Study of the relation between storms and substorms in the terrestrial magnetosphere

F.-A. Metallinou[1], I. A. Daglis[2], J.-H. Seiradakis[1]
[1] *University of Thessaloniki, Department of Physics, Section of Astrophysics, Astronomy and Mechanics, GR-540 06 Thessaloniki, Greece*
[2] *National Observatory of Athens, Institute for Space Applications and Remote Sensing, Penteli, GR-152 36 Athens, Greece*

Abstract

Space storms and substorms are the prime complex phenomena of space weather. Their relationship has long been a matter of dispute among space physicists. The first theory on the storm-substorm relationship was conceived by S. Chapman and S.-I. Akasofu in the 1960s (Chapman, 1962; Akasofu, 1968). Chapman and Akasofu had postulated that a space storm is the result of the superposition of individual substorms. Recently, a number of studies have concluded that storms are not a consequence of substorm occurrence, but the result of the solar wind driven magnetospheric convection. A classical way to study the storm-substorm relationship has been the comparison of time series of certain storm and substorm geomagnetic indices. In this paper we do not follow this line of work. Instead, we investigate if there is any correlation between the energy involved in storms and the energy involved in substorms. We believe that this is a more appropriate way to address the substorm influence on storm development, because substorms are episodic phenomena, and their actual effect on storms is presumably a cumulative effect (Daglis, 2001a). Consequently, substorm effects involve energy dissipation. Therefore, we use the integrals of the squares of the SYM-H and AL Indices (which reflect the level of energy density), over the storm lifetime. We have found that the integrals are linearly correlated for a sample of 25 storms, with the correlation coefficient assuming the value of $r = 0.789$. This indicates that the cumulative energy dissipation during substorms is important for storm development.

1 Introduction

Geomagnetic activity is defined as any change of the magnetic field of the Earth, recorded by instruments (magnetometers) located on the surface of the Earth. Electrical currents flowing in the Earth's magnetosphere and ionosphere (controlled by the solar wind) cause such perturbations. Magnetospheric substorms and space storms (traditionally known as magnetic storms) are the major types of geomagnetic activity.

Magnetospheric substorms are defined as intervals of intense magnetic disturbance, which typically last for a few hours. During a substorm a large sequence of events take place in the Earth's magnetosphere and ionosphere: Quiet auroral arcs suddenly explode into brilliance at the polar regions. The current system of the eastward and westward auroral electrojets develop. Flowing only 100km above the Earth's surface, they create the largest ground disturbance of all current systems. Following dayside merging between interplanetary magnetic field and geomagnetic field, reconnected in the magnetotail, thus adding magnetic flux to the magnetotail and rendering the system energetically unstable. Unloading of the system accelerates charged particles and injects them into the inner magnetosphere.

Space storms cause a global reduction of the magnitude of the horizontal-H component of the geomagnetic field (e.g., Daglis, 2001b). This defining feature led Alexander von Humboldt to adopt the name magnetic storm for this phenomenon in the early 19th century. Space storms have a considerably longer lifetime than substorms: they last for a few days. They are characterized by the ring current development at the equatorial plane, which is considered to be the main cause of the ground magnetic disturbances (Daglis et al., 1999).

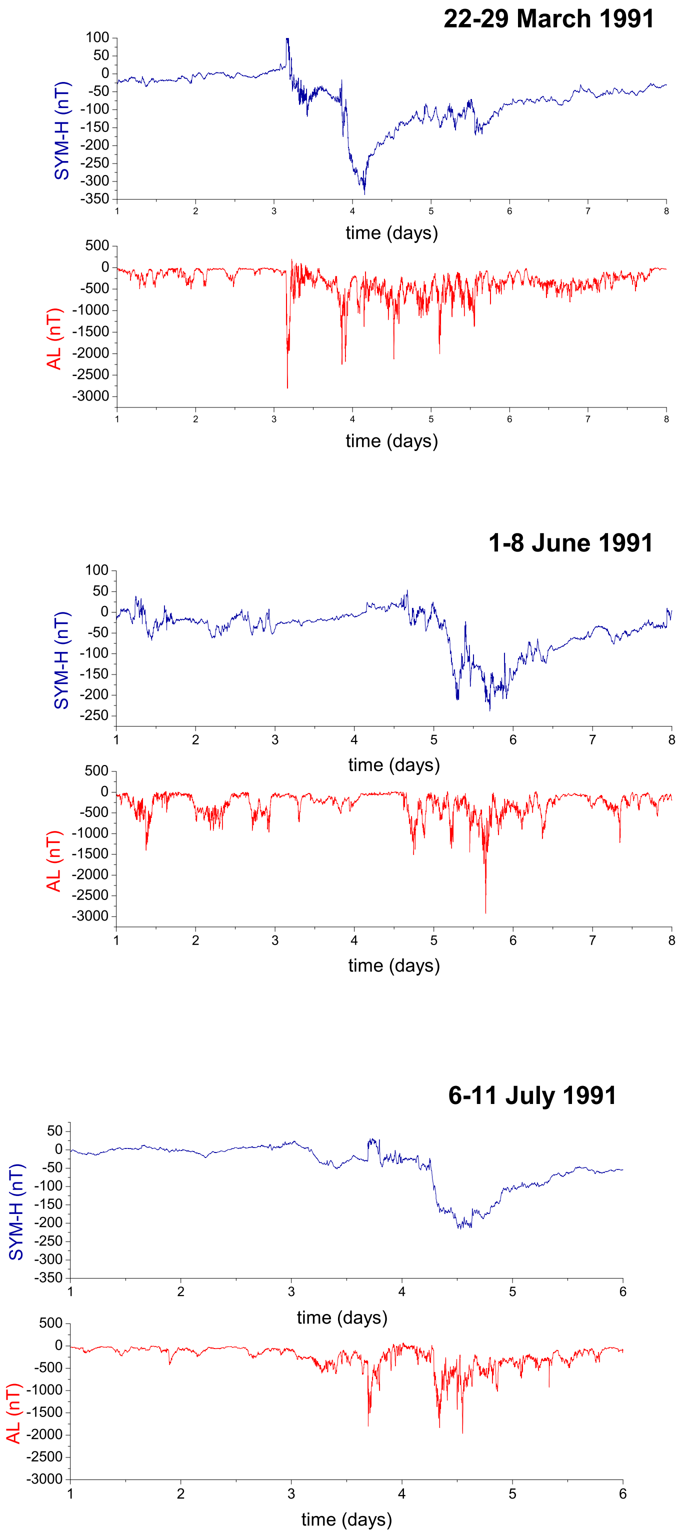

Figure 1. The development of storm and substorms, in three cases of intense magnetospheric activity.

2 The problem of storm-substorm relationship

Observations have shown that no space storms have occurred in the absence of intense substorms. This fact led Chapman (1962) to consider the space storm as a superposition of a number of substorms. Substorms also appear at periods during which no significant storm is in progress (Akasofu, 1968). A dispute on the role of substorms in storm development has emerged during the last few years; the community has not yet reached a definite conclusion (Kamide, 1992; McPherron, 1997; Daglis et al., 2000; Daglis and Kamide, 2002). It has been demonstrated that both storms and substorms need southward orientation of the Interplanetary Magnetic Field (IMF) to develop. The probability of storm and substorm occurrence is determined by the duration of the southward orientation of the IMF and the intensity of the southward IMF component.

3 Analysis

In order to have a numerical description of the geomagnetic activity we define the geomagnetic indices. The geomagnetic indices Dst and AL are the most commonly used measures of storm and substorm intensity, respectively. They are both constructed from magnetograms of ground stations, and involve deviations in the horizontal-H component of the geomagnetic field from quite-time values. The Dst index is used to describe the geomagnetic disturbance fields in mid-latitudes (Sugiura, 1964; Mayaud, 1980). Alternatively, SYM-H is used, which is essentially a Dst index with higher time resolution. The AL index is a measure of the westward electrojet, the current system that develops at the auroral region during a magnetosheric substorm (Kamide and Akasofu, 1983). At this work we examine 25 cases of geomagnetic activity, in the time period March 1981 - July 1991, by using minute values of the SYM-H and AL indices. The data were provided by the World Data Center for Geomagnetism, Kyoto. The plots in Figure (1) present the development of a space storm and one or more magnetospheric substorms, during three intervals of high activity.

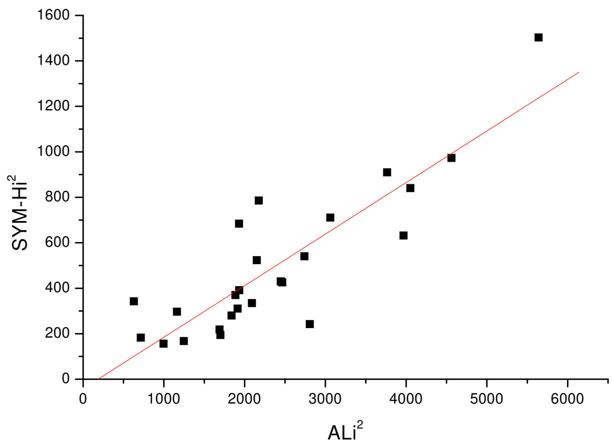

Figure 2. The strong correlation between SYM-$H_i{}^2$ and $AL_i{}^2$ implies that the energy variations responsible for the ring current growth and for the substorms are closely related.

In this investigation we will refrain from simply using time series of the respective storm and substorm indices, which has been the standard line of work. We will rather use the integrals of the squares of the indices, on the basis of the assumption that substorms, which are episodic phenomena, have a cumulative effect, on the ring current buildup (Daglis, 2001a). To explore the existence of this effect, we need to investigate the correlation between time series representing the energy associated with substorms and with storms. Accordingly, we have calculated the integrals of the squares of the SYM-H and AL indices (SYM-H_i^2, AL_i^2), for the time interval from the start of the storm to the end of the recovery phase.

The scatter diagram in Figure 2 shows the relation of the two time series for a group of 25 space storms: each point represents one storm. The least squares linear fit is also plotted in the diagram. The field yields a correlation coefficient of r=0.789.

4 Conclusions

The linear correlation method, as applied to the integrals of the squares of the SYM-H and AL indices, indicates that the energy density variation of space storms is highly correlated with the energy density variations of magnetosheric substorm (during the same time intervals). Accordingly, we conclude that substorms have the potential to influence storm development. We are currently extending our study to include more storms, in order to gain in statistical significance.

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