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INTERRELATION

BETWEEN THE IRREGULAR EVENTS IN THE IONOSPHERE OF THE AURORA ZONE AND THE DISTURBANCES IN THE OUTER RADIATION BELT

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I N T E R R E L A T I O N
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ABSTRACT

The geographical disposition of the zone of irregular events in the lower ionosphere is compared with that of the outer radiation belt. The position of this zone was obtained coinciding with the position of the high-latitude boundary of the outer belt.

The displacement of the zone of ionospheric disturbances to the lower latitudes during magnetic disturbances coincides with the displacement of the boundary of the radiation belt.

The spatial and temporal characteristics of electron fluxes emerging from the belts coincide with the spatial and temporal characteristics of cases of irregular events in the lower ionosphere of the aurora zone.

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The discovery of the radiation belts of the Earth allowed us to take a new approach in the study of the nature of irregular events in the high-latitude ionosphere. Systematic studies of the nature of the agent causing these disturbances or irregular events may be conducted only with the help of satellites. The utilization of satellite data, together with the terrestrial data, allows the understanding of their nature and of the space-

* VZAIMOSVYAZ' NEREGULYARNYKH YAVLENIY V IONOSFERE ZONY POLYARNYKH SIYANIY I VOZMUSHCHENIY VO VNESHNEM POYASE RADIATSII

time characteristics. A great quantity of these works indicating the interrelation of various irregular geophysical events (aurora zone, bay-like magnetic disturbances, bursts of X-ray radiation) with the state of the outer radiation belt have already been published. The first observations (third AES) have shown that the boundary of the outer radiation belt of the Earth coincides with the Fritz zone [1]. It was revealed on the satellite Explorer-6 during a magnetic storm that during fluctuations of electron intensity on some type of drift shell on the Earth, polar aurorae and magnetic storms [2] were observed at the corresponding geomagnetic latitude.

Experimental data show that the escape of charged particles from the outer radiation belt in the dense layers of the atmosphere may occur. Here they can be the cause of polar aurorae, irregular events in the ionosphere and bay-like disturbances of the Earth's magnetic field. These disturbances must be induced either by protons with energies of several Mev or by electrons with energies of several kev or tens of kev. It can be considered generally accepted that electrons must be the cause of irregular events.

The explanation, however, of the nature of irregular events in the high-latitude ionosphere, that is of latitudes of the aurora zone by means of the radiation belts, is beset with specific difficulties. In particular, the maximum of the outer radiation belt is shown lying on the line of force crossing the Earth's surface at geomagnetic latitudes $\sim 55 - 62°$, while the aurora zone lies at higher latitudes. The results of observations, realized on Injun-1, have shown that at the height of 1000 km, fluxes of trapped electrons exist with energy > 40 kev within the limits from $L \sim 2$ to $L \sim 10 - 15$ or $\Phi' = 45°$ to $\Phi' = 75°$ [3]. At the same time the intensity of trapped electrons at the height of 1000 km sharply decreases between $L \sim 10$ and ~ 15, that is precisely in the latitude region where the northern boundary of the polar aurora zone passes. Therefore, the irregular events in the ionosphere of the aurora zone can be conditioned by the processes in the outer radiation zone, or to be more precise, in its most remote part.

In the given article, we shall not be concerned with questions of the escape mechanism of the trapped radiation in the denser atmosphere layers and also of a mechanism filling the reservoir of trapped radiation. We shall endeavor to show that the course of irregular events in the ionosphere of the aurora zone and the certain space-time characteristics of the outer radiation have much in common.

Latitude Distribution. The irregular events in the lower ionosphere ($\lesssim 120$ km), the bay-like magnetic disturbances and the polar aurora are most often observed and most actively unfolded in the narrow latitude region. The corrected geomagnetic latitudes of this region lie within the limits $62° < \Phi' < 75°$ with the maximum near $\Phi' = 65 - 69°$.

It is shown in work [4] that the average position of the maximum in the latitude distribution of anomalous absorption of the auroral type * is located at the latitude $\Phi' \sim 65°$ N. Somewhat more to the North, at $\Phi' \sim 67.5°$N, the maximum of particle appearance, characteristic for the aurora zone of the sporadic E-layer with group lag and the night E-layer [4] is located. These sporadic layers have a comparatively great thickness and by their structure, they are close to the regular layer.**

The latitude distribution of the frequency of PZS (continuous curve) and of the E_{sr}-layer (dashes) is plotted in Figure 1, from which it is clear that the latitude region, where these two forms of irregular events in the lower ionosphere are observed, lies within the limits $\Phi' = 61 - 76°$. These limits are defined for the frequency of PZS appearance and E_{sr} appearance equal to 10%. The zone of anomalous absorption is somewhat narrower than the E_{sr}-zone and its maximum is situated approximately by 2 - 3° further South from the zone.

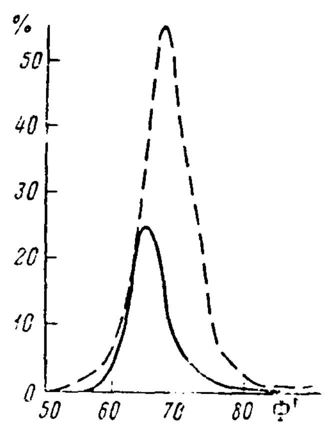

Figure 1

Observations on Injun-3 permitted the obtaining of statistical representations of the latitude distribution of the flux of escaping electrons with energy >40 kev [5, 6]. The statistical distribution of the escape has two most noticeable maxima at $\Lambda \sim 65°$ and $\Lambda \sim 67.5°$. Attention is drawn by the remarkably precise coincidence in the position of these maxima and of the maxima of PZS and E_{sr}-layer appearance (Figure 1). Undoubtedly, the first of these maxima is responsible for the appearance of anomalous absorption and the second for the formation of the E_{sr}-layer. Apparently, particles have the maximum drop to $\Lambda \sim 65°$ ($L \sim 5$) and to $\Lambda \sim 67.5°$ ($L \sim 7.5$) and are differentiated according to the energetic spectrum. Certain experimental data

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* Subsequently, for brevity anomalous absorption in the polar zone will be denoted by the letters PZS.

** Subsequently, both of these varieties of the E_s-layer will be denoted by E_{sr}.

speak also in favor of the fact that the escape is a process dependent on the energy of electrons. The escape maximum of electrons with $E_e \gtrsim 5$ kev is observed at greater latitudes than that of electrons with $E_e > 40$ kev and coincides with the maximum appearance of auroras with $\Phi' \sim 68°$ [7]. It was shown in ref. [5] that electrons with $E_e \sim 1$ Mev do not practically participate in the escape.

Shift along the Latitude as a Function of Local Time. The observation data show that the latitude boundary of particle dumping coincides approximately with the high-latitude boundary of the outer radiation belt. Conditionally chosen for the high-latitude boundary was the latitude at which the intensity of trapped electrons constitutes a specific part of belt's intensity maximum. It is shown in ref. [8] that the daily shift of the outer boundary of the outer belt is comprised within the 4 - 5° limits. The boundary of the belt is located at lower latitudes in nighttime, and at higher latitudes in daytime, which coincides with the data of [9, 10]. The boundary of electrons' escape is defined with a precision to 2°.

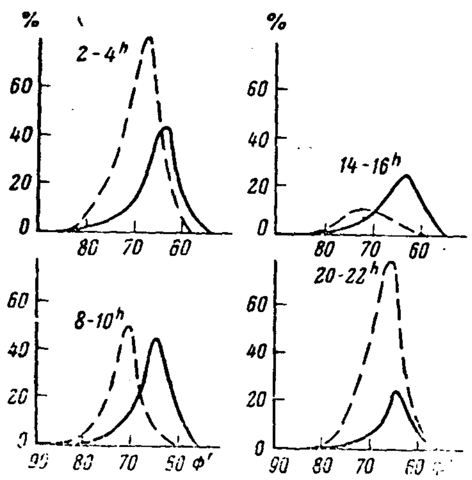

Figure 2

The latitude distribution of the frequency of PZS and E_{sr}-layer's appearance for different hours of local geomagnetic time is shown in Fig.2. It is evident that the position of the latitude distribution maximum of these events shifts along the latitude. In particular, the position of the E_{sr}-layer maximum (dashed curve) in nighttime (2000 to 0400 h.) is situated on $\Phi' \sim 66.5 - 67°$, and in daytime (0800 - 1600 hours) on $\Phi' \sim 71 - 72°$. Therefore, the shift during 24 hours constitutes $\sim 5 - 6°$. The daily shifts of PZS appearance maximum are lesser, and constitute $\sim 2 - 3°$. The position of the high-latitude boundary of the PZS zone and of the E_{sr}-layer chosen conditionally for a frequency of appearance constituting one fourth of the magnitude of the maximum for the given hour, is compiled in Table 1.

Compiled also in the table are the data on the daily shift along the latitude of the outer boundary of the radiation belt, determined according to [8]. The examination of this table and of Figure 3 allows us to conclude that the high-latitude boundary of trapped radiation ($\theta = 90 \pm 20°$) and that of dumping ($\theta < 45°$) practically coincide by latitude (θ is the pitch-angle of charged particles at the height of the satellite flight). From the table it can also be concluded that the daily shifts of the high-latitude boundary of the most frequent appearance of PZS, the E_{sr}-layer and the outer radiation belt are approximately identical in magnitude, coincide in direction and are located at very close latitudes.

Connection with the Magnetic Activity. It is shown in work [11] that as the magnetic activity increases the displacement of the frequency maximum of anomalous absorption appearance at lower latitudes takes place. At passage from days with a magnetic characteristic $15 \leqslant \Sigma K_p \leqslant 24$ to days with $\Sigma K_p \geqslant 35$ constitutes $\sim 3°$ in magnitude. The latitude distribution of the frequency of PZS appearance (solid curve) and E_{sr} (dashes) for various activity levels is plotted in Figure 3 in which this displacement is well seen for both events. It may be seen that as the magnetic activity increases, the percentage of PZS and E_{sr} events rises.

According to the data of the satellites "Injun-1" and "Injun-2," it was found that as K_p increases the flux of escaping electrons rises. Comparison with the data of Explorer-12 shows that the flux of trapped electrons with $E_e \sim 40$ kev in the equatorial plane [5] increases then also. At the same time if the flux of trapped electrons increases by several factors as K_p varies from 0 to 5, the flux of the escaping electrons increases by three orders. The displacement of the boundary of the outer radiation belt to smaller latitudes in periods of geomagnetic disturbances was established in a series of experiments and, in particular, in the work [12]. It was further established that this displacement of the belt boundary is attended by the enhancement of PZS in the vicinity of the belt's boundary [13]. Data on the position of the belt boundary for electrons with $E_e > 100$ kev on the night side of the Earth are plotted in Figure 4 as a function of K_p.

The magnitude of the displacement in degrees along the latitude proved to be of the same order as the displacement of the maximum of PZS and E_{sr} appearance. At the same time the southern boundary of anomalous absorption then shifts by 13 - 14° toward more southern latitudes and is lowered to $\Phi' = 56°$. This follows also from the results obtained by observations in Minneapolis at the geomagnetic latitude $\sim 55°$ [14]. Therefore, during very strong magnetic disturbances the dumping of electrons can occur not only from the periphery of the outer belt but also from its central part.

The angular distribution of escaping electrons was measured on the AES Injun-3. It was then obtained that if prior to the escape the maximum number of particles has a pitch-angle of $\sim 90°$

at the satellite flight altitude (600 - 250 km), the angular distribution of electrons at time of escape becomes isotropic. At the same time the fluxes of trapped as well as escaping particles are enhanced [5]. This allowed us to derive the conclusion that the dumped particles are the "fresh", just formed ones. Data of other authors also show that during their enhanced escape, the flux of electrons is nearly isotropic [15].

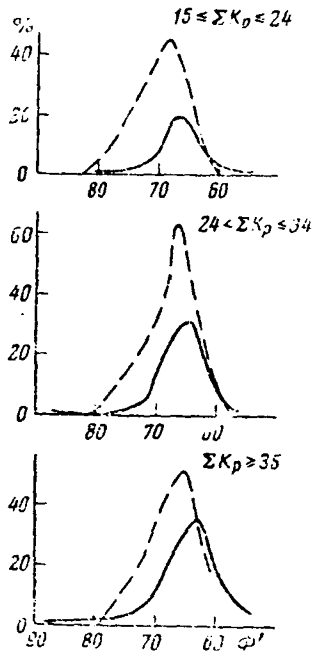

Figure 3

TABLE 1

Type of events \ L.T. →	2 - 4	8 - 10	14 -16	20-22
	70°	71.5°	72°	69.5°
PZS	76	76	80	74
Belt boundary $\theta = 90 \pm 20°$; 10% level	74	75	75	72
Belt boundary $\theta = 90 \pm 20°$ 50% level	71	73.5	72	69
Belt boundary $\theta < 45$; 10% level	72	75	74.5	73

D A I L Y V A R I A T I O N S. It is evident that the daily course of the frequency of appearance of anomalous absorption at zonal stations has one basic forenoon maximum. The analagous form of daily motion is preserved also for absolute values of absorption as this is shown, in particular, in reference [16] by measurements in the ionosphere by the impulse method. It is also well known that the time of this maximum appearance is shifted to later hours as the latitude of the point of observation increases. As the latitude changes from 57 to 86° the onset time of the maximum in the daily course of the frequency of appearance of anomalous absorption varies from 0200 to 1600 - 1900 hours L.T. [4]. The results of [17] show that as the latitude increases the time of the electron escape maximum shifts to later hours. Actually, the time of the maximum for the 65° latitude is centered at 0600 hours L.T., at latitude 68.5° - at 8 hours L.T., and at latitude 72.3° - at 1200 - 1600 hours L.T. Analogously to this [4], the maximum in the daily course of frequency of PZS appearance at these latitudes is observed at 0600, 0800 and 1200 hours of local geomagnetic time.

According to observations at Dixon Island ($\Phi' \sim 68$), the daily course of absorption is studied in [16]. The maximum of absorption is observed at 0800 hours U.T., the maximum at $\sim$ 2000 hours U.T.

Comparison of the data of [16] and [17] allows the formulation of the following conclusion. A very close correspondence is noted between the daily course of the average intensity of escaping electrons with $E > 40$ kev and the daily course of the value of absorption, according to the Dixon observations. In both cases, the maxima and the minima are disposed asymetrically relative to midday. The maximum is located between 1800 and 2200

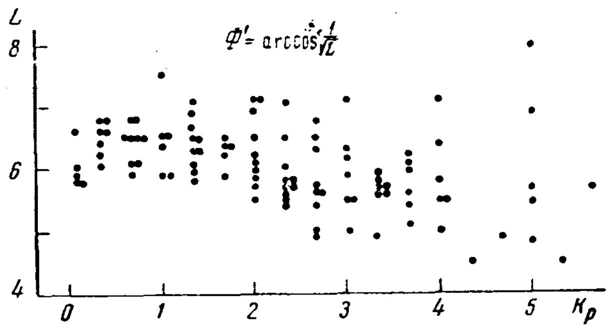

Figure 4

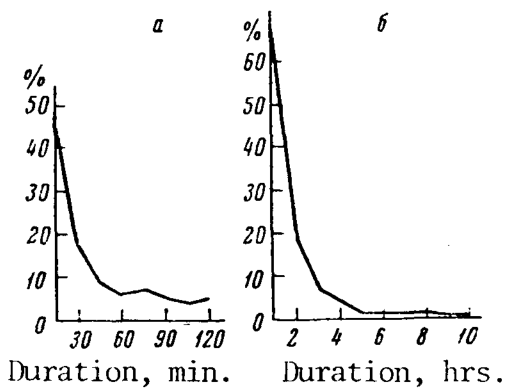

Figure 5

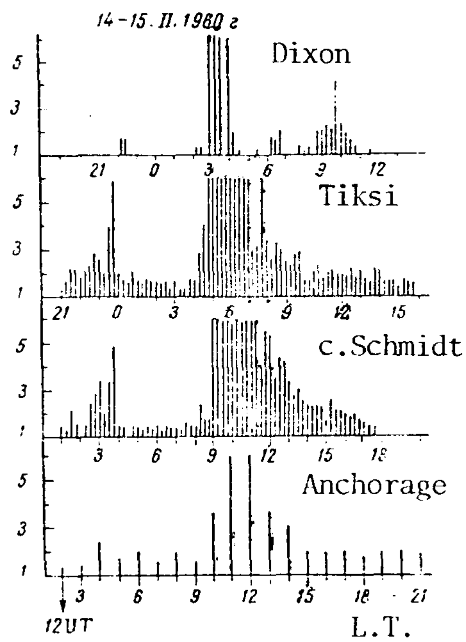

Figure 6

hours in the daily course of the intensity of escaping electrons with $E > 40$ kev as well as in the daily course of absorption.

The sound argument of the daily course of the intensity of the settling electrons and of the absorption in the aurora zone is also referred to in work [18].

<u>Duration and Extension Along the Latitude</u>. According to the material of the vertical sounding of the ionosphere, the

duration of the PZS periods for two zonal stations Dixon Island and Tiksi Bay [4] was determined. The distribution according to duration is obtained for values of minimal frequencies of reflection from the ionosphere, surpassing the value on an undisturbed day by more than 50%. The results of the calculations performed are shown in Figure 5 a, σ, from which it is clear that the duration of PZS periods does not exceed three hours in the overwhelming majority of the cases. Quite typical are the periods with duration not exceeding 45 minutes which constitute ~ 60 - 65%.

Together with this, the PZS phenomenon has a sufficiently large extension along the geomagnetic latitude. Calculations performed according to the material of the stations of vertical sounding of the ionosphere, close by the latitude, but dispersed in longitude [4] permitted the obtaining of the approximate distribution of PZS periods according to the extension along the geomagnetic latitude. It appeared that arcs with simultaneous presence of PZS (with excess of the normal level by 50%) approximately of 53% have an extension along the geomagnetic latitude $\geqslant 125°$.

An example of PZS appearance, observed simultaneously at Dixon Island $(\Phi' \sim 68°)$, Tiksi Bay $(\Phi' \sim 65{,}6°)$, Cape Schmidt $(\Phi' \sim 65.0°)$ and Anchorage $(\Phi' \sim 60{,}7°)$ is shown in Figure 6. Here plotted in references on the ordinate axis are the values of the minimum frequencies of reflection from the ionosphere. The cases of complete absence of reflections (blackouts) are limited by frequency of 6 Mc.

The example shown corresponds to the PZS period, observed simultaneously along the arc encompassing 160°. The arcs of such a great extension are the exception but can be observed approximately in 30% of the cases. They are usually connected with a high level of magnetic activity $(K_p \geqslant 4)$. During the first phase of an even relatively weak magnetic storm and during the development of th main phase of the storm, the arcs, over which PZS is observed, can reach $\sim 180°$ in longitude and $\sim 10°$ in latitude [12].

On the satellites it is impossible to distinguish the temporal and spatial variations of escaping electrons. There exist data about the fact that the escape lasts sometimes for several seconds whereupon the satellite may cover a band $\Delta L \approx 1$. Sometimes the escape continues for several tens of seconds, thus allowing the satellites to cover a band $\Delta L \approx 20$ [5]. It was established with the help of the Electron satellite system that on $L \geqslant 7$ electron fluxes are registered mostly during a single passage of the given shell. This can serve as the indication that such fluxes either exist less than three hours or are localized in the longitude region < 40°. The electron flux was once registered during two subsequent intersections of one and the same shell during 0.0500 hours. At high latitudes one magnetic storm was observed at this time. Therefore, the conclusion was derived that one and the same flux was observed, which had in this case a length ~50° [19] along the latitude.

Earlier it was shown that fluctuations in the outer radiation belt (temporal, latitudinal and those related to magnetic activity) and the space-time regularities of irregular events in the lower ionosphere (anomalous absorption and the E_{sr}-layer) have a great morphological similarity. Using this similarity as a basis, the conclusion can be derived that as a rule, the duration of the dumping of electrons from the outer radiation belt must not exceed three hours.

The range of disturbed longitudes in the outer radiation belt in which a noticeable escape of electrons takes place can be very great and exceed in approximately 50% of the cases 125°. It should be noted, however, that the flux of "dumped" electrons at the given physical moment along this disturbed arc is apparently not similar and can vary within broad limits.

Escape of Protons in the Polar Aurora Zone. Data appeared lately showing that a noticeable share of escaping particles may constitute protons of low-energy [19]. The satellite registered a proton flux with energy $E_p > 8$ kev at ~300 km altitude. During the night the proton escape in the $L \approx 5 \div 10$ range with maximum at $L \approx 6-7$. In the daytime protons escape in the range $L \approx 8 \div 15$. The time interval from 2200 to 0400 hours L.T. was investigated during the night. The escape maximum of protons corresponds to midnight. The time interval from 1120 to 1500 hours L.T. was investigated in the daytime, the maximum of proton escape corresponding to 1400 - 1500 hours. It is interesting to note that in the northern hemisphere escaping protons were observed in the daytime only in the 45°N. - 130°E. longitude range. Unfortunately, no data on proton escape during the day are available for the southern hemisphere. The energy flux of escaping protons may reach several tens of ergs/$cm^{-2}sec^{-1}$. As an average, it constitutes 15% of the flux of escaping electrons. If the spectrum of these protons is sufficiently soft, the estimates, including the accounting for atmosphere density according to the data of reference [20], show that the bulk of the protons are retained at an altitude > 120 km. Therefore, these protons do not induce the ionosphere effects considered in the present work.

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