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V.D. Ozerov

PROPERTIES OF HIGH-LATITUDE IONOSPHERE IRREGULARITIES BASED ON "COSMOS-378" SATELLITE ION TRAP DATA

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The collector current of the spherical ion trap with floating potential of the outer grid often varies with low frequency. These oscillations have as a rule quasicycloidal form and are very often observed in the ionospheric regions characterised by higher gradients of the geomagnetic field and the ionosphere plasma concentration. In this connection the considerations are given in favour of the fact that the cause of the observed oscillations of trap collector current, i.e. flux density of registered ions, is, in particular, drift oscillations of ionospheric plasma. Based on about 400 real time radiotelemetry recordings the properties of probability, or relative frequency, of detection of the given oscillations depending on some geophysical factors and geographic coordinates were investigated. The isoline pattern of this probability in coordinates "latitude-longitude" resembles the known chart pattern of the geomagnetic field intensity module but in this case the mentioned probability increases towards the polar regions and at the place for location of the maximum gradient of the geomagnetic field intensity module in the Eastern-Siberian geomagnetic anomaly region

Three-electrode spherical ion trap with floating potential of the outer grid intended for the concentration measurement of the ionospheric plasma positive ions along the satellite orbit was installed on board the "Cosmos-378" launched on 17.11.70 (orbit inclination is 74^{0}, perigee 240 km, apogee 1740 km). Spherical electrodes of such a trap form the concentric system. The external grid with radius of 3 cm protects the investigated plasma from disturbances caused by the trap internal fields. The internal grid prevents from the origin of photoelectron current from the internal electrode-collector itself and also together with the external grid protects the collector from external interference fields. Free electric charges carried by positive plasma ions are collected at the negatively charged collector and form in its circuit the current depending mainly on the ion flux density equal to the product of its velocity relative to the trap by ion concentration and also on the trap external grid potential, temperature and mass of ions and grid transparency. Resultant transparency of both grids was 0.53. The frequency pass-band width of amplifier was 200 Hz. The elementary estimations and the experimental results show that an ion trap outer grid isolated from any current-carrying electric circuits takes negative potential in plasma surrounding a satellite. As it is known the dependence of attracted particle current on potential considerably decreases (see, e.g., [1]). As a rule the ion flux average velocity relative to the trap is near the value of the satellite velocity and is mainly stipulated by the satellite movement relative to the medium. It considerably decreases the role of the temperature and ion mass influences on the registered value of ion flux density. Therefore the main part of the collector current changes found in the experiment can be stipulated basically by variations of both the concentration and the plasma flux velocity relative to the trap as well.

This point is illustrated by periodic deep decrease of the collector current in the time of the trap hit into the ion shadow cone in the wake of the satellite caused by the satellite rotation. This deep collector current decrease is stipulated by the sharp decrease of ion concentration in this space because of the fact that the thermal velocity of ionospheric ions is on one order less than the satellite velocity. Therefore the behaviour of the collector current of the trap being in free ion flow can serve as the characteristic of the plasma state: quiet and homogeneous or disturbed and non-homogeneous.

By the examination of ~400 real time telemetry photographic recordings of five-ten minute sessions of the collector current measurements made during the period since November, 1970 to July, 1971 the numerous cases of collector current oscillations not associated with the satellite rotation were found. Below the main peculiarities of such recordings are given:

1. The amplitude of current oscillations sometimes reaches several tens of per cents to the average level. The amplitude of ion flux density variations often has the value $(5-10)\cdot 10^{9}$ cm^{-2} sec^{-1}.

2. Frequencies of these oscillations have the value from

some fractions of a hertz to 20-30 Hz. It is apparently real that these frequencies occupy the greater interval (at least up to 150-200 Hz in accordance with the amplifier frequency band width). It is noticeable regarding the chaoticaely dispersed points at the photographic telemetry recording which correspond to the current measurements made in random phases of oscillations.

3. The oscillations with the same periodic structure are usually maintained only during 2-4 sec. It is possibly associated with the limited dimension of the plasma region oscillating as the whole in the satellite movement direction, this dimension being therefore 15-30 km.

4. In the most cases the oscillations are quasiperiodic, their form, frequency and amplitude change in the wide range during some periods. It evidences for a large number of degrees of freedom of the oscillation source.

5. The most typical feature of the majority of quasiperiodic oscillations is anharmonicity. Outwardly the curve of current oscillations looks like cycloid (see Fig. 1a). Its difference from the usual sinusoid is the alternation of sharply outlined maxima and smooth minima or vice versa. Sometimes quasicycloidal form of oscillations loses its symmetry.

6. The presence of oscillations and their amplitude are not single-valued determined by the trap being in the free plasma flow or its leaking into the satellite wake.

7. The oscillation amplitude also can undergo oscillations with lower frequency.

8. The average value of the oscillation amplitude positively correlates with changes of the average ion flux density.

When interpretating these data it should be kept in mind the full absence of noticeable oscillations of the signal level at the amplifier output during the ground-based tests of the measuring equipment complex including the radiotelemetric system (RTS) work.

There was no source of noises with similar spectrum on board the satellite "Cosmos-378". Besides, as it has been already mentioned the trap collector is protected from noises by the system of two grids. As far as the possible influence of RTS is concerned close to isotropic the radiation of the RTS antenna system directed to different sides of the satellite would be effective only in respect of the excitation of high-frequency Langmuir electronic oscillations and whistlers, as far as the excitation of low-frequency ionic oscillations is concerned this effectiveness decreases by m_i / m_e times (m_e and m_i are accordingly electron and ion masses) [2] . But Langmuir electronic oscillations and whistlers in the Earth ionosphere have frequencies considerably exceeding 200 Hz and, respectively, they cannot be identified with observed oscillations of the trap ionic current. As the successful measurement of electronic temperature by means of high-frequency probe on "Cosmos-378" was made at frequencies ~ 100 kHz it can be believed on this basis that interferences from RTS work in the range of high frequencies and especially low frequencies were enough low-effective.

The enumerated peculiarities of ionic current oscillations allow to make such a conclusion that these oscillations are the typical plasma phenomenon: the properties of measuring equipment do not vary so widely and besides in the absence of plasma flow the oscillations are not observed. The absence of the definite dependence on the trap location relative to the wake of the satellite indicates that the oscillations of the trap ionic current have an independent source not connected with the characteristics of the plasma flow near the satellite body. All these points indicate to the detection of oscillations of the plasma flux density existing in the ionosphere independently.

Quasicycloidal form is characteristic practically for all the oscillation samples wherever it is possible to distinguish the form of the current change curve. This fact causes to search reasons of such a form in the most common regularities inherent to the investigated medium oscillations. Let us consider the simplest mechanical model of the influence on the trap collector current of oscillations of the gaseous medium particles in waves of the compression-rarefaction type.

Let $\vec{\xi}$, particle displacement from the equilibrium position, have the form of simple harmonic wave with angular frequency ω , wave number vector $\vec{k}$ and displacement amplitude $\vec{a}$:

$$\vec{\xi} = \vec{a} \cos\left(\omega t - \vec{\kappa}\vec{x}\right),$$

where t is time, $\vec{x}$ is coordinate of the particle equilibrium position, $\omega t - \vec{\kappa}\vec{x}$ is equilibrium phase of oscillations. Let us find the expression for instantaneous frequency Ω , or velocity of phase change, of oscillations of ions found themselves directly on the way of trap movement. Now $w = \omega t - \vec{\kappa}\vec{x}$ is the equilibrium phase for which $\vec{x}$ satisfies the conditon:

$$\vec{x}_t = \vec{x} + \vec{\xi} \quad , \tag{1}$$

where $\vec{x}_t$ is the coordinate of the particle displaced from the equilibrium position and found itself near the trap surface.

Having scalarly multiplied Eq. (1) by $\vec{K}$, time differentiated it and taking into account that $\dot{\vec{X}}_t = \vec{V}_t$ is the trap velocity relative to the medium, we shall obtain:

$$\vec{K}\dot{\vec{X}} = \frac{\vec{K}\vec{V}_t + \vec{a}\vec{K}\omega \sin w}{1 + \vec{a}\vec{K} \sin w}$$

Consequently,

$$\frac{dw}{dt} = \ell(t) = \omega - \vec{K}\dot{\vec{X}} = \frac{\ell_0}{1 + \vec{a}\vec{K} \sin w}, \qquad (2)$$

where $\ell_0 = \omega - \vec{K}\vec{V}_t$

(the difference between ℓ_0 and ω is stipulated by Doppler effect). It means that changes of w occur non-linearly in time, i.e. phase automodulation of the registered particle oscillations takes place. Depth of this phase automodulation depends on scalar product of amplitude of particle displacement by the wave number vector. The velocity of the oscillating motion of particles is equal to

$$\vec{v} = \frac{\partial \vec{\xi}}{\partial t} = -\vec{a}\omega \sin w .$$

The full velocity of particles relative to the trap is

$$\vec{V} = \vec{v} - \vec{V}_t = -\left(\vec{a}\omega \sin w + \vec{V}_t\right) .$$

The consideration of the infinitesimal gas volume deformation stipulated by displacements of the particles filling it from their equilibrium positions leads to the following expression for particle concentration n, oscillating in the wave of given type:

$$n = \frac{n_0}{1+\vec{a}\vec{k}\sin w} = \frac{n_0}{\ell_0}\cdot \ell(t) ,$$

where n_0 = const is the equilibrium particle concentration. Hence the ion flux density $\vec{J}$ registered by the trap is

$$\vec{J} = n\cdot\vec{V} = -\frac{n_0(\vec{a}\omega\sin w + \vec{V}_t)}{1+\vec{a}\vec{k}\sin w} = \frac{n_0}{\ell_0}\left(\frac{\vec{a}\omega}{\vec{a}\vec{k}} - \vec{V}_t\right)\cdot \ell(t)$$

The solution of Eq. (2) is

$$w - \vec{a}\vec{k}\cos w = \ell_0 t + \text{const} .$$

It follows from here that the concentration, the velocity and the flux density of particles oscillating in harmonic wave of compression-rarefaction type and registered by the measuring instrument experience non-sinusoidal oscillations due to the phase automodulation occurred. Such oscillations look like cycloids resembling the oscillation recordings of ionic trap collector currents. This result points to the fact that the cause of the trap collector current oscillations was apparently the ionospheric plasma oscillations of compression-rarefaction wave type.

For finding the connection of the considered oscillations with geophysical factors and geographic coordinates several histograms of relative frequency of ion trap current oscillation detection were plotted. These histograms look like stepped and as a rule extremely cut up profiles hiding basic regularities by many accidental cavities and projections. In order to exclude or, at least, reduce the role of accidental factors and to find hided regularities the series of parabolic regressions of the I-index value for the oscillatory activity of ion flux density was calculated by the least squares method (I = 1, if oscillations are detected; I = 0, if oscillations are not found). These regressions are statistical dependences of relative frequency of ion-trap current oscillation detection on corresponding factors of coordinates. The optimal order for regression was chosen by the principle of minimum of dispersion unbiased estimate. In this case it was found that for such a great number of observations equal to 400 the undesirable statistic dependences between satellite coordinates are neglected, minima of dispersions correspond to approximations of such dependences having zero orders. Therefore such regressions of I value on the corresponding factors or coordinates can be considered as the approximate curves of the oscillation detection probability. The maximum probabilities turn out to belong to the polar and low-latitude regions and the places of locating the maximum gradients of plasma concentration and geomagnetic field intensity, see Fig. 2a) and b) (every set of the curves illustrates the seasonal variations of the corresponding dependence). In Fig. 3a the pattern of isolines for the oscillation detection probability in coordinates Northern latitude - Eastern longitude plotted on the basis of data of two-factor regression of I-value on geographic latitude and longitude is given. At this pattern the most probabilities are also found in the polar region and the low-latitude region characterized by the higher gradients of the geomagnetic field module at the East-Siberian geomagnetic anomaly region. In other aspects this pattern resembles the known chart of the geomagnetic field intensity module [3] (Fig. 3b).

As it is known heterogeneous magnetoactive plasma is unstable relative to the so-called drift oscillations associated with the presence of gradients of its different parameters: concentration, temperature, magnetic field, etc., causing the drift movement of charged particles. According to [4] these waves turn out to be unstable in the ionosphere at altitudes of more than 300-400 km and it leads to their increase. At lower altitudes the drift can result from different collision frequencies of ions and electrons with neutrals [5]. The wave lengths of such oscillations have dimensions across the magnetic field $\lambda_\perp \gtrsim$ 100 m and along the field $\lambda_\parallel \gtrsim$ 10+100 km, oscillation period is $T \gtrsim 10^2-10^3$ sec. With such values of λ the above-mentioned interval for the trap current oscillatory structure periodicity corresponding to the 20-30 km part of the satellite trajectory is in agreement if it is taken into account that the satellite crossed the magnetic force lines under some angle. It is simple to eliminate the apparent in-consistency between such a large period of drift oscillations and a frequency of trap current oscillations if Doppler effect is taken into account for the observer on-board the satellite moving with the velocity $\vec{V}_t$ relative to the medium where there is a simple periodical wave:

$$f_{obs.} = \left| f - \frac{1}{2\pi} \vec{K} \vec{V}_t \right| .$$

Here f obs. and f are the observed and true circular oscillation frequencies, $|\vec{K}| = 2\pi/\lambda$. With the different values of λ within the pointed above limits: $\lambda_\perp < \lambda < \lambda_\parallel$, with all the possible values of angle between $\vec{V}_t$ and $\vec{K}$ and $|\vec{V}_t| \cong 8.10^5$ cm/sec.

$$f_{obs.} \sim 0.001 \div 100 \text{ Hz}.$$

Such a frequency range is fully agreed with the observed one for the experiment considered.

According to [6], drifts essentially modify waves in plasma; and even in-compressible flow, e.g. Alfvén wave which does not form density disturbances in homogeneous plasma, at the presence of concentration gradient disturbs particle density.

Some probability would be also assigned to the effect of very low-frequency acoustic oscillations with frequencies $f \ll \sqrt{m_e/m_i}\,\nu_i$ where ν_i is the frequency of collisions of ions with each other. According to [2], they have decrement fastly decreasing with frequency fall.

In considering the dependence of the oscillation detection probability on the indices of solar activity (SA) and geomagnetic activity (AE and K_p) the positive correlation with indices AE (a measure for polar electrojet intensity) and SA was found. It is not difficult to explain by increasing gradient ion and electron drift velocities V_{dr} because of growing heat influx and rising magnetic field gradients, e.g.:

$$V_{dr,gr} = C \cdot \frac{m_i V_\perp^2}{2eH^3}\left[\vec{H} \times \operatorname{grad} H\right],$$

where C is the light velocity, m_i and e are the mass and charge of an ion, $V_\perp \sim \sqrt{T_i/m_i}$ is the component of the ion velocity perpendicular to the magnetic field, T_i is the ionic temperature, $\vec{H}$ is the magnetic field intensity. In autumn-winter 1970 the positive correlation with K_p-index was failed to find. It is possibly explained by the closer connection of the considered oscillations with the activity of substorm type than with the activity of magnetic storm type. However the data of 1971 show the positive correlation with K_p-index.

From the curve of the dependence on local time the tendency of the oscillation detection probability increase towards after-midday hours is seen with the maximum near about 16-20 hours. The increase of the oscillation detection probability towards the polar regions is apparently associated with the growth of the ionospheric plasma structure heterogeneity and precipitation of auroral electrons [8, 9].

The shorter periods of oscillations of particle flux density are more probable in the auroral region. It can be explained by decreasing wavelengths of plasma oscillations, in accordance with the smaller scale of high-latitude irregularities [9] in comparison with one of low-latitude irregularities [10].

So, it is seen from the given data that the measurement of ion flux density directly at the place of ionospheric irregularity presence includes the capability for clearing up of the intrinsic physical nature of the similar phenomena.

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Fig. 1a The typical wave form of collector current oscillations of spherical ion trap with floating potential of the outer grid, installed on board the satellite "Cosmos-378"; U_T is telemetry voltage.

Fig. 1b Calculated curves of the time dependences of instantaneous frequency ω , concentration n , velocity v and flux density j of particles oscillating in a simple harmonic wave of compression-rarefaction type (in relative units).

Fig. 2a The dependence of the detection probability of ion flux density oscillations on geomagnetic latitude (based on data of the "Cosmos-378" ion trap):

- * - by observations for 200 sessions: orbits 2-796 on 17.11.1970-14.01.1971
- 0 - by observations for 200 sessions: orbits 340-1551 on 12.12.1970 - 9.03.1971.
- × - by observations for 200 sessions: orbits 807-3578 on 15.01.1971 - 31.07.1971
- + - by observations for 400 sessions: orbits 2-3578 on 17.11.1970 - 31. 07.1971

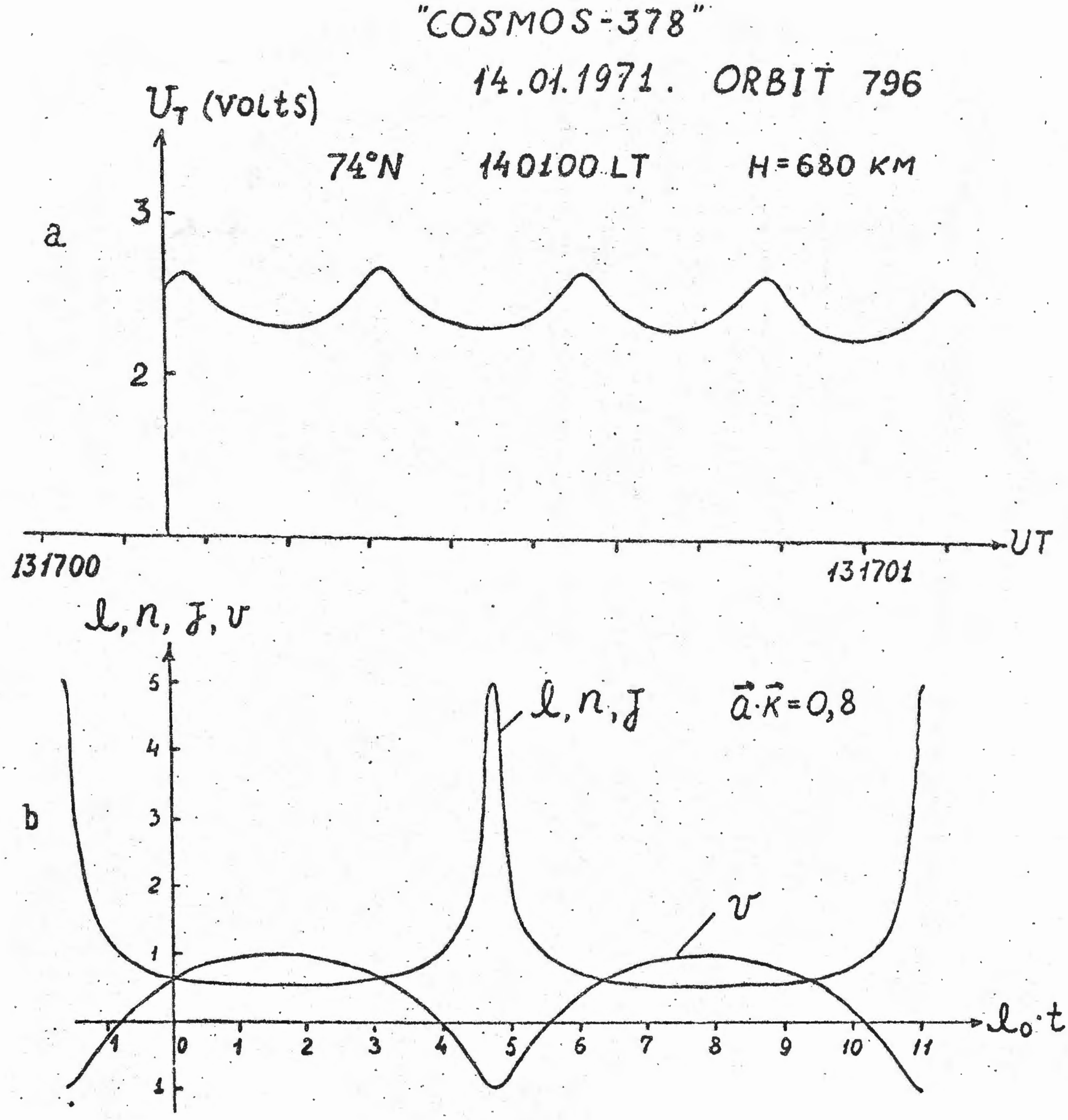
Fig. 2b The dependence of the detection probability of ion flux density oscillations on geographic longitude (by data of the "Cosmos-378" ion trap)

- * - by observations for 200 sessions: orbits 2-796 on 17.11.1970 - 14.01.1971
- 0 - by observations for 200 sessions: orbits 340-1551 on 12.12.1970 - 9.03.1971.
- × - by observations for 200 sessions: orbits 807-3578 on 15.01.1971 - 31.07.1971

+ - by observations for 400 sessions: orbits 2--3578 on 17.11.1970-31.07.1971

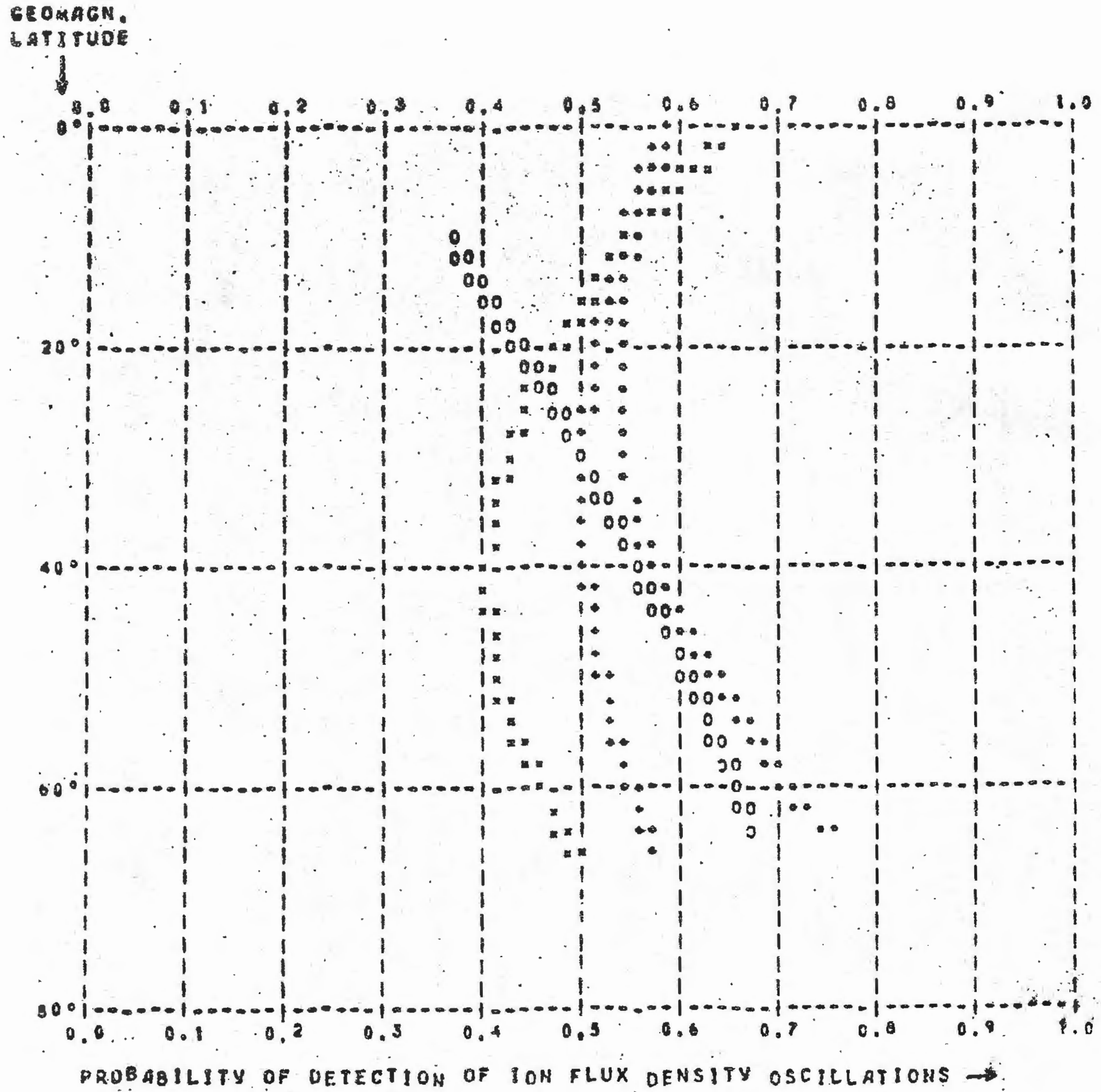
Fig. 3a The pattern of isolines for the ion flux density oscillation probability in coordinates: Northern latitude - Eastern longitude, plotted on the base of two-factor regression of the ion flux density oscillatory activity index I (by data of the "Cosmos-378" ion trap).

Fig. 3b The fragment of the chart of distribution of the geomagnetic field intensity module [3] .



"COSMOS-378"
14.01.1971. ORBIT 796
U_T (volts)
74°N
140100 LT
H=680 KM
a
3
2
131700
131701
UT
l, n, J, v
b
5
4
3
2
1
l, n, J
$\vec{a}\cdot\vec{K}=0,8$
v
0
1
2
3
4
5
6
7
8
9
10
11
$l_0 \cdot t$

Fig. 1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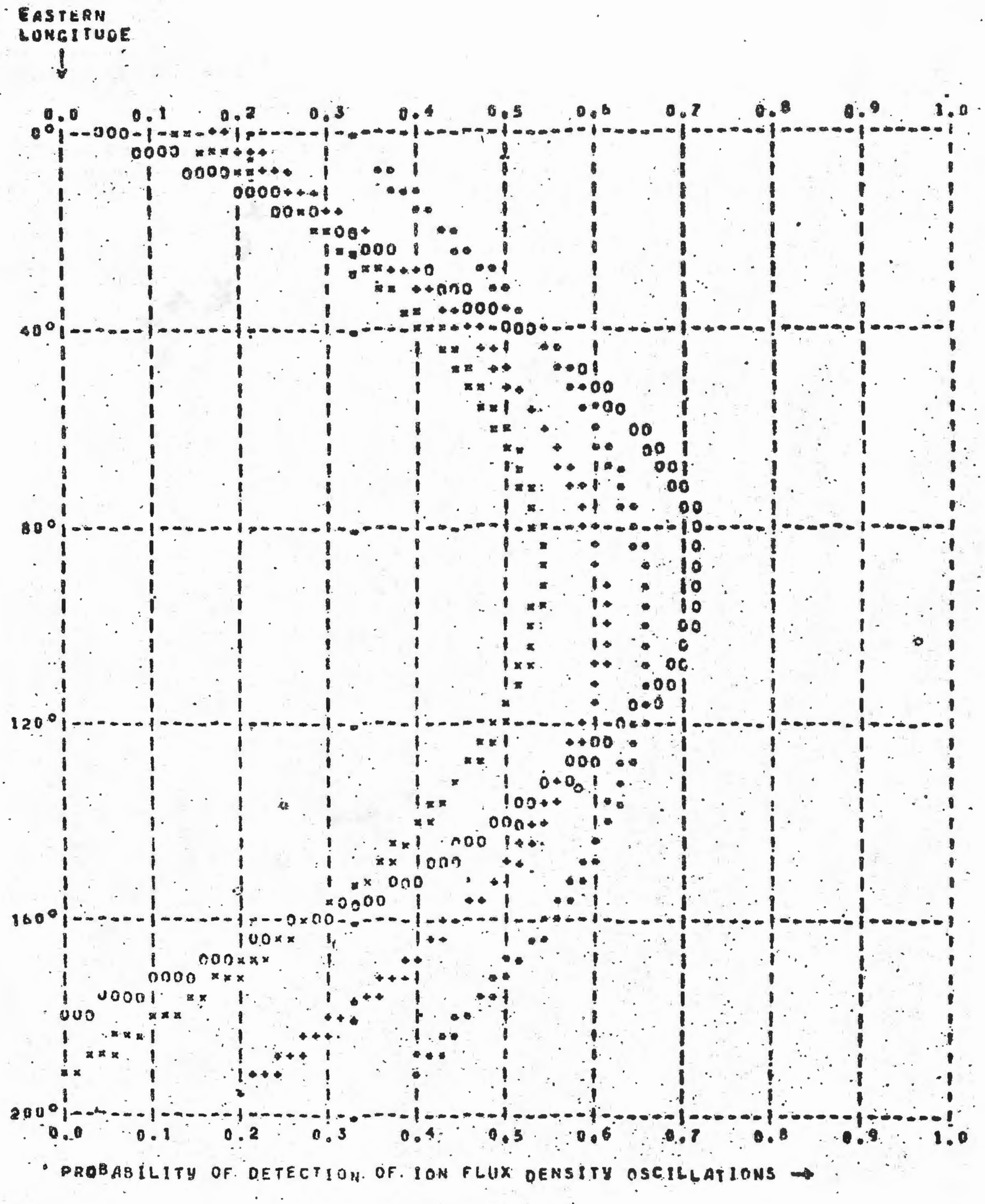
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
0°
20°
40°
60°
80°
PROBABILITY OF DETECTION OF ION FLUX DENSITY OSCILLATIONS →

Fig.2a


EASTERN LONGITUDE
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0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0°
40°
80°
120°
160°
200°
PROBABILITY OF DETECTION OF ION FLUX DENSITY OSCILLATIONS →

Fig. 2b

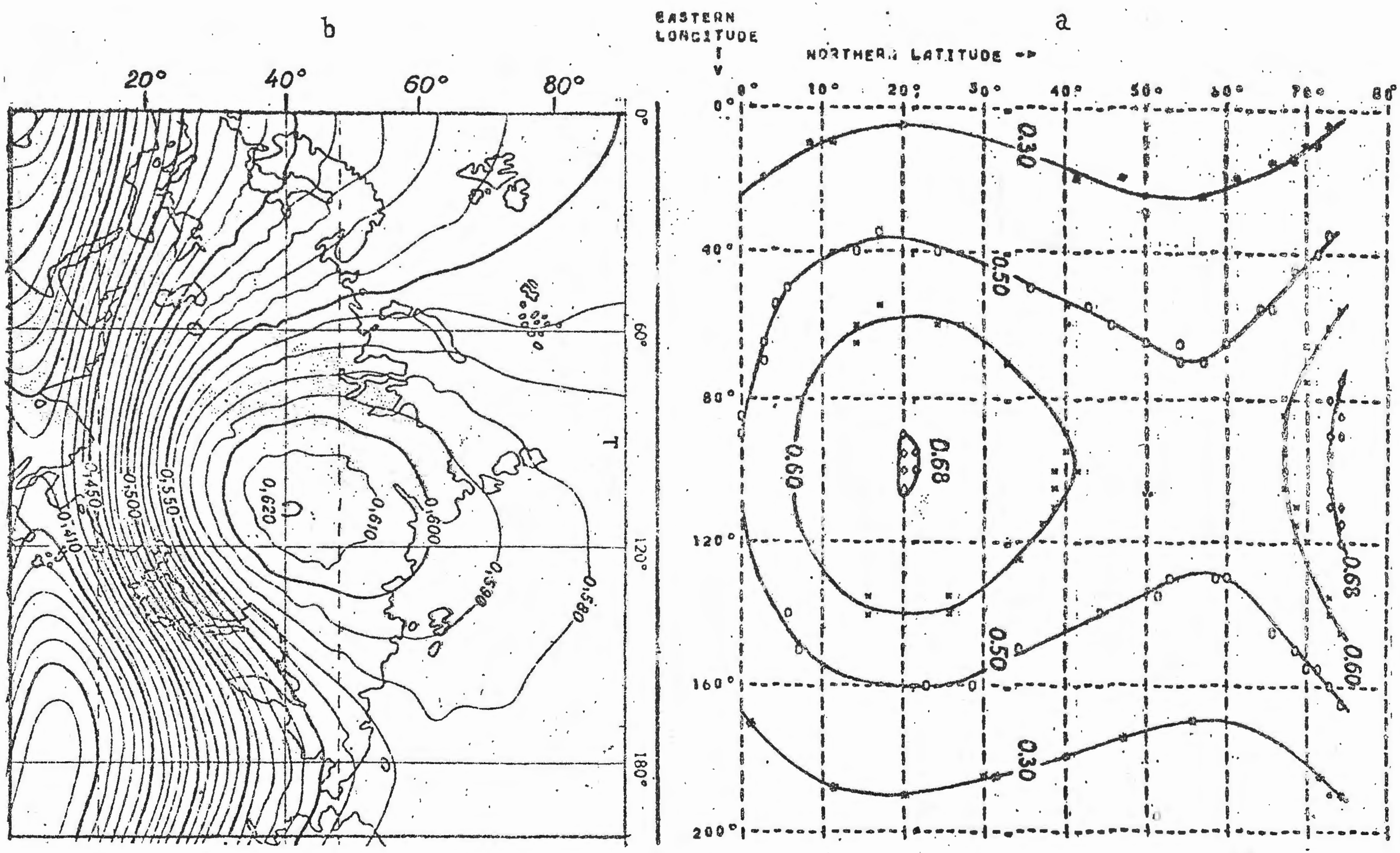
b
20°
40°
60°
80°
0°
60°
120°
180°
T
0,410
0,450
0,500
0,550
0,620
0,610
0,600
0,590
0,580
a
EASTERN LONGITUDE
NORTHERN LATITUDE
0°
10°
20°
30°
40°
50°
60°
70°
80°
40°
80°
120°
160°
200°
0.30
0.50
0.60
0.68

Fig. 3