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CHANGE IN THE SPECTRAL FEATURES OF QP EMISSIONS DUE TO POLEWARD MAGNETIC BAY

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Abstract. Here we discuss a short-time significant change in the spectral features of quasi-periodic VLF emissions observed by ground-based receiver at Kannuslehto (KAN, northern Finland, L = ~ 5.5) in the local evening under quiet geomagnetic conditions (Kp~0-1) on 24 December 2011. This event was previously discussed by [*Manninen et al.*, 2012, 2014]. It was shown the peculiar dynamic spectral structure of repeated long-lasting (up to two minutes) noise bursts with quickly rising frequency up to ~ 5.5 kHz. The relatively stable wave structure suddenly changed at the time, when a small isolated substorm was recorded at the polar geomagnetic latitudes higher than 70° by the IMAGE magnetometers. The AMPERE data showed the magnetic bay-like disturbances and the enhanced field aligned currents at polar latitudes aligned from Svalbard to the East (up to Dixon station). There was no significant geomagnetic and ionospheric activity at Sodankylä (i.e. in the vicinity of VLF receiver). The low frequency VLF (f< 1.7 kHz) waves suddenly occurred and the wave arriving direction changed as well. The dynamic spectra were also modified. KAN monitored also the amplitude of the navigation (f~20-25 kHz) transmitter signals, which involved the polar-latitude propagation paths, showed some variations during this time. We conclude that VLF emission behaviour observed on the ground could be a very sensitive proxy for influence of even short small poleward geomagnetic disturbances to the VLF wave generation and wave propagation properties.

Introduction

We continue the comprehensive analysis of the quasi-periodic (QP) VLF emissions event [*Manninen et al.*, 2012, 2014] recorded at Kannuslehto (KAN, northern Finland, at L = ~ 5.5, Fig. 1) on 24 December 2011 under quiet geomagnetic conditions (Kp ~ 0-1). The studied QP emissions were right-hand polarized (indicating that KAN was located in the vicinity of the ionospheric exit point of the waves) and their frequency rapidly rose up to ~ 5.5 kHz. Very stable spectral shape of QP emissions was suddenly changed at time of occurrence of a small poleward magnetic substorm. The aim of this paper is to study this change in detail.

Observation

Geomagnetic conditions. The relatively stable OP wave structure suddenly changed, when the IMAGE magnetometers recorded a small isolated substorm at the polar geomagnetic latitudes higher than 70° (Fig. 2). There was no significant geomagnetic nor ionospheric activity at Sodankylä station (i.e. in the vicinity of the VLF receiver).

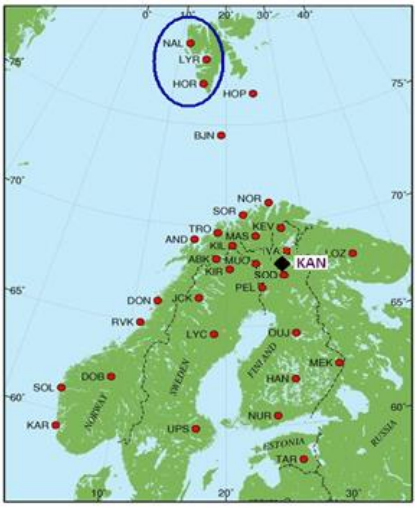


Figure 1. The map of IMAGE stations.

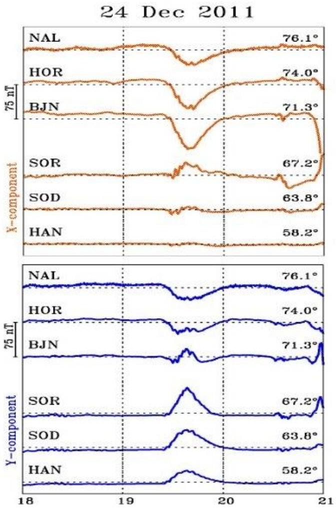


Figure 2. IMAGE magnetograms.

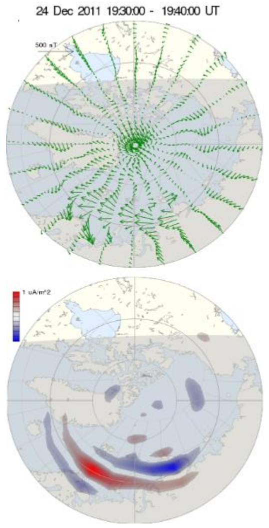


Figure 3. The AMPERE data.

The AMPERE data (Fig. 3), based on simultaneous measurements by the globally distributed 66 low-altitude commercial satellites, showed the development of the magnetic bay-like disturbances and field aligned currents (FAC) at the high latitudes, aligned from Svalbard to the East. It is seen (upper part of Fig. 3) that the centre of the substorm was located far to the North-East from KAN. The Dixon station located near the centre of this substorm recorded the magnetic bay (do not show here) with the amplitude of ~250 nT.

Dynamic spectra of the considered emissions. Before and after the substorm (Fig. 2) the QP emissions (Fig. 4) demonstrated the peculiar dynamic spectral structure of the repeated long-lasting (up to two minutes) noise bursts with quickly rising frequency up to ~ 5.5 kHz. A strong ionospheric frequency cut-off at ~1.7 kHz is seen. In Fig. 4, one can see that the high frequency part (2.5 – 5.5 kHz) of QPs arrived from the E-W direction (green-colour in the scale of the wave arrival direction distribution), but the low frequency part (1.7 – 2.5 kHz) of QPs – from the N-S direction (red colour). However, the both parts belong to the same element of the considered emissions. There is the question: how the different parts of the same burst could come from the different directions?

At 19.25-19.37 UT, i.e. during the substorm (Fig. 2), the low-frequency structure of the emissions suddenly changed and the wave power also occurred at the frequencies lower than the ionospheric frequency cut-off (1.7 kHz). These low-frequency waves arrived at some deviation from the meridian direction. It is clearly seen in Fig. 4. The waves with f < 1.7 kHz were observed only during the poleward substorm and disappeared after the end of substorm.

The fine dynamic spectral feature of the considered emissions is presented in Fig. 5, both in 10 min and 2 min time scale. In the 10-min time scale, the signals look like “candles” with a low-frequency “front foot”. However, in the 2-min scale, one can see that each individual element of QP emissions consists of a cluster of two parts of increasing frequency emissions about 1 min duration which separated by the frequency of ~2.5 kHz. The small dispersive emissions (“front foot”) in the frequency range of 1.7-2.5 kHz continued as strong dispersive waves in the frequency range of 2.5-5.5 kHz (“candle”). Both parts of the waves demonstrate the fine periodic modulation structure with approximately 3 s periodicities as it was previously shown in [*Manninen et al*., 2014].

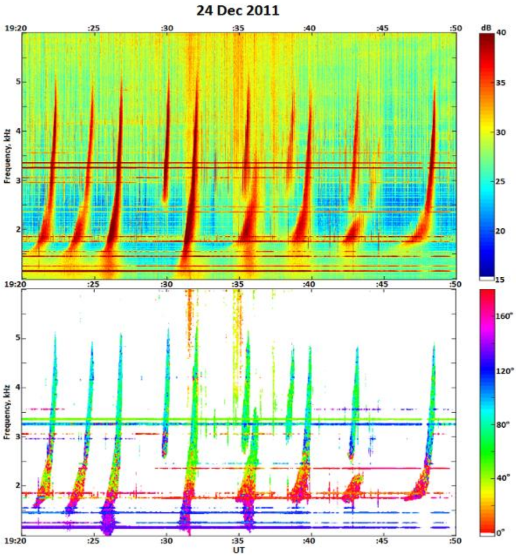


Figure 4. The QP spectrogram (*upper plot*) and the wave arrival direction at different frequencies (*bottom plot*) at 19.20-19.50 UT.

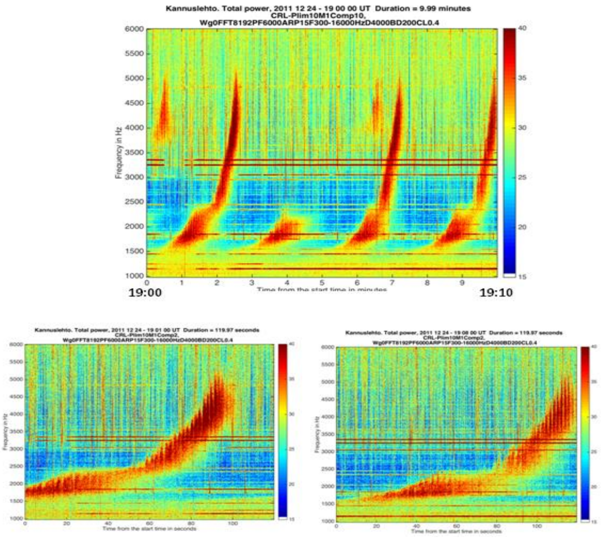


Figure 5. Fine structure of QP emissions showed in 10 min (*upper plot*) and 2 min (*bottom plot*) time scales.

The polar substorm completely changed the dynamic structure of QPs (Fig. 6), but the arrival direction of the different frequency parts did not change and showed the same behaviour as before substorm. The upper plots in Fig. 6 demonstrate five consecutive 2-min spectrograms during the considered poleward substorm. One can see that during the maximum of the substorm (19.35-19.45 UT), the conjunction of the “candles” and “front foots” destroyed, and three “candles” occurred without their “front foots”. It is clearly seen in Fig. 4 too.

The construction of the magnetic field vectors (Fig. 7a) at IMAGE station chain showed the existence of the counter-clockwise magnetic vortex at the polar geomagnetic latitudes (> 70°) which could be interpreted as the poleward increasing of the upward FACs, i.e. soft electron precipitation. The vortex onset was accompanied by the burst of Pi3 type geomagnetic pulsations (Fig. 7b) with the amplitude maximum at SOR station (~67°), i.e. northward from KAN.

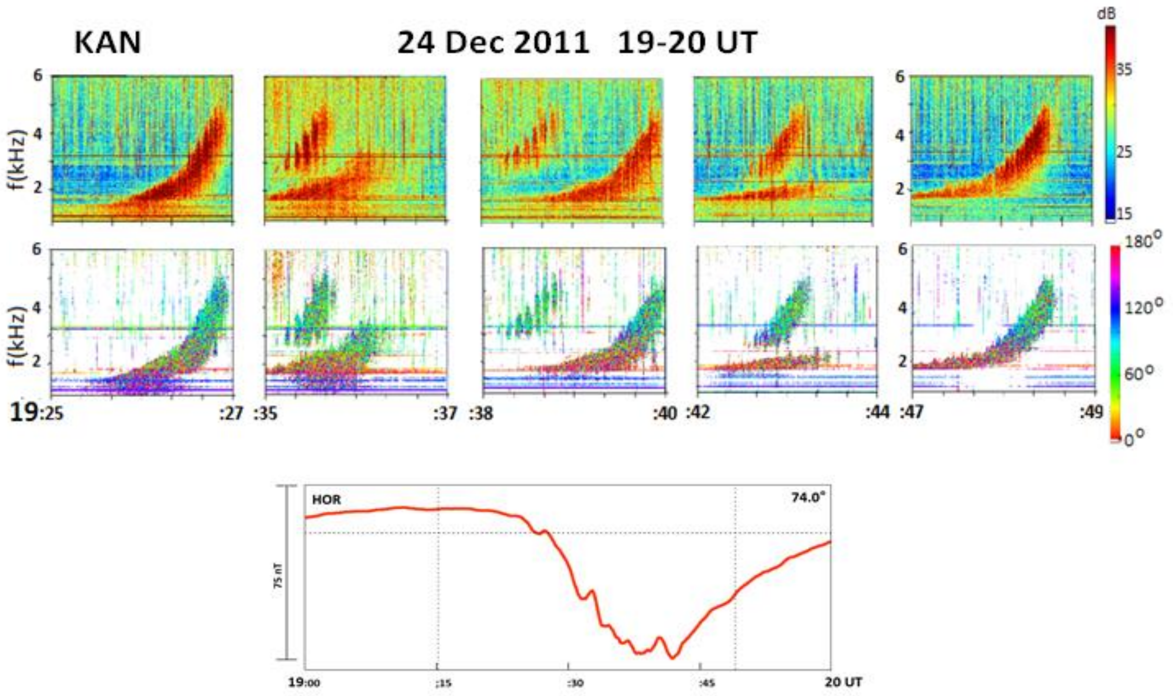
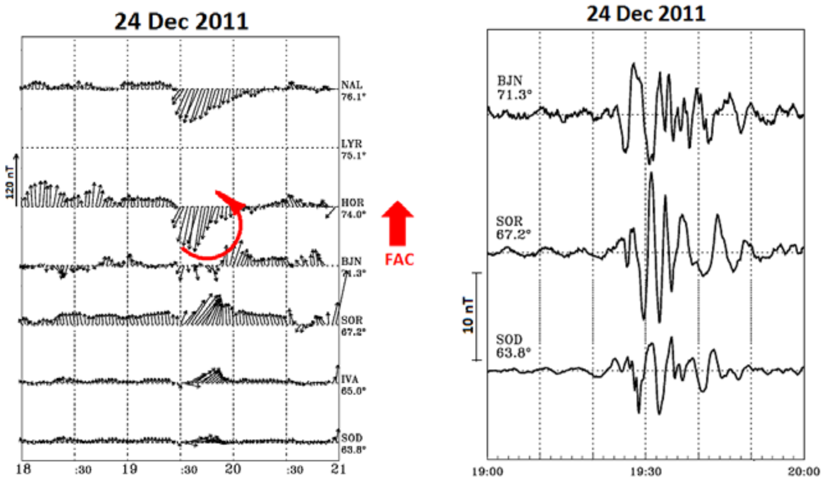


Figure 6. The change of QP dynamic spectral structure during the development of polar substorm (*upper panel*), the *middle panel* - the arriving wave direction, the *bottom* one – the substorm at HOR station.



a ***b***

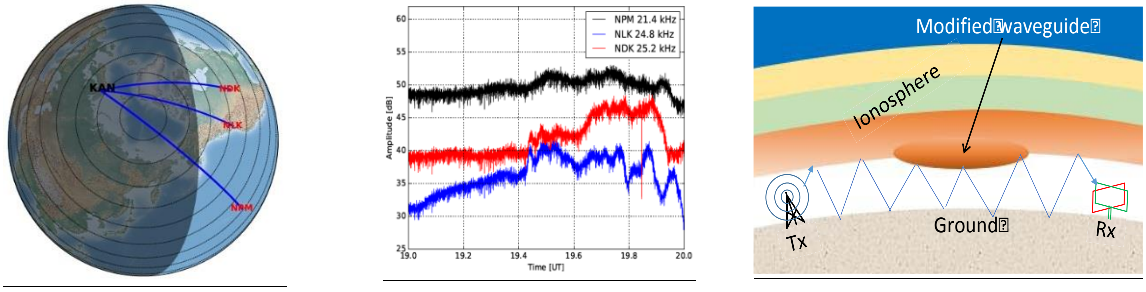
Figure 7. The vectors of the magnetic field (**a**) and Pi3 pulsations (**b**) at the substorm onset.

A possible influence of the considered polar substorm on the VLF wave propagation was observed as amplitude changes of the navigation (f~20-25 kHz) transmitter signals (Fig. 8b) that crossed the polar cap and which were monitored at KAN. In Fig. 8a the shadow represents the night-side region of the Earth at 19:30 UT. The transmitter locations and the VLF the propagation paths between the transmitters and the receiver are shown in Fig. 8a. The scheme of a polar substorm influence on the VLF propagation path is presented in Fig. 8c.

Discussion

We suppose that the frequency of 2.5 kHz, which separated the "candles" and "front foots", roughly coincided with one half of the equatorial electron gyrofrequency (*fce)* value at L-value of the most plausible location of the plasmapause under $Kp \sim 1$ (L ~ 5.1 – 5.2). Then, we could expect that the high frequency (2.5–5.5 kHz) VLF "candles" are generated inside the plasmasphere, and the low frequency (1.7–2.5 kHz) "front foots" – outside. The lowest part (f < 1.7 kHz) of emissions could be generated at higher L-shells by the trapped particles injected by the polar substorm in the magnetosphere.

We note that the high-frequency QP emissions ("candles") seemed to be rather similar to the QP event discussed by *Titova et al*. (2015) comparing the simultaneous observations on RBSP spacecraft above UK and the ground-based data at KAN and concluded that this QP event was generated inside of the plasmasphere. It can confirm our assumption of the mention above scenario of the wave generation. Wide frequency band observed in each individual QP element allows us to assume that the particles injected by polar substorm could scatter in different L-shells inside and outside of the plasmasphere and cause the cyclotron generation of waves simultaneously at different L-shells.



a ***b*** ***c***

Figure 8. The wave paths of three VLF transmitters (**a**) crossing the polar substorm area, the changes in the amplitude (**b**) the scheme of an ionospheric disturbances influence on the wave propagation (**c**).

Summary

The ground-based observations of QP emissions can be a very sensitive tool for studying the state of the magnetospheric maser [*Trakhtengerts and Rycroft*, 2008] controlled conditions of the VLF emission generation. It is shown that even a small substorm at the very high-latitudes located far away from the ground VLF receiver can break the self-oscillation regime of the cyclotron instability and change the dynamic spectra of QP emissions observed on the ground or provide the better conditions for wave to penetrate through the ionosphere.

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