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SPECTRAL RESONANCE STRUCTURE OF THE ELECTROMAGNETIC NOISE IN THE RANGE OF 0.1-4 HZ AT L=5.2: EVIDENCE FOR THE IONOSPHERIC ALFVEN RESONATOR

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Abstract. Long-term and continuous observations of the geomagnetic fluctuations in the frequency range of 0.1-4.0 Hz performed in Sodankylä Geophysical Observatory (L=5.2) were used for comprehensive morphological study of the spectral resonance structures (SRS) seen in the background electromagnetic noise. It is shown that the SRS frequencies and frequency interval (that is difference between neighbouring eigenfrequencies) increase in the night-time and decrease in the daytime. The frequency interval as well as the occurrence rate of the SRS is higher in the night-time than in the daytime. Both the frequency interval and occurrence rate are higher in winter than in summer. Both frequency interval and occurrence rate exhibit clear tendency to decrease from minimum to maximum of the solar activity. We concluded that main morphological features of the SRS are explained on the basis of theory of the ionospheric Alfven resonator (IAR).

Introduction

The investigation of spectra of the electromagnetic noise in the range of the 0.1-10 Hz, which is, presumably, due to radiation from the distant lighting discharges, led to the discovery of the spectral resonance structure (SRS) sometimes appeared at the frequencies from tenths to a few Hz (*Belyaev et. al.*, 1987, 1989a). These first observations have been carried out at mid-latitudes, but recently similar structures have also been found in the records made in the auroral zone (*Belyaev et. al.*, 1999) and at lower latitudes (*Bösinger et al.*, 2001). However, the SRS morphology have been studied insufficiently. Till now, there is only few papers describing the SRS peculiarities, most of them deal with the SRS at mid-latitudes. This paper is devoted to increase our knowledge on the SRS morphology, especially in the auroral zone.

The phenomenon is usually interpreted as the result of the existence of the resonator for the Alfven waves in the ionosphere (e.g. *Belyaev et. al.*, 1989b, 1990; *Lysak*, 1991, 1993). The walls of the resonator are the E-layer and the electron density gradient above the maximum of the F-layer. Thus, the characteristics of the ionospheric Alfven resonator (IAR) should strongly depend on the parameters of the upper ionosphere.

Two important characteristics of the SRS revealed from the observed spectra can be compared with predictions of theory. One of them is the occurrence rate (*P*) of the SRS observation. The resonant structure can be recognised if the background noise intensity varies significantly. Qualitatively, according to the IAR theory, this is the case of sufficiently large modulation of the reflection coefficient of the ionosphere (sufficiently large resonator quality). The magnetic noise intensity modulation depth depends on the plasma density in the F-layer maximum, spatial scale of the F-region, as well as conductivity in the E-region (*Trakhtengerts et al.*, 2000). Another characteristic is the frequency interval between neighbouring spectral structures. According to the IAR theory, the frequency interval does not depend on the neighbouring eigenfrequency number. A simple formula for the frequency interval was obtained by *Belyaev et al.* (1990):

$$\Delta F = c * (2n_a)^{-1} * (l+h)^{-1} \qquad (1)$$

where n_a is the Alfven refractive index at the altitude of the F-layer maximum, h and l are characteristic scales of the electron density profile at and above the F-layer maximum, c is the velocity of light. The Alfven refractive index

$$n_a = c * (4\pi\rho)^{0.5} * H_0^{-1},$$

where ρ is plasma density, H_0 is magnetic field. Thus,

$$\Delta F \sim (M_{eff} * N_e max)^{-0.5} * (l+h)^{-1},$$

where M_{eff} is effective ion mass, $N_e max$ is electron density. Using this formula, *Demekhov et al.* (2000) have demonstrated the consistency of the spectra calculated according to this formula and observations for two particular cases.

Below we will present the result of our statistical study of ΔF obtained from observations at Sodankylä Geophysical Observatory (SGO). The observatory is located in the auroral zone (L≈5.2). We will show that diurnal, seasonal, and long-term behaviour of the SRS occurrence and its frequency interval are in qualitative agreement with the predictions of the IAR theory.

Data

Since June, 1995 the continuous digital registration of ULF magnetic field variations has been established in SGO. The data are routinely treated to produce daily spectrograms (dynamic Fourier spectra). These spectrograms often show the presence of the resonant structures in the background noise, which are a subject of this study. Due to the characteristics of the instrument the frequency range of the variations is from 0.1 up to 4 Hz. As example, Figure 1 presents two daily spectrograms. Even a quick look at the spectrograms makes clear the main features of the diurnal

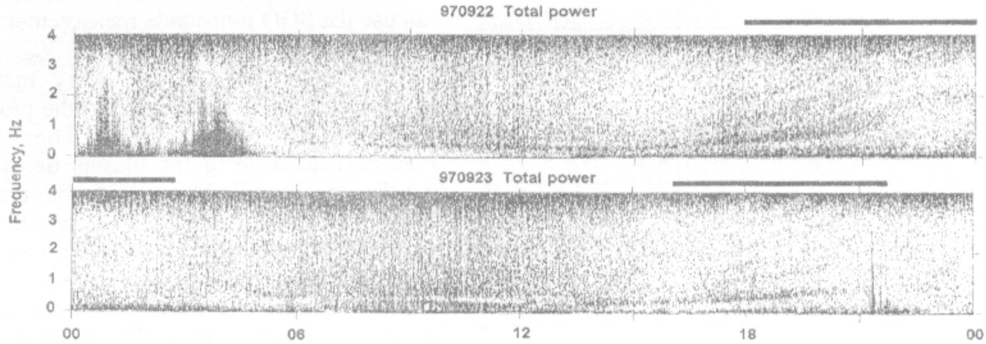

Figure 1. Examples of the Spectral Resonance Structure observed in Sodankylä Geophysical Observatory during two successive days. Thick horizontal bars mark intervals when the SRS is seen. Note that magneticlocal time in SGO is UT-2

variation of the SRS. Both the SRS frequencies and the frequency interval increase in the night time and decrease in the day time. The SRS is more prominent in the night-time. Below we present this and other morphological features on the basis of the statistical analysis. For statistical study we divided every day for eight 3-hour intervals, and consider if the SRS structure was observed during the every such interval. The result was used for determination of the occurrence probability $P=N_0/N_t$, where N_0 is the number of the 3-hour intervals when the SRS was observed, N_t is the total number of the intervals covered in this study. If the SRS was observed, we determined, for the middle of the interval, the frequencies on which the background noise had maximum and minimum, and frequency interval ΔF between the first visible structures. The fixed frequency intervals were used to calculate the median value for given 3-hour time interval (under some conditions, see below).

Diurnal, Seasonal, and Long-Term Behaviour of the SRS Characteristics

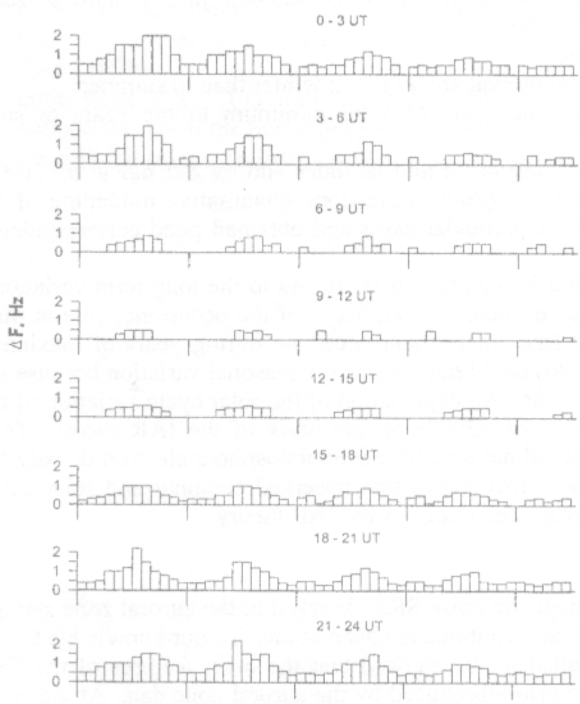

Figure 2. Monthly median values of the SRS frequency interval observed in SGO during 1995-1999. Each panel corresponds to 3-hour interval of UT.

We calculated the monthly median values of the ΔF since June 1995 till December 1999. The result for every 3-hour interval subset is shown in Figure 2. This Figure illustrates the ΔF morphology: diurnal behaviour, season dependence, and variations in the course of solar cycle. Let us consider the diurnal variation. From Figure 2 it is clearly seen that for night hours (18-21, 21-24, 0-3 UT) the ΔF is higher than that for day hours. This is more prominent in winter than in summer. Thus, for January 1996 the ΔF is ~2 Hz at 0-3 UT and ~0.7 Hz at 12-15 UT. For the same hours of UT in June 1996 the ΔF is ~1.0 and ~0.6 Hz, respectively. There is very clear dependence of the ΔF on season; it is larger in winter than in summer. Seasonal variations is more pronounced for night hours; they are stronger for the years close to minimum of solar activity.

The SRS occurrence rate for the analysed period is shown in Figure 3. The occurrence rate is higher in the wintertime, and during years of the solar activity minimum. Diurnal behaviour is also very pronounced. The SRS occurrence is higher for night hours (see Figure 1, the statistics is not shown).

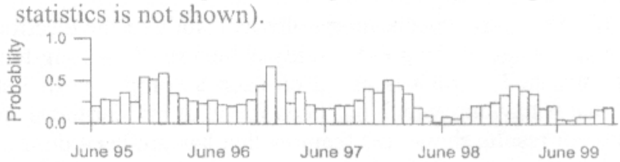

Figure 3 Monthly occurrence rate of the SRS observations in SGO during 1995-1999.

Comparison of the Frequency Interval Observations With Predictions of the IAR Theory

The SRS in the range of Pc1 is interpreted as the result of the IAR. Let us consider if the IAR theory does explain the morphological features described above.

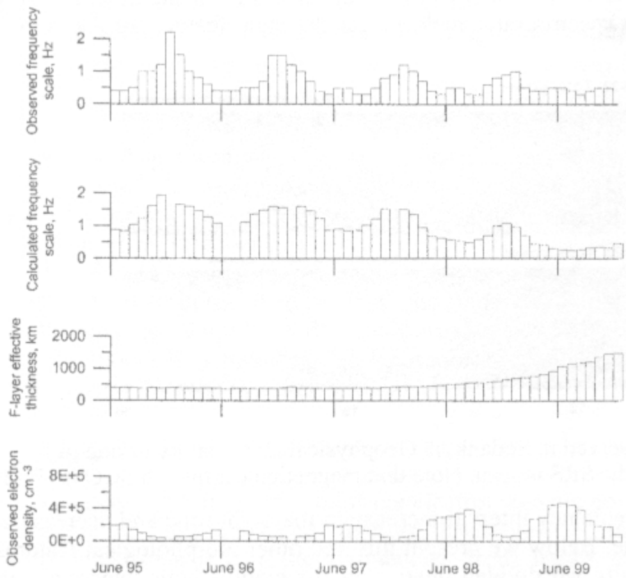

Figure 4. From top to bottom: Observed and calculated values of the SRS frequency intervals during 1995-1999; effective thickness of the ionosphere above the F-layer maximum (estimated from the IRI-95 model), and electron density in the maximum of the F-layer obtained from ionosond observations in Sodankylä.

The formula (1) determines the frequency interval as a function of parameters N_{emax} and l. To estimate N_{emax} (electron density in the maximum of the F2-region) one can use the SGO ionosonde measurements of the critical frequency f_0F2. Figure 4 shows the N_{emax} calculated from median values of f_0F2 for every month within the interval 18-21 UT. Some gaps in the plot are due to the lack of f_0F2 measurements. The parameter l is characteristic scale of the plasma density decay above the F2 maximum. The ionosonde can not measure electron density above the F2 maximum, so another parameter l, entering into the formula (1), has been estimated from the ionospheric model IRI-95. We estimated l from the decay of the altidudinal profile of the plasma density above the F-region maximum. The values of l calculated for every month are also shown in Figure 4. Note that l is rather stable for the years close to solar activity minimum, and it increases during the years close to solar activity maximum. The value h was taken to be equal 200 km. For every month, ΔF has been calculated by substitution of N_{emax} and $l+h$ into the formula (1). The comparison of the calculated and observed ΔF shows their amazing similarity.

Summary and Discussion

We have studied the spectral resonant structure in the background electromagnetic noise in the frequency range 0.1-4.0 Hz observed at Sodankylä Geophysical Observatory, which is situated in the auroral zone, L=5.2. The main morphology results can be summarised as follows:

1. The SRS frequency interval are higher in the night hours.
2. Both the occurrence rate of the SRS and its the frequency interval are higher in winter than in summer.
3. Both parameters exhibit a tendency to decrease from the years of solar minimum to the years of solar maximum.

Similar diurnal variation has been found by *Belyaev et al.* (1989a) at mid-latitudes and by *Belyaev et al.* (1999) and *Semenova et al.* (1999) in the auroral zone. *Demekhov et al.* (2000) have done quantitative modelling of the diurnal changes of ΔF on the basis of the IAR theory for some particular cases and obtained good correspondence with observations.

Seasonal dependence of both P and ΔF has not been noted in the past literature. As to the long-term variations, *Belyaev et al.* (2000) on the basis of 10-year observations have found the behaviour of the occurrence rate in mid-latitudes similar to that reported here. They found minimal (maximal) occurrence rate during years of maximum (minimum) of the solar activity. Note, that *Belyaev et. al.* (2000) could not resolve the seasonal variation because the observations were very scanty (sometimes only few days per year). An explanation of the solar cycle variation of the SRS occurrence rate has been proposed by *Trakhtengerts et. al.* (2000) on the basis of the IAR theory. They demonstrated that the variation is due to difference of the altitudinal profiles of the ionosphere electron density for years of minimum and maximum solar activity. Our Figure 3 also shows that observed seasonal and solar cycle variations of the frequency interval are a good agreement of with predictions of the IAR theory.

Conclusion

We have performed a morphological study of the electromagnetic noise SRS observed at the auroral zone station. The advantage of the present study is the use of the long-term and continuous observations. To our knowledge this is the only study which is based on such a comprehensive statistics. We showed that the main features of the SRS diurnal behaviour, which has been found at mid-latitudes, are also reproduced by the auroral zone data. At the same time our results show new features that has not been described in the past literature. They are the seasonal and solar cycle variations of the frequency interval of the SRS. We showed that these morphological features could be explained on the basis of the IAR theory.

The knowledge of the morphology of the SRS is also important for future experimental investigation of the ionosphere. It could be used for the remote diagnostics of the upper ionosphere and, say, for the prediction of the resonant frequencies in the ULF range during active experiments destined to modulated heating of the ionosphere.

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