SPECTRAL ANALYSIS OF SOLAR WIND DENSITY CAUSED DURING GEOMAGNETIC STORMS DUE TO HIGH SPEED STREAMERS (HSS)

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Abstract

Nuclear fusion is the main reason for the energy production in the hot central core. The activities of the sun are believed to be driven by energy release from the solar magnetic field This main focus on this work is to study the activity of sun and its relationship with Earth's magnetic field giving rise to the phenomenon of geomagnetic disturbance, resulting in the study of HSS. The major three events during solar are taken dated on 5 - 6 th June 2016, 27 - 28 th September 2017 and 25 - 27 th August 2018 which on analyzing led to a conclusion that the geomagnetic disturbances are active during the mean day.

The data set for three particular events were taken using OMNI data explorer for each storm. Solar wind relative to various interplanetary parameters during each storm was analyzed; correlation of Solar wind density with other parameters was evaluated with the help of MATLAB. The correlation of Solar wind density with the other components suggests that, Flow Pressure and AE- Index exhibited an immense role on carrying geomagnetic disturbances. Besides, the other parameters as like speed, components of electric and magnetic fields, pressure do not play a significant role, with correlation coefficient on electric field and AE index showing negative value. The Higher solar pressure with lower density shows large disturbances due to presence of the solar and geomagnetic activities during the solar active period.

In conclusion, during the main phase of the storm, maximum solar wind velocity was observed to be around 800km/s suggesting that the Solar wind velocity (Vsw) has strong impact for the cause of geomagnetic disturbances.

Keywords: Solar Wind, Spectra, Analysis, Geomagnetic, Density, Pressure,

INTRODUCTION

Sun is massive (3.3×10^5 times the mass of the Earth), hot star consisting of hydrogen (90%) and helium (10%), which are mostly ionized because of the very high temperature. Being the nearest star, it is major source of observation and discoveries for researchers. Nuclear fusion is the main reason for the energy production in the hot central core.

A continuous flow of plasma coming out of the sun is called solar wind. The interaction between earth and the solar wind coming out from sun plays important role in earth's climatic as well as seasonal changes. Because of the solar wind, the Earth's atmosphere is blown by the hot, magnetized, supersonic collision less plasma carrying a large amount of kinetic and electrical energy. Our earth has magnetic field which acts like a protecting shield around it called as magnetosphere. Magnetosphere protects Earth's atmosphere from blowing away by solar wind. When strong solar wind interacts with earth's magnetosphere it compressing it and if the process sustains for longer period it causes ejection of energetic particles into the magnetosphere resulting in geomagnetic storm. Also, during these periods, particle acceleration and precipitation may occur in earth's atmosphere leading to the aurora occurrences. Intensity the energy of the particles involved is more when the storm is stronger which leads to more equator ward and wider the aurora. Geomagnetic storm is defined by changes in Dst (Disturbance storm time) index. The short time disturbance (Dst) index is the index which is used to monitor the worldwide magnetic storm level. It is constructed by averaging H from mid latitude and equatorial magneto grams from all over the world. The values of the Dst index is negative which means that a magnetic storm is in progress. This is due to the storm time ring current which flows around the earth from east to west in the equatorial plane. The approximated ranges of Dst recorded are +100nT to -600nT.

Solar wind is found in two states namely fast solar wind and slow solar wind .The major difference between them lies in the speed that is slow solar wind has maximum speed upto 500 km/s and fast solar wind has speed 700 km/s - 800 km/s.

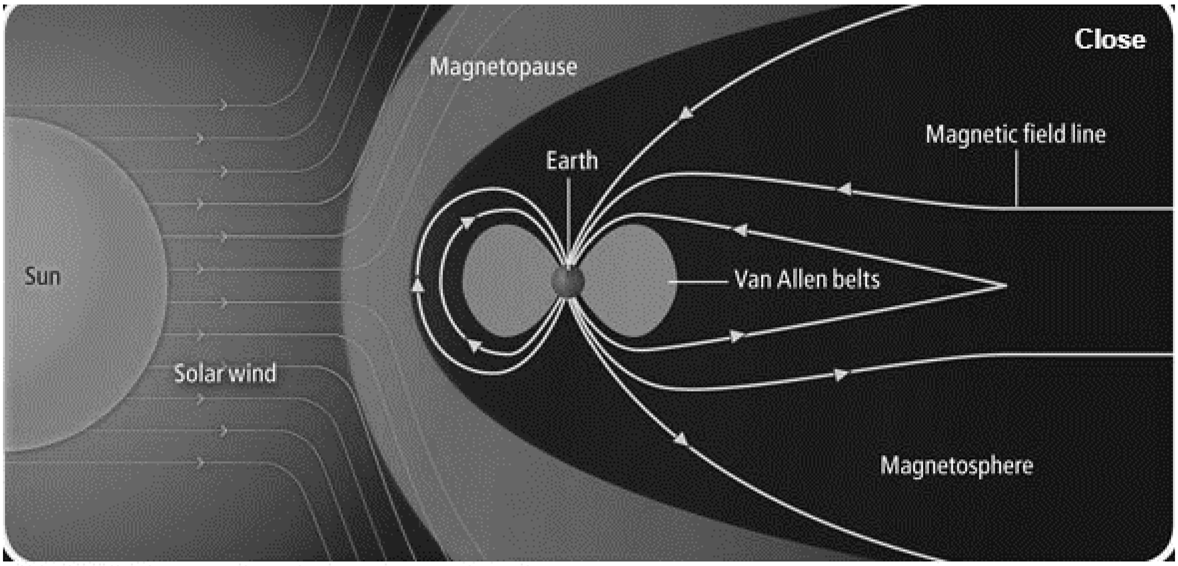


Fig: Interaction of solar plasma and Earth's Magnetosphere
Source: http://en.wikipedia.org/wiki/Geomagnetic_storm

In this work, we will analyze three different geomagnetic storm events where we study variation of solar wind density and geomagnetic indices during solar minima. This quantitative analysis is further extended to correlation analysis between different variables (Solar wind density (NSW) and geomagnetic indices). Correlation analysis helps to uncover the dependency relation between density components and geomagnetic indices. For example, how strong are changes in SYM-H index when there are changes in the solar wind density can be understood by observing the correlation between these variables

As correlation analysis can only uncover direct relationship, we also use cross-correlation relationship to investigate the presence of time – lagged relationship between solar wind density and geomagnetic indices. This analysis sheds light on time lag between changes in density level and the time when these changes are reflected as changes in geomagnetic indices. The results from correlation analysis are presented in this work in context of further studying the density dynamics.

This main focus on this work is to study the activity of sun and its relationship with Earth's magnetic field giving rise to the phenomenon of geomagnetic disturbance, resulting in the study of HSS.

METHODOLOGY

To procure the desired information, solar wind parameters and geomagnetic indices data are all collected, organized into a certain model. We used internet based supply of data provided by the international space related research centers. OMNI (Operating Mission as Nodes on the Internet web system) has been conducting its research using many ground and space based GPS and satellite stations since long ago .OMNI project is an internet based data explorer system developed by the National Aeronautics Space Administration (NASA).The output product of their observation and research work are kept in the website for the benefit of researchers. The data are basically provided in two resolutions, low resolutions and high resolutions.

Low Resolution OMNI (LRO) data are available at 1-hour, 1-day and 27-day cadence from 1963 to the near-present day whereas High Resolution OMNI (HRO) data are available at 1-minute and

5-minute resolution between 1981 and the near-present day [31].

OMNI data center provides magnetic field parameters plasma parameters, velocity(3-dimensional), proton density, proton temperature, flow pressure,3-vector IMF as well as geomagnetic activity indices: Dst (1-hour cadence), Kp (3-hour cadence), AE (1-minute cadence), SYMH(1-minute cadence) and proton fluxes of energy ranges 10 MeV, 30 MeV and 60 MeV.

These data used in this study are freely accessible with variety of functionalities from web page (http://omniweb.gsfc.nasa.gov/form/omni-min.html)

Geomagnetic Indices

Geomagnetic indices are simply measure of geomagnetic activity, which is actually indicates reaction of solar wind and Earth's magnetosphere and ionosphere interaction. Hence, they are very useful to understand the interaction between magnetosphere and solar wind. They are used to detect, describe and quantify space weather events. So, over the years they are regarded as prime factors in weather study [32]. There are almost 16 different indices that describes geomagnetic activity among them Dst, Kp and AE are most important to determine the level of geomagnetic activity.

Dst Index / SYM-H

The global magnetic storm level is observed by using Dst index .The disturbance storm time index (Dst) is based on average value of horizontal component of earth from mid latitude and equatorial magnetograms from all over the world [33] . It is expressed in nano tesla (nT) and represents the axially symmetric disturbance magnetic field at the geomagnetic dipole equator. Majority of disturbances in Dst are negative [34]. The more negative value of Dst the more the intensity of the magnetic storm. The ranges of Dst values depends upon the activity of the sun. Dst is also used to determine occurrence of storm and also it's duration. It also distinguishes between disturbed and quite geomagnetic conditions [35]. During the commencement of a magnetic storm Dst value rises to positive and then falls towards negative axis depending upon the strength of geomagnetic disturbance. The initial rise is due to compression of magnetosphere due to increase in solar wind ram pressure.

Symmetric disturbance field (SYM-H) is essentially same as hourly Dst index [36].The major difference between them is mainly in their time resolution as SYM-H is available at 1 minute resolution whereas Dst is available for 5 min time resolution (JamesA Wansissis .etal,2006).SYM-H is based on average value of the horizontal component of the earth magnetic field measured at four near equatorial geomagnetic observatories. Negative value of SYH-M represent it's greater strength. It is measured in nano tesla (nT). The SYM-H data used in our work is obtained from OMNI website https://omniweb.gsfc.nasa.gov/ow_min .html .

AE index:

Auroral Electrojet Index (AE index) is calculated by taking one minute time datasets of geomagnetic H variation along the horizontal component observed at twelve different auroral zone observatories located around the world (30).The location of these observatories is shown in figure 3.2. AE index represented in difference of amplitudes of upper (AU) and lower (AL) envelops where AU and AL indicate the strength of eastward and westward electrojets respectively. Here, AU-AL that gives AE which represents horizontal current strength. It is the parameter that provides quantitative measure of magnetic activity in auroral zone produced by enhancement of ionospheric current. It is measured in nanotesla (nT).The AE data used in our thesis is also obtained from OMNI website https://omniweb.gsfc.nasa.gov/ow_min .html .

Data Analysis

Wavelet Analysis

For this thesis work the methodology used for data analysis is Wavelet transform method. We have focused in this transformation, their properties and methods to identify multi-scale aspects during geomagnetic disturbances. Wavelet transforms are the analysis tools useful for numerical analysis as well as to manipulate multidimensional discrete signal set.(binod sir thesis).Introduced by Morlet in 1983 ,it was firstly used in field of geophysics .Years later now they are applied to various field including quantum ,medical, optics etc (climate signal detdection.pdf). WT is actually generalized form of both fourier transform and windowed fourier transform (WFT) (Gabur 1946) (climate signal detdection.pdf).

A continuous wavelet transform (CWT) provides a very redundant and finely detailed description of a signal in terms of both time and frequency .It posseses ability to construct a time-frequency representation of a signal .Cwt is formulated as

$$W_f\ (a, b) = \int f(t)\ \Psi^*((t-b)/a)\ dt \quad ()$$

Where *represents the complex conjugate, a and b are dilation and translation parameters varying continuously over R , function W_f (a,b) represents the wavelet coefficients.

Here the scale parameter gives contraction effect or dilation effect .If a>0, then it gives dilation effect whereas if a<0 it gives contraction effect. Hence, we can analyze whether a signal has low/high frequency or long/short period (binod sir article)

Correlation analysis

Cross-correlation is simply a measure of statistical relationships involving two or more variables as a function of time lags applied to one of them(2018 binod sir VSW vs pdf).It is useful as it can indicate strong relationship between two variables .It is defined interms of strong or high and weak or low coefficients. If the variables have a strong or high correlation this shows strong relationship between then while a weak or low correlation shows that the variables are hardly related. The range of coefficients lies between -1.00 to +1.00. The value of -1.00 indicates a perfect negative correlation between the variables and a value of +1.00 shows a perfect positive correlation. A value of 0.00 represents no relationship between the variables. It is also known as sliding dot product or sliding inner product (**Mannucci A et al 2008 reference ma cha**). For continuous functions, f and g, the cross correlation is defined as,

$$(f * g)(t) = \int_{-\infty}^{\infty} f^*(tau)\ g(t + tau)\ dtau \quad .()$$

where f^* denotes the complex conjugate of f .

Similarly, for discrete functions, the cross correlation is defined as:

$$(f * g)[n] = \sum_{m=-\infty}^{\infty} f^*[m]\ g[n+m] \quad ()$$

Scologram

A wavelet transform can be displayed by using visual method which is scalogram. It represents the square amplitude of the modulus of the wavelet coefficients (binod sir article). This increases the dimension of the data represented. For example the scalogram is two dimensional representations for the one dimensional signal provided. This figure gives the same information of result as given by absolute value or mean value.

Events tobe analyzed

In this work, we will analyze three different geomagnetic storm events where we study variation of solar wind density and geomagnetic indices during solar minima. The geomagnetic indices are namely (AE, SYM-H), proton speed, proton density, pressure, component of interplanetary magnetic field Bz, during four different geomagnetically active days. Here, the storm conditions caused by HSS were selected

The list of events is shown in table.

Table 3.1: A table of the event selected with year, month and day

Events	Date
Event – 1	05-06 June 2016
Event - 2	27-28 September 2017
Event - 3	25-27 August 2018

RESULT AND DISCUSSION

We have examined three different geomagnetic storms data, the storms that are driven by HSS. We have tried to relate their behavior with different solar and interplanetary parameters to have better understanding about its characteristics and possible mechanisms involved. We have taken three different events as listed in table 6.1 and their different characteristic features with various interplanetary parameters are discussed below.

Event 1: 2016 June 05-06 [Storm]

Solar Parameter

Figure 1 exhibits the variations of IMF-Bz, Solar wind Parameters (Vsw, Nsw and Psw), and Geomagnetic Indices (AE and SYM-H) during 05-06 June 2016. From top to bottom, the panels show the solar wind velocity (Vsw), Interplanetary southward magnetic field component (Bz), solar wind density (Nsw), magnetic field component (B), Solar wind pressure (Psw), temperature (T), SYM-H index and AE index.

In the figure, Imf Bz shows fluctuation of -19 nT to 10 nT throughout the day. The solar wind speed (Vsw) is around 0 Km/s at early hours of the day and gradually keeps increasing to its highest value ~ 690 km/s on 5th June at 23:00 UT. The value of Vsw keeps on fluctuating between 690-500 km/s and gradually decreases to its lowest value ie 450 km/s at nearly end of the day at 19:00 UT on 6th June. Tsw got its maximum during the night of 5th June and keeps on fluctuating northward/southward until it reaches 11 nT at the end of 6th June. Also, Psw reaches its apogee at 8:00 UT corresponding to the value 17 nPa and keeps on falling afterwards. Same as Psw, Nsw reaches its apogee ie 70 n/cc at ~ 8:00 UT on the morning of June 6 and keeps on fluctuating and then decreases its value at end of the day. The bottom panel indicates the fluctuation of AE index which shows maximum value of around 1500 nT at 05:00 UT corresponding to the value of ~ -30 nT of SYM-H.

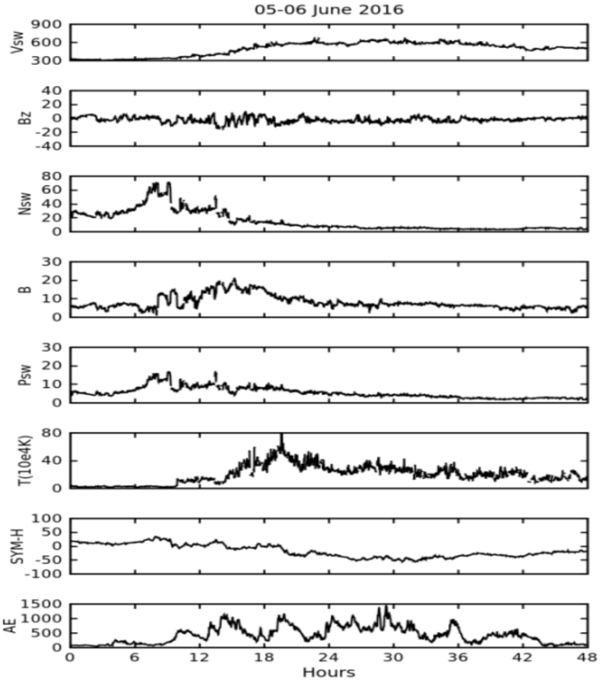


Fig 4.1 From top to bottom the subplots shows solar wind velocity (Vsw in km/s), southward interplanetary magnetic field (Bz in nT), solar wind density (Nsw in kg/cc), B( ), Solar wind pressure(Psw), temperature(T in), SYM-H (in nT) and AE (in nT)

Event 2:2017 September 27-28 [storm]

Solar Parameter

Figure 2 exhibits the variations of IMF-Bz, Solar wind Parameters (Vsw, Nsw and Psw), and Geomagnetic Indices (AE and SYM-H) during 27-28 September 2017. From top to bottom, the panels show the solar wind velocity (Vsw), Interplanetary southward magnetic field component (Bz), solar wind density (Nsw), magnetic field component (B), Solar wind pressure (Psw), temperature (T), SYM-H index and AE index.

In the figure, Imf Bz shows fluctuation of -19 nT to 15 nT throughout the day and at the end of the day ie 27th it reaches 5 nT . The solar wind speed (Vsw) is around 0 Km/s at early hours of the day and gradually keeps on fluctuating throughout the day upto end of 27th September. As from morning of 28th September Vsw keeps fluctuating between 650-600km/s .TSW got its maximum during the night of 27th September and keeps on fluctuating northward/southward until it reaches 14 K at the end of 28th September. Whereas, Nsw gradually keeps fluctuating as the day commences, it reaches highest value 58 n/cc at 7:00 UT and afterwards goes on decreasing such that at the end of the day of 27th September it is almost 0 n/cc.

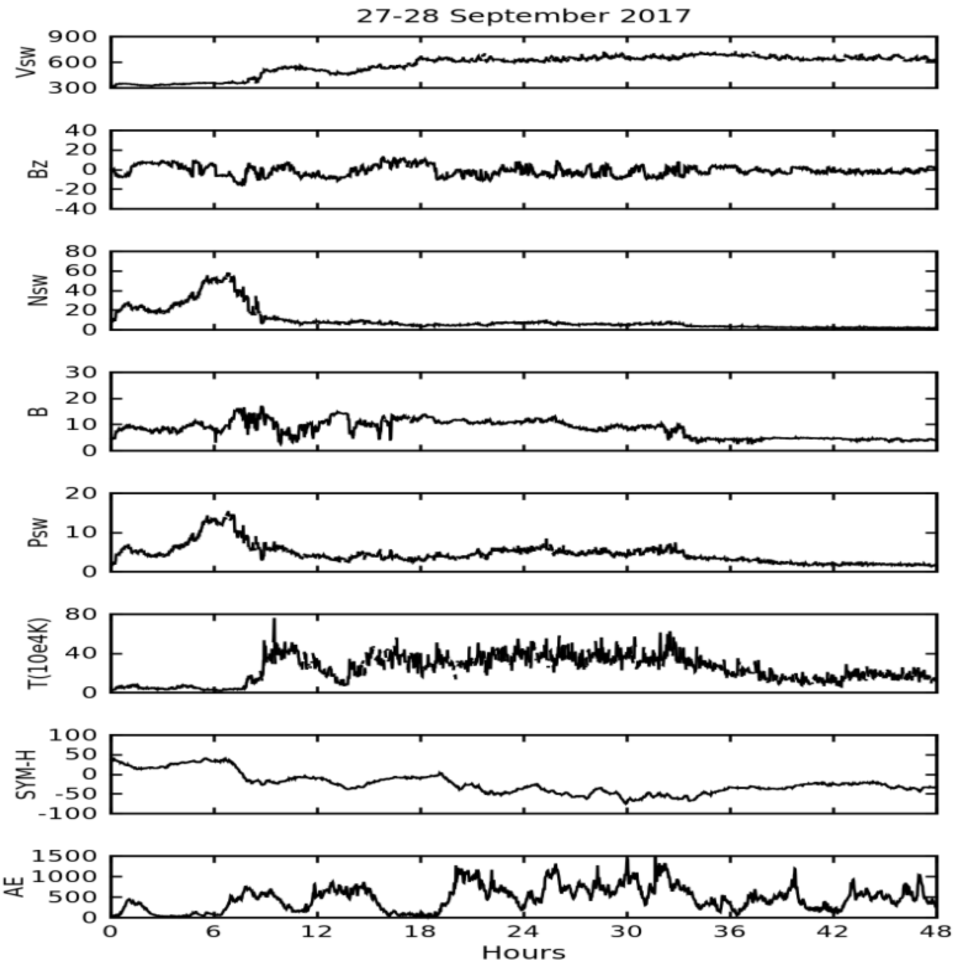


Figure 4.9: [Variations of the interplanetary and geomagnetic parameters during 27 - 28th September 2017 storm.]

Event 3: 2018 August 25 - 27 [storm]

Solar Parameter

Figure 1 exhibits the variations of IMF-Bz, Solar wind Parameters (Vsw, Nsw and Psw), and Geomagnetic Indices (AE and SYM-H) during 25 - 27 August 2018. From top to bottom, the panels show the solar wind velocity (Vsw), Interplanetary southward magnetic field component (Bz), solar wind density (Nsw), magnetic field component (B), Solar wind pressure (Psw), temperature (T) and SYM-H index.

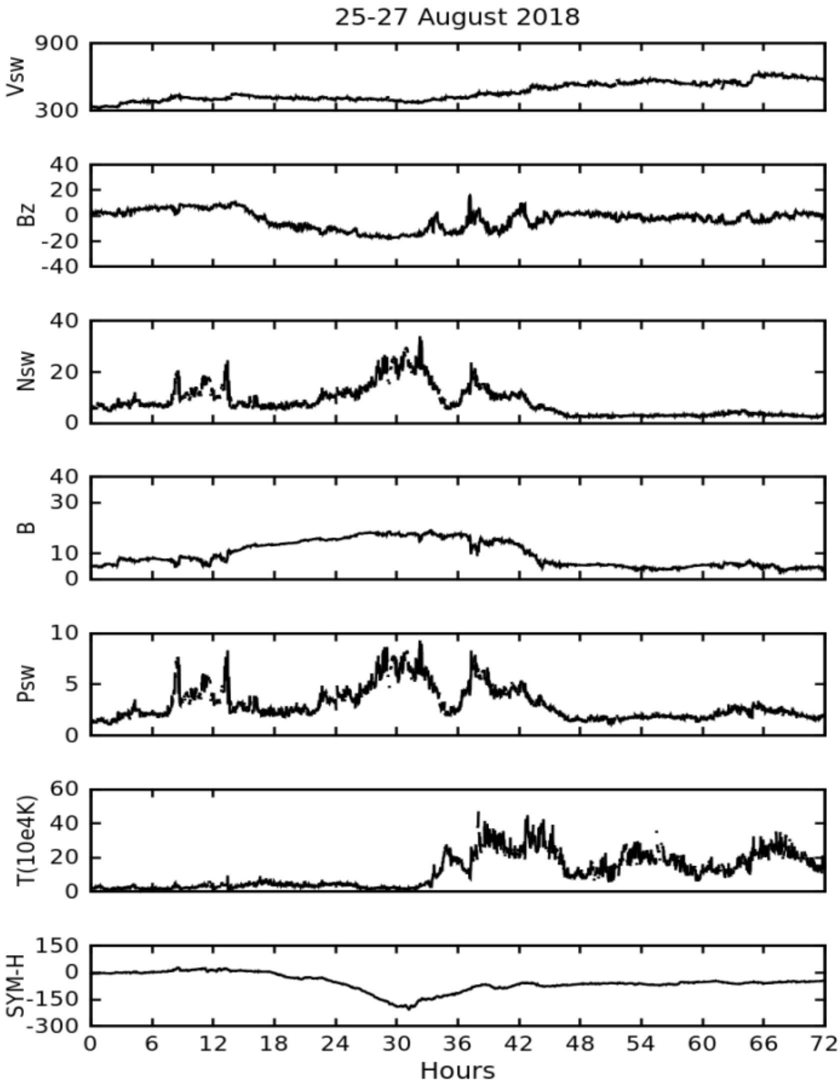


Figure 4.17: [Variations of the interplanetary and geomagnetic parameters during 25 – 27 August 2018 storm.]

Cross correlation:

In this subsection, correlation analysis was inspected between Solar Wind Density with IMF, Solar wind parameters and Geomagnetic indices.

Figure 4 depicts the result of cross-correlation of Nsw with solar parameters and geomagnetic indices during 5-6 June 2016. The horizontal axis represents the scale in minutes and the vertical axis represents the cross-correlation coefficient. In this figure, the Nsw - Bz curve (Sky Blue) shows negative cross-correlation coefficient of around -0.9 with a _ time lag around minutes and it does not show any positive correlation during this event. The negative correlation signifies that if the value of Bz decreases with time then Nsw increases with increasing time and vice-versa. This means they have a negative relationship with each other. Similarly, red curve shows positive correlation between Nsw - Psw with high correlation coefficient of about 1. The Nsw - SYM-H (dark blue) has a good positive cross-correlation with correlation coefficient of about 0.98 at zero-time lag. Similarly, the Nsw - Vsw green curve also shows good positive cross-correlation with correlation coefficient of about 0.95 at 0-time lag. The Nsw - B (pink) shows negative correlation with correlation coefficient of about -0.69 at 0 minutes time lag.

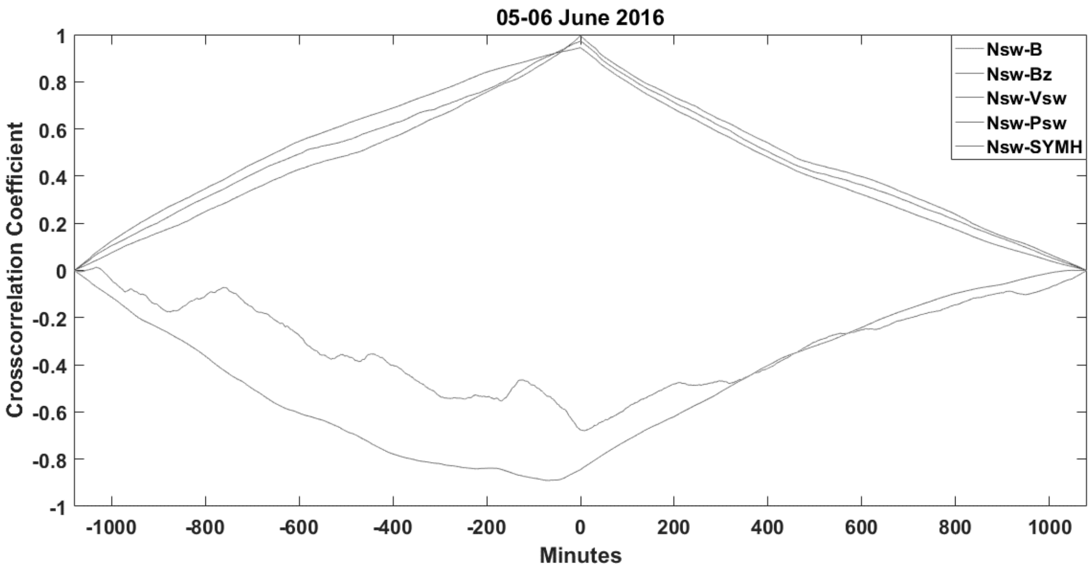


Figure 5 depicts the results of cross correlation coefficient of Nsw with solar parameters and geomagnetic indices occurred on 27-28 September 2017. The horizontal plane represents the time scale ranging from -1000 to 1000 min and the vertical plane represents the cross-correlation coefficient scale from -1 to 1. The red curve shows the correlation between Nsw and Psw. This curve represents strong positive cross-correlation coefficient of about 1 at lag zero. The light blue curve shows good correlation between Nsw - SYM-H with cross-correlation coefficient of around -0.95 at lag of __minutes. The negative correlation signifies that if the value of Nsw decreases with time then SYM-H increases with time and vice-versa. The pink curve of Nsw-Bz represents uncorrelated. The dark blue curve represent correlation between Nsw - B and it shows good correlation with correlation coefficient of about 0.98 at lag zero. Similarly, the correlation between Nsw - Vsw is represented by green color which shows good positive cross-correlation of correlation coefficient about 0.97 at zero lag.

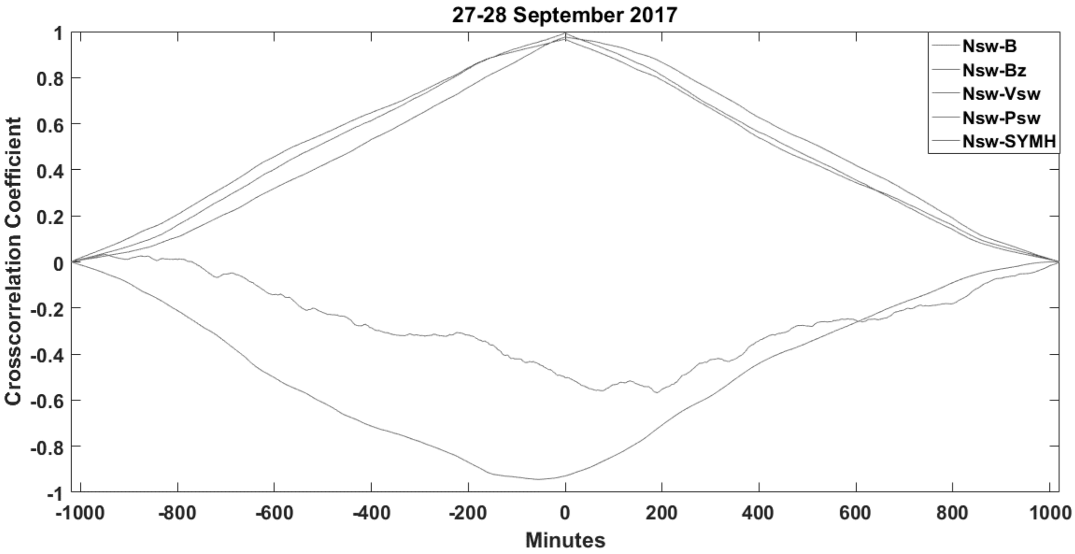
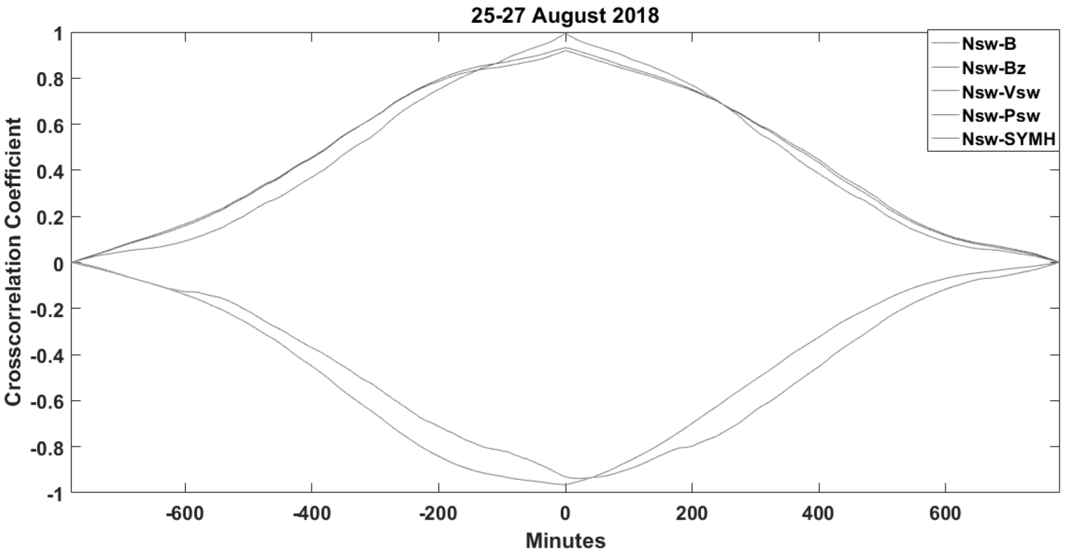
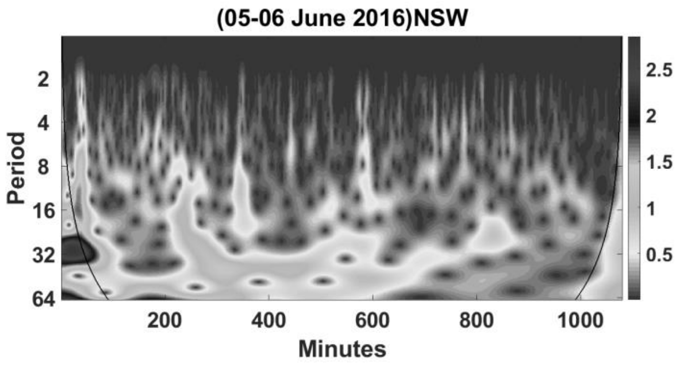
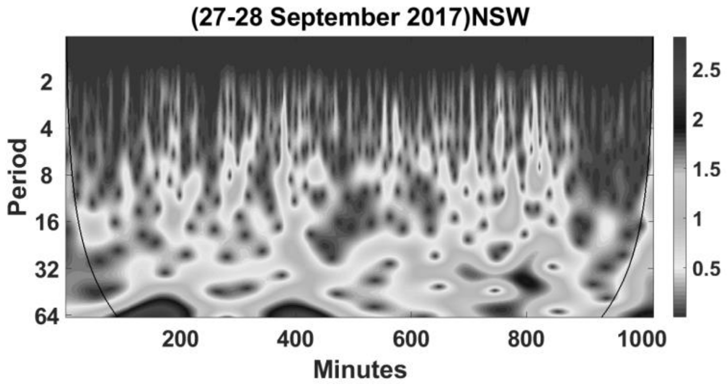


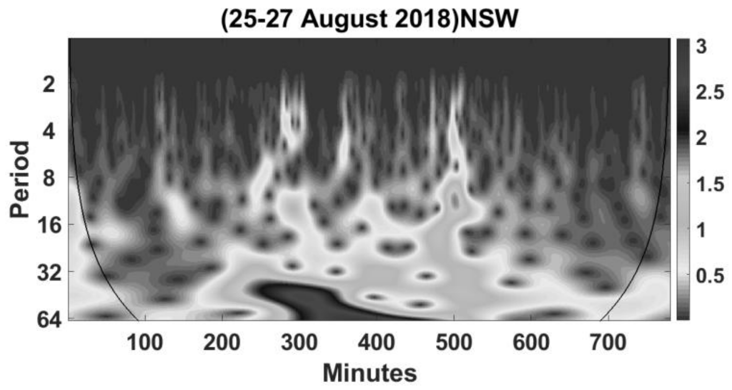
Fig 6 shows the cross-correlation of Nsw with solar parameters and geomagnetic indices during 25-27 August 2018. Here the horizontal axis represents the scale in minutes and the vertical axis represents the cross-correlation coefficient. The red curve shows the correlation between Nsw and B. The curve shows strong positive cross-correlation coefficient of about 1 at lag zero. The correlation between Nsw - Bz is represented by pink curve shows high negative cross-correlation coefficient of around -0.94 at lag of 0 minutes. The negative correlation signifies that if the value of Nsw decreases with time then Bz increases with increasing time and vice-versa. The correlation between Nsw - Vsw (green curve) shows good correlation with correlation coefficient about 0.93 at lag zero. The light blue curve also shows negative cross-correlation between Nsw – SYM - H with correlation coefficient of about -0.98 at zero lag. The correlation between Nsw and B is positive with correlation coefficient of about 0.94 at lag zero.



CWT analysis:







Conclusion

On carrying the thesis on the topic, " ", we took an account of the major three events during solar are dated on 5 - 6 th June 2016, 27 - 28 th September 2017 and 25 - 27 th August 2018 which on analyzing led to a conclusion that the geomagnetic disturbances are active during the mean day. Throughout the events we discussed the different parameters viz. Solar wind Velocity, Pressure, Density, Temperature, SYM-H, AE index and the various components of the electric and magnetic field which claims that during a geomagnetic disturbance, there is an energy input inside the magnetosphere and ionosphere which changes ionospheric parameters, such as composition, temperature and circulation. At the same time, we studied the correlation coefficient for various parameters with solar wind density.

The data set for three particular events were taken using OMNI data explorer for each storms. Solar wind relative to various interplanetary parameters during each storm was analyzed; correlation of Solar wind density with other parameters was evaluated with the help of matlab. The correlation of Solar wind density with the other components suggests that, Flow Pressure and AE- Index exhibited an immense role on carrying geomagnetic disturbances. Besides, the other parameters as like speed, components of electric and magnetic fields, pressure do not play a significant role, with correlation coefficient on electric field and AE index showing negative value. The Higher solar pressure with lower density shows large disturbances due to presence of the solar and geomagnetic activities during the solar active period.

In conclusion, during the main phase of the storm, maximum solar wind velocity was observed to be around 800km/s suggesting that the Solar wind velocity (Vsw) has strong impact for the cause of geomagnetic disturbanc

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