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AURORAL PULSATIONS AND ACCOMPANYING VLF-EMISSIONS

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1. Introduction

Study of correlation between auroral pulsations and very low frequency (VLF) emissions is interesting because it is generally accepted that wistler mode VLF waves play an important role in precipitation of energetic particles (*Kennel*, 1969; *Inan et al.*, 1978). Interacting with electrons close to equatorial plane in the magnetosphere VLF waves scatter them by pitch-angles and cause their precipitation into the ionosphere. *Rosenberg et al.* (1971) were the first who presented an experimental evidence of such interactions. They found out a peak to peak correlation between spikes of X-rays with energies exceeding 30 keV at the altitude of balloon flight and discrete VLF emissions at L ~4.2. The relationship between chorus type VLF emissions and pulsating auroral patches observed by low-light-level TV camera were studied by *Tsuruda et al.* (1981). During more than one hour of observation they found only six cases of peak to peak correlation between chorus elements and pulses of auroral patches. *Manninen et al.* (1991) and *Zaitsev et al.* (1994) also reported about separate cases of correlation between auroral and VLF emission pulsations in the process of postsubstorm occurrence of these phenomena. *Novikov et al.* (1994) were the first who pointed that a structured VLF emissions are connected with fast moving auroral patches.

Comparing the data of VLF and auroral observations one has to take into account two crucial aspects. First one is that a pulsating patch during one pulse of luminosity can have very strong spatial variations, which could look like temporal variations during an ordinary photometer registration. Another aspect is that VLF antenna has field of view about several tens of degrees and in some cases it may register summarised signal from several sources.

The difference of this work from the previous ones consists in digital auroral and VLF data analysis by software developed by us for auroral image processing (*Arinin et al.*, 1995) and for ELF-VLF signal processing. The software for image processing is able to obtain temporal resolution as high as duration of a single TV frame (0.04 s). It allows perfectly separate spatial and temporal variations in auroral luminosity by different methods of analysis, which is very important in study dynamic auroral processes.

2. Results of observations

Results of simultaneous observations of VLF emissions and auroral pulsations in Sodankyla, Finland (L=5) on February 15, 1991 are presented in this work. Auroral pulsations were observed by low-light-level TV camera with 84°x105° field of view (FoV), and VLF data was recorded on a audio track of videotape. Detailed description of the equipment was given by *Manninen and Turunen* (1992).

Magnetic and auroral activity were moderately high, and a clear substorm onset was at about 2340 UT 14 February 1991. Auroral pulsating activity was strong during recovery phase and looked typical representing pulsating patches with characteristic periods about 5-10 s expanding and propagating during their brightening. VLF emissions represented the trains of chorus elements having periodicity of about several seconds the same as auroral pulsations. Typical periods of chorus elements in frequency range 1-2 kHz were 0.3-0.4 s. Both auroral and VLF activity lasted up to the dawn for about 2 hours demonstrating coexistence of both phenomena. The 37 seconds interval (01.34:35-01.35:12 UT) was chosen for detailed computer analysis. Each TV frame 0.04 s duration was transformed to digital matrix with dimensions 256x256 pixels and 64 brightness gradations. These dimensions corresponded to 84°x84° FoV. Hence one pixel corresponded to 0.33°x 0.33° FoV, and the area of a pixel was 0.55x0.55 km at the height level of 95 km.

The results of the analysis are shown in Fig.1. Dynamic spectrum of VLF emissions is shown in the upper panel. It is seen that five chorus trains appeared in this interval. Most of them contained 3-5 chorus elements in the frequency range 1-2 kHz and periodicity 0.3-04 s. Keogram of the event is shown in the second panel from the top of Fig.1. It was made along the cross-section approximately in N-S direction close to the zenith of the station. Auroral pulsations represent rapidly moving luminosity in N-S or opposite directions. There were also five pulsations the same as chorus trains. So the whole interval is divided into 5 parts corresponding to each appearance of VLF chorus train. Duration of each part is about 7.0-7.5 s. They are indicated by thick lines between the panels. The common feature of the luminosity pulsations is that they propagated in a very limited region about 30 km in horizontal plane. The velocity of propagation varied from 6 (first impulse) to 11 km/s (the fourth one).

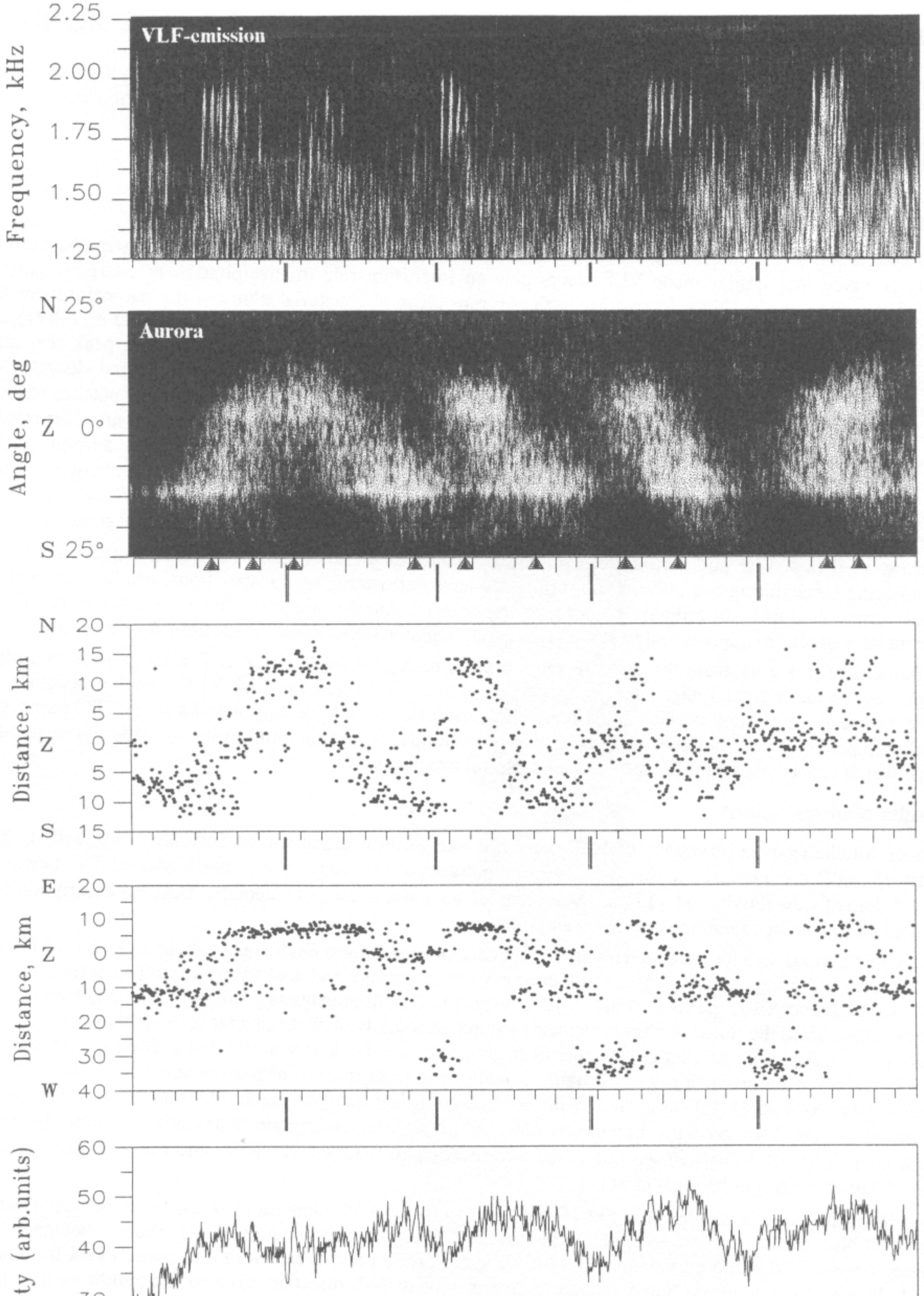

Fig.1. The results of computer analysis of simultaneous VLF emission and auroral pulsations data. First panel at the top shows the dynamic spectrum of VLF emissions in 37 s interval. Five trains of VLF emissions of chorus type is clearly seen in the picture. Second panel - simultaneous auroral data in the form of keogram along N-S direction close to zenith of station. Third panel - N-S coordinates of consequent locations of maximum of luminosity intensity in each TV frame (shown by dots). Forth panel - the same in W-E coordinates. Fifth panel- variations of maximum of intensity in arbitrary units

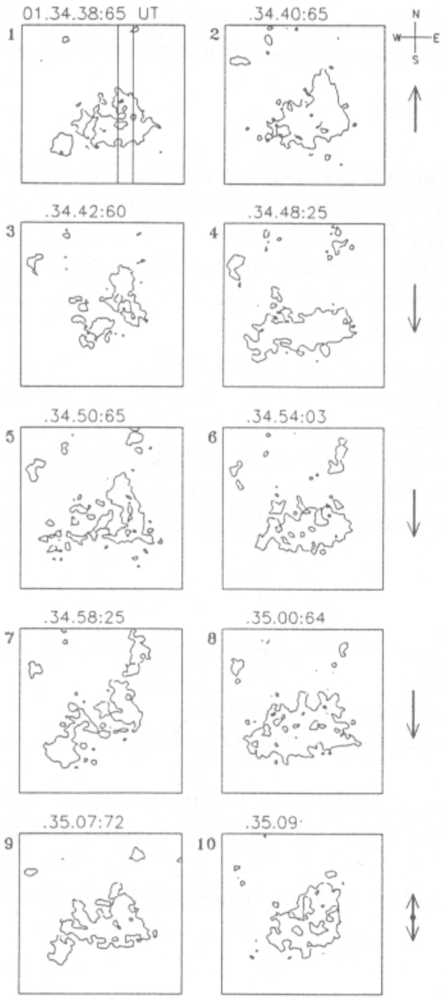

Fig.2. The contours of the auroral patch for the moments when the luminosity was at the extremal northernmost and southernmost positions. The moments are indicated by the triangles below the time axis of the second panel in Fig.1. The arrows show the direction of motion of the luminosity. The cross-section of keogram is shown by vertical lines in the first square.

The contours of the patch on the constant level at different moments are shown in Fig.2. The keogram cross-section is shown in the first square by two vertical lines. The moments were chosen when the luminosity was in the northernmost and southernmost positions. So in Fig.2 they were divided in pairs for each part of the whole interval. The arrows on the right side of the figure show the direction of motion in each interval.

One can easily see mutual correspondence between VLF chorus emissions and auroral pulsations. But keogram analysis contains an uncertainty in determining a maximum of intensity of an auroral pulsation because of field of view decrease. That's why it is not clear weather VLF train coincides with a maximum of a pulsation or with another stage of it.

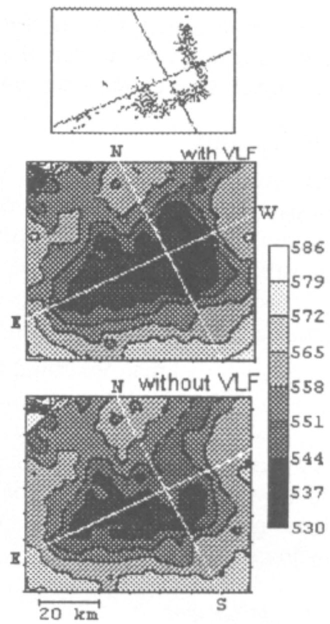

Fig.3. The top panel shows distribution of maxima of luminosity intensity for the whole 37s interval. Mid panel - auroral intensity distribution for the five intervals with VLF chorus trains occurrence. Bottom panel - the same picture, but for the intervals when VLF chorus emissions were absent.

For more detailed analysis a special software was developed to determine location of maximum intensity in each TV frame. It was calculated as a mean value of intensity in a window with any sizes chosen beforehand. So one could follow after the maximum of intensity from frame to frame and determine the luminosity motion in different directions. The results of such analysis are also shown in Fig.1 (3rd, 4th and 5th panels). Here we have chosen the circular window with 20 km in diameter. The 3rd and 4th panels show the motion of the maximum of the auroral intensity in geomagnetic N-S and W-E directions, correspondingly. It is seen that motion in N-S direction revealed by this method repeats in general the behaviour of luminosity shown by keogram (2nd panel), however activity in W-E direction is also high. It is seen that there are rather intensive spatial variations around the zenith, but sometimes a bright patch appears to the west of the zenith. Careful analysis of dispersion of the points of luminosity maximum show that they leap from one part of the active region to another around the zenith with frequency of about several Herts. The distance of the leaps is about 10-20 km. We consider this leaping motion as a kind of the flickering aurora.

It is clearly seen that the western luminosity patch (lower part of the forth panel in Fig.1) doesn't correlate with VLF chorus. Hence we conclude that the latter are connected with auroral activity around the zenith of the station. The fifth panel shows the temporal variations of maximum intensity. The peak values of these variations don't always coincide with a VLF emission train, though the variations of intensity have the same 7.0-7.5 period and the most strong VLF chorus emissions coincide with the maxima of variations (1st, 4th and 5th intervals). In the rest of the intervals (2nd and 3rd) the VLF emissions coincide with rapid motion of auroral luminosity, but they were also close to the peak values of maximum intensity. So we can conclude that in all intervals the VLF emissions corresponded to the moments close to the maximum of auroral intensity.

This conclusion is supported by the results presented in Fig.3. The top panel shows the summarised picture of luminosity maxima for each single TV frame. The compass directions here are shown in geomagnetic coordinates. The summarised and averaged picture of auroral intensity distribution for the five intervals during VLF chorus trains occurrence is shown in the mid panel. The same picture, but for the intervals between the trains is presented in the bottom panel. Comparing the pictures in all three panels one can see that during the VLF chorus emissions the auroral intensity increased and occupied the area to the north-east of the core of active region which is shown as the black spot close to the zenith.

3. Discussion

From the experimental results presented above it seen that behaviour of auroral pulsations accompanied by VLF chorus emissions bears a very complicated character. The main peculiarity is that the auroral pulsations represent unstable rapidly propagating intensity variations inside a spatially restricted region. Moreovere this motion has a fine structure which manifested itself in the spatial to and fro leaps of maximum intensity to the distance about 10-20 km with frequency about several Hz. Similar type of high-frequency pulsations called flickering was observed by *Kunitake and Oguti* (1984), but they belonged to the evening sector discrete type auroras.

Alternative explanations could be given for both the rapid propagation and flickering of auroral patches. The first one is that the instability of luminosity is caused by inhomogenuity of cold plasma in the flux tube. In this case the maser mechanism proposed by *Trakhtengerts et al.* (1986), *Tagirov et al.* (1986) and *Demekhov and Trakhtengerts* (1991) is appropriate for the explanation of the visible auroral pulsations and VLF emissions. Another explanation which we cannot exclude is that propagation and/or flickering could be caused by wave processes in the magnetosphere modulating particle fluxes. Both mechanisms are to be carefully examined in the future studies of pulsating phenomena.

4. Conclusions

1. Mutual correspondence between the flashing of the patches and appearance of VLF chorus trains was found out in 37s interval containing five periods of pulsations of both types of phenomena.
2. Most often chorus emissions coincide with the moments of maximum brightness of the patches.
3. The spatial dimensions of pulsating area were about 30 km. The luminosity propagated inside it with the velocity about several km per second.
4. The fine structure motion of luminosity inside the active area had a complicated character which liked flickering, i.e. spatial leaping of maximum of intensity at a distance of about 10-20 km with the frequency of about several Hz.

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