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A STATISTICAL STUDY OF MAGNETIC STORM RECOVERY PHASE: PRELIMINARY RESULTS

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ABSTRACT

A statistical study has been performed of the magnetic storm recovery phase using the Dst index for 102 storm events in the interval January 1996 to December 1998. In 43 cases (or 42%) out of our 102 events, the recovery phase exhibits fast recovery (taking about 8 hours or less) at its initial stage or for the entire recovery period. Since this fast recovery can be explained by the fast charge exchange loss of O^+ ions which mostly come from the ionosphere, and since a fraction of H^+ ions is of ionospheric origin as well, our statistical result supports the view that the source of ring current ions in many magnetic storms can be terrestrial.

Key words: storm, space weather, ring current

1. INTRODUCTION

The characteristic signature of a magnetic storm is a depression in the horizontal component of the geomagnetic field. The depression is usually monitored by the Dst index. It typically lasts over tens of hours in the storm main phase. The depression is believed to be caused mainly by an enhancement of the ring current which flows in the westward direction encircling the Earth. Then the ring current decays in the storm recovery phase primarily due to charge exchange (e.g., Jorgensen et al. 2001), Coulomb interaction (e.g., Fok et al. 1991), and wave-particle interaction processes (e.g., Daglis et al. 1999).

The standard paradigm for the ring current enhancement, namely, the cause of magnetic storms, has long been the view that storms are simply a collection of several intense substorms (e.g., Gonzalez et al. 1994, Kamide et al. 1998a). A number of recent observations, however, suggest other challenging ideas. It is suggested that the buildup of the symmetric ring current can be done by global, enhanced convection rather than substorm expansion (e.g., Russell et al. 2000). Also other observations suggest that the ring current particles are dominated by the ionospheric-origin ions (e.g., Hamilton et al. 1988).

In this work we have performed a statistical study of the storm recovery phase using 102 storm events. We illustrate that in at least 42% of our events, considerable numbers of the ring current ions come from the ionosphere rather than the tail.

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Table 1. Storm recovery phase classification.

	type I	*type II*	*type III*	*total*[1]
number of cases	37 (36%)	9 (9%)	56 (55%)	102 (100%)
$< \Delta t_r >^2$ (hr)	11.9	54.1	27.5	31.2
fast stage[3]	16 out of 37	9 out of 9	18 out of 56	43 out of 102

total[1]: sum of type I, II and III

$< \Delta t_r >^2$ (hr): average recovery time

fast stage[3]: events that show initial (or entire) stage with fast recovery rate for each of three types

2. STATISTICAL RESULTS

In order to study the storm recovery phase we have used the *Dst* index for the interval from Jan., 1996 to Dec., 1998. Only the cases with $Dst_{min} < -30$ nT were considered. Also in our statistical search the cases of multi-step development (Kamide et al. 1998b) have been excluded in the main phase but allowed in the recovery phase. We have obtained total 102 events that meet the selection criteria above.

We classify the recovery phases of all 102 events into three types as schematically shown in Figure 1. Type I is defined to be a monotonic recovery with time. Type II consists of the initial fast recovery followed by a much slower one. The multi-step recovery phase is classified as type III.

Figure 2 displays the recovery times, Δt_r, as a function of Dst_{min} for each of three recovery types. The range of Dst_{min} in the figure is -207 to -30 nT. In all three types, there is an increasing tendency of Δt_r with the magnitude of Dst_{min} although it is less evident for $Dst_{min} > -60$ or so in types I and III.

As summarized in Table 1, type III recovery patterns constitute more than half of all storms while type II cases do not appear to occur very frequently as compared to the other types. The recovery time is longest in type II events because of the relatively longer-taking second stage with slow recovery rate. The recovery time when averaged over all 102 storms is about 31.2 hours which is not too different from 36.3 hours of Yokoyama and Kamide (1997).

In all 9 events of type II, the initial fast recovery stage takes about 8 hours or less prior to entering the much slower next stage. Similarly, in 18 type III events, the initial stage in the multi-step recovery development is characterized by fast recovery pattern taking $\leq$ 8 hours. In line with this fast stage, 16 type I events also exhibit fast full recovery within 8 hours. We classify these total 43 cases as events that exhibit "fast stage" during their full or partial duration of the recovery as shown in the last row of Table 1. One might consider to classify the recovery patterns by using the "recovery rate", $dDst/dt$, rather than the "recovery time". However, the recovery rate could in general contain not only the pure decay process but also the injection effect. We think that using the recovery time is more suitable for the purpose of our present work where identifying the pure decay process is of major concern.

3. DISCUSSION AND CONCLUSION

The most interesting result in this statistical survey is the finding that 43 cases (or 42%) of 102 storms exhibit the fast stage in their recovery phase. This fast stage, of course, implies a fast loss of the ring current ions. One likely explanation for this fast loss is the charge exchange loss of O^+ ions which are of ionospheric origin since the charge exchange lifetime of O^+ ions is considerably shorter than the H^+ lifetime for ring current energies ($\geq 40keV$) (Smith & Bewtra 1978, Williams

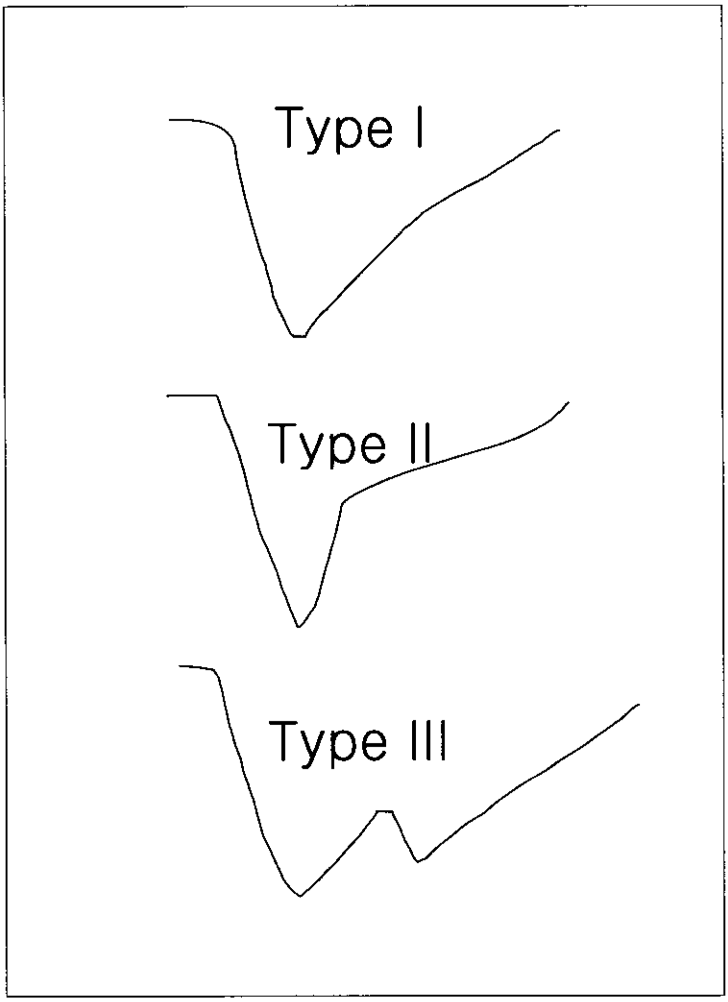

Figure 1. Schematic diagram of three types of *Dst*.

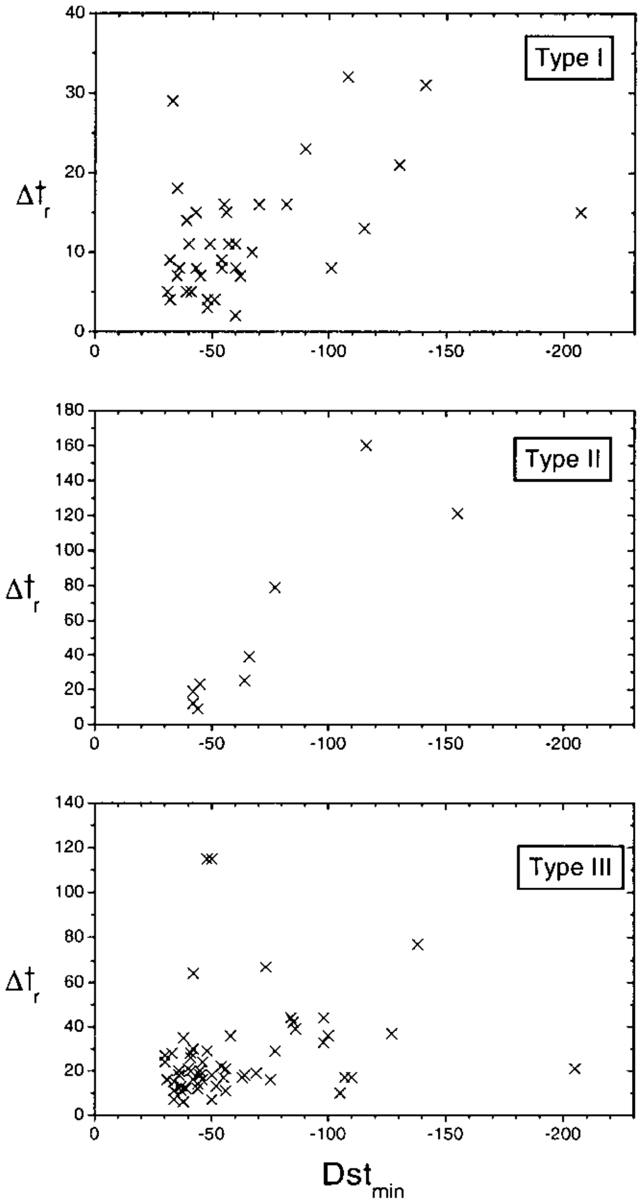

Figure 2. Recovery time as a function of Dst_{min} for three recovery types.

1985, Hamilton et al. 1988, Daglis 1997). The slower recovery part is then due to the charge exchange loss of H^+ or other loss mechanism. However, it should be also noted that a fraction of H^+ is of ionospheric origin as well. This implies that considerable number of ions, fast decaying O^+ and slow decaying H^+, may come from the ionosphere in many storms, at least 42% in the present statistical survey. Further we newly find that the appearance of the fast recovery stage is not only limited to great storms (Hamilton et al. 1988, Daglis 1997) but common over wide range of storm strength, $-155 < Dst_{min} < -30$ in our statistical survey: We have found 21 such events for $-50 < Dst_{min} < -30$, 18 events for $-100 < Dst_{min} < -51$, and 4 events for $Dst_{min} < -101$.

The existence of substantial ionospheric-origin ions during the storm sheds some light on the possible role of substorm expansion in the magnetic storm development. Hultqvist (1996) showed that outflowing ionospheric ions are accelerated by low-frequency large-amplitude electric field fluctuations which occur during intense auroral substorm activity. This suggests that intense substorms during a storm can provide not only tail particle injections but also substantial ionospheric ions which are responsible for the relatively fast decay as manifested by the fast recovery pattern in our 43 events. However, the full answer to the substorm role in a storm is only possible when the lack of correlation between nonstorm-time substorm particle injection/ionospheric outflows and storm development is explained. This matter requires further investigation.

In conclusion, we have found by studying the Dst index of 102 storms that a significant fraction of ring current ions may come from the ionosphere in many storms regardless of the storm magnitude. In future the effect of ion losses due to resonant interactions with plasma waves such as electromagnetic ion cyclotron waves should be investigated for more reliable conclusion since the lifetime for ion losses due to such a process can be substantially shorter than the lifetime due to charge exchange under some conditions (Cornwall et al. 1970). Also the possible correlation between the multi-step recovery phase of type III and the interplanetary magnetic field needs to be examined.

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REFERENCES

Cornwall, J. M., Coroniti, F. V., & Thorne, R. M. 1970, J. Geophys. Res., 75, 4699

Daglis, I. A. 1997, Magnetic Storms Geophys. Monog Ser., 98, 107

Daglis, I. A., Thorne, R. M., Baumjohann, W., & Orsini, S. 1999, Rev. Geophys., 37, 407

Fok, M. C., Kozyra, J. U., Nagy, A. F., & Cravens, T. E. 1991, J. Geophys. Res., 96, 7861

Gonzalez, W. D., Joselyn, J. A., Kamide, Y., Kroehl, H. W., Rostoker, G., & Vasyliunas, V. M. 1994, J. Geophys. Res., 99, 5771

Hamilton, D. C., Gloeckner, G., Ipavich, F. M., Studemann, W., Wilkey, B., & Kremser, G. 1988, J. Geophys. Res., 93, 14343

Hultqvist, B. 1996, J. Geophys. Res., 101, 27111

Jorgensen, A. M., Henderson, M. G., Roelof, E. C., Reeves, G. D., & Spence, H. E. 2001, J. Geophys. Res., 106, 1931

Kamide, Y., Baumjohann, W., Daglis, I. A., Gonzalez, W. D., Grande, M., Joselyn, J. A., McPherron, R. L., Phillips, J. L., Reeves, E. G. D., Rostoker, G., Sharma, A. S., Singer, H. J., Tsurutani, B. T., & Vasyliunas, V. M. 1998a, J. Geophy. Res., 103, 17728

Kamide, Y., Yokoyama, N., Gonzalez, W. D., Tsurutani, B. T., Daglis, I. A., Brekke, A., & Masuda, S. 1998b, J. Geophys. Res., 103, 6917

Russell, C. T., Lu, G., & Luhmann, J. G. 2000, Geophys. Res. Lett., 27, 1371
Smith, P. H., & Bewtra, N. K. 1978, Space Sci. Rev., 22, 301
Williams, D. J. 1985, Space Sci. Rev., 42, 375
Yokoyama, N., & Kamide, Y. 1997, J. Geophys. Res., 102, 14215