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Structure and Motions of Large Inhomogeneities in the Ionospheric Layer F_2

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The last decade in the field of ionospheric research has been characterized, in particular, by the development of theory and experiment connected with the existence of inhomogeneous formations superimposed on the regular ionization of the ionosphere. The presence of these inhomogeneities limits the accuracy and stability of operation of radio equipment using radio waves reflected from the ionosphere. This circumstance, as well as interest in studying the dynamics of ionospheric plasma, has led to the development of such investigations. It has been established that the spectrum of horizontal sizes of inhomogeneities extends from hundreds of meters to hundreds of kilometers. Small-scale inhomogeneities have been studied more fully. Information on large inhomogeneities is rather qualitative in character. The reason for this situation, in our view, lies in particular in the imperfection of methods for studying large formations. Among the known methods of recording large inhomogeneities, the method of measuring group delay ([1]) is insufficiently sensitive (it does not detect variations of the group path of less than 2-3 km), while the high, in essence, sensitivity of the method for measuring variations in angles of arrival ([2]) is in practice reduced because of rapid variations in the angles of arrival caused by scattering from small inhomogeneities.

We have implemented an integral phase method for recording large inhomogeneities and their motions. This method is free from the shortcomings noted above and consists in recording variations of the phase path of the reflected signal. For small inhomogeneities these variations are of the order of 2π, and for large ones, 40–200π. Thus, this method has high accuracy, reaching tens of meters, and high resolving power, which makes it possible to apply a statistical approach in the investigation of large inhomogeneities.

In the present communication new data are given on the form, dimensions, and motions of large-scale inhomogeneities. The apparatus for recording phase variations consists of receiving-transmitting ionospheric stations with phasemeters and photographic indicators ([3]). The phase of the signal reflected from the ionosphere is compared with the phase of a local coherent heterodyne. Phase

Fig. 1

Figure 1: Fig. 1

variations are recorded on motion-picture film in the form of a sequence of sawteeth of different slope. One sawtooth corresponds to a phase change of 2π, and a positive or negative slope of the sawteeth corresponds to an increase or decrease of phase (see Fig. 1).

Three such installations were used, placed at three points on the earth' s surface. The points form a measuring triangle with sides of 30–40 km. At each of the points, variations of the phase of the reflected signal are recorded. Time synchronization of the observations (transmission of time marks, coded control signals) was carried out

using a timing circuit and a radio-relay multichannel communication system. Fig. 1 shows a sample recording of phase measurements at three points. Minute and hour marks are visible.

The recording of phase variations is a regular, smooth course $\varphi_p(t)$, on which changes of a random character $\varphi(t)$, connected with the existence of irregularities in the ionosphere and their motions, are superposed. The presence of $\varphi_p(t)$ is due to the change, from day to night, in the height distribution of ionization of the ionospheric layers. Appropriate processing makes it possible

Fig. 1

to eliminate φ_p and isolate φ. Analysis of the behavior of $\varphi(t)$ provides information on the sizes, shape, and motions of the irregularities. A 4-hour interval of phase recordings proved sufficient from the standpoint of the size of the statistical sample. After removal of φ_p, these records were subjected to correlation analysis. Three normalized cross-correlation functions $\rho_{ij}(\tau)$ $(i, j = 1, 2, 3)$ and autocorrelation functions $\rho(\tau)$ were calculated.

Having these functions, it proves possible to obtain the following parameters (4): the velocity V_d of the horizontal drift in the ionosphere and its direction, determined by the angle β; the mean shape of the ionospheric irregularities, described by a "characteristic ellipse," which is determined by specifying the axial ratio e and the direction of the major axis (angle α); the correlation radius τ_{05} $(\rho(\tau_{05}) = 0.5)$ and the spatial dimensions of the irregularities Δ; the fading time τ_c, or the fading parameter of the irregularities δ. As a result of analyzing the phase variations and the rate of phase change, the angles of arrival of the reflected radio waves are determined. Removal of φ_p and calculation of the correlation functions were carried out on an electronic computer of the "Strela" type.

All the results presented below refer to the F_2 layer. They were obtained for the period from May 1956 to October 1957. Continuous observations lasting from 24 to 76 hours were made once a week. Fifty-three 4-hour intervals were subjected to correlation analysis. Analysis of the data in the form of graphs, distribution curves, and histograms made it possible to obtain a number of important new findings. The basic data are given in summary Table 1.

Shape of the irregularities. It turned out that large irregularities possess a sharply expressed anisotropy of shape—a difference in dimensions depending on direction. The mean shape of the irregularities in the horizontal direction has the form of an ellipse with an axial ratio e lying in the interval from 1 to 7. The most frequently encountered values are $e = 1.5$-2.0. The mean value $\bar{e}$ changes from morning to evening within the limits 2.0-2.6. We note that the division by time of day was made as follows: 00-06 hr—night; 06-12 hr—morning; 12-18 hr—day; 18-24 hr—evening. The time is Moscow, decree time. Averaging was performed over sessions assigned respectively to night, morning, day, or evening. A predominant northern direction of the major axis was found.

From radio-astronomical studies of irregularities with dimensions of 1-10 km, a strong anisotropy ($e > 5$) and a predominant direction along the magnetic meridian have also been found ([5]).

Spatial dimensions of the irregularities. Since the average shape of the irregularities in the horizontal section is elliptical, their horizontal dimensions depend on direction. The mean dimension in the direction of the minor semi-axis is $\bar{\Delta}_{\text{min}} \sim 110$ km (day) and ~ 200 km (night), and for the major semi-axis $\bar{\Delta}_{\text{max}} \sim 220$ km (day) and ~ 500 km (night). The width

Table 1

Parameter*	night	morning	day	evening
$\bar{e}$	2.45	2.0	2.0	2.6
α^{**}	$-9.8°$	$+3.6°$	$+11.0°$	$+12.6°$
$\bar{V}_{\text{d}}$, km/min	10.8	11.9	15.1	10.1
$\bar{V}_{\perp}$, km/min	27.2	15.2	13.5	15.4
β^{***}	$+20°$	$+160°$	$+162°$	$-22°$
$\beta_{\perp}^{***}$	$+16°$	$+110°$	$+158°$	$-70°$
$\bar{\Delta}_{\text{min}}$, km	200	105	110	132
$\bar{\delta}$	0.58	0.3	0.3	0.46
$\bar{\tau}_c$, min.	19	20	21	19
$\bar{\sigma}$ along the major semi-axis	1.0°	1.1°	1.0°	1.2°
$\bar{\sigma}$ along the minor semi-axis	2.5°	2.1°	1.8°	2.5°

* A bar denotes averaging over sessions assigned to the corresponding period of

the day.
** Measured from the northern direction of the geographic meridian.
*** Most frequently occurring values. Measured from the northern direction of the geographic meridian.

of the size spectrum increases toward evening and night in comparison with the morning and daytime hours by a factor of 1.7-2.5. Thus, for example, along the minor semi-axis the limits of the spectrum were: morning 40–240 km, evening 40–500 km, day 40–160 km, night 80–400 km. The values of $\bar{\Delta}$ given correspond to the time period equal to $\bar{t}_{05}$.

Drift velocity V_d. The measured values of V_d lie in the interval 0–40 km/min, while the most frequently occurring values are 8–10 km/min. An increase of $\bar{V}_\text{d}$ from night to day was observed. This dependence is weakly expressed. At the same time, a clearly expressed diurnal dependence of the direction of the vector V_d was found: at night—to the north, in the daytime—to the south, in the morning—to the south with a deviation to the east, and in the evening—to the north with a deviation to the west (see Table 1, angle β). For comparison with the results of other authors, histograms of the distributions of $V_\perp$ were constructed ($V_\perp$ is the value of the apparent velocity constructed in the direction perpendicular to the front of the apparent velocities). In this way an approximation was made to studies in which anisotropy was not taken into account. The form of the histograms and the most frequently occurring $V_\perp = 10$ km/min agree with other data ([1]). During a day $V_\perp$ makes a complete revolution, preserving the direction toward the subsolar point.

Angles of arrival of reflected waves. The presence of irregularities in the ionosphere leads to the fact that the direction of the normal to the front of the reflected wave deviates from the vertical. Measurements showed that the root-mean-square values of this angle were equal: along the minor semi-axis

$\bar{\sigma} = 2.5^\circ$ (night)—1.8° (day); for the major axis $\bar{\sigma} = 1.0^\circ$ (night, day). The value of $\bar{\sigma}$ for the minor axis increases toward night. For the major axis there is no such dependence. In [2], in the study of variations of the angles of arrival, σ was also found to be of the order of 1—2°.

Spreading, lifetime of the irregularities. These were estimated by the parameter δ, which can take values from 1 to 0. A value of 0 corresponds to the absence of spreading, while in the case where there is only spreading and no drift, $\delta = 1$. In our investigations $\bar{\delta}$ varied from 0.3 (day) to 0.58 (night). The spreading time, or lifetime of the irregularities, is $\bar{\tau}_c \sim 20$ min. $\bar{\tau}_c$ tends to increase from night to day. An approximate estimate of the lifetime of large irregularities for F_2, obtained by taking into account the diffusion process [6], agrees with our data. Speaking of the predominant motions in the F_2 layer, one may conclude that during the day drift, wind, predominates, while at night—the spreading of irregularities.

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Note: Figure translations are in progress. See original paper for figures.