The frequency properties of the quasiperiodic variations of midlatitude Es layer traces amplitude

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Abstract

In the present work we report about long-term measurement of echoes from Es-layer performed using Kazan ionosonde with 1 minute period of ionogram registration. Deep quasiperiodic variations resembling interference beats at certain frequency range in amplitude of echoes from Es-layer were observed. A new form of data presentation is introduced, which allows not only to display clearly the critical frequencies of ionospheric layers, but also to demonstrate the fine structure of ionospheric layers. Interference beatings appear at 4 MHz in the afternoon and at 2 MHz at night, and have extent in the frequency range of ~0.5-2.5 MHz. With increasing sounding frequency, the distance between minima increase from 40 to 700 kHz. Es-layer occurrence probabilities depending on structural features of the reflection are determined.

1. Introduction

The amplitude-frequency characteristics (AFC) of echoes from Es-layer (at the vertical sounding ionosphere) for clarification of the physics of Es formation have been studied extensively over many years. The AFC with a glance of the directional antenna diagram represents the frequency dependence of a reflection coefficient of the layers. Naturally the basic interest of researchers has been concentrated on a partial transparency region as on main feature Es-layers [1].

Except researching a partial transparency the variation of AFC (in partial transparency region) were studied [2,3]. Thus in some cases the quasiperiodic beats of the AFC caused by mechanism of mode coupling were observed. The simulation of an interference is performed on the basis of the full wave analysis. Such enhanced model of "simple" thin layer supposing of the beatings of two ordinary mode has been named thin layer model with mode coupling [1].

This model with mode coupling are explained such observed properties of interference beats at high latitudes: 1) the distances between successive interference minimums decreases with increasing sounding frequency; 2) amplitude of the oscillation decreases with increasing sounding frequency; 3) distance between the interference minimums limited of 0,3 MHz [2].

The basic works devoted to the study of AFC in a partial transparency region in 90th of the XX century were carried out. We have not found later works in this direction. In this paper the studying of the properties of quasiperiodic variations of Es-layer traces amplitude is discussed.

2. The equipment and the technique of experiment

Measuring by the ionosonde "Cyclone" near Kazan from february to november 2010 for studying of properties AFC of Es-layers have been carried out. The last updating [5] of a ionosonde "Cyclone" controller allows to sounding an ionosphere in the quickened mode this is necessary for studying of insufficiently known and quick-changing in time processes in the ionosphere. The mode with maximal rate of ionograms registration for our ionosonde has been established (1 ionogram per minute or 1440 ionograms per day). Ionograms recorded at 400 frequencies (from 1 to 7.4 MHz) and the pulse repetion rate was 20 Hz, duration of a sounding pulse was 70 μs. The antenna system was the two crossed delta-antenna (one operated on the transition, another - on reception).

3. Data of experiments and processing

Nearby 400 000 ionograms for this period is registered and processed. The Es-layers of following four types were observed: *f* (flat), *l* (low), *c* (cusp), *h* (high). The daily critical frequency variation of ionospheric layers URSI recommends to present in the f-plot. The example of one in June 29th (LT) is given on fig. 1, it is plotted by software ionosonde "Cyclon". It is seen that the curve of *f*xEs is located above curve of *f*oEs on quantity of half of electron gyrofrequency ($f_H/2$). The given location of a curve *f*xEs relative to *f*oEs is useful further for the explanatory of the new form of data presentation.

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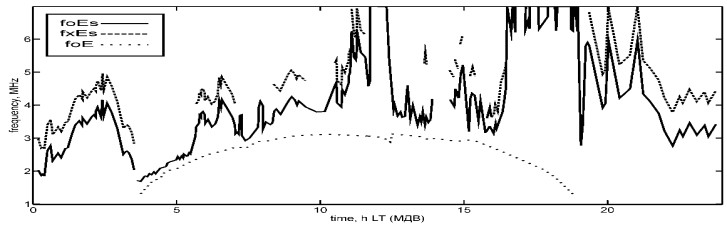

Fig. 1. Variation of *f*oEs, *f*xEs and *f*oE at June 29th 2010 with 1 minute periodically.

Changes of the frequency parameters by quasiperiodic variations of amplitudes of traces Es along an axis of the frequencies similar to the interference beats were often accompanied. The example of one of such ionogram is given in fig. 2 a. On AFC variations for studying of such thin structure of reflections of ionospheric layers need to focus. The AFC-plots in the given work were plotted at processing of ionograms automatically the program of only maximums of amplitudes of the reflected signals (one maximum at each frequency in the high interval specified in program). The interval of heights of 90-150 km was used for sorting of Es-layer AFC. It is clear that reflections from this interval not occur only from Es-layer but also from E-layer. As at such processing exact separation of E- and Es-traces on AFC is not possible they were not parted from each other and formed one AFC.

In fig. 2 below ionogram the AFC of E- and Es-traces are given by two forms of representation. The first is traditional 2D-plot of AFC of E- and Es-traces (fig. 2 c), it is convenient for studying of AFC of one trace. The second is the AFC of E- and Es-traces in the form of a 3D-plot where amplitudes of echoes on the basis of a colour scale are figured (fig. 3 b). Such representation allows the large quantity of AFC-layers to present in the 3D-plot. The interference beats in such 3D-plot will show in the form of interleaving of coloured strips (dark and light strips at the image in grey gradation) along an axis of frequencies.

Limiting (for Es-layer) and critical (for E-layer) frequencies on AFC in fig. 2 are detected by falling of amplitudes of the echoes from Es- and E-layers. Apparently from fig. 2, critical frequency of E-layer correspond to value of ~2,6 MHz and the limiting frequency Es – to value of ~6,8 MHz. Studying of ionograms with beats of AFC of Es-layer have shown that the frequency range of beats is shifted in frequency. Therefore for the description of beatings range are convenient to enter the frequency limits *f*minbEs (an initial beating frequency) and *f*maxbEs (an ending beating frequency), and a beatings range to define as Δ*f*beatEs = *f*maxbEs - *f*minbEs. For an ionogram in fig. 2 *f*minbEs≈4,4 MHz, *f*maxbEs≈5,9 MHz and Δ*f*beat≈1,5 MHz.

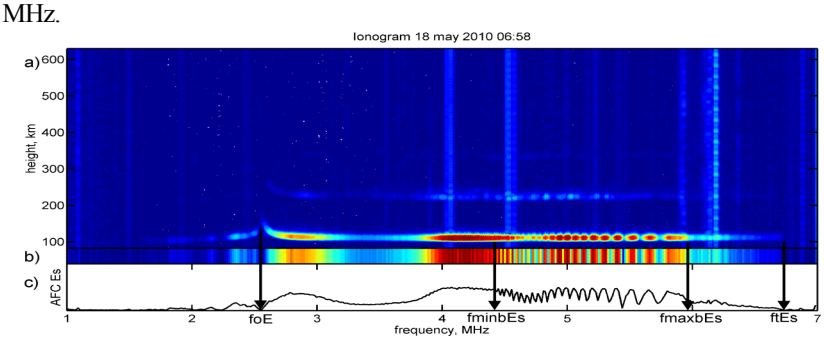

Fig. 2. a) An ionogram showing quasiperiodic variations of amplitudes of Es-trace; b) AFC of Es-trace in colored scale; c) usual AFC of Es-trace.

4. The 3D-plot of the sequence AFC of Es-layer

For studying of beats AFC the *f*-plot is not indicative, but manual extract of such properties of Es-layer is difficult from great number of ionogram. For this purpose it is necessary to search for the new form of data presentation. In fig. 3 a the explanatory formation of the new form of representation in the 3D-plot is given, it is sequence of five AFC (such as on fig. 2 b-c) of Es-layer on May 20th 2010 in time from 18:20 till 18:24 h LT shows. The sequence AFC of Es-traces on the basis of a color scale of amplitudes in fig. 3 is shown. The following values of the frequency parameters in the given time for all AFC of Es-layer are observed: ftEs≈6,5 MHz, fminbEs≈3,4 MHz, fmaxbEs≈5,5 MHz and ΔfbeatEs≈2,1 MHz.

Concerning intensive Es-layers it is considered that in course of an interval of time of ~5 seconds the properties of the layer reflections remain invariable [1]. The Es-layer with properties of scattering on small-scale irregularities with considerably great speed changes, but such layers are not considered here. Time between consecutive AFC (ionograms) is 1 min, and nevertheless the location of separate maximums (minimums) in a range of beatings is feebly shift in the frequency and it form a colored "tracks" (on fig. 3. it are shown by

arrows). Therefore we consider that the interval of stability of the E-region (in the given continuance of time) remains ~1 min, with this step on time it allows to study properties of an interference pattern.

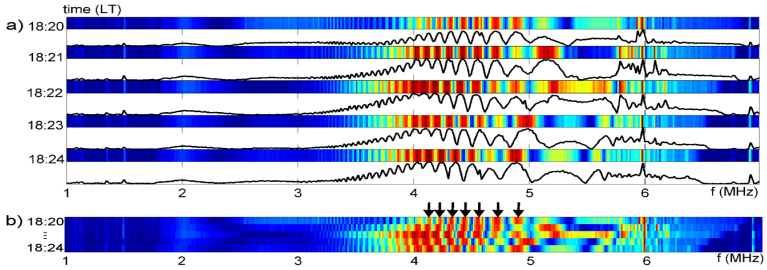

Fig. 3. The explanatory formation of the new form of representation in the 3D-plot: a) usual AFC of Es-traces; b) the sequence of AFC of Es-traces on the basis of a colour scale of amplitudes. Arrows show coloured tracks (see text for more details).

The assembling of AFC for the all day of measurings with a minute step of ionograms registrations in co-ordinates amplitude-time-frequency a 3D-plot generate (further for brevity a ATF-plot). Fig. 4 shows the a ATF-plot for June 29th, it consist only Es- and E-echoes. To understand promptly image on the ATF-plot it is convenient to compare with the f-plot (fig. 1). Because we have not separations magnetoionic modes at recording the ionograms (and the AFC) a x-traces contain. Usually a x-traces echoes amplitudes are less than o-traces echoes amplitudes, and initial frequency of a x-trace on half of gyrofrequency of electrons is above an o-trace, therefore on the ATF-plot x-traces as light "shadow" are appreciable, it on the half of gyrofrequency of electrons to a more dark o-traces are shifted (arrows on fig. 4). For the F-layer ATF-plot also as for E - and Es-layers is calculated, but here we do not give it.

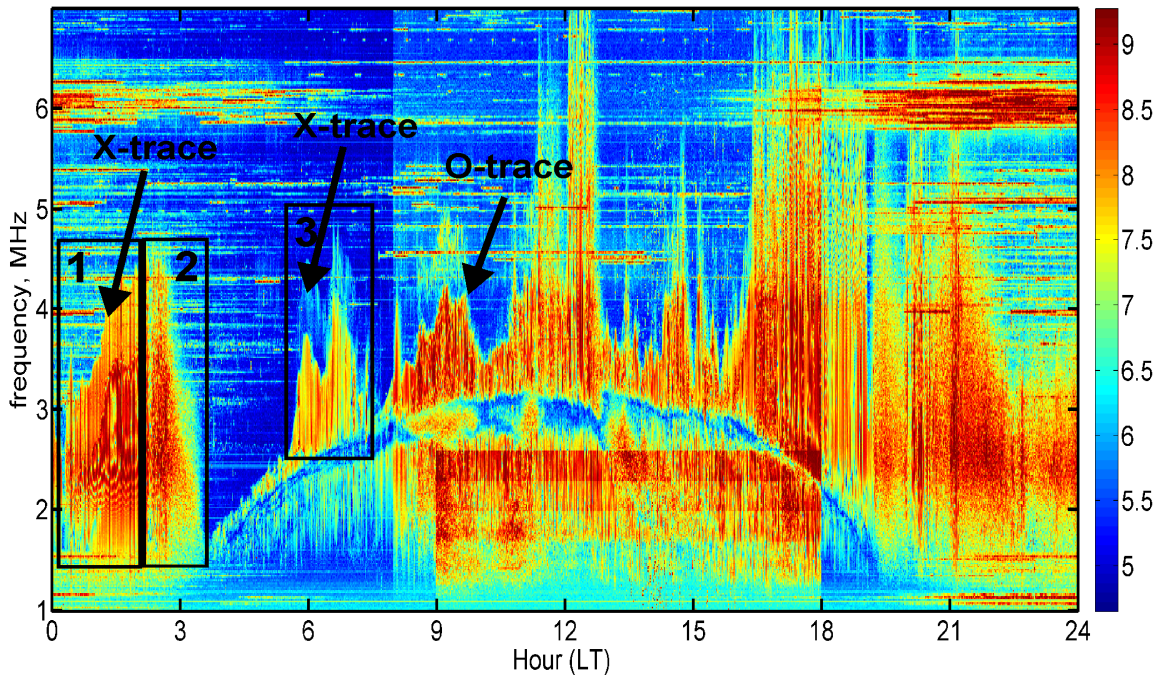

Fig. 4. ATF-plot computed for E- and Es-layer for a 24 h in June 29th. For example the three boxes a Es-traces with different reflection properties marked (1 – the Es-traces with beatings; 2 – the Es-traces with small scale irregularities; 3 – the traces of thin Es-layer;). The arrows show some traces of o- and x-modes.

ATF-plots show that Es-layers have different structural features of echoes which form characteristic AFC of Es-traces and correspond to three basic form of reflections:

1) Es-layer without beats (similar as fig. 4 box 3) at which amplitudes of AFC in the track beginning increase, amplitudes of AFC have equal values in the middle of a track and amplitudes of AFC in to the track extremity decrease. At such tracks the frequency extent is less gyrofrequencies of electrons;
2) Es-layer with quasiperiodic variations of amplitudes (similar as fig. 4 box 1) in a beatings range on the ATF-plot form a pattern in the form of parallel strips (as "veil") and the frequency extent of these tracks is more than gyrofrequency of electrons;

3) Es-layers with properties of small scale irregularities (similar as fig. 4 box 2) are characterized by chaotic variations of amplitudes of AFC.

Using ATF-plots it is not difficult to determine, as a total probability of occurrence (PEs) so a conditional probability (depending on structural features) of reflexions from Es-layer. Besides, it allow for Es-layers with quasiperiodic beatings determain the beatings range and duration of the continuous existence of reflexions from Es-layers.

5. The occurrence of reflections from Es-layer

Probabilities with structural features of reflections of an Es-layer are observed to find out how much often there are Es-layer with beatings. On fig. 5 changes as total probability of existence of reflections from Es-layer, and the probabilities considering structural features of reflections for June 2010 in percentage is shown. As in this month the greatest probability of occurrence of reflections from stratum Es with monthly average value of ~82% is observed. Monthly average value of the occurrence of Es-layers with properties of small-scale irregularities is ~59 %. The probability of occurrence of Es-layers without beatings is approximately equal ~10 %, and with beatings of ~13 %. Apparently from the histogram Es-layers with quasiperiodic beatings is often phenomenon and it is observed almost every day and in some days the value reaches ~25 %.

Recording of ionograms with a standard 15 minute interval would not allow to observe such statistics since in this interval of time properties of reflections of Es-layer can sharply change. And only recording of ionograms with a minute steps has allowed to observe not only occurrence, but also dependence of the frequency limits of beatings range on time of days.

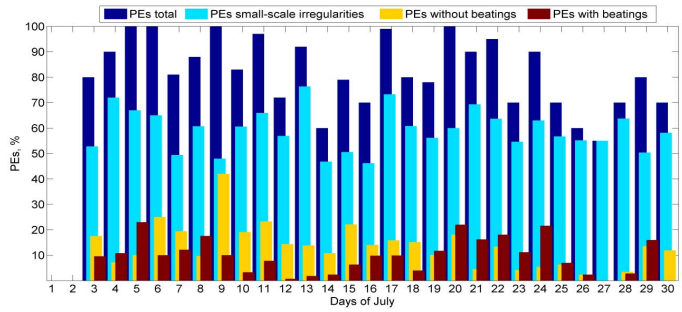

Fig. 5. Histogram of occurrence of Es-layer for June 2010 depending on structural properties of reflection.

6. Conclusions

The long-term measurement of echoes from Es-layer performed using Kazan ionosonde with 1 minute period of ionogram registration. It is registered about 400 000 ionograms. Recording of ionograms with minute periodicity has allowed to find out quasiperiodic beatings in Es-traces and to observe it properties.

The new form of data presentation (the A-card, fig. 4) has allowed to reveal: 1) duration of an stable pattern of beatings of Es-traces varies from ~10 min to ~5 h in summer months; 2) a requirement of occurrence of beatings is necessary frequency Es-trace extent depending on its type: for types *f*, *l* and *h* beats arise when observable frequency extent of Es-trace of more then half of gyrofrequency of electrons, for type *c* - the frequency extent should be more gyrofrequency of electrons (because of cusp presence on a trace); 3) the frequency of beatings range in the daylight differs from night hours and depends on presence of background concentration of E-layer.

The analysis of occurrence of Es-layer depending on reflection structure is carried out. In June 2010 at ~82% of a monthly average total probability of occurrence of reflections from Es-layer, the greatest probability is observed at Es-layer with properties of small-scale irregularities with quantity of 59%. The probability of occurrence of Es-layer without beatings has made 13%, and with beatings - 10%.

7. References

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