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Title: SUBSTORM STATISTICS: OCCURRENCES AND AMPLITUDES

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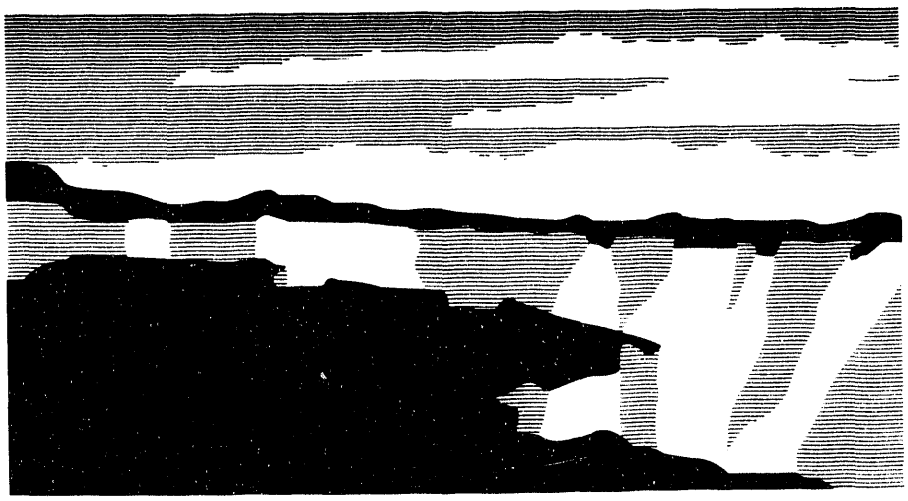
Submitted to: Proceedings of the Second International Conference on Substorms



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SUBSTORM STATISTICS: OCCURRENCES AND AMPLITUDES

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Abstract

The occurrences and amplitudes of substorms are statistically investigated with the use of three data sets: the AL index, the Los Alamos 3-satellite geosynchronous energetic-electron measurements, and the GOES-5 and -6 geosynchronous magnetic-field measurements. The investigation utilizes ~ 13,800 substorms in AL, ~ 1400 substorms in the energetic-electron flux, and ~ 100 substorms in the magnetic field. The rate of occurrence of substorms is determined as a function of the time of day, the time of year, the amount of magnetotail bending, the orientation of the geomagnetic dipole, the toward/away configuration of the IMF, and the parameters of the solar wind. The relative roles of dayside reconnection and viscous coupling in the production of substorms are assessed. Three amplitudes are defined for a substorms: the jump in the AL index, the peak of the >30-keV integral electron flux at geosynchronous orbit near midnight, and the angle of rotation of the geosynchronous magnetic field near midnight. The substorm amplitudes are statistically analyzed, the amplitude measurements are cross correlated with each other, and the substorm amplitudes are determined as functions of the solar-wind parameters. Periodically occurring and randomly occurring substorms are analyzed separately. The energetic-particle-flux amplitudes are consistent with unloading and the AL amplitudes are consistent with direct driving plus unloading.

1 Introduction

This manuscript is a summary of work that has been published for the most part in *Borovsky et al.* [1993] and that has been submitted for publication in *Borovsky and Nemzek* [1994] and *Borovsky et al.* [1994]. For details, the reader is urged to refer to these publications.

Described herein is a statistical study of the properties of substorms that utilized three data sets: (1) one year of Los Alamos geosynchronous energetic-electron-flux data from October 1982 - September 1983, (2) eight years of AL index from 1978 - 1985, and (3) several months of GOES-5 and -6 geosynchronous magnetic-field data from 1983. The criteria for spotting substorm onsets in the Los Alamos energetic-electron data are discussed in *Borovsky et al.* [1993] and the criteria for spotting substorm onsets in the AL index are discussed in *Borovsky and Nemzek* [1994]. The GOES magnetic-field data is not used to spot substorms, it is only used to measure substorm amplitudes.

The results of this study can be divided into two topics, substorm-occurrence statistics (which is the counting of substorms) and substorm-amplitude statistics (which is the measuring of substorms). The conclusions pertinent to these two topics are summarized in the two sections which follow.

2. Substorm-Occurrence Statistics

The conclusions about the occurrence of substorms gleaned from this statistical study are the following.

(1) Substorms occur in two fashions, randomly and periodically. (This notion is also addressed in *Belian et al.* [1994].)

(2) About 1500 substorms occur per year, which is about 4.1 per day on average. Some days may have as many as about 8 substorms and sometimes one or two days will pass with zero substorms occurring.

(3) There is a slight diurnal variation to the occurrence of substorms. The source of this variation has not been discerned, but as noted below it is not owed to gaps in the station coverage, to magnetotail bending, to a dawn/dusk tilt of the magnetic dipole, or to the Russell-McPherron effect.

(4) There is a ~14-day variation in the occurrence rate of substorms which appears to be related to the ~14-day variation of solar-wind stream structure.

(5) There is a seasonal variation to the occurrence rate of substorms. Winter, Spring, and Fall have approximately the same substorm-occurrence rates, but Summer has a lower substorm-occurrence rate.

(6) The coverage of the magnetometer ground stations that are used to produce the AL index and the coverage of the three Los Alamos geosynchronous satellites were statistically checked to determine whether substorms were being missed because they fell between stations. It is concluded that there are no longitudinal gaps in the coverage of either network. Note however that the networks might still miss substorms owing to latitudinal effects.

(7) The dependence of the substorm-occurrence rate on the amount of magnetotail bending (owing to the tilt of the magnetic dipole) was investigated. It was found that the dipole-tilt effect is slight, but substorms occur at a higher rate when the magnetotail is not bent (when the dipole is not tipped toward or away from the sun) than when the magnetotail is bent. These findings are in support the picture of Boller and Stolov [1970] and are

contrary to the predictions of Kivelson and Hughes [1990].

(8) The relationship between the tilt of the magnetic dipole and the toward/away nature of the solar-wind magnetic field is not clear. It is concluded that the Russell-McPherron effect [Russell and McPherron, 1973] does not strongly affect the rate of substorm occurrence.

(9) The substorm-occurrence rate depends on some of the parameters of the solar wind. The occurrence rate is sensitive to v, B_z, and vB_z of the solar wind, and the occurrence rate is insensitive to n, B, and nv^2. (The rate may also be sensitive to the amount of noise in solar wind magnetic field [e.g. Nemzek et al, 1993].)

(10) From substorm-occurrence-rate dependences on the value of the solar-wind parameters described in point (8) above, the statistical data is in support of substorm models that are based on substorm driving by dayside reconnection and the data is contrary to models that are based on substorm driving by viscous interactions. Hence, all of the major substorm models are supported, except the thermal-catastrophe model.

3. Substorm-Amplitude Statistics

The conclusions obtained from statistically analyzing the amplitudes of substorms are the following.

(1) The amplitude distribution function for substorms as measured by the jump in the AL index during the expansion phase is a Poisson distribution, implying that the AL amplitudes of substorms are randomly distributed. The amplitude distribution function for substorms as measured by the maximum amplitude of the >30-keV electron flux at geosynchronous orbit within ± 1.5 hours of local midnight can be fit with a line: this is not a well-known statistical distribution. The amplitude distribution function for substorms as measured by the rotation angle of the geosynchronous magnetic field during dipolarization appears to be a Poisson distribution, but there are too few substorms that have been measured to be certain.

(2) Because none of the substorm-amplitude distribution functions are power laws, it is implied that substorms are not manifestations of self-organized-critical phenomena (e.g. the sand-slide problem [Bak et al., 1988; Grumbacher et al., 1993]).

(3) Because the distribution function for substorm amplitudes as measured by the peak value of the >30-keV electron flux injected at geosynchronous orbit does not have a local maximum, there may be an inconsistency in the picture that energetic-electron fluxes

at geosynchronous orbit are limited by strong diffusion [Baker et al., 1979].

(4) Statistically, periodically occurring substorms have larger amplitudes than do randomly occurring substorms. This is true when substorm amplitudes are measured by the jump in the AL index, by the geosynchronous electron-flux level, and by the geosynchronous magnetic-field rotation. This is discussed further in *Belian et al.* [1994].

(5) When the three different measures of the amplitudes of substorms are cross correlated it is found that the jump in AL is moderately correlated with the geosynchronous field rotation and that the jump in AL is moderately correlated with the geosynchronous electron flux, but the geosynchronous field rotation is poorly correlated with the geosynchronous electron flux. The modest correlations indicate that the partition of energy varies from substorm to substorm.

(6) When correlations are sought between the amplitudes of substorms and the properties of the solar wind at the time of substorm onset, it is found that substorm amplitudes depend on the values of B_z and vB_z and that the amplitudes are independent of the values of n and B.

(7) The findings in point (6) above indicate that the substorm-amplitude statistics are in support of substorm models that are based on substorm driving by dayside reconnection and that the statistics are contrary to models that are based on substorm driving by viscous interactions.

4. Ongoing Substorm Work

Three projects that extend this statistical study are in progress. The first is an investigation of substorm occurrence during the passages of interplanetary magnetic clouds. Such cloud passages are of interest because the solar-wind magnetic field at earth is particularly quiet during such intervals and the southward or northward nature of the field can remain constant for tens of hours, which is much longer than the substorm-recurrence period. The second project is a superposed-epoch analysis of substorms at geosynchronous orbit using plasma data and energetic-particle data. With the Los Alamos geosynchronous data sets, the properties at geosynchronous orbit of substorms can be statistically studied for several local times and periodic and random substorms can be separately studied statistically. The third project is a classification of substorm AL-index signatures by self-organizing neural networks. Through this method the statistical properties of substorms will be studied and new criteria for identifying and typing substorms will be sought.

Acknowledgments. The authors wish to thank Dick Belian, Joachim Birn, Tom Cayton, John Craven, Jim Donart, Rick Elphic, Rob Elphinstone, Chris Goertz, Herb Funsten, Paul Hansen, Michael Hesse, Ed Hones, Cheryl Huang, Joe King, Alex Klimas, Trish Lemons, Bob McPherron, Mark Moldwin, John Phillips, Geoff Reeves, Gordon Rostoker, John Samson, Chuck Smith, and Loretta Weiss for conversations and help during the course of this work. J. B. would especially like to thank Ed Hones, Bob McPherron, and Gordon Rostoker for providing tutorial sessions on substorms. The GOES magnetometer data and the AL index were obtained from WGDC and NSSDC. This work was supported by the U.S. Department of Energy.

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