Slow Magnetic Clouds

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ABSTRACT

Slow ($V_{SW} < 400$ km/s) magnetic clouds have been analyzed to determine their characteristics and geoeffectiveness. It is found that slow clouds have mean field strengths of ~13 nT, peak B_S ~ 9 nT, and dawn-dusk electric fields of E_{SW} ~2.5 mV/m. The clouds are small in spatial size, typically ~0.18 AU. The slowest events may have been accelerated to their speeds by interaction with the slow solar wind. Slow clouds are surprisingly geoeffective. Five out of 27 events caused major ($D_{ST} \leq -100$ nT) magnetic storms.

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INTRODUCTION

A considerable amount of attention has been directed towards fast interplanetary coronal mass ejections (ICMEs) because the southward magnetic fields contained within the Interplanetary Coronal Mass Ejections (ICMEs) proper (magnetic clouds) and their upstream sheaths can cause major ($D_{ST} \leq -100$ nT) magnetic storms (Gonzalez and Tsurutani, 1987; Gonzalez et al., 1994; Tsurutani et al., 1992; Farrugia et al., 1997). If southwardly directed B_Z fields are present within both the sheaths and the trailing magnetic cloud events, "double storms" result, with nonlinearly large storm intensities (D_{ST} values) (Kamide et al., 1998).

Recently, Gonzalez et al. (1998) have demonstrated that there is a linear relationship between magnetic cloud field strengths and cloud velocities at 1 AU. The stronger the field strengths, the higher the velocities and vice-versa. Although a specific mechanism has not been proposed to explain this empirical feature, it is surmised that something similar to "melon-seed acceleration" occurring near the sun, is the responsible process leading to this interesting correlation.

It is the purpose of this letter to identify the properties of slow magnetic clouds and determine their geoeffectiveness. It may be surmised that because of their slow velocities, most will not have upstream shocks. However if they do have upstream shocks, the sheath plasma and fields should be only weakly compressive. Another question that will be answered is "does the velocity-magnetic field magnitude correlation still exists at very low velocities?"

Event Selection

Cloud events with velocities less than 400 km s^{-1} were selected. All events have been previously identified in the literature. We refer the readers to Lepping et al. 1990; Bothmer and Rust, 1997;

Bothmer and Schwenn, 1998; Gonzalez et al., 1998; Lepping, 2001 and Gonzalez, 2001 for further discussion of the events. The velocities at the center of the clouds were used in this study. The latter positions were obtained to avoid compressional effects due to magnetic cloud-solar wind interactions.

RESULTS

Figure 1 is an example of an interplanetary magnetic cloud event that was preceded by an interplanetary shock and sheath. The cloud proper is indicated in the second panel and was identified by the low beta characteristics (third from the bottom panel) and smooth magnetic fields (second panel) (Tsurutani and Gonzalez, 1992). This plasma and field data were obtained by the WIND instrumentation (Lepping et al., 1995; Ogilvie et al., 1995). The southward B_Z component leads to a storm main phase that extends from ~1800 UT, 10 January 1997 to 0400 UT, 11 January. The storm main phase can be noted in the D_{ST} panel.

The sheath B_S fields leads to intense (AE ~1300 nT) substorms prior to the arrival of the cloud at the beginning of the storm main phase. The cloud B_S leads to storm intensification and drives the ring-current to reach the peak D_{ST} values of $\leq$ -135 nT.

Although the velocity just behind the shock was ~450 km s^{-1}, by the middle of the magnetic cloud, the speed had decreased to 395 km s^{-1} and was thus accepted within this study.

Table 1 shows the cloud properties and the resultant peak geomagnetic activity. The values from this Table will be discussed graphically (below).

Figure 2 shows the magnetic cloud field magnitudes as a function of solar wind speeds. There is no apparent relationship .

The velocity distribution was also examined (but not displayed to save space). The velocity was more or less uniformly distributed. There was one exception, however. The greatest number of events (6 out of 27) had velocities in the narrow range of 320-330 km s^{-1} (the lowest range). It is possible that this peak is due to the acceleration of very slow events (<300 km s^{-1}) up to the (slow) solar wind speed. Gopalswamy et al. (2000) have shown such examples by intercomparing SOHO near-solar observations to ~1 AU measurements. They noted a deceleration of the fastest events.

Figure 3a, b show the distributions of the magnetic field strengths at the center of the clouds and the peak B_S within the clouds. Although both values are on average relatively small, it should be noted that there are some events with very large fields. It is these later events that cause the major ($D_{ST} \leq 100$ nT) storm events.

The cloud sizes range from ~0.075 AU to > 0.4 AU with a peak occurrence at ~0.175 AU. These scale sizes are small compared to the ≥ 0.25 AU that was set as a minimum size requirement for the identification of clouds in the original Klein and Burlaga (1982) paper.

If one totals the 10 solar maximum events (defined as events occurring within the years 1968 ± 2, 1979 ± 2, 1989 ± 2), and compares this to the 16 solar minimum (1974 ± 2, 1984 ± 2, 1996 ± 2) events, it is noted that the solar maximum events are slightly larger. The latter are of an average ~0.27 AU size, compared to ~0.19 AU for the solar maximum events.

Figure 4 shows the dawn-dusk electric fields and the peak D_{ST} for the storm events. There is a more-or-less linear relationship between the electric fields and D_{ST} values.

CONCLUSIONS

We have reanalyzed all slow magnetic clouds published to date. It is found that, in general, they are small in size, have low field strengths and typically cause moderate (D_{ST} ~ - 25 to –75 nT) magnetic storm activity. However, 5 of the 27 events caused major ($D_{ST} \leq$ -100 nT) magnetic storms and were thus strongly geoeffective. The cause of their geoeffectiveness was in part due to strong southward electric fields (E_{SW} > 5 mV/m), or long durations of the electric fields (> 5 hrs), or both. The reason for these events having both strong fields and low velocities is not clear at this time. The possibility of unusually rapid deacceleration in the solar wind during this transit from the sun to 1 AU will be investigated in the near future.

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REFERENCES

Bothmer, V. and D.M. Rust, The field configuration of magnetic clouds and the solar cycle, in *Coronal Mass Ejections*, edited by N. Crooker et al., AGU Press, *99*, 139, 1997.

Bothmer, V., Magnetic field structure and topology within CMEs in the solar wind, *Solar Wind 9 Conf. Proceed.*, Amer. Inst. Phys., 1999.

Farrugia, C.J., L.F. Burlaga, and R.P. Lepping, Magnetic clouds and the quiet-storm effect at Earth, in *Magnetic Storms*, edited by B.T. Tsurutani et al., AGU Press, *98*, 91, 1997.

Gonzalez, W.D. and B.T. Tsurutani, Criteria of interplanetary parameters causing intense magnetic storms ($D_{ST} < -100$ nT), *Planet Space Sci., 35*, 1101, 1987.

Gonzalez, W.D., J.A. Joselyn, Y. Kamide et al., What is a magnetic storm?, *J. Geophys. Res., 99,* 5771, 1994.

Gonzalez, W.D., A.L. Clua de Gonzalez, A. Dal Lago, et al., Magnetic cloud intensities and solar wind velocities, *Geophys. Res. Lett., 25*, 963, 1998.

Kamide, Y., N. Yokoyama, W. Gonzalez et al., Two-step development of geomagnetic storms, *J. Geophys. Res., 103*, 6719, 1998.

Lepping, R.F., J.A. Jones, and L.F. Burlaga, Magnetic Field structure of interplanetary magnetic clouds at 1 AU, *J. Geophys. Res., 95*, 11957, 1990.

Lepping, R.P., M.H. Acuna, L.F. Burlaga, et al., The WIND magnetic field

Tsurutani, B.T., W.D. Gonzalez, F. Tang and Y. Te Lee, Great magnetic storms, *Geophys. Res. Lett., 19*, 73, 1992.

Lepping, R.P., M.H. Acuna, L.F. Burlaga, et al., The WIND magnetic field investigation, in *The Global Geospace Mission*, ed. By C.T. Russell, Kluwer, *207*, 1995.

Ogilvie, K.W., D.J. Chornoy, R.J. Fitzenreiter et al., A comprehensive plasma instrument for the WIND spacecraft, in *The Global Geospace Mission*, ed. By C.T. Russell, Kluwer, 55, 1995.

Tsurutani, B.T., W.D. Gonzalez, F. Tang and Y. Te Lee, Great magnetic storms, *Geophys. Res. Lett., 19*, 73, 1992.

Tsurutani, B.T. and W.D. Gonzalez, The future of geomagnetic storm predictions: Implications from recent polar and interplanetary observations, *J. Atmos. Terr. Phys., 57*, 1369, 1995.

Table Captions

Table 1. The properties of the slow magnetic clouds used in this study.

Figure Captions

Figure 1. The January 10-11, 1997 magnetic cloud and related magnetic storm.

Figure 2. The relationship between |B| at the center of the cloud and solar wind velocity, both taken at 1 AU.

Figure 3. In panel a), the distribution of magnetic field magnitude values of slow clouds. Panel b) gives the distribution of peak B_S values.

Figure 4. The relationship between the interplanetary electric field and the maximum D_{ST} of the storm.

Table 1. Solar Wind Electric Fields of Slow Magnetic Clouds.

Date	τ (hour)	E_{sw} (mV/m)	B_{max} (nT)	$B_{s\,max}$ (nT)	V_{max} (km/s)	IS	Size (AU)	$D_{st\,min}$ (nT)
2/27-28/1968	2.9	2.5	10	9	320	N	0.12	-37
1/15-16/1970	2.9	2.5	8.6	7.6	380	N	0.36	-50
6/23/1971	2.8	2	11	8.5	348	N	0.18	-16
11/17/1975	3.6	2.75	16	11	360	N	0.15	-90
1/10-11/1976	7.2	5.5^{+}	20	20	400	N	0.15	-156
1/16/1978	2.6	4	9	8	325	N	0.35	-50
10/30/1978	3.6	9	13	11	360	-	0.21	-90
9/18/1979	5.6	5	18	15	370	N	0.31	-150
12/31/79-1/1/80	2.4	4	8.5	6	400	N	0.17	-44
2/16/1980	5.3	4	15	14	380	-	0.27	-133
3/19-22/1980	2.6	14	16	10	320	Y	0.49	-50
5/7-8/1992	3.6	9	13	9	400	N	0.27	-60
7/20-21/1992	2.6	1.5	13	8	320	N	0.10^{+}	-13
8/22/1995	2.9	2	11.5	9	365	Y	0.27	-60
5/17/1996	2.0	4	6.5	6	395	N	0.09	-26
5/27/1996	3.1	4	9	8	390	N	0.15	-30
7/1/1996	2.8	1	13.5	6	355	N	0.14	-20
8/7/1996	1.5	4.5	8	4.5	342	N	0.16	-22
12/24/1996	2.3	2.5	12.5	7	325	N	0.15	-31
4/21/1997	3.9	3	15	10	390	N	0.18	-107
6/8-9/1997	3.8	2.5	13	10	380	N	0.16	-85
7/15/1997	3.9	4.5	13	12	350	N	0.10	-45
9/18/1997	2.4	2	13	9	343	N	0.19	-55
10/10/1997	4.0	6	12.5	10	395	Y	0.32	-130
2/4/1998	2.3	3	15	7.5	335	N	0.21	-34
3/4/1998	1.8	1	10	7	365	Y	0.26	-35
8/20/1998	3.2	4	16	10	323	N	0.28	-65

WIND solar wind data and geomagnetic AE and Dst for 10/10-11/1997

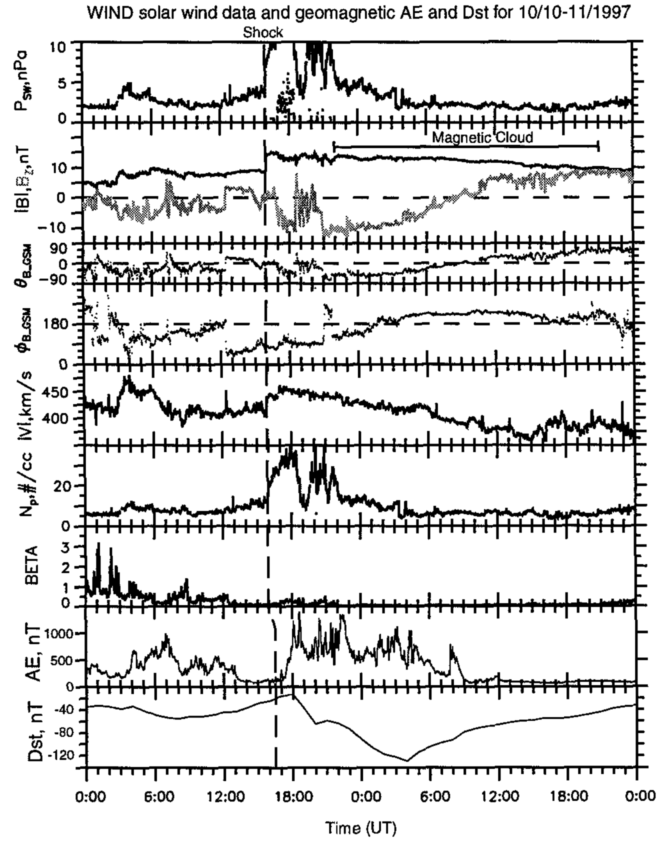
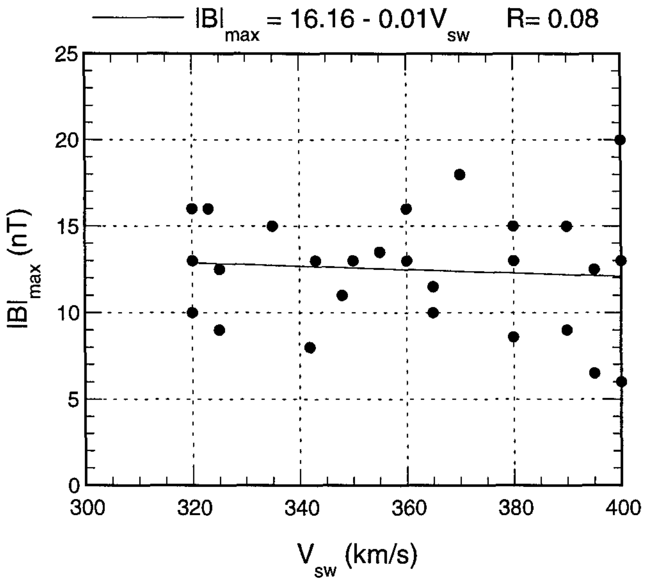


Figure 1



|B|max = 16.16 - 0.01Vsw R= 0.08
25
20
15
10
5
0
|B|max (nT)
300
320
340
360
380
400
Vsw (km/s)

Figure 2

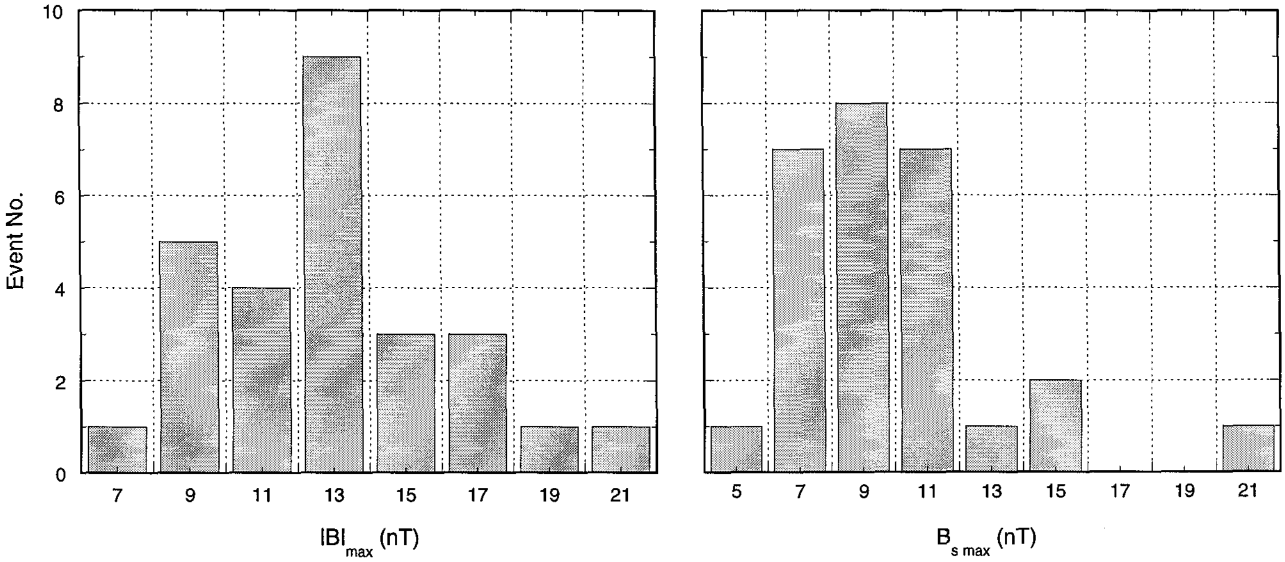


Fig 3a

Fig 3b

Figure 3

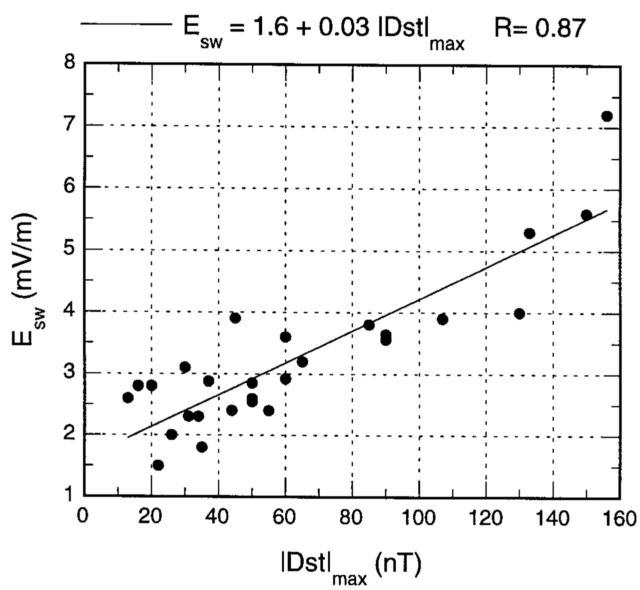

E_sw = 1.6 + 0.03 |Dst|_max   R= 0.87
E_sw (mV/m)
|Dst|_max (nT)
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
140
160

Figure 4