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TEMPORAL CHANGE OF THE VLF HISS POLARIZATION: CASE STUDY OF APRIL 12, 2011

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Abstract. Two hours lasting 1.5-4.0 kHz VLF hiss burst was observed on Apr. 12, 2011 at 04-06 UT in northern Scandinavia at the temporal station Kannuslehto (L=5.3) in the end of the initial phase of the small magnetic storm. In the previous day (11 Apr. at ~16 UT), the very high solar wind dynamic pressure (up to 14 nPa) was observed and that shifted the plasmapause to the lower L-values. The VLF burst can be attributed to a typical plasmaspheric hiss. The temporal dynamic of the wave polarization properties was found. At the beginning, the VLF hiss was characterized by the left-hand polarization which can be interpreted as the waves long travelling in the Earth-ionosphere guide. The most part of the waves arrived from the north-south direction, probably from lower latitudes. About one hour later, the wave polarization gradually changed and turned to the strong right-hand polarization, which can indicate that the ionosphere wave exit point was nearly overhead. To this time, the solar wind dynamic pressure fell down up to 1 nPa and the magnetosphere (and the plasmapause) began to extend to its ordinary state. Thus, now the plasmapause can be mapped near Kannuslehto station (L=5.3). The VLF waves arrived from the north-south direction as well, but the intensity of northern and southern signals became comparable. We suppose that such wave polarization change can be interpreted as the temporal plasmapause location dynamics. The VLF hiss was modulated by simultaneously observed geomagnetic pulsations of the Pc4 range which demonstrated their resonance nature. The Pc4 spectral maxima shifted with time from higher frequency to lower, that can be a result of a latitude shift of the resonant field lines. Thus, the temporal dynamics of the VLF hiss polarization as well as the change of the resonant Pc4 pulsations demonstrate the temporal dynamic of the plasmapause location.

1. Introduction

VLF hiss is a broadband, noise-like whistler mode emission in the frequency range between about 100 Hz and several kHz. On the ground, the hiss emissions are usually divided into two types: (1) auroral hiss which is related to aurora and look like several minutes impulsive burst of emissions and (2) plasmaspheric hiss represented a burst of noise-like VLF emissions lasting up to several hours. Satellite observations at the plasmasphere showed that these noise VLF emissions are almost always presented [e.g., Thorne et al., 1973].

It is widely accepted that the plasmaspheric hiss get their energy from gyroresonant interaction with the electrons of the inner radiation belt near the plane of the magnetic equator [Kennel and Petschek, 1966].

Plasmaspheric hiss can persist during relatively quiet conditions, but the emission intensifies during magnetic storms or substorms [e.g., Kleimenova et al., 1968; Thorne et al., 1974; Larkina and Likhter, 1982; Merendith et al., 2004].

The recent Finnish VLF observation campaign has been carried out in April 2011 at the temporal station Kannuslehto (KAN, geograph. φ =67.74° N, λ = 26.27° E, 64.2°; 107.9° CGM, L=5.3), located near Sodankyla observatory. The description of the instrument is given by Manninen (2005).

One of the most spectacular VLF event, observed during this campaign, was the burst of the VLF hiss emissions on April 12, 2011 at ~04-06 UT, marked by the change of the sense of rotation of the wave polarization with time.

The aim of the present work was to analyse the properties of this hiss event.

2. Observation results and discussion

The small magnetic storm (Dst ~ -40 nT) started on April 11, 2011. In the storm initial phase, the solar wind density (Np) was very strong and the solar wind dynamic pressure (P) reached 14 nPa under IMF Bz>0. The storm main phase started at ~06 UT on April 12, 2011 when the IMF Bz turned to the negative values. The time history of this storm is given in Fig.1.

1. At 04-06 UT on 12 April, the strong VLF hiss burst was observed at KAN station. The frequency band was ~2.3-4.2 kHz in the beginning and ~1.3-3.3 kHz in the end of the event. The temporal dynamics of the hiss spectrogram and the wave polarization is presented in Fig.2, where the upper panel demonstrates the temporal variations of the total power of the VLF hiss, the middle panel - the power of the pure right-hand (R) polarized waves, and the bottom one - the power of the pure left-hand (L) polarized waves.

It is seen (Fig. 2) that in the event beginning, the polarization of VLF hiss was mostly left-handed, which can be interpreted as the ionosphere wave exit point was located far away from this station and the waves came due to long distance propagation in the Earth-ionosphere wave-guide [Yearby and Smith, 1994].

After ~05.15 UT, the wave polarization gradually turned to a strong right-hand direction, which can indicate that the ionospheric exit point of wave was nearly overhead.

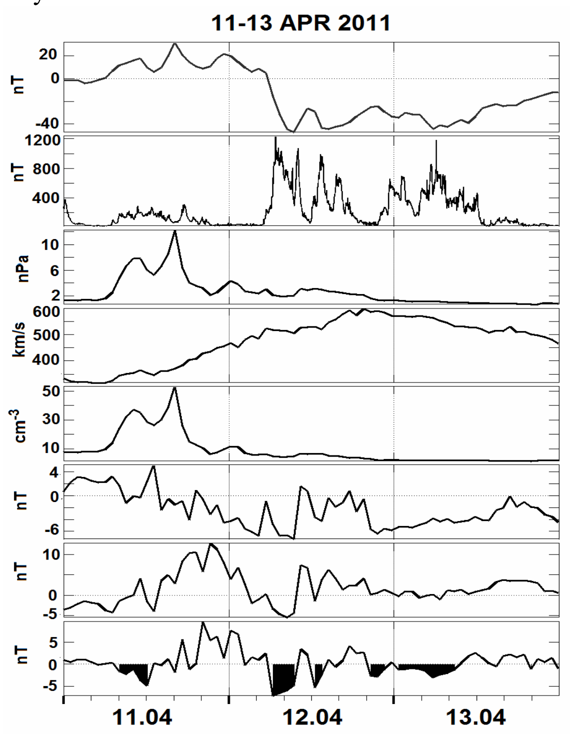

Fig.1. Solar wind and IMF data

In the previous day (11 Apr. at ~16 UT) the very high solar wind dynamic pressure (up to 14 nPa) was observed and strongly compressed the magnetosphere.

The result of the analysis of the wave arrival direction is presented in Fig.2 (bottom panel). The angles were determined as the direction of the minor axes of the polarization ellipses, which makes it possible to determine only the direction, but not the vector of arrival of the waves. This means that it can be argued that the waves came, for example, from the north–south direction, but it remains unknown whether the waves came from the north or the south.

It is seen that the waves arrived mostly from the north-south direction (the angles are <~60º and >~140º). The continuous emissions with arrival angle ~ 130º are the industrial power lines signals.

It is seen that and left-hand (L) polarized waves, observed at ~04-05 UT, came from South or from Nord while the right-hand (R) ones at ~05-06 UT came from both directions.

2. In the discussed time interval (04-06 UT) there were no strong magnetic substorms (Fig.3), however, at ~05 UT the growth phase of substorm started at the night side (Fig.4). The magnetic field lines started to stretch in the tail. At that time the hiss polarization and the arrival angles changed (Fig. 2).

3. The considered hiss burst was accompanied by geomagnetic Pc4 pulsation observed at Scandinavian IMAGE stations (Fig.5). The pulsations demonstrated the resonant nature. The first pulsation burst was observed in the time of the left-hand polarized hiss and the second one – in the time of the right-hand polarized hiss. It is seen that both pulsation bursts modulated the hiss amplitude.

The spectral analysis of pulsations (Fig.6) showed that the pulsations can be classificated as Pc4 type, but the wave spectra during the first and the second bursts were different.

The strongest maximum (12 mHz) in the first wave packet spectrum was observed at the geomagnetic latitudes ~57-59º (MEK-NUR) and in the second packet, the maximum shifted to ~10.5 mHz, and it was observed at the same area with strongest magnetude at HAN (58.6º).

The second maximum at 9 mHz, recorded in botn bursts, also shifted to higher latitude (from SOD to KEV). That can be a result or the shift of the resonant field lines to the higher latitudes.

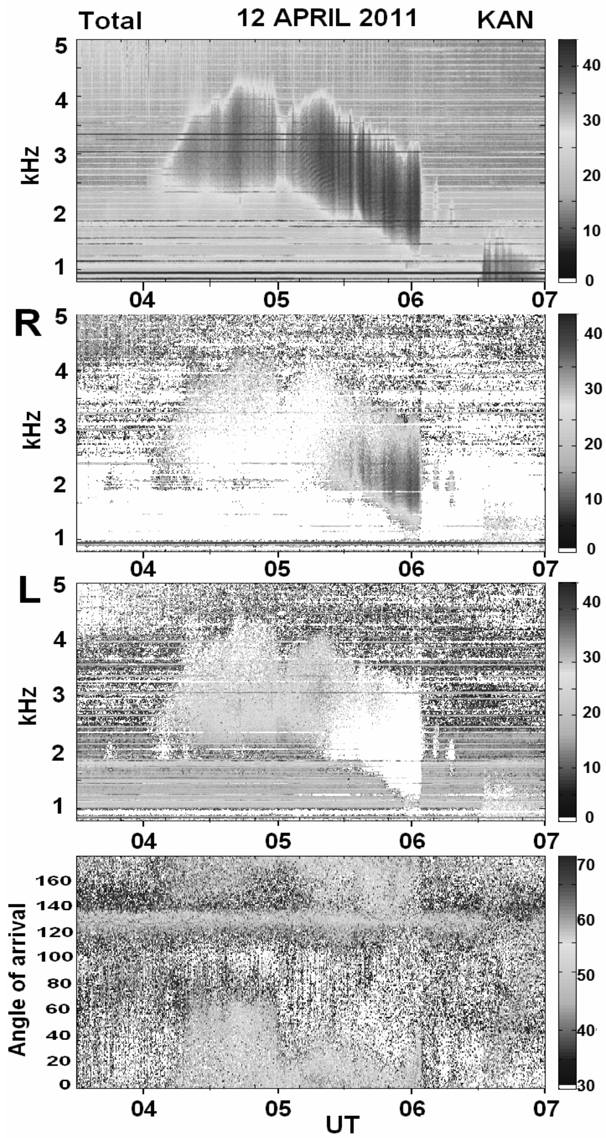

Fig.2. Spectrogram of VLF hiss: the upper panel – the total power; the middle ones - the power of the right-hand (R) and left-hand (L) polarized wave power; the bottom panel - the variation of the wave arrival angle.

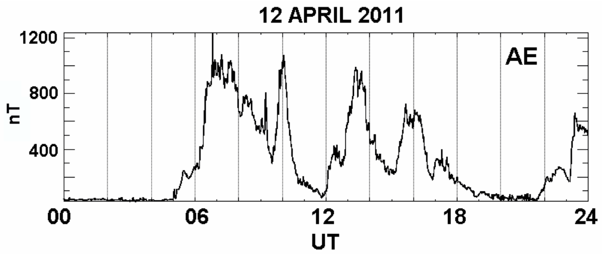

Fig. 3. The variations of the AE index of magnetic activity.

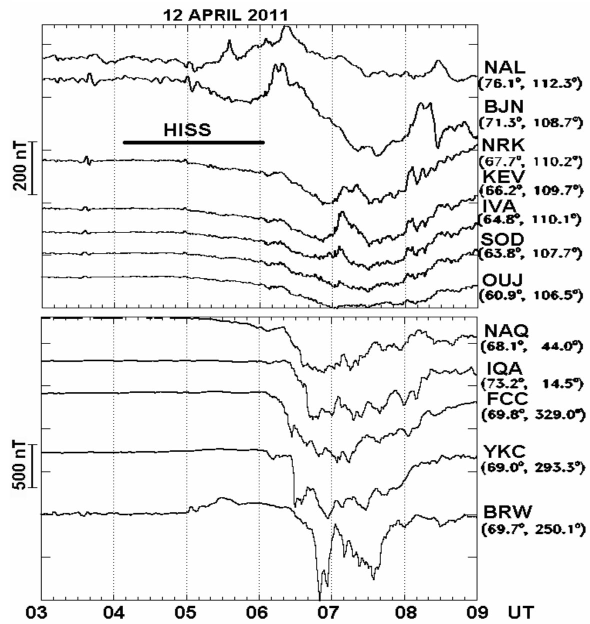

Fig.4. The night and morning sides magnetograms.

The hiss emission very suddenly very suddenly disappeared at 06.05 UT with a substorm onset at the night side (Fig.4).

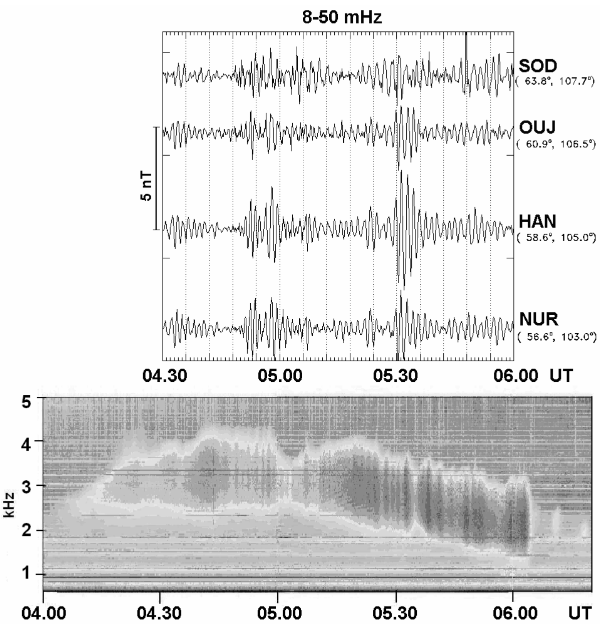

Fig.5. The filtered geomagnetic pulsations at the IMAGE meridian stations and the hiss spectrogram

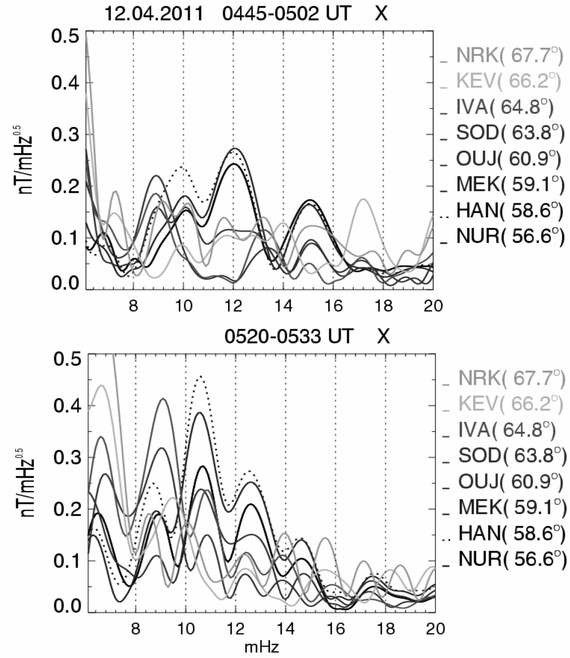

Fig.6. The spectra of the geomagnetic pulsations.

3. Discussion

Based on the morphological properties of the considered VLF hiss burst, it can be attributed to the typical plasmaspheric hiss.

In many papers, for example, [Inan and Bell, 1977, Thorne et al., 1979], when considering the conditions of propagation of the whistler mode VLF emissions in the magnetosphere, the importance of the plasmapause in the guidance of whistler waves is noted.

The ground data also showed that the strongest day-time hiss emissions were observed near the plasmapause location [e.g., Smirnova et al., 1976]. Thus, the plasmapause can be a main wave canal guiding the plasmaspheric hiss from the magnetosphere to the ionosphere. Then, the VLF waves propagate though the ionosphere and due to travelling in the Earth-ionosphere, the waves can arrive to the ground receiver, located far away from the wave exit point. The sense of the polarization vector rotation provides the information how far is the VLF wave receiver location from ionosphere exit point.

We suppose that in the beginning of our event, the VLF receiver (at KAN station) was located far away (left-hand polarized waves) from the wave ionospheric exit which is roughly coincides with the plasmapause projection to the ionosphere. Probably, in that time the plasmapause was located well equatorward from KAN. This suggestion is well reasonable. The strong solar wind dynamic pressure (~14 nPa), observed on the previous day (11 April), significantly compressed the magnetosphere, and at that time the plasmapause could be located at L-value much lower than L=5.3 (KAN station).

To ~05.30 UT on 12 April, the solar wind dynamic pressure dropped up to ~1.5 nPa, and the plasmapause started to move to higher L-values. At this time we observed the gradual change of the sense of rotation of the wave polarization from the pure left-handed to the pure right-handed. It can be interpreted as the approaching the VLF wave ionosphere exit point to KAN station. We suppose that it can be a result of the progressive plasmapause replacing with geomagnetic activity change. According to the satellite observations [e.g., Bezrukikh et al., 2001; Laakso and Jarva, 2001] the response time of the dayside plasmapause to changes in geomagnetic activity is very rapid.

The same was concluded by analysing of the simultaneous temporal change of the Pc4 geomagnetic pulsations spectra.

The statistical behaviour of ground Pc4 pulsations is well documented in the past [e.g., Orr and Matthew, 1971; Kopytenko et al., 1972, Hayakawa and Sazhin, 1992]. The Pc4 amplitude peaks at magnetic latitudes below ~60º. The same results were obtained in ourobervations. The THEMIS data [Liu et al., 2009] showed that the Pc4 wave activities were observed as soon as the satellite moved away from plasmasphere, suggesting that the plasmapause location can play a role in the occurrence rate of the Pc4 ULF waves.

Here we found that in the first Pc4 wave packet (04.45-05.02 UT), the resonance frequency was 12 mHz and in the second one (near 05.30 UT), it decreased to ~10.5 mHz. In both events the spectral maximum was observed at the same latitude area. According to a number of authors [e.g., Milling et al., 2001; Menk et al., 2004], this resonant frequency change can be interpreted as an increasing the plasma density in the resonance region. It can be a result of the plasmapause replacing to the higher L-values.

We would like to note that the time of the temporal change of the Pc4 resonant frequency (Fig. 6) coincided with the time of reversal of the VLF hiss polarization vector.

4. Conclusion

Thus, temporal dynamics of the polarization behavior of VLF hiss as well as the change of the Pc4 resonant geomagnetic pulsation spectra can be a result of the temporal dynamics of the plasmapause location.

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