However, in the present work, in the first approximation, we shall limit ourselves to the investigation of an idealized model, considering the field as a dipole one, symmetrical and not distorted by the effects of ring currents. We shall assume that localization region of quasitrapped particles is bounded by the magnetic shells $L_1 = 6$ and $L_2 = 10$ during the period of magnetic disturbances, and that the density of charged particles within the limits of this region is invariable in radial direction, i.e. $\partial\mu/\partial r^2 = 0$. The main attention in the work will be centered on the character of particle and current dependence along the field line on the form of the distribution function of particles by pitch-angles.

3. It was shown in the work [26] that the distribution function of particles by pitch-angles (1), obtained by Parker [4], is a particular case of a distribution function of a more general form

$$f_0 = K_{\alpha\beta} \sin^{\alpha+1} \theta_0 \cos^{\beta} \theta_0. \tag{2}$$

With such type of function $f(\theta)$ the character of anisotropy will vary along the line of force (at $\beta \neq 0$), with the consequence that the particle density distribution will be substantially different from that in [4](*)

Let us investigate the dependence $n(\phi)$ of particles' density on latitude along the line of force at various correlations and parameters α and β, characterizing the anisotropy in the distribution of corpuscular radiation in the equatorial plane. The distribution of charged particles' density along the line of force is given by the expression (8) in [26]. In real conditions it is necessary to take into account the absorbing action of lower layers of the atmosphere. The particles with pitch-angles smaller than the critical angle ε_k, will have a small life time. Taking this into account, the lower limit of integration in (8) should be taken equal to ε_k. Then

$$n(\varphi) = 2C_{\alpha\beta}\, q^{\alpha/2} \int\limits_{\varepsilon_\kappa}^{\pi/2} \sin^{\alpha+1}\theta\,(1 - q\sin^2\theta)^{\beta/2}\, d\theta,$$
$$C_{\alpha\beta} = \frac{n_e}{2\int\limits_{\varepsilon_\kappa}^{\pi/2} \sin^{\alpha+1}\theta \cos^{\beta}\theta\, d\theta}. \tag{3}$$

(*) Particular cases of such distribution were previously investigated in [27].

USS-T
Nagusner

National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No.NAS-5-12487

ST-PF-GM-10788

CURRENTS OF QUASITRAPPED PARTICLES AND THEIR INTERACTION WITH THE GEOMAGNETIC FIELD

(SYMMETRICAL APPROXIMATION)

by

V.D. Pletnev

O.A. Troshichev

(USSR)

27 DECEMBER 1968

ST-PF-GM-10788

CURRENTS OF QUASITRAPPED PARTICLES AND THEIR INTERACTION WITH THE GEOMAGNETIC FIELD (SYMMETRICAL APPROXIMATION)

Kosmicheskiye Issledovaniya
Tom 6, vyp. 5, pp 707 - 719
Izd-vo "Nauka", Mowcow 1968

by
V.D. Pletnev and
O.A. Troshichev

SUMMARY

A model is investigated of symmetrical (ring) current of quasitrapped particles at high latitudes inside the magnetosphere. Calculated also are the different particular cases of particle distribution in the current, corresponding to the anisotropic form

$$f_0 = K_{\alpha p} \sin^{\alpha+1} 0_0 \cos^{\beta} 0_0.$$

The distribution along the latitude of current density, and its influence on the geomagnetic field are estimated. It is shown that the main phase of the magnetic storm may be explained by the interaction of the current of quasitrapped particles ·ith the field of the magnetosphere.

* * *

1. The characteristic feature of universal magnetic disturbances is the sharp decrease of the H-component of the magnetic field, which is the so called main or basic phase of the magnetic storm. For the explanation of the main phase, the existence of a ring current surrounding the Earth, was postulated in the course of many years. The idea of the ring current was expressed for the first time in 1916 by Schmidt [1].

In the theory of the magnetic storms, proposed in 1930 by Chapman and Ferraro [2], a toroidal model ring current, flowing at a distance of about 10 terrestrial radii from the Earth's center, was assumed. With the discovery of radiation belts, it became clear that the ring current could be explained in a natural way, as a result of drift motion of charged particles trapped by

---

N.B. Please note that we systematically preserved the SLAVIC subscripts in the various formulas, which should read as follows:
обл means "reg" for regional, гр means "boundary", диа means "dia" for diamagnetic. др means "dr" for drift

the geomagnetic field, which was indeed, theoretically predicted by Singer [3]. A detailed investigation of the general character of motion of the low density ionized gas in an inhomogeneous magnetic field was performed by Parker [4]. Taking into account besides the drift currents, the diamagnetic ones, arising in the inhomogeneous plasma and in polarization currents, Parker derived an expression of the total density of a current flowing in an inhomogeneous magnetic field. The results obtained by Parker, were used in a series of works [5-8] for the computation of ring currents and fields produced by these currents on the Earth's surface.

In the Akasofu-Chapman model [5,6] the intensity of ring currents in the dipole field is determined by three factors:

1) Distribution of particles by pith-angles.
2) Radial distribution of particle density in the equatorial plane.
3) The energy spectrum of trapped particles.

It was assumed that the distribution function of trapped corpuscular radiation by pith-angles θ, has in the equatorial plane the form proposed by Parker [4]

$$f_0 \sim \sin^{\alpha+1}\theta_0. \qquad (1)$$

With such a form of function f(θ) the character of anisotropy remains unchanged along the line of force, while the particle density varies inversely proportionally to $B^{\alpha/2}$, where B is the field's magnitude on the line of force. The distribution of such a type with parameter $\alpha \geqslant 0$, apparently takes place in the inner part of charged particles' trapping region (in radiation belts) [9,10]. As regards the density of trapped radiation in the Akasofu-Chapman model ring currents, two hypothetical radiation belts were investigated: V_2 at a distance r_e = 3.5 - 4.5 a and V_3 is at a distance r_e = 5 - 7 a (a is the Earth's radius, r_e is the distance from Earth's center in the equatorial plane); in each of them the Gaussian distribution of particles' density was used.

For illustration, the Maxwellian distribution was taken for the energy spectrum. All the results were expressed in units of density of mean particle energy in the belt's center - n_0E kev/cm^3; however, the magnitude of the mean energy density in the belt V_3 was estimated on the basis of the then existing ideas about fluxes of electrons $\sim 10^{10} - 10^{11}$ e/cm^2·sec in the outer radiation belt maximum. The computations conducted in [5,6], have shown that at such conditions, the magnetic field of the V_3 zone at the Earth's center (H_{zc}) will have a magnitude $\sim -150\gamma$; for the V_2 zone the corresponding value is $H_{zc} \sim -38\gamma$. Subsequently it was clarified that the electron flux in the outer belt maximum does not exceed $\sim 10^8$ e/cm^2·sec and its corresponding ring currents are unable to ensure the values of the main phase (up to 500γ in the period of intense magnetic storms) observed on terrestrial surface. According to the computations performed in [11], the effect of the proton belt on the Earth's surface, is also substantially smaller than in the Chapman-Akasofu model ($\sim -9\gamma$ in the plane of magnetic equator).

Although a specific form of anisotropy could increase the effect of ring currents [8], the results of [5,6,11] are in fact evidence of insufficient intensity of currents flowing in radiational belts, for the explanation of magnetic storms' main phase.

2. In the present work, we shall investigate a model of currents, flowing not in the radiation belt region, but beyond its limits, near the boundary of the geomagnetic trap, as is assumed in the work [12]. For the foundation of such a model, the following facts may be used.

During the flight of AIS "Luna-1" and "Luna-2", fluxes of low energy electrons of higher concentration than those in the radiation belts $\sim 10^8 - 10^9$ (cm^2·sec)$^{-1}$ [13] were revealed beyond the outer radiation belt. The existence of irregular fluxes of soft electrons ($E_e < 10$ kev) and electrons with $E_e > 30$ kev energy in the region between the outer radiation belt and the boundary of the magnetosphere, was subsequently confirmed on the satellites "Explorer-12", "Explorer-14", IMP-I, "Electron-1" [14-18] at different hours local time. As a further corroboration the hypothesis expressed in [12], there appeared the work [19], in which computation was performed of the adiabatic motion of charged particles in the Mead's [20] model magnetosphere and the conclusion was made about the existence in the magnetosphere of a region of quasitrapped particles, i.e. particles that abandon the closed magnetosphere without completing a complete drift along the longitude.

The basic distinction of the region of quasitrapped particles from the outer radiation belt, is in greater (by several orders) intensity variations of fluxes in the zone, by comparison with relatively stable fluxes in radiation belts. The region of quasitrapped particles is precisely the one we shall consider as the source of the magnetic storms' main phase.

The position of the region of quasitrapped particles in space, obtained in [21] in accordance with the observations of satellites "Elektron" and the computations of outer belt boundary from the daytime side [22], is presented in Fig.1. The configuration of the region is such, that its low latitude boundary on the ground is located at the latitudes of the zone of maximum auroral recurrence (ϕ = 63-75°) [17], while the high latitude boundary apparently corresponds to the aurora instant zone, which is the aurora oval ($\phi \sim 78°$ on the daytime side, $\phi \sim 67°$ on the nighttime side according to data [23,24]. Such a configuration of the zone easily explains the correlation between the appearance of intense fluxes and the magnetic disturbances at a great distance from the Earth, and the magneto-auroral perturbations on the ground [18]. On the other hand, the earlier noted correlation between polar substorms and the development of the main phase according to ground date [25], may also be considered as the consequence of the connection between the ring currents in the region of quasitrapped particles and the particle precipitation into the atmosphere along the magnetic field's lines of force.

According to [21], the inner boundary of the region of quasitrapped particles passes along the magnetic surfaces L $\sim$ 7 - 8 from the nighttime and L $\sim$ 9 - 9.5 from the morning-evening sides of the Earth. On the daytime side, at distances L $\sim$ 10, the field differs substantially from the dipole. Any precise computations of particle motion in the region of quasitrapped particles should take this field's asymmetry into consideration.

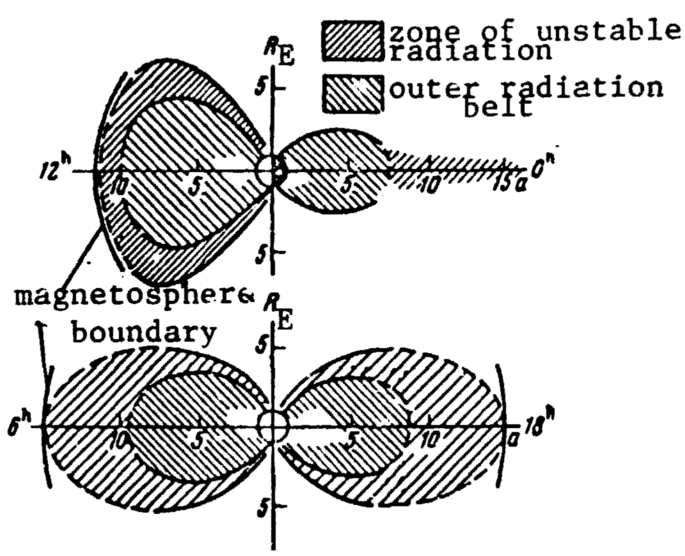

Fig.1
Configuration of (unstable) quasitrapped radiation zone according to [21]

However, in the present work, in the first approximation, we shall limit ourselves to the investigation of an idealized model, considering the field as a dipole one, symmetrical and not distorted by the effects of ring currents. We shall assume that localization region of quasitrapped particles is bounded by the magnetic shells $L_1 = 6$ and $L_2 = 10$ during the period of magnetic disturbances, and that the density of charged particles within the limits of this region is invariable in radial direction, i.e. $\partial n/\partial r^2 = 0$. The main attention in the work will be centered on the character of particle and current dependence along the field line on the form of the distribution function of particles by pitch-angles.

3. It was shown in the work [26] that the distribution function of particles by pitch-angles (1), obtained by Parker [4], is a particular case of a distribution function of a more general form

$$f_0 = K_{\alpha\beta} \sin^{\alpha+1}\theta_0 \cos^{\beta}\theta_0. \tag{2}$$

With such type of function $f(\theta)$ the character of anisotropy will vary along the line of force (at $\beta \neq 0$), with the consequence that the particle density distribution will be substantially different from that in [4](*)

Let us investigate the dependence $n(\phi)$ of particles' density on latitude along the line of force at various correlations and parameters α and β, characterizing the anisotropy in the distribution of corpuscular radiation in the equatorial plane. The distribution of charged particles' density along the line of force is given by the expression (8) in [26]. In real conditions it is necessary to take into account the absorbing action of lower layers of the atmosphere. The particles with pitch-angles smaller than the critical angle ε_k, will have a small life time. Taking this into account, the lower limit of integration in (8) should be taken equal to ε_k. Then

$$n(\varphi) = 2C_{\alpha\beta}\, q^{\alpha/2} \int_{\varepsilon_\kappa}^{\pi/2} \sin^{\alpha+1}\theta\,(1 - q\sin^2\theta)^{\beta/2}\, d\theta,$$
$$C_{\alpha\beta} = \frac{n_e}{2\int_{\varepsilon_\kappa}^{\pi/2} \sin^{\alpha+1}\theta \cos^{\beta}\theta\, d\theta}. \tag{3}$$

(*) Particular cases of such distribution were previously investigated in [27].

Here $q = B_e/B$ is the parameter, characterizing the field variation along the line of force; n_e, B_e are respectively the density of quasitrapped radiation and the magnitude of the field in equatorial plane.

The variation of critical angle ε_k with the latitude is determined by the condition

$$\varepsilon_{\kappa}(\varphi) = \arcsin\left[\frac{(1+3\sin^2\varphi)^{1/4}}{\cos\varphi}\sin\varepsilon_{0\kappa}\right],$$

where ε_{0k} is the value of the critical angle in equatorial plane. In our computation it was assumed, that the absorbptive action of the atmosphere begins to play a role at altitudes $h \leqslant 200$ km, which corresponds to $\varepsilon_{0k} \sim 1°30'$ for the line of force $L \sim 10$. At such conditions the dependence $\varepsilon_k(\phi)$ is shown in Fig.2, where presented also is the variation with latitude of the quantity

$$q(\varphi) = \frac{\cos^6\varphi}{(1+3\sin^2\varphi)^{1/2}}.$$

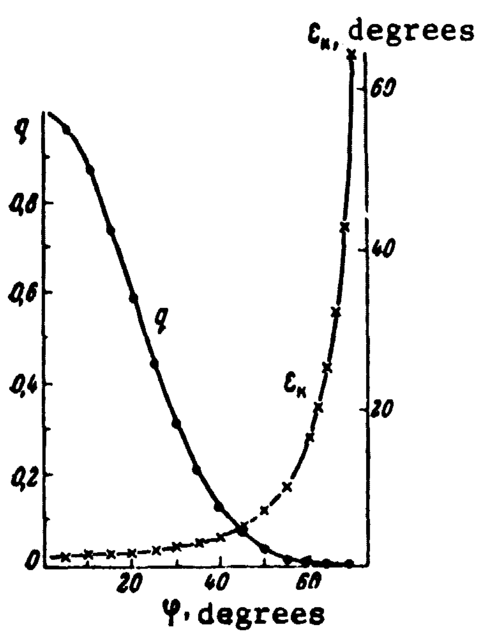

Fig.2

Dependence of critical angle ε_k and of parameter $9 = B_e/B$ on latitude ϕ

The latitude distribution of particle density along the line of force was computed according to formula (3) for the values $\alpha = 0.1, -1$ with β, varying from 0 to 4. The results are presented in Fig.3, where the radiation density in equatorial plane is taken for the unity. The case $\alpha = 0$, $\beta = 0$, corresponds to isotropic distribution of quasitrapped radiation. With the increase of parameter β the density maximum is shifted from the equator to high latitudes (in case of $\alpha \geqslant 0$).

With $\alpha = -1$ the maximum for all values of β fits the latitude $\phi \sim 67°$. In this case the particle density in the maximum (at a distance $\sim 0.5\ R_E$ from the Earth's surface for $L = 10$ is more than by one order higher than that on the equator. Subsequently, during current density computations on the line of force we shall limit ourselves to investigating certain cases of anisotropy ($\alpha = 0$, -1 at $\beta = 0,2$) sufficiently fully reflecting the dependence of currents on the on the type of distribution function by pitch-angles.

4. In the absence of external forces, the total value of current density of the ionized gas, located in a stationary magnetic field, is equal to the sum of the drift current $i_{\text{др}}$ and the magnetization current (diamagnetic current) $i_{\text{диа}}$.

$$\mathbf{i} = \mathbf{i}_{\text{др}} + \mathbf{i}_{\text{диа}}.$$

The total current density in the ionized gas is equal to

$$\mathbf{i} = C\left\{\frac{p_s - p_n}{B^2 R^2}[\mathbf{R} \times \mathbf{B}] + \frac{[\mathbf{B} \times \nabla p_n]}{B^2}\right\}, \tag{4}$$

where R is the curvature radius of the line of force.

In a stationary dipole field we shall obtain the expression for the density of a westward flowing current:

$$i = C\frac{r_e^2}{a^3 B_0}\left\{(p_s - p_n)\frac{3\cos^5\varphi(1+\sin^2\varphi)}{(1+3\sin^2\varphi)^2} - \frac{\partial p_n}{\partial r_e} r_e \cos^3\varphi - \frac{\partial p_n}{\partial\varphi}\frac{2\sin\varphi\cos^4\varphi}{(1+3\sin^2\varphi)}\right\}. \tag{5}$$

The dependence on latitude of the longitudinal p_s and transverse p_n pressures in the case, when the distribution function has the form (2) is expressed in the following manner [26] (taking into account the absorbing action of atmosphere's lower layers):

$$p_n = C_{\alpha\beta}\, q^{\alpha/2}\int_{\theta_{\text{к}}}^{\pi/2} m v_n^2 \sin^{\alpha+1}\theta\,(1 - q\sin^2\theta)^{\beta/2}\,d\theta,$$

$$p_s = 2C_{\alpha\beta}\, q^{\alpha/2}\int_{\theta_{\text{к}}}^{\pi/2} m v_s^2 \sin^{\alpha+1}\theta\,(1 - q\sin^2\theta)^{\beta/2}\,d\theta, \tag{6}$$

$v_n = v \sin\theta$ and $v_s = \cos\theta$ are respectively the transverse and longitudinal velocity components of the particle, v is the total velocity.

The variation with latitude of the longitudinal and transverse pressures of ionized gas, computed according to (6) for various forms of anisotropy, is in Fig.4.

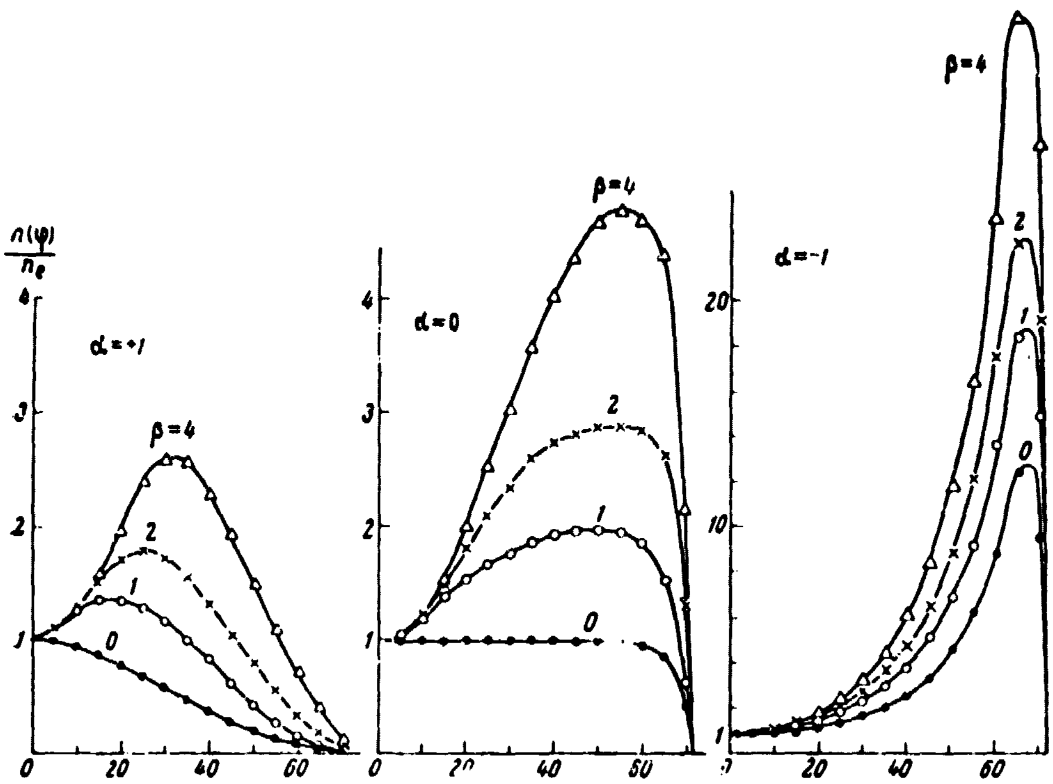

Fig.3.

Variation with latitude of the density of quasitrapped particles on a fixed line of force at different correlations of anisotropy parameters α and β

Substituting the computed values of p_n and p_s into (5), and taking into account that, according to our model, $\partial p_n/\partial r_e = 0$, we shall obtain the distribution of the density of currents along the line of force in the form

$$i_{\text{обл}}(f_e, \varphi) = i_0/f_e^2 a(\varphi), \qquad (7)$$

where $a(\phi)$ is the coefficient, characterizing the dependence on latitude,

$$f_e = \frac{r_e}{a},$$

$$i_0 = \frac{cmv^2 n_e}{aB_0} = 1{,}57\cdot 10^{-16}\cdot n_0 E\ a/см^2,$$

n_0E is the energy density of particles, expressed in kev/cm^3.

Shown in Fig.5-a is the variation with latitude of relative density of currents $i_{\text{обл}}(\varphi)/i_e = a(\varphi)/a(0)$. The positive values of the relative current

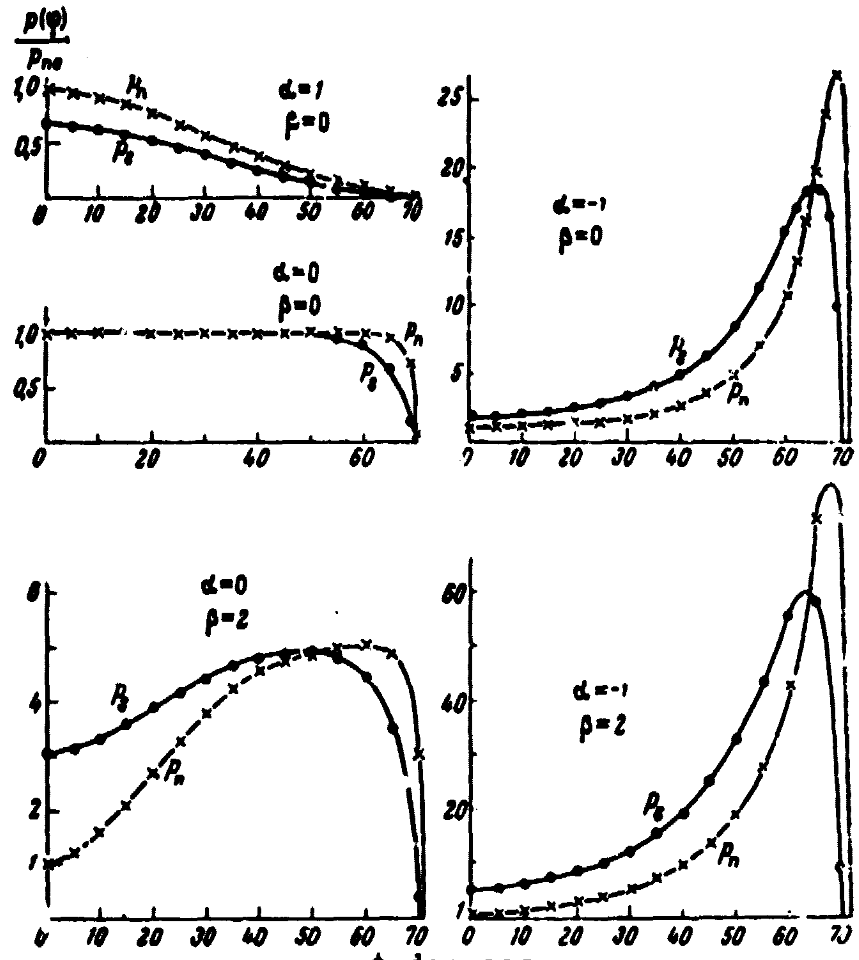

Fig.4

Variation with latitude of longitudinal and transvert pressures p_n and p_s on the line of force. The magni tude of transverse pressure in the equatorial plane is taken for the unity.

density $i_{o6n}(\varphi)/i_e$ corresponds to the westward current direction and the negative $i_{o6n}(\varphi)/i_e$ to the eastward one. The data for the isotropic distribution by pitch-angles ($\alpha = 0$, $\beta = 0$) are not shown in Fig.5-a since in this case the current is negligibly small. (*)

In the remaining cases of anisotropy the currents of westerly direction have the density maximum at low latitudes and in the case $\alpha = -1$, $\beta = 2$ at the high one (**); the currents of easterly direction have the density maximum at middle latitudes. However, the contribution of easterly currents, as well as

(*) At isotropic distribution Akasofu and Chapman [5] obtained the current of westward direction at the expense of the assumed particle density gradient in the radial direction.

(**) It is curious, that in case $\alpha = -1$, $\beta = 2$, two westward current maxima are observed at the equator and at the latitude $\sim 70°$.

of the high latitude westerly ones to total intensity of currents $I_{\text{обл}} = \iint i\,dS$,

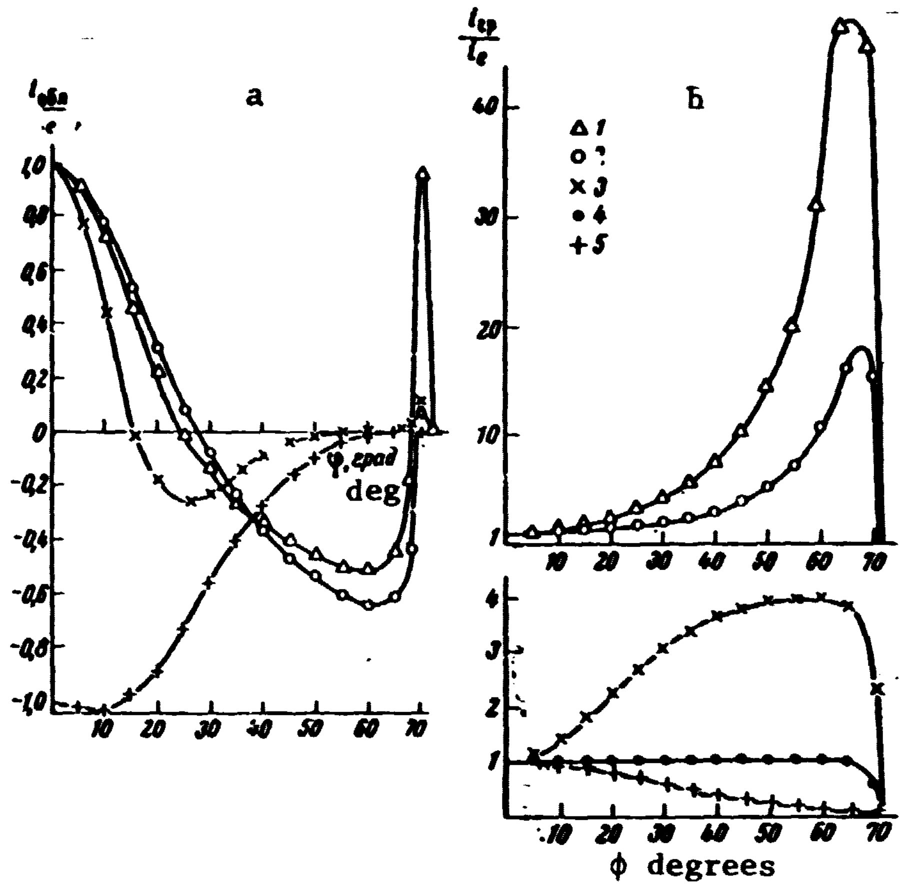

Fig.5

Relative density of currents $i_{\text{обл}}/i_e,\ i_{\text{гр}}/i_e$
as a function of latitude for various forms of anisotropy:
$1 - \alpha = -1,\ \beta = 2$; $2 - \alpha = -1,\ \beta = 0$; $3 - \alpha = 0,\ \beta = 2$; $4 - \alpha = 0,\ \beta = 0$;
$5 - \alpha = 1,\ \beta = 0$

is insignificant due to a sharp decrease of the quantity $dS = a^2 f_e \cos^4 \varphi\, df_e\, d\varphi$ with the increase of latitude.

The variation with latitude of the currents' intensity $I_{\text{обл}}(\varphi)$ may be characterized by the coefficient (Fig.6 a-b)

$$A(\varphi) = a(\varphi) \cos^4 \varphi,$$

then

$$I_{\text{обл}}(\varphi)\,d\varphi = A(\varphi)\,d\varphi\, i_0 a^2 \int f_e^3\, df_e. \tag{8}$$

The values of total current intensity $I = 2 \int_0^{\pi/2} I_{\text{обл}}(\varphi)\,d\varphi$ in amperes, computed for our model with various forms of anisotropy, are compiled in the Table below, n_0E is the energy density of particles, expressed in kev/cm^3.

5. Besides the currents $I_{\text{обл}}$ on the zone surface of quasitrapped particles boundary currents $I_{\text{гр}}$, , will arise. According to our model these currents are caused by a sharp density decrease of quasitrapped particles on the zone's surface. Let us find the magnitude of boundary currents in the assumption that the surface of the zone is the localization boundary of leading centers of quasitrapped aprticles, so that the density of leading centers from

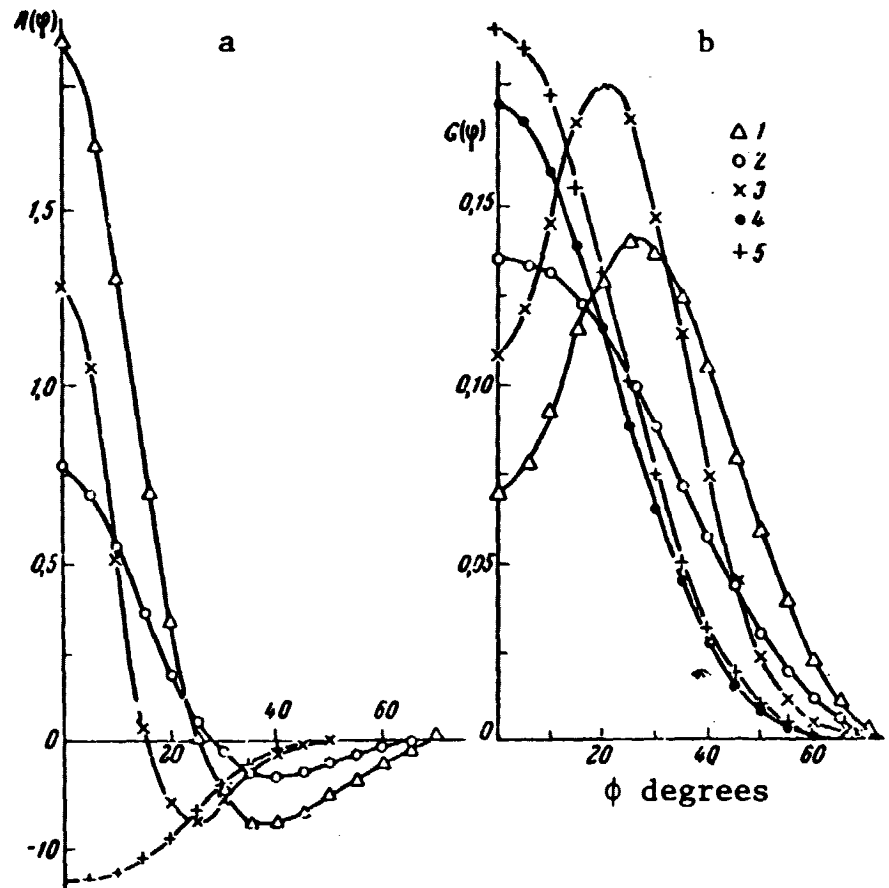

Fig. 6

Depen ence of coefficients A (ϕ) and G (ϕ) on latitude:

1 — α = −1, β = 2; 2 — α = −1, β = 0; 3 — α = 0, β = 2; 4 — α = 0, β = 0; 5 — α = 1, β = 0

the external side of the surface is zero, while the inner is equal to n.
The currents, induced by the drift of leading centers and by the macroscopic velocity of particles, located inside the zone, are accounted for in (4). Besides the part of these particles, whose leading centers lie inside the zone, will be located on the external side of the interface. Let us take these particles

into account, and find their mean velocity following the Spitzer method [28]. Let us isolate on the surface of the zone, the boundary of thickness ρ, where $\rho = mcv_n/eB$ is the particle's cyclotron radius. The number of particles, whose leading centers are located in this layer, is

$$N = \int_0^\rho n\,[r_e^2 \cos^4\varphi\,(1+3\sin^2\varphi)^{1/2}\, d\varphi\, d\Phi]\, dx,$$

where $x = \rho\cos\lambda$ (Fig.7), of these λ/π particles are located outside the layer. The mean velocity of one particle is

$$\bar{v}_\kappa = -\frac{1}{\lambda}\int_0^\lambda v_n \cos\lambda\, d\lambda = -\frac{v_n \sin\lambda}{\lambda}.$$

Summing up by all particles situated from the external side of the interface we shall obtain the velocity of these particles in the direction <u>k</u>

$$\sum v_\kappa = -\int_0^\rho n\,[r_e^2\cos^4\varphi\,(1+3\sin^2\varphi)^{1/2} d\varphi\, d\Phi]\frac{\lambda}{\pi}\frac{v_n\sin\lambda}{\lambda}\,dx =$$
$$= -n\,[r_e^2\cos^4\varphi\,(1+3\sin^2\varphi)^{1/2} d\varphi\, d\Phi]\frac{v_n\rho}{4}.$$

Taking into account $N = n[r_e^2\cos^4\varphi(1+3\sin^2\varphi)^{1/2}d\varphi d\Phi]\rho$, we shall find the mean velocity related to all N particles lying in the boundary layer

$$u = \frac{\Sigma v_\kappa}{N} = -\frac{v_n}{4}.$$

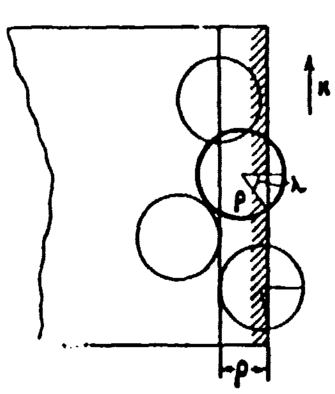

Fig.7.

Deriving the density of boundary currents.

Consequently, the density of the currents flowing along the surface of quasitrapped particles, will be

$$i_{rp} = enu = \frac{v\sin\theta}{4}en$$

or, taking into account (3)

$$i_{rp}(\varphi) = \frac{ev}{2}C_{\alpha\beta}\,q^{\alpha/2}\int_{\theta_\kappa}^{\pi/2}\sin^{\alpha+2}\theta\,(1-q\sin^2\theta)^{\beta/2}\,d\theta \qquad (9)$$

The results of computation of latitude variations of the relative density of boundary currents $i_{rp}(\phi)/i_e$ are presented in Fig.5-a. With $\alpha = -1$, the density maximum of boundary currents is shifted to high latitudes and exceeds by more than one order the current density at the equator. In the remaining cases, the density of boundary currents is distributed more or less evenly along the line of force.

The intensity of currents flowing in the boundary layer is

$$I_{rp}(\varphi)\,d\varphi = i_{rp}dS_{rp},$$

where $dS_{rp} = \rho r_c(1 + 3\sin^2\varphi)^{1/2}\cos\varphi d\varphi$; taking into account that

$$i_{rp} = \frac{v_n en}{4}, \quad \rho = \frac{mcv_n}{eB},$$

we obtain

$$I_{rp}(\varphi) = \frac{cmv_n^2 n}{4B_0} af_c^4 \cos^7\varphi\, d\varphi = \frac{c}{2B_0} p_n(\varphi) af_c^4 \cos^7\varphi\, d\varphi$$

or, taking into account (6), it is possible to present $I_{rp}(\phi)$ in the form

$$I_{rp}(\varphi)\,d\varphi = i_0 a^2 f_c^4 G(\varphi)\,d\varphi. \tag{10}$$

As $G(\phi) \sim \cos^7\phi$, the intensity of boundary currents will rapidly decrease toward high latitudes for any anisotropy character (Fig.6-b). Comparison with Fig.6-a, shows that the distribution of boundary currents along the line of force is to a lesser degree dependent on the form of anisotropy than the current distribution $\tilde{I}(\phi)$. On the external boundary of the zone $f_{e2} = 10$ the boundary currents will have a westerly direction, and it will be easterly on the internal boundary f_{e1}. The total intensity of the boundary currents

$$I = i_0 a^2 (f_{e2}^4 - f_{e1}^4) 2 \int_0^{\varphi} G(\varphi),$$

is given in the Table that follows.

I, 10^5 n, E, a	$\alpha = -1$ $\beta = -2$	$\alpha = -1$ $\beta = 0$	$\alpha = 0$ $\beta = 2$	$\alpha = 0$ $\beta = 0$	$\alpha = 1$ $\beta = 0$
$I_{обл}$	1.33	0,56	0.52	-0.0016	-0.63
$I_{гр}$	1.31	1.15	1.42	1.07	1.22
$I_{обл} + I_{гр}$	2.64	1.71	1.95	1.07	0.59

For further evaluations, data on energy density n_0E of quasitrapped particles are necessary. The direct indications on this account are apparently absent, and any conclusions on the energy density of these particles during period of magnetic storms may be made only on the basis of indirect data. According to the results of observations on AIS IMP-2 and OGO-1 [29], the differential spectrum of particles that break through from the magnetopause into the magnetosphere, have during magnetoquiet periods the form

$$n(E)dE = 1.5E^{-2.6}\,dE,$$

which yields nE $\sim$ kev/cm^3 for the low energy particles. The intensity of fluxes of solar wind particles varies by 1-2 orders [30], while the particle fluxes beyond the boundary of radiation belts vary from $10^8(\text{cm}^2\cdot\text{sec})^{-1}$ during quiet time, up to $10^{10}(\text{cm}^2\cdot\text{sec})^{-1}$ during magnetic storms [14]. The measurements of precipitated and trapped particles conducted on "Injun-3" [31] at latitudes corresponding to the zone of quasitrapped radiation, also showed an increase in the flux of trapped particles by more than one order with the variation K_p from 0 to 6. On the basis of these data, it is apprently possible to assume that the energy density of quasitrapped particles may reach during magnetic disturbances a magnitude of $\sim$ kev/cm^3 higher. Under this condition the magnitude of total current intensity in our model zone of quasitrapped particles will fluctuate, as a function of the character of anisotropy, from $I \sim 2.6\cdot10^7 a$ ($\alpha = -1$, $\beta = 2$) to $I \sim 0.6\cdot10^7 a$ ($\alpha = 1$, $\beta = 0$).

6. Let us investigate further what sorts of effects on the Earth's surface would have taken place from the currents $I_{обл}(\varphi)$ and $I_{гр}(\varphi)$, had these been circular and symmetrical relative to the axis of the geomagnetic dipole. The

computation is performed according to formulas (76), (77) from the work [5]; the results are presented in Figs.8 and 9, in the assumption that $n_0E = 100$ kev/cm^3 (ΔH and ΔZ is the variation of horizontal and vertical components of the magnetic field).

As may be seen in Fig.8, the effect of I currents is determined by the character of anisotropy. The maximum field variation is observed with anisotropy $\alpha = -1$, $\beta = 2$, in this case at the equator $\Delta H \approx -100\gamma$. With isotropic distribution ($\alpha = 0$, $\beta = 0$), the field on the Earth's surface does not practically vary ($\Delta H \sim 0.1\gamma$). The effect of boundary currents (Fig.9) depends relatively little on the anisotropy character. In this case the magnitude of the field variation at the equator fluctuates from $\Delta H \approx -70\gamma$ ($\alpha = 0$, $\beta = 0$) to $\Delta H \approx -100\gamma$ ($\alpha = 0$, $\beta = 2$). The aggregate effect of currents $I_{\text{боп}} + I_{\text{гр}}$ (Fig.10) gives us in optimum variant ($\alpha = -1$, $\beta = 2$) $\Delta H \approx -200\gamma$. Taking into account the currents induced in Earth, this will ensure the field decrease at the equator down to 350γ.

In this way, the model currents generated by the drift of quasitrapped particles investigated by us is apparently capable to explain the observed values of the main phase, on the condition of specific particle distribution by pitch-angles

$$f(\theta) \sim \cos^{\beta}\theta \quad \text{or} \quad f(\theta) \sim \frac{1}{\sin\theta}.$$

In our opinion, following are the results speaking in favor of such a distribution.

1. Significant angular anisotropy (small values of pitch-angles) of the flux of particles injected into magnetosphere through neutral points [32].
2. Correlation between particle flux increase and the intensity variation of the magnetic field observed on "Elektron-2" in the 30-60 latitude region at great distance from the Earth [33].
3. A sharp and simultaneous increase of the precipitating and trapped particles registered on AIS "Injun-3" at small altitudes (300-600 km) during aurorae [31].

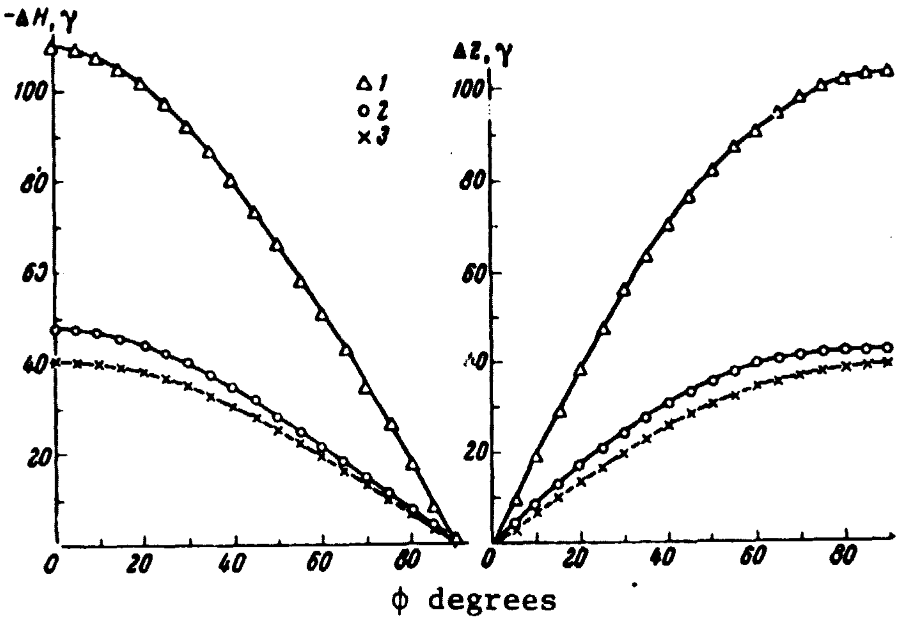

Fig. 8

Effects of currents $I_{\text{обл}}$ on the ground
(n_0E = 100 kev/cm^3)

1 — α = − 1, β = 2; 2 — α = − 1, β = 0; 3 — α = 0, β = 2

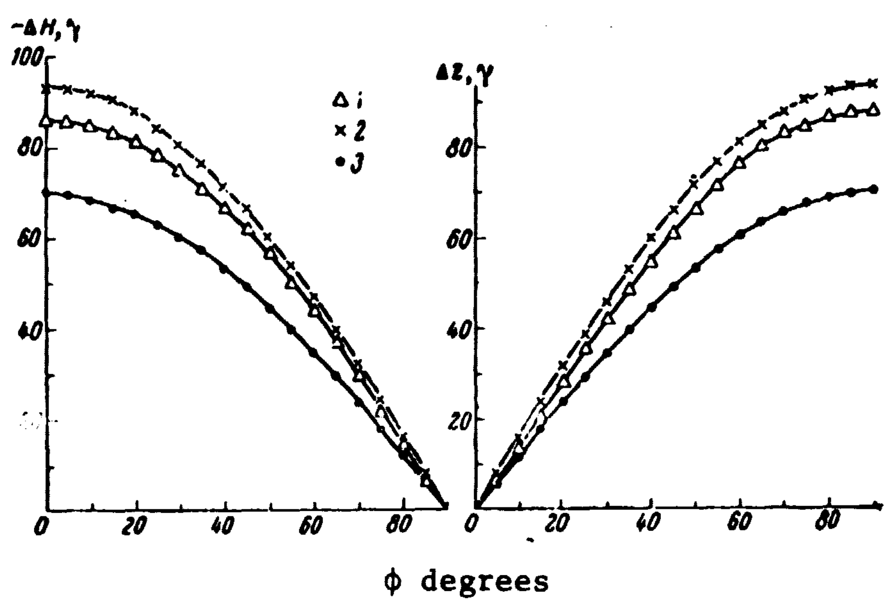

Fig.9

Effects of currents $I_{\text{гр}}$ on the ground
(n_0E = 100 kev/cm^3)

1 — α = − 1, β = 2; 2 — α = 0, β = 2; 3 — α = 0, β = 0

4. The angular distribution getting closer to isotropic at altitudes ∿ 1000 km and at intense particle precipitation [34].

The last result allows us to make a certain choice among several types of angular distribution. The rendering particle flux more isotropic means the equalization of transversal and longitudinal pressures. The great particle

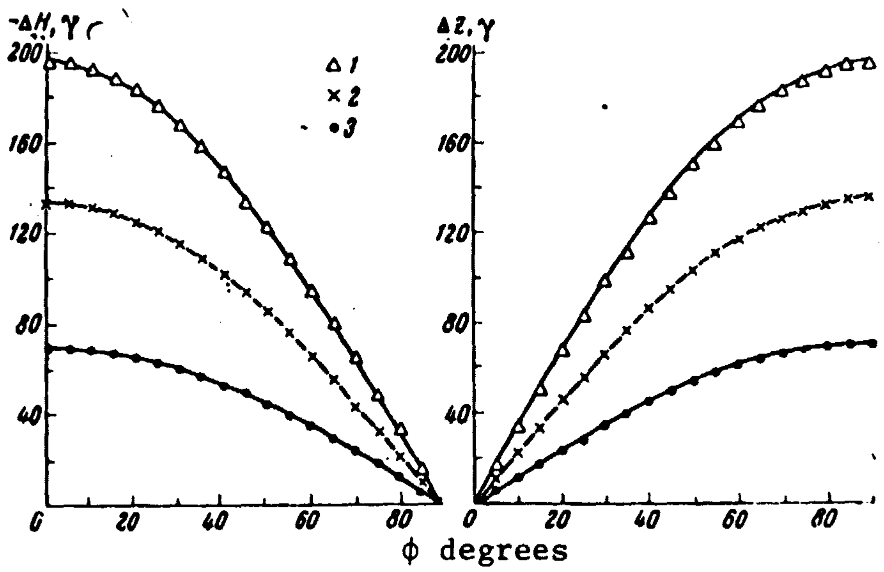

Fig.10

Variation of the magnetic field on the ground under the effect of currents $I_{обл} + I_{гр}$ (n_0E = 100 kev/cm^3)

1 — α = −1, β = 2; 2 — α = 0, β = 2; 3 — α = 0, β = 0

fluxes and the concomitant equalization of the pressures p_n and p_s at small altitudes (i.e. at very small values of $q = B_e/B$) take place with anisotropy $\alpha = 0$, $\beta = 2$.

In this case

$$p_n = mv^2 n_e \left(1 - \frac{4}{5} q\right) \approx mv^2 n_e,$$

$$p_s = mv^2 n_e \left(1 - \frac{2}{5} q\right) \approx mv^2 n_e,$$

i.e. the flux is made isotropic as it moves along the line of force in the direction toward the Earth.

In conclusion, let us note, that this model current of quasitrapped particles does not take into account the azimuthal asymmetry in the distribution of particles linked with the field's azimuthal asymmetry; nor does it account of the influence of the source of charged particles on the daytime side, in the region of neutral points. The indicated effects will be investigated in authors' subsequent works.

Manuscript received
25 December 1968.

*** THE END ***

R E F E R E N C E S

1. A. SCHMIDT, Zs. Geophys., 1, 1924/25.
2. S. CHAPMAN, V.C.A. FERRARO, Terr. Mag. Atmosph. Electronic, 36, 77, 171, 1931; 38, 79, 1933; 45, 245, 1940.
3. S.F. SINGER. Trans. Amer. Geophys. Union, 38, 175, 1957.
4. E.N. PARKER, Phys. Rev., 107, 924, 1957.
5. S.I. AKASOFU, S. CHAPMAN, J. Geophys. Res., 66, 1321, 1961.
6. S.I. AKASOFU, S. CHAPMAN, J.C. CAIN, J. Geophys. Res., 66, 4013, 1961.
7. J.R. APEL, S.F. SINGER, R.C. WENTWORTH, Adv. Geophys., 9, 131, 1962.
8. B. Ye. BRYUNELLI, Geomagnetizm i aeronomiya, 6, 1077, 1966.
9. C.Y. FAN, P. MEYER, J.A. SIMPSON, J. Geophys. Res., 66, 2607, 1961.
10. A.I. YERSHKOVICH, V.D. PLETNEV, Izv. AN SSSR, Ser. geofiz. No.10, 1962.
11. R.A. HOFFMAN, P.A. BRACKEN, J. Geophys. Res., 70, 3541, 1965.
12. V.D. PLETNEV, G.A. SKURIDIN, V.P. SHALIMOV, I.N. SHVACHUNOV, Sb. "Issledovaniya kosmicheskogo prostranstva", Izd-vo "Nauka, 285, 1965.
13. K.I. GRINGAUZ, V.V. BESRUKIKH, V.D. OZEROV, P.E. RYBCHINSKIY, Dokl. AN SSSR, 131, 1301, 1960.
14. J.W. FREEMAN, J.A. VAN ALLEN, L.J. CAHILL, J. Geophys. Res., 68,2121, 1963.
15. L.A. FRANK, J. Geophys. Res., 70, 1593, 1965.
16. H. BRIDGE, A. EGIDI, A. LAZARUS, E. LYON, Space Res., 5,, 969, 1965.
17. K.I. GRINGAUZ, M.Z. KHOKHLOV, Sb. "Issledovaniya kosmicheskogo prostranstva" Izd-vo "Nauka", 467, 1965.

......../

REFERENCES

(continued)

18. S.N. VERNOV, A.YE. CHUDAKOV, P.V. VAKULOV, S.N. KUZNETSOV, YU.I. LOGACHEV E.N. SOSNOVETS, V.G. STOLPOVSKIY.
"Issledovaniya kosmicheskogo prostranstva" Izd-v0 "Nauka, 425, 1965.

19. Y.G. ROEDERER, On the Adiabatic Motion of Energetic Particles in a Model Magnetosphere, NASA, X-640-66-304, Preprint, 1966.

20. G.D. MEAD, In: "Radiation Trapped in the Earth's Magnetic Field, ed. d. Reidel, 1966.

21. S.N. VERNOV, P.V. VAKULOV, S.N. KUZNETSOV, YU.I. LOGACHEV, E.N. SOSNOVETS, V.G. STOLPOVSKIY,
"Geomagnetizm i aeronomiya, 7, 417, 1967.

22. A. YE. ANTONOVA, V.P. SHABANSKIY, Izv. AN SSSR. Ser. Fiz., No.8, 1967.

23. O.V. KHOROSHEVA, Prostransto-vremennoye raspredeleniye polyarnykh siyaniy Dissertatsiya, M., 1965. (Time-Space Distribution of Aurorae) Dissertation, 1965.

24. YA.I. FEL'DSHTEYN, Sb. "Polyarnye siyaniya i svecheniye nochnogo neba", No.13, 98, 1967.

25. S. CHAPMAN, Geofizika, (okolozemnoye prostranstvo). Izd-v0 "MIR", 243, 1964.

26. V.D. PLETNEV, O.A. TROSHICHEV, Kosmich. issled. 6, No.3, 471, 1968.

27. V.D. PLETNEV, Izv. AN SSSR, Ser. geofiz., No.1, 150, 1961.

28. L. SPITTSER, Problemy sovremennoy fiziki, No.2, 26, 1956.

29. Y.H. WOLFE, R.W. SILVA, M.A. MAYERS, Space Res., 6, 1966.

30. F.S. JOHNSON, Okolozemnoye kosmicheskoye prostranstvo (Information data) (Near - Earth Space), Izd-vo "MIR", 105, 1966

31. B.J. O'BRIEN, J. Geophys .Res., 69, 13, 1964.

32. A.I. ERSHKOVICH, V.D. PLETNEV, G.A. SKURIDIN, J. Atmosph. Terr. Phys., 29, 367, 1967.

33. K.I. GRINGAUZ, SH.SH. DOLGINOV, V.V. BEZRUKIKH, YE.G. YEROSHENKO, L.N. ZHUZGOV, L.S. MUSATOV, E.K. SOLOMATINA, U.V. FASTOVSKIY,
Sb. "Issledovaniya kosmicheskogo prostranstva" Izd-vo "Nauka" 336, 1965.

34. B.J. O'BRIEN, In: "Radiation Trapped in the Earth's Magnetic Field", ed. D. Reidel, 321, 1966.

CONTRACT NO.NAS-5-12487
Volt Information Sciences, Inc.,
1145 19th Street, N.W.
Washington, D.C. 20036

Telephone: [202] 223-6700 X 36,37

Translated by
Ludmilla D. Fedine
18 December, 1968
Revised by
Dr. Andre L. Brichant
2 December 1968

END

DATE

FILMED

FEB 5 1969