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Mechanisms and time-scales of the magnetospheric response to the interplanetary magnetic field changes during the 8 May 1986 substorm

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Abstract—On 8 May 1986, between 1113 and 1600 UT, an isolated magnetospheric substorm was observed, during which the AE-index exceeded 700 nT (CDAW 9E event). Three available sets of measurements (a) of the solar-wind parameters (IMP-8 satellite), (b) of the magnetotail energy flux (ISEE-1 spacecraft), and (c) of ground magnetic observatories, allowed us to make a detailed study of the overall magnetospheric response to changes of the interplanetary magnetic field (IMF) direction, during this event of weak solar-wind coupling.

In order to study the mechanisms and time-delays of the magnetospheric response to the abrupt increase of the solar-wind energy input, we have evaluated the total magnetospheric energy output U_T following two different methods: (a) Akasofu's method, taking the ring current decay time τ_R constant, and (b) Vasyliunas' method where the values of U_T are independent of the solar-wind energy input as determined from the epsilon parameter. Both methods suggest that the driven system has been considerably developed during this substorm, while an unloading event has been superposed at the expansion onset.

1. INTRODUCTION

A magnetospheric substorm comprises all phenomena by which the magnetosphere dissipates the enhanced solar-wind energy input (BAUMJOHANN, 1989). ROSTOKER *et al.* (1987) have proposed a definition of a substorm in terms of three physical processes: the driven process, the storage process and the release process. All these processes may operate simultaneously within the magnetosphere–ionosphere system. Storage and release processes are combined in an overall process which has been called the loading–unloading process.

The aim of this study is to determine the energy dissipation processes by which the magnetosphere responds to the abrupt increase of the energy input that was detected during the CDAW 9E event. Therefore we have computed the energy budget of the magnetosphere during this substorm using Akasofu's method (AKASOFU, 1981) on the one hand and Vasyliunas' method (VASYLIUNAS, 1987) on the other.

Akasofu's method has been tested using a constant value for the ring current decay time τ_R. The system always showed the same behaviour independently of the chosen value for τ_R. The growth of the driven system occurs without a time delay as soon as the southward interplanetary magnetic field (IMF) arrives at the Earth's magnetopause. Moreover, Akasofu's method predicts a tendency of the system to dissipate energy explosively at the onset of the expansion phase.

Vasyliunas' method computes the ring current decay time τ_R as a function of the output magnetospheric energy. It gave almost the same results as those in Akasofu's method as far as it concerns the time sequence of this substorm. Regarding the intensity of the processes by which the magnetosphere responds to the enhanced solar-wind input, we have determined some differences between the two methods. (a) The mean value of the ring current decay time according to the Vasyliunas method is 1.33 h; it is the smallest value of all the possible values predicted by existing theories (AKASOFU, 1981; ZWICKL *et al.*, 1987; GONZALEZ *et al.*, 1989) for the examined level of disturbance. (b) Vasyliunas' method shows more unloading behaviour of the system since there is a clear indication of an event of explosive energy dissipation at the onset of the expansion phase.

Finally, our data analysis shows that all three processes have been operating during the early phases of this substorm.

2. DATA PRESENTATION

In order to determine the mechanisms by which the energy that entered the magnetosphere has been dissipated, we have studied the magnetosphere's energy budget. For this purpose, data of solar-wind parameters, of the magnetotail and of ground stations have been used.

(a) *Auroral electrojet indices*

The auroral electrojet indices data have been computed from the *H*-component values of 11 geomagnetic stations located along the auroral oval. These data have been computed specially for the PROMIS period by the WDC-C2 Center for Geomagnetism, and have a 1-min resolution.

The variations of the *AE*- and *AO*-indices from 900 to 1800 UT of the 128th day of 1986 (8 May 1986) are given in the top panel of Fig. 1(a), while the variations of the *AL*- and *AU*-indices are shown in the lower panel of the same figure. A first decrease of the *AL* index is clearly observed at 1126 UT [Fig. 1(a)], while at 1215 UT a second sharp decrease is detected.

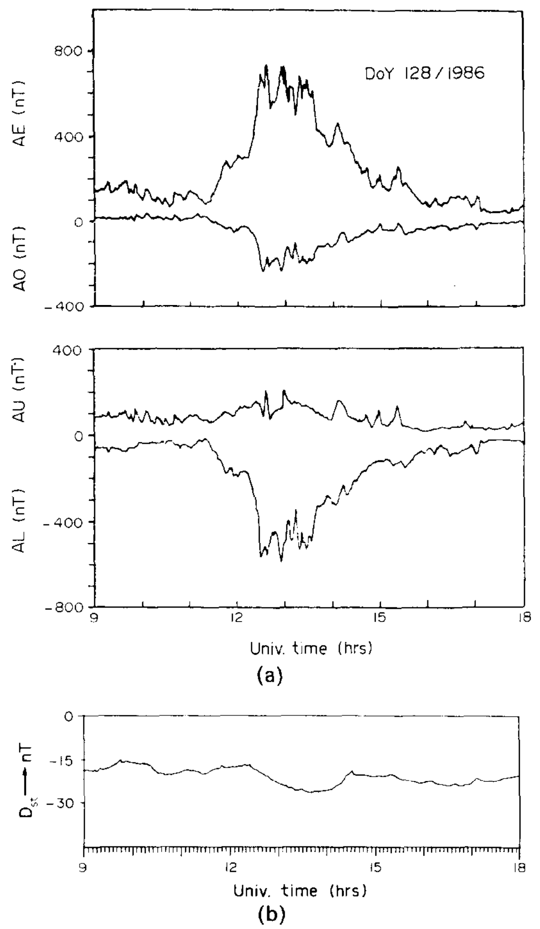

Fig. 1. (a) Time-plots of the 1-min values of the auroral electrojet indices *AL*, *AU*, *AO* and *AE* for the substorm of 8 May 1986, between 0900 and 1800 UT. (b) The 1-min values of the calculated *Dst*-index for the period examined here.

(b) Dst *index*

The 1 min values of the calculated *Dst*-index are shown in Fig. 1(b). The growth of the ring current begins at 1215 UT. Nevertheless a compression of the *Dst* index is observed during the whole time interval presented in this figure ($Dst < -15$ nT).

(c) *Interplanetary medium data*

The interplanetary magnetic field and the solar-wind plasma measurements (bulk speed and ram pressure) have been obtained from the geocentric satellite IMP-8, at $\approx 35\ R_E$. The magnetic field data have a time resolution of 15.5 s, while the plasma data represent 1 min averages. The separation between IMP-8 and the magnetopause results in a delay between the measurements made at IMP-8 and those that would be made at the Earth's magnetopause. This time delay has been estimated to be equal to 7 min since the average solar-wind bulk speed was 420 km/s for this time interval. Time-plots of the interplanetary medium data are presented in Fig. 2. The IMP-8 satellite detected a large discontinuity at 1113 UT which is obvious for all three components of the interplanetary magnetic field. The IMF B_z-component remains directed southward for approximately 4 h, starting at 1113 UT, while at 1134 UT the field becomes instantaneously northward. Our data suggest that the substorm expansive phase intensifications occur during episodes of relatively steady southward interplanetary magnetic field.

(d) *Magnetotail data*

The 6 keV electron flux measurements have been obtained by the particle detector of ANDERSON *et al.* (1978) on ISEE-1. The detector looks southward parallel to the spin axis (i.e. normal to the ecliptic plane). These electrons are representative of the plasma sheet plasma and the plot is particularly useful in identifying the dropout and recovery of the plasma sheet (beyond about 12–15 R_E) that often marks the occurrence of substorms. When the satellite is located in the plasma sheet, the proton or electron ($1 < E < 6$ keV) energy flux detected is greater than 10^7 cm^2/s/sr/keV. When the satellite enters the lobe, the measured flux is of the order of 10^4 cm^2/s/sr/keV. The plasma sheet thinning detected during a substorm may be explained by the movement of the plasma sheet boundary layer. At 1130 UT, the ISEE-1 spacecraft was located south of the neutral sheet at $X = -20\ R_E$ at ≈ 2330 LT (the B_x-component of the tail magnetic field which is not shown here was negative during this event). The

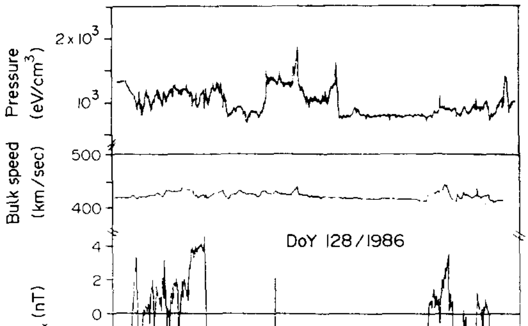

Fig. 2. The solar-wind ram pressure, bulk speed V and the B_x-, B_y-, B_z-, and B-IMF components for the period between 0900 and 1800 UT of 8 May 1986 measured by the IMP-8 satellite.

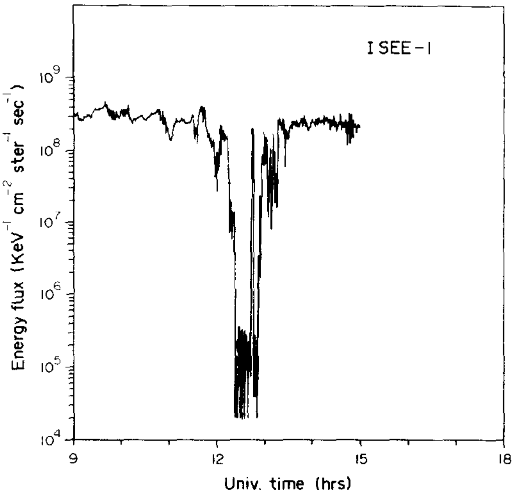

Fig. 3. The 1.5 keV electron flux measured by the ISEE-1 spacecraft with 4 s resolution, for the period examined here.

energy flux measurements from ISEE-1 shown in Fig. 3 give us a typical example of transitory decrease of the particle flux. The plasma sheet thinning has been observed from 1212 to 1251 UT, although from $\approx$1100 UT we can observe some fluctuations in the energy flux measurements which give evidence of turbulence propagation. Because of the small value of the energy flux during the thinning we can suppose that the satellite was located in the south lobe from 1212 to 1251 UT. The plasma sheet appears permanently at 1320 UT. The plasma sheet dropout, detected at $X = -20$ R_E, coincided with the large decrease of the AL-index at 1215 UT. Thus, the slowly developing magnetic bays which appeared between 1120 and 1215 UT are probably the manifestation of the growth phase.

We define the growth phase as the interval which is initiated by the southward turning of the IMF vector and more accurately when $dB_z/dt < 0$. During the growth phase the magnetosphere undergoes a reconfiguration with southward IMF. Energy begins to be stored in the transverse magnetospheric currents. The growth of the tail field is accompanied by the growth of the driven system electrojet and associated field-aligned currents (ROSTOKER *et al.*, 1987). Weak auroral disturbances called psueodo-breakups can occur during the growth phase (MCPHERRON, 1979).

Returning back to the event studied here, we think that the major substorm intensification takes place after 1215 UT [Fig. 1(a)]. In the following paragraph we examine this point in more detail using ground signatures.

(e) *Ground magnetograms*

In order to have a picture of the substorm signature on the ground we have examined the magnetograms from both auroral oval and low latitude stations. These data have been taken from WDC-A for solar–terrestrial physics. The geographic and the geomagnetic coordinates of the stations are given in Table 1. The time-plots of the geomagnetic field H-, D- and Z-components from the auroral oval stations are presented in Fig. 4(a), while the time-plots of the H- and D-components from the low latitude stations are presented in Fig. 4(b). All the magnetograms show clear substorm magnetic signatures after 1215 UT in all geomagnetic components. The main magnetic bays which developed after 1215 UT have also been monitored by all the AE stations. Apart from this disturbance there is noticeable activity on the Anchorage

Table 1. The geographic and geomagnetic coordinates of the auroral oval stations used in this work

Station	Abbreviations	Geographic coordinates Latitude (deg)	Geographic coordinates Longitude (deg)	Geomagnetic coordinates Latitude (deg)	Geomagnetic coordinates Longitude (deg)
Barrow	BRW	71.3	203.3	68.5	241.2
College	COL	64.9	212.0	64.6	256.5
Anchorage	ANC	61.2	210.1	60.9	258.1
Sitka	SIT	57.1	244.7	60.0	275.3
Kakioka	KAK	36.2	140.2	26.0	206.0
Tucson	TUC	32.3	249.2	39.9	311.4

and College H-magnetograms beginning at 1130 UT. This initial negative variation of the H-component has been monitored by some AE stations. If this preliminary activity refers to the expansion phase of the substorm, then the peak which appeared in the AE-index at 1215 UT simply corresponds to the time when the electrojets move to a location that is better detected by one of the AE stations. If not, then at 1215 UT a drastic strengthening of the electrojet occurs and thus the initial activity observed between 1130 and

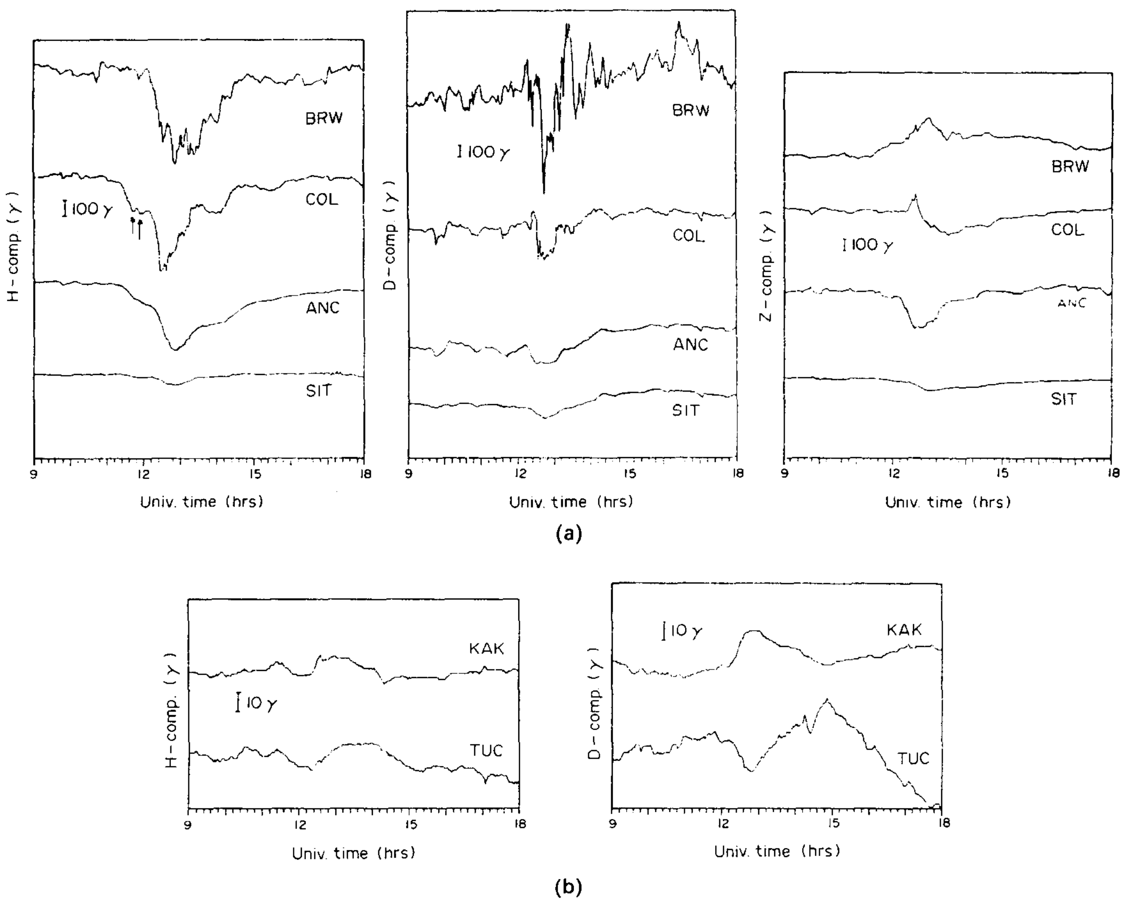

Fig. 4. (a) Time-plots of the 1-min values of the H-component (left), D-component (centre) and Z-component (right) from the observatories Barrow, College, Anchorage and Sitka located in the auroral oval. (b) Time-plots of the 1-min values of the H-component (left) and of the D-component (right) from the low-latitude observatories Kakioka and Tucson.

1215 UT corresponds to the growth phase of the substorm. In order to make this point clear we have examined the magnetograms from Tixie Bay and Cape Wellen stations (these magnetograms are not presented here) which are located east of College. Tixie Bay did not present any remarkable activity at all. Cape Wellen showed weak activity in the Z-component at 1125 UT which did not exceed the disturbance level measured at College. Therefore we think that the slowly developing magnetic bays at some stations correspond to the effect of the driven electrojet's growth. The two successive excursions at 1140 and 1152 UT [indicated with arrows in Fig. 4(a)] measured from College appeared as Pi2 pulsations, and may be characterized as pseudo-breakups that occur during the growth phase of the substorm. It is possible that those pseudo-breakups have been triggered by the instantaneous northward turning of the IMF-B_z component at 1134 UT.

The main onset happens at 1215 UT at Barrow; the positive D spike is not preceded by a slowly developing negative bay. Also, before 1215 UT the low latitude D-magnetograms do not show any perturbation.

3. DETERMINATION OF MECHANISMS AND TIME-SCALES

The study of a magnetospheric substorm is concerned with the issues of how the solar-wind mass, momentum and energy are transferred to the magnetosphere, the physical process that affects the transfer and the time-scales on which these processes operate.

In order to determine the mechanisms by which the energy input has been dissipated in the magnetosphere we have studied the energy budget of the magnetosphere during this multiple onset, isolated substorm. In the following, we have supposed that the rate of solar-wind energy input into the magnetosphere is expressed by the solar-wind–magnetosphere coupling parameter ε, proposed by Perreault and Akasofu (1978):

$$\varepsilon = VB^2 \sin^4 (\theta/2) l_0^2 \qquad (1)$$

where B is the magnitude of the interplanetary magnetic field, V is the solar wind bulk speed, θ is given by $\tan^{-1}(B_y/B_z)$ or by the angle's supplement for $B_z < 0$, and l_0^2 is an effective cross-sectional area of the magnetosphere, where l_0 denotes the linear dimension of R_E.

In order to examine how the energy input has been dissipated in the inner magnetosphere–ionosphere system and the near-Earth magnetotail, two different methods have been used: (a) Akasofu's method (1981) and (b) Vasyliunas' method (1987).

(a) *Direct coupling method*

According to the direct coupling method (Akasofu, 1981), the state of the magnetosphere is determined in principle from the solar-wind–magnetosphere energy coupling ε with a time delay no longer than some minutes. It is known that the total energy consumption rate U_T of the magnetosphere is given by the sum of the Joule heat production rate in the ionosphere U_J, the auroral particle energy flux U_A, and the ring current energy injection rate U_R, where:

$$U_A = AE \times 10^{15} \text{ erg/s}$$

$$U_J = 2 \times 10^{15}\, AE \text{ erg/s}$$

$$U_R = 4 \times 10^{20}\, (\mathrm{d}Dst/\mathrm{d}t + Dst/\tau_R) \text{ erg/s}$$

and thus

$$U_T = U_A + U_J + U_R. \qquad (2)$$

The most uncertain parameter in the above formulation is the time τ_R, which denotes the lifetime of the ring current particles. Zwickl *et al.* (1987) have shown that, when τ_R is a multistep function of ε, the energy U_T contains some unphysical steplike changes whenever a new τ_R step is encountered. When τ_R is a continuous function of ε, the energy U_T shows a very obvious correlation with ε and, therefore, it is not surprising that U_T and ε are highly correlated in Akasofu's (1981) study. On the other hand U_T derived with a constant τ_R shows no evidence of such a correlation. Therefore, in the present analysis we have calculated the output energy U_T according to Akasofu's method, taking the time τ_R to be constant. In order to choose the most appropriate value for the ring current decay time τ_R, we have considered first Akasofu's (1981) suggestions, where he proposed that τ_R must be equal to 20 h for $\varepsilon < 5 \times 10^{18}$ erg/s, although in a later publication of Zwickl *et al.* (1987), it is suggested that τ_R is 2 h for $10^{18} < \varepsilon < 5 \times 10^{18}$ erg/s. Secondly, we have considered the results of Gonzalez *et al.* (1989), where they concluded that the best value of τ_R must be 4 h for $Dst > -50$ nT. In the case studied here, the Dst index has been calculated using the low latitude records of the H-component from all the stations whose data were available. This index, due to the paucity of stations from which it is computed, does not distinguish between contributions from the symmetric ring current and the asymmetric ring current. Each of these currents has quite different time constants, with the decay of the symmetric ring current requiring several tens of hours and the decay of the asymmetric ring current requiring at most 2–4 h (ROSTOKER *et al.*, 1987). It is obvious [Fig. 1(b)] that we can determine the time constant of the asymmetric ring current which is ≈ 2 h, from 1215 to 1430 UT. Moreover, keeping in mind that this substorm happened during the recovery phase of the magnetic storm initiated at ≈ 0400 UT on 6 May 1986, the symmetric ring current is found in its decay, containing mainly H^+ and He^+, whose lifetime is several tens of hours. So the most probable lifetime of the symmetric ring current particles is ≈ 20 h. The effect of the symmetric ring current appeared in Fig. 1(b) as a compression of the *Dst*-index ($Dst < -15$ nT) which occurred during the whole time interval presented in the above time-plot. So an appropriate value for the decay time τ_R is 10 h; this is considered as the mean lifetime of the symmetric and the asymmetric ring current particles.

Another problem with the above-mentioned definition of the total magnetospheric energy output U_T is that the changes of the magnetic energy stored in the magnetotail are not directly included and hence the energy input (ε) need not equal output (U_T). ROSTOKER *et al.* (1987) proposed that, in dealing with the energy budget of a substorm disturbance, the total energy should be represented by the expression (2) added the term U_{MT} which is the energy rate stored in the magnetotail during the storage process of the substorm. So, we define a new function for the total energy consumption rate of the magnetosphere–ionosphere system U'_T, given by the following expression

$$U'_T = U_T + U_{MT} \tag{3}$$

which is the sum of the energy consumption rate in the ionosphere-ring current (U_T) and the energy stored in the magnetotail currents (U_{MT}). Since there is some evidence that the magnetotail currents and the outer ring current are intimately connected (ROSTOKER *et al.*, 1982) the energy budget of a substorm which is related to the input of energy from the solar-wind should include the contribution from the process of energy storage in the magnetotail and its subsequent dissipation in the release process (ROSTOKER *et al.*, 1987).

In the present work, the values of the magnetotail-stored energy have been theoretically calculated, under the assumption that the input solar-wind flux ε is always equal to the energy consumption rate in the magnetosphere. This has a physical meaning after the introduction of the term U_{MT} in the output energy calculation.

Consequently, we have estimated at first the energy consumption rate in the ionosphere, that is, the Joule heat production rate (U_J) and the auroral particle energy flux (U_A) by the expression:

$$U_I = U_J + U_A = 3 \times 10^{15}\, AE. \tag{4}$$

Secondly, the energy consumption rate in the ionosphere and the symmetric ring current is given by the expression:

$$U_T = 3 \times 10^{15}\, AE + 4 \times 10^{20}\,(\mathrm{d}Dst/\mathrm{d}t + Dst/\tau_R). \tag{5}$$

Taking in consideration the effect of the solar-wind time delay between IMP-8 and the magnetopause, which was found to be 7 min, the residuals of the values $U_T(t)$ from the values of the epsilon parameter $\varepsilon(t-7)$ give us the values of the magnetotail stored energy $U_{MT}(t)$

$$U_{MT}(t) = \varepsilon(t-7) - U_T(t). \tag{6}$$

The time plots of the 1-min values of the energy rates ε, U_I, U_T and U_{MT} are given in Fig. 5.

At 1113 UT, the B_z-IMF component became southward. This southward field arrives at the magnetopause 7 min later, at 1120 UT. Simultaneously both U_I and U_T begin to increase slowly, showing an immediate response to the solar-wind input, as we can note in Fig. 5(b) and (c). This comment leads us to the result that the driven system begins to grow at 1120 UT. At the same time the rate of energy storage in the tail increases (loading process) as we can see

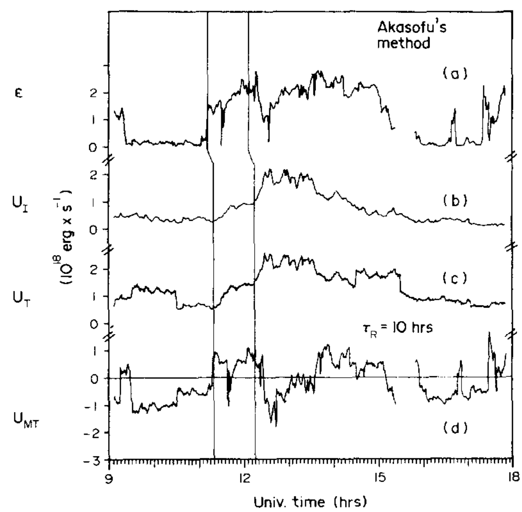

Fig. 5. From the top the 1-min values of (a) the epsilon parameter, (b) the energy consumption rate in the ionosphere U_I computed from equation (4), (c) the energy consumption rate in the ionosphere and the ring current U_T computed from equation (5), and (d) the energy rate stored in the magnetotail currents U_{MT}, computed from equation (6) according to Akasofu's direct coupling method are shown.

in Fig. 5(d). This means that part of the input flux described by the parameter epsilon [Fig. 5(a)] is immediately stored in the tail. At 1215 UT, where the onset of the expansion phase occurred, as was determined from the ground magnetograms, the rate of energy storage in the tail started to decrease, indicating that the unloading process takes place. The released tail energy enhances the field-aligned currents which drive the auroral electrojets. This scenario has been predicted by Akasofu's model, since from Fig. 5(b) we can see a sharp increase in the time-plot of U_I. From the above description we can set the 'start of the substorm' at 1120 UT. At this moment the driven system current begins to grow in response to an increase in the input solar-wind flux. Therefore the time-scale τ_2 (ROSTOKER *et al.*, 1987) associated with the preliminary storage of energy in the transverse electric currents circulating in and confined to the magnetotail is equal to 55 min.

Just after the major onset, at 1215 UT, the rate of energy dissipation U_T in the ionosphere and the ring current increases explosively, while the rate of energy input decreases and $dU_{MT}/dt < 0$ (unloading process). At the same time the dropout of the energy flux persisted in the tail (Fig. 3). This means that the energy needed for the explosive energy dissipation at the expansion onset was supplied from the tail.

In order to have a better understanding of the relative importance of the two mechanisms (directly driven and loading–unloading) and therefore to have a more global view of the magnetospheric response to the enhanced solar-wind input energy, we have carried out a cross-correlation analysis between the parameter ε and the rate of energy dissipation in the ionosphere and the ring current U_T. The best correlation coefficient was found to be 0.70 for a time lag of 29 min, which becomes 22 min taking into consideration the time delay between IMP-8 and the magnetopause. This value shows that, although the directly driven process is the main process of energy dissipation during the CDAW 9E event, the unloading of the energy stored in the tail plays a very important role at the expansion phase onset.

(b) *Evaluation of* U_T *independently of* ε

According to VASYLIUNAS (1987), the dependence of the time τ_R on the ε parameter may lead to problems of circular reasoning and the artificial interdependence of quantities when the statistical relation between U_T and ε is investigated. To avoid these problems he proposed that τ_R can be taken as a function not of ε but of U_T itself as was defined from equation (5). Thus, values of U_T independent of ε can be

Table 2. The multistep function $v = v(U_T)$ according to VASYLIUNAS' method (1987)

v (per h)	U_T (erg/s)
0.05	$U_T \leqslant 10^{18}$
$0.33\,[U_T/10^{18}]^{0.6}$	$10^{18} < U_T \leqslant 6.4\times10^{19}$
4	$U_T > 6.4\times10^{19}$

obtained. The equation (5) may be written as:

$$(U_T - U_0)/Dst = 4\times10^{20}\,v(U_T) \qquad (7)$$

where $U_0 = 4\times10^{20}\ dDst/dt + 3\times10^{15}\ AE$ which depends only on the geomagnetic indices, and $v(U_T) = 1/\tau_R$ is the loss rate that replaces the loss time τ_R. The right-hand side of equation (7) represents a fixed curve, the assumed dependence of v on U_T, while the left-hand side represents a straight line with slope and intercept fixed by the observed quantities Dst and U_0; the intersection of the theoretical curve and the experimental line gives value of U_T. The analytical expression for $v = 1/\tau_R$ is given in Table 2.

The 1-min values of the energy consumption rate in the ionosphere and the ring current U_T computed according to this method are given in Fig. 6, together with the time-plot of the energy consumption rate U_I and the 1-min values of the energy rate stored in the magnetotail currents U_{MT} computed from equation

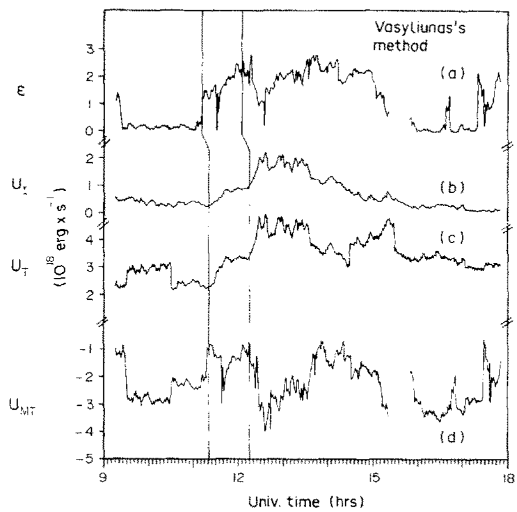

Fig. 6. From the top (a) the epsilon parameter, (b) the energy consumption rate in the ionosphere, U_I, computed from equation (4), (c) the energy consumption rate in the ionosphere and the ring current U_T, computed from the values given in Table 2, and (d) the energy rate stored in the magnetotail currents U_{MT}, computed from equation (6) according to Vasyliunas' method, are presented.

(6). The time-plot of the epsilon parameter is given in the top of Fig. 6 for comparison. It is important to note here that, in our study, where we have used two different methods in evaluating the magnetospheric energy output U'_T, the input energy has been computed by the same formulation of PERREAULT and AKASOFU (1978), that is the solar-wind–magnetosphere coupling parameter epsilon. Therefore, the differences that may be found in the following comparison of the two methods will be due only to the differences in the evaluation of the magnetospheric energy output U'_T.

From the comparison of the results of the two methods used here, shown in Figs 5 and 6, we can note two points. The first is that at 1215 UT the U_T energy rate increases much more rapidly than in Akasofu's method, emphasizing the unloading process that takes place at the expansion onset. The second is that the values of the U_T energy rate are generally greater than those computed according to Akasofu's method. Consequently the values of the U_{MT} energy rate are smaller and always negative. This is caused by the mean value of the ring current decay time τ_R computed according to Vasyliunas' method being equal to 1.33 h. This value is smaller than that predicted by any other method (AKASOFU, 1981; ZWICKL *et al.*, 1987; GONZALEZ *et al.*, 1989). Nevertheless we have to note that Vasyliunas' method shows clearly that we have two independent systems.

The cross-correlation coefficient between the epsilon parameter and the U_T energy rate computed according to Vasyliunas' method was found to be 0.64 for the same time lag (22 min). This result verifies the results obtained from Akasofu's method concerning the overall magnetospheric response.

From the comparison of the two methods we can say that Akasofu's method, modified to use a constant ring current loss time that is appropriate for this event and to include the rate at which energy is stored in the magnetotail, provides a more realistic approach to the magnetospheric energy budget than does Vasyliunas' method.

4. DISCUSSION AND CONCLUSIONS

In order to study the mechanisms by which the magnetosphere dissipates the enhanced energy input, we have made an effort to consider the energy budget of the magnetosphere during the whole time interval of the substorm disturbances, first following the Akasofu model of a directly driven system. In order to have a more realistic approach of the magnetospheric response and therefore to calculate the most accurate magnetospheric energy output, we have introduced two improvements. The first is concerned with the loss time of the ring current particles τ_R. As was already discussed in Section 3, this time τ_R was defined originally as a function of the parameter ε. But since, during the substorm event studied here, $\varepsilon < 3 \times 10^{18}$ erg/s and $Dst > -30$ nT, the time τ_R predicted from the theory is constant (AKASOFU, 1981; ZWICKL *et al.*, 1987; GONZALEZ *et al.*, 1989). In this work we have taken the ring current decay time to be equal to 10 h. We have examined how the curves of U_T and U_{MT} change using a smaller constant value for τ_R evaluating Akasofu's method (a) for $\tau_R = 20$ h (AKASOFU, 1981), (b) for $\tau_R = 4$ h (GONZALEZ *et al.*, 1989), and (c) for $\tau_R = 2$ h (ZWICKL *et al.*, 1987). The comparison of the U_T and U_{MT} values shows that the shape of these curves is exactly the same, although the U_T curves are shifted to higher values as τ_R gets smaller, and consequently the U_{MT} curves are shifted to smaller values. Therefore, our qualitative results concerning the mechanisms which dissipate the input energy and cause the time sequence of the substorm are independent of the value which we choose for the constant ring current decay time τ_R.

The second improvement is a fourth term that has been included in the computation of the total magnetospheric energy output. This term represents the rate at which energy is stored in the magnetotail currents during the storage process of the substorm (ROSTOKER *et al.*, 1987). The terms U_I and U_{MT} defined from equations (4) and (6), respectively, play the most important role in order to determine the mechanisms by which the magnetosphere dissipates the enhanced solar-wind input energy, at each phase of the substorm.

The results taken from the cross-correlation analysis between the input epsilon parameter and the energy rate dissipated in the ionosphere and the ring current lead us to the conclusion that, although the driven system has been considerably increased in strength during this substorm, a part of the input energy ε has been dissipated according to the unloading process.

From all the above-detailed analysis of the magnetospheric substorm of 8 May 1986 and the discussion it is concluded that:

1. The magnetosphere responds immediately to the southward IMF, while the time associated with the preliminary storage of energy in the transverse electric currents circulating in and confined to the magnetotail is equal to 55 min.

2. The tail plays a significant role in supplying the energy needed for the explosive energy dissipation at the onset of the expansion phase.

3. During the CDAW 9E event, the driven system has grown in strength while the onset of the expansion phase has been followed by an event of explosive energy dissipation, that is an unloading event at 1215 UT which has been superposed on the driven system.

4. Akasofu's method predicts the magnetospheric response well, although Vasyliunas' method emphasizes that when two independent systems (solar-wind–magnetosphere) interact the unloading process is the most prominent mode of the magnetospheric response at the expansion onset.

The extension of this study to other isolated magnetospheric substorms and the existence of continuous tail magnetic field data will help us to arrive at a better understanding of their correlation with interplanetary medium parameters and to a more accurate determination of the processes during the different phases of the magnetospheric substorm.

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