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MULTISATELLITE INVESTIGATIONS OF SUBSTORM ONSETS

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ABSTRACT

Substorm onsets, identified by Pi2 pulsations observed on the AFGL Magnetometer Network, have been studied using ISEE 1 electric and magnetic field data and GOES 2 and GOES 3 magnetic field data. The relative positions of the spacecraft with respect to the substorm current system were determined from the Pi2 polarizations. One onset occurred when ISEE 1 and GOES 2 were on the same field line but in opposite hemispheres. During this onset ISEE 1 and GOES 2 observed magnetic signatures which appear to be due to conjugate field-aligned-currents flowing out of the western edge of the westward electrojets. A broadband burst of wave noise was seen in the ISEE 1 electric field at the same time as field-aligned-currents were observed. These may be current driven ion cyclotron waves. A three minute perturbation in the electric field data prior to the initial substorm onset indicates that there was an azimuthal westward flow of plasma starting ∿ 1 min before the substorm onset.

INTRODUCTION

Our understanding of magnetospheric substorms has been vastly improved with the advent of satellites which can make in situ measurements in the magnetosphere and ground based radars which provide plasma and electric field data of the ionosphere /1/. Modelling the ionospheric processes has helped infer what should occur in the magnetosphere. Unfortunately ionospheric electric fields cannot be mapped along field lines in the auroral zones owing to the large parallel electric fields which decouple the ionosphere and magnetosphere. Satellites also have a problem in that they can only make localized measurements in a volume which is enormous. As it is not yet possible to accurately predict when or where a substorm will take place we must rely on our instruments being in the right place at the right time.

There is increasing evidence that much of the time substorms are limited in local time and do not affect the tail across its entire width /2/, /3/, /4/. In this paper we describe a substorm onset whose spatial location we could determine from midlatitude Pi2 polarizations /5/, /6/. This enabled us to locate the spacecraft within the region of substorm activity, which is impossible to do using spacecraft data alone.

OBSERVATIONS

The onset described here occurred at ∿ 0430 UT on 1 July 1979 at which time ISEE 1 was in the LT sector spanned by the AFGL Magnetometer Network and near local midnight. Figure 1 shows the positions of ISEE 1, GOES 2 and GOES 3 and the longitudinal extent of the AFGL chain. At 0430 UT, ISEE 1 and GOES 2 are, as near as can be determined, on the same field line but are in opposite hemispheres.

Figure 2 shows all the data used in this study. The top two panels show band pass filtered (4-25 mHz) AFGL magnetometer data /7/. Hodograms made from this data (not shown) were used to identify 7 Pi2 pulsations with distinct polarization patterns. The vertical lines in Figure 2 indicate the start times of these pulsations. Although no bay structure was observed on the ground, the central meridian of the current system can be identified using the major axis of the Pi2 hodograms /5/. Events 1, 2, 5, 6 and 7 have their central meridian toward the west of the Network somewhere between Rapid City and Mt. Clemens. Event 4 appears to be centered at Sudbury at the eastern end of the Network while event 3 could be either to the west of Rapid City or east of Sudbury. (Since no significant activity occurred at GOES 3 we infer it to be the latter case.) After 0509 UT the pulsation activity becomes too complicated to interpret.

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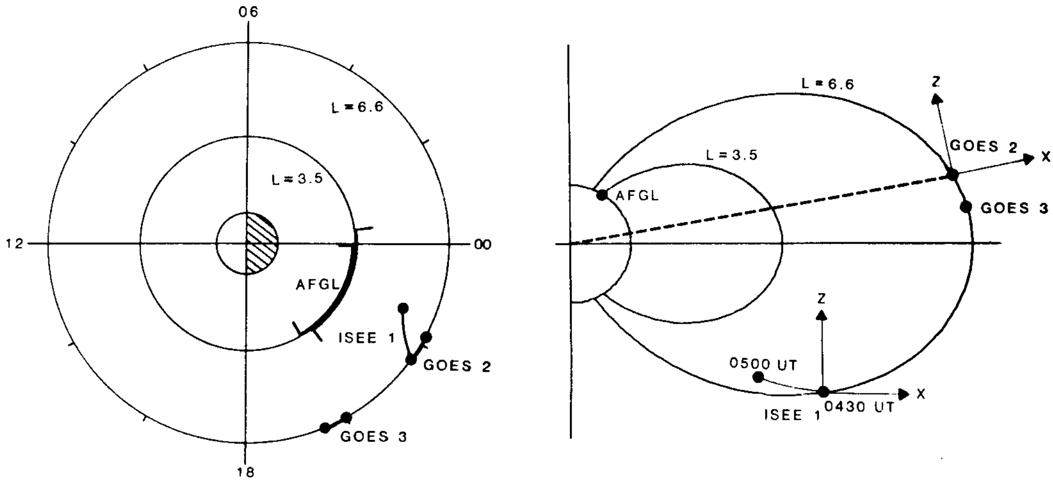

Fig. 1. Positions of the spacecraft and ground stations used in this study in L-shell/magnetic local time (left) and radial distance/magnetic latitude (right).

The largest perturbations in the ISEE 1 magnetic field, shown in the third panel, are in B_y and B_z, so are perpendicular to $\underset{\sim}{B}$ and are signatures of field-aligned-currents (FAC). Two major perturbations, each lasting 10-15 min, occur. The first starts at 0431 UT coincident with the first Pi2 on the ground; subsequent changes in slope, especially of B_y, coincide with changes in Pi2 polarization on the ground (lines 2, 3 and 4). The second major perturbation begins at 0505 UT coincident with the last Pi2 onset. The B_y perturbations at 0431 and 0505 UT have opposite polarity -- the first is a negative perturbation indicating a current flowing out of the southern hemisphere ionosphere while the second is positive and therefore due to a current flowing into the ionosphere. This helps to demonstrate the localized nature of these events.

The ISEE 1 electric field, shown in the fourth panel, shows a marked increase in its "noise" level at the time the FAC signatures are observed in the magnetic field. This noise, of which only the lowest frequency part is visible here, is observed over four decades of frequency. Its power peaks in the 3-14 Hz range near the ion gyrofrequency so it may be the result of current induced ion cyclotron instabilities. About one minute before the 0431 UT onset there is a $\sim$ -10 mV/m perturbation in E_z which lasts for $\sim$ 3 minutes. This electric field signature indicates that there is a westward flow of plasma. Similar but smaller signatures can also be seen at 0500 UT and 0505 UT. (These signatures are more easily identified in 15 s averaged data.) Integrating under the curve around 0430 shows that the total plasma displacement is $\sim$ 700 km.

The bottom three panels of Figure 2 show magnetometer data from the geosynchronous spacecraft GOES 2 and GOES 3 /7/. The field at GOES 3 remains relatively quiet throughout this interval which means that the substorm activity was localized west of GOES 3 (cf. Figure 1). The gradual decrease in inclination is due to the spacecraft moving into a more taillike field as it approached midnight. GOES 2, on the other hand, sees more activity. At 0431 UT, when GOES 2 and ISEE 1 are located on the same field line but in opposite hemispheres, the field at GOES 2 begins to become more taillike and a positive perturbation in B_y begins, coincident with the onset on the ground and at ISEE 1.

The B_y components at ISEE 1 and GOES 2 are reproduced in Figure 3 with the GOES 2 data inverted. Except for being of opposite sign, they have a strikingly similar shape until $\sim$ 0445 UT. If the spacecraft are earthwards of the substorm current system, these magnetic perturbations are consistent with the signatures of conjugate FACs flowing out of the western edge of a westward electrojet and presumably connecting with the cross tail current beyond the spacecraft position, as is pictured in Figure 4.

The ISEE 1 B_y and B_z perturbations between 0431 UT and 0437 UT are reminiscent of the magnetic signature of a line current moving past an observer. If we assume that this is a FAC whose foot is connected to a westward travelling surge moving westward with a velocity of 1-2 km/s, calculations using an infinite line current approximation indicate a total current of 0.5 - 1×10^6A whose closest approach to ISEE 1 is 0.3-0.7 R_E.

Spectral analyses of the data showed that the ground Pi2s have a period T $\sim$ 115 s whereas the only significant peak in the ISEE 1 B_x and B_z components occurred at T $\sim$ 85 s. The ISEE 1 signal, which can be clearly seen in Figure 2, had a strong compressional component

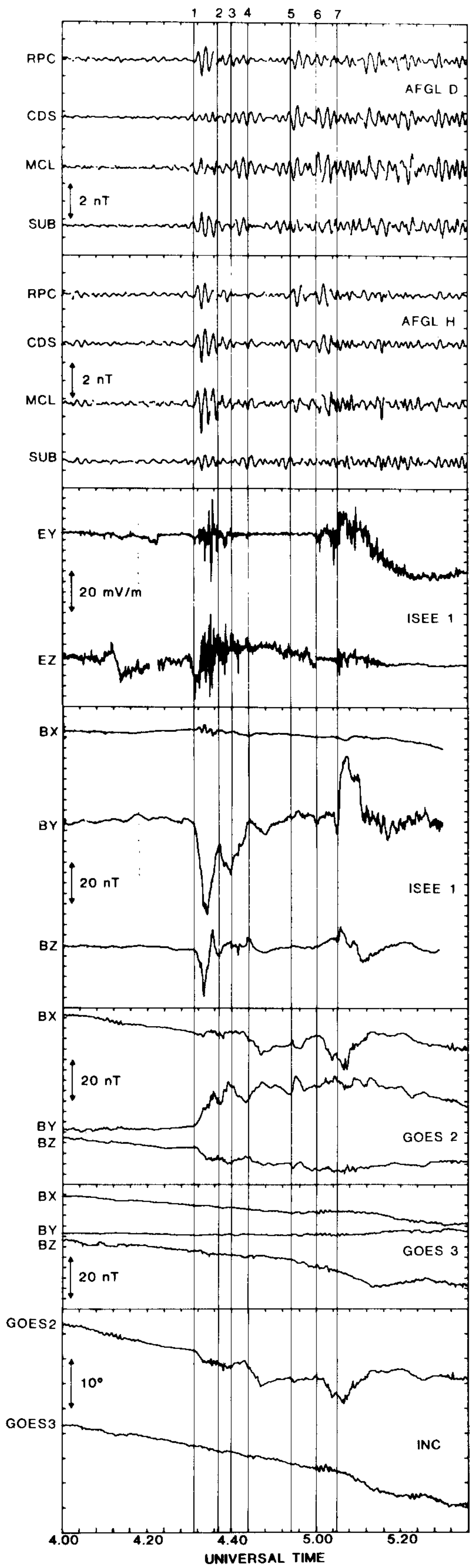

Fig. 2. Data illustrating the succession of substorm onsets or intensifications on 1 July 1979. The top two panels show band pass filtered (4-25 mHz) AFGL magnetometer data /7/. The third panel shows ISEE 1 magnetic field data /7/. A background field (determined using a sixth order polynomial least squares fit to 13 data points chosen during undisturbed times) has been removed from the magnetic field data, so the traces shown are perturbations on the background field. The background field happens to be almost exactly parallel to the x axis in this co-ordinate system which has z anti-parallel to the Earth's dipole axis, x radially outwards and y eastwards. The fourth panel shows ISEE 1 electric field data in the same coordinates. The data has been rotated into these coordinates assuming $\underset{\sim}{E} \cdot \underset{\sim}{B} = 0$. E_x is negligible and is not shown. The gradual drift of the E_y baseline after 0500 UT is due to incorrect removal of the effects of spacecraft motion. The bottom three panels show magnetometer data from the geosynchronous spacecraft GOES 2 and GOES 3 /7/. The coordinate system used has z parallel to the Earth's spin axis, x radially outwards and y eastwards. The lowest panel shows the field inclination, defined as $\tan^{-1}(B_z/B_x)$, at GOES 2 and GOES 3. It provides a measure of how taillike or dipolar the field is at geostationary orbit -- an increase in inclination indicates a change to a more dipolar configuration. The vertical lines indicate times of midlatitude Pi2 polarization changes observed with the AFGL Magnetometer Network.

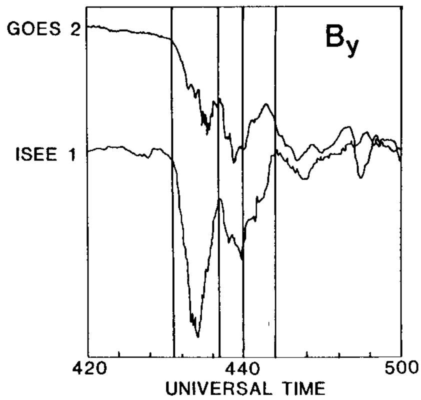

Fig. 3. Azimuthal magnetic perturbations observed by ISEE 1 and GOES 2. The GOES 2 data has been inverted. The vertical lines mark changes in midlatitude Pi2 polarization (cf. Figure 2).

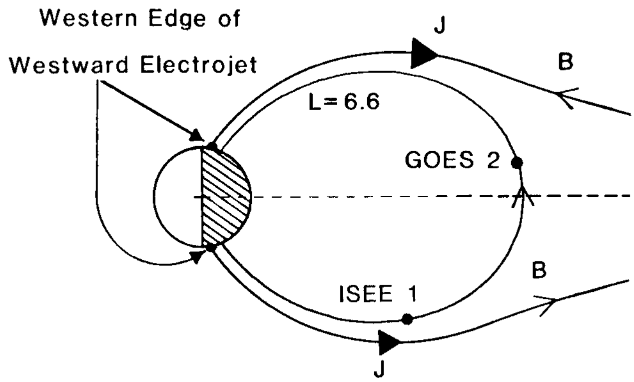

Fig. 4. A cartoon illustrating a possible reason for similarity of the traces shown in Figure 3, which could be because GOES 2 and ISEE 1, which are on the same field line, are observing conjugate field-aligned-currents.

but did not occur again after the initial onset. No peaks were evident in the GOES 2 spectra. The ISEE 1 electric field spectra do not have any dominant peaks but the shorter periods contain proportionally much more power than the magnetic field. It is surprising that there is no significant power at a period of 85 s as in the magnetic field, since we expect these pulsations to be Alfven waves. Given the measured magnetic signal we expect an electric field of $\sim$ 4 mV/m for a travelling Alfven wave. As it is unlikely that ISEE 1 is near an electric field node of a standing wave we conclude that the other signals present mask the electric field components of the Alfven waves.

CONCLUSIONS

To summarize, we observed:

(1) simultaneous substorm onsets on the ground and in space
(2) conjugate field-aligned current flow out of the ionosphere in space
(3) increase in electric field noise spanning four decades when FAC are observed
(4) azimuthal plasma flow lasting $\sim$3 min and starting $\sim$1 min before substorm onset
(5) different ULF frequencies in space and on the ground

Although conjugate FACs in space have been used in substorm models for many years and electric field "noise" associated with FACs comes as no surprise, their observation has not been reported before. However, more work is needed to understand why substorm onsets occur simultaneously on the ground and in space rather than delayed by the Alfven travel time. Further observations of azimuthal plasma flows at onset are required to understand its connection with the substorm process. It may for instance be related to the IMF compressing the magnetospheric cavity prior to substorm onset.

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