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THE BROAD SPECTRAL MAXIMUM IN THE LOW FREQUENCY BACKGROUND MAGNETIC NOISE

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Abstract. We present the first systematical study of an observational feature of the spectrum of ULF background magnetic noise called broad spectral maximum (BSM) at frequencies 2 - 6 Hz. The mechanism of BSM formation is proposed and investigated. The main cause of such maximum is the presence of strong variation of refractive index of ULF waves at heights between the ionosphere bottom and the base of *F*2 – layer. It is shown that such spatial structure could explain the existence of BSM with frequency scale determined by the integral ULF optical thickness of the lower ionosphere. The main frequency of BSM in the range of 2 – 6 Hz corresponds to the first fundamental frequency of the large scale lower ionosphere structure and depends on its parameters.

1. Introduction

The spectra of the background noise in the frequency range of (0.1 – 15) Hz markedly differ by great variety compared to the range of (30-300) Hz. Namely, just at these frequencies the influence of the near Earth resonance structures becomes apparent. Such structures are MHD waveguide (responsible for the spectra below 1 -2 Hz, [*Greifinger*, 1974], [*Fujita* 1988]), Schumann resonator (responsible for Schumann resonances) and Ionospheric Alfven resonator (IAR – responsible for resonance spectral structure at frequencies 1- 7 Hz in the night time, [*Polyakov and Rapoport,* 1981], [*Belyaev et al*., 1990]).

The special spectral shape – the broad spectral maximum (BSM) – was first distinguished as a separate spectral form at frequencies below the 1-st Schumann resonance in the paper [*Belyaev et al*., 2002]. A long time investigation of the background magnetic noise at the multitude station of New Life showed that the BSM appears under quiet magnetic conditions after sunset and disappears just after midnight or before sunrise. The drift of the central frequency of BSM toward the 1-st Schumann resonance during all the time of its existence was typically observed. The hypothesis on the BSM origination due to the propagation phenomena in the ionospheric MHD waveguide was claimed in the same paper [*Belyaev et al*., 2002].

The new experimental data on simultaneous BSM observations at two mid latitude stations (New Life, Russia and Nurmijärvi, Finland) will be presented below. The difference in dynamics of BSM evolutions is the evidence of the locality of the phenomenon.

The analyses of gradient measurements on a small spatial base (~50 km) did not reveal small scales in the spatial structure of BSM. The presence of such small scales would be one of major evidence of the relation between the BSM and the propagation of MHD waves in the ionospheric waveguide, because the wave length over there is about 30 – 60 km.

It is well known that the IAR exists due to the presence of two reflecting areas for MHD waves at heights of about 100 and 1000 km. We paid attention to the existence of the strong night time variation of ULF refractive index between the ionosphere bottom (70 – 80 km) and a low part of F_2 – layer (250 -300 km) connected with the so-called "valley" – a minimum in the electron density profile at height 130 – 150 km. This structure must possess its own resonance abilities different from the IAR due to the presence of high gradients of ULF refractive index at boundaries of the structure mentioned above. Particularly this region could be responsible for the appearance the BSM phenomenon. We call this resonance structure sub – IAR by analogy and for distinction with traditional IAR definition.

A numerical simulation of BSM for the layered ionosphere model including all peculiarities of the altitude distribution of the ionospheric parameters was done. This simulations allows us to explain the basic experimentally observed properties of BSM.

2. Observational results

The sets of data on the magnetic noise in H_{N-S}, H_{E-W} components from four stations were analyzed in this paper: two Russian stations - New Life, (.55,97ºN, 45,74º E) and Fominki (.55,67º N. 45,24º E), and two Finnish ones - Nurmijärvi (60.5º N, 24.7º E) and Rovaniemi (66,6º N, 25.8º E). The major criterion in picking up the data sets was the existence of BSM at one of the station or simultaneously at two of them in the night time in 2001, 2003 and 2005. The data processing consisted in taking the 10 - seconds spectrum and subsequent averaging over 80 – 100 spectrum realizations that corresponded to 15 – 20 minutes of data sequence.

The case of the registered BSM at New Life on July 06, 2003 without superposition with SRS is presented in Fig. 1 (left panel). The BSM appeared just after sunset in the E-W component of the magnetic field and then evolved to

N-S one around the local midnight. The noise spectra from Nurmijärvi for the same night are presented in Fig. 1 (right panel). Here, a very weak BSM appeared only 2.5 hours later than at New Life station and in E-W component only. This BSM existed for 1.5 hour then spread and vanished. At the same time the BSM at New Life existed for more than four hours and vanished just before sunrise. Thus, this case evidently testifies that the BSM strongly depends on local ionospheric properties above the observation point. The BSM detected at mid latitude station of Nurmijärvi and sub auroral station of Rovamiemi were also compared. It was shown that the BSM for stations separated by 500 km was not detected under the magnetically disturbed time. The polarization properties of BSM were also investigated for several cases. This study shows definite dependences of the polarization parameter on frequency, time, point of observation and geomagnetic activity. Corresponding graphs are not presented here to fit the paper length and will be published elsewhere.

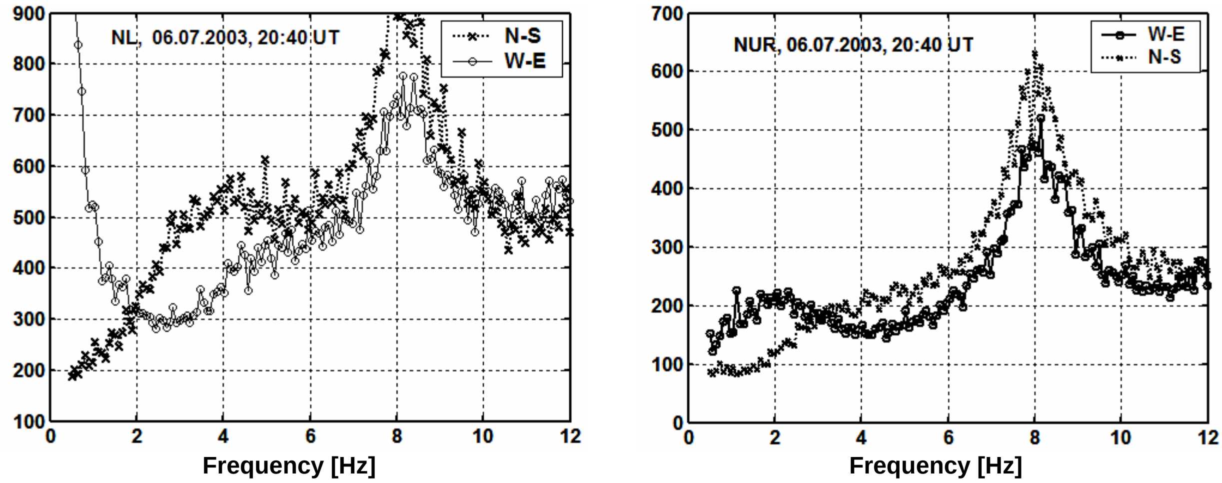

Fig.1. Simultaneous observations of the BSM at New life and Nurmijärvi stations

The result of special differential data processing is presented in Fig. 2. The series of synchronized data with distinct BSM from two stations separated only by a 50 km distance (New Life and Fominka) was subtracted one from another and then the obtained new series was analysed. As one can see from Fig. 2 the BSM is completely absent in the differential signal. That means the absence of small scales (less than 50 – 80 km) in spatial distribution of the magnetic field forming the BSM.

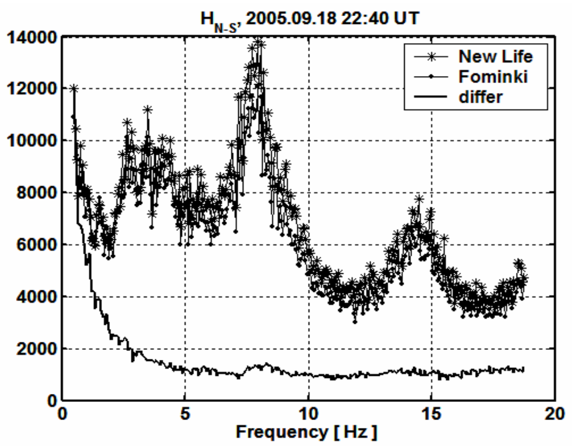

Fig. 2. The results of differential data processing for two closely settled stations

Finally all the obtained experimental results allow us to summarize the main BSM properties:

- The central frequency and polarization of the BSM feature strongly depends on local ionospheric conditions;
- The spatial correlation radius of magnetic fields on BSM frequencies is no less than 50 km;
- The polarization of the magnetic fields at BSM frequencies depends on the frequency, and differs from both the polarization of magnetic noise without BSM structure or polarization in Schumann resonances.

3. Simulation procedure, ionosheric models and results

As shown above, the BSM properties strongly depend on ionosphere local conditions at the observation point. Therefore, we have used the results of the paper [*Sobchakov et al.*, 2003] obtained for the problem of excitation of the plane wave guide by electric and magnetic dipoles. Differentiating the vertical components of the corresponding Hertz vectors one can find the expressions for magnetic field components from a vertical electric dipole (lightning) at an observation point.

The surface impedance matrix $\hat{Z}$ for a uniform ionosphere should be replaced by the surface impedance matrix for plane multi - layer anisotropic medum using traditional method [*Zhdanov,* 1968] for recalculating the impedance matrix at the lowest boundary of the slab with thickness *d* by known matrix at the upper boundary.

Also the altitude profiles of the refractive indices $n_{1,2}$ and polarization coefficients $P_{1,2}$ of normal waves are needed for calculations of the impedance matrix, in other words we need to choose a proper model of the ionosphere.

The set of ionospheric parameters (electron and ions distributions, neutral temperature and composition, geomagnetic field parameters) was picked up for certain mid - latitude point from NASA site http://modelweb.gsfc.nasa.gov/ using international models for the ionosphere (IRI-2001), atmosphere (MSIS-E-90) and geomagnetic field (DGRF/IGRF). Then $n_{1,2}$ and $P_{1,2}$ were calculated using the well known formulas from the book [*Ginzburg,* 1967] extended to the case of the multi ion plasma. Such an approach allows us to simulate the ULF spectra under various ionospheric conditions like time of day, season, solar activity, etc for various observation points.

An example of height profile of the real part of refractive indexes of normal waves is presented in Fig. 3 for New Life station at the time of maximum of solar activity (January 15,1991, 00:00 LT).

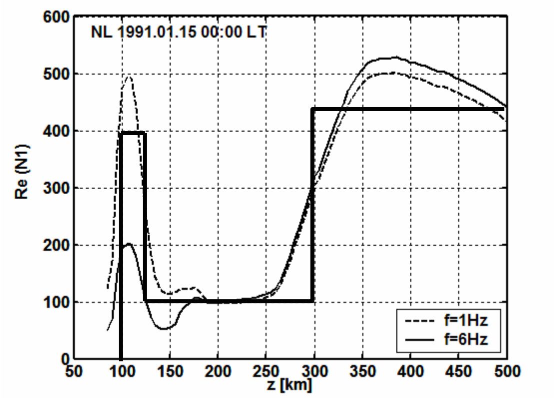

Fig. 3. Model of the real part of refractive index for New life at maximum solar activity by IRI-2001 and the 3 - layer model

As one can see this curve is very structured due to the extended region of depressed $\mathrm{Re}(N_{1,2})$ at 150 – 250 km. Such altitude distribution of the refractive index is also characterized by the presence of the additional region of the violation of geometrical optics at the base of *F* – layer (250 – 300 km). It was suggested that this structure named sub - IAR could possess their own resonance ability to influence the ULF spectra.

To make one sure there was introduced a more simple three layer model, which reproduced the main structure of refractive index curve from Fig. 3.

Slab 1 – (E- layer) is the region of gyrotropic plasma of thickness $d1$ with refractive index typical for whistler's band: For calculations there were taken the following parameters:

$$N_e = 4*10^3\ 1/cm^3,\ \nu_{in} = 1000 s^{-1},\ d1 = 30 km$$

Slab 2 – is the region with a depressed value of the refractive index ("valley"). The refractive index is specified here as Alfven one ($n_A = 100,\ \nu_{in} = 6\ s^{-1},\ d2 = 170 km$).

Slab 3 – is half space with parameters corresponding to the maximum of the *F* – layer (also with the Alfven refractive index and small collision frequency, $n_A = 450,\ \nu_{in} = 0.6\ s^{-1}$).

First, the radial component of magnetic field was calculated for the 3- layer model (see the Fig. 4). A broad band resonance structure appears with the maximum at the frequency of 3.5 Hz. The calculation for the case of a more realistic model with "valley" from Fig. 3 gives us a similar result for the first resonance both in the shape and the amplitude but very small secondary maximum at 15 Hz. This fact could be explained in terms of geometrical optics: at higher frequency the wave length becomes closer to refractive index scale length at the reflection point at the base of the *F* – layer.

Also the dynamical evolution of the BSM was calculated for the period from 2003.07.06. 20:00LT to 2003.07.07 02:00 LT using IRI-2001 model for New Life (the appropriate plots will also be published elsewhere). The BSM was observed in New Life station for the same time (see Fig. 1). The central frequency of the BSM moved with time toward the 1-st Schumann maximum both in the experiment and in the simulation results. The comparison with changes in the height dependence of refractive index shows us that the BSM appears when the difference of the refractive index at the "valley" and the maximum of the F- layer becomes ≥ 500. The further depletion of the refractive index causes an increase in the central BSM frequency.

Basing on the simulation results for period 2003.07.(06-07), the time dependence of the main BSM frequency and value S (roughly proportional to the optical thickness) calculated by formula presented in Fig. 5.

$$S \propto \left(\sqrt{N_{E\max}} \times L_{E\max} + \sqrt{N_{E\min}} \times (h_{F2} - h_{E\max})\right)^{-1}$$

Here $N_{E\max}$ is the electron density at the *E* – layer maximum, $L_{E\max}$ is the half thickness of the *E* – layer, $N_{E\min}$ is the minimum electron density in the "valley", h_{F2} and $h_{E\max}$ are the heights of these maxima.

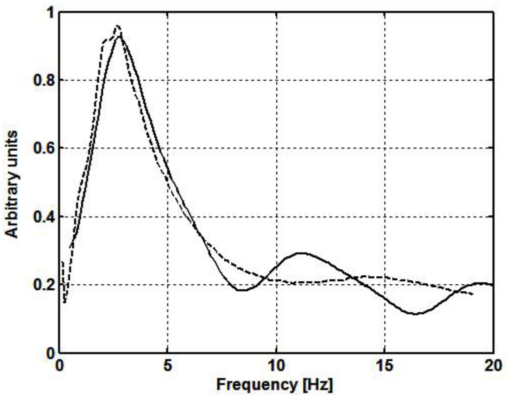

Fig. 4. The simulations result for 3-layer model(solid) and for multi layer one (dash)

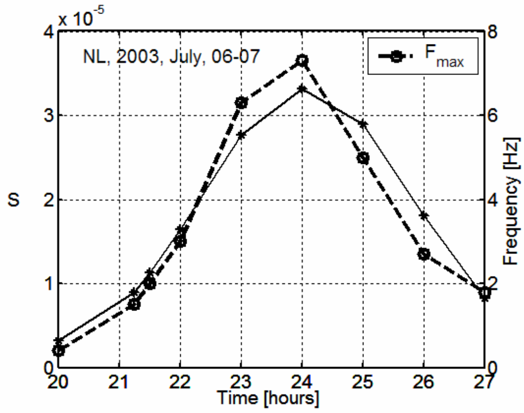

Fig.5. The time dependence of BSM central frequency and of the optical thickness

As one can see from Fig. 5 these two curves are fairly similar. Hence if one can find F,E – layers heights and electron densities by alternative methods (e.g. from ionosonde data) then the $N_{E\min}$ value could be estimated using the BSM data. Note that this part of the ionosphere may be accessed only by rocket measurements.

Thus, the following conclusion can be drawn: strong variation in the ULF refractive index at heights from the ionosphere bottom to the base of the *F* – layer (250 – 300 km) is the cause of an enhancement of the magnetic field intensity at frequencies (2-7) Hz, which we call the BSM. The central frequency of BSM and its width depend on the optical thickness of the mentioned part of the ionosphere which serves as a separate resonator and we call it sub – IAR.

Conclusions

The BSM simulations performed for a plane multi – layer ionosphere model allows us to explain the main properties of BSM observed experimentally:

- The BSM exists only in the night time;
- The BSM can be observed under quiet geomagnetic conditions:
- The BSM can be observed in both N-S and E-W components but as a rule it is more prominent only in one component;
- The polarization inside the BSM strongly depends on the frequency;
- The possibility to observe BSM at the time of absence of the SRS (e.g. during the years of Solar activity maximum);
- The drift of the maximum central frequency after sunset from values (2-3) Hz to (5-5.5) Hz;
- The influence of the local ionospheric properties on the BSM parameters (frequency, amplitude and broadness);
- The spatial scale of the BSM is comparable with Schumann resonance one.

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