THE CHARACTERISTICS OF STORM-TIME SUBSTORMS AND NON-STORM SUBSTORMS

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ABSTRACT

It has been suggested that there may be a fundamental difference between substorms that occur during magnetic storms and those that occur at other times. Baumjohann presented evidence that there is no obvious change in lobe field in “quiet-time” substorms, but “storm-time” substorms exhibit the classic pattern of storage and release of lobe field energy [Kamide et al., 1997]. This result led him to speculate that the former is caused by current sheet disruption while the latter is caused by reconnection of lobe flux. In this paper we examine this hypothesis with a much larger data set using both his definition of the two types of substorms as well as additional more restrictive definitions of the classes of event. Our results show that the only difference between the various classes is the absolute value of the lobe field and the size of the changes. When the data are normalized to unit field amplitude we find that the percent change during storm-time and non-storm-time substorms is nearly the same. The above conclusions are demonstrated with superposed epoch analysis of lobe field (Bt and Bz) for four classes of substorms: active times (Dst < -50 nT, mostly recovery phase), main phase substorms, non-active times (Dst > -25 nT), quiet-time substorms (no evidence of storm in Dst). Epoch zero for the analysis was taken as the main substorm onset (Pi 2 onset closest to sharp break in AL index). These preliminary results were obtained using the position of the spacecraft to define the location of the plasma sheet. For a subset of the magnetic field data there is also plasma data. For this subset we separately examine events inside and outside the plasma sheet boundary as defined by plasma pressure. For events inside the plasma sheet we also infer the lobe field behavior from pressure balance. Our results suggest that there is no qualitative distinction between the various classes of substorms and so they are all likely to be caused by the same mechanism.

INTRODUCTION

The characteristic signature of a magnetic storm is a depression in the H component of the surface magnetic field lasting over some tens of hours. This depression is caused by the ring current circling the Earth in the westward direction and can be monitored by the Dst index. Most researchers believe that the ring current enhancement is at least partly associated with the injection of energetic particles associated with substorm expansion phase activity. Yet some substorms seem to have little effect on storm development. It has been suggested by Baumjohann et al. [1996] that most substorm tail signatures are greatly affected by magnetic storm activity. He proposed that several classical substorm expansion signatures in the near-Earth tail including magnetic field dipolarization and a lobe magnetic pressure decrease only occur during the main phase of a magnetic storm. Baumjohann et al. [1996] and Kamide et al. [1998] both speculate that the storm-time substorm may be a consequence of the inability of the distant neutral line to reconnect all the magnetic flux merged at the dayside magnetopause so that a surplus of magnetic flux accumulates in the tail lobe and then suddenly reconnects at a near earth neutral line. On the other hand they suggest that the non-storm substorm may be the result of instability in the near-earth region due to the strongly enhanced current flow associated with enhanced convection.

If this speculation were correct, current models of substorm activity would need significant revision. To examine the suggested difference in the tail signatures between storm-time substorms and non-storm substorms we use a procedure similar to that used by Baumjohann et al. [1996] to classify these two types of substorms. With these events the tail signatures will be examined to see whether any differences exist in these two classes.

STORM-TIME AND NON-STORM SUBSTORMS

In this study we use the substorm onset database developed by Hsu and McPherron [1996, 1998] to investigate possible differences between storm-time substorm and non-storm substorms. There are almost a thousand substorms onsets in this database, about five hundred of these were timed by both AL and Pi 2 pulsations. Using the Dst index, we separate these

![Figure 1: Schematic diagram showing the selection procedure used to define the four classes of substorm through their relation to magnetic storms.](image)
substorms into two classes, storm-time substorms and non-storm substorms. More refined subclasses of substorms are also defined for both classes: main-phase and active time substorms for storm-time substorms, non-active and quiet time substorms for non-storm substorms. Table 1 lists the criteria defining these subclasses.

Figure 1 illustrates schematically the event selection procedure. Three different lines are drawn in this figure at -50 nT, -25 nT and 0 nT respectively. The class of active time substorms includes all of the class of main phase events except substorms with Dst > -50 nT. The same thing applies to the quiet time substorms because all quiet time substorms satisfy the criterion of non-active substorms.

Table 1: Four classes of substorms defined by their relation to magnetic storms.

<table>
<thead>
<tr>
<th>Class</th>
<th>Subclass</th>
<th># Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm-time substorms</td>
<td>Main phase (in storm main phase)</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Active time (Dst&lt;50 nT; mostly recovery phase)</td>
<td>79</td>
</tr>
<tr>
<td>Non-storm substorms</td>
<td>Non-active (Dst&gt;25 nT)</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>Quiet time (without apparent storm disturbances)</td>
<td>44</td>
</tr>
</tbody>
</table>

TAIL FIELD IN STORM-TIME SUBSTORMS

Active time substorms are associated with a strong tail lobe magnetic field as evident in Figure 2. For the events used in the analysis, tail lobe was defined as the spacecraft being more than 3 Re from the expected neutral sheet location. Quartile lines show the result of superposing magnetic field data relative to substorm onsets. These lines show the classical substorm temporal behavior, i.e. tail energy storage prior to onset and release after onset. Also shown in Bz is the change from tail-like to more dipolar field [e.g. Hsu and McPherron, 1996, 1998, McPherron et al., 1993]. The magnitude of the changes in field for these active storm-time substorms is much larger than during typical substorms. The changes for main phase substorms (not shown) are more pronounced than the class of all active time substorms although the overall temporal features are the same. Stronger field changes during storm active times and main phase is not surprising. Magnetic storms occur after a prolonged, strong southward IMF.
energy storage and release. Thus there appears to be no qualitative differences between storm-time and quiet-time substorms however defined.

Figure 4 shows the superposed tail magnetic field for different classes of substorms to magnetic storm. It is obvious that the storm-time substorms have larger field changes than the quiet-time substorms, but the waveforms of the variation for the different classes are the same. This fact is more clearly seen by normalizing the data before superposing.

NORMALIZED TAIL MAGNETIC FIELD

To eliminate the possibility that an unusually large event dominates the superposed results we have normalized the data. For each event we find the maximum value of Bt and divide all values of Bt during the event by this value. For Bz we offset each trace so each curve was entirely negative and normalized by the magnitude of the minimum value of Bz. We then superposed the data relative to substorm onset as done before.

Figure 5 shows the results of superposing the normalized data. There is little qualitative difference in temporal behavior between storm-time and non-storm substorms in 45 minutes before and after onset. The only significant difference is that the normalized changes during storm-time substorms start at a slightly higher level than they do during non-storm substorms. This is not unexpected as storm-time substorms occur during continuous activity while non-storm substorms are more isolated.

RESULTS USING PLASMA DATA

In the preceding discussion we defined tail lobe data by the spacecraft being located at a distance |Zns| > 3 Re.
With this definition it is possible that the spacecraft is in the plasma sheet at either the beginning or end of the event. In such cases the diamagnetic effects of the plasma would bias the field to weaker values causing the superposed field to appear small relative to the field at onset. To eliminate this possibility we have selected substorm events from our list for which plasma data were available and the spacecraft was clearly in either the plasma sheet or the lobe. The criterion for making this distinction was that used by Angelopoulos et al. [1994], i.e. whether the plasma pressure was greater than (0.01 nP) [plasma sheet], or less than this value [tail lobe]. The requirement that there be simultaneous plasma data significantly reduces the number of events available. To make this number as large as possible we have made two compromises. First we considered only the two classes of substorms originally defined by Baumjohann rather than the four classes discussed above. Second we have allowed occasional encounters of the plasma sheet to occur in each event. For lobe events we allowed as many as 30% of the samples to have \( p > 0.01 \) nP, and similarly allowed up to 30% of the plasma sheet samples to be lobe data. In both cases we used lobe field magnitude inferred from the total pressure in our superposed epoch analysis of \( B_t \).

The results of normalizing and superposing these data are presented in Figure 6. Results for non-storm substorms are shown on the left and for storm-time substorms on the right. In each panel the dashed trace corresponds to lobe data and the solid trace to plasma sheet data (more events). For plasma sheet data the total pressure was used to infer \( B_t \) in the lobe. For \( B_z \) the measured field was used in either the lobe or plasma sheet. Clearly this more precise definition of plasma sheet and lobe does not alter the conclusion that both types of substorms exhibit tail lobe energy storage and release and the development of a tail-like field followed by dipolarization.

**DISCUSSION**

*Baumjohann et al.* [1996] performed a superposed epoch analysis to determine the behavior of the tail magnetic during storm-time substorms and non-storm substorms. Their results seemed to show that substorms during storm-time and non-storm-time behave differently. His storm-time substorms exhibited the typical substorm tail features, i.e., loading of tail energy during growth phase, energy release after substorm onset, and the dipolarization at substorm onset. However, substorms during quiet times did not show an increase and decrease in the tail lobe field. These results led to speculation that substorms might be caused by two different mechanisms Near-earth reconnection for storm-time substorms [e.g. *McPherron et al.* 1973; *Hones*, 1984] and current sheet disruption for the non-storm substorms [e.g. *Lui et al.*, 1988]. However, our study was not able to reproduce the results of *Baumjohann et al.* [1996]. Both classes of substorms display the typical substorm features as *Hones et al.* [1984] described. In terms of absolute values and changes of magnitude the storm-time substorms are larger. However, after normalization (Figure 5) we found that the storm-time substorm does not differ significantly from non-storm substorms. This suggests that both storm-time substorms and non-storm substorms are caused by the same mechanism. We conclude that storm-time substorms are much stronger than non-storm substorms, but it is unlikely that there are two different types of mechanisms responsible for storm-time and non-storm time substorms.

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**REFERENCES**


