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GEOMAGNETIC DISTURBANCES AND ULF WAVES RELATED TO THETA-AURORA

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Abstract. We have developed a technique for studying simultaneously the ground ULF activity in the nominal Pc5-6 frequency band and global patterns of UVI emission measured from Polar satellite. This technique produces a sequence of 2D snapshots of the UVI images with overlaid magnetic disturbance vectors at station locations. For several events in 1997-99 the occurrence of theta-aurora has been compared with dynamics of simultaneous ULF activity. The equivalent ionospheric currents estimated from ground magnetic disturbances were found to be oriented approximately along trans-polar auroras. The ULF dynamic spectrograms have been inferred from the polar arrays (Greenland, MACCS) of geomagnetic stations. The comparison of the time variations of UVI intensity integrated over the part of the polar cap, dominated by theta-aurora, and dynamic spectra from the polar magnetic stations enabled us to reveal the ULF activity related to the theta-aurora activation. The occurrence of these quasi-periodic variations in the polar cap signifies that a theta-aurora is indeed developed on closed field lines.

Introduction

The polar cap can be considered approximately as a dark region inside the auroral oval. However, during northward IMF conditions ($B_z>0$), the magnetospheric field line geometry is very complex and a lot of high-latitude upper atmospheric emissions are observed (*Cumnock* [2005] and references therein). During periods of steady northward IMF, a special kind of aurora, named theta aurora (Θ-aurora), is observed sometimes. Theta aurora may have embedded bright discrete Sun-aligned trans-polar arcs [*Vorob'ev et al.,* 1996]. The origin of the energetic (up to several keV) field-aligned particle fluxes causing transpolar aurora remains unknown [*Carlson and Cowley,* 2005].

The mechanism of fast conversion of the solar wind flow into the auroral particle energization is related to the reconnection. A small contribution of IMF to the magnetospheric magnetic field has a strong control on the outer magnetosphere structure. For $B_z<0$, the reconnection region is placed in the equatorial part of the dayside magnetopause, and in the magnetotail, while for $B_z>0$, two reconnection sites are located in the cusp regions. Observational evidence suggests that the dayside part of the transpolar aurora is formed due to quasi-continuous merging between the IMF and the lobe magnetic field tailward of the cusp, while the nightside part is associated with the Harang discontinuity.

The overall topology of the IMF and magnetospheric field reconnection during Θ-aurora events is still uncertain. Some authors [*Alexeev and Belenkaya,*1985; *Alexeev*, 1986; *Belenkaya*, 1998; *Frank et al*., 1986], suppose that these phenomena are associated with closed field lines in the open magnetosphere. However, *Reiff and Burch* [1985] explained the trans-polar aurora under northward IMF, assuming the open magnetic flux across the tail lobes.

This ambiguity may be resolved with the study of local electrodynamic features in the vicinity of the transpolar arcs. *Robinson et al.* [1987] constructed from radar and magnetometer data a model current system associated with the sun-aligned auroral forms. In this model the ionospheric plasma convects anti-sunward within the arc. The westward electric field in the arc, coupled with enhanced conductances, produced perturbations in the *D* geomagnetic components. The model implies that the upward field-aligned current is at the western arc edge, and downward current is at the eastern edge. Additional strong upward and downward field-aligned current pair is present at the location where the polar arc intersects the auroral oval.

Additional information about basic field line geometry may be provided by the observations in the ULF frequency range. The occurrence of specific ULF oscillations related to the Θ-aurora may indicate that this auroral pattern is the projection of closed field lines. The first indications on the possible occurrence of long-period pulsations with specific east-west polarization was found by *Kleimenova et al.* [1996]. However, the above observations of theta-aurora electrodynamics were made near the regions of arc intersection either with nightside auroral oval [*Robinson et al.*, 1987] or dayside oval [*Kleimenova et al.,* 1996]. In these regions the intense intrinsic auroral fluctuations and ULF waves can mask a specific aurora-related disturbances. In this study we concentrate mostly on the search of ULF images of Θ-aurora in the region of nominal polar cap.

Polar UVI and Ground Magnetometer Data

To monitor ULF activity and ionospheric current system the magnetometer data from the Greenland Coastal Chain with 20-sec sampling rate have been used. The west coastal part of the array (~40°) covers the CGM latitudinal range from sub-auroral latitudes to the polar cap (stations THL, SVS, NRD). These data were augmented with the simultaneous data from MACCS network of identical fluxgate 5-sec magnetometers with one station in the polar cap (RES) and others along geomagnetic latitudes ~79° (e.g., CRV) and ~75°. Besides those, the station ALE was added, which are on the opposite side from RES of the geomagnetic pole. Orientation of IMF is taken from 1-min OMNI database.

The data from POLAR spacecraft takes UV images of auroral emissions in the molecular nitrogen N**2** band centered at 1700 Å (LBHL) and 1500 Å (LBHS). The LBHL filter is proportional to total energy flux (insensitive to particle energy), while the LBHS line is more sensitive to soft precipitation. The UV images were converted to “CGM Lat. – MLT” coordinates, and the line-of-sight correction and removed day glow was applied.

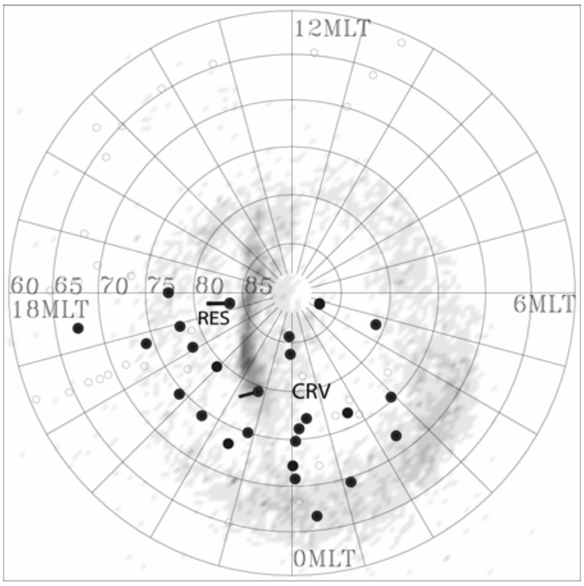

Fig.1. 2D snap-shot at 023937 UT on 98022 of simultaneous Polar UV image (S filter) with overlaid magnetic disturbance vectors (indicated by arrows) at high-latitude ground stations RES, CRV in geomagnetic coordinates.

Visualization and mapping technique

The technique for simultaneous mapping of the global patterns of UVI auroral emission and ionospheric electrodynamics produces a sequence of 2D snapshots of the UV images with overlaid magnetic disturbance vectors at all available ground stations. The magnetic disturbances have been measured taking a reference time before the onset of aurora-related activation.

To obtain a times series of UVI auroral intensity in the polar cap, from the Polar images the pixels within the latitude range of 80-90 CGL have been selected and summed up. Whenever possible, the boundaries of dayside magnetospheric regions derived from DMSP charged paricle flux measurements were plotted along DMSP tracks.

The ULF dynamic spectrograms have been inferred from the polar stations in the vicinity of transpolar aurora.

Case Studies with the Mapping Technique

For several events in winter months of 1997-99 the occurrence of theta-aurora was compared with dynamics of simultaneous ULF activity and geomagnetic disturbances.

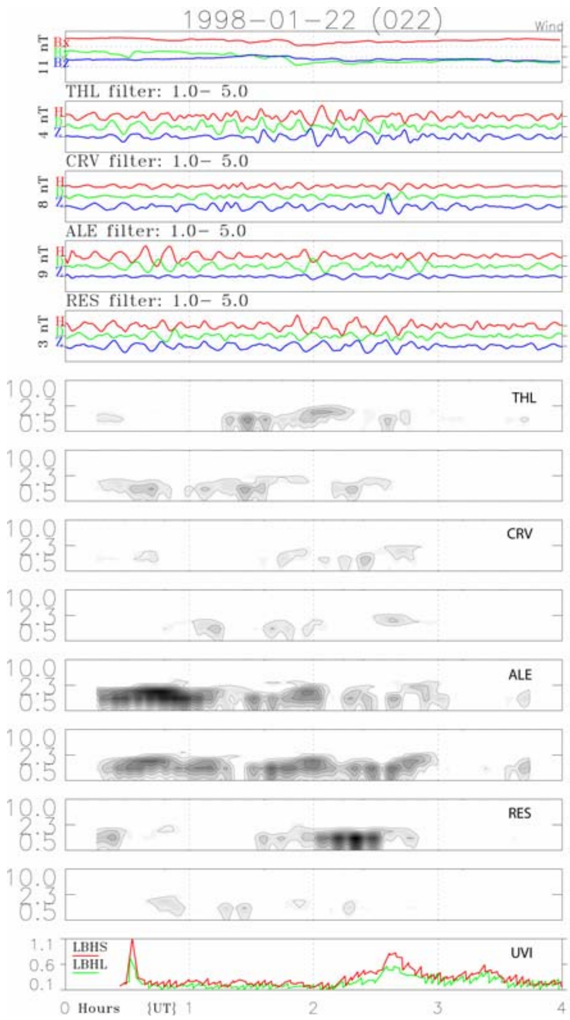

Fig.2. Time variations on 98022 (0-4 UT) of IMF *Bx, By, Bz* components, band-filtered (1-5 mHz) magnetograms from THL, SRV, ALE, RES, and dynamical spectra of *H, D* (upper and lower panels) components from these stations, and cap-integrated UVI in the S and L channels.

1998, January 22 (DOY 022)

The Θ-aurora occurred for a short time, from ~0220 UT to ~0300 UT. The IMF *Bz* and *Bx* components were positive and steady. Just before the Θ-aurora appearance, AT ~0145 UT IMF *By* component changed from *By*>0 to *By*<0. A snapshot during maximal auroral activation at 023937 UT is shown in Fig.1. At this moment the station CRV approaches the eastern edge of the trans-polar aurora, whereas RES is near the west edge. THL and SVS are farther away.

Magnetic disturbances (in respect to the reference moment 0200 UT) indicate a sunward equivalent ionospheric current along the trans-polar aurora above CRV and RES.

Just before and during the activation of transpolar aurora ULF fluctuations with *f*~1-2 mHz started at polar stations of RES, ALE, and THL (Fig.2). This enhancement was not observed at other stations (NRD).

1999, February 11 (DOY 042)

During this event, the trans-polar aurora appeared at ~15 UT, but intensified from ~2050 to 2210 UT (Fig.3). The IMF Bx was weakly negative, and IMF By~0 till 2150 UT, when it increased to By>0. During this moment a previously northward IMF (Bz>0) decreased to small values, Bz~0 (Fig.4).

During the peak of UVI activity (215300 UT) stations ALE, NRD were approaching the west edge of aurora, and at 220022 UT ALE and NRD were beneath trans-polar aurora (Fig.3). Magnetic disturbance vectors at ALE and NRD (reference moment 2100 UT) indicate that the equivalent currents have a sunward component.

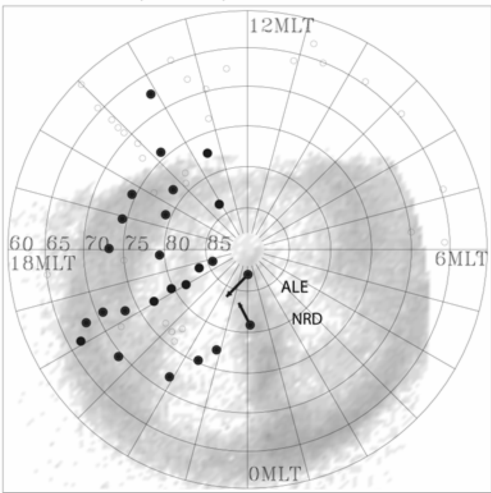

Fig.3. Snapshot at 220022 UT on 98042 of simultaneous Polar UVI (L filter) with overlaid magnetic disturbance vectors at high-latitude stations ALE and NRD in CGM coordinates.

However, it is hard to relate unambiguously the ULF oscillation burst to the transpolar arc because the polar cap is not a quiet place, but is filled with long-period large-scale Picap3 fluctuations with T~5-15 min, specific for the polar cap region [*Pilipenko et al.,* 2004]. Much more intense sources of ULF activity are cusp and nightside auroral oval. Moreover, to excite an oscillatory response of the field lines related to theta-aurora some external buffeting/impact is necessary. The global magnetospheric response to this impact may obscure specific aurora-related oscillations.

Right after the peak of UVI intensity, oscillations with frequency *f*~2-2.5 mHz started at polar stations ALE, THL, and NRD. These pulsations were not very coherent between these stations. The oscillations were mainly polarized along East-West direction, *D*>>*H*. The station RES was near the intersection of trans-polar aurora and dayside auroral oval, and at this station intense long-period (~1 mHz) fluctuations, typical for dayside cusp region, were observed (not shown).

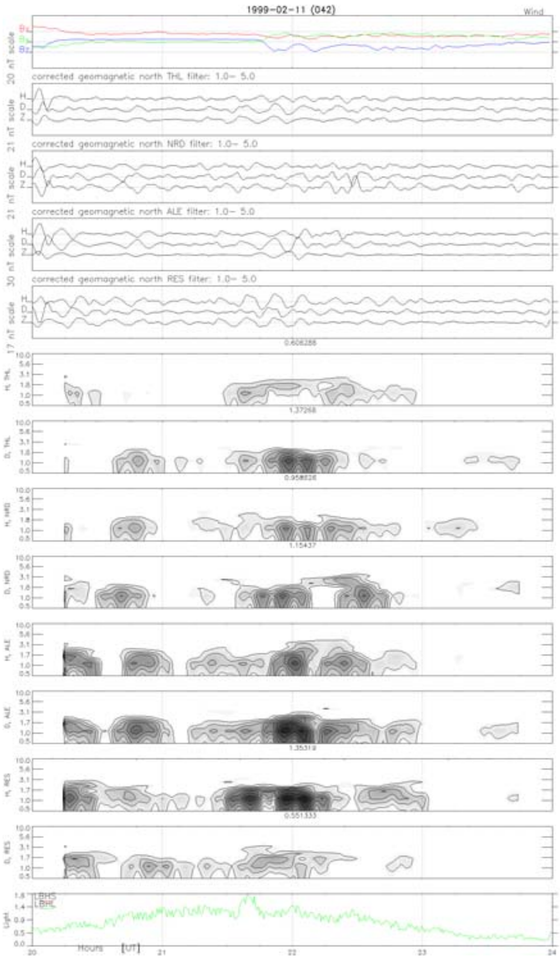

Fig.4. Time variations on 98042 (20-24 UT) of the IMF *Bx, By, Bz* components, band-filtered (1-5 mHz) magnetograms from THL, NRD, ALE, dynamical spectra of *H, D* components from these stations, and cap-integrated UVI (L channel).

Discussion

In the Northern hemisphere for *Bz*>0, when *By*>0, a theta aurora separating two counter-rotating convection cells is expected to be located in the dusk sector [*Blomberg et al.,* 2005]. The time delay between the IMF change and the auroral and convection response is probably to be > 20 min. The auroral pattern in Fig.1 supports these ideas. Moreover, according to the predictions of this model the gap in luminosity between the dayside part (a spot near the cusp) and the nightside part (the long arc) of theta aurora has been observed.

The sunward convection around a transpolar arc is to be accompanied by anti-sunward convection inside it (or sunward Hall currents along the theta aurora) [*Blomberg et al.,* 2005]. The mapping of Polar UVI during intervals with theta-aurora occurrence onto array of Northern magnetometer stations revealed that the activation of polar aurora above the station is accompanied with bay-like magnetic disturbance. The equivalent current detected by polar ground magnetometers has preferably the sunward direction indeed.

The comparison of polar cap integrated UVI intensity has shown that the activation of polar aurora is also accompanied by ULF oscillations with *f*~2 mHz. The concomitant ULF fluctuations are rather weak, about few nT. Nevertheless, their occurrence may signify the theta-aurora develops in the region with extended closed field lines.

Conclusions

The equivalent ionospheric currents estimated from ground magnetic have been found to be oriented approximately along theta-auroras, preferably in the sunward direction. The comparison of time variations of the UVI intensity integrated over a part of the polar cap, dominated by theta-aurora (>85^0 CGM latitude), and dynamic spectra from the polar magnetic stations enabled us to reveal the ULF activity related to the theta-aurora activation. The occurrence of these quasi-periodic variations in the polar cap signify that a theta-aurora develops on closed field lines indeed.

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