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On the two-phase decay of the Dst-variation

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Abstract. We discuss the well known observation that during the storm recovery phase the *Dst*-variation shows a two-stage decay pattern, decaying first quickly and then decaying with a larger decay parameter. This finding is discussed in the context of the magnetic storm which was observed on November 25-27, 1986. Contrary to frequently used interpretations as two spatially separated ion populations or two different atomic ion components, we propose an alternative explanation for this feature. We argue that during the recovery phase of the magnetic storm the *Dst* decay is controlled by the decay of a two current system: the ring current (*DR*) and the magnetospheric tail current (*DT*).

Introduction

It is generally observed that during the storm recovery phase the *Dst*- variation shows a two-stage decay pattern. decaying first quickly and then decaying with a larger decay parameter. To date, two suggestions try to explain this peculiar feature. The first proposed by *Akasofu et al.* [1963] assumes that the two-phase recovery in the Dst-variation is caused by two spatially separated ring current populations. The outer component was assumed to exist in storms of all sizes and to produce the slow part of the recovery in large storms. The inner population was suggested to exist only in very large storms. Its decay was identified with the rapid initial recovery. The difference in decay times for the two components of the ring current was attributed to the radial dependence of the neutral hydrogen density causing a difference in charge exchange lifetimes. The second explanation proposed by *Hamilton et al.* [1988] did not add another ring current to the picture but suggested that the two-phase recovery in a large storm results from a ring current made up of two different atomic components (H^+ and O^+) which decay with two different decay times. Using the Chamberlain model, giving a neutral density of about 310 atoms cm^{-3}, they calculated for 75 keV hydrogen a decay parameter of $\tau_{H+} = 73.0$ hours and for 75 keV oxygen a parameter of $\tau_{O+} = 17.3$ hours [*Hamilton et al.*, 1988]. *Daglis* [1997] has supported this explanation, noticing that the O^+ fraction of the ring current energy drops simultaneously with *Dst*. Unfortunately, one has to admit that no experimental verification for the explanation of Akasofu et al. has been reported and that Hamilton et al.'s two-ion species explanation faces some difficulties as well for moderate storms.

Takahashi et al. [1990] have made a simulation of the storm-time ring current. They examined the behavior of charged particles in a dipole magnetic field upon which they imposed a time-dependent electric field. They argued that the *Dst* recovery is a combination of a "flow out" effect (or decrease of injection) and a loss process of trapped particles by charge exchange. The combination of these two processes can generate various patterns of ring current decay. Protons with energies of 20 keV and more which are once trapped can escape from the model magnetosphere through the dayside magnetopause. This can also be a cause for the fast initial ring current decay. Undoubtedly, to examine the *Dst*-variation it is necessary to take into account the loss processes of trapped particles different from charge exchange processes. Such processes are, in particular, precipitation of ions into the upper atmosphere [*Kozyra et al.*, 1998]. Losses of ions due to drift through the dayside magnetopause as well as due to precipitation into the atmosphere exist generally in the day-afternoon side of the magnetosphere during the main phase of the magnetic storm. They cause an abrupt asymmetry (*ASY*) of the longitudinal distribution of the magnetic disturbance ΔH on the Earth's surface and a fast decay of the *ASY* near the transition from the main phase to the recovery phase of the magnetic storm [*Feldstein et al.*, 1994].

The storm of November 25-27, 1986

To exemplify the difficulties which the above two explanations encounter we have chosen the storm of November 25-27, 1986. The measurements presented in this paper were made with the charge-energy-mass spectrometer (CHEM) on the AMPTE/CCE which detects ions in the energy per charge range 1-310 keV/e. The data, collected during Pass 8 (1549 UT - 1851 UT on November 25, 1986) and Pass 10 (0733 UT - 1029 UT on November 26, 1986), were used to calculate the en-

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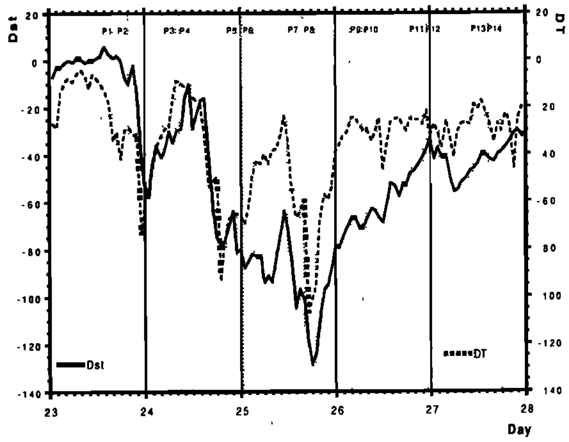

Figure 1. *Dst* geomagnetic index (left axis) and *DT* magnetic field variation (right axis) during the magnetic storm on November 23-27, 1986. AMPTE/CCE pass numbers and durations at $2.5 \leq L \leq 6.5$ are shown on the panel.

ergy densities for different ions during the above given time intervals. Figure 1 presents the *Dst* index between November 23 and 27. From 1800 UT on November 25 until 0600 UT on November 26 one observes a very rapid recovery of the *Dst* values. AMPTE/CCE passes are shown on the panel. Figure 2 shows the hydrogen ion energy density (marked by dots), the oxygen energy density (marked by the dashed line), and the total energy density for five ions species (marked by the solid line). Figure 2 reveals that during the main phase maximum (Pass 8) and during the next available pass (Pass 10) the ions which are the carriers of the ring current create a single large-scale region. The local time of the passes was 17 - 22 hr, the satellite crossed L-shells 2.5 - 6.5 during 3 hours. Obviously, no breakdown in two separate zones is seen.

Addressing Hamiltons' explanation we note that there are indeed two ion populations which decay during the recovery phase. Using AMPTE/CCE data the decay parameter for oxygen is 10.5 hours and for hydrogen 71.5 hours. However, analyzing the data more closely, we find that during the storm's main phase maximum and the recovery phase the oxygen ions energy density is only about 10 density (see Figure 3 for L-shells 4.5-5.0, the same values are on all L-shells from 2.5 to 6.5). This storm is not a special case. The oxygen ions contribution to the total energy of the ring current during the main phase was about 27-29 the moderate storm of September 4-7, 1984 [*Gloeckler et al.*, 1985; *Krimigis et al.*, 1985]. It is evident that the measured oxygen energy can't explain the first rapid decay of the intensity of the *Dst*-variation during the beginning of the recovery phase even if they would have disappeared from the ring current region completely.

Discussion and conclusions

We propose here an alternative explanation for the two-stage *Dst* decay. We suggest that during the recovery phase of the magnetic storm the *Dst* decay is controlled by the decay of two different currents: the ring current (*DR*) and the magnetospheric tail current (*DT*). The magnetic field variation (*DCF*) controlled by the solar wind pressure (P_{SW}) is not taken into account because during the recovery phase of this storm P_{SW} changes less than 2 nPa. The values of the magnetotail current system (*DT*) during the magnetic storm on November 23-27, 1986 is being published in *Dremukhina et al.* [1999] and are presented in Figure 1. We have used the *DT* values which were calculated using the paraboloid model of the magnetospheric magnetic field by *Alexeev et al.* [1996]. Comparing the calculated values of *DT* with the measured *Dst* values we see that *DT* contributes significantly to the *Dst*-variation. Since we observe that *DT* recovers first very fast and then remains in a narrow range we divide the recovery phase of the magnetic storm into two phases.

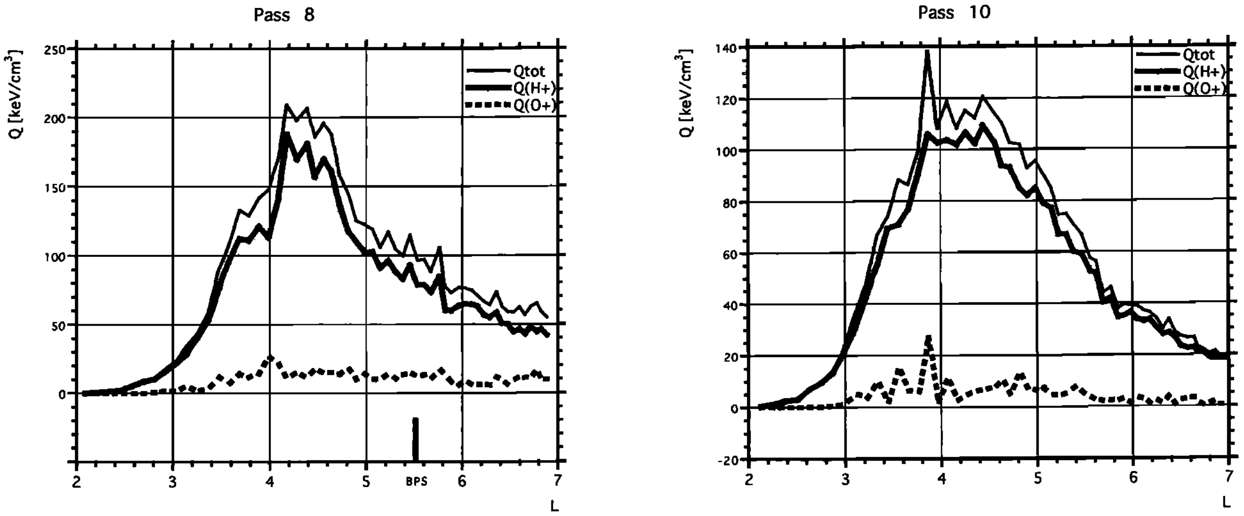

Figure 2. Energy density Q [keV/cm^3] of ions as function of L for the main phase maximum (pass 8) and the recovery phase (pass 10). The thick line with points shows H^+ data, the dashed line shows O^+ data, the thin line shows the total Q of ions H^+, O^+, He^+, He^{++}, and N^+.

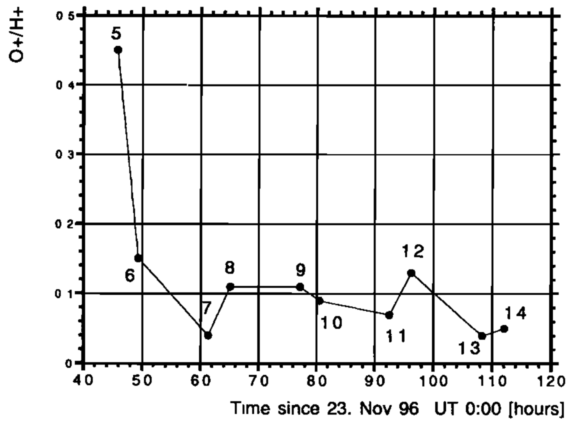

Figure 3. Variation of the energy density ratio $Q(\mathrm{O}^+)/Q(\mathrm{H}^+)$ in the ring current region during the main and recovery phase of the magnetic storm at $4.5 < L < 5.0$. The numbers in the figure denote the satellite passes.

Analogously *Dst* can be divided into two phases, a fast and then a slower recovery phase. The first phase lasts until UT 04:00 of November 26 and then the second phase begins. We notice that the decay parameter τ_{DT} is of the order of a few hours during the first stage of the recovery phase. During the second stage of the recovery phase, when the contribution of DT is negligible, the magnetic field variations are mainly determined by the DR decay. From plasma measurements we know that the DR decay parameter τ_{DR} is equal to several tens of hours and therefore the magnetic field intensity changes are slower during the final stage of the recovery phase than during the beginning stage.

In order to determine the magnetotail current decay parameter τ_{DT} we assume that the intensity DT decays exponentially. Therefore we used the normal procedure to calculate τ_{DT} by forming the ratios DT_1/DT_i in one hour intervals where DT_1 is the minimum value of DT at the beginning of the recovery phase. In Figure 4a we display the values $\ln(DT_1/DT_i)$ for the first interval. In Figure 4b which shows the values $\ln(DT_1/DT_i)$ for the second interval, DT_1 is in this case the value of DT at the beginning of pass 9 (this point also marks the end of the fast recovery of DT). We use the data in Figure 4 to compute τ_{DT} during the beginning stage of the recovery phase (on the left panel) and during the final stage of the recovery phase (on the right panel).

It is seen that at the beginning stage of the recovery phase τ_{DT} is equal to 7.3 hours. This means that the *Dst* intensity decreases 2.7 times during the 7.3 hour interval. Since the DT intensity variation is the substantial part of the *Dst*, we argue that it is possible to interpret the observed change of the *Dst* magnetic field by the decay of the magnetotail current system during the first stage of the recovery phase. After the first rapid decay of DT, DT decreases only gradually with $\tau_{DT} \sim 183$ hours (on the right panel of Figure 4) and its contribution to the *Dst*-variation is negligible. Instead, the *Dst* variations are now controlled by the ring current decay, mainly its proton constituent, with τ_{H+} equal to 71.5 hours.

Kozyra et al. [1998] have modeled the magnetic storm of February 1986 including ion precipitations into the atmosphere as an additional loss mechanism. *Liemohn et al.* [1999] also took into account the gains of particles and energy through the nightside boundary and the loss through the dayside boundary due to convective drift for modeling the two storms of July 1991 and September 1998. Both examinations show a good agreement with observed *Dst* values during the main phase and early phase of the *Dst* recovery. *Liemohn et al.* [1999] inferred that the convective drift loss out of the dayside magnetopause is the dominant process in removing ring current particles. The ratio of the dayside outflow energy loss rate to the charge exchange energy loss rate exceeded 10 during the main phase for September 1998

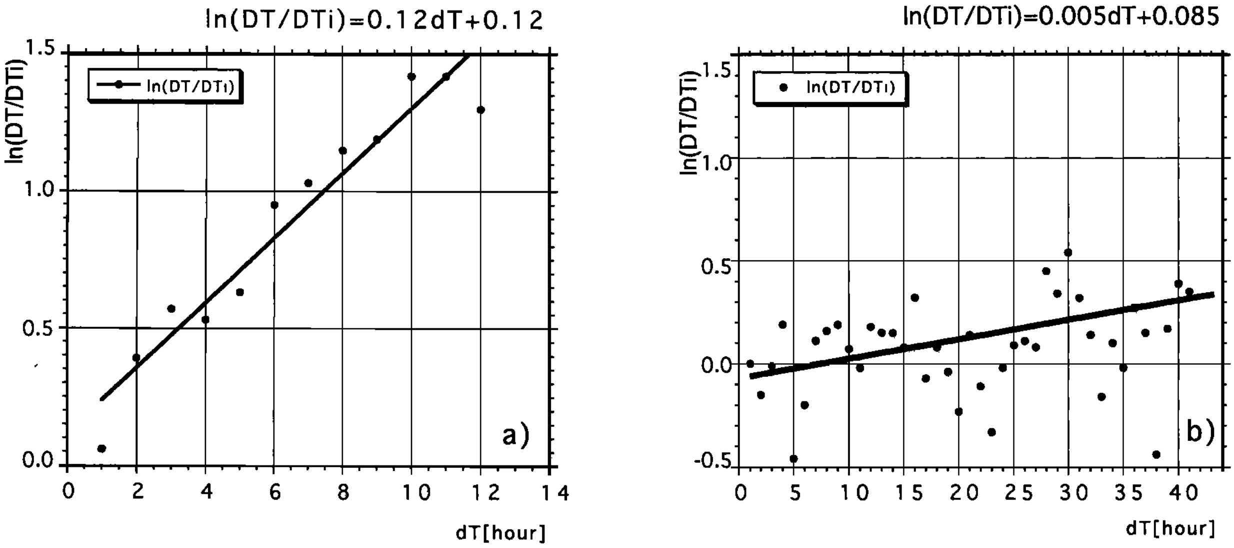

Figure 4. Variations of the tail current magnetic field intensities ratio ($\ln(DT_1/DT_i)$ during the early recovery phase (a), and in the late recovery phase (b). Corresponding values of the decay parameter are $\tau \sim 7.3$ hours and $\tau \sim 183$ hours respectively.

storm and always exceeds unity during the early recovery phases of both storms. Possibly, this ratio changes from one storm to another storm. This is indirectly shown by the results of a successful model by *Kozyra et al.* [1998] which does not take into account the losses out of the dayside magnetopause. Results from calculations of particle and energy losses due to different loss mechanisms obtained by *Liemohn et al.* [1999] allow one to interpret some known experimental features in the behavior of the ring current decay parameter τ during the main (τ_{MP}) and recovery (τ_{RP}) phases of the magnetic storm [*Feldstein*, 1992]: 1) τ_{MP} values are smaller than is inferred from the charge exchange mechanism. This means that dissipation is faster; 2) τ_{MP} is controlled by the rate of energy injection into the inner magnetosphere (F). τ_{MP} decreases while F increases (from $\tau_{MP} \sim 8$ hr for injection $F \sim -10$ nT/hr to $\tau_{MP} \sim 2$ hr for $F \sim -100$ nT/hr; 3) parameter τ has different values during the main phase and the recovery phase of a storm. $\tau_{MP} < \tau_{RP}$, that means faster dissipation of the ring current energy occurs during the main phase than during the recovery phase; 4) τ_{RP} increases as the ring current decays from $\tau_{RP} \sim 8$ hr for $DR \sim -100$ nT to $\tau_{RP} \sim 14$ hr for $DR \sim -10$ nT.

The above presented experimental features of the decay parameter's behavior is explained naturally on the basis of the conclusion by *Liemohn et al.* [1999] that there is an essential influence of convective drift losses on the magnetospheric energy budget. Drift losses through the dayside magnetosphere are more intensive during the main phase of a storm than during the recovery phase, and they are the largest during the intensive injections. Although injection intensities decrease as the recovery phase begins, some level of injection exists throughout the whole recovery phase especially during its early stage.

Presumably, a fast recovery of *Dst* after the main phase maximum of a storm can be caused by two reasons: particle losses due to drift through the dayside magnetopause and rapid decay of the tail current system. The energy of ions drifting through dayside magnetopause is few tens of keV while the tail current closed through dayside magnetopause is generated in the magnetospheric plasma sheet by particles with characteristic energies of about few keV. Thus these two sources for rapid *Dst* recovery are caused by two different plasma species and can exist simultaneously. The relative contribution of each species to the rapid *Dst* recovery can change from one storm to another. To determine it elaborate calculation of each contribution due to every source to *Dst*-variation is required. The Dessler-Parker relationship [*Dessler and Parker*, 1959] holds only for trapped particles in the Earth's magnetic field. One should take into account that the relation of Dessler and Parker is used by *Liemohn et al.* [1999] to determine the contribution to *Dst* by particles drifting through the dayside magnetopause. These particles are not trapped and the magnetic field generated by them should be determined by another procedure.

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