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STUDY ON THE PARTICLE INJECTIONS DURING HILDCAA INTERVALS

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ABSTRACT

The relation between substorm occurrences and HILDCAA events has been an issue. We have studied the association of particle injections with substorm onsets during HILDCAA intervals for the first half of year 2003. The examination of aurora images observed by IMAGE spacecraft and electron flux data measured by LANL satellites exhibits a close association of repetitive particle injections with substorm activity. We also find that HILDCAA events can occur equally frequently during slow speed solar wind streams as long as the interplanetary magnetic field exhibits Alfvénic wave feature.

Key words: HILDCAA events, substorm, particle injections, solar wind conditions

1. INTRODUCTION

There are times when AE (Auroral Electrojet) index is continuously high for a prolonged time intervals, which are so-called "HILDCAA (High Intensity Long Duration Continuous AE Activity)" events. The term HILDCAA was first introduced by Tsurutani & Gonzales (1987). HILDCAA was known to occur during corotating high speed solar wind streams accompanied by Alfvénic fluctuations in interplanetary magnetic fields.

Tsurutani et al. (1995a,b) have examined interplanetary magnetic field (IMF) and plasma data to investigate the causes of magnetic storms and substorms during corotating high speed solar wind streams in the declining phase of the solar cycle. HILDCAA events are usually found during the recovery phase of magnetic storms with making the recovery phase abnormally long. Also, when not in a storm time, HILDCAAs can lead to more less constant Dst of a small negative value for days.

One of the issues regarding the response of magnetosphere to HILDCAA events is to understand the physical cause for the prolonged small reduction in Dst index. As a cause for it, Tsurutani et al. (1995b) initially proposed the repetitive particle injections by consecutive substorms occurring associated with Alfvénic fluctuations. However, later Tsurutani et al. (2004) studied the relationship between AE increases and substorm onsets using POLAR UVI aurora images, and found a little (or no) correlation between them. Such results led them to suggest that enhanced inward convection by dawn-to-dusk electric fields could cause the particle injections during HILDCAAs.

Sϕraas et al. (2004, 2005) and Sandanger et al. (2005) also investigated particle injections during HILDCAA events. They obtained the results that low level decrease of Dst index during HILDCAAs is due to proton injections into the outer part of ring current regions. The reconnection between dayside magnetopause and Alfvénic waves were suggested for the cause of the enhanced particle injections.

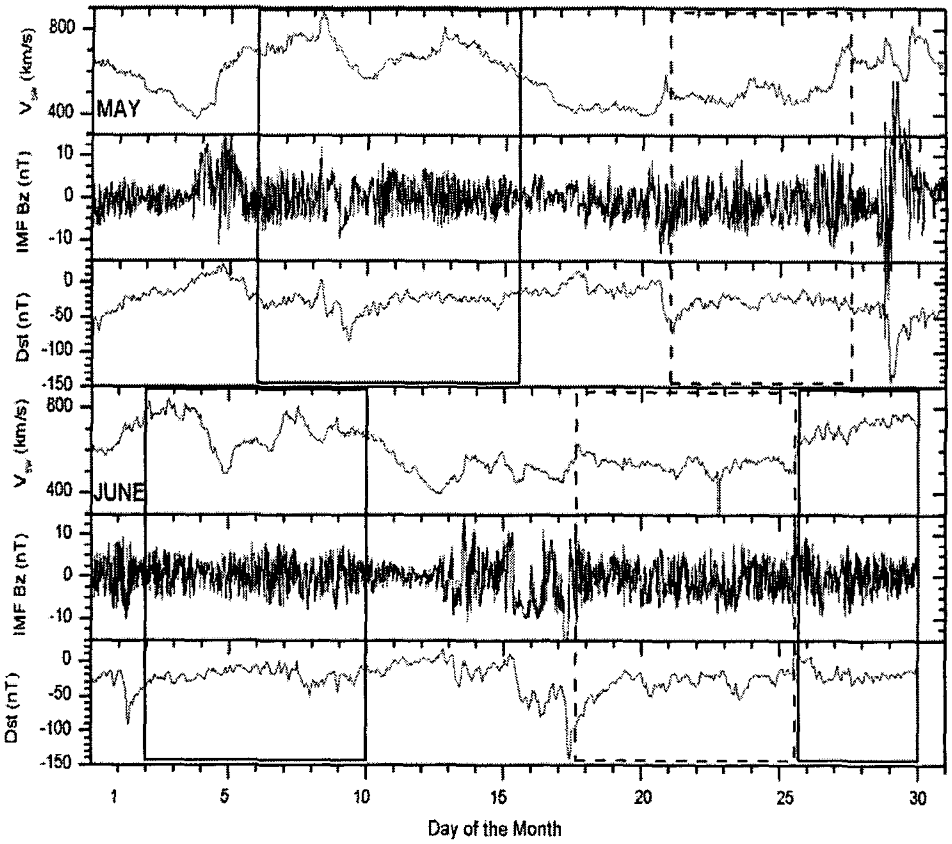

Figure 1. Solar wind parameters measured by ACE and Dst variations for May and June in 2003. HILDCAA events can occur associated with slow speed solar wind streams (dashed boxes) as well as high speed streams (solid boxes).

Substorm-associated particle injection into the inner magnetosphere is a well known feature. Although Tsurutani et al. (2004) found no clear correlation between AE increases and substorms, it does not necessarily imply that the particle injections during HILDCAAs are irrelevant to substorm activity. As a matter of fact, AE index may not be a good indicator for substorm.

The present study examines the substorm occurrence during HILDCAA intervals for January to June in 2003. We analyze geosynchronous electron flux data and aurora images to survey the relationship between particle injections and auroral substorm onsets. Repetitively occurring electron injections with a 0.5-4 hour period are found to be closely associated with substorm activity. These continuous substorm-associated electron injections would contribute to the sustained small decreases in Dst. HILDCAA intervals can be identified by using the data of IMF Bz and Dst index without knowing AE values. That is, if IMF Bz shows Alfvénic waves and Dst persists more or less constant within 0 to –50 nT for days, one can expect a HILDCAA interval. As the Alfvénic wave feature in interplanetary magnetic fields can appear regardless of the solar wind speed, it is unrare to observe HILDCAA intervals even during slow speed streams.

Table 1. HILDCAA intervals for Jan - June, 2003.

High speed streams	Slow speed streams
1/19-1/26	2/6-2/9
2/15-2/25 (no IMAGE data for 2/15-2/18)	3/4-3/11
3/15-3/24	4/21-4/27
4/10-4/18 (no IMAGE data)	5/22-5/27
5/7-5/16	6/19-6/26
6/3-6/10, 6/27-6/30	

2. RESULTS OF DATA ANALYSIS

In order to investigate the association between substorms and repetitive particle injections, we first need to identify HILDCAA intervals. As AE index is not available for 2003, we can not find HILDCAAs based on AE variations. However, the HILDCAA intervals can be obtained by examining solar wind data and Dst index. As depicted in Figure 1, there are time intervals of large amplitude Alfvénic IMF Bz fluctuations and prolonged small decreases in Dst index. It is notable that HILDCAAs can be accompanied either by high speed solar wind streams (solid box) or by slow speed streams (dashed box). Quick-Look AE data provided at the URL http://swdcwww.kugi.kyoto-u.ac.jp/aedir/quick.html show high AE values during the designated time periods.

Table 1 shows the HILDCAA intervals found for Jan-June, 2003 using solar wind data and Dst values. Note that the storm main phase of Dstmin < -50 nT and also the times of Dst < -50 nT should be excluded from the intervals in Table 1 when analyzing HILDCAA events. HILDCAA intervals can be accompanied by slow speed streams as well as high speed solar wind streams, like shown in Table 1.

Next we need to identify repetitive injections during the HILDCAA intervals, using LANL electron flux data. In the present study, particle injections are called repetitive when at least three injections take place consecutively with 0.5-4 hour period. Total 415 repetitive injections are identified for the HILDCAA intervals in Table 1 from which, however, the times of no IMAGE data available and dissatisfied Dst conditions are excluded.

Figure 2 shows an example of repetitive particle injections on May 7 measured by six LANL satellites located at different local times. Local noon and midnight of each satellite are denoted by thick gray and black lines, respectively. Solid and dashed lines across the panels indicate the electron flux injection events. Sharp flux enhancements at all energy channels start near local midnight and then drift to other local times with energy dispersion. On May 7, there are total 12 repetitive injections found.

For the study of substorm association, we then examined aurora images observed by IMAGE-FUV instrument at the times of particle injections. The IMAGE spacecraft was launched on March 2000 in a highly elliptical polar orbit with the orbital period of about 14.14 hours (Mende et al. 2000). Due to the orbital limitation and the data quality, meaningful comparison with aurora data was made only for 116 events out of 415 repetitive injections.

The aurora image data provided in the IMAGE-FUV web-site at the URL http://sprg.ssl.berkeley.edu/image/ show the auroral brightening for all the 116 injection events. For a robust check of the occurrence of substorm onsets, we utilized the substorm onset list by Frey & Mende (2006). Frey & Mende (2006) summarized substorm onset observations measured by IMAGE-FUV for May 2000 - December 2005. The criterior for the substorm onset identification used in Frey et al. (2004) is as follows: (1) a clear local brightening of aurora has to take place. (2) The aurora has to expand to the

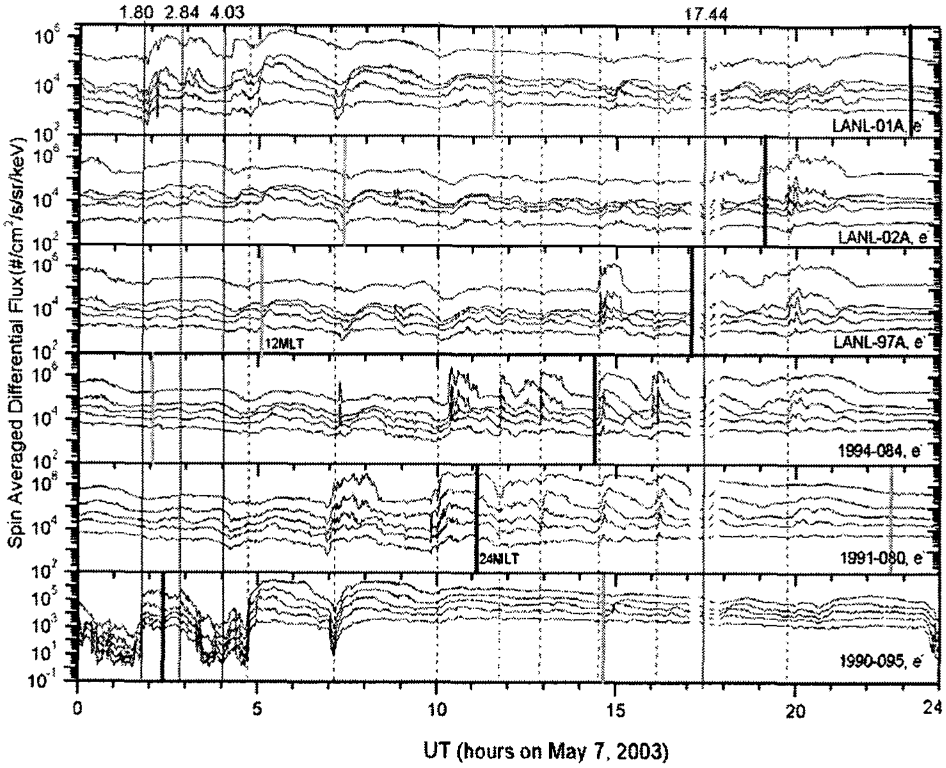

Figure 2. Electron flux data by six different LANL spacecrafts for energies of 50-75 keV, 75-105 keV, 105-150 keV, 150-225 keV, 225-315 keV. Vertical (solid and dashed) lines across the panels indicate electron injection events. Solid lines denote the four injection events for which IMAGE aurora data were able to determine the occurrence of a substorm.

poleward boundary of the auroral oval and spread azimuthally in local time for at least 20 min. (3) A substorm onset is accepted as a separate event only when it occurs at least 30 min. after the previous onset.

Among 116 events, 100 injection events match with the substorm onsets on the list by Frey and Mende. For the rest of the events, careful examination is required to determine whether the observed auroral brightenings are for pseudo-breakups, multiple onsets, or substorm onsets which are missed in Frey and Mende list. This will be performed in a future study.

The four electron injection events on May 7, denoted by solid lines in Figure 2, are examples of the 100 substorm-associated injections. The numbers above the top panel indicate the UT of the injection events. Those times are marked as cross in the trajectory of IMAGE spacecraft in Figure 3. The time gaps between injection events and the associated substorm onsets are within 5 min. for about 80% of the identified substorm-associated events. And the rest are either within $\sim$10 min. time gap or unable to determine the precise injection time for no LANL satellite near local midnight.

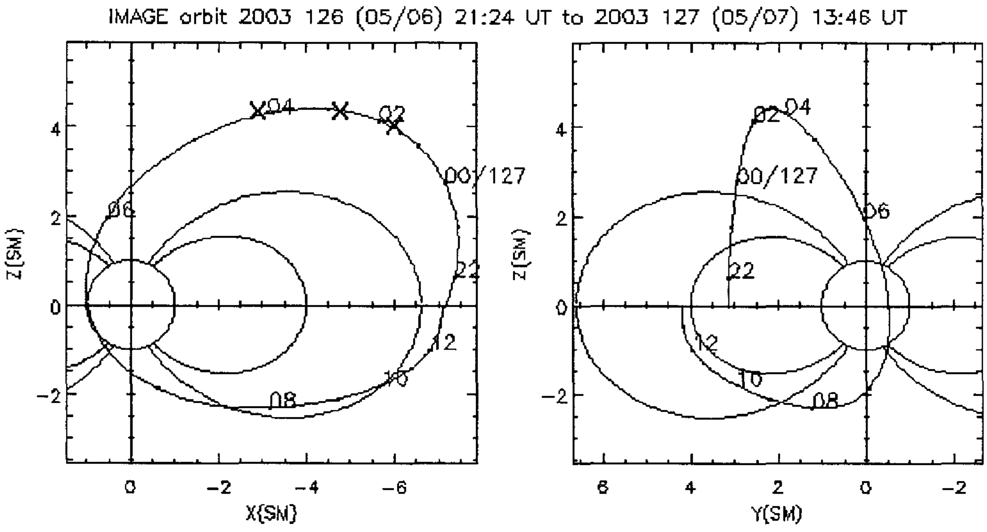

Figure 3. IMAGE trajectory for an interval of May 7. The crosses on the left panel indicate the locations of IMAGE satellite when auroral onset brightening were observed. Around those times, particle injection events took place, as depicted in Figure 2.

3. DISCUSSION

We analyzed LANL electron flux data and aurora images observed by IMAGE-FUV to survey the relationship between particle injections and auroral substorm onsets during HILDCAA intervals. All of the repetitive injection events for which the occurrence of substorm onsets were checked are found to be substorm-associated. About 80% of the events took place within 5 min. from the auroral onset brightenings. These results lead us to the conclusion that the repetitive particle injections during HILDCAAs are associated with substorm activity. And thus such continuous substorm-associated electron injections may account for the prolonged low level of Dst decrease.

A sustained time period of Alfvénic fluctuations in IMF Bz and more or less constant small decrease in Dst, which are apparently caused by Alfvénic Bz changes, is the primary feature of the HILDCAAs. Therefore, HILDCAA intervals can be identified by using IMF Bz and Dst data without invoking AE index. Also, as the Alfvénic waves in interplanetary magnetic fields can appear regardless of the speed of solar wind streams, it is not rare to observe so-called HILDCAA intervals even during slow speed solar wind streams.

Recently Lee et al. (2006) found that the repetitive particle injections during high speed solar wind streams are associated with the northward turnings of IMF Bz. In order to complete the present study on the association of repetitive particle injections with substorm onsets, we will examine the substorm signatures observed by space- and ground-based magnetometers as well as POLAR aurora data in future.

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REFERENCES

Frey, H. U. & Mende, S. B. 2006, in Proc. 8th Int. Conf. Substorms (ICS-8), eds. M. T. Syrjasuo & E. F. Donovan (Alberta: University of Calgery), p.71

Frey, H. U., Mende, S. B., Angelopoulos, V., & Donovan, E. F. 2004, JGR, 109, doi:10.1029/2004JA010607

Lee, D.-Y., Lyons, L. R., Kim, K. C., Baek, J.-H., Kim, K.-H., Kim, H.-J., Weygand, J., Moon, Y.-J., Cho, K.-S., Park, Y. D., & Han, W. 2006, JGR, 111, doi:10.1029/2006JA011685

Mende, S. B., Heetderks, H., Frey, H. U., Stock, J. M., Lampton, M., Geller, S. P., Abiad, R., Siegmund, O. H. W., Habraken, S., Renotte, E., Jamar, C., Rochus, P., Gerard, J.-C., Sigler. R., & Lauche, H. 2000, Space Sci. Rev., 91, 287

Sandanger, M. I., Soraas, F., Aarsnes, K., Oksavik, K., Evans, D. S., & Greer, M. S. 2005, in the Inner magnetosphere: Physics and Modeling, vol.155, Geophys. Monogr. Ser., eds. T. I. Pulkkinen, N. A. Tsyganenko, & R. H. W. Friedel (Washington, D.C.: AGU), p.249

Sϕraas, F., Aarsnes, K., Carlsen, D. V., Oksavik, K., & Evans, D. S. 2005, in the Inner magnetosphere: Physics and Modeling, Geophys. Monogr. Ser., vol.155, eds. T. I. Pulkkinen, N. A. Tsyganenko & R. H. W. Friedel (Washington, D.C.: AGU), p.237

Sϕraas, F., Aarsnes, K., Oksavik, K., Sandanger, M. I., Evans, D. S., & Greer, M. S. 2004, J. Atmos. Sol. Terr. Phys., 66, 177

Tsurutani, B. T. & Gonzales, W. D. 1987, Planet. Spce Sci., 35, 405

Tsurutani, B. T., Gonzales, W. D., Gonzales, A. L. C., Frances, T., Arballo, J. K., & Okada, M. 1995a, JGR, 100, 21717

Tsurutani, B. T., Gonzales, W. D., Guarnieri, F., Kamide, Y., Zhou, X., & Arballo, J. K. 2004, J. Atmos. Sol. Terr. Phys. 66, 167

Tsurutani, B. T., Ho, C. M., Arballo, J. K., & Goldstein, B. E. 1995b, GRL, 22, 3397