"Physics of Auroral Phenomena", Proc. XXIX Annual Seminar, Apatity, pp. 145 - 148, 2006

Polar Geophysical Institute

CORRESPONDENCE BETWEEN NEAR-NOON ULF WAVE ACTIVITY AND FIELD-ALIGNED CURRENTS

V.A. Martines-Bedenko[1], V.A. Pilipenko [1], F. Christiansen[2], and J.F. Watermann [3]

[1]*Institute of the Physics of the Earth, Moscow*
[2]*Danish Space Research Institute, Copenhagen*
[3]*Danish Meteorological Institute, Copenhagen*

Introduction

Much of the energy and momentum transfer from the solar wind through the magnetosheath into the magnetosphere occurs at the dayside magnetospheric boundary layers, which are geomagnetically projected in the cusp – the region of direct penetration of turbulent magnetosheath plasma into the magnetosphere/ionosphere. This transfer involves field-aligned currents (FAC), transported by precipitating particles, which drive the regional magnetosphere-ionosphere current system. The specific ionospheric current systems in the cusp region are DPY system, which, in its simplest form, is an east-west oriented Hall current formed between the ionospheric ends of two FAC sheets, and the NBZ current system that resides poleward of the cusp. The energy transfer from the solar wind into the magnetosphere and ionosphere has a turbulent character, thus, it might be expected that in the magnetospheric boundary regions MHD noise and pulsations of the geomagnetic field can be generated. Indeed, at high latitudes, intense quasi-periodic pulsations in the nominal Pc5-6 range (from fractions of mHz to few mHz) are commonly observed. An intriguing but still not resolved problem is the identification on the ground of specific ULF wave signatures of boundary phenomena. In early studies, it was suggested that a probable source of the dayside high-latitude long-period pulsations was related to the cusp. The disturbances in the period range of 3-15 min were claimed to be a typical feature of the dayside cusp and coined as IPCL pulsations [*Troitskaya and Bol'shakova,* 1977; *Bolshakova et al.,* 1988] or broadband ULF pulsations [*Engebretson et al.,* 1995; *Clauer et al.,* 1997]. *Lanzerotti et al.* [1999] found small-amplitude quasi-monochromatic Pc5 waves at the dayside and suggested that they might be a signature of near-cusp closed field lines and could be used as cusp discriminator. However, this goal can hardly be achieved by simple means. Szuberla et al. [2000] succeeded in identifying a cusp signature in coherent Pc5 waves only using polarization spectra. Observations also showed an occurrence of very long period (~ few tens of min period) short-lived pulsations with large peak-to-peak amplitudes ~80-400 nT in the cusp region [*Bolshakova et al.,* 1987]. *Pilipenko et al.* [2000] showed that these pulsations $P_{DPY}6$ pulsations were driven by large-scale Alfven waves in the solar wind under favorable IMF orientation. The commonly adopted source of dayside ULF waves - Kelvin-Helmholtz (K-H) instability at the flanks of the magnetosphere, hardly could be operative near noon meridian, where the magnetosheath plasma flow is slow. Various hypotheses have been suggested for the interpretation of the dayside high-latitude ULF disturbances, including a fluctuating fluxes of precipitated electrons [*Engebretson et al.,* 1991], and the K-H instability in the region of the convection reversal boundary [*Clauer et al.,* 1997]. The Pc5/IPCL activity at near-noon hours could be impulsively driven pulsations which occur in response to the magnetosheath plasma discontinuities and buffeting. In line with this idea, analysis of IPCL bursts by *Kurazkovskaya and Klain* [2000] indicated that these signals possess rather distinctive features, which might be a manifestation of the intrinsic dynamic turbulence of FAC. So far, the exact physical mechanisms for all these ULF disturbances in the cusp region have not yet been firmly established.

The occurrence of natural magnetospheric MHD waveguides and resonators may result in the magnetospheric noise's partial filtering and amplification producing quasi-monochromatic pulsations. The position of the resonance shell is determined by the match between the local Alfven frequency and frequency of an external source, irrespective of a particular source mechanism. According to this notion, the latitude of maximal ULF intensity is determined by the features of the magnetospheric plasma distribution, and should not be directly related to large-scale FAC. However, in the morning sector, the peak of resonant ULF waves was reported to be located near the R2 FAC [*Martines-Bedenko et al.,* 2003], or the westward auroral electrojet [*Pilipenko et al.,* 2001]. The correspondence between the positions of FAC and ULF resonant peak still needs further observational confirmation and satisfactory interpretation.

To put ULF studies in a more global magnetosphere/ionosphere context, we propose in this paper an approach that enables one to study simultaneously the ULF spatial pattern together with ionospheric electrodynamics and identification of ionospheric projections of dayside magnetospheric regions. We have combined observations from Greenland Coastal Array (GCA) of magnetometers to produce an instantaneous (on the scale of the time window) latitudinal profile of ULF wave power and FAC pattern derived from the magnetic measurements of low-orbiting Orsted satellite. We also have tried to relate this to magnetospheric regions defined with DMSP particle data. This tool has been applied to the problem of how the specific ULF pulsations observed in the dayside cusp are related to the magnetospheric domains and regional FAC systems.

Databases used: Greenland array, Orsted magnetometer, and DMSP-identified magnetospheric regions

To monitor ULF activity and ionospheric current system the magnetometer data from the GCA, an array of 17 magnetic stations deployed along the West (~40°) and East (~95°) coasts of Greenland, was used. The determination of FAC above the ionosphere is based on high-precision magnetic survey data from the polar low-orbiting (~800 km) satellite Ørsted. Magnetic perturbations are first calculated subtracting the main field given by the Ørsted initial field model and then transformed into CGM coordinates. To categorize the ionospheric projections of magnetospheric boundary layers we have used the charged-particle precipitation characteristics (in the 30 eV to 30 keV range) at DMSP satellites, identified with the automated dayside region recognition program.

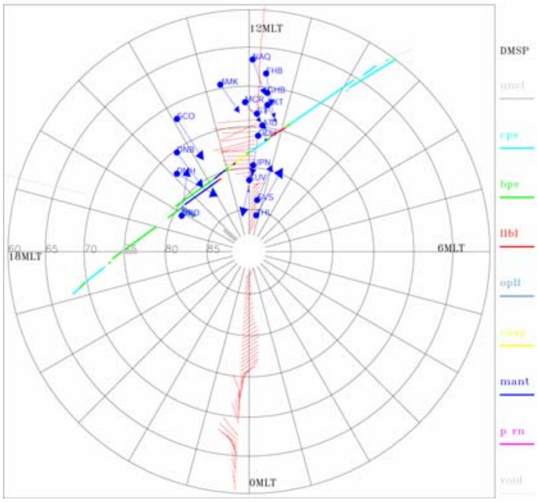

Fig. 1. Mapping of the Orsted track with magnetic disturbance vectors, magnetic disturbance vectors at Greenland stations, and the magnetospheric domains (color coding at the left-hand panel) along DMSP track.

Visualization and mapping technique

The technique for simultaneous mapping of the ionospheric electrodynamic pattern and ULF spectral power is as follows. At each GCA station, H component is FFT transformed into the frequency domain in 1-hour window. The spectra in the 2.0-8.0 mHz frequency band are used to construct the latitudinal distribution of ULF power at each frequency. The instant vector values of the horizontal magnetic disturbance during the satellite fly-by over the array are calculated and plotted for each station. The position of center of the wesward ionospheric electrojet may be estimated from the locations of peak value of H component and inversion of Z component. For the calculation of the spatial distributions of FAC over the high-latitude ionosphere the data from the Orsted measurements are taken. The vectors of magnetic disturbance (northward *Bx* and eastward *By* components) are plotted along the satellite orbit. The FAC density is estimated from the satellite magnetometer measurements, assuming that FAC are elongated in east-west direction, as

$$\mu_0 j_z = \frac{\partial B_y}{\partial x} \qquad (1)$$

The positive values of $\partial B_y / \partial x$ correspond to downward FAC, whereas negative gradients are due to upward currents. From the combination of basic field-current relationships for the 1D current sheets and homogeneous ionosphere one may deduce that variations of satellite *By* and ground *H* magnetic disturbances should be coherent along latitude, that is *By~H*. This conclusion may be used to verify a consistency of current pattern reconstructed from satellite and ground observations.

To establish a correspondence between the spatial distribution of ULF intensity, FAC, and magnetospheric boundaries, we overlay on a plot the ULF spectral power distribution along the GCC, Orsted-derived FAC, latitudinal profile of *H* and *Z* component disturbances, and the available DMSP satellite tracks with the automatically identified magnetospheric boundaries. The ground track of each DMSP orbit is plotted in geomagnetic coordinates with the footpoints of the magnetospheric regions marked by different shades.

Case studies with the mapping technique

The mapping technique has been used to analyze the relationship between the large-scale ionospheric and magnetospheric current systems, intensity of ULF waves, and their relations to the dayside magnetospheric boundaries, whenever possible, during 1999. Here we present a typical event on 1999/08/19 (day 231).

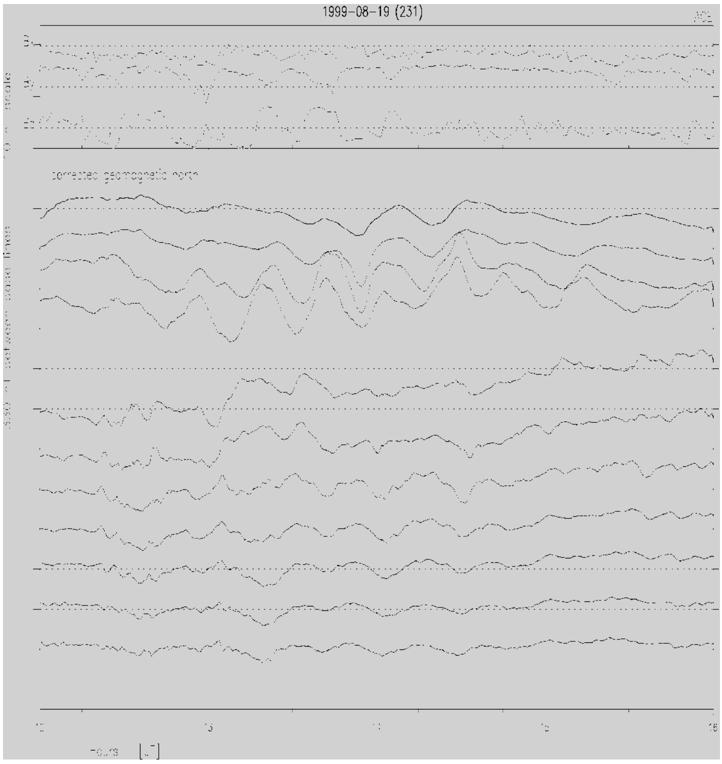

Fig. 2. Magnetograms from GCA (H component). Upper panel shows the time-shifted ACE IMF data.

Orsted passed along GCA around noon meridian at ~14 UT (Fig. 1). During this interval the ground magnetometrs recorded long-period (~15 min) periodic variation, possibly IPCL or $P_{DPY}6$ pulsations, at high-latitude ($\Phi \geq 79^o$) part of the array: KUV, UPN (Fig. 2). The comparison with the time-shifted ACE IMF data (upper panel in Fig. 1) shows that these pulsations are caused by the quasi-periodic variations of the IMF Bz and By components. At lower latitudes ($\Phi < 75^o$) weak Pc5 activity can be seen.

Orsted detected rapid increase of *By* component ~600 nT at ~13:39 UT (~73^o) and more gradual decrease of it in the interval 13:40-13:45 UT (Fig. 3, 2-nd and 3-rd panels). These variations correspond to the trespassing through downward and upward FAC, correspondingly. However, these currents cannot be imagined as infinite current sheets, because *Bx* component is substantially disturbed too, ~400 nT. The peak values FAC, estimated from magnetic field gradients, are ~8 $\mu A/m^2$ in the downward FAC region and ~-4 $\mu A/m^2$ in the upward FAC. The peak of east-west ionospheric electrojet is located at ~79^o (according to H component). The peak values of H-component disturbance is ΔH~100 nT.

Frequency-latitude distribution shows that peak of Pc5 activity is located in the region of downward FAC (Fig. 3, 6-th panel). Long-period IPCL/$P_{DPY}6$ type variations are concentrated near in the poleward boundary of upward FAC.

DMSP tracks makes it possible to identify the probable magnetospheric domains. In this event the DMSP orbit was rather far from the GCA (Fig. 1). One may say that the location of downward FAC corresponds to the CPS/LLBL interface, though rather uncertainly (Fig.3, 1-st panel).

Discussion and Conclusion

We have examined simultaneous snap-shots of ULF activity in the Pc5-6 frequency band and FAC in the near-noon region. The analyzed events demonstrate the spatial correspondence between the poleward boundary of extended negative FACs (~81^o) and geomagnetic fluctuations with time scales ~10 min, suggesting that these fluctuations are probably the ground image of the fluctuating FAC part. The broadband Pc5 power is concentrated equatoward from the region of long-period fluctuations, in the region of localized positive FAC (~74^o). Thus, in contrast to the existing notions, the locations of the ionospheric-magnetospheric current system in the cusp region and ULF waves are coupled. The preliminary analysis of many similar events has confirmed that long-period (~10-20 min) variations near the nominal cusp latitudes (~80^o) are related to FAC, and are the ground image of its fluctuating part.

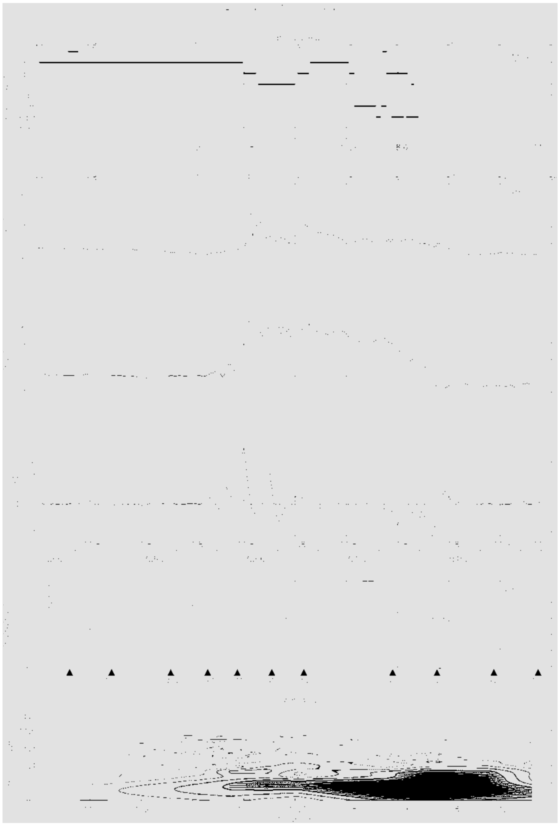

Fig. 3. Magnetospheric domains as determined from DMSP observations (1-st panel); Bx and By components (2-nd and 3-rd panels); estimated density of FAC (4-th panel); H, D, Z components of ground magnetic disturbance (5-th panel); latitudinal plot of horizontal ULF spectral power (6-th panel).

Acknowledgements. Providing help with DMSP data by P. Newell is appreciated. This study was supported by the INTAS grant 03-51-5359.

References

Bolshakova O.V., B.I. Klain, Kleimenova N.G., Kurazkovskaya N.A., and Friis-Christensen, Features of latitudinal distribution of very long period pulsations (VLP) at polar latitudes, Geomagn. Aeronomy, 27, N6, 982-986, 1987.

Bolshakova O.V., N.G. Kleimenova, and N.A. Kurazkovskaya, Dynamics of polar cap according to the observations of long period geomagnetic pulsations, Geomagn. Aeronomy, 28, 661-665, 1988.

Clauer, C., A. Ridley, R. Sitar, H. Singer, A. Roger, E. Friis-Christensen, V. Papitashvili, Field line resonant pulsations associated with a strong dayside ionospheric shear convection flow reversal, J. Geophys. Res., 102, 4585, 1997.

Engebretson, M.J., W.J. Hughes, and J.L. Alford, Magnetometer array for cusp and cleft studies observations of the spatial extent of broadband ULF magnetic pulsations of cusp/cleft latitudes, J. Geophys. Res., 100, 19371, 1995.

Kurazkovskaya, N.A., and B.I. Klain, Peculiar features of burst series of long-period irregular IPCL-type geomagnetic pulsations in the vicinity of the dayside cusp, Geomagn. Aeron. Int., 2(2), 129, 1990.

Lanzerotti, L.J., A. Shono, H. Fukunishi, and C.G. Maclennan, Long-period hydromagnetic waves at very high geomagnetic latitudes, J. Geophys. Res., 104, 28423, 1999.

Martines-Bedenko, V.A., V.A. Pilipenko, V.O. Papitashvili, M.J. Engebretson, J.F. Watermann, P.T. Newell, Correspondence between ULF activity, field-aligned currents, and DMSP-based dayside magnetospheric domains, Geomagn. Aeronomy Int., 4, N2, 141, 2003.

Pilipenko, V. A., E.N. Fedorov, M.J. Engebretson, V.O. Papitashvili, and J. Watermann, Poleward progressing quasi-periodic disturbances at cusp latitudes: The role of wave processes, J. Geophys. Res., 105, 27569, 2000.

Pilipenko, V., J. Watermann, V. Popov, and V. Papitashvili, Relationship between auroral electrojet and Pc5 ULF waves, J. Atmosph. Solar-Terr. Phys., 63, 1545, 2001.

Pilipenko, V.A., V.A. Martines-Bedenko, M.J. Engebretson, V.O. Papitashvili, and P.T. Newell, High-latitude mapping of ULF activity, FACs, and DMSP-based dayside magnetospheric domains at high latitudes, AGU Monograph 133 “The LLBL and its dynamic interaction with the solar wind and magnetosphere”, 231, 2002.

Szuberla C.A., J.V. Olson, M. J. Engebretson, M.G. McHarg, and W.J. Hughes, Spatiotemporal characteristics of cusp latitude spectra, J. Geophys. Res., 105, 7695, 2000.

Troitskaya V.A., and O.V. Bolshakova, Diurnal latitude variation of the location of the dayside cusp, Planet. Space Sci., 25, 1167, 1977.