Formation of Large-Scale, `Giant' Undulations at the Equatorial Boundary of Diffuse Aurora and Pc5 Magnetic Pulsations during the January 14, 1999 Magnetic Storm

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FORMATION OF LARGE-SCALE, "GIANT" UNDULATIONS AT THE EQUATORIAL BOUNDARY OF DIFFUSE AURORA AND Pc5 MAGNETIC PULSATIONS DURING THE JANUARY 14, 1999 MAGNETIC STORM

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ABSTRACT

In the present study we investigate the undulations at the equatorial boundary of diffuse aurora and their relationship to the development of magnetic and auroral substorms and excitation of Pc5 magnetic pulsation on January 14, 1999. The observed undulations had wavelength of ~200-300 km and amplitude of ~50-250 km and they propagated westward with the velocity of ~0,7 km/s. It is found that the undulations began ~40 min after the substorm onset and lasted for ~80 min, all the way to the end of the substorm. During both active and recovery phases of the substorm the undulations were accompanied by the enhancement of the DP2 equivalent current system and by the formation of WTS. Concurrently with undulations, there were observed Pc5 magnetic pulsations of an oscillation period roughly equal to the ratio of the undulation wavelength to their propagation velocity. Observations are interpreted in terms of the shear/ballooning instability excitation near the plasmapause and subsequent generation of drift hydromagnetic waves.

INTRODUCTION

Large-scale undulations at the equatorial boundary of diffuse aurora were first described by *Lui et al.* [1982] on the basis of DMSP satellite observations. It was found that undulations occur in the evening sector during the main phase of a magnetic storm and that they have wavelengths of ~ 200-900 km and amplitudes of ~40-400 km [*Lui et al.*, 1982; *Kelley*, 1986]. However, the dynamics and propagation characteristics of undulations as well as their relationship to the substorm development have not been explored in great detail. In this study we focus on the relation of undulations to different substorm phases and to excitation of Pc5 geomagnetic pulsations during one specific event, January 14, 1999.

OBSERVATIONS

We used data obtained with the all-sky TV camera at Zhigansk (Φ′=61,1°; Λ=191,8°; L=4,1), auroral images from the Polar satellite, CUTLASS F convection data in the dayside sector (1000-1400 MLT), magnetic field variations according to the 210° MM chain, magnetometer projects IMAGE, MACCS, Canopus, Greenland coast chain and also the IMF data from the Wind and IMF-8 satellites. Figure 1 shows variations of the IMF B_Z-component, AE-index and the range-time-velocity plot of CUTLASS radar observations at Hankasalmi, (Φ′=62,3°; Λ=26,6°), beam #5, from 0730 to 1200 UT on January 14, 1999. Time interval of auroral undulations observed at the equatorial boundary of diffuse aurora by the TV camera at Zhigansk is indicated by a rectangle at the central panel. From Figure 1 one can see that the undulations appeared ~90 min after the IMF B_Z southward turning during the period of enhanced convection and ~40 min after the sharp enhancement of AE-index at 0842 UT. Undulations were observed for ~80 min lasting to the end of magnetic disturbances. SuperDARN data show that the onset of undulations corresponded to the time of increased cross-polar cap potential of 85-90 kV though the potential decreased by ~40 kV to the end of the undulation interval.

Figure 2 is a composite diagram illustrating the main body of the data for the event. Panel (a) shows TV images illustrating undulations while panel (b) shows the position of the equatorial diffuse aurora boundary projected on the Earth's surface (assuming the luminosity

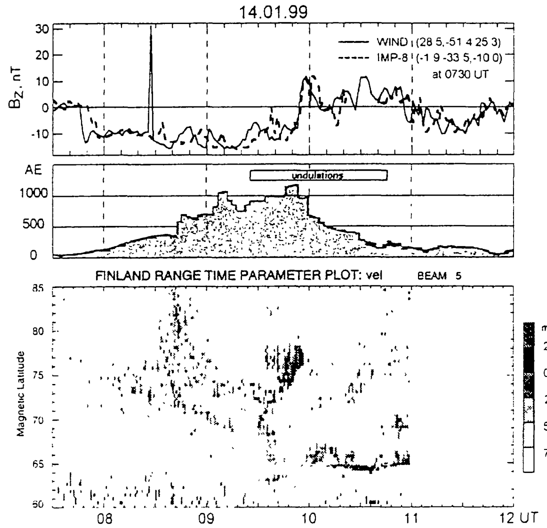

Figure 1: Variations of the IMF B_Z component according to the WIND (solid line) and IMP-8 (dashed line) satellites, AE-index and the range-time-velocity plot (beam #5) for the Hankasalmi radar (Φ′=62,3°; Λ=26,6°) from 0730 UT to 1200 UT on January 14, 1999. Interval of undulations registration is marked by a rectangle at the middle panel.

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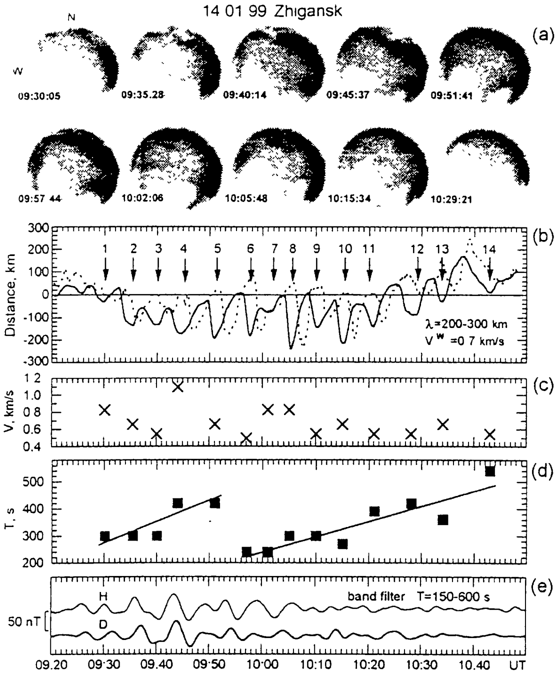

Figure 2: TV images (a), locations of the projection of equatorial diffuse aurora boundary on the Earth's surface for ~110 km luminosity height at the meridian of observations (solid line) and ~100 km to the west of it (dashed line) (b), westward velocity of undulations (c), the oscillation period of undulations (d) and variations of H-, and D-components filtered in 150-600 s range (e) at Zhigansk on January 14, 1999.

height of ~110 km) at the meridian of observations and ~100 km to the west from it. Undulations of ~200-300 km wavelength consisted of 14 luminosity "tongues" with the amplitude of ~50-250 km and propagated westward with the average velocity of ~0,7 km/s.

The IMF B_Z southward turning at 0750 UT led to the enhancement of the eastward and westward electrojets at ~ 0800 UT in the evening (Figure 3a) and night-morning (Figures 3b and 3c) sectors, as manifested by the H-component variations. Current intensification indicates the enhancement of the DP2 equivalent current system and the substorm growth phase onset.

The substorm expansion phase began at 0842 UT and was accompanied by a sharp enhancement of the westward electrojet in the postmidnight sector, its poleward expansion (Figure 3b) and formation of the auroral bulge (Figure 4, Polar satellite, images 1-5). At low latitudes in the evening sector (~18 LT, Figure 3a) there were observed enhancements of the negative magnetic bays which reflected an increase of the ring current intensity. Maximum magnitude of the $|D_{st}|$ index was ~90 nT.

Undulations at the equatorial boundary of diffuse aurora appeared at ~0925 UT (~18 LT), i.e. ~40 min after the substorm expansion phase onset. They were accompanied by a growth of AE-index from ~0750 to 1100 nT (Figure 1) and by a southward shift of centers of eastward and westward electrojets (see H- and Z-components in Figure 3 and the equatorward progression of the CUTLASS echoes at the bottom panel of Figure 1). Estimations show that the westward electrojet in the postmidnight sector moved to the south with the velocity of ~0,65 km/s. Simultaneously the westward electrojet region expanded into the evening-dayside sectors (Figure 3a, HOP, KTN, and CHD stations). Such development of the eastward and westward electrojets is indicative of DP2 equivalent current system enhancement which, as shown in Figure 4 (images 6-10), was accompanied by the formation and expansion of WTS into the evening sector.

The substorm recovery phase began at ~1000 UT after the IMF B_Z northward turning and a sharp decrease in a number of HF echoes at the dayside (Figure 1). During the substorm recovery phase, westward electrojet in the postmidnight sector (Figure 3b) was noticeably weakening. More smooth weakening of the westward electrojet was observed in the morning sector (Figure 3c) and even its enhancement was seen at some stations (GDN, SKT). In the evening sector (see CHD in Figure 3a) the westward electrojet changed to the eastward electrojet. Thus during the substorm recovery phase, the DP2 equivalent current system was dominant, which is consistent with the results of *Kamide and Kokubun* [1996]. The sharp IMF B_Z northward turning at ~1000 UT led to a sudden change of undulation periods from ~7 min to ~2,5 min (Figure 2d) and to decrease of their amplitude (Figure 2b). However, later the undulation amplitude again increased and undulations were observed until the substorm end. The oscillation period was gradually increasing while the propagation velocity did not change noticeably (Figures 2c and 2d).

Generation of undulations led to excitation of Pc5 magnetic pulsations at latitudes of the diffuse aurora boundary (Figure 2e) with periods of T=200-400 s that are equal to the ratio of the undulation wavelengths to the wave propagation velocities. After the beginning of the substorm recovery phase (~1000 UT), the undulation amplitude did not vary strongly, as compared to the active phase of the substorm. However, the Pc5 amplitude decreased noticeably.

DISCUSSION AND CONCLUSIONS

It is known that one of the mechanisms of undulation generation is the Kelvin-Helmholtz (K-H) instability due to strong shear flows of plasma near the equatorial boundary of auroral oval. These shear flows are caused by excitation of an intense electric field and strong subauroral ion drifts (SAID) [*Kelley*, 1986; *Yamamoto et al.*, 1991, 1993]. The alternative mechanism can be the drift instability leading to excitation of surface waves on the inner boundary of plasma sheet [*Fedorovich*, 1988].

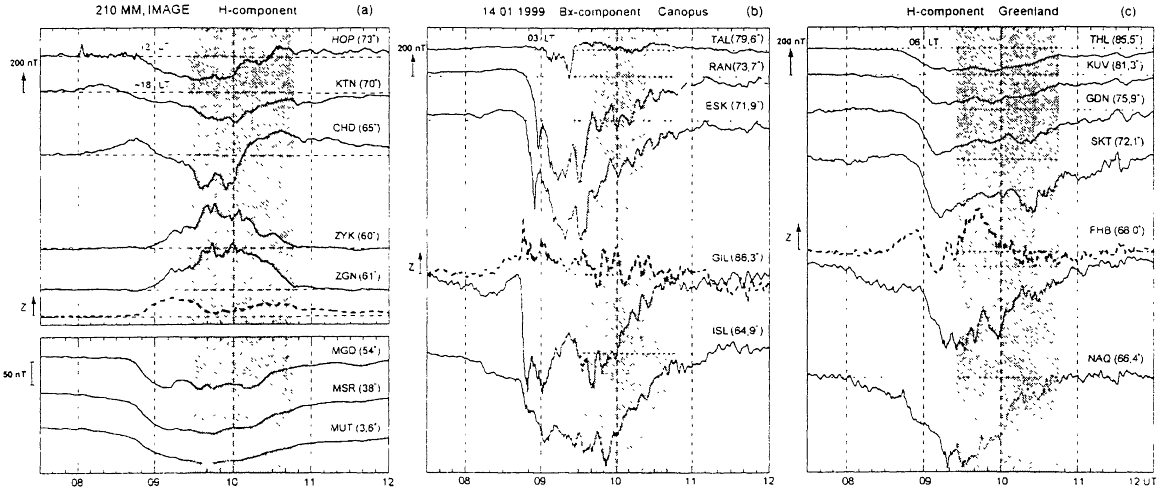

Figure 3: Variations of H-component in the evening sector according to the 210° MM and IMAGE magnetometer chains (a), in postmidnight sector according to Canopus magnetometers (b) and in the morning sector according to Greenland coast magnetometer chain (c) on January 14, 1999. The dashed lines are variations of Z-component. Shaded areas correspond to the interval of undulation observations.

SAID are formed in the ionosphere during substorms and often seem to coincide with the ionospheric projection of the plasmapause [e.g., *Smiddy et al.*, 1977; *Spiro et al.*, 1981]. Also SAID can be observed in the magnetosphere [*Maynard et al.*, 1980]. According to [*Anderson et al.*, 1993; *Yamamoto et al.*, 1993] both the enhancement of the northward electric field (E_N) at the equatorial oval boundary and proton precipitation are associated with the decrease of the Pedersen conductivity at the heights of the F-region. According to the *Keyser* [1998] model, E_N is generated in the magnetosphere due to interaction of the hot injected particles with cold plasma of the plasmasphere, meaning that E_N is of the thermoelectric origin. *Anderson et al.* [1993] showed that SAID appeared more than 30 min after the substorm expansion onset during its recovery phase. We found in this study that undulations appeared ~35 min after the substorm onset, i.e. very likely simultaneously with SAID generation. However, in contrast to *Anderson et al.* [1993], undulations in our event began during the substorm active phase, ~40 min before the magnetic substorm recovery phase beginning and lasted to the substorm end (Figures 1, 3 and 4). During the substorm active phase, undulations were accompanied by the enhancements of the eastward and westward electrojets, their equatorward shift, and formation and propagation of WTS. Our data thus testify that during this period the intense injection and drift of hot plasma to the Earth and to the evening side have been observed. The appearance of hot plasma at evening hours near the plasmapause ~40 min after the substorm expansion phase onset may lead to generation of the thermo-electric field, as suggested in the model by *Keyser et al.* [1998], and to excitation of undulations due to the K-H instability [*Yamamoto et al.*, 1991].

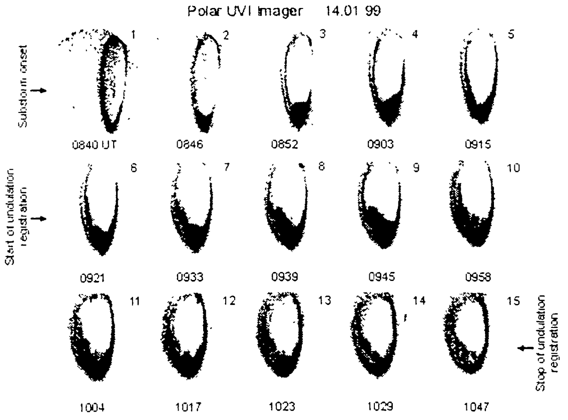

Figure 4: Auroral images from Polar UVI Imager illustrating the substorm development at the night side of the Earth on January 14, 1999.

During the substorm recovery phase it can be assumed that the SAID generation continued since, as one can see from Figure 2 and Figure 4 (images 11-15), the particle precipitation at latitudes of diffuse aurora boundary and WTS formation were observed until the substorm end.

Yamamoto et al. [1993, 1994] showed that the K-H instability development in the presence of strong electric field (and SAID) alone cannot explain "giant" undulations having the crest-to-trough amplitude comparable to their wavelength. In our event "giant" undulations were observed not only during period of strong cross-polar cap potential but also for moderate its values meaning that, besides the K-H instability related to SAID, other reasons sustaining the undulations have to considered.

It is believed that in the region of thermo-electric field near the plasmapause the earthward plasma pressure gradient must exist. Such pressure gradient would favor the development of the ballooning instability leading to the intensification of the K-H waves [e.g., *Voronkov et al.*, 1997] and subsequently to the development of "giant" undulations propagating along the plasmapause as drift surface waves. During the surface wave propagation the undulation wavelength increases [*Fedorovich*, 1988] which is consistent with our observations (Figures 2c and 2d). *Vinas and Madden* [1986] showed that the shear/ballooning instability development near the plasmapause can lead to excitation of hydromagnetic drift waves in the Pc4-5 range of periods. Our observation of Pc5 magnetic pulsations concurrent with undulations (Figure 2e) can be explained by this effect.

Thus, presented data show that the generation of undulations at the equatorward boundary of diffuse aurora in the evening sector during magnetic storm reflects the structure of convective disturbances which are characterized by the enhancement of the DP2 equivalent current system and WTS formation.

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