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First Detection of Spectral Resonance Structures of the Ionospheric Alfvén Resonance in ULF/ELF Magnetic Field Recorded at Suwałki, Poland

Anna ODZIMEK[1,✉] and Mariusz NESKA[1]

[1]Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

✉ aodzimek@igf.edu.pl

1. INTRODUCTION

The ionospheric Alfvén resonance (IAR) results from the resonant interference of the shear mode of the magnetohydrodynamic Alfvén waves in a cavity created by the bottom conductive ionosphere in the E-layer and by the gradient of the mass density in the Earth's ionospheric upper F-layer (Polyakov and Rapoport 1981), where the waves are partly reflected. The eigen-frequencies of the resonance depend on the parameters of the Alfvén speed profile in the F layer, proportionally dependent to the ambient geomagnetic field, and inversely proportional to the square root of mass density. The parameter defining the resonance frequencies is a parameter called the IAR frequency scale, Δf, which is also in approximation equal to the interval between first modes:

$$\Delta f = v_{AF}/2h = B_0/[2h\,(\mu_0\,\rho_F)^{1/2}] \qquad (1)$$

where v_{AF} is the minimum Alfvén speed, i.e. approximately at the mass maximum, in F-layer, h – geometric dimension defined by thickness of the maximum and the spatial scale of the decrease of the density above, B_0 is the geomagnetic field, ρ_F – maximum F-layer plasma (ion) mass density, μ_0 – magnetic permeability of free space.

The Alfvén ionospheric resonant modes transmit through the bottom ionosphere down to the ground creating the so called IAR spectral resonance structures, or IAR SRS (Belyaev *et al.* 1987), which are characterised by similar resonance frequency pattern. The resonances can be observed in the natural ULF/ELF (ultra low and extremely low frequency) electromagnetic noise in the range from one half to several Hz, at both middle, low and high latitudes on the globe (e.g. Yahnin *et al.* 2003, Molchanov *et al.* 2004, Bösinger *et al.* 2002, Semenova *et al.* 2005, Odzimek *et al.* 2006). Multiple sources have been considered for the excitation of the resonances which include atmospheric and magnetospheric sources: lightning and thunderstorm activity, neutral winds, magnetospheric phenomena (Belyaev *et al.* 1989, Lysak 1991, Fedorov *et al.* 2006).

2. MAGNETIC OBSERVATIONS IN ULF/ELF FREQUENCY RANGE IN SUWAŁKI REGION

Measurements of the magnetic horizontal components of electromagnetic natural background in the ULF/ELF frequency range have been carried out at Suwałki region (54.012 N, 23.183 E, L = 2.47) since mid-June 2016. The “Suwałki” site is located in the National Park of Wigry (Wigierski Park Narodowy) and thus is relatively far from anthropogenic infrastructure and relatively clean in terms of artificial electromagnetic noise.

The measurement set-up consists of two induction coils for each horizontal component, placed in N-S and E-W directions, and an ASR 01/2004 console manufactured in early 2000’ in Belsk Observatory of the Geophysical Institute PAS, along with a 24-bit NDL data logger. The sampling frequency is 100 Hz. The filter characteristics pass frequencies from 0.1 to 35 Hz (Neska *et al.* 2019). The measurements have been carried previously at Belsk for the purpose of research investigation of the Schumann Resonance (Neska and Sátori 2006).

3. IAR SRS DETECTION IN THE ULF/ELF MAGNETIC FIELD AT SUWAŁKI

In search of the signatures of the ionospheric Alfven resonance in the magnetic ULF/ELF data from Suwałki we have initially analysed the first month of observations made over June–July 2016.

The spectral analysis of the magnetic signal have been carried out in accordance with the method used for example in Odzimek *et al.* (2006), i.e. using Fourier transforms of 5-min time series divided into smaller sections of 2048 samples (equivalent to ~20.5 s). The shorter series are Fast-Fourier-transformed and windowed using a Hamming window. A power spectrum is next calculated as an incoherent average of the transforms (Lyons 2000) and with 50% overlap of the data input to FFT. Then, each average power spectrum of 5-min intervals – starting from 15 UT of the day, is denoted by amplitude-coloured pixels (one pixel per one FFT point) and assembled into 24-hour spectrograms in frequency range up to 5 Hz.

An example of such spectrogram which features visually recognised spectral resonance structures of the IAR is shown in Fig. 1. In this case, on 16/17 July 2016, the SRS IAR can be

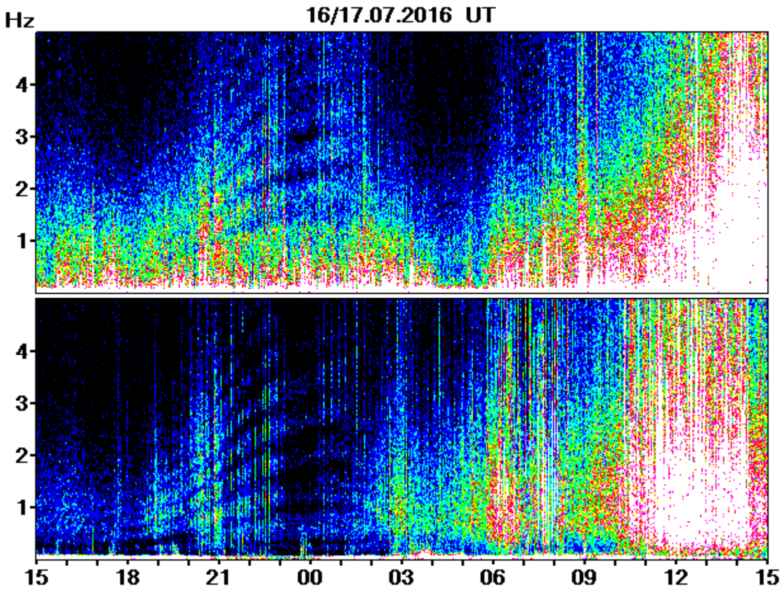

Fig. 1. Example of SRS IAR in the magnetic ULF/ELF signal observed at “Suwałki” site on 16/17 July 2016. The spectral resonance structures are seen in the power spectra of the magnetic components registered by both antennas (N-S upper panel, E-W bottom panel). The increase of the spectral amplitude at mid-day is likely due to local thunderstorm activity. An arbitrary logarithmic scale is used.

Table 1

Summary of SRS IAR detection from June 18th to July 16th, 2016, at "Suwałki" site, Poland

Date – period of 24 h from 15 UTC	SRS IAR in N-S antenna*	SRS IAR in E-W antenna*	Onset time UT	Ending time UT
2016/06/18				
2016/06/19	+	+	19:30	23:00
2016/06/20		×		
2016/06/21		+	18:00	04:00
2016/06/22		+	19:00	01:00
2016/06/23		+	19:00	01:00
2016/06/24	×	×		
2016/06/25				
2016/06/26				
2016/06/27		×		
2016/06/28		+	19:00	23:00
2016/06/29		+	18:00	00:00
2016/06/30		×		
2016/07/01	×	×		
2016/07/02				
2016/07/03	×	+	20:00	23:00
2016/07/04		+	18:00	22:00
2016/07/05		×		
2016/07/06				
2016/07/07				
2016/07/08				
2016/07/09		+	18:00	00:00
2016/07/10		×		
2016/07/11				
2016/07/12		+	19:00	00:00
2016/07/13				
2016/07/14		×		
2016/07/15	+	+	20:00	01:00
2016/07/16	+	+	19:00	01:00
2016/07/17		×		
2016/07/18		+	18:00	00:00

*presence denoted by "+", not clear "×", empty space – absence or not detected with current analysis settings

visible as brighter peaks in approximately same frequency interval Δf at a time, starting at ~19:00 UT (E-W antenna), 16 July 2016, to ~01:00 UT (both antennas), on 17 July 2016. The structures appear in the local evening and persist at night-time as observed previously at other locations. The SRS IAR frequency interval, Δf, evolves in time as the ionosphere evolves and its parameters change in general as expected (e.g. Odzimek *et al.* 2006). The presence of SRS IAR in the analysed material, its onset and ending determined by visual inspection of calculated spectrograms, are notified in Table 1. The approximate value of the Δf in this period is from a fraction of Hz to a maximum of about 1 Hz.

4. SUMMARY AND FUTURE WORK

The spectral resonance structures of the ionospheric Alfven resonances have been detected for the first time in the magnetic signal of the ULF/ELF field measured near Suwałki in Poland. We conclude that:

- The preliminary analysis of ULF/ELF magnetic signal at Suwałki reveals presence of the SRS IAR features in agreement with similar events observed at other mid-latitude sites.
- In the summer period from mid-June to mid-July on about thirteen days the SRS IAR events have been observed during local night-time (in majority of cases in the signal from E-W antenna), and their frequency scale varied from a fraction to one Hz.
- The magnetic ULF/ELF observations at Suwałki are suitable for the investigation of the IAR.

More detailed analysis of longer data series from the Suwałki site with regard to SRS IAR is planned for future work. The neighbourhood of simultaneous observations of ULF/ELF magnetic field at e.g. Hylaty, Poland (49.317 N, 22.933 E, L ≅ 2.0) (Kulak *et al.* 1999, 2014), gives a unique possibility of investigating the aspects of IAR such as generation, propagation, and diagnosis of the ionosphere on a regional scale.

Preliminary analysis of data measured over the same period at high-latitude location in Hornsund, Svalbard (Neska *et al.* 2019), have not yet revealed pronounced SRS IAR events but we aim to monitor the spectral features of the data from both observation sites.

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PIERWSZE OBSERWACJE WIDMOWYCH STRUKTUR REZONANSOWYCH JONOSFERYCZNEGO REZONANSU ALFVÉNA W POLU MAGNETYCZNYM ULF/ELF REJESTROWANYM W REJONIE SUWAŁK W POLSCE

Streszczenie

Analiza widmowa zmiennego pola magnetycznego w zakresie ultraniskich częstości ULF/ELF rejestrowanego na przełomie czerwca i lipca 2016 r. w Wigierskim Parku Narodowym – rejon Suwałk (54.012 N, 23.183 E, L = 2.47), wykazała istnienie rezonansowych struktur świadczących o działaniu jonosferycznego rezonansu Alfvéna (IAR), czyli detekcji tzw. rezonansowej struktury widmowej SRS IAR. Jonosferyczny rezonator Alfvéna (IAR) powstaje w obszarze F nocnej jonosfery w specyficznych warunkach zależnych od profilu masowej gęstości jonowej. Analiza 24-godzinnych spektrogramów w przedziale częstotliwości

do 5 Hz, opartych o uśrednione widmach mocy 5-minutowych serii czasowych, wykazała istnienie SRS IAR w trzynastu na trzydzieści rozważanych pomiarów dobowych. Cechy SRS IAR są zgodne z podobnymi przypadkami obserwowanymi w innych miejscach pomiarowych na średnich szerokościach geomagnetycznych. Parametr Δf SRS IAR w analizowanych przypadkach waha się w granicach od ułamka Hz do około 1 Hz. Obserwacje IAR w Suwałkach stwarzają dodatkowe możliwości badawcze studiów nad zjawiskiem IAR i jonosferą, w szczególności generacją rezonansu, propagacją fal oraz diagnozą parametrów jonosferycznych, od których zależą cechy rezonansu. Opisane przypadki SRS IAR są pierwszymi obserwacjami tego zjawiska zarejestrowanymi w punkcie pomiarowym IGF PAN koło Suwałk w Polsce.