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Two-point direction finding of magnetospheric VLF emissions exit regions

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Abstract. Twenty-four-hour direction-finding measurements made on 19 February 1999 at the mid-latitude stations separated 150 km apart in latitude have shown that VLF emissions can be released from various ionospheric regions at each station, although from the same azimuthal directions. In this case low-frequency chorus and high-frequency hiss arrived mainly from the different azimuth sectors. The exit points of hiss from the ionosphere are usually located in a southern or southeastern direction from the station zenith and for chorus, in the zenith or in the northern direction.

1. Introduction

The investigation of the exit regions of magnetospheric VLF emissions to the Earth's surface was carried out in the vicinity of Yakutsk ($\theta = 62°$N, $\varphi = 129°$E) in February 1999. The direction-finding of the exit points of VLF-emissions from the ionosphere into the Earth-ionosphere waveguide has been simultaneously realized at two points separated from each other by $r \approx 150$ km. The first point is located at a distance of 30 km southwest of Yakutsk (southern point) and the second one is 140 km to the north (northern point).

The direction-finding of the exit points has been carried out with the identical receiving complex. The receiving part represents a system of three antennae consisting of two orthogonal frames to receive the magnetic component of VLF-emissions and a vertical monopole for the electric component. After preliminary enhancement, the signals are transmitted to the registering part where after the additional enhancement through the 12-order analog-digit converter, they are transferred to a PC. Signals of 5 s duration have been recorded every 30 min. Signals are recorded with a temporal resolution of 16 mcs/channel (62.5 kHz). Joint calibration of receiving-measuring complexes (coordinate system reference) has been performed by signals of navigation VLF radiostations (11–15 kHz) and electromagnetic signals of thunderstorm discharges (by atmospherics). To determine the spatial arrival angles the method described in *Okada et al.* [1977, 1981] is used.

The analysis of simultaneous signal records for two points is as follows. At first, for all 5-s recording intervals spectral analysis using fast Fourier transform has been performed. The time reference has been carried out using a correlation method employing atmospherics and VLF radiostation signals. Spatial angles (azimuth and zenith) of the signal arrival have been determined for sequential recordings with the duration corresponding to 10–15 wave periods. Signals of right polarization have been considered.

2. Arrival Angle Measurement Results

A day of high VLF-emission activity (19 February 1999) was chosen. By using plotted dynamic spectrograms for all 24 hours, the recordings with well-expressed magnetospheric VLF-signals of various types (hiss, chorus, whistlers) were selected.

Chorus, 0100 UT. As seen from dynamic spectrograms in Figure 1a (northern point) and Figure 1b (southern point), the chorus has been registered in the frequency band up to 7 kHz within two frequency intervals: 0.5–3.0 kHz and 3.5–7 kHz. The exit points of VLF-emissions from the ionosphere relative to the zenith of corresponding stations at the frequency 2.2 kHz in the interval of 0.5 s are shown to the right of the spectrograms. The points pre-

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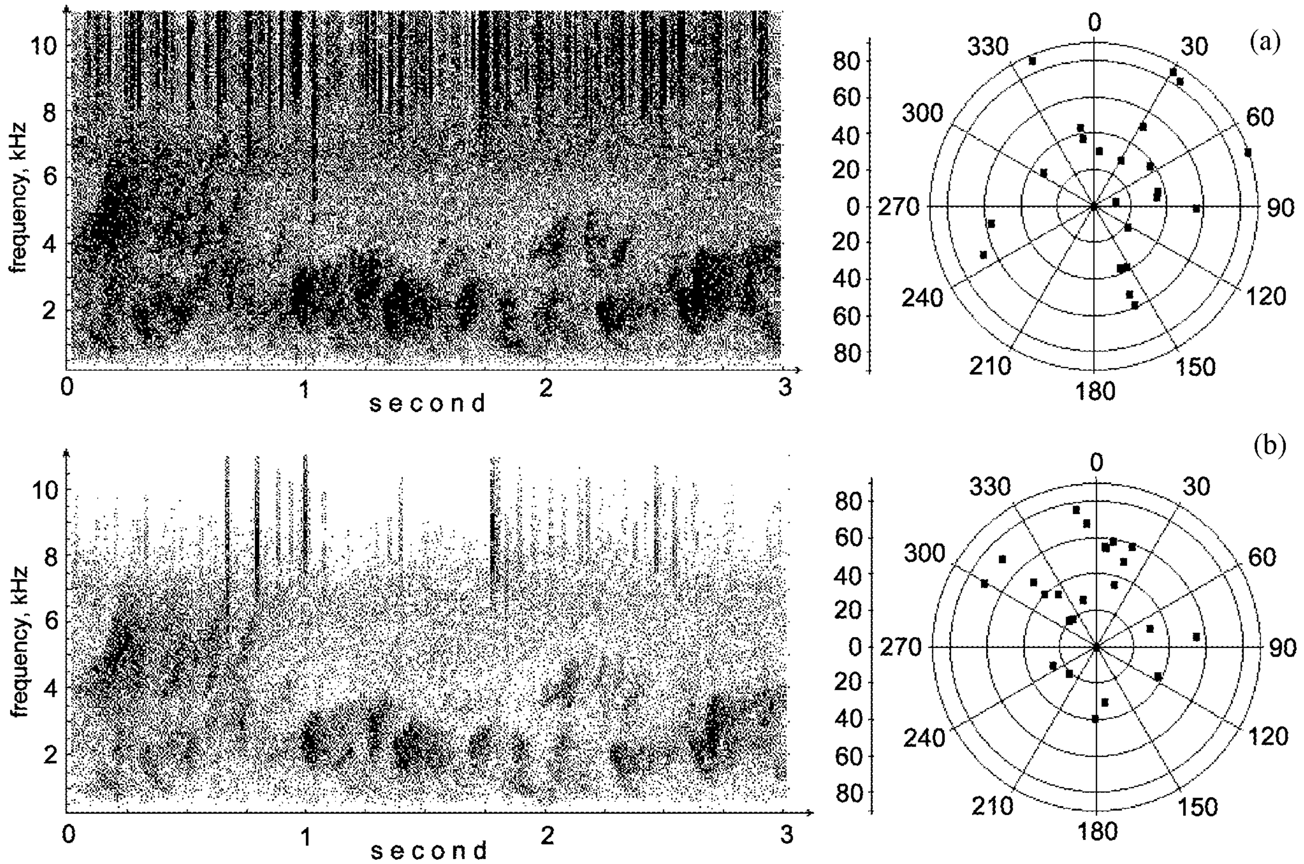

Figure 1. Dynamic spectrograms of the chorus at a northern point (a) and a southern point (b). The exit points of the chorus from the ionosphere relative to the zenith of corresponding stations at the frequency 2.2 kHz in the interval of 0.5 s are shown to the right of the spectrograms.

sented correspond to those times when polarization characteristics of VLF-emissions could be confidently determined at two stations simultaneously. As is seen in Figure 1, the VLF-emission exit points at both stations are separated relative to the station zenith, but at the southern station for low-frequency chorus, the northern direction is prevalent.

Whistlers, 1235 UT. Spectrograms of whistlers are given in Figure 2a and 2b. The range of signal frequencies is 3–10 kHz. As follows from the spectrograms, the event consists of two whistlers; the first is expressed clearly, and the second is diffuse. The frequency analysis of spatial arrival angles has been performed for both whistlers. The whistlers have been registered against a background of the additional enhancement of high-frequency modulated hiss (see below). On polar diagrams the simultaneous exit points in the frequency range 6–7 kHz for the first (Figure 2c) and second (Figure 2d) whistlers are given. At both stations, the whistlers were emitted to the east or southeast from the station zenith. Analysis of whistler dispersion using the method in *Tarcsai* [1975] shows that L shells of channels (ducts) on which the mentioned signals are propagated in the magnetosphere correspond to more southern latitudes than the station latitude. For the northern station latitude ($L = 3.16$) the duct has been located on $L = 3.01 \pm 0.05$; for the southern station ($L = 3.06$), it is on $L = 2.86 \pm 0.05$.

Quasi-periodic hiss. Between 1230 and 1245 UT, the quasi-periodic modulation of VLF hiss was observed. Disperse wave packets (two groups of alternating packets) follow one after another with a period of ∼2 s (Figure 3).

Simultaneous measurements at two stations were carried out at 1230 UT. At 1232 UT, a sharp intensification of hiss with an expansion of the frequency band occurred. The upper boundary of the band increased from 8 to 10.5 kHz (the northern station, Figure 3c), where the rising tones are observed.

As follows from polar diagrams, VLF hiss escaped mainly from the regions to the south or southeast of the station zenith. The given azimuth direction was reserved during the whole analyzed interval (the registration at the northern station). Synchronous behavior (approximately identical spatial arrival angles of signals at both stations) is observed for one-third of the points. In Figure 3d, the position of

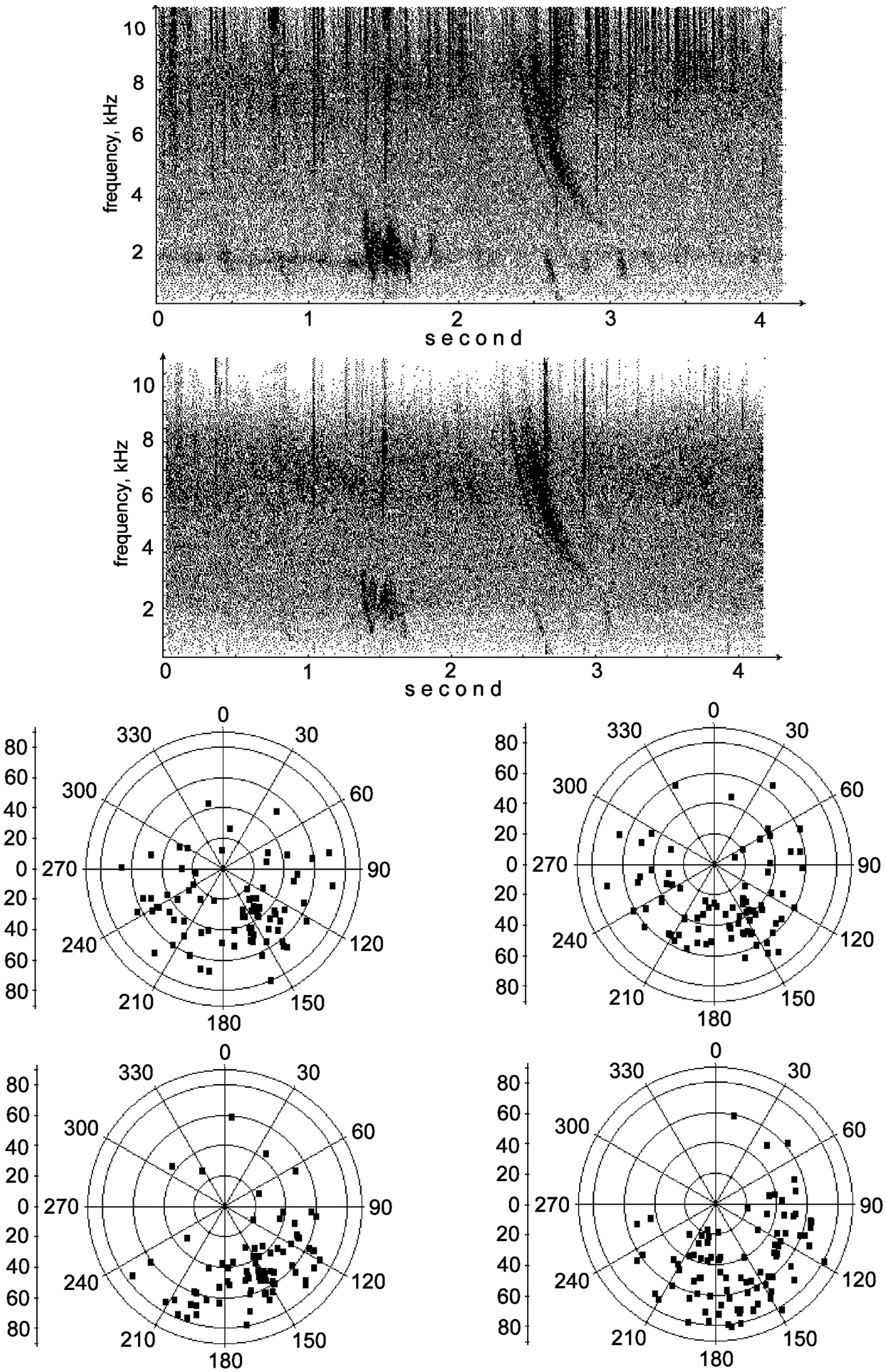

Figure 2. Spectrograms of whistlers at a northern point (a) and a southern point (b). The exit points of those emissions are shown in the frequency range of 6–7 kHz from the ionosphere for the first (c) and second (d) whistlers.

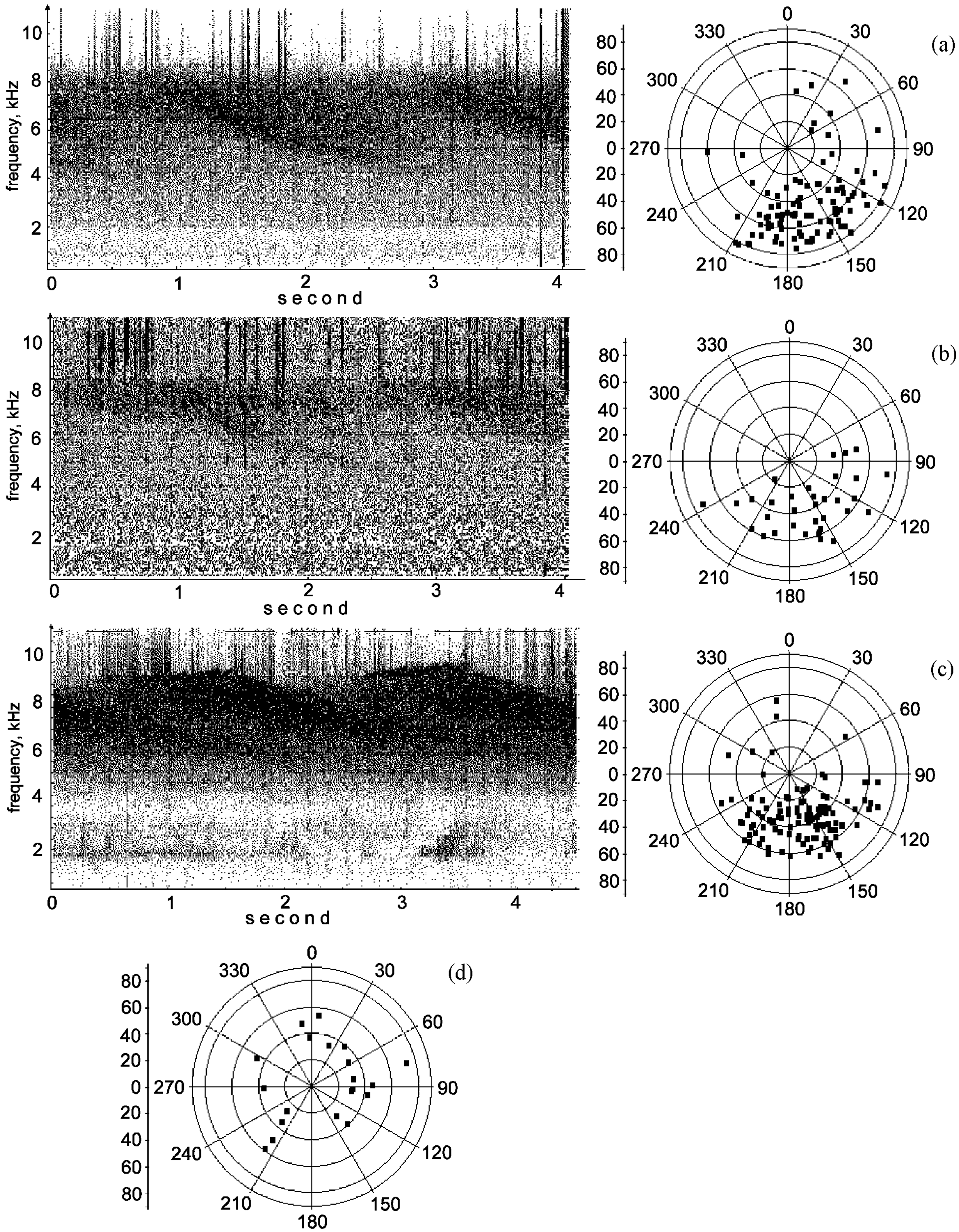

Figure 3. Spectrograms of quasi-periodic hiss at 1230 UT at a northern station (a), at a southern station (b), and at 1232 UT at the northern station (c). The exit points of hiss from the ionosphere relative to the zenith of corresponding stations are shown to the right of the spectrograms. The exit points of the chorus are shown in the panel (d) in the range of 1.5–3.0 kHz.

exit points for chorus at 1232 UT is observed in the range of 1.5 to 3.0 kHz. It is seen that in contrast to hiss for the exit points of chorus at this moment one cannot indicate the primary quadrant.

As is evident from the results of measurements, generally the region of "lighting" of the ionosphere by VLF-emission is no less than 200 km. No events have been registered when the VLF emission was observed at only one station. During all 24 hours on 19 February 1999 VLF emissions were registered at two stations from various ionospheric exit regions for each stations. In this case the noisy emissions, hiss, exited the ionosphere mainly in southern or southeastern directions from the station zenith. Discrete emissions, chorus, exited from separate points, sometimes shifted northward.

The difference in exit regions of chorus and hiss at each station and, at the same time, the coincidence of quadrants of the hiss and whistler arrival in both stations point to the complex character of the VLF-wave propagation process in the lower ionosphere. One can propose that the registered high-frequency emissions (whistlers and hiss) at the exit from the ionosphere to the Earth's surface apparently have been exposed to additional canalization on small-scale ionospheric irregularities extended along the geomagnetic field. The absence of additional canalization of chorus in this case can be associated with its larger wavelength (smaller frequency). The results of *Maltseva et al.* [1985] should also be taken into account where it had been determined that under disturbed conditions, a source of chorus in the magnetosphere could be located at higher latitudes (beyond the plasmapause) than the station latitude and could provide the wide region that "lights" the Earth's surface.

3. Conclusions

Through 24-hour direction-finding measurements at the mid-latitude stations separated 150 km in latitude, it has been determined that VLF emissions can escape from various ionospheric regions for each station, although from the same azimuth directions. In this case, low-frequency chorus and high-frequency hiss arrived mainly from different azimuthal sectors. The exit points of hiss from the ionosphere are usually located in the southern or southeastern direction from the station zenith, and the exit points of chorus are located in the zenith or in the northern direction.

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