"Physics of Auroral Phenomena", Proc. XXVII Annual Seminar, Apatity, pp. 69-72 , 2004

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ESTIMATION OF TRIPLET FREQUENCIES IN THE FIRST MODE SCHUMANN RESONANCE

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Abstract. The average frequency of the first mode Schumann resonance is ~7.8 Hz. The first mode presents in reality a triplet. If the Earth-ionosphere cavity were horizontally homogeneous the three frequencies would be equal. The day-night ionospheric asymmetry as well as the auroral ionization enhancement lead to the frequency splitting. The splitting is difficult to reveal because damping masks it. We calculate the splitting from the diurnal variation of the first mode Schumann frequency using a simple resonance field model. The total magnetic field of the resonance is supposed to consist of three axially symmetric fields, each of the fields oscillating with a constant frequency. The orthogonal axes of symmetry are fixed in the solar-geographic coordinate system. One of the axes is directed sunward. The other axis is close to the Earth rotation axis. The third axis is perpendicular to the two ones. The summary field has rather complex polarization. Its effective frequency being a combination of the triplet frequencies is a function of the solar-geographic coordinates, i.e. the latitude and local time. There is no dependence on the universal time in the simple model. When an observatory rotates together with the Earth, it registers the effective frequency varying with the local time, the variation being different in the *H* (north-south) and *D* (east-west) components. Observations at Kola and Kamchatka peninsulas were utilized for calculations of the triplet frequencies. The following values have been obtained for five quiet spring days: 8.10, 7.84, and 7.75 Hz. The model calculations of diurnal variation of the effective frequency coincide very well with the observation results at the both observatories. One of predictions of our model is that the *D* component at the Earth equator has no diurnal variation.

Introduction

The first mode Schumann resonance frequency reveals a pronounced diurnal variation [*Balser and Wagner*, 1962]. An example of the variation at Barentzburg (Spitzbergen) is shown in Figure 1 taken from [*Roldugin et al.*, 2004]. Surprising facts were that the variation appeared to differ for *H* and *D* magnetic components as well as it is related to the local time rather than to the universal time [*Roldugin et al.*, 2004]. These phenomena can not be explained in the framework of traditional concepts operating with a single resonance frequency even if this frequency varies in time [*Bliokh et al.*, 1968, 1980; *Sentman*, 1996]. We think that the LT variation of the frequency arises due to the first mode frequency splitting owing to the horizontal inhomogeneity of the ionosphere so that the first mode is a triplet. The aim of this paper is to find the triplet frequencies.

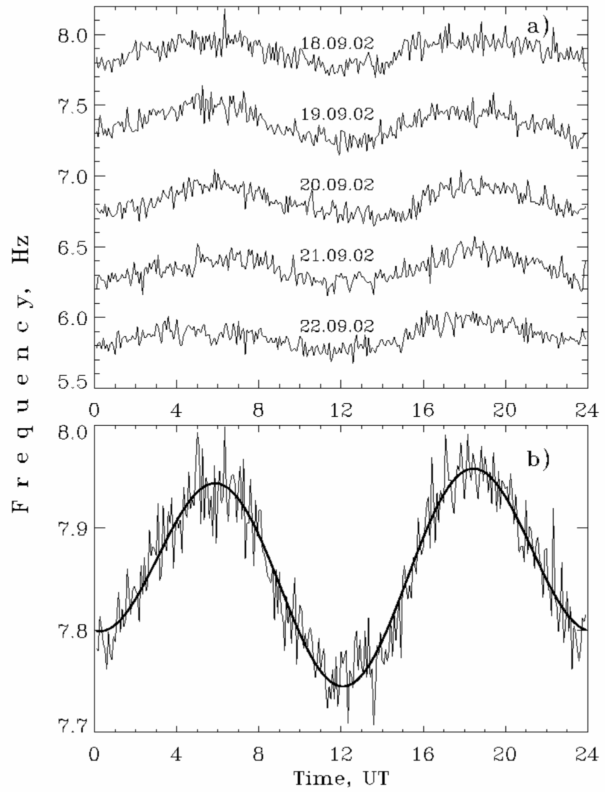

Figure 1. The diurnal variation of the first SR mode frequency in the *NS* component in Barentzburg. Top: the variation for each of five days near the autumnal equinox. The frequency is indicated correctly for the first day only, the second and the following curves are shifted downward by 0.5 Hz relative to the preceding one. Bottom: the variation averaged over the five days. The thin line is observation, the thick line is approximation by the sum of 24-hour and 12-hour harmonics.

Model

We suppose that there are three slightly differing frequencies (triplet) in the first Schumann resonance. Each frequency is related to a certain wave polarization fixed in the GSM coordinates. Figure 2 shows the magnetic polarization for each frequency (mode). The each mode is a standing wave. Any standing wave is a sum of two waves travelling in opposite directions. The *x* mode presents two waves propagating in the day-night direction, *y* mode is two waves in the dawn-dusk direction, *z* mode is in the north-south direction. The choice of the modes shown in Figure 1 is not accidental. It is related to pronounced ionospheric inhomogeneities. In particular, the *x* mode corresponds to the day-night asymmetry, the *z* mode is related to the auroral precipitation, the *y* mode is the addition of the *x* and *z* modes.

The effective frequency of the summary field is a combination of the triplet frequencies and depends on the latitude and local time. When an observatory rotates together with the Earth, it registers the effective frequency varying with the local time, the variation being different in the *H* (north-south) and *D* (east-west) components.

The pattern in Figure 2 is very simplified. In reality the magnetic field lines in the each mode is hardly to be a precise concentric circles. They are somewhat distorted, especially for *y* and *z* modes propagating along the terminator. However we think that the distortion is not very large.

Effective frequencies for the H and D magnetic components can be expressed as follows

$$f_H = \frac{H_x f_x + H_y f_y + H_z f_z}{H_x + H_y + H_z} \qquad (1)$$

$$f_D = \frac{D_x f_x + D_y f_y + D_z f_z}{D_x + D_y + D_z} \qquad (2)$$

where f_x, f_y, and f_z are the frequencies of the *x*, *y*, and *z* modes, respectively; H_x, H_y, H_z, D_x, D_y, D_z are *H* and *D* magnetic components of these modes. It is easy to obtain from Figure 1 the values of the components

$$H_x = A_x \sin^2\varphi \qquad D_x = A_x \cos^2\varphi \sin\Lambda$$
$$H_y = A_y \cos^2\varphi \qquad D_y = A_y \sin^2\varphi \sin\Lambda$$
$$H_z = 0 \qquad D_z = A_z \cos\Lambda$$

where A_x, A_y, and A_z are the amplitudes of the *x*, *y*, and *z* modes; Λ is latitude, $\varphi = 2\pi$ LT/24 is longitude, LT is local time. The amplitudes A_x, A_y, and A_z do not experience diurnal variation.

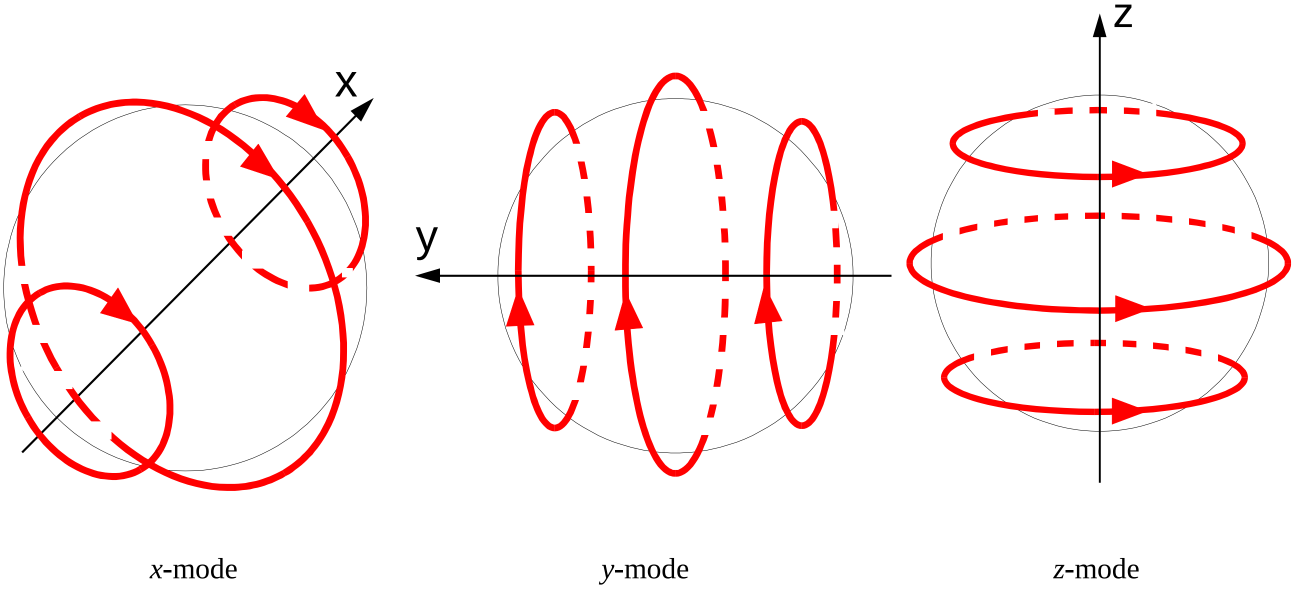

Figure 2. Splitting of the first Schumann resonance mode into three modes differing by their polarization. The *x* axis is directed sunward, *y* axis is directed from dawn to dusk, *z* axis is directed northward. The thin circle is the Earth. The thick circles with arrows show magnetic fields of the each mode. The fields of the different modes oscillate with slightly differing frequencies.

Data

Measurements in Lovozero (the Kola peninsula) and Karymshino (the Kamchatka peninsula) were used. We chose several days of 2002 for Lovozero and 2001 for Karymshino. The averaged and smoothed behavior of the first-mode frequency is shown in Figure 3 by the solid lines.

Calculation results

We fitted A_x, A_y, A_z , f_x, f_y, f_z for the two observatories. The fitting yielded:

$$f_x = 8.10 \text{ Hz}, f_y = 7.84 \text{ Hz}, f_z = 7.75 \text{ Hz}.$$

The model effective frequencies calculated from expressions (1) and (2) are shown in Figure 3 by the dashed lines. One can see that the experimental and theoretical curves re rather close.

Discussion

Attempts to explain the diurnal variations were undertaken by *Balser and Wagner* [1962], *Bliokh et al.* [1968, 1980], *Sentman and Fraser* [1991], *Sentman* [1996], *Schlegel and Füllekrug* [2000], who supposed that there is some UT variation either in the resonance source or in resonator properties. These models predict the UT variation in the resonance frequency whereas in reality the LT variation dominates.

The idea of splitting due to the horizontal inhomogeneity of the ionosphere was considered in [*Egeland and Larsen*, 1968; *Bormotov et al.*, 1973; *Sentman*, 1989]. Since the horizontal inhomogeneity is controlled mostly by the local time, the multiplets arising due to the splitting are related to LT. However the idea was not carried to completion in these papers.

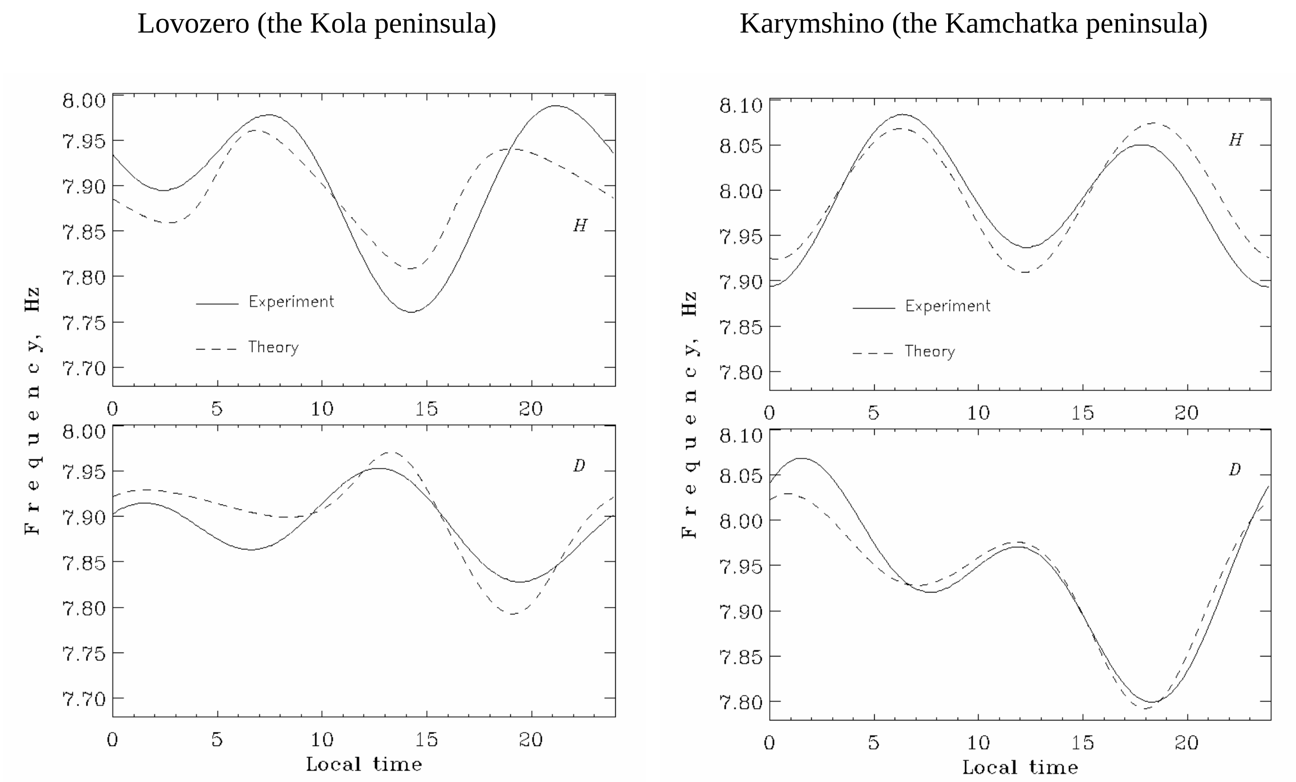

Figure 3. Observed and modeled diurnal variation of the effective frequency of the Schumann resonance in Lovozero and Karymshino.

One should remember that the processed data for Lovozero and Karymshino are separated by one year so that the approximation can not be very precise. Nevertheless the difference between experimental and modeled curves in Figure 3 is small. Thus we can hope that the model shown in Figure 2 is valid in spite of its simplicity. We modeled the triplet properties for several other days. The triplet frequencies may differ for different days, however the difference is not very strong.

A possible modification of our model concerns mainly the *y* and *z* modes. The ionospheric conductivity disruption at the boundary of the dayside and nightside parts of the ionosphere must cause breaks of the magnetic field lines on the terminator. As a result one can expect sharp changes in the effective frequency of the *H* (north-south) magnetic component near the terminator.

Another prediction of the model shown in Figure 2 refers to near-equatorial regions. At the equator ($\Lambda = 0$) we have $D_x = 0$, $D_y = 0$. We observe there $D_z = A_z$. Since A_z has no diurnal variation, we will not observe the diurnal variation in the *D* component at the equator.

Conclusions

A simple model of triplet allows explaining the diurnal variation of the first-mode Schumann resonance frequency. The frequency varies in local time and differs for different magnetic components. The model frequency agrees satisfactorily with observations. One of the model predictions is the absence of the diurnal variation in the *D* (east-west) component at the Earth equator.

Acknowledgments. This study was supported by the Russian Basic Research Foundation (grant 03-05-20003-BNTS) and by the Division of Physical Sciences of the Russian Academy of Sciences (program DPS-16). We are grateful to A. N. Vasiljev, A. Y. Schokotov, G. G. Belyajev for the data they kindly made available to us.

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