3.9 **Correlation study of strong geomagnetic storm and the ionosphere**

Donald E. Cotten*, Paul J. Marchese, and Tak David Cheung
City University of New York Queensborough Community College

1. Abstract

Statistical analysis is performed for parameters in the inner and outer terrestrial magnetosphere as well as for the ionosphere during a strong geomagnetic storm. Dst value less than -150 nT was used as criteria and examples were chosen from 1999 through 2002. The parameters are interplanetary magnetic field (imf), solar wind velocity, storm disturbance index Dst, total electron content TEC index, and normalized foF2 ratio. The time series data are obtained from satellites and ground stations, via the internet web. High frequency interplanetary magnetic field fluctuation appears to be associated with large peak Dst value. Large Dst is found to be associated with more fluctuation in normalized foF2 ratio. The peak Dst correlates well (coefficient=0.94) with a number (the number of sigma B values > 0.5) taken to be proportional to the tail area of the sigma B distribution. Similar correlation (coefficient=0.82) is found between the peak Dst value and the peak deviation in the foF2 ratio. The cross correlation values of various inter-dependent time series data are interpreted via an energy input mechanism.

2. Introduction

Geomagnetic storm prediction has been an active research area. It was reported recently that all models so far used quiet day baseline subtraction and that would dilute the result (Tsyganenko 2003). Therefore this project focused on strong storm events with no input from quiet days. The objective was to find correlation between the data series.

Correlation study is a powerful method in weather research. Recent examples include such diverse topics as fluctuation analysis of cloud radar data (Ivanova 2003), and solar wind parameters (Hnat 2003). It was thus shown that the fluctuation in the interplanetary magnetic field energy density $B^2/2\mu$ is a mono-scaling single parameter probability density function of the Levy type (long-tailed distribution as compared to the Gaussian distribution) and is indicative of an underlying Langevin equation (or Fokker-Planck equation) dynamics associated with non-Brownian diffusion. On the other hand, the interplanetary magnetic field magnitude fluctuation $\delta B(t,\tau) = B(t+\tau) - B(t)$ for lag $\tau = 2^k \times 46$ sec, given k = 1, 2, …14 (that is, from about 2 min to 26 hours) was found to create a probability density function $P(\delta B, \tau)$ that had no apparent rescaling property and was described as multi-fractal, consistent with earlier results(Forman 2003).

The method in this project is to directly utilize the data posted on the web by NASA from satellites ACE, GOES and WIND. The principle of minimal data massaging was implemented to prevent unnecessary errors. Given the complex nature of the interplanetary magnetic field, this project instead focused on a fundamental fluctuation parameter in the statistics, the sigma B values. The peak values of the responses in the inner magnetosphere and ionosphere were used for an exploratory investigation of correlation effects. The cross correlation between time series data was also explored.

3. Data and Analysis

The data for strong geomagnetic storms were selected. The criterion was –150 nT or lower in the Dst index. The Dst data source was obtained from the site swdcdb.kugi.kyoto-u.ac.jp/Dstdir/index/html.

The interplanetary magnetic field fluctuation was represented by the σ_B value. The variance of |B| over the time interval, in nT, $\sigma_B = \sqrt{\left(|B| - |\overline{B}|\right)^2}$. The σ_B is calculated for the 4-minute average. It is calculated using the 16-second averages as input. Data source is from California Institute of Technology website (www.srl.caltech.edu/ACE/ASC/level2/index.htm). The Ionospheric data foF2 is obtained from NOAA (spidr.ngdc.noaa.gov). The Ionospheric data TEC is from ionosphere.rcru.rl.ac.uk.htm. The solar wind data was obtained from NASA (http://lepmfi.gsfc.nasa.gov/mfi/windmfi.html.).

The following graphs appear to show that a high frequency fluctuation in sigma B is related to a large peak Dst value.

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* Affilation: (DEC) City University of New York Space Science Research Alliance, (PMJ and TDC) City University of New York Queensborough Community College, email: p.marchese@qcc.cuny.edu, decotten@aol.com, tcheung@qcc.cuny.edu.

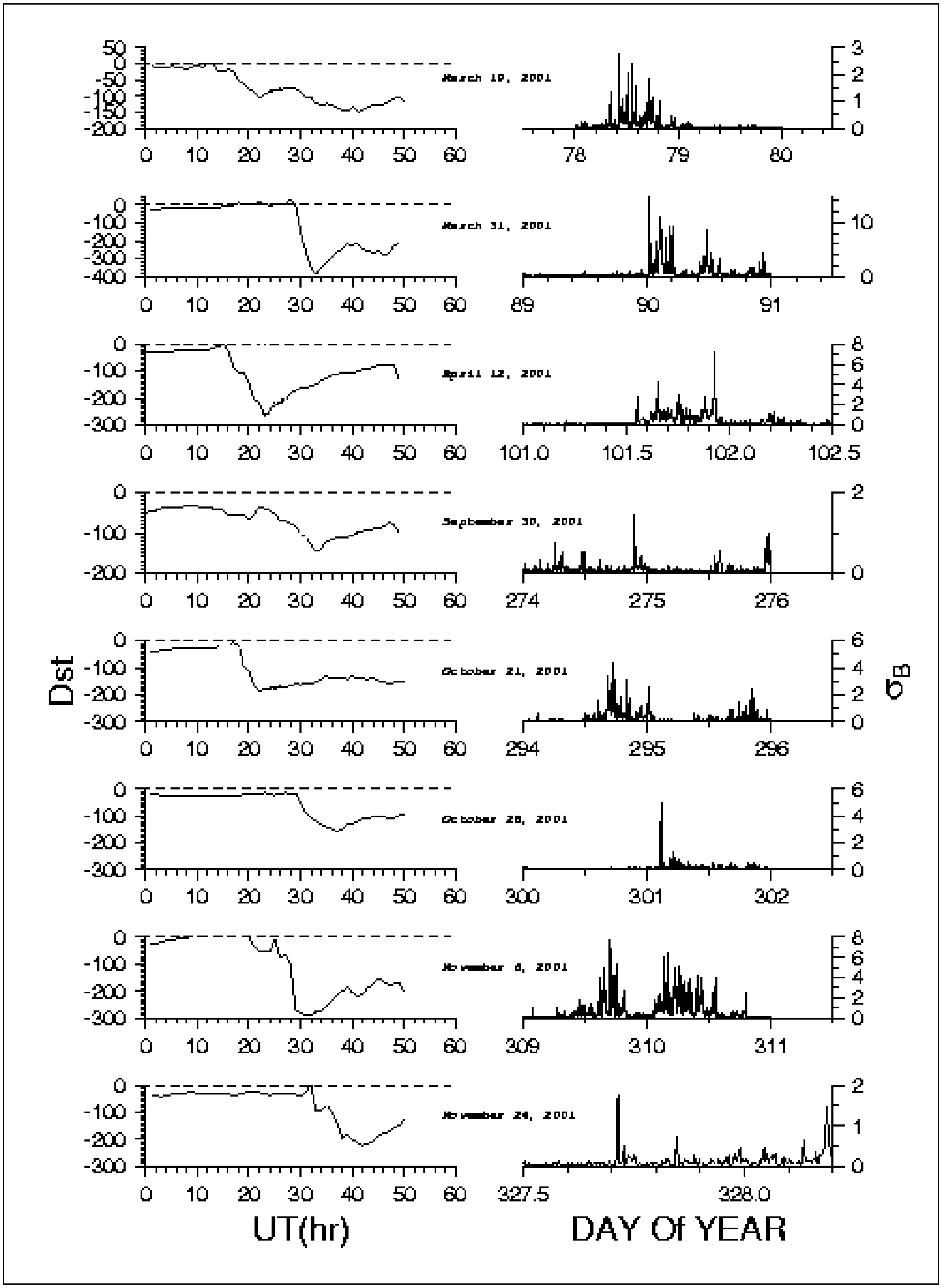


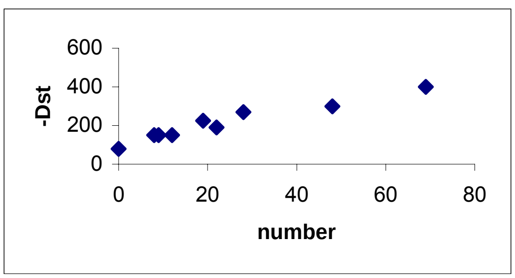
Figure 1. Dst value versus hourly data starting at UT:0 (left column) and σ_B versus day of year (right).

This project assumed that the σ_B distribution tail area is proportional to the fluctuation severity. That is, the tail area is proportional to the number of σ_B values larger than a certain value. A value of 0.5 was used as the cut off. The number of σ_B values larger than 0.5 in the 6-hour pre-storm interval for each storm was listed together with the Dst value.

Data table (year 2001) of number of σ_B value > 0.5 and the corresponding (Dst) value. The last data entry of (0,80) represents the definition threshold of a storm for Dst of –80 nT.

(Nov24)	19	-225nT
(Nov 6)	48	-300nT
(Oct 28)	9	-150nT
(Oct 21)	22	-190nT
(Sept 30)	8	-150nT
(Apr 12)	28	-270nT
(Mar 19)	12	-150nT
(Mar 31)	69	-400nT
(onset)	0	-80nT

The graph showed a correlation coefficient of 0.972.



The (–Dst) versus the number of sigma B values > 0.5 (year 2001)

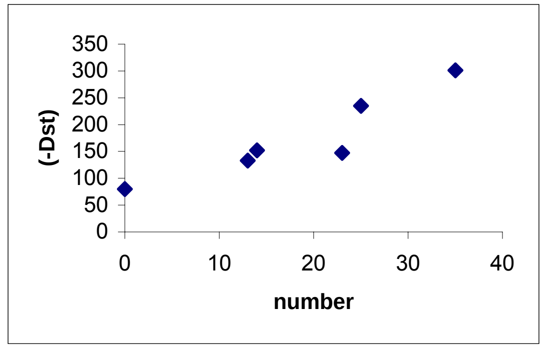
The inclusion of the (0,80) point decreased the correlation by only 0.001 suggesting that the (0,-80) assumed point is very close to the intercept.

Similar study was performed for the year 2000.

(Nov11)	14	-152nT
(Aug 11)	25	-235nT
(Jul 16)	35	-301nT
(May23)	23	-147nT
(Feb 11)	13	-133nT
(on set)	0	-80nT

Data table (year 2000) of number of sigma B value > 0.5 and the corresponding (Dst) value. The last data entry of (0,80) represents the definition threshold of a storm for Dst of –80 nT.

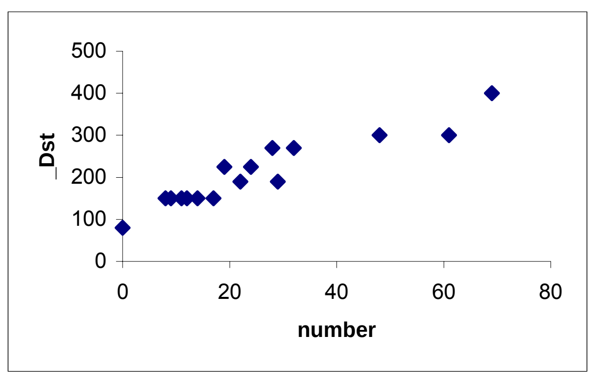
The graph shows a correlation of 0.925



The (–Dst) versus the number of sigma B values > 0.5 (year 2000)

The Feb 11 2000 storm had a Dst of –133 nT and in principle did not satisfy the criterion of –150 nT. However the exclusion of the Feb 11 2000 data reduced the correlation to 0.921. The inclusion of (0,80) increased the correlation by 0.02 suggesting that the (0,80) data point is very close to the intercept. The April 5, September 12, and October 5 storms in 2000 showed complex double extreme points in the Dst versus time curve and were excluded in the current study.

It is interesting to combine the 2000 data and the 2001 data.

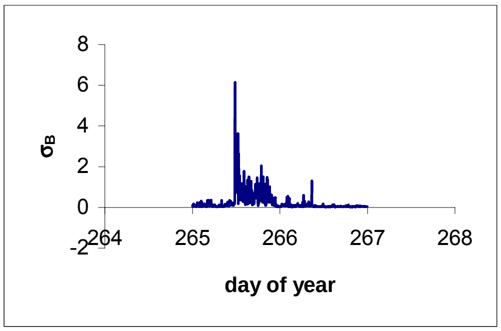


The (–Dst) versus the number of sigma B value > 0.5 (year 2000 and year 2001)

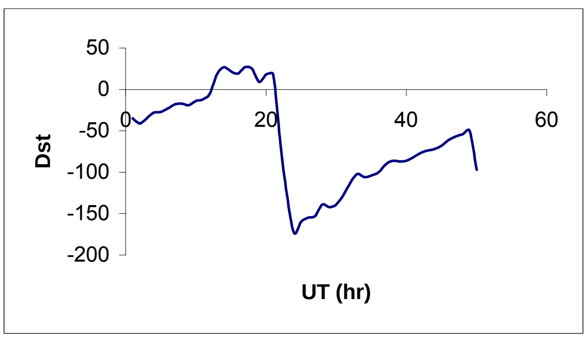
The correlation coefficient is 0.938. The exclusion of the (0,80) data point gave a correlation of 0.932.and an intercept of (0,116) with a slope of 3.79 units.

The September 22, 1999 storm was excluded. The storm has 57 sigma B values > 0.5 in the 6-hr pre-storm interval with a peak Dst of –173 nT. This large sigma B fluctuation should give a Dst of about -250 nT according to the correlation graph. The inclusion of this September 22, 1999 storm would give a correlation coefficient of 0.825 with the (0,-80nT) data point and 0.798 without the (0,-80 nT) data point.

September 22 1999 storm



The sigma B values versus time graph 1999



The Dst started at September 22, 1999 (DOY 265)

The following three storms were also excluded. The Sept 3 2002 storm had a double-peak in the Dst value so it was excluded. The Oct 1 2002 storm has only one sigma B value > 0.5 in the pre-storm 6 hours with a Dst peak at –180 nT. The Oct 22, 1999 storm has one sigma B value > 0.5 in the pre-storm 6-hour period with a Dst peak of –240 nT. Fifteen storms were included.

Ionosphere response

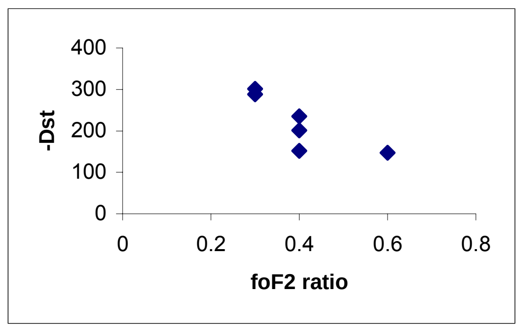
The ionosphere indices TEC and foF2 were also studied. The 2002 TEC data at Halisham station (long 0, lat 50) showed that the TEC ratio (observed/monthly median) was 65/37 for the Oct 1 2002 storm with a Dst of –183 nT and was 28/38 for the September 3, 2002 storm with a Dst of –170 nT.

However the archived TEC and foF2 data on the internet showed some incompleteness. Therefore this project focused on well-accepted data in the literature, for the six storms tabulated below (Araujo-Praere 2002). The above correlation method was applied for the Dst value and normalized foF2 ratio (observed/monthly median) for the storms in 2000.

4/5/00	0.3	-288 nT
5/23/00	0.6	-147nT
7/13/00	0.3	-301nT
8/10/00	0.4	-235nT
9/15/00	0.4	-201nT
10/3/00	0.4	-152nT

Data table of peak foF2 ratio (observed/monthly median) and Dst values. The peak foF2 ratio values at Chilton station were from Araujo-Prasere (2002)

The graph is shown:

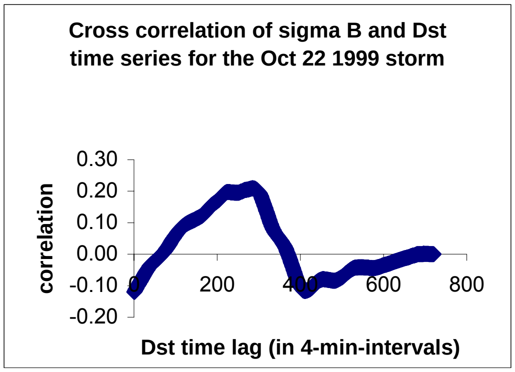


The (-Dst) versus foF2 ratio graph

The correlation coefficient was -0.82 and was indicative that large storm, lower Dst values correlate with larger foF2 deviation, (1- ratio).

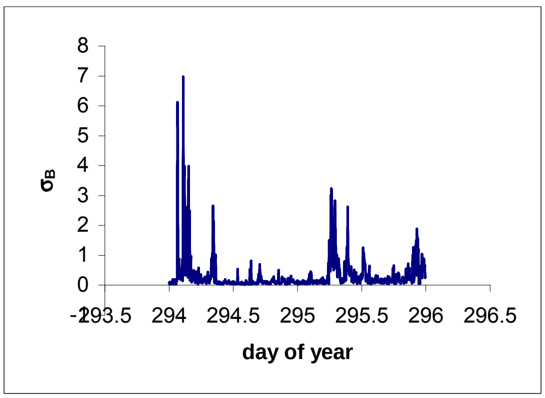
Cross correlation

The cross correlation of Dst and imf sigma B time series data shows a Dst time lag relative to the imf fluctuation. For those storms with high correlation between Dst and the number of large sigma B values, the lag is small. For the outliers, which did not so well correlate, the lag is larger. For example, the Oct 22 1999 storm cross correlation of sigma B and Dst time series data showed a peak with a lag of about 15 hours. The hourly Dst data was interpolated at 4-min intervals for consistency with the 4-min sigma B data.



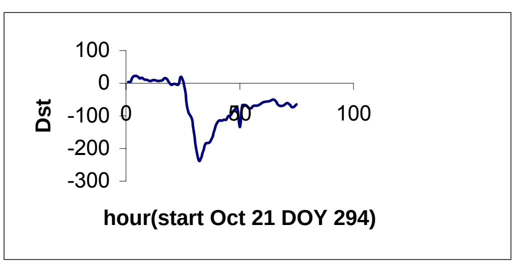
Cross correlation (relative units) of sigma B and Dst time series (4-min data) for the October 22 1999 storm.

Oct 22, 1999 storm
The sigma B fluctuation was less at the time of the Dst peak.



The sigma B values versus time graph 1999

From the sigma B time series viewpoint, there were 37 sigma B values > 0.5 in the pre- storm 24-hr period, 12 sigma B values > 0.5 in the pre-storm 18-hour period, 5 sigma B values >0.5 in the pre-storm 12-hour period and one sigma B values >0.5 in the pre-storm 6-hour period.



Dst started at Oct 21 DOY 294, 1999

The solar wind velocity generally increased from 400 km/sec by about 100-300 km/sec. The cross correlation with the Dst time series did not show a peak as did the sigma B cross correlation, nor did the proton flux cross correlation with the Dst time series.

4. Discussion

The correlation coefficient of about 0.9 for the 6-hr pre-storm sigma B versus peak Dst index implies prediction capability of the storm severity. The threshold of 0.5 for the sigma B values was stable as another threshold of 0.4 gave similar correlation values. The –150 nT criterion was selected so that a fair number of strong storms could be included. This simple result would supplement those earlier results such as those using a neural network algorithm and a storm model that uses quiet day baseline (Kugblenu 1999 and Araujo-Prasere 2002).

There were four excluded storms. The September 22 1999 storm had a large number of sigma B values > 0.5 but yet the Dst has a moderate peak value of -173 nT. The September 3, 2002 storm was a double peak Dst storm and did not have a strong correlation with Dst peak value. The two storms (Oct 1, 2002 and Oct 22, 1999) were characterized by only one sigma B value > 0.5 in the pre-storm 6-hour period suggesting different energy interactions. In the Oct 22, 1999 storm, the sigma B time series and the Dst time series cross correlation indicated a time delay of about 10-20 hours for the Oct 22, 1999 storm. The delayed time of response to the strong sigma B storm may indicate that such stronger interplanetary magnetic fluctuations interact more strongly with the geomagnetic tail than with the day-side magnetosphere, while the well-correlated interplanetary magnetic disturbances interact more strongly with the day-side magnetosphere, which they pass earlier by a few hours. This mechanism merits further study. The cause of double-peaked Dst response also merits further study.

5. Conclusion

This study presented evidence that the interplanetary magnetic field sigma B was correlated to the peak Dst value. The peak Dst value is correlated with the normalized foF2 ratio. The result also supported the –80 nT criterion for the onset of a storm since it did not reduce the correlation by any significant amount.

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