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Study of the Effectiveness of Various Solar wind Parameters in the Development of Geomagnetic Storms During Interplanetary Events

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Abstract

We have selected some interplanetary events responsible for geomagnetic disturbances of varying magnitude, fairly different from one another. We then tried to find the heliospheric structure (e.g. shock/sheath and/or CME/magnetic cloud) responsible for individual disturbances. We have discussed and inter-compared these structures in their plasma and field parameters as well as in their geomagnetic effects. As a parameter for geomagnetic disturbance we have chosen index Dst, to compare it with variations in field and plasma to heliospheric response structures. We considered parameters such as total field strength, its north-south component, solar wind density, temperature and velocity. In addition, we have considered the magnetic field variance during the passage of interplanetary events. Field variance has been used (a) to study its role in influencing the level of geomagnetic activity, (b) as a measure of turbulence level during the passage of heliospheric events and (c) to identify the cause of a large northward/southward field in the sheath i.e. whether it is due to turbulence or not. All the heliospheric disturbances responsible for individual events, discussed in the paper, are due to coronal mass ejection – some of them are magnetic clouds. Among the CMEs/magnetic clouds, some are associated with shock/sheath. A geomagnetic disturbance may start during the passage of a sheath and/or CME/magnetic cloud, as observed a event to event basis. During the passage of a sheath, the shock compression, turbulence, draping of magnetic field or shocked heliospheric current sheet may lead to large southwards fields and, whenever this happens, a large geomagnetic disturbance is likely to be observed. We suggest a method to distinguish between these four causes of southward field in the sheath. A geomagnetic disturbance is observed to start during the passage of a CME/magnetic cloud whenever magnetic field becomes large southward. From the variations in various plasma and field parameters during these disturbances, plasma density does not appear to be directly involved in the development of geomagnetic storms. The large variance (turbulence) in the magnetic field observed in the sheath is (sometimes) responsible for a large southward field that initiates the geomagnetic storm. The total field strength itself does not play an essential role in the development of geomagnetic storms unless accompanied by southward field of appreciable magnitude. However, southward component of the magnetic field plays a crucial role both in creating and in determining the magnitude of geomagnetic storms. Solar wind speed, from independent evaluation of the effectiveness of individual parameters, appears to be only a minor factor for the creation of storms. This conclusion, apparently poses some constraints on the generally accepted reconnection/merging models. However, in these models, the multiplicative combination of solar wind speed and the southward component of the field is an important physical quantity controlling geomagnetic activity, it is possible that dependence on velocity might not appear clearly when the southward field is small.

Key Words: Geomagnetic storms, interplanetary magnetic field, Coronal mass ejections, interplanetary shocks.

1. Introduction

After solar wind plasma and field data became available there has been a search for geomagnetic disturbances variations in solar wind parameters and various geomagnetic indices. These studies have suggested that geomagnetic activity is related to variety of solar wind plasma/field parameters viz. solar wind velocity, solar plasma density, magnetic field strength, its north-south component and various combinations of these parameters [1, 2]. Two parameters that appear most in these relations are the north-south component of magnetic field and solar wind velocity [3], although there is no general agreement on the relative importance of these two parameters in causing large geomagnetic disturbances and on the functional form of a predictor of geomagnetic activity involving these quantities. Nevertheless, other parameters also appear in these relationships and they are: total field strength [4, 5], solar plasma density [6, 7] and magnetic field variance [8, 9]. The mechanism involving the solar wind-magnetosphere interaction can be fully understood and forecasting of the geomagnetic storm will become easier if the relative importance of various solar wind plasma and field parameter, for the creation/development of geomagnetic disturbance, is unambiguously identified. However, the possible internal correlation between various parameters has been one of the difficulties in identifying them clearly. For instance, the reported correlation of geomagnetic activity with solar wind velocity, solar plasma density, total field strength, its variance and its north-south component may not be completely independent. If one parameter is not independent of the other, then it is possible that the disturbance caused by one of these variables would cause a spurious correlation to the other.

There is also the question of whether solar flares or coronal mass ejections play a key role in large geomagnetic disturbances. For example, Gosling et al. [10, 11] found that large geomagnetic disturbances are associated with earth passage of either a shock or CME or both. Gosling [12] suggested a new paradigm where CMEs substitute flares in the central role of solar-terrestrial relationship. Bothmer and Schwenn [13], and Watari and Watanabe [14] have also reported that CMEs are the source of major storms. Bravo and Rivera [15] have searched for the solar source of some intense storms and reached the conclusion that solar source was a region where a flare or prominence eruption took place adjacent to a coronal hole. Recently, Bravo et al. [16] studied the solar source of intense geomagnetic storms observed in 1980 and found that, in every case, these storms were associated with a flare in active region adjacent to a coronal hole.

Once the solar wind parameter of primary importance and/or the relative contribution of important parameters leading to major geomagnetic storms is identified/ascertained, understanding their solar and interplanetary causes and exact cause-and-effect relationship is key to solar-terrestrial relationship; both for understanding the solar sources and the interplanetary evolution of solar wind and for obtaining advance warning of an impending storm hours to days in advance by utilizing interplanetary and solar observations (see valuable reviews by Tsurutani and Gonzalez [17], and Kamide et al., [18].

To study the storm dependence on solar wind plasma/field parameters, the best way is to perform cross correlation analysis between the parameters and a geomagnetic index [19-21] or by making a case-by-case examination of individual events [22-24]. Most of earlier work with this aim and making a case-by-case individual storm examination have selected some of the intense geomagnetic disturbances [11, 13, 15, 16, 24, 25] and tried to find the solar and interplanetary causes of these disturbances. We have adopted a somewhat different approach. We selected the events of varying magnitude, fairly different from one another, both in respect of heliospheric disturbances and their geomagnetic effects. Moreover, in addition to plasma and field parameters such as V, F, N, T, θ and Bz, we have also considered the magnetic field variance (σ_F) during, before and after individual disturbances. σ_F is a measure of turbulence in the field. In high field regions, if σ_F is small, this region is regarded as undisturbed and uniform. On the other hand, if σ_F is large in these regions, the magnetic field is regarded as turbulent. For example, in heliospheric transients (shock/CME/magnetic cloud) a region is identified as magnetically quiet (turbulent) where the variance of the magnetic field is lower (higher) than average [26-30]. As shock/sheath are magnetically turbulent and CMEs/magnetic clouds are quiet, the consideration of σ_F will help in identifying the duration of passage of two regions (sheath and CME/magnetic cloud) in addition to looking for any possible role of variance in the field for the geomagnetic disturbances. Thus for the purpose of study in this paper, we have utilized, in addition to geomagnetic index Dst, solar wind velocity V, magnetic field strength F, its variance σ_F and its north-south component Bz as these plasma/field parameters and/or their functions have been associated with geomagnetic activity [2]. In addition we have chosen three more parameters, namely, solar wind plasma temperature T, plasma density N and latitude angle of the average field vector θ. T and N, in addition to those mentioned above, will help distinguish the duration of passage of shocked plasma/field (sheath) from the ejecta following it; and θ will help in identifying whether the ejecta is a magnetic cloud or not.

2. Results

2.1. Inter-comparison of interplanetary events

Figure 1 shows two events: one starting at hour zero (event 1) and the other at hour-36 (event 2). This figure shows plotted values of Dst (nT), V (Km/sec), F (nT), σ_F(nT), T (K), N (cm^{-3}), θ (degrees) and Bz (nT). During event 1, there is a large and sudden increase in the values of F, σ_F, V, T and N; it indicates the arrival of the shock. Transient interplanetary shocks are formed due to compression of ambient plasma and field by high speed ejecta of close structure [31], some of them may be magnetic clouds as defined by Burlaga et al. [32]. The compressed region of ambient solar plasma and field between shock front and driver ejecta is referred to as the sheath. During event 1 there is a short duration increase (sudden impulse) in Dst at -and just after- the arrival of the shock, possibly due to solar wind ram pressure effects [33]. After this sudden impulse, Dst begins to decrease during the passage of the sheath. That the sheath is turbulent is evident from enhanced σ_F. Meanwhile, Bz is highly fluctuating between +18 nT and −12 nT and other plasma/field parameters (V, F, σ_F , N and T) exhibit increase. Thus, from this event alone it is difficult to talk about the relative effectiveness of these parameters and/or the most effective parameter for the creation of this geomagnetic storm (Dst $\sim$ -100 nT).

During event 2, plasma parameters V and T are in fact decreasing from the pre-event level, σ_F is small and has not increased much (i.e., it is a quiet region), and plasma parameter N and field parameter F increase to some extent. In fact, increase in N starts earlier but it decreases for a short duration during this event. Note, though the change in Bz towards negative value is quite significant. A moderate geomagnetic storm (Dst $\sim$ -60 nT) is observed; the decrease in Dst is simultaneous with the decrease in Bz value. Thus, we observe that for this event V, N and σ_F are not the most important parameters causing geomagnetic storm; instead, the southward field (field strength) may be the major cause.

After few hours of sudden jump in F, V, σ_F, N and T at hour zero (event 1) bidirectional electron heat flux events as well as bidirectional proton events were observed. Note that bidirectional events are regarded as a signature of the passage of CME [34]. Thus, the heliospheric structure responsible for event 1 is a CME driven shock. The other event (event 2) is due to a magnetic cloud; magnetic clouds are interplanetary manifestations of CMEs [35]. In case of event 1, Dst starts decreasing during the passage of sheath. It is evident from enhanced σ_F, that the sheath is highly turbulent and this turbulence appears to be the cause of Bz fluctuating first it is northward then southward after the arrival of shock front (hour zero). The Dst decrease in the case of event 2 coincides with the negative Bz part of the magnetic cloud.

It is a point worth noting that magnetic clouds are an important subset of CMEs [31, 35, 36], their relationship between passage at earth orbit to magnetic clouds and geomagnetic storms is well established [13, 21, 26, 37-44], and they are the most geoeffective interplanetary CMEs [17, 45, 46].

A comparison of these events, one a shock associated CME and the other a magnetic cloud, shows that all the plasma and field parameters (V, F, σ_F, N, T, Bz) during event 1 have greater enhanced than during event 2 and the intensity of geomagnetic disturbance is more intense (Dst $\sim$ -100 nT) during event 1 than event 2 (Dst $\sim$ -60 nT). The disturbance associated with event 2, i.e. the magnetic cloud associated with the geomagnetic disturbance, starts on the arrival of the $-Bz$ part of the cloud and the shock-associated event (event 1) is responsible for a larger geomagnetic disturbance. Though it is not possible to specify any of the parameters responsible for the difference in the geomagnetic response between the two events, we do state that the result is consistent with the earlier findings that intense geomagnetic storms are, in general, associated with shock associated CMEs [10, 13, 18, 21, 24, 47, 48].

In Figure 2 three events are shown, and are quite different from one another with respect to the heliospheric disturbances as well as the geomagnetic effects. During the event at hour zero in Figure 2 (event 3), there is a small increase in parameters F, σ_F, N and T; but parameters V and Bz (positive) are quite large. No appreciable geomagnetic disturbance is produced by this event. Due to another event, also in this figure at hour −42 (event 4) there is a large increase in parameters F, σ_F, N and T; but increase in V is smaller in comparison to event 3. However, there is a large change in Bz towards negative value, and during this event a severe geomagnetic storm (Dst ∼ -200 nT) is observed. Another event of moderate geomagnetic intensity (Dst ∼ - 80 nT) is shown in this figure at hour −70 (event 5). This storm of moderate intensity is observed during such heliospheric condition that most of the parameter (V, F, σ_F , N, T) remain either the same or even decreased to some extent with respect to previous values. However, Bz changes to a large negative value during this event.

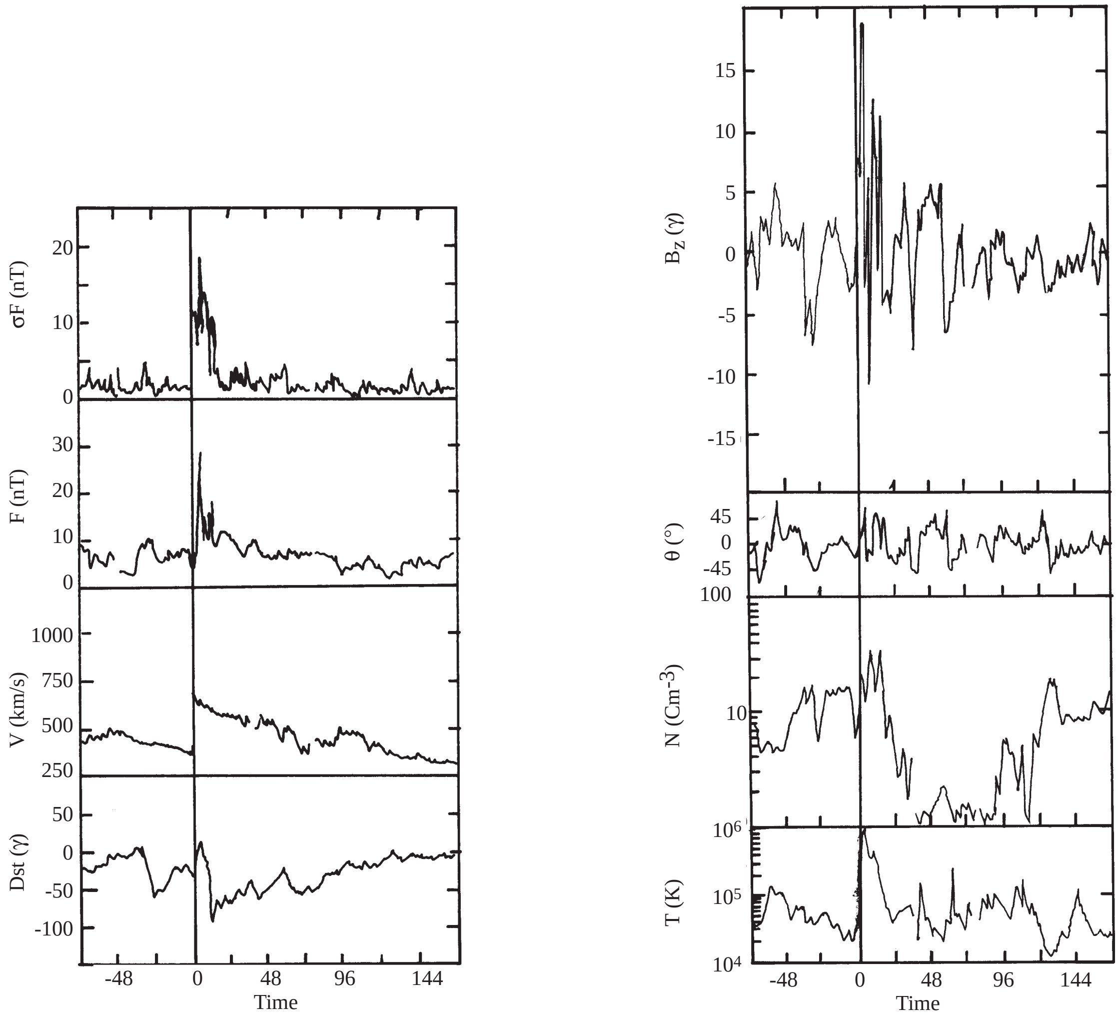

Figure 1. Figure shows geomagnetic disturbances and variations in solar wind velocity (V), magnetic field vector (F), its variance (σ_F) and its north-south component (Bz), field angle (θ) solar plasma temperature (T) and its density (N) due to a magnetic cloud at hour –36 and a shock associated disturbance at zero hour.

Regarding the heliospheric disturbances during these three events, two of them (event 3 and 4) are shock associated. Event 3 does not produce any appreciable geomagnetic disturbance but the other shock-associated event (event 4) is responsible for a severe storm (Dst ∼ -200 nT). The sheath in this case is turbulent (σF is high) and Bz decreases during the passage of the sheath itself due to compression/turbulence. This compression/turbulence in the sheath is responsible for a large negative Bz and the leading edge of ejecta following the sheath also appears to be southward during this event The sheath is followed by a helium enhancement [49], indicating that this shock is driven by a CME. Note that event 5 also exhibits as a CME.

A comparison of these three heliospheric disturbances shown in Figure 2, where two of them are shock associated while the other is a CME, shows that F, σ_F, N, T and Bz (negative) is highest during event 4, producing a severe geomagnetic storm. However, the plasma parameter V is highest during other shock associated event (event 3) whose geomagnetic effect is almost negligible. The parameters V, F, σ_F, T are, comparatively, lowest during event 5 which was responsible for a moderate geomagnetic storm of $Dst \sim$ -80 nT. However, a comparison of the north-south component of the field Bz shows that it is positive during the event not producing any geomagnetic disturbance, but it is negative during the event producing moderate geomagnetic storm and it is more negative during the event responsible for severe geomagnetic storm. Comparison of these events, shown in Figure 2, is consistent with the suggestion that velocity may not be the most important parameter in causing geomagnetic storms but the strength of the southward field may be the dominant cause [24].

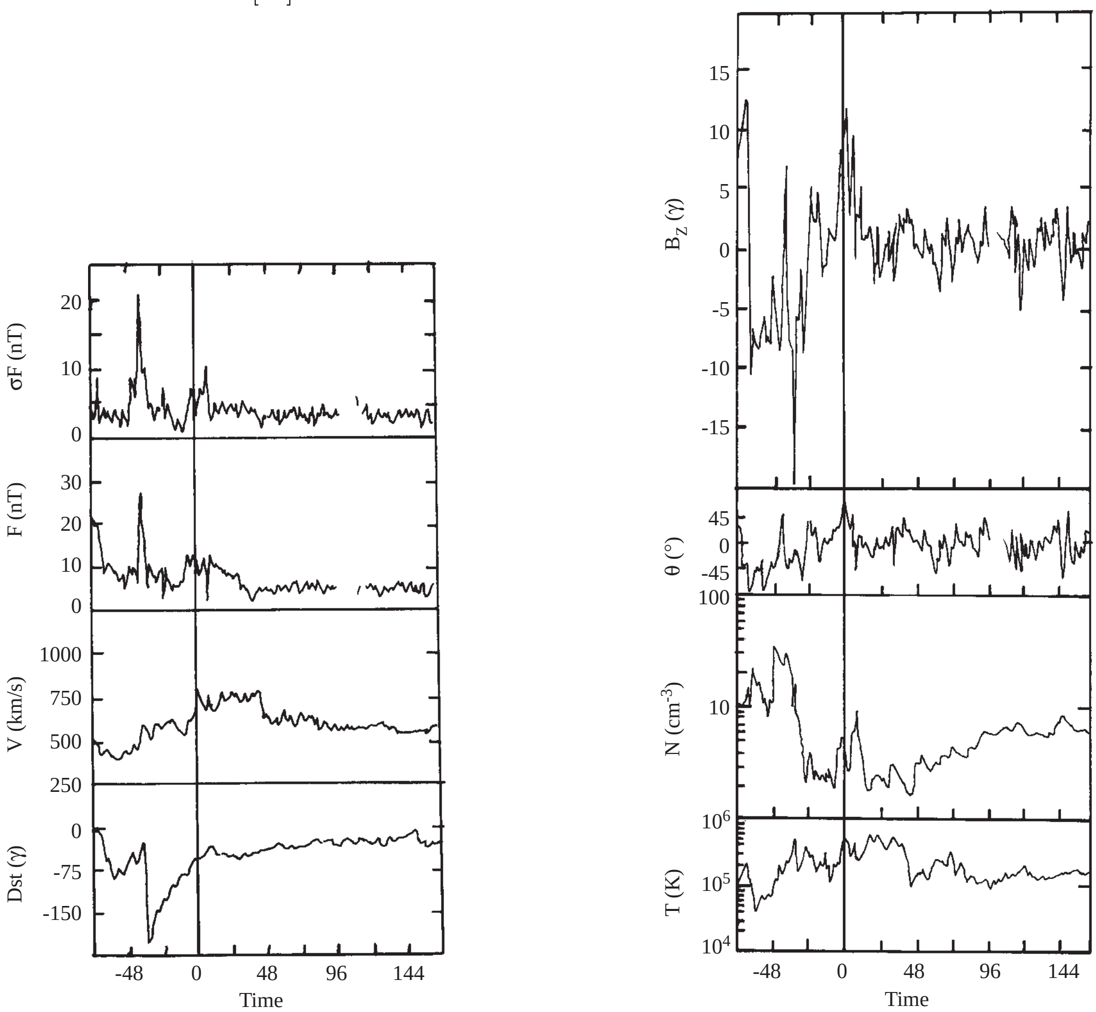

Figure 2. A plot showing variations in Dst, V, F, σ_F, Bz, θ, T and N in association two disturbances due to shocks, one at zero hour and other at hour –42 and another due to a disturbance without a shock at hour –70.

In Figure 3 we show two events: one at hour zero (event 6) and one at hour –40 (event 7). During event 6, there is a large increase in all the plotted plasma and field parameters (V, F, σ_F, N, T and Bz) and they decrease after remaining enhanced for a few hours; yet there is no decrease in Dst for the duration of this period of enhanced solar wind parameters. However, there is a small depression in the geomagnetic index ($Dst \sim$ -25 nT) after about 12 hours of the arrival of the heliospheric event at zero hour, when Bz becomes slightly negative and V increases again to some extent. In spite of the fact that all the solar wind parameters are quite enhanced during this event, it could not produce even a moderate geomagnetic storm. During other event (event 7) shown in this figure, there is appreciable increase, but much smaller than event 6, in F and N and the increase in σ_F and T is also small. Except for a very small increase in V at the start of the event (at hour –40, Figure 3) the velocity is continuously decreasing, at least in comparison to the previous 32 hours. However, there is a large change in Bz towards negative value during this event. This heliospheric disturbance is responsible for a severe geomagnetic storm ($Dst \sim$ -200 nT). This storm starts during the passage of a not-much-turbulent sheath (as evident from a small change in σ_F). Draping appears to be the main cause during this event for the large southward field during the passage of the sheath.

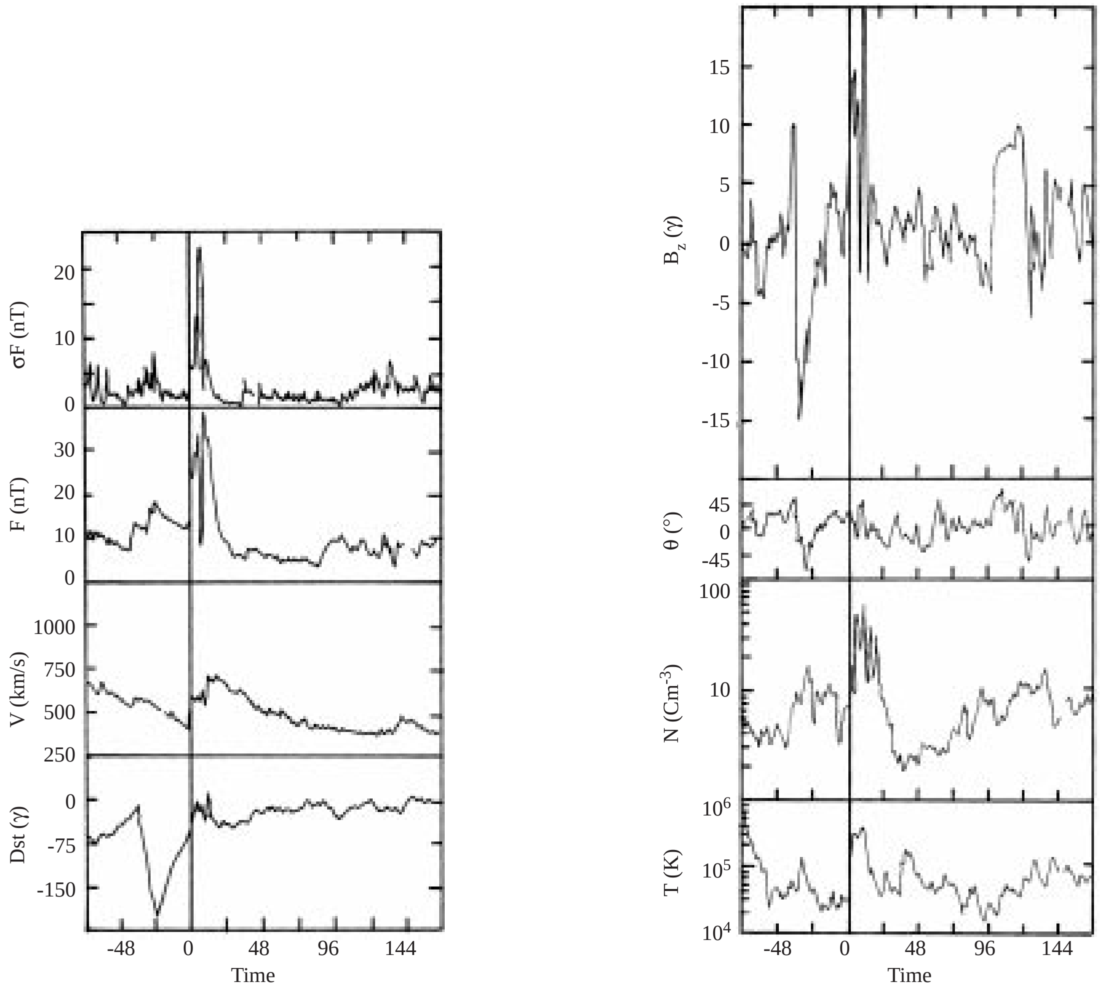

Figure 3. Variations in Dst index, V, F, σ_F, Bz, θ, T and N in association with two shock related disturbances one at zero hour and other at about 40 hours earlier.

Both these disturbances are shock associated, their plasma β is low, both the shocks (event 6 at hour zero and event 7 at hour –40, Figure 3) are driven by CMEs and one of them, associated with large geomagnetic disturbance, is a magnetic cloud [26]. In the case of event 7, just behind the sheath the leading part of the cloud is also southward.

A comparison of these two events, shown in Figure 3, clearly shows that the solar plasma and field parameters (V, F, N, σ_F, T) are all much enhanced in the case of event 6, which does not produce any appreciable geomagnetic disturbance on its arrival at earth. On the other hand event 7, in whose case these parameters are much less enhanced, is responsible for a severe geomagnetic storm ($Dst \sim$ -200 nT). However, there is a crucial difference in Bz; the enhancement in Bz is towards positive value in the case of event 6 while it changes towards large negative value during event 7.

In Figure 4 we have shown one event (event 8) at zero hour. There is a sudden increase in parameter V, F, T, Bz, including σ_F, at zero hour. This event is responsible for a moderate geomagnetic storm ($Dst \sim$ -50 nT); the decrease in Dst starts a few hours after arrival of shock front, when Bz turns to a large negative value. The sudden enhancement in almost all the heliospheric parameters shows the arrival of shock at zero hour. A bidirectional electron event was observed [34] and there was a sector crossing also on this day (P. H. Scherrer, private communication); bidirectional electron events are signature of the passage of a CME [34] and sector crossing shows the passage of heliospheric current sheet at the location [50, 51]. During this event Bz is fluctuating and σF is also high; the turbulence in the magnetic field in sheath region may be responsible for large fluctuation in Bz which leads to enhanced southward field after initial increase to large northward field, thus the cause of negative Bz, in this case, is turbulence/compressed heliospheric current sheet.

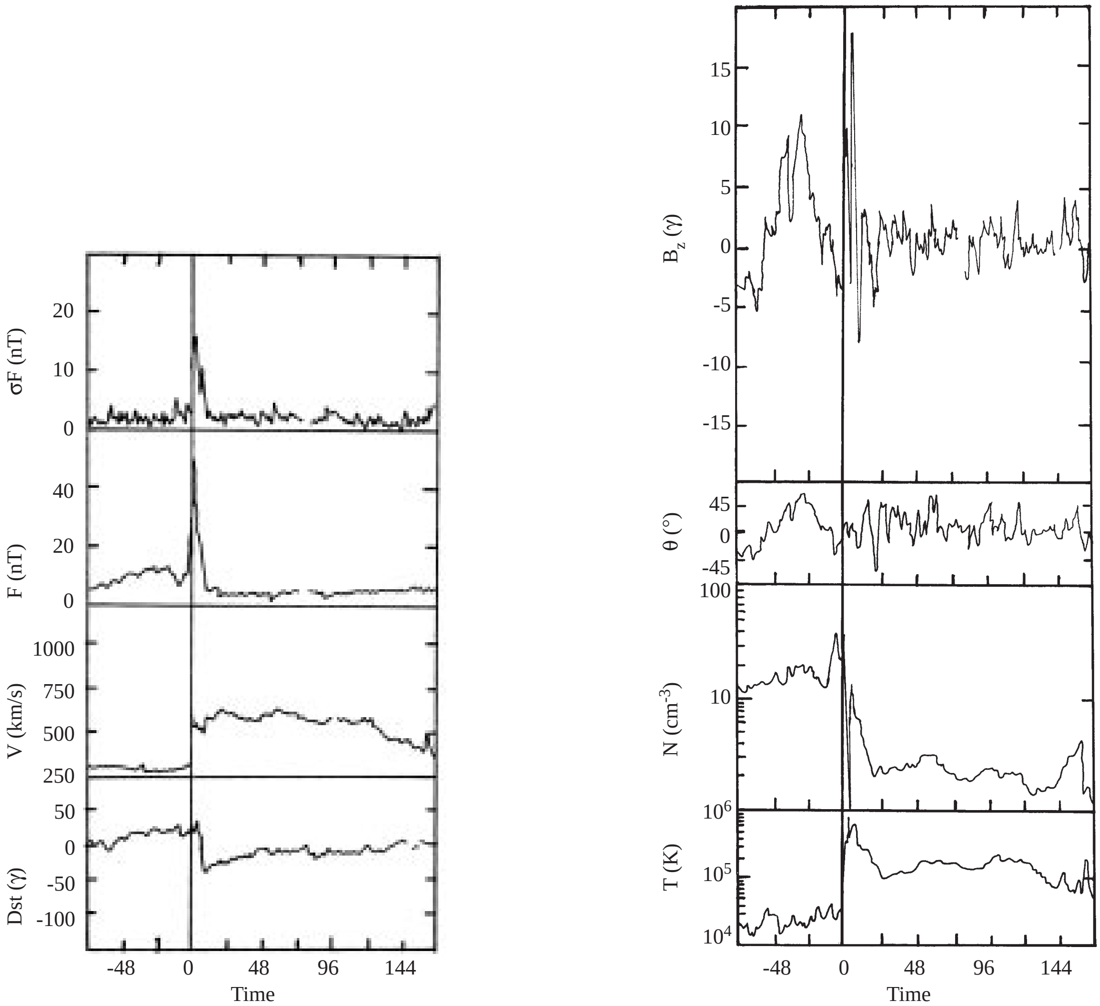

Figure 4. Figure shows a geomagnetic disturbance and variations in V, F, σ_F, Bz, θ, T and N due to a shock associated disturbance.

2.2. Inter-comparison of solar wind parameters

2.2.1. Solar wind plasma density

From an inter-comparison of all the events, discussed above, we see that the plasma density N is enhanced during events 3 and 6 producing almost no geomagnetic disturbance; it is reduced during a moderate geomagnetic disturbance (event 8); density during big storm (event 7) is smaller than event 6 which is responsible for geomagnetic disturbance of very small intensity, if any. But the density during a large geomagnetic disturbance (event 4) is larger than the density during event 3, not producing any geomagnetic disturbance. Thus we conclude that plasma density does not appear to be directly involved in the creation/development of geomagnetic storm [21] and density related dependence reported by earlier workers [7, 52] is secondary in nature [53].

2.2.2. Total field strength

The total magnetic field strength F is high (> 25 nT) in the case of events 1, 4, 6 and 8. However, there is no geomagnetic disturbance during the passage of regions of very high field intensity ($\sim$ 35 nT) in case of event 6; the disturbance starts after the passage of most part of the high field region during event 8. The field is enhanced ($\sim$ 28 nT) during a large storm (event 4) while it is not much enhanced (< 20 nT) during another intense storm (event 7) and the field is smaller (< 10 nT) during the storm of moderate intensity (event 5 and 2). However, during these events, geomagnetic disturbance takes place when the north-south component of the field becomes southward to a large extent. Thus we conclude that when total field strength has a large magnitude and a large southward component, the intensity of geomagnetic disturbance becomes large. On the other hand, even when the total field strength has a large magnitude but large northward component, no geomagnetic disturbance takes place.

2.2.3. Field variance

The field variance σ_F is high (> 15 nT) during events 1, 4, 6 and 8. It is very high ($\sim$ 22 nT) during the passage of the sheath in case of event 6; but there is no geomagnetic disturbance during the sheath passage of this event. In case of other events with large σ_F (events 1, 4, and 8), the geomagnetic disturbance does not take place until Bz becomes large southward. Event 1, with large variance, is not geoeffective as it lacks large southward field (instead it is largely northward). Thus during the passage of a compressed/turbulent sheath, a geomagnetic disturbance takes place if and when it leads to a large southward field. The cause of large southward field in the sheath appears to be due to turbulence during event 1; draping appears to be the cause during event 7; and compression/turbulence is most likely cause of the large southward field during event 4. During event 8 it may be due to shocked heliospheric current sheath and/or turbulence in the field.

2.2.4. Solar wind speed

There is this question: How crucial is the role of the solar wind velocity for the creation/development of geomagnetic storms? Gosling et al. [11] concluded that speed of transient heliospheric disturbances is the most crucial factor in creating large geomagnetic disturbances. On the other hand, Tsurutani et al. [24] reached at the conclusion that southward component of the field rather than solar wind speed plays the crucial role in intense geomagnetic storms. During the period when high speed streams from coronal holes are more frequent, Schreiber [54] found that generation of disturbances is affected more by the magnitude of the solar wind than that of the southward field. However, Watari and Watanabe [14] found that the high speed stream from coronal holes had a weak effect, on geomagnetic disturbances. We can see that during some events, the velocity increases to a very high value (events 1, 3, 6, 8). However, during the two largest geomagnetic disturbances ($Dst \sim$ -200 nT) the velocity is not so high, though there is a small increase in velocity during these two events (events 4 and 7). During the two other events (events 2 and 5), which had been responsible for moderate geomagnetic intensity, there is no enhancement in speed. High speed ($\sim$ 750 Km/sec) events 3 and 6 are unable to produce the geomagnetic disturbance, of any appreciable intensity. On the other hand, high speed events 1 and 8 do produce geomagnetic disturbance though with a time lag. Thus, whether the effect of recurrent high speed solar wind from coronal holes on geomagnetic disturbance is weak [14] or during long-lived coronal holes with high solar wind velocity the geomagnetic activity is generated more by the magnitude of solar wind velocity [54] needs to be looked into. From an inter-comparison of the solar wind velocity during events discussed above we conclude that, at least during transient interplanetary disturbances, solar wind velocity is not the most important parameter but is only a minor factor for causing geomagnetic storms [17, 21].

2.2.5. North south component of magnetic field

The north-south component of the interplanetary magnetic field Bz is large but northward during events 3 and 6; and these events do not produce any appreciable geomagnetic disturbance. This component is large southward during the events (2, 5 and 8) responsible for moderate geomagnetic storms; and it is much larger and southward during events 4 and 7, producing geomagnetic storms of very high intensity ($\sim$ -200 nT).

Thus, southward component of the interplanetary magnetic field plays a crucial role both for causing the geomagnetic storm and in determining the magnitude of the storm.

2.3. CME versus Solar Flares

In recent years it has been extensively debated whether solar flares or CMEs play a central role in large (especially non-recurrent) geomagnetic disturbances. Though we do not intend to discuss here the solar flare myth postulated by Gosling [12], all the individual disturbances discussed in this paper can be associated with a CME.

3. Discussion and Conclusions

Understanding the causes of southward fields is important from the point of view of understanding and prediction of geomagnetic storms [55]. During transient heliospheric events causing geomagnetic disturbances, the southward fields can be either a part of a sheath magnetic field behind the interplanetary shock or part of the driver gas, or both. When one finds them consecutively in both the regions, the intensity of the storms tends to be larger. The driver gas is a fast CME/magnetic cloud. The large southward field, if observed within the driver gas, is actually part of the CME/magnetic cloud. However, the southward field in the sheath is caused by shock compression, turbulence, draping of the field around ejecta or a shocked heliospheric current sheet [3]. Due to shock compression, a high intensity field sheath is created downstream from the shock. If the upstream field is originally southward, shock compression will lead to an intense negative Bz in the sheath [18, 46, 47, 56]. In the case of draping, magnetic field draping around a CME leads to a squeezing of plasma out the ends of the magnetic flux tubes. Although dynamic pressure is maintained across the whole sheath, draping leads to lower beta plasma and higher field strength [17]. The value of the field variance σ_F is regarded as a measure of level of turbulence; a high field region (e.g., sheath/CME) is regarded as quiet and uniform if σ_F is small, it is regarded as turbulent when σ_F is large [26]. Sector crossing observed at earth is due to passage of heliospheric current sheet [50, 51], a sector crossing observed at the time of shock passage may lead to shocked heliospheric current sheet. These properties can help in distinguishing the cause of intense southward field, if observed, in the sheath. (The duration of passage of sheath at earth is about 12 ± 6 hours. If an intense ($\geqslant 10$ nT) southward field is observed, even for three hours, a geomagnetic storm is likely to be observed [17]).

Our results concur with the conclusion that the primary cause of magnetic storms are large southward fields, the solar wind velocity is only a minor factor, the plasma density is not directly involved in the creation of geomagnetic storms and total field strength may show a correlation with the level of geomagnetic activity during southward fields only. Based on results presented in this paper, and those of earlier workers [9, 10, 13, 21, 24, 46-48, 57] a simplified description of geomagnetic activity, due to transient heliospheric disturbances and its solar and interplanetary causes is as follows: When solar ejecta responsible for transient heliospheric disturbances propagates at a speed comparable to ambient solar wind, the ejecta itself can produce geomagnetic disturbance whose intensity depends upon the magnitude of the southward field, when it reaches the earth magnetosphere. If the ejecta propagates at a speed higher than that of the upstream slow solar wind, a shock develops. The ejecta are most likely to be a fast CME. The ambient plasma and field between shock front and ejecta gets compressed and a high intensity field sheath region is created downstream from the shock. The shock compression, turbulence, draping of magnetic field or shocked heliospheric current sheet may lead to intense southward field in the sheath. The intense southward field can be found in sheath, ejecta or both, and when such fields are found consecutively in both regions the resulting magnetic storm intensity is higher.

As the shock/sheath is formed when ejecta propagates at a high speed relative to ambient plasma, the compressed sheath magnetic field is likely to increase due to compression of ambient field. In the sheath there is the possibility that the magnitude of the Bz component is enhanced (positive or negative) due to compression, turbulence or draping. The total field strength in the sheath and magnitude of its Bz component (northward or southward) may be interrelated in the sense that when one increases (decreases), the other also increases (decreases). The plasma density also enhances in the compressed region and both the Bz component as well as the plasma density will increase when compression is more. Thus, if the large southward field responsible for geomagnetic disturbance in the sheath is due to compression, dependence may be seen due to enhancement in both Bz and N during some events. During certain events, high speed ejecta may lead to high intensity magnetic field in the sheath due to compression, consequently its Bz component may also increase. Thus it is not surprising, if during such events, geomagnetic activity shows a dependence on total field strength, plasma density and/or solar wind velocity during the large southward Bz component, that is essential for the creation of geomagnetic storms. As the southward component of the magnetic field plays crucial role in determining the amount of solar wind energy, which is transferred to the magnetosphere presumably via magnetic reconnection, large geomagnetic activity does not show a dependence on solar wind parameter (e.g. plasma density, field strength) associated with the northward Bz component.

The solar wind dawn-to-dusk electric field directly drives magnetospheric convection. These electric fields are caused by a combination of solar wind velocity and southward interplanetary magnetic field ($V \times Bs$, Bs is the southward field). Thus solar wind velocity and southward component of interplanetary magnetic filed are essential quantities causing geomagnetic activity. However, either both parameters are equally important or one is more important than other is a question of interest. In the interplanetary cross tail electric field the solar wind and southward field play an equal role. However, experimental evidences suggest that southward field is more important [3, 24, 46, 57] and solar wind speed is usually only a minor factor for the creation of geomagnetic storm [17, 21]. Considerable progress have been made in quantitative prediction of storm development [58, 59] since Burton et al. [22] published an empirical relation between a geomagnetic index and product of solar wind velocity and southward interplanetary magnetic field; without the emergence of true consensus on the precise form of the input function for solar wind energy involving these two quantities [3]. Possibly the lack of general agreement on the functional form of a predictor of geomagnetic activity is due to the reason that we have yet to quantify the relative importance of these two parameters, assuming that both are essential quantities causing geomagnetic activity.

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