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Electromagnetic Coupling on Solar-Terrestrial System: Possible effects on seismic activities

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Abstract
Solar wind parameters play significant roles in electromagnetic coupling of the Sun – Earth system. By having a long period of observation and analysis of solar activities and its influence on geomagnetic or seismic activities, it is possible to reveal the interconnection between them. In the present paper, we analyzed the earthquake (EQ) events as seismic parameters, which extracted from Advanced National Seismic System (ANSS) database. The different earthquake magnitudes were analyzed with the solar parameters; high-speed solar wind (HSSW) events, and solar wind dynamic pressure (SW Pdyn). All of these analyses were done from year 1964 to 2008, which covers the latest entire solar cycles (cycle number 20 to 23). In the analysis, we propose how the electromagnetic energy can be transferred from the solar wind to the lower ionosphere and finally affected the geomagnetic activities by showing the plots and the statistical analysis on plasma speed event (Vsw), solar wind dynamic pressure (SW Pdyn), solar wind input energy and ring current (Dst) index. The analyzed results show a significant relationship between solar and terrestrial parameters.

1. Introduction

The physical processes of transferring electromagnetic energy from sun to the earth can be referred as Space – Terrestrial interaction. It involves terrestrial atmosphere, the outer part of geomagnetic field, and the solar events, which influence them. The correlation of space – terrestrial system and it's influenced on the geomagnetic activities has been demonstrated by a number of researchers [1-6]. The analyses were done on different elements of solar activities, for instance; solar proton fluxes [1], solar and lunar tides [2], high-speed solar wind [3], and electromagnetic effects from released coronal mass ejections (CMEs) from the sun [4]. Other than that, the studies on the energy coupling between the solar wind and magnetosphere by Akasofu (1981) [7] has been able to "connect the dots" between solar and terrestrial system. However the analysis was done for a short term period (few days) geomagnetic disturbances.

In this paper we investigate the solar – terrestrial relationship by considering various possible aspects and parameters of extraterrestrial and terrestrial data at a longer time period. The analyses include the data of solar activities at different solar cycle phases (minimum, maximum, descending and ascending), high-speed solar wind (HSSW) and high solar wind dynamic pressure (SW Pdyn) at different global earthquake magnitudes. The observation covers four most recent solar cycles 20 to 23, (started from October 1964 until November 2008). These results are characterized and discussed in terms of possible relationship of different solar parameters with seismic events based on analyzed criteria.

2. Data and Analysis

The global earthquake events from year 1963 to 2010 are extracted from ANSS, hosted by Northern California Earthquake Data Center (http://www.ncedc.org/anss/). The earthquakes were selected based on the depth of epicenter less than 100 km to ensure the possible triggering factors are from external sources. The correlation analyses were done based on two categories:

2.1 HSSW during Big Earthquake (EQ) Events (M ≥ 6.0)

Solar wind is a highly ionized gas originated from the sun [8] and can be categorized into slow and fast solar winds, which have different origins in the solar corona [9 and 10]. It is one of the most prominent features in interplanetary magnetic field (IMF) and acts as a medium to most of the solar perturbations to penetrate into the earth ionosphere. During the analyzed period, we have identified 1603 cases of HSSW. In this study, a HSSW is characterized based on four factors [9 and 10]; considerable enhancement in plasma stream speed ($\Delta V_{SW} \geq 100$ km/s), higher temperature (T in K), a high variation of proton density (N in cm^{-3}) and higher magnitude of inteplanetary magnetic field IMF (B in nT). All the parameters of HSSW were extracted from OMNIWeb Data Explorer, Space Physics Data Facility (NASA). For this analysis, we compared day-to-day variations of big EQ (with magnitude 6 or greater) relative to the day of arrival of HSSW to the earth. The results in Figure 1 shows the number of big earthquake keep increasing until the day of the arrival of HSSW and reached maximum 1 day after the arrival of HSSW. The graph shows a significant connection between HSSW and seismic events. From 1603 cases of HSSW within the period of observation, 997 events or 62% of HSSW recorded on the day or within 4 days before the big EQ events.

2.2 Solar Wind Dynamic Pressure (SW Pdyn)

In space weather study, the effects of solar wind to the earth system are very significant. The enhancement of dynamic pressure caused by solar wind flow; called solar wind dynamic pressure (SW Pdyn) has been widely discussed by previous researchers. According to our preliminary observation for the recent solar cycle (23), the average daily value of SW Pdyn was 2.12 nPa. Based on this result, the value of 3 nPa has been chosen as upper threshold value to compare the day to day variation of high SW Pdyn with the occurrences of EQ events. Figure 2 shows the superposition of Solar Wind Dynamic Pressure with EQ events for different magnitudes. From this result, we further analyzed the occurrence of EQ by comparing the day-to-day variation with high SW Pdyn onset as in Figure 3. It can be seen clearly the number of EQ occurred during all phases reached their peaks on the day of detected high SW Pdyn. From 91,515 EQ events (magnitude 3.0-9.9), 56% of them occurred on the day and 4 days after the detected high SW Pdyn.

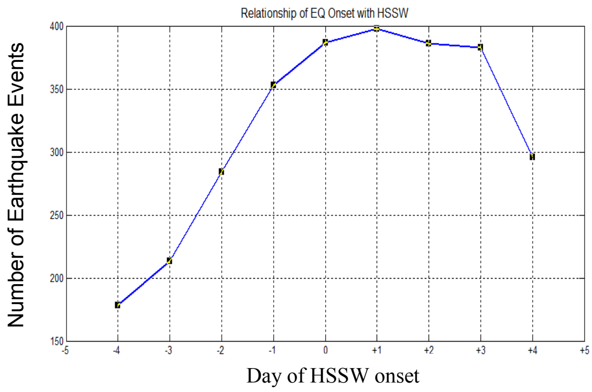

Figure 1: Relationship of earthquake onset with HSSW

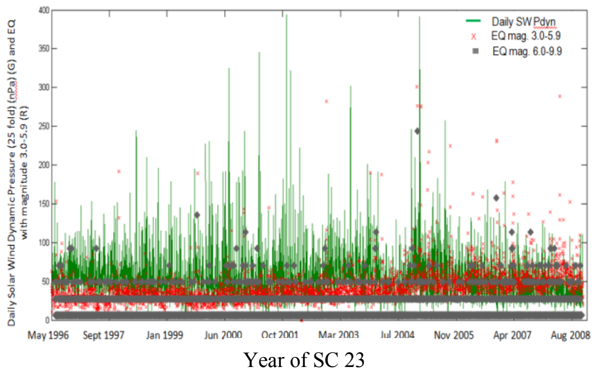

Figure 2. Superposition of Solar Wind Dynamic Pressure with earthquake events

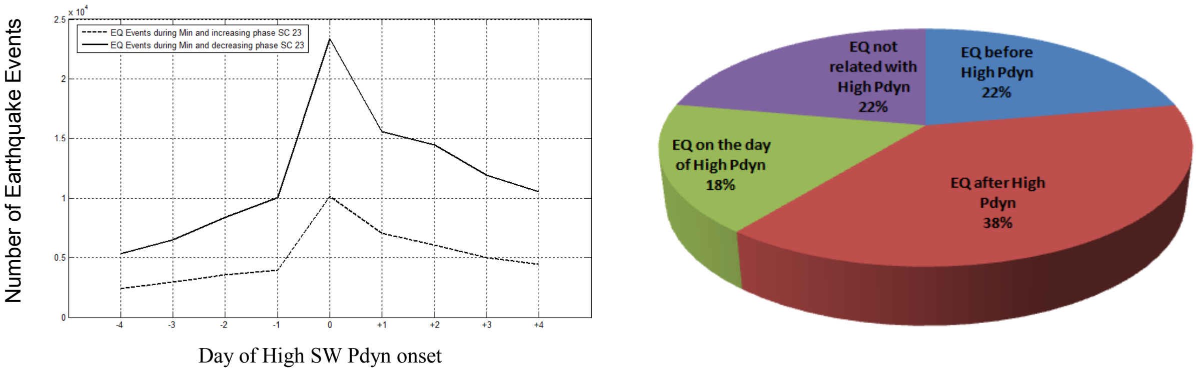

Figure 3 : The correlation of High SW Pdyn and EQ (Mag. 3.0-9.9) during SC 23. Graph on left panel shows the day-to-day variation of EQ with high SW Pdyn onset. The continous line shows the number of EQ triggered during descending and minimum SC 23 while the dotted line shows the EQ triggered during ascending and maximum SC 23. Pie chart on the right panel shows the percentage of EQ with respect to day of high SW Pdyn onset time.

3. Discussion

In the previous sections, the significant relationship between the earthquake onset and HSSW was presented quantitatively. Amongst the factor that has been used to characterize the HSSW, the plasma speed, V_{SW}, which was found to be associated with the increase of SW Pdyn. Hence, the magnetosphere will be compressed, causing an increase of the ring current magnetic field intensity by reflecting the value of Dst index. Figure 4 shows the variation of solar wind parameters and Dst index during the period of EQ with magnitude 8.1 on April 01, 2007 (indicates by the dashed line). A distinct sudden storm commencement (ssc) was observed at 23:55 UT on March 31 is associated with the significant increase of the SW Pdyn. This is understood as solar wind input energy, sharply increased at the time of ssc. One can easily see the correlation between SW Pdyn and solar wind input energy at this time. Note that the depression of the Dst index occurred well after the subsidence of the sharp increase of SW Pdyn. The earthquake occurred at 20:39:58.71 UT, few hours after the main phase developed at the period of increasing V_{SW}.

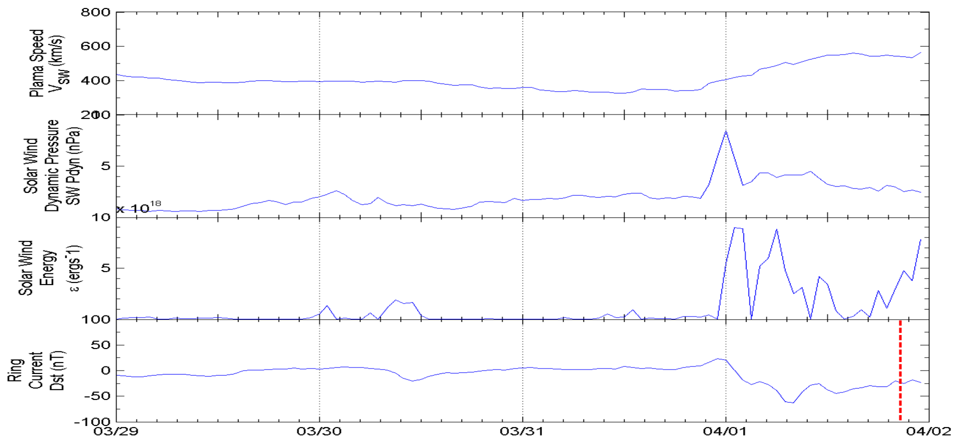

Figure 4: Solar wind parameters with Dst index. The red-dotted line indicates the time of EQ event.

Table 1 shows the correlation coefficient, R, calculated among the parameters and index plotted in Figure 4. The earthquake studied happened at the mid latitude dayside region on April 2 at 07:08:9.03 LT with -8.4660 and 157.0430 latitude and longitude respectively. The results obtained indicate the solar wind control on the geomagnetic activity associated with earthquakes. This was further supported by the value of V_{SW} which is negatively correlated with Dst index, -0.8151, at the exact time. The connection can be explained by the development of ring current at the time of increasing value of V_{SW}. We also noted a high correlation between SW Pdyn and ε, 0.7592, at 1 hour time delay, which represents the time lag after the compression of magnetosphere. The negatively high correlation between solar wind input energy and Dst, -0.6622, at time delay 2 hours represent the period required for the solar wind energy transfer.

Table 1: Correlation coefficient between solar wind parameters and geomagnetic index

Correlation coefficient, R	ε	Dst
V_{SW}	-	-0.8151
SW Pdyn	0.7592 (1 h)	-
Solar wind input energy	-	-0.6622 (2 h)

4. Conclusion

It is known that during the minimum and descending phases of solar cycle, there is an increase of HSSW events compared to the maximum and ascending phases of solar cycle. We have found that when the number of HSSW events increases, there is an increase in the occurrences of EQs of all kinds (magnitude 3.0 – 9.9) during the minimum and descending phases of solar cycle. But one HSSW event does not trigger one earthquake. Rather, the increase of solar wind energy / dynamic pressure increases the probability of the occurrence of EQs during the entire solar cycle. The significant number of big earthquakes detected around the arrival of HSSW opens a new perspective of sun – earth coupling mechanism. This surely warrants a further analysis and evaluation involving extension of observational data and also some advanced statistical analysis method to ensure the relationship of solar activity and global seismicity can be comprehensively explained.

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