General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

USS-T

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

ST – PF – GM – 10805

ON THE POSSIBLE INJECTION OF CHARGED PARTICLES INTO THE ZONE OF TRAPPED RADIATION DURING THE MAIN PHASE OF A MAGNETIC STORM

by

V. P. Shalimov

(USSR)

8 FEBRUARY 1969

ST-PF-GM-10805

ON THE POSSIBLE INJECTION OF CHARGED PARTICLES INTO THE ZONE OF TRAPPED RADIATION DURING THE MAIN PHASE OF A MAGNETIC STORM

Kosmicheskiye Issledovaniya
Tom 6, vypusk 6, 941 - 943,
Izdatel'stvo "NAUKA", 1968

by V. P. Shalimov

SUMMARY

The possible injection of charged particles into the zone of trapped radiation during the main phase of a magnetic storm is discussed. The velocity of particle shift across drift shells is computed for a specific structure of the ring current. Some estimates are given of electric field magnitudes and directions. The cases of particles with great and small pitch-angles are considered separately. Possible consequences are evaluated of particle injection from the high-latitude region of quasi-trapped radiation into the outer radiation zone.

*

* *

Data on protons with energy 200 ev < E < 50 kev in the zone of trapped radiation (2 < L < 8) during magnetic storms are brought out in [1]. Here L is the McIlwain parameter and the distances are measured in Earth's radii. The intensity of such low-energy protons on the inner L-shells increases substantially toward the end of the storm's main phase. According to [1], this is explained by equatorial injection of plasma into the outer radiation zone in the course of the initial phase of the storm.

However, the same data allow us to assume that the injection of particles takes place in the period of the main phase. Such particles cannot be equatorial (i.e. they cannot have pitch-angles ~ 90°), for during that time, at preservation of the magnetic flux encompassed by the shell along which the particle's leading center drifts, the trapped charged particles must shift outward across the drift shells. (The rotational electric field $\mathscr{E}$, induced during the enhancement of the ring current responsible for the main phase of the storm is directed to the East). Only particles with small pitch-angles can penetrate inside during the main phase of the storm (because of the zone of quasi-trapped radiation), and this on the condition that there exists at high geomagnetic latitudes a region, in which the electric field has a westerly direction. This assumption is also necessary to explain the close correlation of DP-disturbances with the energy of the ring current [2].

The existence at high latitudes of a region with such a westerly electric field is possible with the peculiar configuration of the ring current, inducing the D_{st}-variation.

It is shown in [3] that the main phase of a magnetic storm may be explained by the current of quasi-trapped particles flowing in the westerly direction near the boundary of the trapping region. In this current the distribution function of particles has the form $f \sim \sin^{\alpha}\theta_0 \cos^{\beta}\theta_0$ (θ_0 being the equatorial pitch-angle), but the current is maximum near the geomagnetic equatorial plane for any values of parameters α and β. However, it follows from [3] that at some types of charged particle distribution at high latitudes, the current may have an easterly direction. The latter, generally speaking, exists alongside with that of westerly direction in any ring current models (see for example, the review [4]); however, for distributions of the type $f \sim \sin^{\alpha}\theta$ the westerly current is always stronger; (at 50 to 60° latitudes, at $\alpha = -1$, $\beta = 2$ and at $\alpha = 0$, $\beta = 2$).

In this case, as the current of quasi-trapped particles is amplified during the main phase of a magnetic storm, there arises at low and middle latitudes a rotational electric field directed eastward, and at high latitudes — directed westward.

The velocity of particle displacement across drift shells in a geomagnetic field $\vec{B}$ with such a ring current structure may be determined by the formula

$$\frac{dL}{dt} = c \left\langle \frac{\mathscr{E}}{B} \right\rangle, \qquad (1)$$

where c is the speed of light, and the parentheses denote the averaging for the period of particle oscillation along the field line between reflection points.

For particles with great pitch-angles $dL/dt > 0$. Particles having small pitch-angles "live" mainly at high latitudes and this is why one may expect that the prevailing influence upon them will be exerted by the westerm electric field; then $dL/dt < 0$.

Let us assume that the displacements of particles across L-shells have been found ($L_2 < L_1$). Then, from the conditions of preservation of the first two adiabatic invariants, that is, the magnetic moment μ and the longitudinal invariant J, it is possible to determine the acceleration and the variation of equatorial pitch-angles of particles. In a dipole geomagnetic field these conditions have the following form:

$$\frac{v^2 \sin^2\theta_0}{B_0(L)} = \text{const}, \qquad (2)$$

$$vL = \text{const (in the assumption of small } \theta_0\text{)}.$$

Here $\underline{v}$ is the velocity of the particle, θ_0 is the equatorial pitch-angle, $B_0(L) = 0.32/L^3$ is the intensity of the magnetic field in gauss at the distance L in the plane of the geomagnetic equator.

Hence it follows that, as L decreases, the particle's energy rises by $\sim L^{-2}$, while the equatorial pitch-angle increases according to the law $\sin\theta_0 \sim L^{-1/2}$. If, for example, $L_2/L_1 = 2$, then $E_2/E_1 = 4$, $\sin\theta_{02}/\sin\theta_{01} = 1.414$.

The increase of equatorial pitch-angles of particles results in the variation of the velocity dL/dt. When θ_0 reach sufficiently high values, the drift of particles inside must cease; subsequently, such particles will behave as the quasi-trapped ones.

It is natural that the quantitative characteristics of the flux of injected particles may be determined from the solution of the kinetic equation for the distribution of particles in a magnetic field, given by a model of most adequate physical reality. In the present work we shall limit ourselves to some estimates of electric field magnitudes and of displacement velocity of particles across the drift shells.

Assume that the geomagnetic field is induced by a dipole with constant magnetic moment $M = 8.07 \cdot 10^{25}$ gauss$\cdot$cm^3, located at the origin of the coordinates and directed along the negative semi-axis $\underline{z}$, and by a system of currents consisting of three rings symmetrical relative to axis $\underline{z}$. The first ring with radius a_0 is located in the plane xy (dipole's equatorial plane); the current I_0 flows along it in the "westerly" direction (clockwise); the second and the third rings, of identical radius a_*, with "easterly" current I_* lie in the planes $z = l$ and $z = -l$.

The vectorial potential of such a current system's magnetic field (see, for example [5]) has one component $A_\phi = A_\phi^{(0)} + A_\phi^{(*)}$, where

$$A_\varphi^{(0)} = -\frac{4I_0}{ck_0}\sqrt{\frac{a_0}{\rho}}\left[\left(1 - \frac{k_0^2}{2}\right)K(k_0) - E(k_0)\right], \tag{4}$$

$$A_\varphi^{(*)} = \frac{4I_*}{c}\sqrt{\frac{a_*}{\rho}}\left\{\left[\left(\frac{1}{k_1} - \frac{k_1}{2}\right)K(k_1) - \frac{1}{k_1}E(k_1)\right] + \right.$$
$$\left. + \left[\left(\frac{1}{k_2} - \frac{k_2}{2}\right)K(k_2) - \frac{1}{k_2}E(k_2)\right]\right\}, \tag{5}$$

where

$$k_0^2 = \frac{4a_0\rho}{(a_0+\rho)^2 + z^2}, \quad k_1^2 = \frac{4a_*\rho}{(a_*+\rho)^2 + (z-l)^2}, \quad k_2^2 = \frac{4a_*\rho}{(a_*+\rho)^2 + (z+l)^2},$$
$$\rho^2 = x^2 + y^2, \quad K(k) = \int_0^{\pi/2}(1 - k^2\sin^2 t)^{-1/2}dt, \quad E(k) = \int_0^{\pi/2}(1 - k^2\sin^2 t)^{1/2}dt.$$

These formulas are also valid in the case of linear variation of currents with time. The rotational electric field $\mathscr{E}$, then emerging, is determined by the relation

$$\mathscr{E} = -\frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}. \tag{6}$$

Consequently $\mathscr{E}_\varphi = \mathscr{E}_\varphi^{(0)} + \mathscr{E}_\varphi^{(*)}$, and, as currents accrue ($dI/dt > 0$)

$$\mathscr{E}_\varphi^{(0)} = -\frac{1}{c}\frac{\partial A_\varphi^{(0)}}{\partial t} > 0, \quad \mathscr{E}_\varphi^{(*)} = \frac{1}{c}\frac{\partial A_\varphi^{(*)}}{\partial t} < 0.$$

The calculations by formulas (4)-(6) at $a_0 = 8$, $l = a_* = 2{,}83$ $I_0 = (2 \div 4)\cdot 10^7$ a, $I_* = (1 \div 2)\cdot 10^7$ a show (*) that at the distance of 1 to 2 R_E from the ring current not lying in the equatorial plane, the predominant field $\mathscr{E}_\varphi^{(*)}$ has westerly direction and its magnitude is of the order $(1 - 2)\cdot 10^{-6}$ v/cm.

For particles with small pitch-angles, long "living" in the region of the field $\mathscr{E}_\varphi^{(*)}$ the displacement velocity across the dipole field lines is

$$d\xi / dt \approx c(\mathscr{E}_\varphi^{(*)} / B).$$

As an average, in the considered region $B = 5\cdot 10^{-3}$ gauss, which yields an estimate of velocity: $\Delta\xi/\Delta t \approx 0.1 - 0.2$ R_E/hour. This means that, say, in

(*) At coordinate origin such currents induce a magnetic field of 100-200γ ($1\gamma = 10^{-5}$ gauss).

10 hours, particles are capable of drifting in the depth of the trap by some 1 to 2 R_E. The distance along the normal to dipole field lines passing through the point r = 4, L = 8, between shells with L_1 = 8 and L_2 = 4, constitutes 1.7, so that such a displacement is quite possible. This transition corresponds to the velocity in the equatorial plane $dL / dt = \kappa L^5$, $\kappa \sim 10^{-4} R_E$ / hour.

Let us now examine the possible consequence of particle injection from the high-latitude region of quasi-trapped radiation into the outer radiation zone. In the first place, these particles may ind ce a "ring"current inside the trap, which contributes notably to the D_{st}-variation. Therefore, it is probable that the D_{st}-variation may be composed of two parts, of which the "faster" is induced by the current of quasi-trapped particles and the "slower" and smooth one — by the ring current inside the outer radiation zone. A similar subdivision of the D_{st}-variation into two parts having different sources, was encountered in [4].

Quite probable is also the possibility of longitudinal asymmetry of currents and particle injection; however, with the commencement of the recovery phase of the storm, when the current increase of quasi-trapped particles and, consequently, the considered injection cease, the current inside the trap must become symmetrical.

During the recovery phase of the magnetic storm the current of quasi-trapped particles dissipates and, as a result, there emerges the western electric field $\varepsilon_\phi^{(0)} < 0$, which now induces a shift of particles across L-shells toward the Earth already with great pitch-angles. This process amplifies the current inside the trapping region, and, by way of consequence, it dissipates significantly slower.

The author is grateful to A. I. Yershkovich, G. A. Skuridina, O. A. Trochicheva for discussing the theme of the present work.

***** T H E E N D *****

Manuscript received on
31 July 1968

References follow...

REFERENCES

1. L. A. FRANK. J. Geophys. Res., 72, No.15, 3753, 1967.
2. T. N. DAVIS, R. PATHASARATHY. Ib. 72, No.23, 5825, 1967.
3. V. D. PLETNEV, O. A. TROSHICHEV. Kosm. Issl., 6, No.5, 707, 1968.
4. S. I. AKASOFU. Space Sci. Rev., 2, No.1, 91, 1963.
5. A. I. MOROZOV, L. S. SOLOV'YEV. Sb."VOPROSY TEORII PLAZMY", vyp.2.,p.3, Gostekhizdat, 1963.

CONTRACT No.NAS-5-12487
VOLT INFORMATION SCIENCES, INC.
1145 - 19th St.NW,
WASHINGTON D.C. 20036.
Tel: 223-6700 (X-36)

Translated by ANDRE L. BRICHANT

on 7 February 1969