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MONITORING OF IONOSPHERE COMMUNICATION CHANNELS

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The method of monitoring of ionosphere channels of short-wave communication Dushanbe-Bălți and Khabarovsk-Bălți with the use of small-power LFM-ionosondes of oblique sounding is presented.

At present, there is a growth of requirements to the characteristics of information transmission system via ionosphere communication channels and to signal processing devices, to their reliability and productivity [1, 2]. It is impossible to ensure corresponding radio-channel parameters and normal conditions of information transmission under quickly changing conditions of ionosphere without regular monitoring of radio channels in real-time scale and without using operative and long-time forecast of the conditions of radio wave propagation. Under operative forecast is meant the prediction of short-wave signals characteristics with the timelines from some minutes to one hour.

With regular monitoring of radio channels, the received information gives us a possibility to solve the following multiparameter tasks: to define the number of propagation modes; to define the optimal operating frequencies of single-mode channels; do define the possible speed of information transmission; to take into account the variation of each mode’s amplitudes and phases, etc.

Modern methods of long-term forecast of the conditions of ionosphere radio-wave propagation error is ~ 20%. And in transition hours, when the parameters of ionosphere change most sharply, the error increases up to 50% and even more. The reason of relatively big errors in long-term forecast is the changeableness of the flow of the Sun radiation from day to day and the complexity of the ionosphere reaction to geomagnetic perturbations [3]. In this connection, along with perfection of the methods of long-term forecast, considerable attention is paid to the methods of direct monitoring of the parameters of an ionospheric radio channel using different systems in oblique and vertical-oblique sounding and to operative forecast of the conditions of radio-wave propagation. Introduction of the first systems of direct monitoring which worked in impulse regime, Pathfinder [4], CHEC [5], CURTS [6, 7], increased considerably communication reliability. In particular, the operation of the CURTS system shows that communication reliability has grown up to 90%.

To monitor the ionospheric channels of short-wave communications, it is necessary to create a net of experimental-technological radio routes. Such a net can be created on the basis of operating radio routes, the equipment of which needs to be complemented with equipment for the diagnostics of radio communication channels and with corresponding software. The equipment for the diagnostics of a communication channel should measure the characteristics of the radio channel quality when transmitting test communications, record information about the changes of the ionospheric parameters and suggest an optimal variant of uninterrupted work of the radio channel.

The use of small-power LFM-ionosondes of oblique sounding of the ionosphere is a considerable progress in the development of the methods of the ionosphere channels of short-wave communication diagnostics. In this case, the problem of the ionosphere monitoring is solved with acceptable mass and dimension characteristics of the equipment, less energy consumption and better electro-magnetic compatibility. The availability of LFM-ionosondes of oblique sounding on diagnostic radio routes allows to synthesize ionograms for operating radio routes, to estimate the expected quality of radio communication, to manage effectively frequency resources. It reduces twice the appearance of a code error [8]. And the most important thing is that it becomes possible to use antennas working in the system of the operating radio routes to diagnose the channel. Diagnostic radio routes of different length (from 5 to 10000 km and more) and orientation can be used to control the parameters of ionosphere radio channels.

At present, LFM-ionosondes are widely used in adaptive systems of short-wave communication for dynamic control of operating frequencies. Because of its adaptivity, the system automatically supports the quality of short-wave radio communication during a communication session by changing the main parameters of transmission in accordance with the change of the current ionosphere condition.

Such an approach to constructing adaptive systems of short-wave communication with the use of LFM-inosondes allows to obtain data which is used for operative forecasting and extrapolation of information about ionospheric radio wave propagation to other regions.

The main task of the equipment, which does the monitoring of the ionosphere radio channel, consists in the operative choice and forecasting of optimal operative frequencies of communication by the results of the analysis of ionosphere radio wave propagation conditions and of noise situation (conditions, environment) for the given radio channel. The equipment system of radio channel monitoring should consist of an LFM-ionosonde, an analyzer of short-wave radio channel loading, and a packet of applied software on the choice of the main operating frequencies for the communication system. Different methods can be used for radio channel monitoring.

Here is an example of one method of short wave radio channel monitoring, which includes the following stages:

1. transmission of an informational communication by the transmitter of a communication system on the frequency chosen according to the data of long-term forecasting (in this case, the optimal operating frequency can be chosen close to the maximum of the used frequency (from the available resource) by the criterion of minimum noise level in radio channel with a set band);
2. oblique FLM-sounding of the ionosphere in the band ~ 3- 40 MHz;
3. analysis of the loading of the communication channel with noise and setting of optimal operating communication frequency from available resource (a strategy of the choice of the optimal operating frequency consists in defining the frequency range with maximum signal-to-noise ratio on condition that, in the region of multimode propagation, the amplitude of one mode exceeds the amplitude of another mode by not less than 10 dB);
4. transmission of information via the operating radio channel on the optimal operating frequency chosen in the process of operative forecast.

In all the cases it is necessary to define the percentage of error in the information communication.

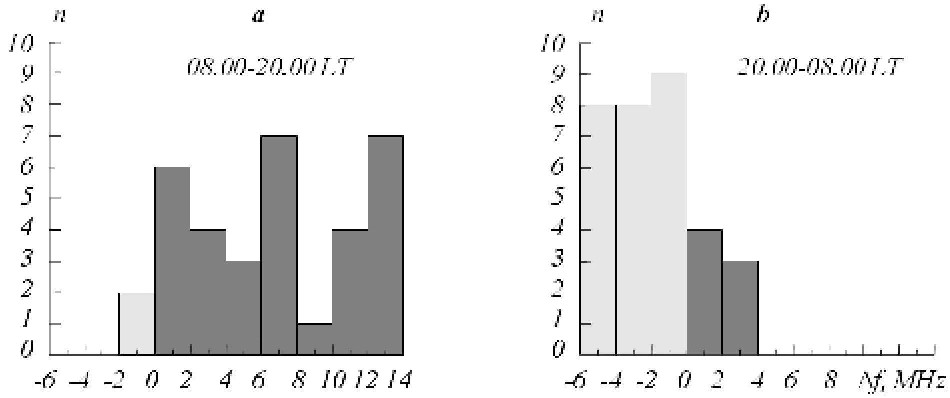

Fig. 1. Histograms of distribution of frequency defference of the related signals, $\Delta f = f_1 - f_2$, selected by knowledge of the long-term (f_1) prediction and short-term (f_2) prediction for diurnal (a) and nocturnal (b) hours [3].

To compare the effectiveness of a connected radio line work on long-term forecast and on operative forecast we shall give an experiment data represented in the work [9].

Tests of the monitoring system based on LFM-sound were done in October 1990 on the middle-latitude route Alma-Ata –Moscow with the length of 3000 km. The same antennas were used for the transmission/reception of the LFM-signal and for informational communication, which excluded the necessity of recalculating the energetics of connected and sounding radio lines.

The power of informational communication received two values: 5 W and 100 W. In this case, the optimal operating frequency was chosen close to the maximum of the used frequency (from the available resource) by the criterion of minimum noise level in the channel with a band of 3 kHz. The results of the tests are given in Fig. 1a (daylight, evening hours – 08.00-20.00 LT Moscow) and in Fig. 1b (night, morning hours –20.00-08.00 LT Moscow) in the form of distribution histograms of the difference of communication operation frequencies $\Delta f = f_1 - f_2$, where f_1 was the frequency chosen by long-term forecast, and f_2 - frequency chosen by operative forecast.

As it is seen from Fig. 1, in daylight hours, the difference of frequency $\Delta f > 0$, i.e. the frequency chosen by long-term forecast is higher than the one chosen by operative forecast. In this case, by the long term forecast, the work of connected short-wave radio line was carried out on the frequencies close to maximum observed frequencies and by the operative forecast, it was done on the frequencies with maximum signal-noise ratio, which in most cases fall on double-shock mode of propagation. In night and morning hours, when the maximum observed frequency was considerably decreasing (by 10-15 MHz) and the range of the short wave signal passing was narrowing, the distribution of frequencies difference was biased to negative values, i.e. the operating frequency chosen by the operative forecast was higher than the one chosen by one-term forecast. Such a choice of optimal operating frequencies is conditioned by the necessity of working at the given time on maximum high frequency where the level of station noise is lower.

Data concerning the effectiveness of informational communications reception transmitted by long-term forecast (black color) and by operative forecast (gray color) are given in fig. 2.

According to received data, correct reception of informational communications with the use of operative forecast occurred in 84% of the cases in daylight hours and in 90% of the cases in night hours. At the same time, the work of radio line based on long-term forecast data ensured correct reception of communications only in 54% of cases in daylight hours and in 46% of cases in night hours. Besides, in night and morning hours, when working by long-term forecast, in about 25% of cases were registered considerable mistakes ~19-21%, connected with the fact that in transitional time of the twenty-four-hour period, a reconstruction of the ionosphere takes place, which is badly described by the algorithm of long-term forecast [3].

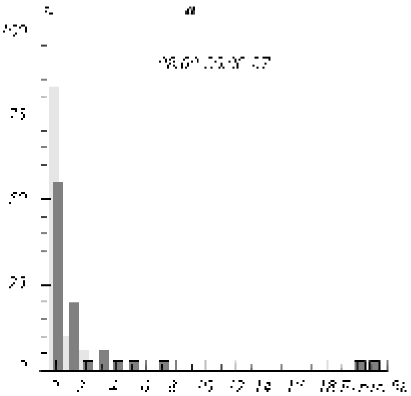

Fig. 2. Histograms of distribution of the percentage of mistakes in the text information transmitted according to the long-term prediction (dark color) and according to short-term prediction (light color) during diurnal (a) and nocturnal (b) hours [3].

With an increase of the power of connection signal, the probability of correct reception when working by long-term forecast was increasing in proportion to the power logarithm. The dependence of communication reliability on power allowed to estimate the necessary power of a connection signal when the system worked by long-term forecast and on the basis of LFM-monitoring on condition of equal reliability. It turned out that the work of a connection transmitter with the power of ~600w, when choosing optimal operating frequency of communication by long-term forecast, provided the same communication reliability as when choosing optimal operating frequency with the help of LFM-monitoring in the case of using a connection signal with the power of 5 W.

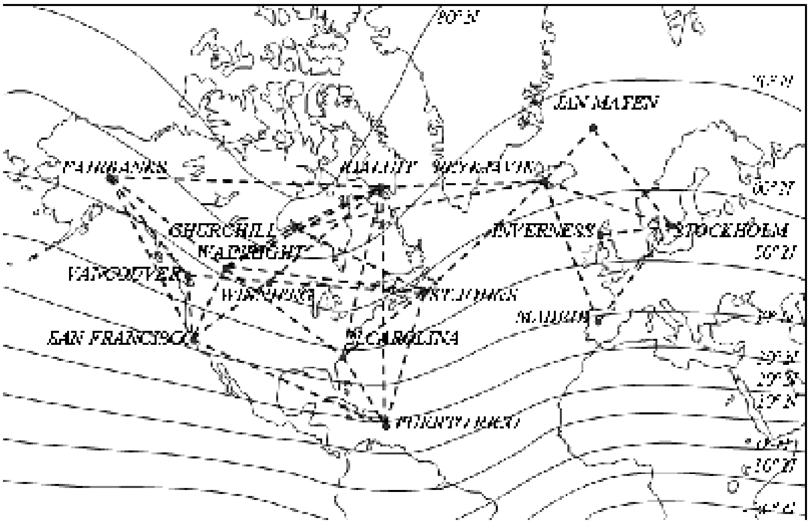

Fig. 3. Geometry of radio paths for measurement of stability of short-wave radio communication using LFM ionosondedes for diagnostics of the United States-Europe ionospheric channel.

In the USA and NATO countries was also carried out a great number of experiments on the use of LFM-sound in adaptive systems of short-wave radio communication on radio routes crossing high-latitudinal regions, northern lights zone, as well as on middle-latitudinal radio lines with transmitters power of 10…100 W [10 – 13]. Figure 3 shows the geometry of the routes in experiments conducted in the USA and Western Europe. In the course of long experiments, data for more than forty radio lines where received and analyzed. The investigations showed that communication reliability approaching 100% can be achieved on condition that several stations situated about great territory are accessible and when there is a set of about ten operating frequency. It is important to note that with the change of magnetic activity, the routing of communication organization can change.

Besides, the appearance of sporadic layer E_S during strong disturbances in the F-region of high-latitudinal ionosphere can be used to organize a communication channel via layer E_S. To get a full-scale estimation and good quality forecast, it may be necessary to put together the information received from a great number of LFM-sounds as well as geophysical information.

In the cases when a communication line and a sounding route don’t coincide, it is expedient to use the method of direct diagnostics of the communication channel characteristics, suggested in the works [14, 15]. The suggested method is based on the use of adiabatic relation of the diagnostic signal characteristics and of the investigated radio channel with changes of ionosphere parameters. It is established that with changes of ionosphere parameters within the limits of 20%, the following changes little:

- the value h which is equal to the ratio of the group path P_m, corresponding to the delay of the signal received on the maximum used frequency f_m, to the distance to the border of the lighted zone D_m;
- the value c, equal to the ratio of maximum used frequencies of some modes for different radio routes;
- the ratio of the group path of the oblique sounding signal to the length of radio route on the relative frequency network (grid, lattice) $b = f / f_m$.

When using the data of oblique sounding, the found adiabatic ratios allow to extrapolate the data on the route which doesn’t coincide with the standard one by length or by azimuth. In this case, weak dependency of value c is used, which equals the ratio of maximum used frequency of any modes for two routes. Value c is calculated by the results of modeling of the ionograms of oblique sounding for the given routes. After this, for every instant, maximum usable frequency of the diagnosed route is defined as the product of the value c and the value of maximum usable frequency of standard route.

The working capacity of the given algorithm was checked when comparing the results of the diagnostics of maximum usable frequencies on the routes Magadan – Irkutsk, Khabarovsk - Irkutsk [3], Khabarovsk – Bălți and Dushanbe –

Bălți, which allowed to considerably lower the error in calculation of maximum usable frequencies as compared with long-term forecast.

The effectiveness of short-wave range resources management depends to a large extent on the exactness and operativeness of defining optimal operating frequencies of communication. Therefore the development of new methods of operative forecast of optimal operating frequencies and of other characteristics of short-wave signals with the use of different kinds of ground-based sounding of the ionosphere and of automatization systems of data processing remains relevant to the present time [1, 16].

When constructing graphs of diurnal variation of maximum usable frequencies by the experimental data of LFM-sounding of the ionosphere, short-periodic variations are observed, which are conditioned by both small-scale heterogeneity and different wave processes. The sign of such variations can change from session to session even during 10-15 minutes. For optimal solution of the problems of operative forecast it is advisable to point out the most significant variations of maximum usable frequencies and to smooth the variations connected with both small-scale heterogeneous structure of the ionosphere and experimental errors when defining maximum used frequencies but with preservation of most essential variations with the period constituting 1 hour and more. To smooth short-period variations of experimental data, different modes can be used, for example linear smoothing at three of five points and smoothing with polynom in the third degree at seven points [3].

The use of linear smoothing of experimental data at three points is the most optimal for the solving of the problems of operative forecast. This method allows to reduce the number of errors, conditioned by inaccurate determination of maximum usable frequency, especially at night, because of *F*-scattering, and to take into account the general tendency of the change of maximum usable frequency in the course of time with preservation of the most significant variations, though, on the other hand, a forecast error is introduced a priori because small-scale heterogeneity is not taken into account.

Figure 4 shows examples of diurnal variation of experimental data of maximum usable frequencies and forecasted maximum usable frequencies on the routes Ioshkar-Ola–Bălți, Dushanbe-Bălți and Khabarovsk-Bălți received on November 21 1991 [17]. To carry out an operative forecast, maximum usable frequencies of regular model of radio-signal propagation, received as a result of oblique sounding in different seasons of 1991, were used. The operative forecast was calculated by the formula of linear extrapolation using model calculation with a ten-minute timely interval.

It is seen that, on the whole, long-term forecast describes qualitatively correctly the diurnal variation of maximum usable frequencies. But in certain hours, the experimental values differed from the ones calculated by long-term forecast by more than 35%. An analysis of diurnal variation of relative errors showed that for magneto-quiet days, there are time intervals during sunrise and sunset hours when maximum forecast error can be observed (see Fig. 4).

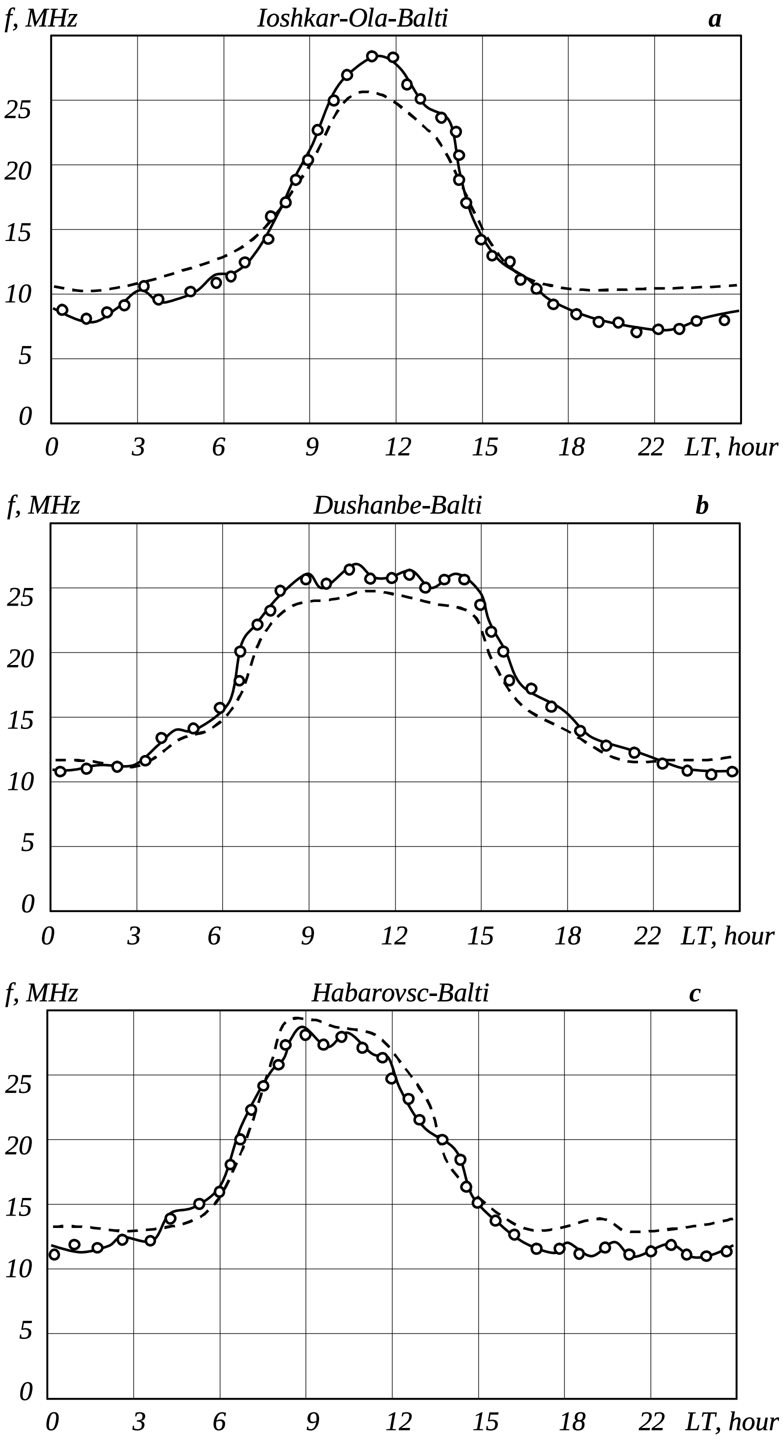

Fig. 4. Diurnal variations of values of MOF for long-term and operative forecast obtained on November 21, 1991; solid line is the operative forecast, dashed curve is the long-term forecast, and circles are the experimental data.

Such error movement during evening time is probably connected with generation of wave disturbances by the passing of the terminator through the route midpoint. This phenomenon leads to noticeable gradients of ionization and to variations of observed maximum usable frequencies, which are not taken into consideration in a long-term forecast model.

Methods of parameter extrapolation of the ionosphere short-wave channel by means of adapting the ionosphere model by the sounding results on the control route were also approved on the routes of LFM-sounding. The application of such method is possible in the case of significant space-time correlation of the examined parameters. The investigations were conducted on two pairs of middle-latitude routes with different orientation of basic receiving stations spacing with regard to radiation station: Dushanbe - Bâlți, Dushanbe – Kiev and Khabarovsk - Bâlți, Khabarovsk - Kiev.

Space correlation of maximum observed frequencies (MOF) was examined. The investigations were conducted in 1988-1991.

According to the experimental data, space correlation factor of maximum usable frequencies of the model $2F_2$, $3F_2$ and $4F_2$ for the radio lines oriented along basic receiving stations spacing was high and constituted ~0.92-0.96, with the spacing of receiving stations across the route, the space correlation factor constituted ~ 0.8. High values of space correlation allowed to apply for the extrapolation of maximum usable frequencies the method of ionosphere model adaptation by the results of oblique sounding on control routes. In the experiments, the control routes Dushanbe – Bălți and Khabarovsk – Bălți were provided with diagnostic means, and the routes Dushanbe – Kiev and Khabarovsk – Kiev where considered operating. For the routes Dushanbe – Kiev and Khabarovsk – Kiev, the values of maximum usable frequencies where defined with the help of extrapolation, using the adaptation of an ionosphere model to the data oblique sounding received on the control route.

The adaptation of the model consisted in the selection of an entrance of the model-sun-spots number *W*. Taking into account this parameter allowed to adjust the theoretical value of the maximum usable frequency on the control route to the experimental value on the same route with some error. Adapted in such a way model was used in calculations to define maximum used frequencies on the work route. The selection of a new value was done only if the deflection of maximum observed frequencies exceeded the prior set error. References model of the ionosphere SMI-88 was used as an empirical model.

Figure 5a adduces data of the diurnal variation of maximum observed frequencies (experiment) for the control route Dushanbe – Bâlți (circles) and Dushanbe – Kiev (points). Full lines stand for forecasted maximum usable frequencies (1), and the results of extrapolation of maximum observed frequencies from the control to the work line (2). Analogical data are given in Fig. 5b with the same symbols for the routes Khabarovsk – Bălți (circles) and work route Khabarovsk – Kiev (points). Data analysis showed that for the radio lines ~2000…3000km long and quiet ionosphere conditions, the model correlation can be done on average in 6-7 hours, and for the routes ~6000…7000 km long in 2-3 hours. In this case, extrapolation errors of the values of maximum observed frequencies constitute ~4-5%, which is considerably less than the errors of long-term forecast.

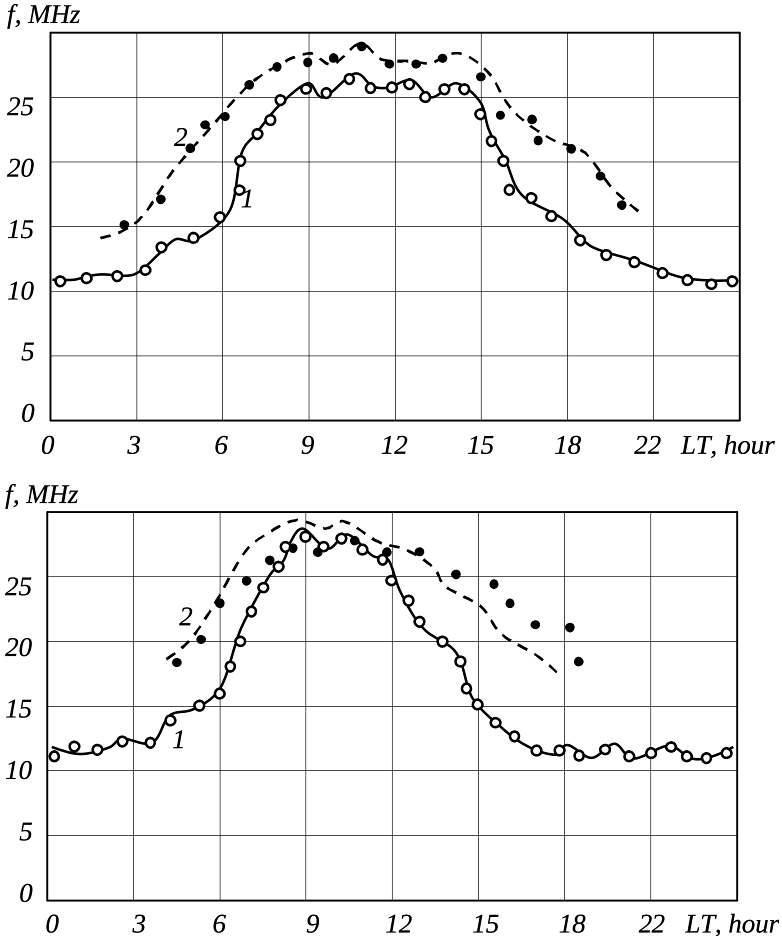

Fig. 5. (a) Diurnal variations of maximum observed frequencies: ○ – control trace Dushanbe-Bălți (experiment), • - work trace Dushanbe-Kiev (experiment); by 1 is denoted the corrected prediction of maximum observed frequencies using data of the oblique sounding for the trace Dushanbe-Bălți, by 2 is denoted an extrapolation of maximum observed frequencies from the control route to the work trace Dushanbe-Kiev.
(b) Diurnal variations of maximum observed frequencies: ○ – control trace Khabarovsk-Bălți (experiment), • - work trace Khabarovsk -Kiev (experiment); by 1 is denoted the corrected prediction of maximum observed frequencies using data of the oblique sounding for the trace Khabarovsk-Bălți, by 2 is denoted an extrapolation of maximum observed frequencies from the control route to the work trace Khabarovsk-Kiev.

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MONITORIZAREA CANALELOR IONOSFERICE DE COMUNICAȚIE

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În lucrare este prezentată metoda de monitorizare a canalelor ionosferice Dushanbe-Bălți and Khabarovsk-Bălți de comunicare prin unde scurte cu utilizarea ionosondei cu modulaie liniară în frecvență în regim de sondare oblică.

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