Spontaneous and trigger-associated substorms compared: Electrodynamic parameters in the polar ionosphere

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**Background:**

- **Current debate on substorm triggering**
  - Substorms are triggered by changes in the solar wind, including sudden a northward turning of the IMF, and a reduction in the magnitude of IMF $B_y$, as well as sudden changes in the solar wind dynamic pressure. [Caan et al., 1975, 1977; Rostoker 1982, 1983; Lyons 1995; Kokubun et al., 1977; Troshichev 1977]
  - Substorm results from plasma instabilities within the magnetosphere. [Horwitz 1985; McPherron et al., 1986; Henderson et al., 1996; Angelopoulos et al., 1996]

- **Statistical Results**
  - McPherron et al. [1986]: IMF northward turning was responsible for triggering 44% of substorm onset, while 28% without triggers
  - Hsu and McPherron [2003]: At least 40% substorms occur without obvious IMF triggering
• *Hsu and McPherron* [2004, 2009] found that the two types of substorms hold the same signatures, such as Pi2 pulsations and depolarization in the magnetotail. They also demonstrated that the magnitude of the response is stronger for triggered substorms than for spontaneous substorms.
Objective of our study:

Instead of quantifying the intensity of substorms based only on the AL index, the present study investigates the development of electrodynamic parameters, including the ionospheric current vector, the electric potential, and the current function in the polar ionosphere for spontaneous and trigger-associated substorms to examine whether there is a critical difference between the two categories of substorms in terms of the two-dimensional distribution of ionospheric parameters.
Event selection: IMAGE FUV data and AL index:

Auroral breakup and a sharp decrease in AL were needed for a chosen substorm.

Triggered-associated substorm: A substorm that occurred following a northward turning of the IMF.

Spontaneous substorm: a substorm event that occurred during a relatively steady IMF condition (in Bz, By, and dynamic pressure)

Five phases of spontaneous substorms and trigger-associated substorms were identified: Quiet time, Growth phase, Expansion phase, Peak time, and Recovery phase.
Data and Procedure (2)

- Magnetic data on the ground:
  - Ground magnetometer data from 101 stations at high latitudes (IMAGE, Greenland, CARISMA, CANMOS, MACCS, 210MM, ALASKA, and stations included in WDC and INTERMAG) constitute our database.
  - The KRM programme [Kamide et al., 1981] was utilized to deduce the distribution of ionospheric current vectors and the electric potential, as well as the current function for all substorm events.
  - The statistical distribution of the electrodynamic parameters at the five phases was determined by averaging all the 5 min data on the parameters during the corresponding phase.
Current vector in the polar ionosphere

**Similarity:**
- Gradual increase of the eastward and westward current at the growth phase;
- Abrupt enhancement of the current around the midnight sector at the expansion phase

**Difference:** the current on the night side extending from midnight through early morning sector decreases rapidly. However, for spontaneous substorms, only a small decrease in the early morning sector is seen, although there is a sharp decrease of the current around the midnight sector.
**Electric potential**

**Difference (1):** From the quiet time to the growth phase, PCP increases from 16 kV to 29 kV, by a factor of 81% for spontaneous substorms, while for trigger-associated substorms, an increase only by 36% is noted. On the other hand, from the growth phase to the peak time, the PCP increase of 34% and 84% is obtained for spontaneous and trigger-associated substorms.

**Difference (2):** At the recovery phase, PCP decreases only slightly during recovery phase of spontaneous substorms, while for trigger-associated substorms, PCP shows a drastic decrease.
Current function (equivalent current)

Similarity:
- Two-cell convection pattern
- Obvious enhancement of the current near the midnight sector

Difference:
The average maximum total current is 0.313 MA and 0.402 MA for spontaneous and trigger-associated substorms.
Similarity between spontaneous and trigger-associated substorms

- A two-cell current system begins to enhance at the growth phase, and the westward electrojet near midnight begins to develop explosively at the expansion onset. The potential drop across the polar cap continues to increase from the growth phase to the peak of substorms. These features are consistent with those of typical substorms studied by Ahn et al. [1995], Kamide et al. [1996] and Cai et al. [2006].

Directly driven process and unloading process coexist during both spontaneous and trigger-associated substorms
Discussion (2)

Difference between spontaneous and trigger-associated substorms (1)

At the growth phase, a PCP enhancement existed for spontaneous substorm.

This means that the spontaneous substorms are subject to much stronger energy storage available to substorms to come. If there is no IMF triggering, as is the case for spontaneous substorms, the amount of energy stored in the tail lobe by the time of the end of the growth phase would be larger, leading to a larger PCP value. On the other hand, it seems likely that the magnetotail with more energy stored provides a more preferable condition for the instabilities for expansion onset to develop.
Difference (2): Expansion phase

After the expansion onset, a larger PCP enhancement exists for trigger-associated substorms.

PCP enhancement associated with substorm expansion onset is related to the effects of the polarization of electric fields in the ionosphere, which is enhanced considerably during the expansion phase of substorms, having a direct relationship with the unloading process [Kamide et al. 1996].

A relatively effective polarization process must works for trigger-associated substorms.
Difference (3): Recovery phase

A large PCP and a strong current at the early morning sector still exist for spontaneous substorm.

For trigger-associated substorms, a large decrease of PCP occurred after the peak, meanwhile the current at the nightside and the early morning sector decrease sharply.

Spontaneous substorm: a still strong directly driven process in association with the southward IMF

Trigger-associated substorms: a weak directly driven process and a sharp decrease of the unloading process
Summary

- Our statistical study demonstrates that nearly no differences exist in essence between the two types of substorms in sense that both the directly driven process and the unloading process do coexist during both types of substorms.

- Some differences do exist. The enhancement of the polar cap potential is more obvious at the growth phase for spontaneous substorms. At the expansion phase, a larger enhancement of the polar cap potential exists for trigger-associated substorms. These results suggest that the spontaneous substorms have a more powerful growth phase, dominated by the directly driven process, while the unloading process seems to play a much more important role in trigger-associated substorms. A strong directly driven process at the recovery phase of spontaneous substorms. For trigger-associated substorms, however, both the directly driven process and the unloading process become weak after the peak time of substorms.

Thanks