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A study on the peak Dst and peak negative Bz relationship during intense geomagnetic storms

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[1] This paper is a study of the relationship between the geomagnetic storm index Dst and the southward component, Bs, of the interplanetary magnetic field (IMF) driver. This study was performed during the ACE observational period (1997–2002), for which 64 intense geomagnetic storms (Dst ≤ -85 nT) were analyzed. After taking into account the propagation time between the L1 point and Earth ($\sim$1 h) and the magnetosphere/ring current response-time to solar wind forcing ($\sim$1 h), it was determined that the average delay between the peak Bs and the peak Dst values is $\sim$2 h. It was also observed that the Bs value at peak Dst is $\sim$75% of the peak Bs value in the entire event. When these results are analyzed in terms of the interplanetary electric field, associated with Bz, some interesting additional studies are indicated, for which some simple results, of practical space weather forecasting use, are anticipated. **Citation:** Gonzalez, W. D., and E. Echer (2005), A study on the peak Dst and peak negative Bz relationship during intense geomagnetic storms, *Geophys. Res. Lett.*, *32*, L18103, doi:10.1029/2005GL023486.

1. Introduction

[2] For the association of geomagnetic storm intensity and the interplanetary magnetic field driver, it is usually assumed that the peak value of the storm, as measured by the storm index Dst, is attained after the southward component of the interplanetary magnetic field, Bz, has also reached a peak value [e.g., *Burton et al.*, 1975; *Gonzalez et al.*, 1994; *Tsurutani and Gonzalez*, 1997; *Kamide et al.*, 1998].

[3] However, since there has not been done as yet a quantitative study of this assumed relationship, in this paper we try to perform such a study for the ACE observational period of 1997–2002, during which 64 intense magnetic storms (Dst < -85 nT) were identified, as described in the following section.

[4] We believe that this study is important not only as a forecast tool in space weather applications, but also for a better physical understanding of solar wind-magnetosphere interaction and ring current dynamics during intense storms.

2. Methodology of Analysis

[5] The 1 hour Dst geomagnetic index was used in this work to characterize the geomagnetic storm development and it was obtained from the World Data Center for Geomagnetism, WDC-Kyoto. One-hour data of the interplanetary magnetic field Bz component and of the solar wind speed V_{sw} were obtained from the MAG and SWEPAM experiments on the ACE spacecraft, as given by the ACE Science Center.

[6] The period selected for our analysis is the ACE observational period from September 1997–December 2002, for which the Dst index was available in its final form when this work was performed. We have selected intense geomagnetic storms that reached, at least, a Dst peak of -85 nT. Considering this criterion, and also selecting storms with multiple, but well separated, peaks corresponding to different energy injection events, a total of 71 events were obtained. From this data-set, 64 storms were used in the study. The storms that were neglected had a lack of interplanetary data (16 July 2000, 10 November 2000, 26 September 2001 and 6 November 2001) or had a very complex profile, with multiple and not well separated peaks, which did not allow a simple study of their Dst-Bs peak relationships (Bs stands for negative Bz). The storms that were excluded on the basis of this criterion were 23 November 1997, 13 November 1999 and 05 October 2000.

[7] Figure 1 shows a scheme illustrating how the analysis was done. Figure 1 shows idealized Bz and Dst profiles as a function of time (t). The Dst and Bs peaks are identified by the labels Dst_{peak} and Bs_{peak}. The storm main phase duration is indicated by the thinner line and by the t_m label. Two dotted vertical lines passing through the Dst and Bz peaks are shown, and the corresponding values of Dst and Bz in their intersection with the curves are determined. The Bz and Dst variations were calculated as the ratio between their peak values and the values in those intersections (the variations are shown as ΔDst and ΔBz in Figure 1). The delay time between Dst and Bz peaks is also determined and is indicated by Δt in Figure 1.

[8] This procedure was performed for each storm. The relative variations are calculated as $\Delta Dst = Dst'/Dst_{peak}$ and $\Delta Bz = Bz'/Bz_{peak}$, where Dst′ and Bz′ mean the values of Dst and Bz at the time when the Bz and Dst peak values are observed, respectively. The main phase duration t_m and the delay Δt between the peaks were determined, as well as the ratio between them, $r_t = \Delta t/t_m$.

[9] For each geomagnetic storm, the hourly values were provided by WDC (Kyoto). This value was corrected in two hours, i.e., the Dst curve was displaced two hours backwards in time, in order to take into account the propagation time, of about 1h, between the Lagrangian point L1, where ACE is orbiting, and Earth. The magneto-

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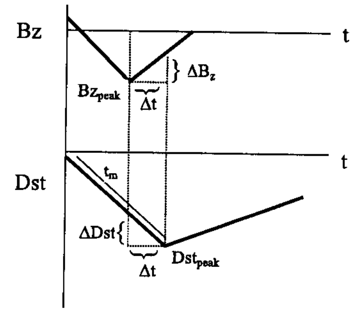

Figure 1. Scheme of Bz and Dst profiles during intense magnetic storms. The peak values of Bz and Dst are indicated by Bz_{peak} and Dst_{peak}, the main phase duration by t_m, the delay between the Dst-Bz peaks by Δt and the relative variations by ΔDst and ΔBz.

sphere/ring current response time to Bs was also considered to be of 1 h [*Akasofu*, 1981].

3. Results

[10] Figures 2 and 3 show examples of geomagnetic storms studied in this work. Both Figures 2 and 3 present the hourly averages of Bz and Dst. The position of peak Dst is marked by a vertical dotted line, whereas the duration of the main phase before this peak is indicated by a horizontal bar. The peak values of Dst and Bz are also indicated by labels.

[11] In Figure 2, the storm during 17–20 September 2000 is shown. This was a typical 'simple', one-step magnetic storm. The Dst peak occurred at 22:00 of September 17 (hour corrected) and of the Bs peak at 21:00 of September 17. Thus the Δt between these peaks was of 1 hour in this storm. Dst peak reached −201 nT and Bz peak −23.9 nT. The storm main phase was fast, t_m = 4 h, giving a delay/main phase ratio of $r_t = 0.25$. The IMF Bz varied rapidly and reached a peak in a few hours, giving a Bz variation of ΔBz = 0.43, i.e., the value at peak Dst was 43% of its maximum value. The Dst index responded slowly and its relative variation was ΔDst = 0.85, i.e., the Dst value at peak Bz was 85% of its peak value.

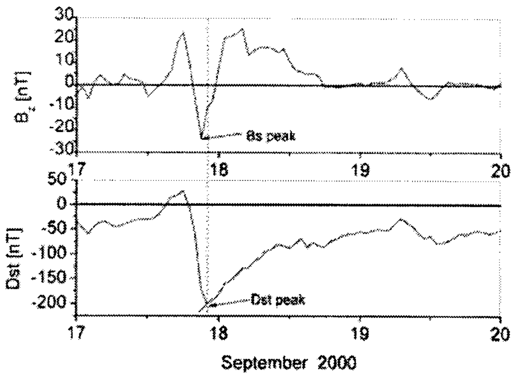

Figure 2. Geomagnetic storm during 17–20 September 2000. The Bz and Dst hourly averages are shown. The Dst peak is indicated by a dotted line. This was a typical 'simple', one-step, magnetic storm.

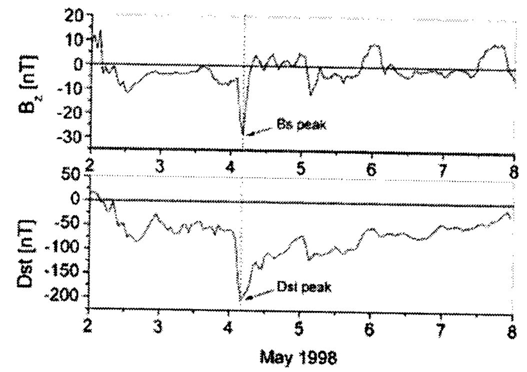

Figure 3. Geomagnetic storm during 2–8 May 1998. The Bz and Dst hourly averages are shown. The Dst peak is indicated by a dotted line. This was a typical complex, double-step, magnetic storm.

[12] Figure 3 shows the geomagnetic storm during 2–8 May 1998. The Bz and Dst hourly averages are shown. This was a typical 'complex', double step magnetic storm. This storm is more complex than that of Figure 1, with two Bs peaks. If one considers only the second storm, peak Dst was in phase with peak Bs (Δt = 0 h), after correcting for propagation time and magnetospheric response. In this case ΔBs and ΔDst = 1. The storm main phase lasted ~4 h. The peak of this storm was −205 nT and the Bz peak was −28.6 nT.

[13] Table 1 shows the average and standard deviation parameters for the 64 storms studied. The values are the Dst peak (Dst_{peak}), the Bz value during the time of Dst peak (Bz'), the Bz peak (Bz_{peak}), the Dst value during the time of Bz peak (Dst'), the main phase duration (t_m), the delay between the peaks of Bz and Dst (Δt), the ratio between Δt and t_m (r_t), and the relative variation of Bz (ΔBz) and Dst (ΔDst).

[14] We can see that the average delay between the Bz and Dst peaks is around 2 hours. As the main phase duration is around 10 hours, the ratio between these two periods is ~0.2. The relative Bz and Dst variations are 0.75 and 0.82. This means that the Bz value at peak Dst is 75%, on average, of the minimum Bz value, while the Dst value at peak Bz is, in average, 82% of the Dst peak.

[15] Figure 4 shows the distribution of the number of storms (left axis; percentage of storms on the right axis) as a function of the delay Δt between the Bz-Dst peaks. It is seen that most of the storms have a delay between 0–4 hours (more than 70% of the storms), while Table 1 gave an average of 2 hours. Less than 5% of the storms had a

Table 1. Average Storm Parameters for 64 Storms (1997–2002)

Parameter	Average ± Standard Deviation
Dst peak	−134.6 ± 55.8 nT
B_z in the Dst peak	−11.9 ± 7.1 nT
B_z peak	−15.6 ± 6.6 nT
Dst in the B_z peak	−112.5 ± 58.6 nT
main phase duration	9.9 ± 5.3 h
Δt_p	1.9 ± 2.2 h
ratio t_p/main phase duration	0.23 ± 0.26
rB_z	0.75 ± 0.26
rDst	0.82 ± 0.17

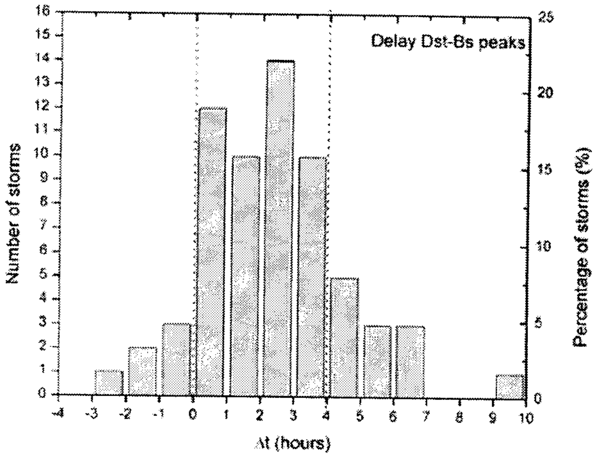

Figure 4. Distribution of the number of storms (left axis; percentage of storms on the right axis) as a function of the Bz-Dst delay Δt. It is seen that most of the storms have a delay between 0–4 hours between the Bz-Dst peaks.

negative delay between the Bz-Dst peaks, i.e., the Dst peak occurred before the Bz peak.

[16] The average delay of 2 hours between the Bz-Dst peaks is also observed when the peak electric field Ey (V_{sw}Bz) values are taken in relation to Dst. Thus the histogram for the delay between peak Ey and peak Dst looks practically the same as that of Figure 4, with most of the delay times running between zero and four hours.

[17] Figure 5 is a plot of the integrated Ey, up to the time of Bs peak, versus peak Dst, which is being shown due to its forecasting value, as discussed below.

[18] Another interesting parameter to study is the integral of Ey during the main phase up to the time of peak Bs, as compared to the integral of Ey during the whole main phase (up to the time of peak Dst), in order to have an idea of how much additional Bz flux (Ey) is needed to reach peak Dst from the flux level at peak Ey. We have done this integration for the domain -85 nT > Dst > -150 nT, in which more than 80% of the studied storms were located. This study indicates that 23.7 mV/m-hr is accumulated up to the time of peak Ey, while 34.3 mV/m-hr is accumulated during the whole main phase, therefore, about 30% of additional integrated Ey is needed to reach peak Dst from peak Ey. When considering all the storms, the results are practically the same, with, on average, 26.6 mV/m-hr being accumulated up to the time of Bs peak and 39.8 mV/m-hr until the time of the storm (Dst) peak, giving a value of ~33% of additional integrated Ey needed to reach peak Dst from peak Bs/Ey.

4. Discussion and Conclusions

[19] The main result of the present study indicates that the average delay between the peak Dst value of an intense magnetic storm and the corresponding peak of the driving Bs value is about two hours. Since the average duration of the main phase intervals of the studied storms is 10 hours, this two-hour delay represents 20% of the average main phase duration.

[20] Thus, for storm-forecasting purposes, one can expect that the peak of the storm's intensity, as measured by the Dst index, will occur about two hours after the driving Bs component of the IMF has reached its peak value.

[21] It was also found that the Bs value at the time when Dst reaches its peak is, on average, ~75% of the peak Bs value, whereas the Dst value at the time when Bs reaches its peak is, on average, ~82% of the peak Dst value. These two percentages are somewhat similar.

[22] The result shown by Figure 4, that peak Dst occurs with a delay between 0 and 4 hours (with an average of 2 hours) after Bs has reached its peak, may suggest a physical response time of the ring current to the solar wind driver at the peak interval of an intense magnetic storm. This information would be of interest for modeling efforts of the ring current dynamics and studies of loss processes near the peak of the storm. We should note that delay times between Dst and Bs at other moments of the storm evolution may take different and usually larger time lags [e.g., *Gonzalez et al.*, 1994].

[23] The corresponding result that the Bs value at the time of peak Dst is, on average, 75% of the peak Bs value, could suggest that the storm continues growing for a time interval of about 2 hours, even though Bs is already decreasing in magnitude. Again, this time lag can be associated to the loss processes that need such a time constant to overcome the energy input associated to Bs at this phase (near maximum) of the storm evolution.

[24] The two-hour delay can also be used in studies of storms for which one knows the peak Dst value but, for the corresponding solar wind driver, one does not have a measured value of peak Bs, only a modeled value from indirect observations and also one does not know the time at which to select the peak Bs value. This was the case of a recent study of the historical super intense storm of September 2, 1859, for which *Tsurutani et al.* [2003] assumed a direct and simultaneous time association for the occurrence of the Bs and Dst peaks. This assumption was correct within a 25% error of time displacement between the peaks, according to the present study.

[25] A correlation was performed between the peak Ey and peak Dst. Since the correlation coefficient of this

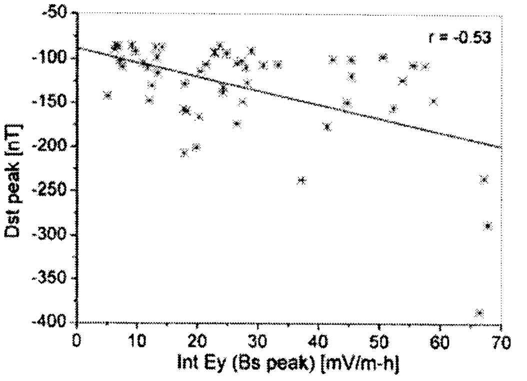

Figure 5. Relationship between the Dst peak and integral of Ey until the time of Bs values during the magnetic storms studied in this work. The linear fit is shown and correlation coefficient is r = -0.53.

dispersion is pretty high (r = −0.87; the correlation between peak Dst and Bs peak was slightly lower, r = −0.82), this means that, regardless of the knowledge of how much integrated Ey is still necessary to reach peak Dst from the level of peak Ey, one can already have a good indication of the peak Dst value just from the knowledge of peak Ey. This information should be useful for space weather forecasting purposes, in order to expect a given level of peak ring current intensity from observations of the interplanetary Ey (vBz) measured from zero to four hours in advance, with an average lag of two hours [*Burton et al.*, 1975].

[26] Figure 5 shows that there is a relationship between the peak Dst and the integrated Ey up to the time of Bs peak. This relation is reasonable (r = −0.53) but one can notice that there is a trend for saturation over very high Dst values. There is still a correlation with the total Ey accumulated during the storm main phase (r = −0.63, not showed). Therefore there is practical importance in knowing the integrated Ey up to Bz peak to space weather forecasting.

[27] However, as mentioned above, it is interesting to know that about 30% of integrated Ey still needs to get accumulated in order to achieve the peak Dst after the level of peak Ey is attained. In order to do a more complete study of this issue, a more detailed treatment of the data would be necessary, for different levels of Dst domains, since each event is different, both in the shape of the Ey structure as well as in its duration. This type of study is outside the scope of the present letter.

[28] To our knowledge, the main results addressed in this letter have not been treated in magnetic storm models, probably because models usually tend to predict specific events, while we have done a more statistical study. Thus, we would like to suggest that coming models, whenever possible, tend to use the information provided by our results.

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