"Physics of Auroral Phenomena", Proc. XXII Annual Seminar, Apatity, pp.105-108, 1999

Polar
Geophysical
Institute

PERIODIC SUBSTORM ONSETS ON THE BASIS OF COORDINATED GROUND SATELLITE OBSERVATIONS

V.R. Tagirov *(Polar Geophysical Institute, Apatity, Russia)*
V.A. Arinin *(Russian Federal Nuclear Center, Sarov, Russia)*
K. Liou, C.-I.Meng, and D.G.Sibeck *(The John Hopkins University, Applied Physics Laboratory, Laurel, USA)*

Abstract. We have conducted a campaign of auroral substorm observations using a low-light-level all-sky TV observations at Loparskaya (65.0º N, 114.2º E geomagnetic) located on the Kola Peninsula in northwest Russia. We produce keograms to compare the ground observations with those in the ultraviolet and visible wavelength range by the UVI and VIS instruments on the POLAR spacecraft during a three-hour sequence of substorm onsets on December 9, 1996. The ground and spacecraft observations provided remarkably similar views of periodic onsets leading to substorms with about 75 min durations. Only UVI recorded the weak first onset at Λ = 66º to 68º and 2020 UT. The next onset was more intense and occurred at Λ = 64º to 67º and 2132 UT. The third one was very strong and started at at Λ = 63º to 65º and 2250 UT. It ultimately expanded throughout the entire oval and widened in the longitudinal direction to cover more than 1000 km. From this, we conclude that the more intense onsets occur closer to the Earth. The aurora leapt poleward and then moved equatorward during all the onsets. The IMF conditions that preceded the three were very different. The first onset took place for slightly positive and constant IMF B_Z component, the second for slightly negative IMF B_Z, and the third for a ~40 min interval of strong negative constant IMF B_Z (~ -14 nT). There were no obvious IMF or solar wind plasma triggers. While external factors did not trigger the substorm onsets, they played a very important role in determining substorm intensity and dimensions.

Introduction

At present there are different approaches to the triggering factors, which lead to substorm onset and expansion. One of them is that the main triggering factor has the external nature which can be sharp variations in IMF B_Y and/or B_Z components or in solar wind parameters [*Lyons*, 1995]. Another point is that the triggering factor of substorm could have internal nature as, for example, current disruption in the magnetosphere (see, e.g., *Lui* [1996]).

Another problem, which at present attracts an attention is spatial scales of substorms and naturally connected with it the problem of where is the boundary between "pseudo-breakups" and substorm onsets [*Koskinen et al*., 1993; *Nakamura et al*, 1994; *Pulkkinen et al*, 1996; *Tagirov et al,* 1998].

In conjunction with NASA's Polar satellite program, we have conducted a campaign of auroral substorm observations using a low-light-level all-sky TV camera with fish-eye lens at Loparskaya (68.6° N, 33.3° E geographic, 65.0° N, 114.2° E geomagnetic) located at Kola Peninsula, North-West of Russia. The observations were carried out during the winter season from October 1996 to April 1997. The total amount of auroral TV data was more than 300 hours of observations.

In this paper, we present the results of local and global optical observations of three consequent nightside auroral breakup onsets on December 9-10, 1996. The onsets were distinctly registered both by ground-based all-sky TV camera and POLAR satellite optical instruments in UVI and visible wavelength range. The whole range of optical observation presented here covered the interval from 2000 UT to 2400 UT on December 9, 1996. They took place at intervals of different characteristics of IMF and solar wind, which were measured by WIND satellite. The IMAGE and Greenland magnetometer network data sets were also used for analysis as well as photographic images of auroral displays from DMSP-F12 satellite.

Results of observations

Figure 1 shows simultaneous ground based and satellite optical data of auroral display for the interval from 2000 to 2400 UT on 9 December 1996. They are presented in form of keograms, which cross-sections lay across the zenith point of Loparskaya along geomagnetic meridian. The upper two panels show the behavior of auroral display registered by UVI imager in LLBH emission band. The first one of them presents the data in the full field of view of the UVI imager in geomagnetic latitude range 60º-80º, the second panel shows UVI keogram with cross-section exactly corresponding to that, which was used for presenting of ground based auroral TV data. The latter are shown in the third panel of Fig. 1. Auroral TV observations started later than satellite ones at 2121UT because of bad weather conditions. The temporal resolution of UVI observations was about 30 seconds, whereas the temporal resolution of TV keogram was 1 second. In spite of such discrepancy the keograms obtained by different methods demonstrate good similarity even in some details.

One can easily see that there were three distinct onsets of auroral substorms during the interval at the following moments and locations. The moments are shown by white arrows in the upper panel. The first one occurred at ~2021 UT at 66º-68º geomagnetic latitudes, the second one at ~2132UT between 64º-67º and the last one at ~2250 UT at 63º-65º latitude range. As it is seen from keograms the common feature of all onsets was poleward leap of auroral luminosity and then slow equatorward shift of the whole display.

POLAR satellite visual images presented by (Tagirov et al, 1998) showed characteristic development of a small auroral substorm at the interval from about 21:30 UT to 21:50 UT (the second onset). Although quiet until 2128 UT, the auroral oval was clearly disturbed by the appearance of a nightside bulge over Scandinavia at 2131 UT. POLAR VIS camera images with high spatial resolution showed that the first onset took place just above Loparskaya. The second onset occurred above Northern Atlantic, but the disturbance quickly expanded more eastward and reached Loparskaya in 1-2 minutes

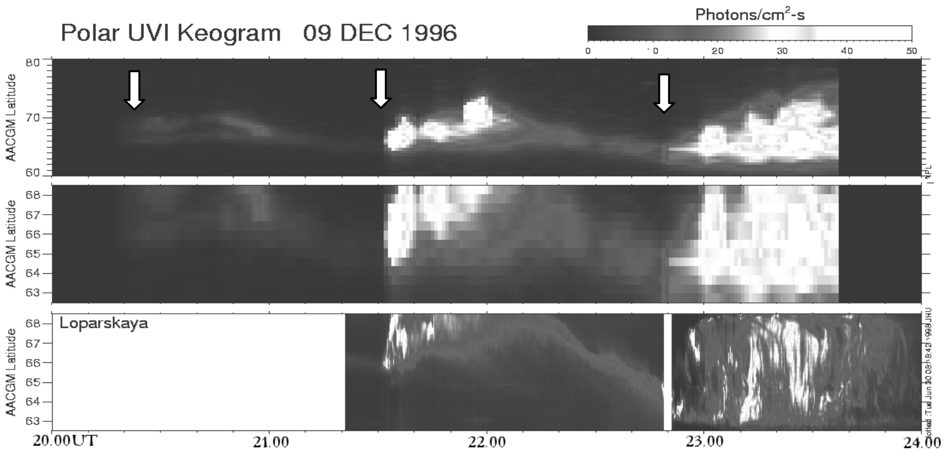

Fig.1.UVI keogram in full field of view of UVI imager on board of POLAR satellite is shown in the upper panel. The second panel shows the UVI keogram in the same field of view as ground-based all-sky TV camera at Loparskaya. The third panel presents the auroral keograms along N-S direction constructed on the basis of Loparskaya all-sky TV data.

POLAR UVI images (not shown here) indicated that the brightness and dimensions of the bulge following the second onset continued to grow until 22:09 UT. The bulge had nearly faded by 22:18 UT. The next substorm onset took place about half an hour later. There was little activity over Scandinavia at 22:43 and 22:46 UT, and only a slight increase by 2249 UT. A substantial bulge had appeared by 22:57 UT, and this bulge continued to expand until at least 00:15UT December 10 (Tagirov et al, 1998).

Figure 2 presents four pictures made from DMSP-F12 satellite showing the auroral display at various moments of our interval. The first three pictures demonstrate part of quite auroral oval before and between the onsets whereas the last one shows the moment when at last the disturbance expanded over the entire oval and widened in longitudinal direction to the scales more than 1000 km.

DMSP-F12 satellite data **December 09-10, 1996**

19:05 UT **20:47 UT** **22:29 UT** **00:10 UT**

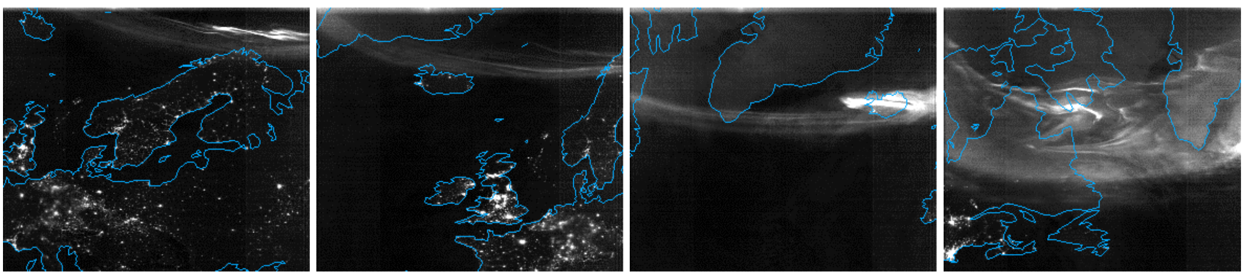

Fig.2 Pictures of auroral display, obtained by DMSP-F12 satellite at different moments of development of auroral substorms on 09 December 1996 (provided by National Geophysical Data Center, USA)

Ground optical observations indicate that the first auroral onset happened at about 21:30-21:31 UT. The intensification started from a very quiet and faint diffuse arc, which transformed into bright discrete rayed auroral structure within several tens of seconds. The auroral forms rapidly leapt poleward at 21:31 UT and propagated there up to about 21:55 UT. By about 22:00UT the forms faded to a quiet diffuse aurora and began to slowly move southwards.

The third intensification began when the poleward edge of the diffuse aurora crossed the zenith of Loparskaya as it shifted equatorwards. At first several short-living discrete forms moving westwards appeared on the poleward edge of diffuse aurora. At about 22.48 UT the auroral display developed to a burst-like onset, rapid poleward leap of discrete forms, and further development of the substorm. This one was typical. According to the keograms (Fig.1) and all-sky images (Tagirov et al, 1998) one can see very active discrete rayed forms, which appeared over Loparskaya from 22:48 to 23:11UT. Diffuse forms replaced the discrete aurora during the interval from 23:09 to about 00:00 UT. Then they were followed by pulsating aurora, which appeared at the recovery phase of substorm. Constant eastward drift of diffuse and pulsating auroral forms with velocities 600-700 m/s was observed at this interval.

Fig. 3 presents variations of X-component of geomagnetic field at IMAGE magnetometer network covering geomagnetic latitude range from 60.92° to 76.08°. The time interval from 19 to 24 UT includes all three substorms the moments of their onsets being indicated by three arrows in the upper part of the figure. One can easily see the difference between the signatures of each onset in the ground based magnetometer data. The first onset didn't cause any reply of geomagnetic field and this one, seen only in auroral UVI data from POLAR satellite didn't lead to an expanding current wedge may be considered as pseudo-breakup. **(**see, e.g., Yahnin et al, [1984]**).** The second onset was short living, local and registered mainly by stations located around Northern Scandinavia. Although there was rapid poleward leap of the auroral structures (Fig.1) the substorm didn't develop to recovery phase. But after this breakup the growth phase of another substorm started until the initiation of the regular substorm expansion, which began after the third onset. The magnetometer data (Fig.3) show that magnetic disturbance was very strong and the magnitude of disturbance exceeded 800 nT at BJO station.

The magnetograms from Greenland magnetometer network (not presented here) show that there were no any signatures nor of the first neither of the second onsets in magnetic data. The third one started approximately simultaneously with the intensification at North Scandinavia and gave rise to very intensive substorm at the eastern coast of Greenland with negative amplitude reaching -889 nT at about 72° geomagnetic latitude. At the western coast of Greenland the negative disturbance was registered about an hour later and was much weaker.

Now let us see the space conditions, which corresponded to ground-based and POLAR satellite observations, described above. Figure 4 shows WIND satellite solar wind and IMF observations during the interval from 19:00 - 24:00 UT on December 9-10, 1996. We use the WIND satellite, and ground observations to determine appropriate lag times from the solar wind monitor to the magnetosphere. Although WIND was located near GSE (x,y,z) = (65.9, -45.1, -0.6) R_E, the features which it observed arrived nearly only a few minutes later at the dayside magnetopause, thanks to the Parker spiral IMF orientation. Again we show the moments of onsets by arrows in the upper panel. Note that the first two onsets took place at relatively high solar wind pressure, which varied from 12 to 15 nPa, whereas the last, most intensive substorm occurred at the magnitude of solar wind pressured about three times less, than the previous ones. So it's improbable, that intensity of substorms was dependent on dynamic solar wind pressure. Also there were no any peculiarities in variations of IMF B_x and B_y -components, which could be considered as possible triggering factors for substorms onsets. Most interesting are variations in IMF B_z-component. About an hour-long interval of constant positive B_z-component preceded to the first, mostly weak intensification. The second onset occurred following an hour-long interval of weak southward B_z-component (-1 nT). This intensification resulted in local and short-living substorm. At last the interval of strong and constant negative B_z-component (-14 nT) preceded the third onset.

We noted above that there were no any peculiar variations of solar wind pressure preceding all of the onsets. But on the other hand the second onset and especially the third one were followed by sharp increases of solar wind pressure. The variations of solar wind

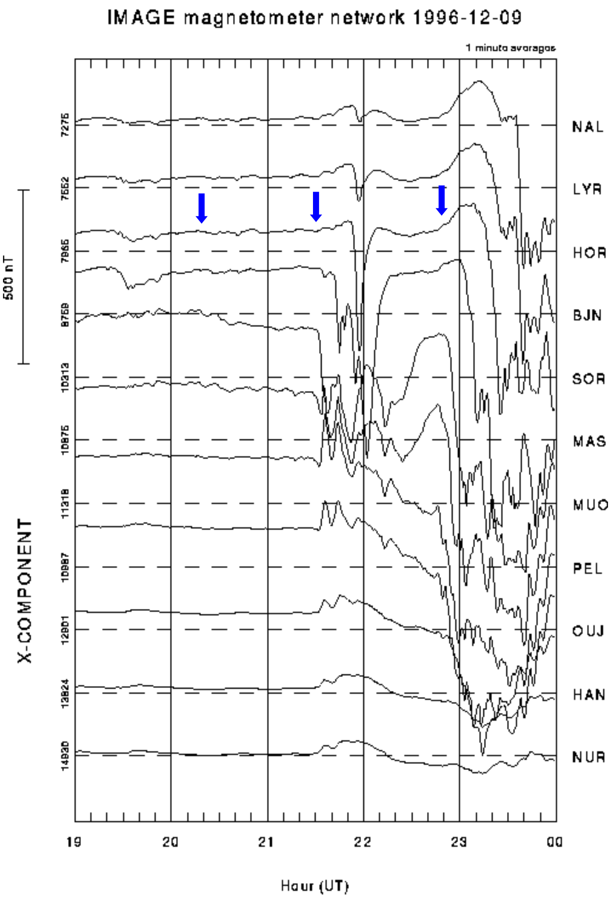

Fig.3. Variations of X-component measured on IMAGE magnetometer network. The moments of substorms onsets are indicated by arrows (provided by A.Viljanen).

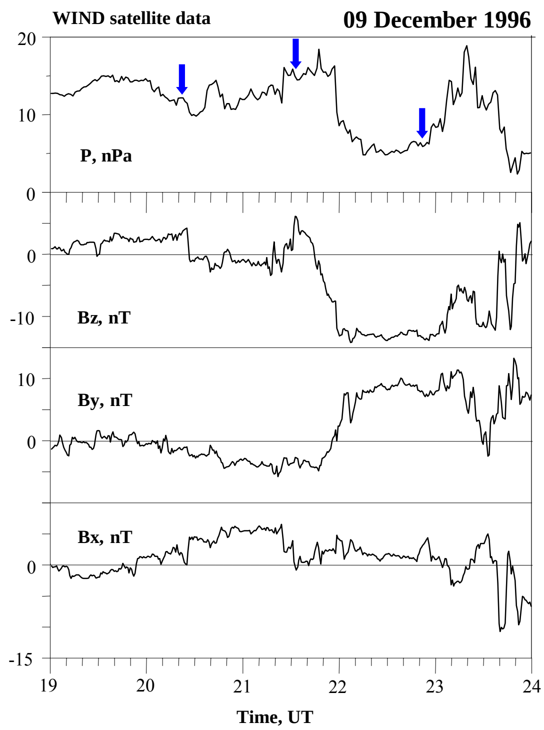

Fig.4. Variations of solar wind pressure and IMF measured by Wind satellite on December 9, 1996. The moments of substorms onsets are indicated by arrows (provided by R.P.Lepping).

pressure were due only to its density, the velocity module being stable for the whole time interval and equal to about 350 km/s during the whole interval from 19:00 to 2400UT.

Simultaneously with the solar wind pressure increase during the second onset the northward turning of IMF was observed. The increase of solar wind pressure from 22:55 to 23:20 UT (following the third onset) appears on the ground several minutes later as perturbations in the dayside GOES -8 observations from 23:00 to 23:30 UT (not presented here), thus confirming that the third onset developed to the global auroral disturbance.

Discussion

Direction of IMF plays crucial role in interaction processes between the Earth's magnetosphere and IMF. Northward directed field lines of IMF hardly reconnect with geomagnetic field lines making the magnetosphere "closed". At this situation energy flux from the solar wind doesn't transfer to magnetospheric cavity, except some very local regions of dayside region (dayside auroral transients) and far magnetosphere (more than 50 R_E). At the latter case the magnetospheric field lines are less connected with total dipole magnetic field and more freely reconnect with IMF. From the other hand at these distances stretching of the tail plays essential role. So at this moment two conditions were present: incoming energy from solar wind and formation of neutral field line. At this case a pseudo-break-up might be happen as we have seen at the case of the first onset.

During strong southward IMF, as we have seen at the third onset, the situation is different and the whole magnetosphere interacts with IMF by reconnection. The energy flow of the solar wind transferred through the whole magnetosheet. Moreover at these conditions WIND observed sharply increasing solar wind plasma pressure up to ~19 nPa, which was due only to density of the solar wind. The result was very intense magnetospheric substorm, the auroral disturbance spreading both eastwards and westwards from the midnight, covered the whole oval.

The case of second onset one can consider as transitory between the two ones mentioned above. The IMF B_z-component was slightly negative. There was small northward excursion of B_z-component about 12 minutes prior to substorm onset and the increase of solar wind pressure also happened a few minutes before it, which one might consider as triggering factors of the substorm. On the other hand it is seen (Fig.4) that about the same changes both in solar wind pressure and B_z-component happened a few tens of minutes earlier (21:40-21:50 UT), but didn't cause any magnetospheric disturbance.

Conclusion

We conclude that there were no any external factors, which could be considered as triggering mechanisms, causing substorm onsets. On the other hand the external factors are very important, because they create conditions for substorm development and display in intensity of substorms and their scales. This might be energy transfer from the solar wind into magnetospheric tail during reconnection of IMF field lines with the field lines of the Earth's magnetosphere. Triggering factors could be various instabilities inside the magnetosphere, the character of instability being dependent on its location, energy of particle flux, etc.

References

Koskinen, H.E.J., R.E.Lopez, R.J.Pellinen, T.I.Pulkkinen, D.N. Baker, and T.Bцsinger, Pseudobreakup and substorm growth phase in the magnetosphere and ionosphere, *J.Geophys.Res., 98,* 5801, 1995.

Lui, A.T.Y., Current disruption in the Earth's magnetosphere: Observations and models, *J.Geopys.Res., 101*, 13067, 1996.

Lyons, L.R., A new theory for magnetospheric substorms, *J.Geophys.Res., 100*, 19069, 1995.

Nakamura, R., D.N.Baker, T.Yamamoto, R.Belian, E.A.Bering III, J.R.Benbrook, and J.R.Theall, Particle and field signatures during pseudobreakup and major expansion onset, *J.Geophys.Res., 99*, 207, 1994.

Pulkkinen, T.I., Pseudobreakup or substorm?, *Proceedings of the Third International Conference on Substorms (ISC-3), Eur. Space Agency Spec. Publ., ESA SP-389,* 285,

Tagirov, V.R., V.A.Arinin, C.-I. Meng, D.G.Sibeck, A.T.Y. Lui, K. Liou, A.G. Ivanov, L.A. Frank, D. Morgan, and G. Parks, Comparison of two substorm onsets on the basis of coordinated ground-satellite observations, *Proceedings of the Fourth International Conference on Substorms (Substorms-4), Edited by S.Kokobun and Y.Kamide, Terra Scientific Publishing Company/Kluwer Academic Publishers,* 339, 1998.

Yahnin, A.G., V.A. Sergeev, I.B. Iyevenko, S.I. Soloviev, R.A. Rakhmatulin, Characteristics of phenomena accompanying flares of auroral arcs, (in Russian) *Magnetospheric researches No5, Moscow,* 93, 1984.