GEOMAGNETIC EFFECTS OF INTERPLANETARY SHOCK WAVES DURING SOLAR MINIMUM (1995-1996) AND SOLAR MAXIMUM (2000)

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ABSTRACT

In this paper the interplanetary shock wave effects on geomagnetic activity, quantified by the maximum hourly Dst and tri-hourly a_p indices, in a period of 3 days after the shock, are evaluated. Correlations between shock parameters and Dst and a_p geomagnetic indices during solar minimum (1995-1996) and solar maximum (2000) periods are obtained. It is observed that solar wind speed and total magnetic field variations through the shock are the parameters with the most significant correlations during both solar maximum and solar minimum. The dynamic pressure variation, however, shows higher correlation with a_p than with Dst. This result is explained because a_p depends on magnetospheric currents, more affected by the dynamic pressure. The distribution of index values per magnetic activity level increases substantially in the shocked period in relation to the whole period. For both indices the distributions are similar.

1. INTRODUCTION

It is well known that the prime cause of intense geomagnetic activity is the presence of long duration and intense southward interplanetary magnetic fields [1, 2]. However, shock waves can have an important role amplifying magnetic fields and increasing the geomagnetic activity levels [2, 3]. In the present work a statistical analysis of interplanetary shock wave effects on geomagnetic activity, quantified by the maximum hourly Dst and tri-hourly a_p indices, in a period of 3 days after the shock is performed. Results for solar maximum (year 2000) and solar minimum (1995-1996) periods are compared. In previous works, interplanetary shock parameters distribution [3], their effects on the sudden impulses [4] and on the geomagnetic storms through Dst index [5] were studied.

2. METHODOLOGY OF DATA ANALYSIS

2.1 Geomagnetic indices

The K_p index, available since 1932, represents the intensity of planetary magnetic activity as seen in sub-auroral latitudes and it is given for 3-h time interval. The K index, for each of the contributing mid-latitudes observatories, reflects the maximum range of any component of the field over the 3-h time interval at each station. The K_p index is the average of the K values from all contributing observatories. A conversion scale transforms the quasi-logarithmic K_p to a linear index named a_p [6, 7].

The ring current Dst index was introduced in 1964 and it primarily measures the effects of ring current in the magnetic field. It is based on hourly averages of the horizontal component recorded at four low-latitudes observatories subtracting the average solar quiet variation and the permanent magnetic field from the disturbed one. It is available since 1957 [7, 8].

The K_p/a_p index is then a mid-latitude index that is sensitive to auroral phenomena, associated with particle precipitation and field aligned currents (sub storms and auroras), represented by AE index; and to the equatorial ring current, represented by Dst index. It is an integral index of the magnetospheric activity. In general, the a_p is better correlated with AE, but during geomagnetic storms, specially the intense ones, it is dominated by Dst [9].

In order to evaluate the magnetospheric response to shock wave disturbances, Dst and a_p indices were used. The hourly Dst index was obtained from the World Data Center for Geomagnetism, Kyoto. The tri-hourly a_p index was obtained from National Geophysical Data Center – NGDC.

2.2 Interplanetary shock parameters

Interplanetary magnetic field and plasma high resolution data used in this study were obtained by sensors onboard WIND spacecraft (60 and 90 s for magnetic and plasma measurements, respectively) [10], during solar minimum and by the ACE spacecraft (16 and 64 s for magnetic and plasma measurements, respectively) [11], during solar maximum. Shocks were identified through the International Solar-Terrestrial Physics Program-ISTP Solar Wind Catalog Candidate Events (http://www-spof.gsfc.nasa.gov/scripts/sw-at/Catalog_events.html).

Plasma and magnetic field parameters were then plotted in order to select only fast forward shocks [3]. A total of 15 fast forward shocks during 1995-1996 and 50 fast forward shocks during 2000 were selected for analysis. For 6 events during 2000, plasma sensor onboard ACE was saturated, and plasma data were obtained from Proton Monitor onboard SOHO spacecraft.

A 10 min time window was centered on each shock. Two other 10 min windows were also defined, immediately before and immediately after the shock window, considered to be the upstream and downstream regions, respectively. Average shock parameters have been calculated for both upstream and downstream sides and the difference was determined, resulting in the parameter variation across the shock (ΔX). This parameter variation was used to make correlations with the geomagnetic activity, as an indicator of the shock strength. Figure 1 shows the interplanetary shock on August 24^{th} 1995. The panels are (from top to bottom): proton temperature T (K), speed V (km/s), density N (cm^{-3}) and total magnetic field B (nT). The continuous line indicates the shock. The dotted lines are the time window limits: upstream (U), centered on shock (S) and downstream (D) regions.

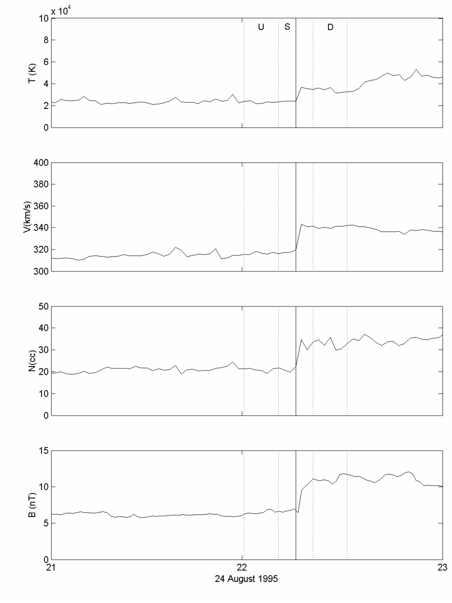

Fig. 1. Example of plasma and magnetic field variations through an interplanetary shock (August 24^{th} 1995). The upstream (U), shock (S) and downstream (D) windows are indicated.

3. RESULTS AND DISCUSSION

Correlation analysis results are described in terms of the square correlation coefficient or variance r^2. The correlations were performed between shock parameter variations (ΔX) and Dst-a_p maximum values during 1-3 days after the shock. The results are presented in Table 1 for solar maximum and solar minimum. The correlations not statistically significant at 95% confidence level (t-test) are identified by the symbol '*' in Table 1. Correlation of some shock parameters with Dst peak have been presented in Ref. [5] and are again reported here.

It is observed that density variation (?N) is not correlated neither with Dst or a_p peaks during solar minimum and solar maximum. Temperature variation (?T) is uncorrelated with Dst during solar minimum and with a_p during solar maximum. Statistically significant correlations are found for proton speed and total magnetic field variations (?V and ?B) during both maximum and minimum periods with both indices. Statistically significant correlations are also found for temperature variation with Dst peak, during solar maximum, and with a_p during solar minimum. Correlation between ?V and Dst peak is higher during solar minimum (56%) than during solar maximum (15%). Correlation between ?B and Dst peak is also higher during solar minimum (39%) than during solar maximum (12%). Similar correlations are observed between ?V and a_p during both maximum and minimum periods. The ?B and a_p peak have higher correlation during solar minimum than during solar maximum. Dynamic pressure variation (?P_{dyn}) presents high correlations with a_p peak during both periods. However, it is significantly correlated with Dst peak only during solar maximum. Alfvenic Mach number M_A is well correlated with a_p peak during solar minimum. With Dst peak the correlation is significant only during solar minimum.

The general behavior of the correlation between shock parameters and geomagnetic activity is similar for both indices, with higher correlations occurring during solar minimum. The exception is the correlation between ?P_{dyn} and a_p peak, higher than the correlation between ?P_{dyn} and Dst peak. It could be explained because Dst related activity is dependent on the southward magnetic field, and the ring current is not much affected by dynamic pressure variation. On the other hand, a_p is sensitive to other irregular magnetic field variations that can be more dependent on solar wind ram pressure (?P_{dyn}), such as the magnetopause current.

Nevertheless the correlation coefficients are low, generally smaller than 50%, which indicates that a substantial fraction of the shocks were not associated with geoeffective southward magnetic field structures [4]. This result also confirms that the shock strength is not proportional to the geomagnetic activity strength [12]. It is necessary to remember, however, that different data set lengths are being used; the number of events during solar maximum (50) is much higher than during solar minimum (15). The correlations found in this work needs to be further evaluated with the addition of more shock events from other solar minima [4].

Table 1- Shock parameters versus maximum Dst and a_p indices

Parameter	Dst S. Min.	Dst S. Max	ap S. Min	ap S. Max
? N	*	*	*	*
? V	56%	15%	29%	29%
? T	*	12%	36%	*
? B	39%	12%	35%	26%
? P_{dyn}	*	10%	36%	26%
M_A	35%	*	16%	7%

Correlations between the Dst and a_p indices are 67% and 62% during solar maximum and solar minimum, respectively. These large correlation coefficients between the indices also stress that both indices are similarly affected by shock events. In general, shocks are periods associated with stormy activity, when the correlation between a_p and Dst is known to be high [9].

Table 2 shows the average Dst and a_p for the whole period during solar minimum and maximum (all) and for the shocked period (S).

Table 2- Distribution of Dst and a_p indices for shocked (S) and whole (all) periods.

Period/ parameter	S. Min. all	S.Min S	S. Max all	S. Max S
<Dst>	-14 ± 16	-18 ± 20	-16 ± 28	-32 ± 39
$\langle a_p \rangle$	11 ± 13	12 ± 14	15 ± 24	25 ± 36

Both Dst and a_p have highest averages during solar maximum. Considering the whole period, the difference of index averages between solar maximum and minimum is small. In some cases a_p average could be even higher during solar minimum, as for example occurred during 1974 minimum as compared to 1979 maximum [9]. Comparing shocked period with the whole period, it can be seen that during solar maximum the index averages have larger variation than during minimum.

During 1995-1996 the shocked period averages are only 10% higher for a_p and 30% for Dst than for the whole period averages. During 2000 the shocked averages are 66% and 100% higher for a_p and Dst, respectively. It must be observed, however that the standard deviations of the periods are high, of the order of mean values.

The amplification of the geomagnetic activity during shocked periods relatively to the whole period seems to be larger during solar maximum, than during solar minimum. Although the shock strength relative to the solar wind background is not very different during solar minimum and maximum [3], there are more extreme events during solar maximum, and the magnetic field absolute variation is also higher [3] in this period. An intense southward magnetic field is the most important parameter to high geomagnetic activity levels [14], which seems to be more probable to occur during solar maximum. Moreover, structures driving interplanetary shocks seem to be different during solar maximum and minimum, respectively coronal mass ejections and co-rotating interaction regions [4].

Table 3 shows the geomagnetic activity intensity classification. The conversion criteria from Dst to K_p (and a_p) was taken from Ref. [2].

Table 3- Classification of geomagnetic activity in intensity levels for Dst and a_p.

Level/Index	Dst	ap
intense	Dst = -100	ap=111 ($Kp=7_o$)
moderate	-100<Dst =-50	56=ap<111
weak	-50<Dst=-30	32=ap<56
quiet	Dst>-30	ap < 32 $Kp < 4_+$

Using criteria shown in Table 3, the percentage of data in every geomagnetic activity level was calculated for the whole period (1995-1996 and 2000) and for the shocked period. Figure 2 shows the percentage of a_p (top panel) and Dst (bottom panel) values in each geomagnetic activity level. The bar diagrams shows: the whole solar minimum period (black bars), the shocked solar minimum period (dark grey bars), the whole solar maximum period (light grey bars) and the shocked solar maximum period (white bars).

It is observed from Figure 2 a higher fraction of intense values during solar maximum than during solar minimum (for Dst, 2.0% against 0.1% and for a_p, 1.2% against 0.2%). The percentage of intense values increases during the shocked periods. During solar minimum the percentage of intense values increases from 0.1 to 1.2% in Dst and from 0.2 to 0.5% in a_p. During solar maximum, the intense activity percentage varies from 2.0% to 5.6% in Dst and from 1.2 to 3.4% in a_p.

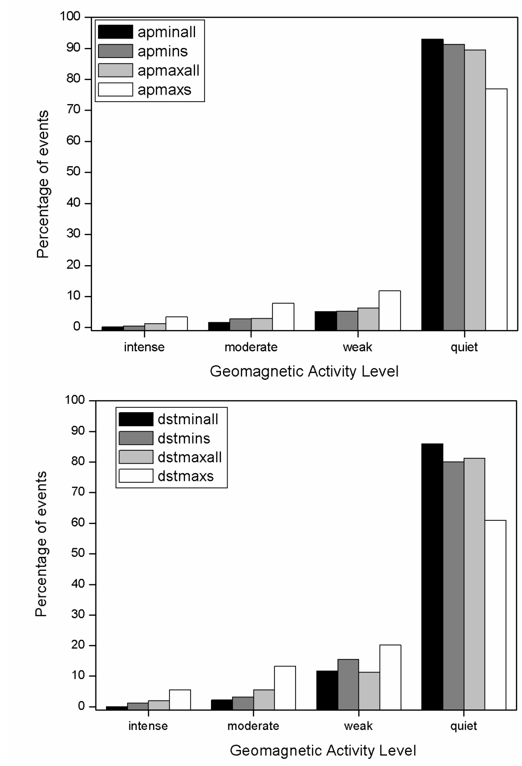

Fig. 2. Bar diagrams of a_p (top panel) and Dst (bottom panel) percentage of values for each geomagnetic activity levels.

4. CONCLUSIONS

Correlation analysis between shock parameters and Dst and a_p peak values in a period of 1-3 days after the shock, was performed during solar minimum (1995-1996) and solar maximum (2000). It was observed that solar wind speed and total magnetic field variations through the shock are the parameters that are better correlated with geomagnetic indices during both solar maximum and minimum. The dynamic pressure variation, however, has higher correlation with a_p than with Dst, because a_p depends on magnetospheric currents that are more affected by this parameter. The correlations coefficients were however lower than 50%. The distribution of index values for each geomagnetic activity was also determined and significant increases in the percentage of values with intense and moderate activity were observed. The distributions for Dst and a_p are similar. The percentage of a_p and Dst intense values was observed to increase from the whole period to shocked period. During solar minimum, the intense value percentage increases from ~2% to 3-4% for a_p and Dst; during solar maximum, the increase was from ~ 4-7% to 11-19% for a_p and Dst.

5. REFERENCES

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