A study on the solar cycle and annual distribution of geomagnetic storms

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Abstract

A list of geomagnetic storms for the period 1957-2008 was compiled using the geomagnetic Dst index from World Data Center for Geomagnetism – Kyoto. Geomagnetic storms with peak Dst ≤ -50 (moderate and intense) have been selected. A total of 1377 geomagnetic storms were identified. An exponential fit is derived to give the probability of occurrence of a geomagnetic storm of a specific strength. An updated analysis for the solar cycle and yearly distributions of storms is shown. The well known distributions with solar cycle and along the year are confirmed: dual peak variation with solar cycle, with one peak near solar maximum and other in the declining phase; semiannual variation with maximum intensity around equinoxes. It is also confirmed the increase in July in the number of storms, for more intense events. The solar cycle variation also shows change in the storm occurrence with the level of intensity, with less intense storms occurring predominantly in the declining phase, while more intense storms close to solar maximum or immediately afterwards.

Introduction

Geomagnetic storms are disturbances in the geomagnetic field and in the magnetosphere, that have been studied for more than 200 years [e.g. Chapman and Bartels, 1940; Gonzalez et al., 1994; Tsurutani et al., 1997 and references therein]. Geomagnetic storms are usually defined by the geomagnetic field horizontal component variations, but they actually are disturbances in the plasma populations and current systems present in the entire magnetosphere. Nowadays, it is well known that the prime cause of geomagnetic storms is the presence of a southward interplanetary magnetic field structure in the solar wind. This magnetic field orientation makes possible the energy to be transferred to the Earth's magnetosphere through the magnetic reconnection mechanism (Dungey, 1961; Gonzalez et al., 1994, 1999; Echer et al., 2005a).

Geomagnetic storms are characterized by enhanced particle fluxes in the radiation belts. These enhanced fluxes can be indirectly measured by decreases in the Earth's magnetic field horizontal component caused by the diamagnetic effect generated by the ring current. A standard measure of this is the Dst index, which is proportional to the total kinetic energy of 20–200 keV particles that flow in the westward direction the region of 4-6 terrestrial radii (RE), during the growth of the storm main phase. The inner edge of the ring current is located at 4 RE or less from the Earth's surface during intense storms. For lesser intensity storms, the ring current is located further away from the Earth [Gonzalez et al., 1994; Daglis et al., 1999; Echer et al., 2005a]. The Dst index is available since 1957 (Sugiura, 1964), and it measures primarily the effects of the ring current in the geomagnetic field, although it has contributions from other current systems such as the Chapman-Ferraro magnetopause current and the magnetotail current (Gonzalez et al., 1994). Dst is derived from hourly averages of the horizontal component of geomagnetic field, recorded at four low-latitude observatories subtracting the average solar quiet variation and the permanent magnetic field from the disturbed one. The recovery phase is characterized by a decay of the ring current due to a combination of several different energetic particle loss mechanisms (Gonzalez et al., 1994; 1999). For more details on Dst index see Sugiura (1964) and Rostoker (1972).

The distribution of storms with solar cycle has been previously studied, and a dual peak in the occurrence of storms was found, with one peak near the sunspot maximum and other near the descending phase (Gonzalez et al., 1990; 2007; Echer et al., 2008). This is usually attributed to the solar cycle dependence of solar wind structures, with storms close to solar maximum caused by the remnants of CMEs, and in the descending phase by corotating interaction regions (e.g, Gonzalez et al., 1999, 2007; Echer et al., 2005a, 2008 and references therein). There is a well know seasonal variation in the magnetic storms with two peaks around equinoxes (Priester and Cattani, 1962; Russell and McPherron, 1973), attributed to axial, equinoctial and Russell-McPherron mechanisms (Russell and McPherron, 1973; Gonzalez et al., 1994). An annual variation, with a peak around July for more geomagnetic intense activity, has been recently reported (Clua de Gonzalez et al., 2001, 2002). This has been tentatively attributed to an asymmetry in ionospheric conductivity (Clua de Gonzalez et al, 2001), or to the interplanetary shock occurrence near Earth's orbit (Echer et al., 2005b).

The distribution of geomagnetic storms along the solar cycle and during the calendar year is very important for space weather. Both scientific research and technological operations can be planned with this knowledge. In this work a catalogue of magnetic storms during 1957-2008 is compiled. Storms with peak values of Dst ≤ -50 nT were selected. An exponential fit function for the entire storm distribution is presented that may be useful for space weather applications. Using this list of storms, an update analysis is performed on the solar cycle and semi-annual/annual distribution of storms.

Method

A list of geomagnetic storms occurred during 1957-2008 was compiled using the Dst data from World Data Centre for Geomagnetism – Kyoto (swdcwww.kugi.kyoto-u.ac.jp). Hourly average plots and data were checked and storms with peak Dst ≤ -50 nT were selected. A total of 1377 storms were found. Each storm profile was analyzed to identify individual storms from complex events. A full Table with date, time of peak and peak Dst for all the storms is available on request to the author.

Sunspot number annual averages from Sunspot Index Data Centre www.sidc.oma.be) were used to study the solar cycle distribution of geomagnetic storms.

The analysis consists in summing the number of storms for each year, to study the solar cycle variation, and for each calendar month, to study the annual variation. These distributions were also studied according to the storm strength levels. For this, the following classification has been used: a) -75 < Dst ≤ -50; b) -100 < Dst ≤ -75; c) -100 < Dst ≤ -50; d) Dst ≤ -100; e) -200 < Dst ≤ -100; b) Dst ≤ -150; f) < Dst ≤ -200; g) < Dst ≤ -250.

Results

Figure 1 shows the distribution of peak Dst for all storms. The number of storms versus –Dst is plotted. The average peak Dst is 94 nT and the median is 76 nT. Note that the number of storm follows roughly an exponential law, with the number of storms decreasing rapidly as the storm strength increases. Therefore, an exponential decay function was fitted to the distribution, of the form: N = yo + A1*exp(-t1/Dst); From the fit results, one has the following law for storms (in normalized occurrence):

$$P(Dst_p) = 0.0013 + 1.19 e^{\frac{-Dst_p}{34}} \quad (1)$$

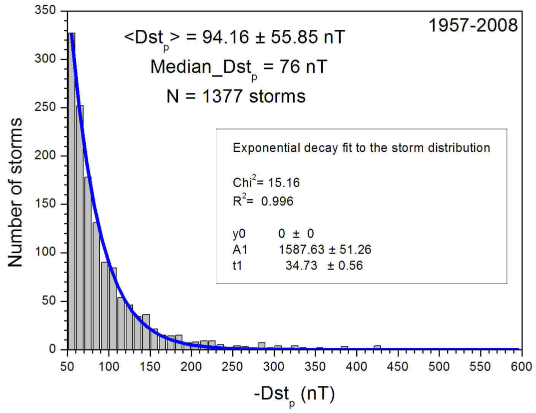

Figure 1: Histogram of the peak Dst (Dst_p) for all storms (bars) and exponential fit (blue line).

Figure 2 shows the number of storms per year, and the yearly average sunspot number, in the top panel, and the average and standard deviation of peak Dst for all storms during a given year in the bottom panel. The distribution of the number of storms shows clearly the dual-peak distribution with a peak around solar maximum and other during the declining phase. There is some trend for the average of storm peak Dst to be higher near solar maximum, but this is not observed for all cycles.

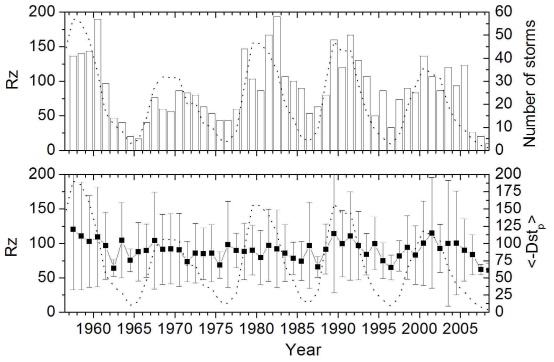

Figure 2: Number of storms per year (bars) and sunspot number annual averages (dotted lines), top panel. Average of peak Dst with errors (points and bars) and sunspot number (bottom panel).

The number of storms per year and sunspot number for different levels of storm strength were also studied (not shown). It was observed that there is a trend for less intense storms show a peak in their occurrence around declining phase, while more intense storms have higher occurrence near solar maximum.

Figure 3 shows the number of storms per month of year in the top panel, and average and standard of peak Dst for all storms during a give month, in the bottom panel. A semi-annual variation can be clearly seen in the number of storms, with peak around equinoctial months, March-April and September-October-November. For the average Dst, it can be seen that, besides the semi-annual variation, there is a trend for high values of Dst to occur around July, with intensity similar to the equinox months.

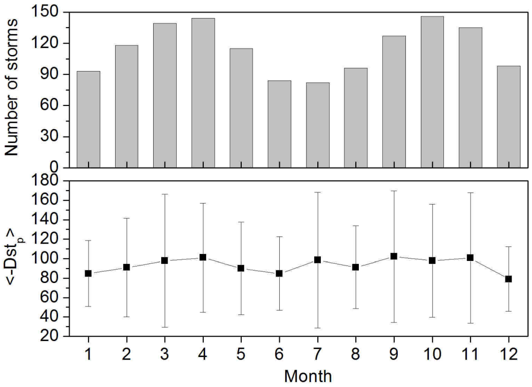

Figure 3: Number of storms per month of year (top panel). Average and standard deviation of peak Dst for all storms (bottom panel).

The annual/semiannual variation was investigated for different storm intensity levels (not shown). It was found that the semi-annual variation is observed for all storm strength levels, but when one goes to more intense events, a peak in July starts to be seen. This is in agreement with previous works (Clua de Gonzalez et al., 2001, 2002).

Conclusions

Using a newly derived list of geomagnetic storms with Dst ≤ -50 nT for 1957-2008 interval, the statistical distribution of, solar cycle variation and annual/semi-annual variation of storms was analyzed. It has been concluded that:

-geomagnetic storms show a distribution that can be fitted by an exponential function. This gives the probability of obtain a storm with a given peak Dst.

-the solar cycle distribution of storms shows clearly the dual peak variation, with a maximum occurrence around solar maximum and other in the declining phase. When studying storms according to their strength level, it was observed that less intense storms show a higher occurrence peak near the declining phase, while more intense storms show a higher occurrence close to solar maximum.

- the semi-annual variation, with peaks at equinoxes ,is clearly seen for all storms. However, both the average peak Dst, and the occurrence of more intense storms, show an enhancement in July.

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