Irregular pulsations in simultaneous TV, IRIS and VLF observations

B.V. Kozelov[1], E.E. Titova[1], J. Manninen[2], F. Honary[3], S. Marple[3], T. Turunen[2]

[1] Polar Geophysical Institute, Apatity, Murmansk region, Russia
[2] Sodankylä Geophysical Observatory, Finland
[3] Dept.Communication Systems, Lancaster University, United Kingdom

Abstract. The models of VLF emission generation are based on cyclotron wave-particle interaction mechanism. According to such models the generation of waves is accompanied by a modification of particles pitch-angle distribution, that can lead to their precipitation in a loss cone. The dissipation of energetic particles in the atmosphere is accompanied by excitation of auroral emissions at altitudes of 100-200 km, that is observed by optical instruments. If the precipitated particles are rather energetic to penetrate at altitudes below than 90 km, the ionization by them of atmospheric gases leads to an absorption of radiowaves, that is observed by riometers. However, to find direct correlation between VLF waves and particles precipitation is complicatedly. Only a few papers with examples of such correlation are known. In this report we consider simultaneous morning time observations of VLF antenna, IRIS riometer array, and TV all-sky camera located at Kilpisjärvi and Porojarvi, Finland. We used the continuous wavelet transformation of original data sets to find similarities in variations seen at time scales from 1 to 100 seconds.

Keywords: 2407 Auroral ionosphere, 2483 Wave-particle interactions, 2704 Auroral phenomena, 2716 Energetic particles, precipitating, 2431 Ionosphere-magnetosphere interactions

1. Introduction

Pulsing electron precipitations are usually considered connected with developing of the instability in the magnetosphere [Trakhtengerts, 1984, Davidson, 1990, Trefall et al., 1975]. Simultaneous registration of such events as pulsing auroral forms, riometric absorption and ELF/VLF choruses in morning sector is usual for recovery phase of substorm and supports this point of view. [Helliwell, 1965, Tagirov, 1986,]. However one-to-one correspondence for variations of precipitated electron flux and ELF/VLF waves is observed seldom [Tsuruda et al., 1981, Rosenberg et al., 1971, Helliwell et al., 1980, Tagirov et al. 1999]. It can be explaned by features of low-frequency electromagnetic waves propagation in the magnetosphere and ionosphere of the Earth. The ray trajectories of nonductedly propagating ELF/VLF waves oblique from a magnetic field line that can essential displace an exit point of the wave from L-shell of generation region [Huang, 1883]. Reflection and absorption of low-frequency waves in the lower ionosphere also hinder the ground-based observations of VLF waves.

However, search of connection between precipitated electrons and ELF/VLF emissions is very important for the analysis of wave-particle interaction and non-stationary magnetospheric processes. Observations of aurora by highly sensitive television (TV) cameras and riometric absorption by IRIS image riometer allows ones to research spatial-temporal dynamics of precipitated particles. Here we present some results of an analysis of simultaneous observations of ELF/VLF emissions, aurora and riometric absorption for two events of 8 and 12 January 1997.

2. Geometry of observations

In this report we consider simultaneous observations of VLF antenna, IRIS riometer array, and television all-sky camera located at Kilpisjärvi and Porojarvi in northern Finland.

The Imaging Riometer for Ionospheric Studies (IRIS) [Browne *et al.*, 1995] is located at Kilpisjärvi in northern Finland, (69.05° N, 20.79° E). IRIS samples the cosmic radio noise at 38.2 MHz and consists of an imaging array (7x7 imaging beams) and a single, wide beam riometer. The whole array is sampled every second.

The television all-sky camera (TVASC) was located at Porojarvi (69.17° N, 21.47° E) and observed the aurora in “white” light with a broad maximum at blue-green wavelengths. The TV data were recorded by a VHS recorder in a PAL video system, at 25 images per second. The TV data were digitized using an Acorp TV-Capture plate with an output resolution of 5 images per second, 160×144 pixels, 8 bits per pixel.

Stereo sound track of VHS video tape used to store ground-based observations of ELF/VLF electromagnetic waves up to 20 kHz. The signal was digitized with sampling rate 44.1 kHz, 16 bit per channel, simultaneously with TVASC data.

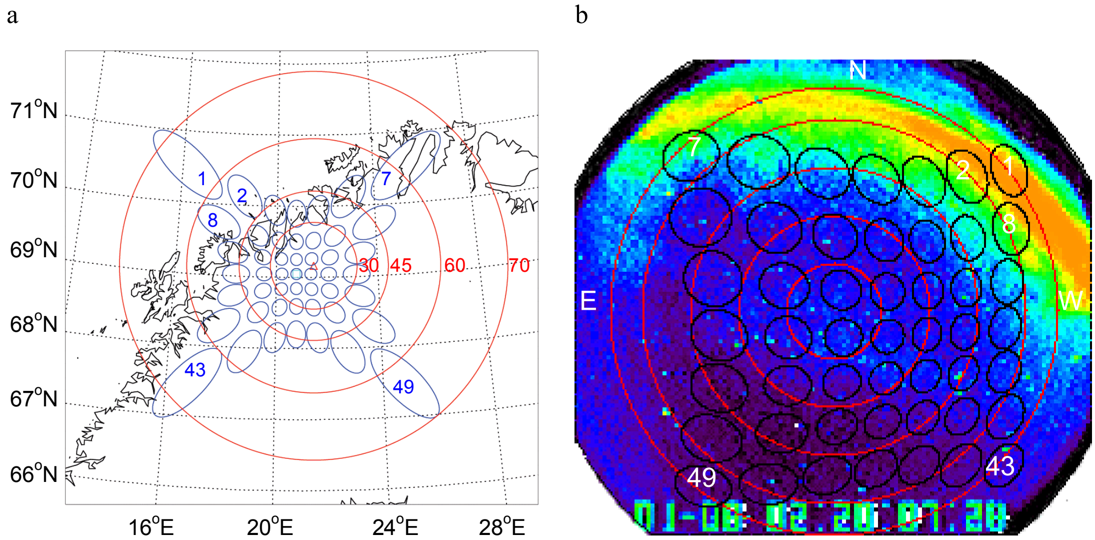

Figure 1. Geometry of observations for IRIS and Porojarvi TV all-sky camera: a – map of projections of IRIS beams to 110 km (blue ovals and numbers) and all-sky camera (red circles for zenith angles of 30°, 45°, 60° and 70°); b – projections of IRIS beams to 110 km in all-sky camera field of view (black ovals), red circles show zenith angles of 15°, 30°, 45°, 60° and 70°.

3. Selected events

For the analysis we chosed two morning events, during which occurrence and the increase of discret chorus activity was accompanied by gradual approximation of band of pulsing auroral forms. We hoped, that the gradual development of an observable phenomenon gives us possibility to clarify a connection between wave activity and particle precipitation.

The dynamic spectrum of waves during event of January 8 is shown in Fig.2 together with keograms, constructed by IRIS and TV data. Section of the field of view for keograms were taken approximately along the magnetic meridian (~30 degrees from north to west relative to geographic meridian).

The TV keogram demonstrates the southward movement of a boundary of the pulsing auroral patches that formed arc-like structures. Same movement is seen in IRIS keogram. The boundary of the pulsing patches corresponds to the equatorial boundary of the auroral oval, well seen from the DMSP F13 satellite, Fig.3.

The dynamic spectrum of the electromagnetic waves (Fig.2-a) shows that ELF/VLF chorus observed from 450 to 1500 Hz and the top frequency of the ELF/VLF chorus increases during this event. ELF/VLF waves observed permanently at frequencies < 400 Hz and >1800 Hz relate with discrete atmospheric emissions (sferics).

Second event, January 12, 1997, has the same morphology, but some slower. We can note that both event were observed during mainly quiet conditions after small substorm-like intensification, Table 1.

Table 1. Geophysical conditions during considered events.

	January 8, 1997 02:20-02:35 UT	January 12, 1997 05:20-05:35 UT
Dst	<10	~10
Kp	3	2
AE	~200	<100

4. Spatial regions of correlation

Whether there is a connection between the particle precipitation causing riometric absorption and optical aurora? For the answer to this question there were selected the virtual photometers appropriate to projections of IRIS beams in TV ASC frames on an altitude 110 km. We compare variations of an spatial-integrated intensity of TV signal in each virtual photometer with variations of absorption in the appropriate beam of IRIS. The figure 4 by color code presents results of calculations of linear Pearson correlation coefficient between values of riometric absorption and auroral intensity in each IRIS beam. The numbers designate numbers of beams. One can see, that aurora and riometric absorption are well correlated in northern part of the field of view, for some beams the correlation coefficient reaches values of ~0.8.

Whether it is possible to localize a spatial area of particle precipitation connected with measured chorus emissions? The frequency band, in which the chorus were observed, was divided into 3 bands: 450-700 Hz, 700-1000 Hz and 1.0-1.5 kHz. The correlation coefficient between intensity of waves in each band and data of IRIS and TV ASC are shown in a Figure 5. From figure 5 we can conclude:

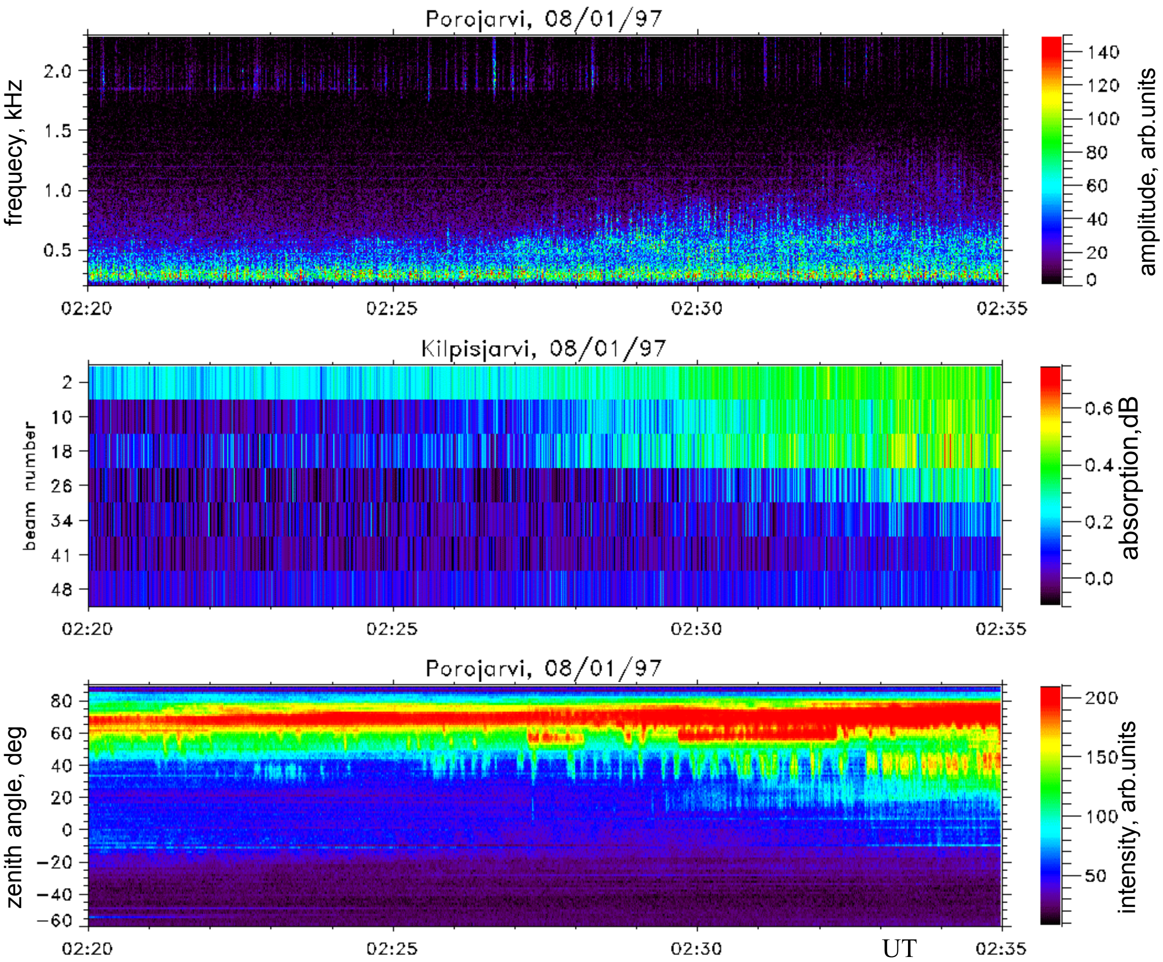

Figure 2. Dynamics of ELF/VLF activity and particle precipitations during event of January 8, 1997: a - dynamical spectra of ELF/VLF waves; b - keogram of riometric absorption from IRIS data; c - TV ASC keogram. The keograms were taken along the magnetic meridian.

1) The waves correlate better with the data of an IRIS (correlation coefficient reaches value of 0.7), than with TV (correlation coefficient is not more than 0.4).

2) Waves in the lower band of 450-700 Hz is better correlated with riometric absorption.

3) There is a region of anti-correlation (correlation coefficient ~0.4) of waves in band of 450-700 Hz and optical aurora. This is a region of oscillated boundary of sub-visual diffuse aurora, the boundary is well seen in figure 2-c at –20 zenith angle. This diffuse aurora decreases during the event, so we have anti-correlation with increasing wave activity.

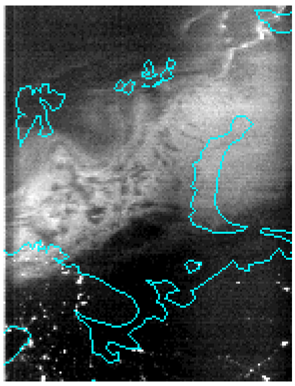

Figure 3. Auroral structure observed by DMSP F13, 08 January 1997, 02:45 UT.

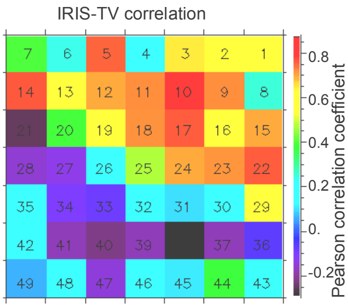

Figure 4. Correlation between absorption in IRIS beams and optical emissions in correspondent regions of the TV all-sky image during event of 08 January 1997, 02:20-02:35UT. Value of linear Pearson correlation coefficient presented by color coding in IRIS beams array. Note, that the scintillation due to Cassiopeia is located in beam 4, and due to Cygnus - in beams 6 and 7.

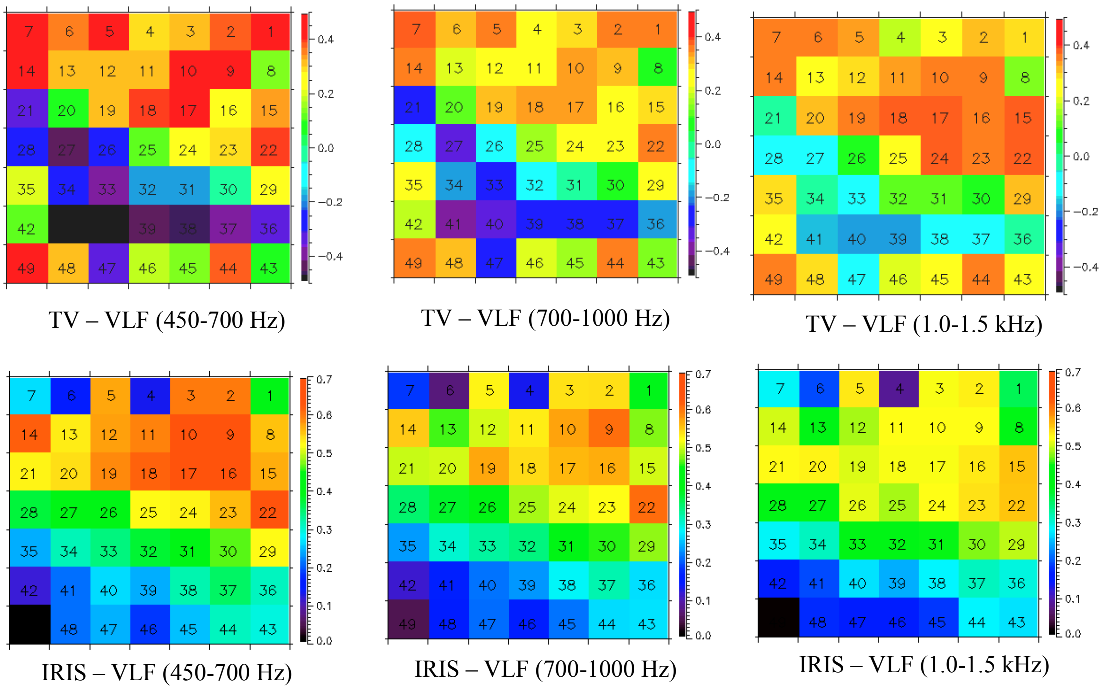

Figure 5. Spatial distribution of correlation between particle precipitation and ELF/VLF waves in three frequency bands during event of January 8, 1997, 02:20-02:35UT: top row- for TVASC data, bottom row - for IRIS data. Value of linear Pearson correlation coefficient presented by color coding in IRIS beams array. Note, that for bottom row the scintillation due to Cassiopeia is located in beam 4, and due to Cygnus - in beams 6 and 7.

5. Top frequency of chorus and position of generation region

The increase of top frequency of chorus band deserves special attention. Whether it is possible to connect the observed increase of top frequency of chorus emissions with a possible position of generation region? The characters in Figure 6 mark the top frequency of chorus depending on a latitude of equatorial boundary of pulsing patches (by IRIS and TVASC data). The solid lines show the latitude dependence of a half of electron hyro-frequency calculated by values of equatorial magnetic field according to the magnetospheric model of Tsyganenko-96 [Tsyganenko and Stern, 1996]. One can see, that for two considered events the experimental and theoretical dependencies of the frequencies are close.

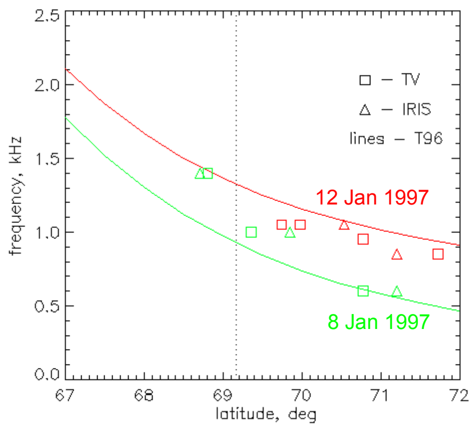

Figure 6. Comparison of observed top frequency of chorus band as a function of latitude of equatorial boundary of pulsing patches and $f_H/2$ calculated by Tsiganenko-96 magnetic field.

6. Pulsations at scales 1-100 s

Correlation coefficients discussed in section 4 were calculated for full interval (15 minutes) and characterize large-scale changes of considered signals. Whether it is possible to find time intervals of one-to-one conformity of small-scale variations of measured signals?

For this analysis we used the continuous wavelet transformation (CWT), because these variations can be irregular. The Morlet wavelets of 6 order were used for the transformation. Wavelet analysis has shown, that there is no periodic structure in VLF signal at time scales from 1 to 100 seconds. The examples of wavelet-spectra of considered signals for beam 17 are shown in a figure 7.

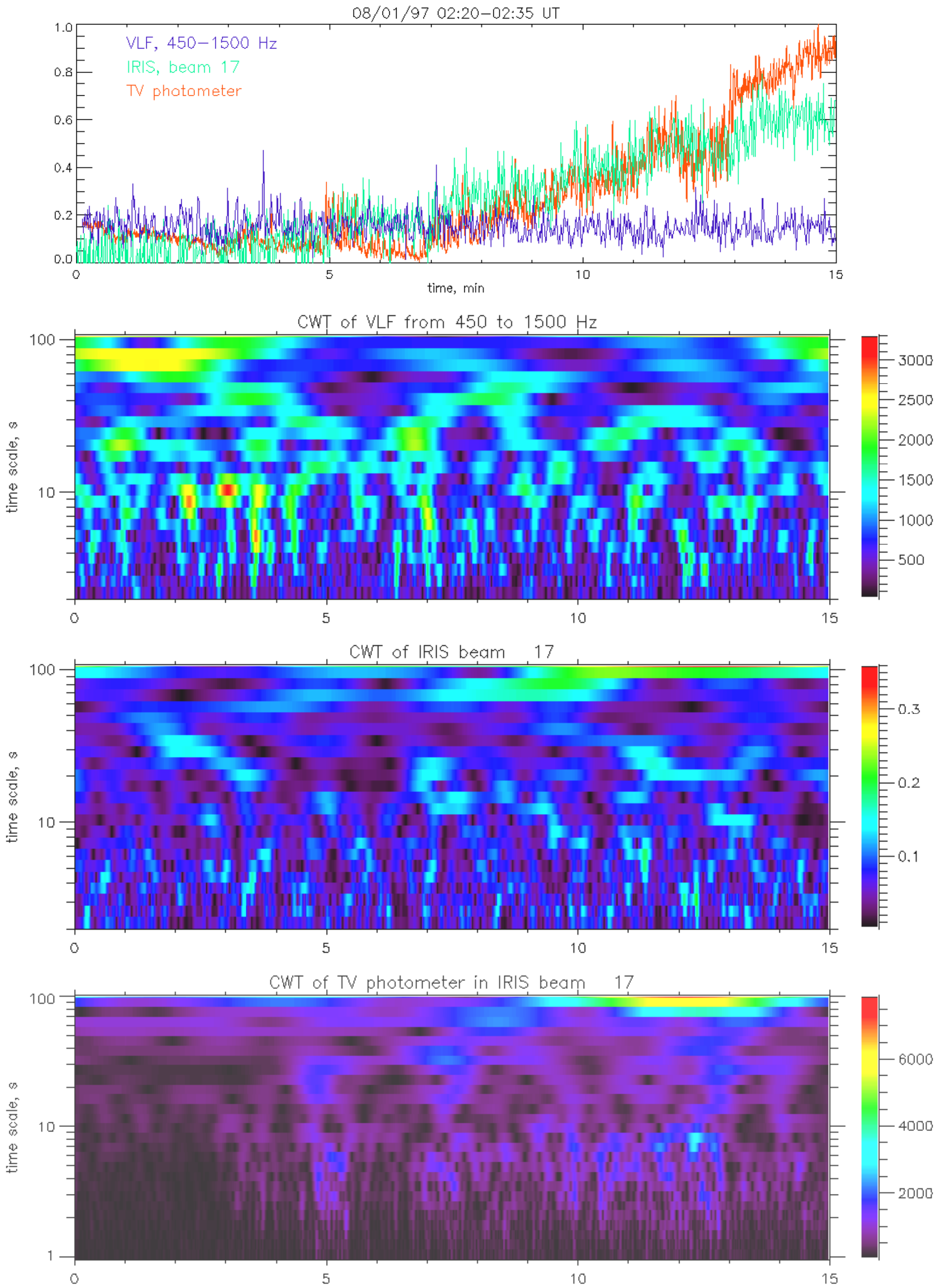

Figure 7. Analysis of small scale variations of three kind of signals: ELF/VLF waves integrated from 450 to 1500 Hz; beam 17 of IRIS; TV ASC virtual photometer in projection of beam 17. Considered signals is shown in top panel, other panels are continuous wavelet transformations of the signals.

The power spectra of the signals were obtained by integration of wavelet-spectra from figure 7 along the time axis. The power spectra are shown in figure 8. Obviously, that despite of large values of a coefficient of correlation (figures 4 and 5), the one-to-one correspondence between variations of signals on small scales is absent. Moreover, it is possible to say, that for considered events it is impossible to find a continuous conformity between small-scale variations of waves and particle precipitation in any fixed position in the sky. Detailed study of a beginning of January 12 event has shown, that the groups of chorus elements may be associated sometimes with pulses of aurora patches near aurora boundary. The Fig. 9 demonstrate this relationship, however location of aurora patches are different. The position of the three series patches is shown in figure 10.

However, at small scales it is possible to find anti-correlation between ELF/VLF chorus and particle precipitation also. Such example is presented in figure 11, where series of chorus elements is observed between pulses of aurora. This event may be explained by reflection or/and absorption of waves in the ionosphere. The reflection and absorption conditions is strongly depends on altitude profile of electron density which varies by precipitated particles [Bespalov, 2004].

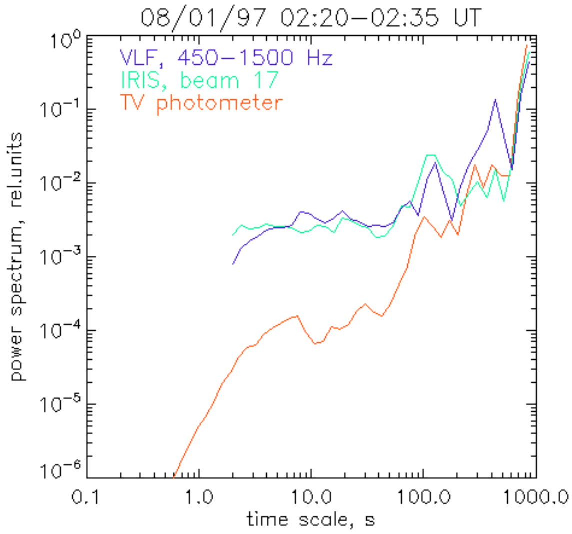

Figure 8. Power spectra for signals from fig.7

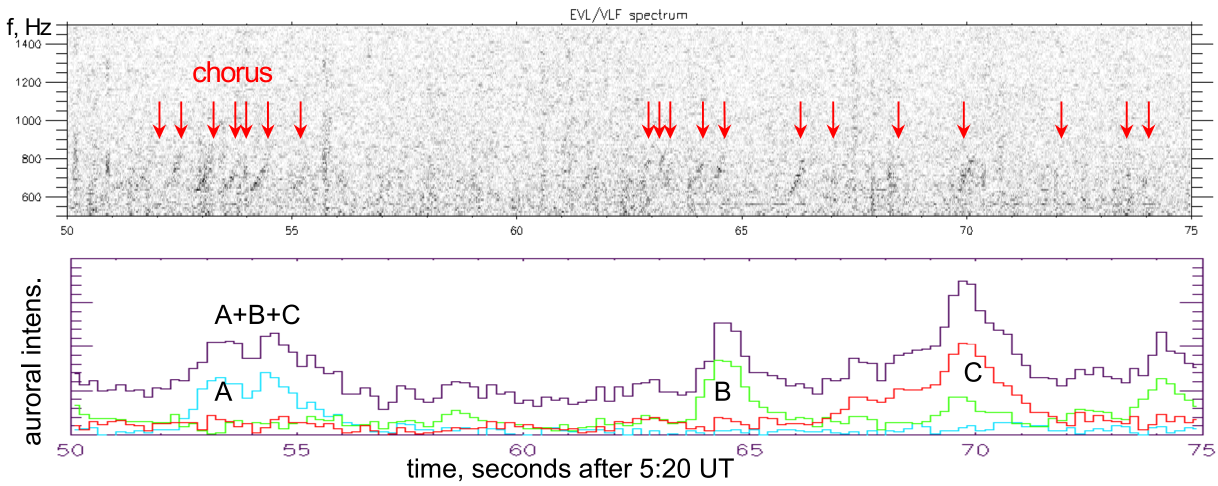

Figure 9. Example of small scale correspondence of the ELF/VLF chorus and pulses of aurora. Top panel is a dynamical spectra of ELF/VLF waves, chorus elements are marked by arrows. Bottom panel presents variation of auroral intensity in three virtual photometers (A,B, and C) on the TB ASC field of view. Positions of the virtual photometers are shown in figure 10.

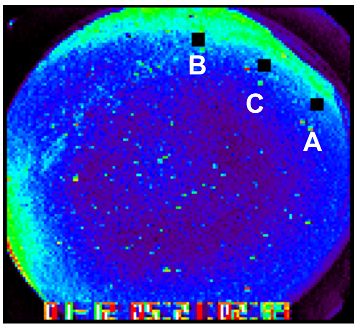

Figure 10. Positions of the virtual photometers used in figure 9.

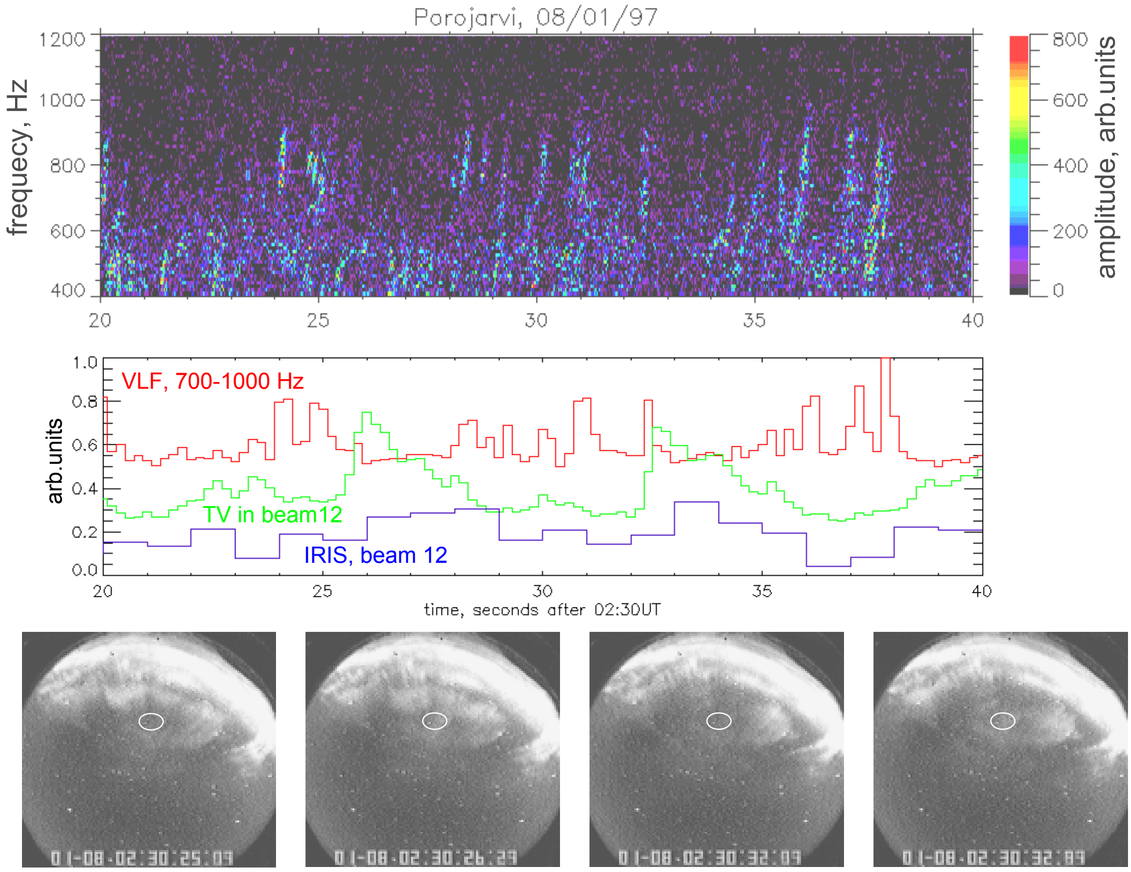

Figure 11. Example of anti-correlation between VLF and particle precipitation, time interval 02:30:20-02:30:40 of 08 January 1997: top panel – dynamic spectrum of ELF/VLF waves; middle panel – variations of ELF/VLF waves integrated from 70 to 1000 Hz, riometric absorption in beam 12 of IRIS, and auroral intensity in projection of beam 12 on TV ASC field of view; low panel – examples of TV ASC frames.

7. Conclusions

We consider two events of simultaneous morning time observations of VLF antenna, IRIS riometer array, and TV all-sky camera located at Kilpisjärvi and Porojarvi, Finland. During these events the band of pulsing aurora approached on area of observations from northwest. This motion was accompanied by appearance and increasing of ELF/VLF emissions.

Wavelet analysis has shown, that usually there is no periodic structure in VLF signal at time scales from 1 to 100 seconds.

The waves correlate better with the data of an IRIS (linear Pearson correlation coefficient for some beams reaches value ~0.7), than with TV (correlation coefficient is not more than 0.4).

There is no one-to-one prolonged correspondence between pulses in VLF, optical aurora and riometer absorption. However during some time intervals at a weak VLF signal with rare discrete elements it is possible to find such correspondence. The analysis of appearance of chorus elements in the band 0.5-1.1 kHz and optical pulsation on auroral emission boundary has shown, that the optical pulses correspond to groups of choruses. Position of the pulses at the boundary is changing.

However, it is possible to find time intervals of not only correlation, but also anti-correlation between ELF/VLF chorus and particle precipitation.

It was found that the observed increase of top frequency of chorus emissions is possible connected with position of generation region in the magnetosphere.

Acknowledgements. The work was partly supported by the basic research program of the Division of Physical Sciences of Russian Academy of Sciences ”Plasma processes in the solar system”, by the grants INTAS 03-51-4132 and RFBR 04-05-64955. BVK thanks the Organizing Committee of 31 AM for support of his participation in the meeting. Authors thanks site at http://sd-www.jhuapl.edu/Aurora for auroral images from DMSP F13 satellite.

References

Bespalov, P.A., and Mizonova, V.G., Reflection coefficient of whistler mode waves normally incident on the ionosphere, Geomagnetizm i aeronomia, 44, 55-59, 2004.

Browne, S., Hargreaves, J. K., and Honary, F. An Imaging Riometer for Ionospheric Studies, Elect. Comm. Eng. J., 7, 209–217, 1995.

Davidson, G. T., Pitch-angle di.usion and the origin of temporal and spatial structures in pulsating aurorae, Space Sci. Rev., 53, 45-82, 1990.

Helliwell, R. A., Whistlers and related ionocpheric phenomena, Standford University ress, Palo Alto, Calif., 1965

Helliwell, R. A.; Doolittle, J. H.; Armstrong, W. C.; Carpenter, D. L.; Mende, S. B. Correlation between lambda 4278 optical emissions and VLF wave events observed at L approximately 4 in the Antarctic. Journal of Geophysical Research, vol. 85, July 1, p. 3376-3386,1980.

Huang, C. Y.; Goertz, C. K., Ray-tracing studies and path-integrated gains of ELF unducted whistler mode waves in the earth's magnetosphere, Journal of Geophysical Research, 88, 6181-61871, 1983.

Rosenberg, T. G., R. A. Helliwell, and J. P. Katsufrakis, Electron precipitation associated with discrete very low frequency emissions, J. Geophys. Res., 76, 8445-8456, 1971

Tagirov, V. R., V. Y. Trakhtengerts, and S.A. Chernouss, The origin of pulsating auroral patches, Geomagn. Aeron., 26, 501-505, 1986.

Tagirov V. R., V. S. Ismagilov, E. E. Titova, V. A. Arinin, A. M. Perlikov, J. Manninen, T. Turunen, and K. Kaila, Auroral pulsations and accompanying VLF emissions, Ann. Geophysicae 17, 66-78, 1999.

Trakhtengerts, V.Y., Relaxation of plasmas with anisotropic velocity distribution. In: Galeev, A.A., Sudan, R.N. (Eds.), Handbook of Plasma Physics, Vol. 2, Basic Plasma Physics II. Elsevier, New York, pp. 519-552, 1984.

Tsyganenko, N.A. and D.P. Stern, A new-generation global magnetosphere field model, based on spacecraft magnetometer data, ISTP Newsletter, V.6, No.1, P.21, 1996.

Trefall, H. , S Ullaland, J. Stadsnes, I. Singstad, T. Pytte, K. Bronstad, J. Bjordal, R. Karas, R. Brown, J.Muench, Morphology and fine time structure of an early-morning electron precipitation event, J. Atmos. Terr. Phys, 37, 83-105, 1975.

Tsuruda, K. S.; Machida, T. Oguti, S. Kokubun, K. Hayashi, T. Kitamura, O. Saka, T. Watanabe, Correlations between the very low frequency chorus and pulsating aurora observed by low-light-level television at L approximately 4.4. Canadian Journal of Physics, vol. 59, p . 1042- 1047, 1981.