

## ARE THE SUBSTORM ONSETS TRIGGERED OR SPONTANEOUS?

Yu.P. Maltsev (*Polar Geophysical Institute, Apatity, Russia*)

**Abstract.** The average behavior of the solar wind parameters in the course of substorms was analyzed with the use of the superimposed epoch method. The onset was assumed to be a zero time. The solar wind data with five-minute resolution were used. It is shown that the onset is not accompanied by any sufficiently sharp changes in the IMF  $B_z$ , IMF modulus, and solar wind dynamic pressure. An average substorm occurs under negative  $B_z$ , the average integral of  $B_z$  over the time from the moment of the southward turning of  $B_z$  up to the substorm onset being  $\sim 140$  nT $\times$ minutes. This proves in favor of spontaneous nature of onsets.

### Introduction

Substorm onset marks the transition from a comparatively quiet growth stage to the explosive stage. Whether this transition is spontaneous, i.e. initiated by some magnetospheric processes, or it is caused by sharp changes in the solar wind, is a subject of many controversies.

The supporters of the spontaneous origin of the onsets point out distinct changes in the magnetosphere that are associated with accumulation of energy and can lead to an explosive energy release. In particular, the tailward stretching of the magnetic field lines at the growth stage is accompanied by thinning of the current sheet in the magnetotail. If the factors leading to the thinning act permanently the cross-tail current eventually disrupts. The field line collapse will give rise to dipolarization and to release of the accumulated energy.

The supporters of the triggered origin of the onsets try to find sharp changes in the solar wind occurring simultaneously with the substorm onsets. Usually one looks for jumps in the two parameters: the north-south IMF component and solar wind dynamic pressure. Many onsets occur without any jump. Such substorms are generally known as spontaneous. Some onsets happen almost simultaneously either with jumps of the IMF northward [Caan *et al.*, 1977] or with leaps in the dynamic pressure [Kawasaki *et al.*, 1971; Burch, 1972; Kokubun *et al.*, 1977]. Such substorms are called triggered.

The question is whether these changes really serve as a detonator for explosion or they just occasionally coincide with it in time. After all, many sharp changes in the solar wind do not lead to any substorm onset. The answer can be obtained from statistics, in particular, by superimposed epoch analysis with assuming the onset to be a zero time. Foster *et al.* [1971] did not find statistically any distinct changes in the solar wind related to substorm onsets. Caan *et al.* [1975] having superimposed 20 onsets (the IMF data being available for 15 events) obtained the northward IMF turning at the very instance of the substorm explosion onset. The same authors after using more representative statistics denied this result. After processing 1800 onsets, Caan *et al.* [1978] showed that the averaged IMF displayed no sharp changes. Sergeev *et al.* [1986], having obtained the similar result by superimposing 80 substorms stressed that northward step-like IMF variations occurred more often near the onset.

In spite of the absence of statistical relation of the onsets to any distinct changes in the solar wind, the idea of triggered onsets is still rather popular. For instance, Lyons [1995] suggested a substorm mechanism in which the onset is triggered by a deceleration of magnetospheric convection caused by a northward IMF turning.

The aim of this paper is to look once more for any relation of the substorm onset to changes in the  $z$ -component, modulus of the IMF, and solar wind dynamic pressure as well as to discuss the role of the northward and southward step-like IMF variations.

### Results

In Table 1 are shown the moments of 49 substorm onsets chosen from Proceedings of ICS1 and ICS3. The solar wind data obtained by the IMP-8 satellite with 5-minute resolution were used. The data are recorded at a CD-ROM prepared by the Institute of Geophysics and Planetary Physics, UCLA.

Figure 1 shows averaged behavior of some solar wind parameters obtained by the superimposed epoch method for the 49 substorms. The zero time corresponds to the substorm onset. The behavior of  $B_z$ IMF is shown on the top panel by the solid line. The IMF data are available for 61% of time, which corresponds to about 30 "complete" substorms. The dashed line shows the results of Caan *et al.* [1978]. The both curves do not expose any distinct changes in  $B_z$ IMF at  $t = 0$ .

**Table 1.** Moments of onsets used (year, month, day of month, day of year, hour, minute)

76 03 03 063 20 00	79 08 22 234 08 40	85 05 02 122 10 23	86 07 27 208 12 16
78 04 03 093 23 58	79 11 13 317 06 46	86 01 02 002 03 27	86 07 29 210 07 29
79 01 15 015 19 27	80 02 16 047 06 55	86 01 08 008 00 17	86 08 03 215 20 15
79 01 19 019 23 43	81 10 20 293 16 51	86 03 25 084 20 00	86 08 28 240 11 53
79 01 22 022 22 30	81 10 20 293 18 56	86 03 25 084 22 00	86 09 19 262 16 33
79 01 26 026 19 35	81 10 20 293 20 35	86 03 25 084 23 00	86 10 19 292 11 32
79 01 30 030 20 35	81 11 08 312 08 00	86 03 26 085 01 20	88 01 14 014 15 40
79 03 04 063 00 11	81 12 02 336 21 34	86 04 01 091 18 51	88 06 13 165 02 11
79 03 04 063 22 36	85 04 10 100 22 00	86 04 09 099 17 40	86 08 31 244 20 27
79 03 22 081 11 24	85 04 11 101 01 20	86 05 03 123 01 11	91 01 24 024 00 25
79 03 22 081 14 36	85 04 11 101 03 45	86 05 03 123 09 36	91 03 04 063 19 38
79 04 24 083 11 12	85 05 02 122 09 00	86 05 08 128 12 15	91 06 11 162 17 05
79 07 06 187 19 25			

The averaged dynamic pressure of the solar wind is presented on the middle panel. One can see no significant changes at  $t = 0$  either. However, the pressure data are very scarce, ~14%, which corresponds to 7 “complete” substorms. But in this case the IMF modulus  $|B|$  must change at the pressure jump. To check it up  $|B|$  was also averaged over 30 “complete” substorms (the bottom panel). One can see that there are no visible changes in  $|B|$  that proves the absence of pressure leaps at  $t = 0$ .

Figure 1 shows that both the dynamic pressure and IMF modulus are enhanced during substorms. The pressure is ~4 nPa for four hours prior the onset and ~3 nPa for four hours after the onset (the pressure of the quiet solar wind being of about 2 nPa),  $|B| \approx 12$  nT instead of ~5 nT for quiet wind.

The distribution of the onsets under various  $B_z$  IMF is shown in Figure 2. The  $B_z$  component for each event was averaged within the 2-hour time interval, one hour before the onset and one hour after it. The spread is rather large, nearly  $\pm 5$  nT. About a quarter of substorms occur under northward IMF.

### Discussion

Figure 1 proves in favor of the spontaneous nature of onsets. As it is commonly supposed the southward IMF component leads to accumulation of energy in the magnetosphere. After exceeding some threshold, this energy begins releasing explosively. The threshold southward flux may be estimated as follows

$$F = - \int_{\tau_0}^0 B_z dt$$

where  $t = \tau_0$  corresponds to the southward turning of the IMF,  $t = 0$  corresponds to the onset of the substorm explosive stage. The solid line in Figure 1 yields  $\tau_0 \approx -70$  minutes and  $F \approx 140$  nT×minutes. *Caan et al.* [1978] assumed  $\tau_0 \approx -4$  hours and obtained  $F = 74$  nT×minutes for weak substorms (with the mid-latitude intensity  $H = 10-11$  nT),  $F = 244$  nT×minutes for moderate substorms ( $H = 12-15$  nT), and  $F = 298$  nT×minutes for strong substorms ( $H \geq 16$  nT). *Dmitrieva and Sergeev* [1985] obtained  $F = 255$  nT×minutes for isolated substorms.

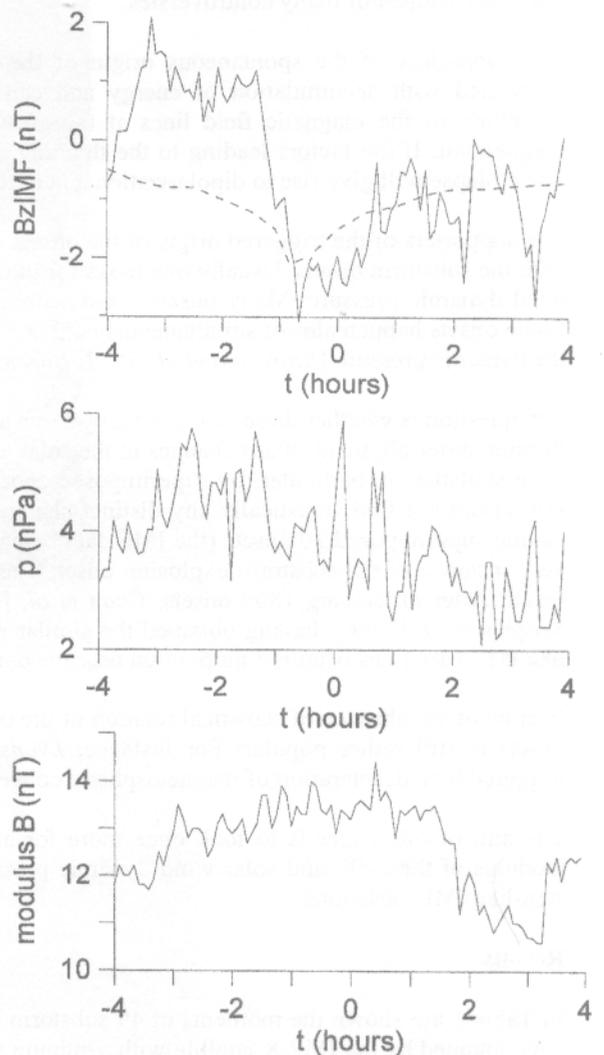


Figure 1. Averaged behavior of the  $B_z$  IMF (the top panel), solar wind dynamic pressure (the middle panel), and IMF modulus (the bottom panel) for 49 substorms. The dashed line at the top panel shows the results of *Caan et al.* [1978].

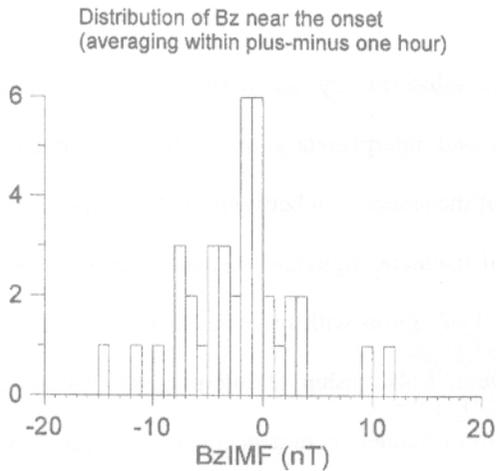


Figure 2. The histogram showing the distribution of the onsets under various  $B_z$ .

The same order of  $F$  can be obtained from the paper by *Sergeev et al.* [1986] where along with the superimposed epoch analysis a supplementary study of IMF step-like variations was performed. Some results of that paper are reproduced in Figure 3.

*Sergeev et al.* [1986] argue that there are the following three reasons in favor of triggered nature of the onsets:

- 1) the onsets occur in average on the recovery of the IMF southward component (Figure 3a);
- 2) the positive IMF step-like variations dominate near the substorm onsets (Figure 3c);
- 3) the time delay between the changes in the polar cap convection and substorm onsets correlates with the solar wind discontinuity orientation (Figure 3d).

Nevertheless all the three reasons are not sufficiently convincing:

- 1) Even if substorm onset does not relate to the solar wind it must occur on either growth or recovery stage of the southward IMF. The fact the onsets happen on the recovery stage can be just an occasion result.
- 2) It is quite natural that the positive IMF step-like variations are concentrated on the recovery stage of the southward IMF. At the stage of  $B_z$  descending (30-60 minutes before the onset) one can see the dominance of the negative step-like variations (Figure 3b).
- 3) The correlation of the time delay  $t_{pi} - t_{PC}$  with  $n_x$  shown in Figure 3d can be caused by the  $n_x$  correlation with  $t_{PC}$  but not with  $t_{pi}$ .

### Conclusions

Averaged behavior of the solar wind parameters does not expose any sharp changes of  $B_z$ , IMF modulus, and dynamic pressure at the onset of the substorm explosive stage. This proves in favor of spontaneous nature of onsets owing to some internal magnetospheric processes. The energy for the substorms is loaded due to the IMF southward flux. Dominance of positive step-like variations near onset may be connected with the recovery of the southward IMF and does not prove that some onsets are triggered.

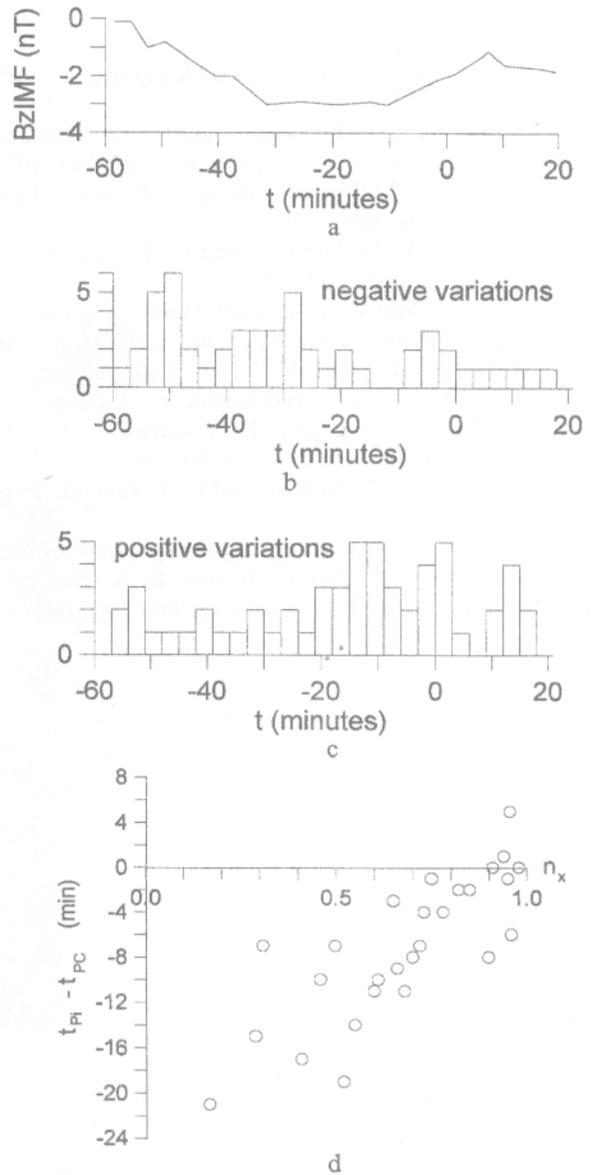


Figure 3. Results of the paper by *Sergeev et al.* [1986]. a). The averaged  $B_zIMF$  for 29 isolated AE events with a clear impulsive spike of AL index within 15 min from the zero time. b). The histogram showing the distribution of the cases of negative step-like variations of  $B_zIMF$  for 80 substorm events. c). The same as in Figure 2b but for positive step-like variations. d). The time delays between the changes of the polar cap convection and substorm onsets for 27 events;  $t_{pi}$  is the moment of the onset determined as a train of Pi2 pulsation;  $t_{PC}$  is the moment of the weakening of the convection;  $n_x$  is the projection of the normal to the x-axis of the solar wind discontinuity.

## References

- Burch, J. L., Preconditions for the triggering of polar magnetic substorms by storm sudden commencements, *J. Geophys. Res.*, 77, 5629, 1972.
- Caan, M. N., R. L. McPherron, and C. T. Russell, Substorm and interplanetary magnetic field effects on the geomagnetic tail lobes, *J. Geophys. Res.*, 80, 191, 1975.
- Caan, M. N., R. L. McPherron, and C. T. Russell, Characteristics of the association between the IMF and substorms, *J. Geophys. Res.*, 82, 4837, 1977.
- Caan, M. N., R. L. McPherron, and C. T. Russell, The statistical magnetic signature of magnetospheric substorms, *Planet. Space Sci.*, 26, 269, 1978.
- Dmitrieva, N. P., and V. A. Sergeev, Duration of the growth stage of substorms with spontaneous onset of explosion (in Russian), *Geomagnetism and aeronomy*, 25(3), 425, 1985.
- Foster, J. C., D. H. Fairfield, K. W. Ogilvie, and T. J. Rosenberg, Relationship of interplanetary parameters and occurrence of magnetospheric substorms, *J. Geophys. Res.*, 76, 6971, 1971.
- Kawasaki, K., S.-I. Akasofu, F. Yasuhara, and C.-I. Meng, Storm sudden commencements and polar magnetic substorms, *J. Geophys. Res.*, 76, 6781, 1971.
- Kokubun, S., R. L. McPherron, and C. T. Russell, Triggering of substorms by solar wind discontinuities, *J. Geophys. Res.*, 82, 74, 1977.
- Lyons, L. R., A new theory for magnetospheric substorms, *J. Geophys. Res.*, 100, 19069, 1995.
- Sergeev, V.A., N. P. Dmitrieva, and E. S. Barkova, Triggering of substorm expansion by the IMF directional discontinuities: time delay analysis, *Planet. Space Sci.*, 34, 1109, 1986.