 0.25 AU at 1 AU. These are further having a low proton temperature coefficient defined by plasma beta (β) [9]. Soon after the discovery of these magnetic clouds several studies have been performed to observe their association with geomagnetic activity. Large disturbances in geomagnetic field with arrival of a magnetic cloud have been noticed and a strong association between the initiation of geomagnetic storms and the onset of magnetic cloud at earth was observed [1, 10]. This result was ascertained by a number
of investigators [5, 11]. We have analyzed the influence of two types of magnetic clouds namely positive and negative, on geomagnetic activity, measured by Dst index and also on various interplanetary features solar wind velocity, temperature, density, B, Bx, By and Bz component of interplanetary magnetic field. We have listed both kinds of the magnetic clouds along with some of their coefficients studied during this research period in table 1 and 2 for positive and negative magnetic clouds respectively. These tables consists of estimated start and end times of the clouds based on the result of the magnetic cloud at spacecraft onset model given by Burlaga et al. which assumes that the field within the magnetic cloud is force free, i.e. the electrical current and the magnetic field are parallel and proportional in strength everywhere within its volume. [4]

2 Data and method of analysis

We have applied superposed epoch analysis to study the short-term effects of magnetic clouds with various solar and interplanetary features. By this statistical technique one can detect the periodic or recurrent, and non-periodic variation. In the present analysis data event position having special features are taken as zero position or zero epoch day. Then average value of each time interval is calculated and their deviations from average values of relevant day (zero epoch day) are also calculated. The value of deviation for each day is plotted against the column number of both sides of the zero epoch time and a curve is obtained. The curve depicts the expected variations in the values of a particular physical quantity with respect to time. In order to increase the number of epochs, we have identified 21 magnetic clouds on the basis of criteria adopted in earlier studies. We have taken the time period from Feb. 1995 to Nov. 1998. We have used the magnetic field and solar wind plasma measurements from IMP 8 and ISEE 3 spacecrafts provided by the National Space Science data center [12, 13], and considered all the 34 possible magnetic clouds events during the above mentioned period.

3 Results and discussion

Relations between solar wind parameters and magnetic clouds are examined using superposed epoch analysis. In figure 3 the time dependent behavior of the bulk solar wind speed V, proton density, NP and proton temperature, TP for the intervals, believed to contain magnetic cloud at the spacecraft are compared. The error bars shown in the figures establish the quantitative nature of this study and also support our results in statistical framework. This figure is divided in to two panels for the two cases of clouds with southward directed magnetic field at spacecraft onset – a negative magnetic cloud (left panel) and the northward directed magnetic field at spacecraft onset – a positive magnetic cloud (right panel). Inspection of figure shows distinctly higher solar wind velocity than elsewhere in the vicinity of the negative magnetic cloud comparing to the case of positive magnetic clouds where velocity goes on increasing and reach its maximum after 24 hours of onset of the clouds. Furthermore, one can easily observe that average background density level is much higher for positive clouds than for negative clouds, while the velocity in this case (for negative clouds) remained higher and constant during and after the passage of clouds. The temperature is higher comparing to its surrounding in case of negative clouds, where it starts decreasing and goes minimum after 12 hours of the onset of the clouds and later it remains higher. For positive clouds temperature is lower at the onset time, during the passage of cloud it shows some transients fluctuations.

Similar superposed analysis has been done for interplanetary magnetic field (IMF) B and all its three components BX, BY, BZ. It is seen from figure 4 that the variation of the magnetic field B for both positive and negative clouds is similar though the peak is shifted closer to the onset time of the magnetic clouds. For Bx and By components there is a little difference between the plots for two types of clouds. If we compare the BX and BY curves with those in figure 3, there is no apparent evidence for any significance except the NP curve of the clouds. This appears to show a strong density enhancements associated with the positive clouds that contradicts previous studies, which associate lower densities with magnetic enhancements 3. In case of BZ component of IMF, as it is seen that the IMF BZ for negative clouds becomes more southward after the passage of the cloud and then becomes northward (after 12 hours) whereas in the case of positive clouds, IMF BZ, which is initially northward becomes weakly southward. Results obtained for negative clouds are found quiet different from the results of positive clouds. This behavior significantly indicates different interplanetary conditions during the passage of these two types of magnetic clouds substantiating the previous results [14, 15]. In an earlier theory it is said that the higher solar wind speed and the density is noted during the passage of the negative magnetic clouds, due to its association with interplanetary shocks.

However, the geomagnetic responses to magnetic clouds have been reported in earlier work [4]. In this contest further analysis has been done to observe the effects of these two types of clouds on earth’s magnetosphere. We have taken Dst as a geomagnetic index assumed to be primarily due to the equatorial ring current in the earth’s magnetosphere. Figure 5 depicts superposed epoch analysis plots of the Dst geomagnetic index that is shown in right and left panels respectively. For the negative clouds the Dst index decreased just after the onset time of clouds and further increased during the passage of the clouds, whereas, for the positive clouds maximum decrease is found after 24 hours of arrival of clouds. These results substantiate the hypothesis that predicts the fact the geomagnetic activity is greater when the magnetic field is southward rather than when it is northward [7, 16]. Speed of the solar wind to be well correlated with the geomagnetic activity, hence we observe minimum Dst values during the passage of nega-
tive magnetic clouds. From the figure 5, we see that minimum $D_{st}$ was $-80$ nT for the negative clouds and $-57$ nT for positive clouds. It is noted that the difference cannot be attributed to the strength of the maximum southward component of the magnetic field, which was nearly the same for these two classes of the magnetic clouds. We know that all the clouds are not responsible for generating a geomagnetic storm, even though all clouds had a large southward component of the magnetic field at some point during their duration. Now it is proposed that the difference in $D_{st}$ is related to the differences in the plasma parameters for the two classes of magnetic clouds. The average behavior of $D_{st}$ and $B_Z$ for intervals of time containing magnetic cloud is very suggestive that when a magnetic cloud has a southward $B_Z$ at earth, coupling between the magnetosphere and the solar wind occurs and energy enters the magnetosphere resulting in increased geomagnetic activity. When a cloud has a northern $B_Z$ at earth, coupling between the magnetosphere and the solar wind is inhibited and no energy enters the magnetosphere. In another mechanism it is stated that the solar wind streams interaction with the magnetic cloud may have directly discontinuous field arise [15]. The magnetic cloud stream interaction region is unusual and its nature is not likely to be determined fully from single spacecraft observations. Here we speculate several possibilities, one is a compound stream follows by the magnetic clouds and the two streams interfaces would correspond to the corresponding streams. Second possibility is this that corotating streams were interacting with the heliospheric plasma sheet in which the multiple directional discontinuities might represent crossing of the heliospheric current sheet. A third possibility is that a single corotating stream interacted with magnetic cloud and produced instabilities that formed a complex boundary. In 1990 occurrence of coronal mass ejections (CME’s) in terms of ejecta are investigated as magnetic cloud related disturbance in interplanetary space[17]. Recently it has been explained that magnetic clouds are substructure of ejecta and the field structure observed depends upon where the ejecta is intercepted, the investigator also demonstrated close association between ejecta (as defined for example by regions of depressed solar wind proton temperature) and short –term particle decrease [18]. Ejecta are produced as the result of a gas dynamical explosion, in which magnetic field is carried positively. The radial speed gradient across the CME and the resulting expansion of the CME as it propagates antisunward are viewed as a resulting dynamical effect in the interplanetary space and momentum exchange with ambient medium.

4 Conclusions

This study has inferred that negative magnetic clouds are more responsible for the depression in the $B_Z$ component of the interplanetary magnetic field, while the positive magnetic cloud produce large decrease in $B_Z$ component after the 24 hours of onset time of clouds. The decrease in $D_{st}$ values show different variational pattern for positive and negative clouds, it is greater for clouds with higher speed than for clouds with lower speeds. As here, Negative clouds show large decrease just after arrival of clouds onset with early recovery, on the other hand positive clouds show maximum decrease in $D_{st}$ values after 24 hours of onset with late recovery taking 72 hours of time span.

Figure 1 Distribution of the yearly occurrence rate of intense geomagnetic storms ($D_{st} > 100$ nT) in relation to sun-spot numbers (shown by the solid line).

Figure 2: Relation between $D_{st}$ index and $|V_{BZ}|$ values of the geoeffective CMEs. Where V is the initial speed of CME and $B_Z$ is IMF.

References


