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Multipoint observations of Ionospheric Alfvén Resonance

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Among the processes that form properties of the geospace in the circumterrestrial plasma the electromagnetic resonances of the Earth, such as Schummann Resonance (SR) and Ionospheric Alfvén Resonance (IAR) are of great importance. IAR is more localized in space than SR and its properties largely depend on the characteristics of the propagation medium. In contrast to the SR, which has global nature and which is continuously observable at any time of the day, IAR signals are registered mostly during the nighttime and demonstrate more variability of the parameters than SR signals. At the Earth surface IAR is registered as Spectral Resonance Structure of the natural electromagnetic noise at frequency range 0.1–40 Hz. In this work we studied an influence of the environment characteristics on IAR parameters by the means of multipoint observations. Annual data series recorded at Ukrainian Antarctic Station "Akademik Vernadsky", Low Frequency Observatory of the Institute of Radio Astronomy near Kharkov (Ukraine) and magnetic station of Sayan Solar Observatory Mondy near Irkutsk (Russia) were used for the analysis. We investigated the behaviour of IAR parameters, such as probability of resonance lines registration and frequency spacing ΔF, for annual and diurnal intervals. These parameters were compared with characteristics of the ionosphere above all of the observation points and geomagnetic activity.

Key words: radio science: ionospheric physics, waves in plasma

INTRODUCTION

The maxima of the Pedersen and Hall conductivity at the heights of E-layer of the ionosphere lead to the forming of effective reflection wall for the Alfvén mode of the magnetohydrodynamic (MHD) waves spread at the upper ionosphere and magnetosphere. This leads to existence of a field line resonator (FLR) in the closed field lines, i. e. the system of the standing waves along the field lines of the geomagnetic field [9]. The magnetic structure of FLR is formed when MHD waves reflect from the ionosphere at the different ends of the field line in the magnetoconjugate regions of the South and Northern hemispheres. However, if additional conditions for MHD waves reflection appear at 1000–1500 km then the cavity with existing resonance processes is decreased and becomes bounded by the plasmapause at the top and the lower ionosphere at the bottom. Such a phenomenon is named ionospheric Alfvén resonator (IAR) and was first described in 1981 by Polyakov & Rapoport [17]. At the heights of E-layer of the ionosphere MHD waves transform into electromagnetic ones and can be registered at the Earth surface as spectral resonance structure (SRS) of the natural electromagnetic noise in the frequency band 0.1–5 Hz. From that time IAR was studied by many authors both in theoretical [16, 8, 12] and experimental means [2, 7, 19]. The analysis of IAR morphology and its relationships with ionospheric parameters were investigated in [5]. Authors of [3] studied IAR parameters during the solar cycle and have found the inverse dependence between IAR observability and solar activity. It was shown theoretically [4] and experimentally [5] that the upper limit of SRS observability can be up to 10 Hz. It should be noted, however, that most of the experimental observations used in the above-mentioned works were cases studies of fragmentary observations.

Monitoring of horizontal magnetic components of ULF/ELF fields has been made at the Ukrainian Antarctic Station (UAS) from the beginning of the current century. Together with the data got at the Antarctic station Arrival Heights [18] these are the longest series of data in this frequency band. We used these data for systematic search of SRS corresponding to IAR [6]. The data analysis allowed us to develop a technique for evaluating the critical frequency of $F2$ layer of the ionosphere using the IAR records [1]. In addition, the analysis of the UAS data shows the existence of SRS at the frequencies up to 40 Hz [10], what is significantly higher than 10 Hz limit reported in [4, 5]. Since these resonances are global, we are interested in simultaneous measurements at stations with big spatial separation. Therefore, IAR monitoring have been started in 2008 on the basis of the Institute of Radio Astronomy of the National Academy of Sciences of

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Ukraine (IRA NASU) and in 2010 by the initiative of IRA NASU in the Eastern Siberia at the Institute of Solar-Terrestrial Physics of the Siberian branch of the Russian Academy of Sciences (ISTP SB RAS). In this article, the comparative analysis of the IAR morphology obtained from the observations on all three stations was made.

THE METHOD OF CALCULATIONS

Comparative analysis of IAR data was performed at the three receiving sites, namely: UAS "Akademik Vernadsky" (65°15′ S, 64°16′ W), Low Frequency Observatory (LFO) of IRA NASU (49°56′ N, 36°57′ E) and magnetic station of the Sayan Solar Observatory (SSO) of ISTP SB RAS (51°37′ N, 100°55′ E). Despite the different geographic location, the geomagnetic latitudes and McIlwain parameter of the stations are quite similar (UAS — 2.6, LFO — 2.2, SSO — 2.1). IAR registrations were performed with induction-coil magnetometers. The magnetometers Lemi-419ANT (frequency range: 0.001–80 Hz) and Lemi-30 (frequencies: 0.001–40 Hz) made by the Lviv Centre of the Institute of Space Research were used at UAS and SSO, respectively. At LFO the ELF receiver (frequency range: 0.5–40 Hz) made by IRA NASU [14] was used. All magnetometers measure horizontal components of the geomagnetic field in the directions of the geographical meridian (x) and parallel (y). They are equipped with GPS systems to synchronize with absolute time and have similar characteristics.

Also, there are ionosondes at or near the sites. This allows comparing IAR parameters with the characteristics of the ionosphere. At UAS there is an ionosonde IPS-42 at a distance of 500 m from the magnetometer, so it allows considering that these are single point measurements. This ionosonde was upgraded and supplemented with a block of digital registration therefore ionograms are available in digital format. All of the ionograms are processed by an operator within the standard URSI technique [15]. DPS-4 digisonde is located in Irkutsk at the distance about 200 km from SSO that makes searching for the reaction on the ionospheric disturbances more complicated at small and medium scales. Nevertheless, this distance is less than the characteristic large-scale gradients in the ionosphere that allows making comparison with its regular variations. The data is processed automatically every 15 min. At LFO there is no ionosonde near the station.

The data received synchronously at all the stations through the whole 2010 year were used for the analysis. Such amount of the data allows describing diurnal and seasonal variations of IAR parameters.

The straight through processing of ELF data was performed for every station. It included spectral processing in which for every x and y component instantaneous spectra were made with frequency resolution 0.1 Hz (duration of realization is 10 s):

$$S_{x,y}(f) = \frac{1}{T}\int_{T_1}^{T_2} B_{x,y}(t)e^{-i2\pi ft}\mathrm{d}t.$$

Hereafter, instantaneous spectra were used for computing the power S_{xx}, S_{yy} and cross S_{xy} spectra calculated with a time resolution 10 min (60 instantaneous spectra were averaged). Values of the power spectra and absolute values and phases of the cross spectra were used for computation of the polarization parameters ($r(f)$ is ellipticity ratio, $\Psi(f)$ is position angle of the polarization ellipse, $I_p(f)$ is intensity of the polarized component, $P(f)$ is degree of polarization) within the technique described in the article [11]. In this work we do not stop on the interpreting of the polarization parameters and focus on the analysis of IAR observability and the average difference between SRS eigenfrequencies — ΔF. For calculation of these parameters the following algorithm was used. At first the daily spectrograms of the signal intensity for every polarization channel were calculated. Then an operator chose SRS lines using specially created software. The frequencies of IAR modes with equal number from different channels were averaged if they existed in both channels. The averaged value of the resonance frequencies were used for calculation of ΔF. Besides that the fact of the IAR presence was fixed. It was considered that IAR is detected if there were three or more resonance maxima. With the ionosonde data for every 10 min we determine SRS presence (1 – SRS exists, 0 – SRS does not exist) and, if SRS exists, another two parameters: ΔF, f_0F2.

COMPARATIVE MORPHOLOGY OF IAR BEHAVIOUR

The data obtained from the three stations allowed a comparative analysis of the IAR morphology. For all observational stations there are identical distinct seasonal and diurnal dependencies of the behaviour of IAR parameters. Seasonal-diurnal dependencies for the probability of IAR registration are shown in Fig. 1. For easy comparison all the data are shown for local time and for local seasons. It is seen the smooth variation of the probability during the day. The beginning of the increasing and decreasing of the probability of IAR registration depends on the sunset and sunrise, respectively. The maximum of the probability falls on midnight and the minimum falls on midday. There is clearly expressed dependence on the season of the year as well. In winter the probability of IAR registration is very high and almost does not depend on the time of the day (especially at SSO). In autumn it is high too but there is clear difference between daytime and nighttime. In spring and summer it is much lower, and SRS are not observed near midday. However, there are some differences between IAR behaviour at different stations. In winter the probability of IAR registration at LFO is much lower than at the other stations and has clear diurnal behaviour. In summer the lowest probability of SRS registration is observed at UAS. Moreover, as it is known and as it will be confirmed onward, the probability of IAR registration has dependence on the critical frequency of $F2$ layer of the ionosphere. There is an anomaly in f_0F2 behaviour at UAS in summer when the critical frequency in nighttime is higher than in daytime [13]. This explains why the probability of IAR registration at UAS in summer is much lower than at the other stations. But it does not explain why it is higher in summer night than in summer day. In daytime f_0F2 is lower than in nighttime so the probability of IAR registration is supposed to be higher. However, the opposite is observed. Therefore, the critical frequency of the ionosphere is not the prime factor of IAR registration. Perhaps, the conditions at the resonance boundaries are much important.

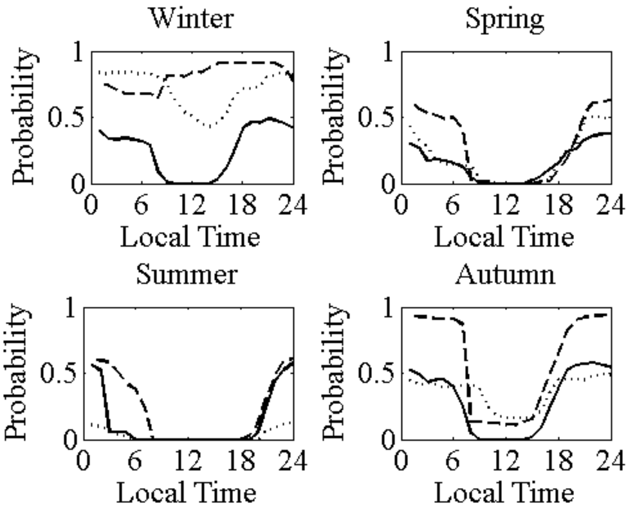

Fig. 1: Diurnal-seasonal dependencies for probability of IAR registration. UAS data are shown with dotted line, SSO — with dashed line, and LFO data — with solid line.

Seasonal-diurnal variations of SRS frequency separation are shown in Fig. 2. The diurnal dependence of ΔF characterized by smooth variations with the minimum occurring at the midday. The maximum is reached on sunset, and during the night ΔF is stable. Seasonally ΔF is slightly higher in the winter and slightly lower in the summer. In the spring and autumn it has similar values. The diurnal and seasonal dependencies of ΔF from every station are qualitatively similar and have comparable values. But, as well as for probability of registration, there are a couple of inconsistencies. First one is much lower ΔF value at UAS in the summer. ΔF has a clearly seen dependence from the critical frequency so the anomaly of f_0F2 fully explains this fact. Another one is the maximum of ΔF value at UAS on sunrise. It is almost imperceptible in the winter, meaning in the autumn and very large in the spring.

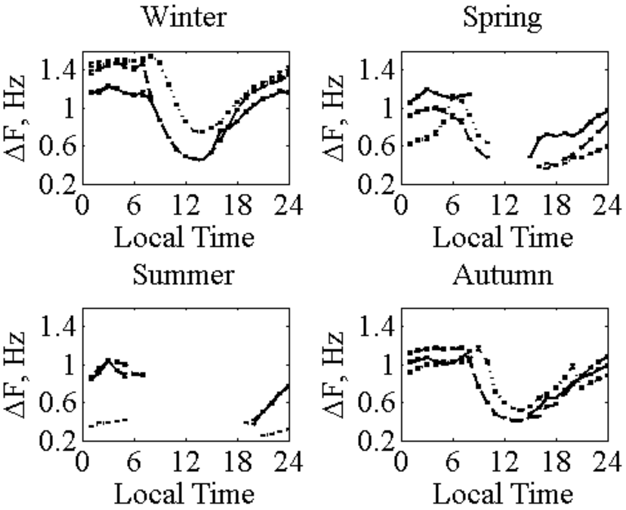

Fig. 2: Diurnal-seasonal dependencies for ΔF. UAS data are shown with dotted line, SSO — with dashed line, and LFO data — with solid line.

As it is known SRS was registered at frequencies not higher than 10 Hz. Earlier IAR modes at the frequencies higher than 10 Hz were found by the authors of [10] (further we will call such modes as high frequency IAR modes). Now we compare the observability of such events at different stations. A histogram of the annual distribution of the number of registered high frequency IAR modes is shown in Fig. 3. The probability of such events registration is different at different station. It has seasonal dependence when in the local winter it is much higher than in the local summer. We should note one fact does not seen on this histogram: the high frequency IAR modes are not registered synchronously at different stations. There are less than 20% of days when such events are registered more than at one station. Even for LFO and SSO despite similar seasonal dependence of the observability. So it is achieved the statistical confirmation that to a greater extent IAR depends on the local characteristics of the ionosphere above the observation point, not on a global ones.

An analysis of the relationship between IAR parameters and geomagnetic activity was made. There is the dependence of the probability of IAR registration on the local k-indices in Fig. 4. As it is known from [3] the probability of SRS observation and geomagnetic activity have inverse relationship. However, there is no clearly seen inverse dependence between these parameters in our data (see Fig. 4 left panel). The expected dependence was found when we calculated these parameters using only data obtained when high frequency IAR modes were registered. The result is shown in Fig. 4 (right panel).

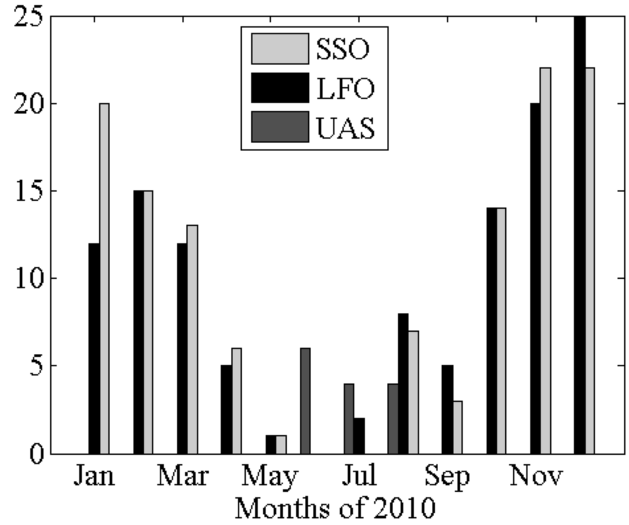

Fig. 3: The observability of SRS higher than 10 Hz.

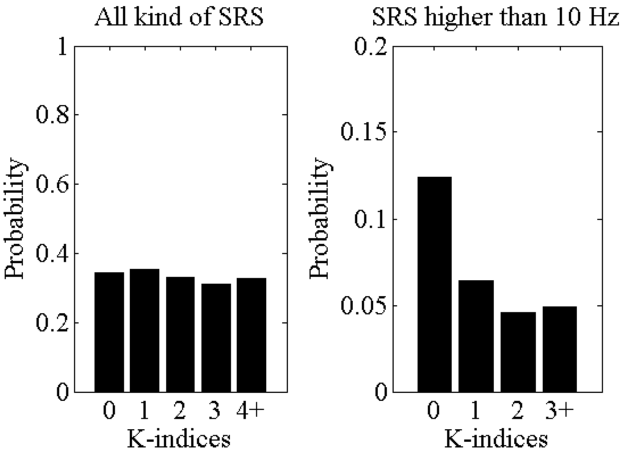

Fig. 4: Probability of IAR registration from local k-indices.

Since IAR is determined by the ionosphere conditions it is advisable to found the relationship between the resonator parameters and ionosphere characteristics. For this reason the IAR data obtained at UAS and SSO were compared with the ionosonde data. Fig. 5 displays the monthly values of the probability of IAR registration (bars) and the critical frequency of the ionospheric $F2$ layer (lines). The inverse relationship between two parameters is clearly seen. The monthly values of the critical frequency at SSO have fewer variations than at UAS. In the local summer the critical frequency at SSO is lower than at UAS and the probability of IAR registration at SSO is higher than at UAS. In the local winter f_0F2 at UAS is much lower than at SSO, but the probability of IAR registration at UAS is not higher than at SSO. So, again, it is needed to conclude that the critical frequency of $F2$ ionospheric layer is not the main factor for IAR observability.

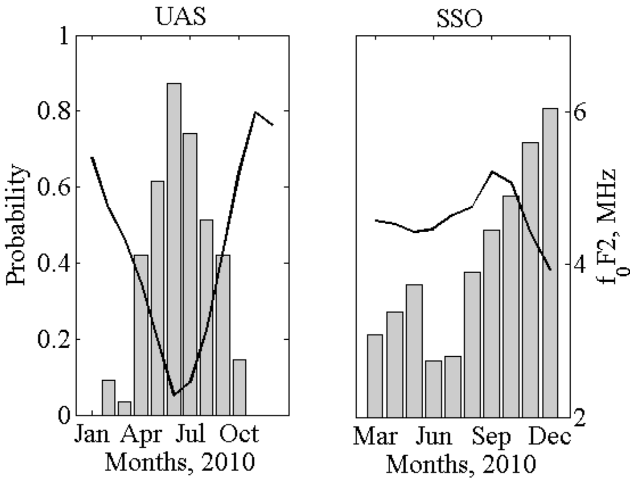

Fig. 5: Probability of IAR registration from f_0F2.

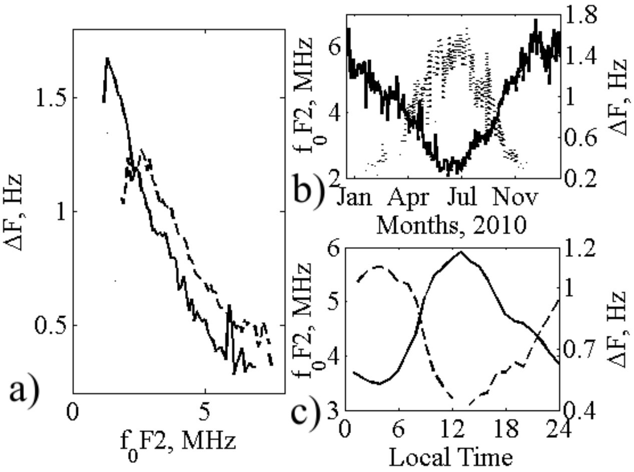

Fig. 6: The comparison of ΔF and f_0F2 behavior at different stations (a), for the whole year (b), and the diurnal variation (c) at UAS. Solid line corresponds to UAS data, dashed line — to SSO data.

Also ΔF was compared with f_0F2. Fig. 6 shows the data for the whole year (b) and the diurnal variations of these values (c). The critical frequency is shown by the solid line and for ΔF the dashed line is used. For the data from both stations the inverse relation is clearly seen. The dependencies between ΔF and the critical frequency at different stations are shown in Fig. 6(a). As it can be seen the dependence between f_0F2 and ΔF for SSO data differs from those obtained at UAS. In [10] it was shown that this is caused by differences of the magnetic field values over the stations.

RESULTS AND CONCLUSIONS

The comparative analysis of the SRS registration data was made for the purpose of searching and allocating the local features of the resonance parameters. It is shown that diurnal-seasonal behaviour of IAR parameters is qualitatively similar at each station and depends on the time of the local sunrise and sunset. There are some local differences but they do not affect the overall picture as a whole.

The annual distribution of the high frequency IAR modes confirms that IAR is primary influenced by the local characteristics of the ionosphere and not by the global ones.

Synchronous analysis of the probability of IAR registration and local k-indices confirms the inverse dependence for the SRS observability on the geomagnetic activity. It is shown that this dependence is better expressed for the high frequency IAR modes than for all events of IAR registration independently from the frequency range.

The matching of IAR parameters with the critical frequency of F2 layer of the ionosphere confirms the inverse relation between them.

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