

Evaluation of geomagnetic storm effects on the GPS derived Total Electron Content (TEC)

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Abstract. The geomagnetic storm represents the most outstanding example of solar wind-magnetospheric interaction, which causes global disturbances in the geomagnetic field as well as triggers ionospheric disturbances. We study the behaviour of ionospheric Total Electron Content (TEC) during the geomagnetic storms. For this investigation we have selected 47 intense geomagnetic storms ($Dst \leq -100nT$) that were observed during the solar cycle 23 i.e. during 1998- 2006. We then categorized these storms into four categories depending upon their solar sources like Magnetic Cloud (MC), Co-rotating Interaction Region (CIR), SH+ICME and SH+MC. We then studied the behaviour of ionospheric TEC at a mid latitude station Usuda (36.13N, 138.36E), Japan during these storm events produced by four different solar sources. During our study we found that the smooth variations in TEC are replaced by rapid fluctuations and the value of TEC is strongly enhanced during the time of these storms belonging to all the four categories. However, the greatest enhancements in TEC are produced during those geomagnetic storms which are either caused by Sheath driven Magnetic cloud (SH+MC) or Sheath driven ICME (SH+ICME). We also derived the correlation between the TEC enhancements produced during storms of each category with the minimum Dst. We found the strongest correlation exists for the SH+ICME category followed by SH+MC, MC and finally CIR. Since the most intense storms were either caused by SH+ICME or SH+MC while the least intense storms were caused by CIR, consequently the correlation was strongest with SH+ICME and SH+MC and least with CIR.

1. Introduction

Energy emitted from sun drives the earth's magnetosphere, thermosphere and ionosphere. The most powerful solar events like Coronal Mass Ejections (CME) are a result of plasma outbursts from active region of the sun [1]. CMEs interact with solar wind and Interplanetary Magnetic Field (IMF) during their propagation and disrupt the solar wind flow. Geomagnetic storms are largely associated with CMEs from the sun. CMEs faster than ~500 Km/s eventually drive shock waves which normally strike the earth's magnetosphere in 24 to 36 hours after the event onset on sun.



The solar wind energy deposited into the magnetosphere during geomagnetic storms will eventually be dissipated into the ionosphere and thermosphere. Therefore various physical and energy transport processes takes place in the ionosphere [2]. The high latitude electric field can penetrate into mid, low and equatorial ionosphere during a geomagnetic storm causing significant disturbances in ionospheric conditions [3, 4, 5]. The disturbed ionosphere is manifested as a large increase or depletion of electron density from their normal level. This kind of response of ionosphere to the geomagnetic storms is known as ionospheric storm. Description and prediction of the features of the ionospheric storms and understanding of the related processes has been a topic of intensive research from decades [6,7, 8, 9, 10].

Ionospheric storms are of two types: positive and negative. During the geomagnetic storms, ionospheric, peak electron density (N_{max}), electron density (N_e) and Total Electron Content (TEC) increase or decrease dramatically from their normal level, known as positive or negative ionospheric storms. The positive ionospheric storms can cause many serious problems such as time delay, range error and scintillation in satellite communication and navigation. The positive ionospheric storms have been studied by many researchers [11, 12, 13]. Negative ionospheric storms can cause radio blackouts in ground based HF radio communication. Physical mechanisms of the negative storms are more or less well understood [14, 15].

Since every geomagnetic storm has its unique character and therefore prediction, forecasting and now casting of the response of ionosphere during geomagnetic storms is an interesting topic of study for researchers from decades.

2. Data and Methodology

We have selected the 47 geomagnetic storm with minimum $Dst \leq -100nT$ for the study, observed during solar cycle 23 i.e. 1998 – 2006. To study the effect of these geomagnetic storms on the ionosphere we have selected a mid latitude station Usuda (36.13N, 138.36E), Japan. The storm intensity is characterized by the Dst index. The data of Dst is available at various websites for downloading. However, for our study we have downloaded the data of Dst index from Space Physics Data Facility OMNI website (<http://omniweb.gsfc.nasa.gov/>). We have used the hourly values of Dst for the investigation.

We have also taken the IMF B_z from the measurements of ACE satellite at www.srl.caltech.edu/ACE with 1h resolution to characterize the Interplanetary Magnetic Field conditions.

We identified the solar and interplanetary sources that were responsible for causing each storm. For doing so we have taken help from various online catalogs and properties of various magnetic cloud structures. On the basis of solar sources we then categorized these storms into four categories.

The state of ionosphere is described by a number of parameters derived from the measurements of different instruments. The most widely used instruments for studying the ionospheric behaviour are the Ionosonde and GPS. From both ionosonde and GPS measurements we can define and derive a number of parameters that describe the state of ionosphere. However for the present investigation we have used the Total Electron Content (TEC) derived from the GPS measurement

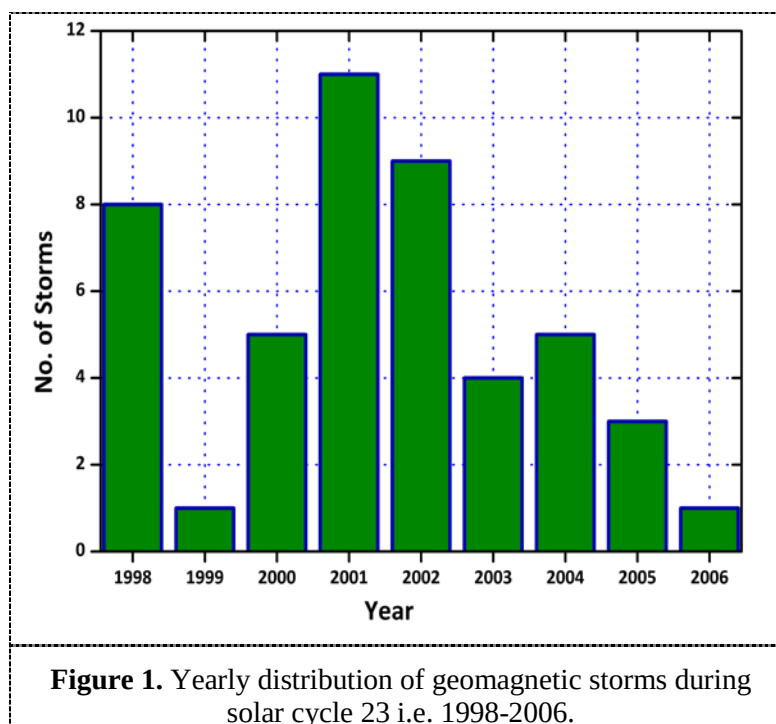
A network of GPS receivers is spread over the globe and data is recorded regularly. The data recorded at all the stations which form the part of International GPS Service (IGS) is freely available to users and can be downloaded from the URL <http://sopac.ucsd.edu/dataArchive/>.

The data downloaded from the web is in RINEX format, which is then processed to get the required Total Electron Content (TEC). For our investigation we have used the TEC data of the Usuda (36.13N, 138.36E) station of Japan. The temporal resolution of the data is usually 30s. However, for our study we have constructed the hourly averages of TEC. We calculated the deviation of TEC from the quietest day of the month.

3. Results and Discussion

We studied the ionospheric response to geomagnetic storm produced by four different solar and interplanetary sources. For doing so we have selected 47 geomagnetic storm associated with four types

of solar sources namely Magnetic Cloud (MC), Sheath and Magnetic Cloud (SH+MC), Sheath and ICME (SH+ICME) and Corotating Interaction Regions (CIR). The occurrences of geomagnetic storms vary considerably from year to year during a particular solar cycle as well as from cycle to cycle also. Figure 1 shows the yearly distribution of geomagnetic storms during solar cycle 23. From the figure we find that maximum number of intense geomagnetic storms (11) occurred during year 2001 followed by 2002 (09). The least number of intense storms were observed during 2006 (01). The occurrence of geomagnetic storms depends on the state of solar activity. Since maximum number of active regions appear on the sun during solar maximum, consequently the frequency of storms increase during these years. Similarly during solar minimum the solar activity conditions remain quite low and accordingly during these less number of storms are observed.



We then identified the solar source of each of the 47 geomagnetic storms that were responsible for causing them. To identify the solar sources of selected geomagnetic storms we have taken the help from various online catalogs and properties of interplanetary structures. The distribution of geomagnetic storms with various solar sources is shown in figure 2. The major solar sources of selected geomagnetic storms were identified as Magnetic Cloud (MC), Sheath and Magnetic Cloud (SH+ MC), Sheath and ICME (SH+ICME) and Corotating Interaction Region (CIR). The maximum number of storms (17) were found to be produced by SH+ICME followed by SH+ MC, CIR and MC. It therefore follows from the figure that the effective drivers of geomagnetic storms are Sheath driven ICME or Magnetic Cloud.

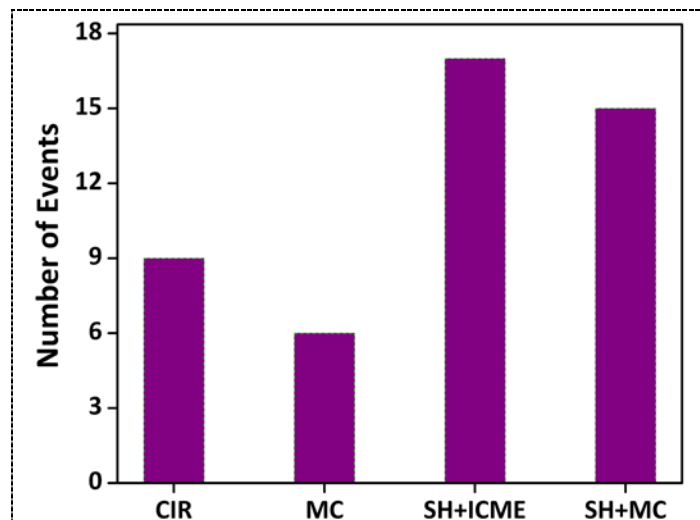


Figure 2. Distribution of selected geomagnetic storms with their solar and interplanetary sources.

We then performed the single regression analysis to quantify the magnitude of effect of storms produced by different sources on the ionospheric TEC. To draw the scatter plots and derive the correlation between TEC and storm index for four different categories of storms, we took the peak values of TEC and peak values of Dst. The scatter plot of peak values of TEC and Dst for all the storms of each category is shown in figure 3. From the figure we found that the scatter of points between Dst and TEC is quite large both for storms produced either by CIR or MC, while opposite pattern is observed for storms produced by SH+ICME and SH+MC. We also derived the correlation coefficients between the Dst and TEC for all the four categories of storms and are shown in figure 3. The correlation coefficient between Dst and TEC is 0.28, 0.39, 0.52 and 0.68 for storms produced by CIR, MC, SH+MC and SH+ICME respectively.

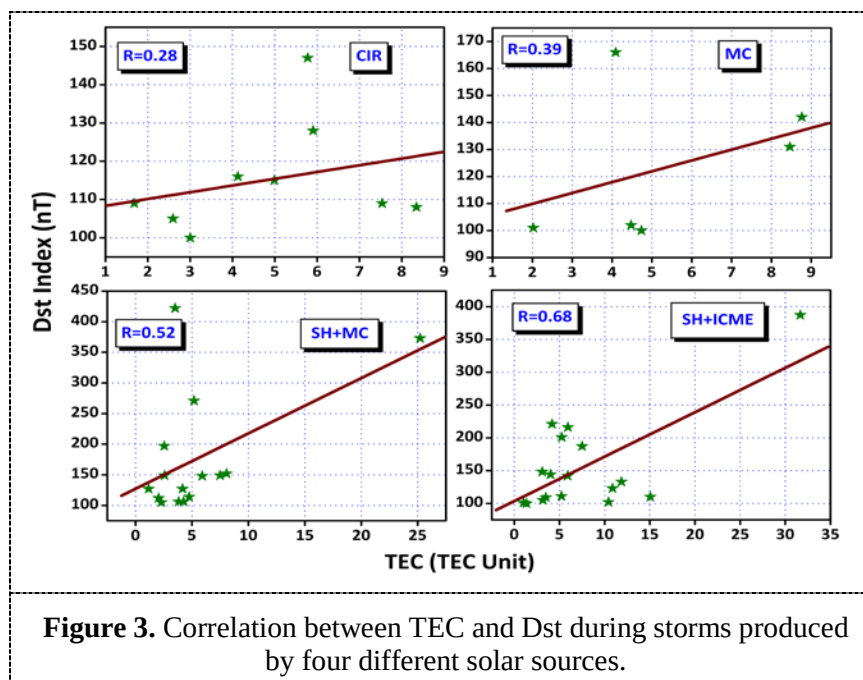


Figure 3. Correlation between TEC and Dst during storms produced by four different solar sources.

4. Conclusions

We studied the effect of geomagnetic storms caused by different solar sources, on the ionospheric TEC. The main conclusions of the study are enumerated below:

- The geomagnetic storms significantly affect the ionosphere having any of the solar origin. A positive deviation of TEC was observed during all the storms having different solar sources.
- The strongest effect is produced by those geomagnetic storms which are produced by SH+ICME and SH+MC. The TEC undergoes strong and rapid fluctuations as well as exhibits largest deviations during the storms produced by these two solar drivers.
- The effect of geomagnetic storms which have CIR and MC as their solar sources have a less impact on ionosphere.

The TEC exhibits a strong correlation with Dst during geomagnetic storms produced either by SH+ICME and SH+MC.

5. Acknowledgements

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6. References

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