"Physics of Auroral Phenomena", Proc. XXIV Annual Seminar, Apatity, pp.17-20, 2001

Polar Geophysical Institute

POLARIZATION JET FORMATION DURING A SUBSTORM BRAKE UP PHASE: RESULTS OF GROUND- BASED MEASUREMENTS

V.L.Khalipov[1,2], Y.I.Galperin[1], A.E.Stepanov[2], L.V.Shestakova[2], E.D.Bondar'[2]
[1]*Space Research Institute, Moscow*
[2]*Institute of Cosmophysical Research and Aeronomy, Yakutsk E-mail:* Khalipov@iki.rssi.ru

Introduction

Polarization jet (PJ) phenomena or subauroral ion drifts (SAID) events were first described by Cosmos-184 data (Galperin, 1973) and then their characteristics were studied in the experiments aboard AE-C (Spiro, 1979) and S3-2 (Rich, 1980) satellites. The values of northward electric fields in these structures are 50 – 70 mV/m on average, but sometimes they can be as high as 250 mV/m. Polarization jet is observed in time sectors 18.00 - 02.00 MLT and have a latitude dimension of ~ 2 degrees.

According to DE 2 satellite measurements at ionospheric heights (~ 400 km), in the region of polarization, jet electron density N_e is reduced by 5-10 times, electron (T_e) and ion (T_i) temperatures are significantly increased and upflowing fluxes of O^+ ions with the velocity of 500 – 800 m/s are observed (Anderson, 1991).

Formation of the band of intense ion drifts result in rapid significant variations of electron density in subauroral F – region close to the polar edge of the main ionization trough. These density variations are reliably recording by ground-based ionosondes.

In the ionosphere signatures of polarization jet were studied in detail with the data of Yakutsk ionosonde chain and simultaneous satellite data (Galperin, 1986). The development of polarization jet close to the zenith of ionospheric station causes a formation of additional traces on ionograms ($F3_s$ – reflections) due to rapid (15 - 30 min.) electron density decrease in ionosphere F – region.

To understand physical processes responsible for the formation of polarization jet it is important to determine the substorm phase when this phenomenon appeared. Regular ground-based observations of ionosphere are performed every 15 minutes and have much better coverage of PJ events than satellite observations.

In the present paper the dynamics of polarization jet development during substorms is considered using the data of ionospheric station in Yakutsk (L = 3.05; MLT = UT+9^h; geographic coordinates: φ = 62°, λ = 129.8°E) and AE – indices from the World Data Center (*http://swdcdb.kugi.kyoto-u.ac.jp*). Local magnetic activity was analyzed by the data of Yakutsk and Zhigansk stations (L = 4.06, φ = 66.8°, λ = 123.4°E).

Experimental data analysis

110 cases of PJ registrations by Yakutsk station were found during 11 months of observations in winter and close to equinox in 1989-1991. It was found that PJ develops at the latitude of Yakutsk (L = 3) at night hours when the value of AE index is higher than 500 nT. The moments of PJ appearance in the ionograms were compared with the times of substorm disturbances with AE ~ 500 nT and higher. Only the events were chosen when during 5 hours prior to the PJ appearance no more than 1 substorm activization occurred. Fig.1 presents the statistical dependencies of the chosen PJ events on geophysical parameters. These dependencies show that at the latitudes of Yakutsk almost all PJ events are observed for K_p > 3- (~ 80 %, fig.1a) and mostly at 20.00 < MLT < 01.00 (~ 73 %, fig. 1b). Distributions in Fig.1 are in agreement with those known from satellite measurements (Spiro, 1979).

Fig.2 shows the distribution of time delay between the moments of chosen PJ appearance in the ionograms and the onsets of corresponding substorms. (Crosses mark the cases with AE ≥ 1000 nT.) It is seen that the time delay is minimal for substorms occuring at 13.00 – 17.00 UT that corresponds to 22.00 – 02.00 MLT. Average time delay is higher when substorm onset time moves to early evening and evening local hours. Linear correlation coefficient between the substorm onsets and the moments of PJ appearance above the Yakutsk station is R_1 = –0.75 for substorms with 500 nT < AE < 1000 nT and R_2 = –0.78 for substorms with AE ≥ 1000. There are also 6 events with the time delay of more than 5 hours.

Fig.3 demonstrates even more pronounced correlation between the moments of substorm onset and the PJ registration by the Yakutsk station; here only the events with the time delay less than 3 hours are shown. This limitation is justified since the typical time of PJ phenomenon as a band of fast plasma westward drift, is also about 3 hours. This time was determined using satellite measurements (Anderson 1991). At the same time the resulting structure of narrow trough forming in the ionosphere can exist in the dark ionosphere for a longer time. For the events in Fig.3 correlation coefficient between the substorm onsets and PJ appearance is 0.95. The dashed line in Fig.3 marks zero delay between these phenomena. For 5 events time delay is not higher than 5 minutes and for 10 events more it is less than 15 minutes.

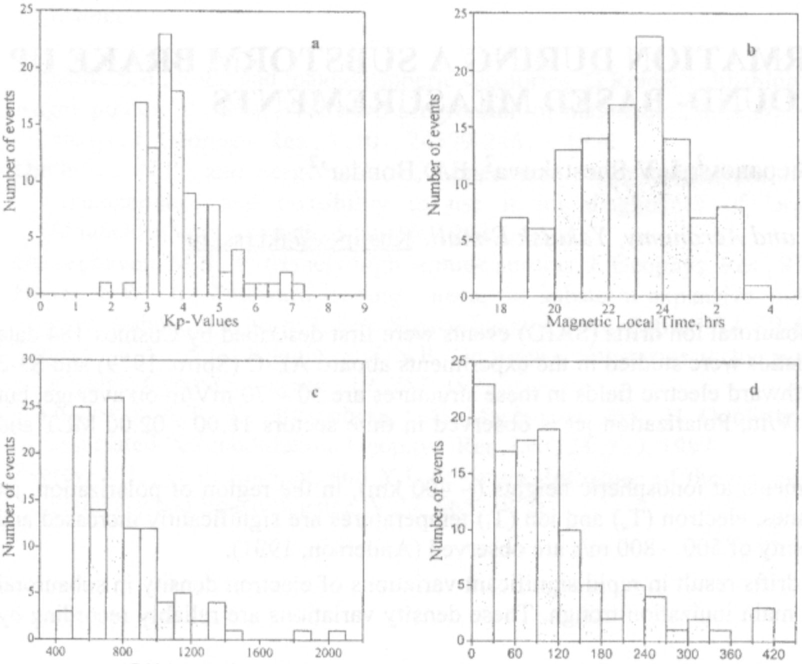

Fig.1 Distribution of cases of polarization jet (PJ) observations at Yakutsk station as a function of K_p – index (a), magnetic local time (b), auroral activity index AE (c), and time delay between the PJ registration and commencement of the substorm with AE > 500 nT (d).

Comparison of the point fitting line with the line of zero time delay shows that the delay is higher during the early hours of magnetic local time. The average time delay is ~ 2 hours in the early dusk sector and ~ 0.5 hours close to midnight. These average delays agree with the results of DE-2 measurements (Anderson, 1991; Anderson, 1993). However the results of ground-based measurements evidence that *noticeable part of events in the midnight sector (15) correspond to the PJ appearance during the brake-up phase of substorm.* This result contradicts to the commonly accepted point of view that PJ appears only during the recovery phase of substorm (Anderson, 1993; Karlsson, 1998).

In our opinion, this contradiction is connected with the peculiarities of ground-based ionosonde PJ measurements having better time resolution and larger statistics of PJ observations due to their continuous monitoring, in comparison to satellite measurements. For the registration of the starting of the process of PJ formation it is necessary to perform continuous observations from the stationary platform after substorm onset during midnight hours. Now this can be realized only by ground-based observations and choosing some successful events from a long time set, because the probability of PJ formation above the station is rather low. The problem of the conditions for PJ appearance, its connection with the geomagnetic activity level, is very important for the elucidation of the nature of large local electric fields at subauroral latitudes. Below the event when the PJ appears with minimal time delay after the substorm onset will be considered in more details.

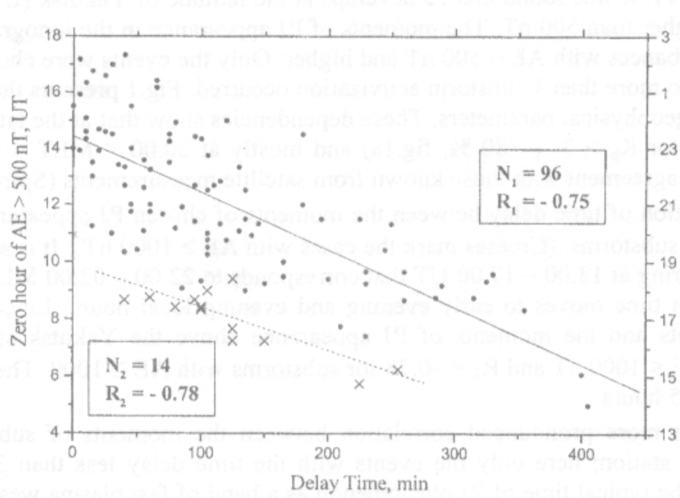

Fig.2 Time delay between the PJ registration at Yakutsk station and commencement of the substorm with 500 ≤ AE ≤ 1000 nT (dots) and with AE > 1000 nT (crosses), for all the observations in the dusk and midnight MLT sectors.

In the event of March 12, 1990 (Fig. 4) the substorm brake-up occurred at 15.05 UT after more than 5 hours of low geomagnetic activity. AE achieved 500 nT at 15.05 UT and PJ developed at 15.15 UT as was observed by Yakutsk ionospheric station. At this moment in Yakutsk the magnetic variation ΔH ~ +50 nT and ΔH changed its polarity after 15.30 UT (not shown in the figure). Even more apparent short time 'bay-shape' magnetic variations typical for the Harang discontinuity, are observed 4 degrees poleward in Zhigansk.

It can be concluded that quick PJ formation in ≤ 10 minutes after the substorm brake-up was accompanied by bipolar magnetic variation that is likely correspondent to the fast pass of Harang discontinuity above the station. As observed by ionosonde PJ began to form already before the positive phase of magnetic variation.

Some more cases of the PJ appearance above the station were found, which were also accompanied by similar local magnetic variations.

Hence, it is possible to state that when PJ formed just above the station its time delay relative to the substorm brake-up can be rather small (≤ 10 min.) that means PJ can form during the brake-up phase. In this case local magnetic variation is quite similar to the fast westward pass of Harang discontinuity above the station. These effects are not always observed, but they are observed only close to midnight at L = 3, that means they correspond to high magnetic activity level (AE ≥ 500 nT). One of previously proposed mechanisms for the PJ appearance (Southwood, 1978) is connected with the injection of energetic ions into the inner magnetosphere near midnight during a substorm. In the pre midnight and evening sectors the particles penetrate deeper into the magnetosphere due to betatron acceleration of ions during their drift in the presence of westward component of electric field. According to this model PJ is formed by the poleward electric field which appears under the action of charges of energetic ions at the equatorial boundary of particle penetration. Hence, it is natural to expect the fastest manifestation of this phenomenon in the near midnight sector or close to the injection meridian, and its development in the evening sector with some time delay as the population of hot ions is drifting westward. It can be estimated that ionospheric projection of the location of injected ions in a wide energy range will be shifted westward and equatorward already during the first 10 minutes. This will lead to the electric polarization at the equatorial boundary of particle penetration. Simultaneously, as the region of positive charge will evolve westward the whole Harang discontinuity will be displaced westward. This is in qualitative agreement with the ground-based measurements described above.

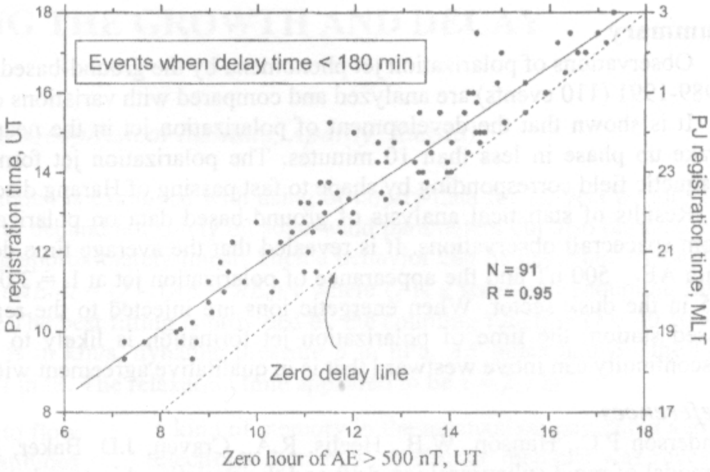

Fig.3 Onset time of PJ observation at Yakutsk station versus the time of commencement of the substorm with AE ≥ 500 nT, for the cases when the time delay between these two events is less than 3 hours. Dashed line marks the absence of time delay.

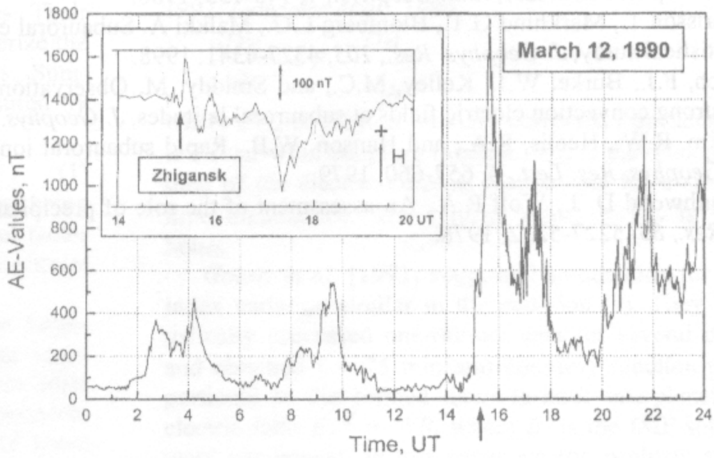

Fig.4 Variations of auroral activity index and local magnetic activity as observed by Zhigansk station (insert) at the time of polarization jet registration in Yakutsk on March 12, 1990. Arrow marks the time of PJ appearance.

Summary

Observations of polarization jet phenomena by the ground-based ionospheric station in Yakutsk (L = 3.0) in 1989-1991 (110 events) are analyzed and compared with variations of the AE – index and local magnetic activity.

It is shown that the development of polarization jet in the near midnight sector may occur during a substorm brake up phase in less than 10 minutes. The polarization jet formation is then related to a specific variation in magnetic field corresponding by shape to fast passing of Harang discontinuity above the station.

Results of statistical analysis of ground-based data on polarization jet phenomenon well correspond to those from spacecraft observations. It is revealed that the average time delay between the commencement of a substorm with AE 500 nT and the appearance of polarization jet at L = 3.0 is equal to 0.5 hour near midnight and to 1.0 – 1.5 in the dusk sector. When energetic ions are injected to the region of Harang discontinuity above the ground based station, the time of polarization jet formation is likely to be ~ 10 minutes and in this case the Harang discontinuity can move westward that is in qualitative agreement with observations.

References

Anderson P.C., Hanson, W.B., Heelis, R.A., Craven, J.D. Baker, D.N., and Frank, L.A., A proposed production model of rapid subauroral ion drift and their relationship to substorm evolution, *J. Geophys. Res.*, *98*, 6069-6078, 1993.

Anderson, P.C., Heelis, R.A. and Hanson, W.B., The ionospheric signatures of rapid subauroral ion drifts, *J. Geophys. Res.*, *96*, 5785- 5792, 1991.

Galperin Yu. I., Ponomarev V.N., and Zosimova, A.G.., Direct measurements of ion drift velocity in the upper atmosphere during a magnetic storm, *Space Res.*, *11*, 273-296, 1973 (in Russian).

Galperin, Yu. I., Khalipov, V.L., and Filippov, V.M., Signature of rapid subauroral ion drifts in the high-latitude ionosphere structure, *Ann. Geophys*., *4*, 145-153, 1986.

Karlsson T., Marklund G.T., Blomberg L.G., Malkki A. Subauroral electric fields observed by the Freja satellite: A statistical study, *J. Geophys. Res.*, *103*, 4327-4341, 1998.

Rich, F.J., Burke, W.J., Kelley, M.C., and Smiddy, M, Observations of field aligned currents in association with strong convection electric fields at subauroral latitudes, *J. Geophys. Res.*, *85*, 2335-2340, 1980.

Spiro, R.W., Heelis, R.A., and Hanson, W.B., Rapid subauroral ions drifts observed by Atmospheric Explorer C, *Geophys. Res. Lett.*, *6*, 657-660, 1979

Southwood D. J., Wolf R.A., An assessment of the role of precipitation in magnetosheric convection, *J. Geophys. Res., 83*, 5227-5232, 1978.