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On the earthquake effects in the regime of ionospheric Alfvén resonances

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Abstract

Earthquakes can affect various parameters of the upper atmosphere above the epicenter. Ionospheric Alfvén resonances are known to be very sensitive to the state of the ionospheric layers. They are observed only for magnetically quiet conditions, so that an impact from earthquakes can easily destroy the resonance structure of waves. Starting from this consideration we searched for seismic effects in the behaviour of ionospheric Alfvén resonances using the data from a mid-latitude observational point. Our study revealed various examples of the ionospheric response to earthquake impacts. The results are given in the paper.

Keywords: Ionospheric Alfvén resonances; Earthquake

1. Introduction

Ionospheric Alfvén resonances (IARs) are a relatively well-known wave phenomenon, which have been discussed in several papers (Polyakov and Rapoport, 1981; Belyaev et al., 1990, 1997, 1999; Demekhov et al., 2000; Pokhotelov et al., 2000, 2001; Bösinger et al., 2002; Molchanov et al., 2004; Surkov et al., 2004). Cavity, where IARs are formed in, is located between two Alfvén velocity maximums: at the lower side of the ionospheric F region electron density peak, and at a height of approximately 1000–3000 km. Shear Alfvén waves get trapped in this cavity, and standing waves are formed thus (Belyaev et al., 1999). The resonator quality Q may be as much as 5–10. Eigenfrequencies of the resonator can be estimated by the relation

$$\omega_s = 2\pi f_s = (s+1)\frac{\pi V_A}{L},$$

where $s = 0, 1, 2, \ldots$ is the number of harmonics, $s = 0$ corresponds to the fundamental frequency, $V_A = B/\sqrt{4\pi\rho}$ is the Alfvén velocity, ρ is the plasma density, B is the magnetic field intensity, and L is a vertical scale of the resonator. For the typical ionospheric conditions, frequency difference between two adjacent harmonics $\Delta f = f_{s+1} - f_s$ falls in the range 0.3–3 Hz.

IAR observations (Belyaev et al., 1990, 1997) show that in the frequency–time display these resonances have a form of multi-band frequency varying emission in the range of 0.1–7 Hz, sometimes extending up to 10 Hz. IAR is not every day phenomenon, and it requires certain ionospheric conditions: occurrence probability decreases with growth of the global magnetic activity. Multi-band structure is best seen in the evening and night times, while the structure is totally blurred around local noon. The IAR structure pattern is usually more clearly seen in the spectrograms of Y-component as compared to X-component. A probability of IAR observation increases with decreasing solar activity: they are frequent phenomena during solar minimum and are not observed at solar maximum (Belyaev et al., 1997).

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IARs are observed both at high- and mid-latitudes. In the paper by Molchanov et al. (2004), the IAR properties at middle latitudes have been studied using 2.5-year observations at a mid-latitude Kamchatka station. Seasonal peak variation of IAR occurrence shows the predominance in December.

2. Properties of IAR structures from observations at Borok observatory

We studied local particularities of IAR manifestation at the Geophysical Observatory Borok (58.0°N, 38.2°E). A typical example of a good-developed ionospheric Alfvén resonance pattern is demonstrated in Fig. 1. Before 1600 UT we see some unstructured wave activity in the frequency range below 4–5 Hz, and then several clearly defined bands with approximately equidistant values of frequency arouse from the diffused stain. Their frequencies slowly increase until local night. This event was observed during magnetically quiet time with *Kp* index not exceeding the value of 2_-.

Magnetic tape records for three years from 1985 to 1987 were analysed, and it was a period of the 21st solar cycle minimum. We studied IAR properties by means of spectrograms. Time–frequency display of signals in the range between 0 and 5–7 Hz allowed us to search for the IAR events and then we measure their frequency and dynamic particularities graphically. Main dependences of IAR characteristics at Borok are the same as those obtained from the observations at other sites: night time occurrence, preference for low magnetic activity, and prevalence of *Y*- over *X*-component. Detailed results of the study will be published later. Here, we would like to attract one's attention to the response of IAR resonant structure to external effects.

3. IAR structure response to the seismic events

Among other IAR characteristics at Borok we have checked a response of the resonance intensity and frequency variations to the ionospheric disturbances caused by some external impacts. We found that remote earthquakes have their effects in the regime of IAR. For example, Fig. 2 illustrates the breakdown of IAR after a remote earthquake.

It is worth to note that there were different types of IAR response to the seismic effects. Let us consider them in more details. In Fig. 2 we see a total and abrupt disappearance of the IAR signal along with its resonant structure at the moment of seismic wave arrival to Borok. The disappearance happened before 2000 UT. Without an external impact the resonant structure can be clearly seen much later, until 2300–2400 UT, as we can see from Fig. 1; and it dissolves gradually.

In Fig. 3 we see a different type of the seismic effect. Here, the impact from the earthquake produces not disappearance, but a steep decrease of the IAR structure ampli-

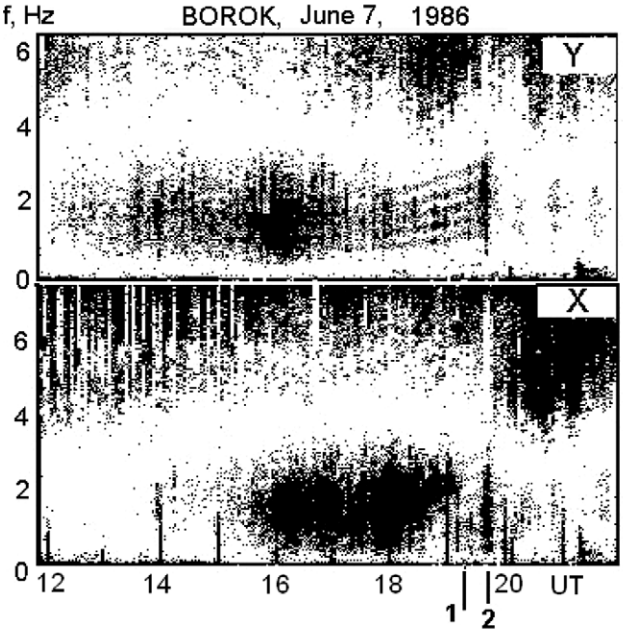

Fig. 2. An example of the IAR breakdown when seismic waves arrive at Borok. The $M = 5.5$ earthquake occurred at 1916 UT (time mark 1) in the point with coordinates $\varphi = -14.7°$ and $\lambda = 176°$. The seismic waves reached Borok at 1935 UT (time mark 2).

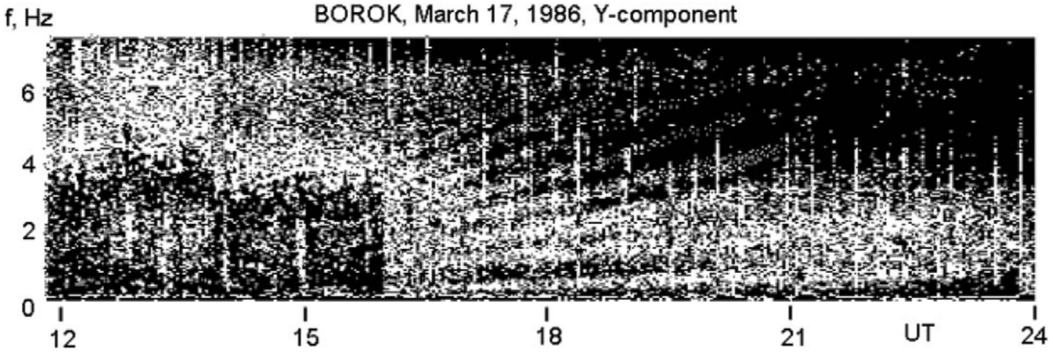

Fig. 1. A typical example of a good-developed ionospheric Alfvén resonance pattern observed at Borok observatory on 17 March 1986. Local time at Borok is LT = UT + 3 h.

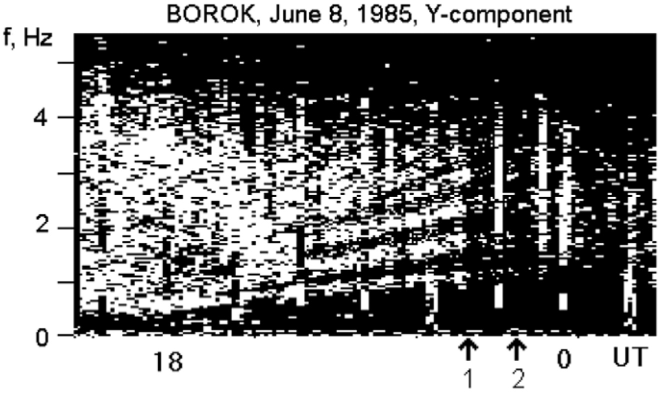

Fig. 3. An example of the IAR breakdown at the moment of the earthquake. The $M = 4.8$ earthquake occurred at 2234 UT (time mark 1) in the point with coordinates $\varphi = -46.1°$ and $\lambda = 167.2°$. The seismic waves reached Borok at 2314 UT (time mark 2).

tude at 2234 UT. Nevertheless, the resonant structure itself retains, changing neither the frequency band positions, nor the relative intensity distribution between the frequency bands. Another distinction from Fig. 2 is that the effect in this case is connected not with the arrival of seismic waves, but with the time of the earthquake itself (time mark 1).

Quite different physical process is illustrated in Fig. 4, where the seismic event at 1732 UT stimulates arising of the IAR structure, even if it is a weak one. Here, the time delay between the earthquake and seismic wave arrival was about 8 min, so it is hard to say what factor produced the effect. The resonant structure is not intense, but nevertheless it is evident.

We observed also many other events of the action on IAR structure by earthquakes, all of them demonstrated features that are illustrated in Figs. 2–4.

4. Discussion and conclusion

In recent years the search for electromagnetic effects accompanying earthquakes has become more intense (Sobolev, 1993; Hayakawa, 1999, 2001; Surkov, 2000; Hayakawa and Molchanov, 2002; Liperovsky et al., 2005; Readdy and Conviner, 2005; Schekotov et al., 2005). Magnetometric surveys are being formed in seismoactive regions, more sensitive instruments are being used for observations, mechanisms for the precursor rise are being suggested, and new search methods are being developed based on a comprehensive approach to the problem (see for example Guglielmi et al., 2004). This line of investigation offers very wide field of research, and the keen interest of the scientific community in this field is well founded. Some achievements in this way may bring a hope for success of the effective forecasting of earthquakes. But some specialists express a concern on the bad repeatability of the electromagnetic precursors and vague general understanding of physical processes initiating these signals. An additional source for a widespread (but not universally true) skepticism about the forecast possibility is connected with some radical judgments that intensity of electromagnetic precursor depends slightly (or does not depend at all) on distance from the epicenter and even on the earthquake magnitude.

As has repeatedly been intimated in the literature, the enhanced complexity of processes setting the stage for earthquake is the natural reason of such unfavorable situation, and we must agree to this opinion. At the same time, it is beyond the reasons to consider efforts to collect and systematize facts as being groundless, even though they do not always fall into a customary theoretical pattern. In this preliminary report, we tried to give an account of new facts which admittedly testify the connection between tectonic and ionospheric processes. At present we have found about 20 events when IAR structure responds to an earthquake. This is not a sufficiently large sample to provide a statistical study; however, it is difficult to argue with a conclusion that the surprising coincidence of sharp changes of IAR regime with seismic events cannot be accidental. Ionospheric Alfvén resonances represent a wave structure that is very sensitive to the state of the ionosphere. Even a weak disturbance, whether it is of magnetic

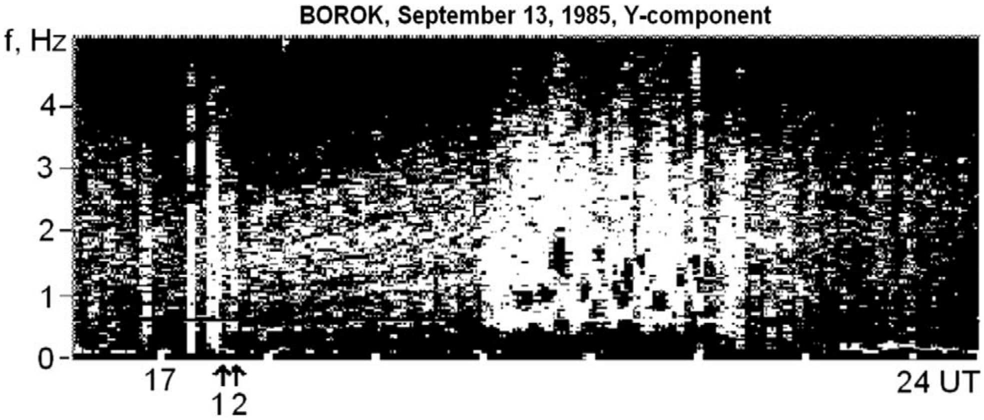

Fig. 4. An example of the IAR stimulation under the action of seismic event. The $M = 4.5$ earthquake occurred at 1732 UT (time mark 1) in the point with coordinates $\varphi = 39.4°$ and $\lambda = 75.6°$. The seismic waves reached Borok at 1740 UT (time mark 2).

or mechanic nature, can destroy the resonances. In this work we have shown the results of the earthquake influence on the IAR structure.

It is much more difficult to explain stimulation of the IAR structure by seismic action. To do that, we need both more experimental data and theoretical considerations. Our observations provoke questions which have no unambiguous answers yet. For example, what is distinction in the condition of earthquake influence on IAR shown in Fig. 4 in comparison with two events shown in Figs. 2 and 3? Then, we have noted that the seismoelectromagnetic effect can arise both at the moment of seismic wave arrival and sometimes at the moment of earthquake occurrence. The physical processes associated with the earthquakes are not enough understood to explain these properties. General consideration on the interaction of the geosphere shells would obviously be insufficient here. Nevertheless we would like to presume that the most promising way to answer the questions posed lies within the framework of notion about acoustic disturbances connected with the seismic wave front and about perturbation of global electric circuit by the aero-electrical processes in the epicentral zone/region. Both types of processes can play a significant role in the lithosphere–ionosphere relations.

On the whole, in this work we have demonstrated one more linkage between the seismic processes in the Earth's crust and the electromagnetic processes in the ionosphere. We hope that further observations will clarify the problem of the origin of above linkage.

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References

Belyaev, P.P., Polyakov, S.V., Rapoport, V.O., Trakhtengerts, V.Y., 1990. The ionospheric Alfven resonator. J. Atmos. Terr. Phys. 52, 781–788.

Belyaev, P.P., Polyakov, S.V., Ermakova, E.N., Isaev, S.V., 1997. Experimental investigations of the ionospheric Alfvén resonator from electromagnetic noise background over the solar cycle of 1985–1995. Radiophyzika XL, 1305–1319.

Belyaev, P.P., Bösinger, T., Isaev, S.V., Trakhtengerts, V.Y., Kangas, J., 1999. First evidence at high latitudes for the ionospheric Alfvén resonator. J. Geophys. Res. 104 (A3), 4305–4317.

Bösinger, T., Haldoupis, C., Belyaev, P.P., Yakunin, M.N., Semenova, N.V., Demekhov, A.G., Angelopolous, V., 2002. Spectral properties of the ionospheric Alfven resonator observed at a low-latitude station ($L = 1.3$). J. Geophys. Res. 107, 1281. doi:10.1029/2001JA005076.

Demekhov, A.G., Trakhtengerts, V.Yu., Bösinger, T., 2000. Pc1 waves and ionospheric Alfvén resonator: generation or filtration? Geophys. Res. Lett. 27, 3805–3808.

Guglielmi, A.V., Potapov, A.S., Tsegmed, B., 2004. On the excitation of magnetic signals by Love waves. Ann. Geophys. 47, 171–177.

Hayakawa, M. (Ed.), 1999. Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes. Terra Sci. Pub. Co., Tokyo, 996 p.

Hayakawa, M., 2001. Electromagnetic phenomena associated with earthquakes: review. Trans. Ins. Electr. Engrs. Jpn. A 121, 893–898.

Hayakawa, M., Molchanov, O., 2002. In: Hayakawa, M., Molchanov, O.A. (Eds.), SeismoElectromagnetics: Lithosphere–Atmosphere–Ionosphere Coupling. TERRAPUB, Tokyo, 477 p.

Liperovsky, V.A., Meister, C.-V., Doda, L.N., et al., 2005. On the possible influence of radon and aerosol injection into the atmosphere and ionosphere before earthquakes. In: EGU General Assembly 2005, Vienna, Austria, 24–29 April 2005. Abstract number: EGU05-A-10347.

Molchanov, O.A., Schekotov, A.Yu., Fedorov, E., Hayakawa, M., 2004. Ionospheric Alfvén resonance at middle latitudes: results of observations at Kamchatka. Phys. Chem. Earth 29, 649–655.

Pokhotelov, O.A., Pokhotelov, D., Strelkov, A., Khruschev, V., Parrot, M., 2000. Dispersive ionospheric Alfven resonator. J. Geophys. Res. 105, 7737–7746.

Pokhotelov, O.A., Khruschev, V., Parrot, M., Senchenkov, S., Pavlenko, V.P., 2001. Ionospheric Alfven resonator revisited: feedback instability. J. Geophys. Res. 106, 25813–25824.

Polyakov, S.V., Rapoport, V.O., 1981. Ionospheric Alfven resonator. Geomagn. Aeron. 21, 610–614.

Readdy, P.R., Conviner, 2005. In: 42nd Annual Convention and Meeting on "Earth System Processes Related to Earthquakes, Tsunami and Volcanic Eruptions". Indian Geophysical Union, Barkatullah University, Bhopal, India, 7–9 December 2005.

Schekotov, A., Molchanov, O., Fedorov, E., et al., 2005. Preseismic ULF magnetic field depression. New results. In: EGU General Assembly 2005, Vienna, Austria, 24–29 April 2005. Abstract number: EGU05-A-02742.

Sobolev, G.A., 1993. The Principles of the Earthquake Prediction. Nauka, Moscow, 313 p.

Surkov, V.V., 2000. Electromagnetic Effects Caused by Earthquakes and Explosions. MEPhI, Moscow, 447 p.

Surkov, V.V., Pokhotelov, O.A., Parrot, M., Fedorov, E.N., Hayakawa, M., 2004. Excitation of the ionospheric resonance cavity by neutral winds at middle latitudes. Ann. Geophys. 22, 2877–2889.