Magnetic Field Variations in the Near Geomagnetic Tail Associated with Weak Substorm Activity


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Magnetic field observations obtained with the UCLA Ogo 5 fluxgate magnetometer on an inbound pass, during which the satellite remained close to the magnetic meridian and traveled almost parallel to and approximately 2 Re above the expected position of the neutral sheet, are used to illustrate the variations in the configuration of the tail field during weak substorm activity. Beyond 10 Re from the earth, changes to dipolar fields are accompanied by a reduction in field strength presumably due to plasma sheet expansion. Within approximately 10 Re changes to a more dipolar field are accompanied by no change or by an increase in field strength. In both regions, these changes are accompanied by turbulence or noise. Occasional twisting of the field out of the usual magnetic meridian is also observed.

Magnetic field measurements taken with the synchronous equatorial satellite ATS 1 show that the magnetic signature of the expansion phase of a substorm as observed at 6.6 Re on the night side of the earth is an increase in the magnitude of the field from a depressed state accompanied by a return to a more dipolelike field [Cummings et al., 1968; Lezniak and Winckler, 1970]. Changes in the configuration of the magnetic field in the geomagnetic tail in the region from 25 to 33 Re behind the earth at times of auroral zone activity were recently described by Fairfield and Ness [1970]. They find that close to the expected position of the neutral sheet these changes consist of a gradual increase of field magnitude, probably associated with a thinning of the plasma sheet, followed by a rapid decrease of the field magnitude, presumably as the plasma sheet expands. Simultaneous with this decrease the tail field becomes more dipolar. Thus, the signatures in the tail and at synchronous orbit are similar in the return to a dipole-like field but are different in the behavior of the field magnitude. Studies have also been made by Heppner et al. [1967] with data from the Ogo 1 magnetometer in this region and by Camidge and Rostoker [1970] with data from the Imp 1 and 2 magnetometers obtained between 12 and 32 Re behind the earth. The first study considered the relative timing of events without examining the changes in field configuration; the second study considered the configuration changes coincident with substorms identified from ground-based magnetograms.

Our main purpose here is to illustrate with data from one inbound pass of the Ogo 5 satellite the 'substorm-related' behavior of the magnetic field between the regions covered by the ATS 1 and Imp 4 observations, and to demonstrate that configuration changes occur even in the absence of well-developed substorm activity.

**Observations**

Figure 1 shows 1-min averages of the three components of the magnetic field in the geocentric solar magnetospheric (GSM) coordinate system as measured by the UCLA Ogo 5 fluxgate magnetometer from 1600 UT on August 9 to 0300 UT on August 10, 1968. The satellite was close to the noon–midnight meridian on this pass, staying just above the expected position of the neutral sheet [Russell and Brody, 1967] as the X GSM position of the spacecraft changed from $-16.7$ to $-6.5$ Re. The position of the spacecraft and the expected position of the neutral sheet during the period of interest are given in Table 1.

Figure 1 shows four events of the type described by Fairfield and Ness [1970]. Using the
Fig. 1. One-min averages of the magnetic field in the geocentric solar magnetic (GSM) coordinate system on an inbound pass of the Ogo 5 satellite on August 9 and 10, 1968.

Figures 2 and 3 show the same data expressed in terms of the difference in field magnitude between the measured field and the main field of the earth $A_{LB}$, the inclination and declination of the field as described by Mead and Cahill [1967] together with the $B_z$ GSM component and the total rms deviation of the field. The inclination is simply the complement of the angle between the measured field and the radius vector from the center of the earth to the satellite. The declination is the angle between the component of the field perpendicular to a radius vector and the dipole north pole. It is measured clockwise looking toward the center of the earth. This angle measures the twisting of the field out of the dipole magnetic meridian. The rms deviation is the square root of the sum of the powers in each of the three vector components in the frequency range from $0.07 \text{ Hz}$ to the Nyquist frequency, and is calculated every minute. Throughout most of the interval studied in this paper the Nyquist frequency was $0.43 \text{ Hz}$. This


$Z_{ns}$ is the expected height of the neutral sheet above the GSM equator at that $Y$ GSM position of the satellite. $Z-Z_{ns}$ measures the expected distance of the satellite from the neutral sheet.

<table>
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<tr>
<th>Time, UT</th>
<th>$X$</th>
<th>$Y$</th>
<th>$Z$</th>
<th>$Z_{ns}$</th>
<th>$Z-Z_{ns}$</th>
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<td>0.4</td>
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</table>
rms deviation is an invariant of the coordinate system.

Figures 2 and 3 show that the field magnitude does not decrease below the main field value until 0120 UT, when the X GSM coordinate is $-9.1 R_E$. Thereafter, the field becomes more and more depressed relative to the main field even though the measured total field is continually increasing. The inclination shows the rapid change to a more dipolelike configuration at each event followed by a slow redevelopment of a tail-like field before the next event occurs. The inclination signature is quite variable, however. The inclination begins to recover very shortly after the start of the first event, whereas in the second event the depression does not recover for over an hour. In the third event, the inclination does not become dipolelike at all and remains at a constant but depressed value for about a half-hour. The final event shows two decreases of inclination, and the inclination never recovers to a tail-like field.

The declination in general appears to be decoupled from the variations in the field magnitude and the inclination. In association with the four events described above, there are fluctuations of about 40° as the inclination decreases. During the fourth event, these declination fluctuations are much smaller. However, the major changes in declination occur when the field is

![Graph](image_url)
otherwise relatively steady. For example, there are three negative declination enhancements starting at 1800, 1855, and 1955 UT between events one and two. At 0030 UT there is a positive enhancement preceding the fourth event. These declination changes may be similar to the 'D-spikes' observed on the ATS satellite attributed to field-aligned currents [Cummins et al., 1969; McPherron and Coleman, 1970].

We also note that the rms deviations indicate the presence of noise at the start of each event, which appears to decrease in intensity closer to the earth. However, one should keep in mind that our sample is limited. The three declination enhancements between events one and two are also associated with higher frequency fluctuations, but of much smaller amplitude.

Figure 4 shows a higher resolution plot of the vector field in the GSM coordinate system from 1700 to 1735 UT. The fluctuations are quite irregular, with no predominant frequency component. The amplitudes in all three vector components are similar. At this time the satellite was recording at its lowest telemetry rate, providing one field sample every 1.152 sec.

The last of the four events that mark the entry of the satellite from a tail-like region into the magnetosphere proper differs from the other three in some respects. The first apparent difference is probably due to the fact that temporal changes are superimposed on changes due to the satellite motion through spatial gradients. Referring to Figure 3, we see that starting about 0105 UT $\Delta|B|$ began to decrease slowly toward the depressed condition characteristic of the nightside magnetosphere [see Sugiuura et al., 1970] and that the inclination and declination

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**Fig. 3.** Same as Figure 2 for the period 2130 to 0305 UT.
began to slowly change to a more dipolar state. These changes are probably those due to motion through spatial gradients. Then there are two stages of rapid change in the inclination and the $B_z$ component. These changes are probably temporal.

The second difference is that in contrast to the behavior at larger radial distances there is no rapid decrease in the depression of the field accompanying the first of the two rapid changes in $B_z$ and the inclination. In fact, the second rapid change in $B_z$ and the inclination is accompanied by a recovery of the field magnitude. Such an increase in field magnitude at the time

![Graph showing vector field in GSM coordinates](image)

**Fig. 4.** A high time resolution plot of the vector field in GSM coordinates from 1700 to 1738 UT of August 9, 1968, showing the turbulent entry into the plasma sheet.

![Location of Sodankyla, Leirvogur, and Great Whale River](image)

**Fig. 5.** The location of Sodankyla, Leirvogur, and Great Whale River relative to the normal auroral zone at four times during the satellite pass.
of the relaxation from a tail-like field is a common signature at the ATS orbit [Cummings et al., 1968].

The positions of three auroral zone observatories, Sodankyla, Leirvogur, and Great Whale River, at the time of these four events are shown in Figure 5. Figure 6 shows $H$, $D$, $Z$ as traced from the magnetograms of these three stations. At the time of the first event, these stations are at relatively poor positions to observe auroral substorm effects. However, if large substorms occurred for the last three events, a typical substorm signature should have been evident at one or more of these stations. We do see continual activity throughout this period, and there are features associated with each of these last three events in the magnetograms, but the activity is weak. Thus we must conclude that the auroral oval was more poleward than usual and/or that these events are associated with weak auroral zone activity.

**Summary and Conclusion**

From this one pass of the Ogo 5 satellite we see that the variations of the configuration of the geomagnetic tail observed by Fairfield and

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![Image of magnetograms from Sodankyla, Leirvogur, and Great Whale River during the satellite pass. The onset of the four events at the satellite at 1705, 2010, 2250, and 0120 are indicated by the arrows labeled 1, 2, 3, and 4, respectively.](image-url)
Ness at 25 $R_\odot$ behind the earth are indeed seen as close as 10 $R_\odot$. However, as the satellite enters the region in which the total field is less than that due to the main field, the substorm signature becomes more like that observed at ATS. The observed changes to a more dipolelike configuration are accompanied by irregular fluctuations in the field at frequencies below the proton gyrofrequency. Data from the Ogo 5 search coil magnetometer at these times show no ELF activity from 10 to 1000 Hz (R. E. Holzer, personal communication). These changes of field configuration can occur as frequently as every 3 hours even at what we would usually call quiet or only moderately disturbed times upon examining normal auroral zone magnetograms.

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