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DYNAMICS OF THE MAGNETOSPHERIC MID-TAIL INDUCED BY SUBSTORMS; A MULTISATELLITE STUDY

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ABSTRACT

The dynamics of the mid-tail region during substorms is examined using multi-satellite measurements. This study shows that partial cross-tail current disruptions detected at radial distances of the order of 20 to 30 earth radii in the anti-solar direction, linked with a gross-scale decrease of the magnetic field of the tail, correspond to substorm onsets. The period which preceedes the onset is associated with a lobe magnetic field increase which is either due to an enhanced reconnection, as evidenced by concurrent southward turnings of the interplanetary magnetic field, or/and to an increase of the solar wind pressure. These two effects are shown to act together to the thinning of the plasma sheet which leads to substorm onset. It is also shown that multiple substorms can occur during an overall increase sequence of the magnetic field of the tail, which can be interpreted in the context of the control of the lobe magnetic field by the solar wind properties.

INTRODUCTION

Assessing the dynamics of the magnetosphere-ionosphere system during substorms has motivated a number of studies in the recent years (e.g 1/-/12/). During periods of southward directed interplanetary magnetic field, when the solar wind powers the magnetosphere through the magnetic reconnection process, the role of the cross tail current sheet has been recognized as fundamental to the energy storage, plasma energetization and magnetic field reconfiguration. However, the nature of the instability which causes the stored energy to be dissipated during substorms in the inner magnetosphere and in the upper atmosphere is still unresolved.

The partial disruption of the cross-tail current sheet is directly linked with substorm onsets detected as break-ups of auroral forms in the ionosphere and as the impulsive acceleration of energetic particles in the near earth plasma sheet. Electromagnetic energy is here suddenly converted to particle energy through induced electric fields resulting from the relaxation of the magnetosphere toward a low energy state. Plasma dynamics linked to substorm events, such as the injection/acceleration of particles toward the inner magnetosphere, the antisolar ejection of plasma bubbles from the far tail, the formation of double auroral ovals have been clearly established. However, the links between such processes are still not clearly understood.

It thus appears an an important topic to identify the behaviour of the mid-tail during substorm periods and i) to establish its links with the dynamics of inner and far tail, and ii) to distinguish processes directly driven by the solar wind from processes where stored energy is dissipated inside the magnetosphere. This is the aim of this multisatellite study.

RELATION BETWEEN IMF, SUBSTORMS AND CROSS TAIL CURRENT DISRUPTIONS

August, 22, 1983

Mutisatellite measurements can help to clarify the relationship between various processes linked to substorms. Such a study has been undertaken using the data obtained on August 22, 1983 in auroral ground stations, onboard several satellites: ISEE-1/2 in the solar wind, IMP-8 in the tail lobe, the LANL 1977-007 satellite at geosynchronous orbit and ISEE-3 in the far tail/solar wind interface (250 R_E from the earth). Here for simplicity reasons we will not discuss the data obtained onboard the ISEE-3 satellite.

Figure 1 gives from the top to the bottom, during the time interval 18:00 to 21:30 UT, i) the B_Z component of the interplanetary magnetic field measured in the solar wind onboard ISEE-1, ii) the intensity of the tail lobe magnetic field measured onboard IMP-8 located at R= 37 R_E and , MLT = 01H, and iii) the auroral electrojet index variations. Data from the ISEE-1 Fast Plasma Analyzer (not shown) indicated that the solar wind pressure was nearly constant during this time interval. The IMF showed a strong southward component from 18:05 to 20:15 UT. The magneto hydrodynamic coupling between the solar wind and the magnetosphere was thus expected to be strong during this period. Estimation of the poynting energy flux $VB^2 \sin^4(\theta /2) l_0^2$ resulting from magnetic reconnection lead to values of the order on 1 to 4 10 ^{18} erg/sec which according to the works of Akasofu /13/, /14/ is above the level necessary to trigger substorms inside the magnetosphere. This conclusion is confirmed by the very high level of the AE index which continuously increased between 18:20 and 20:14 UT. Inside the tail lobe, the magnetic field was also increasing during the period of southward directed interplanetary magnetic field, however, at 20:12UT, in coincidence with a further increase in the AE index the tail lobe field was strongly reduced which according to Jacquey et al. /7/, /8/ and Jacquey and Sauvaud /11/ indicated a partial cross-tail current disruption. The lobe B field decrease reached about 13 nT, i.e. about 45% of the pre-disrupted field. Note that thisl decrease occurred when the IMF was still southward directed.

Figure 2 gives some insight of the behaviour of the inner magnetosphere during the time interval 19:00 to 21:00 UT for the same day. At the top and at the bottom, the flux of the electrons measured near midnight at the geosynchronous orbit onboard the 1977-007 satellite presented with different scale in order to stress the large scale changes and smaller injections. The middle panel shows the $|B_X|$ and B_Z components of the tail lobe field which show the classical B_X decrease beginning around 20:08 UT in association with the V shaped structure of the B_Z component, and coincident with a double ion injection at the geostationnary orbit occurring at 20:03 and 20:06 UT. The time delay separating the ion injections at 6.6 R_E and the B_Z minimum at IMP-8 which signals the passage of the cross-tail current partial disruption under the satellite is on the order of 8 to 11 minutes. Considering that the cross-tail disruption is initiated much closer to the geosynchronous orbit than to IMP-8 as shown by Jacquey et al., 1993, and given the satellite separation along the X axis, this gives an aproximate propagation velocity of of the cross tail current disruption front between 274 and 377 km/s.

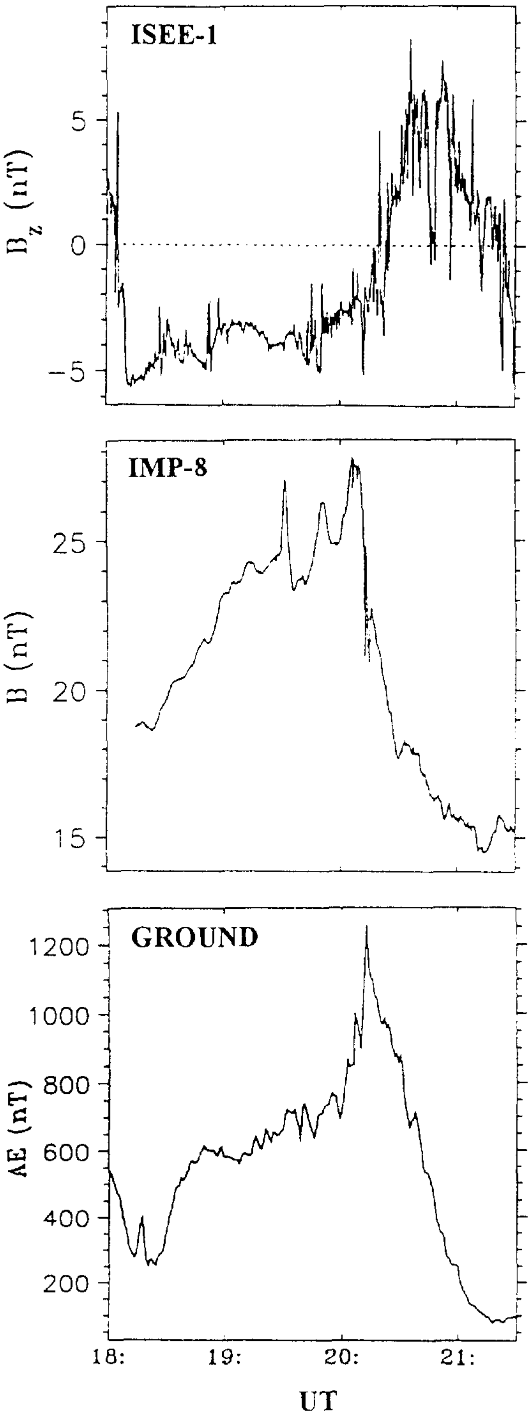

Fig. 1: August, 22, 1983. Top: Solar wind magnetic field B_Z component (ISEE), middle: Lobe magnetic field (IMP-8), bottom: Auroral Electrojet index.

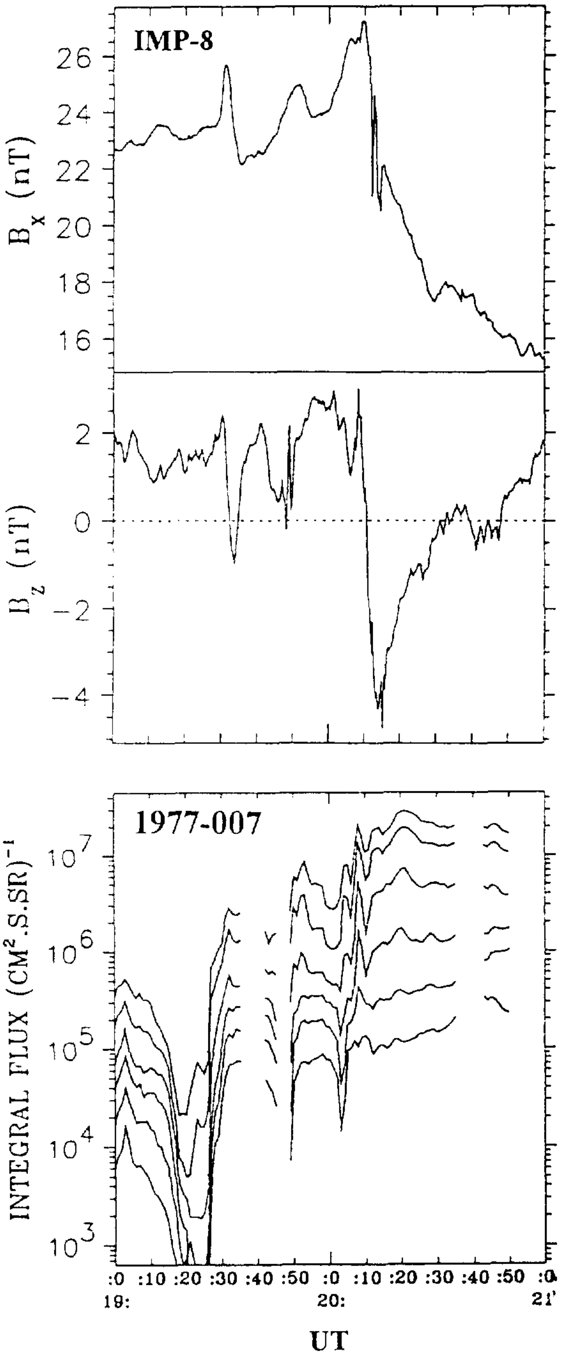

Fig. 2: August 22, 1983.Top panels: |BX| and BZ components of the magnetic field in the tail lobe (IMP-8), bottom panel: Integral fluxes of ions with energies higher than 147 keV at 6.6 R_E near the midnight (1977-007).

It must be stressed that during the preceeding period, several substorm associated injections are detected at 6.6 R_E. The first one correspond to a flux recovery occurring at 19:26 UT. Nearly simultaneously, a magnetic field pulse is recorded inside the magnetotail lobe. Figure 3 gives the result of a principal axis analysis.

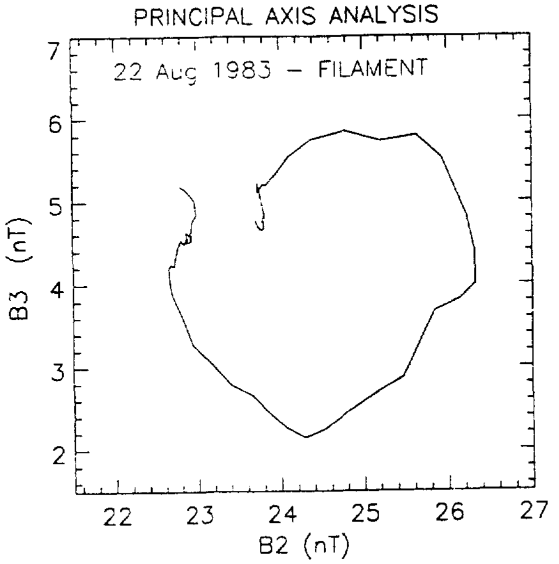

Fig. 3: Hodogram of the main magnetic components of the current filament detected around 19:30 UT onboard IMP-8 (see Fig. 2)

The signature is that of a current filament directed from dawn to dusk which result in a circular and nearly closed contour of the magnetic field. The difference in time between the plasma injection and the maximum of the tail B field which signals the passage under IMP-8 of the current filament is 7.5 minutes. A fit of the data has been performed with a current filament directed from dawn to dusk. We suppose the transverse size of the filament is small compared to the distance from the satellite to the neutral sheet i.e.5.5 R_E. The total current reache 1.3×10^6 A and the tailward propagation velocity is of the order of 500 km/sec, the filament is found to be formed at about 11 R_E from the satellite, i.e. at 24 R_E from the earth.

Finally note that another flux rope is detected around 19:50 UT corresponding not to a plasma injection but more probably to a plasma dropout seen at geosynchronous orbit.

To conclude this case study, we can state that current disruption is correlated with a plasma injection, occurs first close to the earth, in the vicinity of the geostationnary orbit and propagates tailward. During the preceding period the lobe magnetic field is increasing and the IMF is southward directed. Several substorms occur during this "growth phase" period. They are related to plasma injection/dropouts at the geostationnary orbit and are associated with tailward propagating current filaments, directed along the Y axis. A possible interpretation of such filaments is that they result from a partial current disruption occurring close to the earth which does not developp completely. In that case, the decrease in the current density does not allow anymore the $\mathbf{j}\times\mathbf{B}$ force to balance the $-\nabla \mathbf{p}$ force which can drag the plasma and current toward the tail.

As the tail lobe field was globally increasing during the period 18:30 to 20:00 UT, we can conclude that during the period of strong coupling between the solar wind and themagnetosphere preceeding the cross-tail current disruption, the energy input was higher than the loss of electromagnetic energy due to plasma injection and to the ejections of current filament. This eventually led to the cross-tail current disruption of ≈ 20:03-20:06 UT.

August,10, 1986

Here the AMPTE/CCE satellite was located in the plasmasheet near its apogee when IMP-8 was in the mid-tail north lobe. During the period extending from 04:00 to 09:00 UT two successive weak increases of the tail lobe B field were registered. Figure 4 focuses on the second event. From the top to the bottom, the B_X and B_Z components of the B field at IMP-8 located at 32 R_E in the evening sector (22.7 H MLT) and 9.6 R_E above the neutral sheet. The middle panel shows the B_X and B_Z components of the magnetic field at AMPTE located near

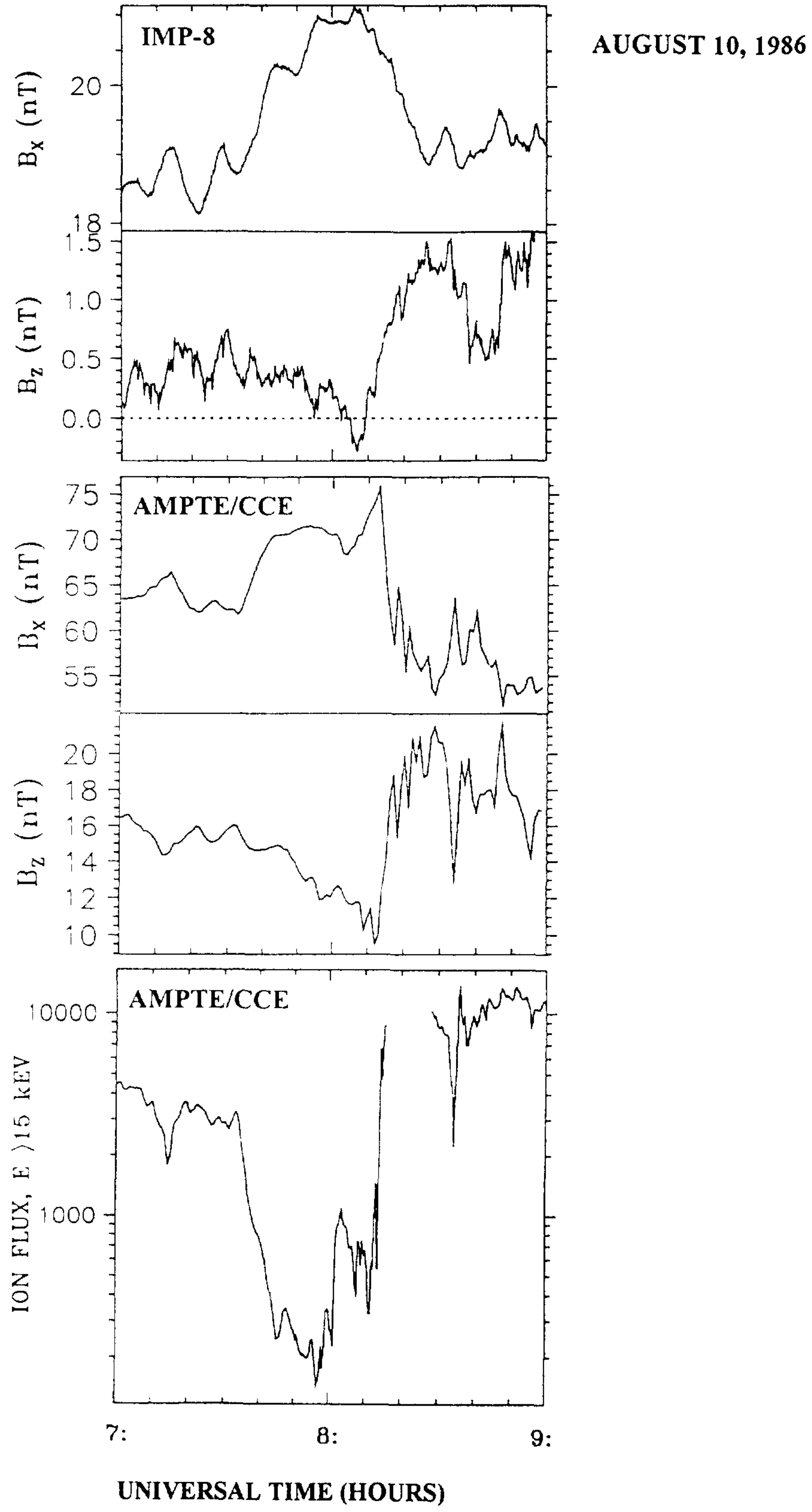

Fig. 4: Top panel: B_X and B_Z GSM components of the lobe B field measured onboard IMP-8 ($X = -28.8\ R_E$, $Y = 9.9\ R_E$, $Z = 10.4\ R_E$), middle panel : B_X and B_Z components of the B field measured onboard AMPTE/CCE, in the near-earth plasma sheet ($R = 8.8\ R_E$, MLT = 1.3 H), bottom panel: Flux of ions with energies greater than 15 keV.

midnight, MLT=1.3 H, at a radial distance of 8.8 R_E, the bottom panel gives the variations of the flux of ions with E >15 keV at AMPTE.

An increase/decrease sequence of the B_X component onboard IMP and the associated V shaped signature of the B_Z component were clearly apparent. This allow to estimate that the cross-tail disruption reached the cross-tail current located under IMP-8 at ≈08:08 UT. Note that concurrently with the B field increase at IMP-8 there was a B field increase at AMPTE. The B_X and B_Z components are here indicative of a field line stretching associated to an increase of the cross-tail current. Note also that the B field increases seen onboard the two satellites are almost simultaneous, so that they can not be easily attributed to the effect of a travelling pressure enhancement in the solar wind which would lead to a time delay between the events seen onboard the two satellites. The B field increase was more probably due to the overall increase of the cross-tail current.

Note that as the magnetic field increase at the IMP-8 and AMPTE orbit, the low energy ion flux strongly decreased in the near plasma sheet. This thinning of the plasma sheet/flux drop-out is thus not only a near earth event but is linked to the large scale dynamical behaviour of the tail which could result from the increase of the convection electric field.

Near coincident with the time when the B_Z component of the B field at IMP began to strongly decrease, a small ion injection was recorded onboard AMPTE. The time delay between the injection at AMPTE and the minimum in B_Z at IMP gives a propagation velocity of the order on 300 km/sec for the disruption front associated with the injection.

LOCATION OF THE DETECTION OF CROSS-TAIL DISRUPTIONS SEEN ONBOARD IMP-8

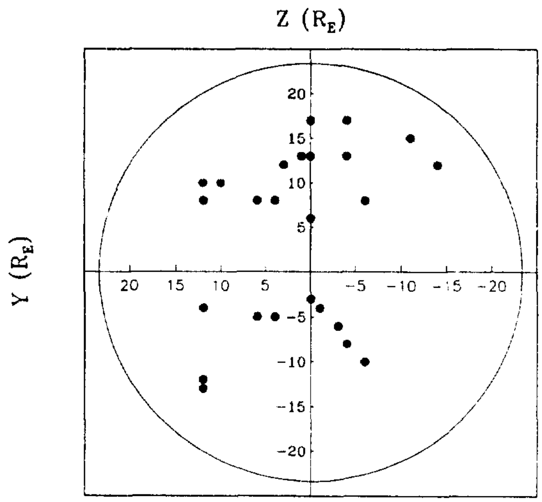

Fig. 5: Location in the X,Y GSM plane of detected cross-tail current disruptions onboard IMP-8 in at radial distances between of ~ 30 R_E

IMP-8 having a circular orbit with an altitude of ~ 35 R_E, the remote sensing detection of cross-tail current disruption is accomplished during some days every satellite rotation, i.e., 12.6 ays, when the satellite is in the lobe of the tail. We have examined data obtained during the springs of 1979, 1983, 1986 and found 26 clear cases. Figure 5 gives the locations of the event detections in the (Z,Y) GSM plane. X is in the range -25 to -32 R_E. No case is found for small |Z| values, i.e. in the plasma sheet. Events are detected for a very large range of Z and Y values. The distribution of event detections clearly indicate that cross-tail current disruption is a very large scale plasma processes which affects the whole section of the mid-tail. Note that it is expected that for satellite positions close to the magnetopause, the solar wind pressure changes can become a dominant effect.

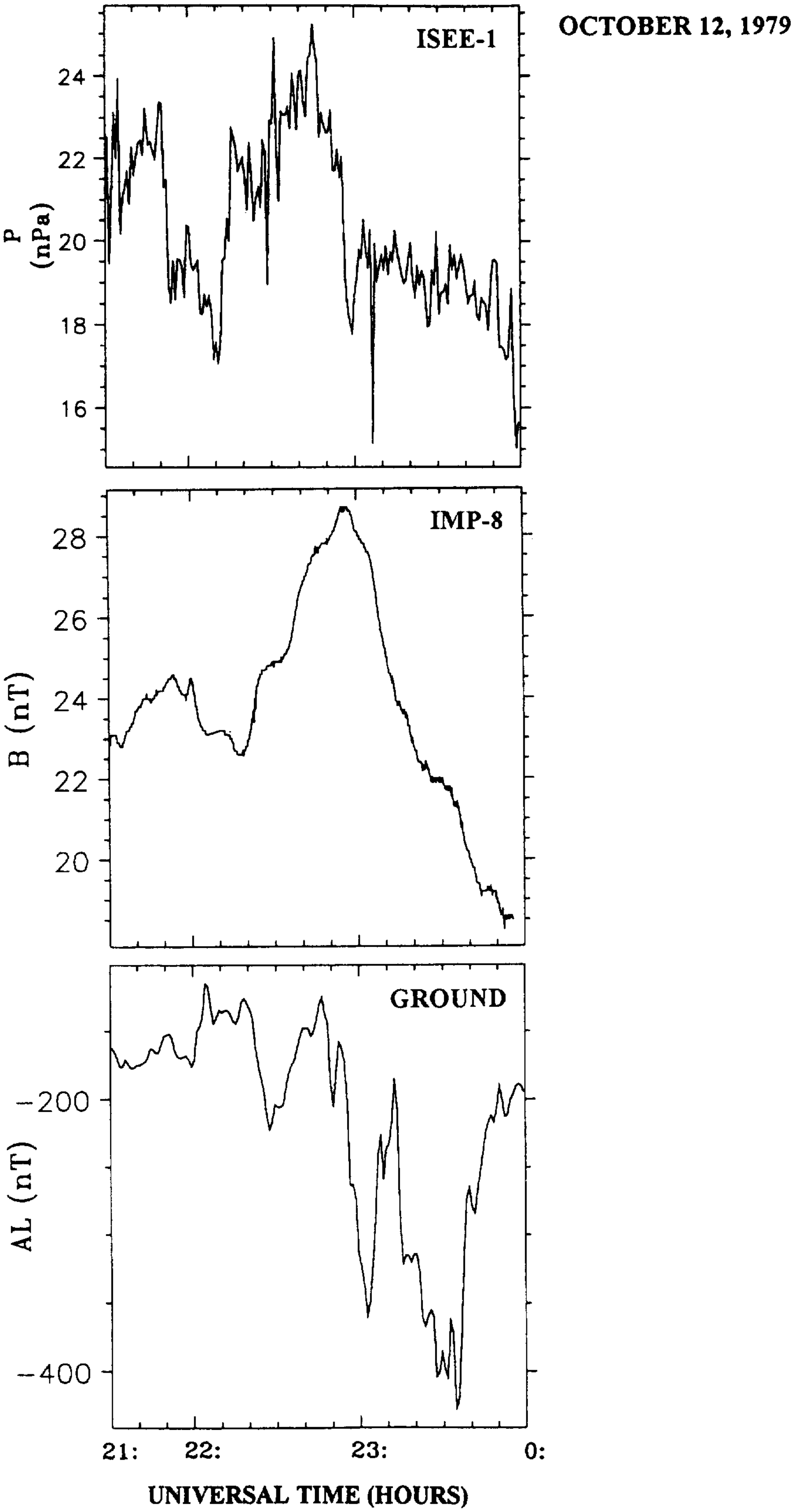

Fig. 6: Top panel: Solar wind pressure measured onboard ISEE-1 (X= 20.5 R_E), middle panel : Lobe magnetic field measured onboard IMP-8 (Xgsm=-27.4 R_E , Ygsm= 3.0 R_E, Zgsm=-16.5 R_E), bottom panel: Auroral AL index

RELATION OF CROSS TAIL CURRENT DISRUPTION WITH SOLAR WIND PARAMETERS

Figures 1 and 2 emphasised the relationship between the cross-tail current increase/ decrease sequence with the orientation of the interplanetary magnetic field. For such southward directed IMF, a part of the flowing solar wind energy impinging on the magnetosphere is converted via reconnection into electromagnetic energy which feeds the magnetospheric currents. Here, measurements made in the solar wind confirms that the solar wind pressure is nearly constant so that the increase of the B field in the lobe can not be attributed to pressure enhancement which by reducing the size of the magnetosphere concurs to an increase of the tail magnetic field.

It must be noted however that an increase of the tail magnetic field either due to an enhancement of the convection electric field resulting from an enhanced reconnection or/and due to an enhancement of the solar wind pressure correspond in both cases to an increase of the magnetopause and tail cross tail current. We have looked for events which could be due to solar wind pressure changes and found events of the kind of that displayed on figure 6. This figure gives from the top to the bottom, during the time interval 21:30 to 24:00 UT on October 12, 1979, the solar dynamical pressure measured onboard ISEE-1 n the solar wind, the tail lobe magnetic field measured onboard IMP-8 and the AE index. It is clearly apparent that the lobe field and solar wind pressure are correlated with a time lag of ≈12 minutes. During that period the ε function (not shown) giving an estimate of the power transmitted from the solar wind to the magnetosphere was varying between 1 and 5 10^{18} ergs/sec which indicates that the solar wind was continuously feeding the magnetosphere with energy, at a level which according to Akasofu was sufficient to drive substorms.

There existed a striking non linear correlation of the AE increases with the enhancements of the solar wind pressure which strongly suggest that here pressure increases directly drive substorm onsets.

DISCUSSION AND CONCLUSION

Example taken during on August 10, 1986 during low level magnetic activity show that lobe field increase can be linked to classical growth phase of substorm and is related to plasma sheet thinning/flux dropouts. The propagating cross-tail current disruption which follows correspond in that case to a weak plasma injection in the inner earth plasma sheet. This is apparently quite different from the August 22, 1983 example where a lobe field increase occurred during a substorm series with associated particle injections. In both case however, the lobe field increases correspond to a period where the electromagnetic solar wind-magnetosphere coupling is strong.

The solar wind pressure also plays a role in substorm initiation as evidenced by the October, 12, 1979 case. Here, the AE index shows that the the occurrence of a series of substorms is related to increases in solar wind pressure and associated lobe field enhancements. Note that these events also occured during a strong electromagnetic coupling with the solar wind.

The case studied clearly exemplify the complexity of the solar wind/magnetosphere coupling leading to substorm onsets and appeals for more extensive studies using multisatellites data.

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