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# INTERACTION OF THE INTERPLANETARY MEDIUM WITH THE EARTH'S MAGNETOSPHERE IN A PERIOD OF SOLAR ACTIVITY DECREASE

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## SUMMARY

This paper examines the interaction of the interplanetary medium with the Earth's magnetosphere in a period of solar activity decrease. Daily and 3-hourly values (in the plane of the magnetic equator) are computed of the position of the magnetopause, of the bow shock wave, of the thickness of the transitional region near the subsolar point and of the field of magnetopause currents on the Earth's surface.

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* *

The daily and three-hourly values (respectively for the periods Sept.-October and 29 August to 11 September 1962) of the magnetosphere boundary $r_c$, of the bow shock wave $r_s$, of the transitional region's thickness near the subsolar point $\Delta r_0$ ($r_c$, $r_s$ and $\Delta r_0$ being expressed in Earth's radii $R_E$), of the northern field component of magnetopause currents on the Earth's surface for complementing the geomagnetic latitude $\theta = 90°$ (X) and $\theta = 45°$ (X sin 45°), are computed in the gas dynamics approximation [3] on the basis of measurement data on MARINER-2 of the velocity V, concentration n, plasma temperature T and of the magnetic field H [1, 2].

The respective parameters are represented in Figure 1 (daily) and Fig.2 (three-hourly); their mean values (further denoted by a stroke above) and the threshold (limit) ones (in parentheses) are compiled in Table 1.

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N.B. - Wherever Russian letter э appears in a formula as subscript or otherwise, it stands for "e" - for "experiment"; and з stands for "sound" or "acoustic".

It is shown that the variability of experimental $r_c^e$ and $r_s^e$ on the daytime side [5 - 9] observed on satellites, is well explained on the basis of variations of n, V, T, H.

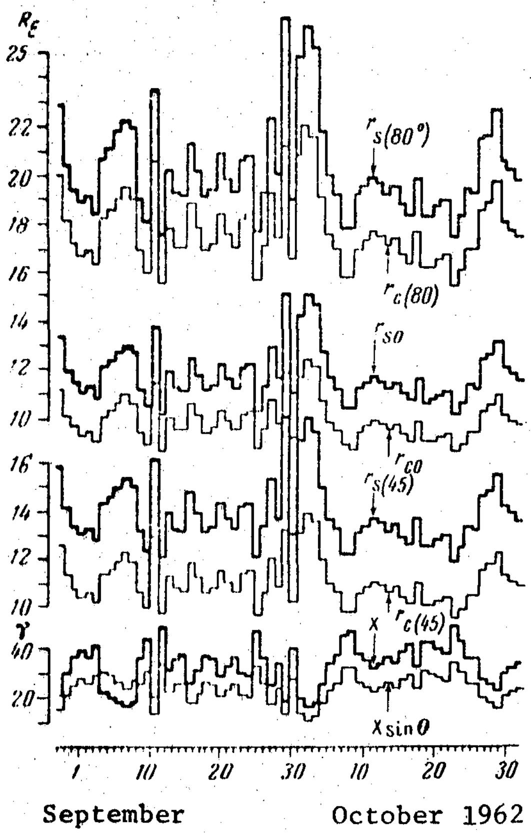


Fig.1

We shall make use for the characteristic propagation velocity of perturbations the velocity of the fast magneto-acoustic wave $V_{M3+}$ and the magneto-acoustic Mach number $M_{M3+}$ [3]. We consider that the Earth's magnetic moment $\vec{M}_E$ is perpendicular to the ecliptic plane, $\vec{V}$ is radial toward the Sun [2], $\vec{H}$ lies in the ecliptic plane at an angle $\phi = -45°$ counted from the line Earth-Sun [2], (in the afternoon quadrant $\phi > 0$). Inasmuch as the computations of $r_c$ are confined within the limits $\Phi = \pm 80°$ and the statistical pressure $p_2$ is much less than the dynamic pressure $p_1 = mnV^2$ [3], we shall neglect $p_2$.

Utilizing the conditions and the expressions from [4, 10], after a series of transformations, we shall obtain

$$r_c = r_{c0}[1/\cos\psi]^{1/3}, \qquad (1)$$

where the distance to the magnetopause at the subsolar point is

$$r_{c0} = \left[\frac{H_э^2}{2\pi K mnV^2}\right]^{1/6}, \qquad (2)$$

$H_e = 0.312$ gauss is the intensity of the field on the Earth's surface on the geomagnetic equator; $\psi$ is the angle between $(-\vec{V})$ and the external normal to the magnetopause $\vec{n}$; K is a constant. We consider that for the examined part of the magnetosphere $r_c$ is symmetrical relative to the line Earth-Sun. In the Newtonian approximation $K = 2$ [4, 10], which is overrated [3].

It may be shown, after [4, 11], that at $\gamma = 1.5$ (adiabate exponent), $K = 0.881$ [3]. Plasma measurements on a shock wave [12] point in favor of $K < 1$ [3].

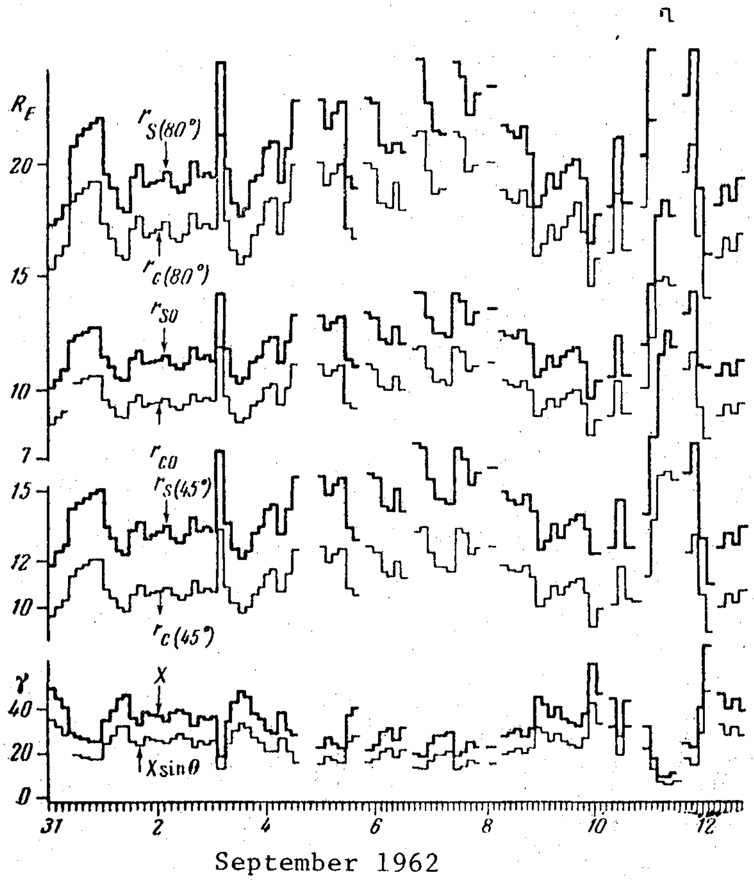


Fig.2

According to [13],

$$r_s = 1{,}24 r_{c0} \sec\alpha (1 + \sec\alpha) / (1 + \sec\alpha \cos\varphi), \quad (3)$$

where

$$\alpha = \arcsin(1 / M_{M3+}) = \arcsin(V_{M3+} / V), \quad (4)$$

$$V_{M3+} = [{}^1/_2 (V_3^2 + V_A^2) \sqrt{(V_3^2 + V_A^2)^2 - 4V_3^2 V_A^2 \cos^2\theta'}]^{1/2}, \quad (5)$$

$$V_A = H / \sqrt{4\pi m n}, \qquad V_3 = \sqrt{\gamma k T / m}, \quad (6)$$

$k = 1.38 \cdot 10^{-16}$ erg$\cdot$deg$^{-1}$; $\theta'$ is the angle between $\vec{H}$ and $\vec{r}_S$, linked with $\phi$ by the relation $\theta' = \phi + 45°$. In accord with [4, 11], but using $M_{M3+}$ [3]

$$\Delta r_0 = 1{,}1 \left[ \frac{H_3^2}{2\pi K m n V^2} \right] \frac{(\gamma - 1) M^2_{M3+} + 2}{(\gamma + 1) M^2_{M3+}}. \quad (7)$$

TABLE 1

| Parameters | 31.VIII–11.IX | September | October | Sept.–Oct. |
|---|---|---|---|---|
| $r_{c0}$ | 10,13 (8,06–14,89) | 9,91 (8,63–11,76) | 9,78 (8,56–12,27) | 9,84 |
| $r_{s0}$ | 12,1 (9,57–18,24) | 11,82 (10,24–15,03) | 11,67 (10,17–15,01) | 11,74 |
| $\Delta r_0$ | 2,44 (1,85–4,22) | 2,36 (1,97–4,11) | 2,34 (1,99–3,44) | 2,35 |
| $r_{c(45)}$ | 11,37 (9,05–16,71) | 11,13 (9,69–13,20) | 10,97 (9,61–13,78) | 11,05 |
| $r_{s(45)}$ | 14,21 (11,22–21,48) | 13,88 (12,00–17,78) | 13,70 (11,94–17,69) | 13,79 |
| $r_{s(-45)}$ | 14,17 (11,19–21,40) | 13,85 (12,00–17,68) | 13,65 (11,89–17,58) | 13,74 |
| $r_{c(80)}$ | 18,06 (14,45–26,69) | 17,77 (15,47–21,07) | 17,52 (15,34–22,00) | 17,64 |
| $r_{s(80)}$ | 20,61 (16,34–31,52) | 20,23 (17,47–26,38) | 19,97 (17,38–25,93) | 20,10 |
| $X, \gamma$ | 31,85 (9,34–58,80) | 32,72 (18,99–48,04) | 34,50 (16,69–49,23) | 33,61 |
| $X \sin 45°, \gamma$ | 22,54 (6,60–41,60) | 23,13 (13,43–33,97) | 24,40 (11,80–34,81) | 23,76 |

As is shown in Fig.3, plotted according to data of Table 1 (the upper part corresponding to the three-hourly values and the lower one – to daily values, the squares representing the threshold positions of $r_s$ and the circles – of $r_c$), $r_c$ and $r_s$ were computed respectively for $\psi = 0°$ and $\phi = 0°$ ($r_c$, $r_s$), $\psi = 45°$ and $\phi = 45°$ ($r_{c(45)}$, $r_{s(45)}$), $\psi = 80°$ and $\phi = 80°$ ($r_{c(80)}$, $r_{s(80)}$). Note that for $\phi = 45, 80°$ etc. we shall denote $r_c$ as ${}^{\varphi}r_{c45}$, ${}^{\varphi}r_{c80}$ and so forth. If we utilize the coeff cients from [21], we may be able to show that ${}^{\varphi}r_{c45} = 1{,}069\ r_{c0}$, ${}^{\varphi}r_{c80} = 1{,}25\ r_{c0}$, ${}^{\varphi}r_{c90} = 1{,}349\ r_{c0}$, $r_{c(45)} = {}^{\varphi}r_{c57} \approx 1{,}12\ r_{c0}$ (i. e. $\psi = 45° \leftrightarrow \varphi \approx 55 \div 60°$), $r_{c(80)} = {}^{\varphi}r_{c117} \approx 1{,}79\ r_{c0}$ (*)

Analysis of the data allowed us to obtain a eeries of results. First of all let us draw attention to the strong variability of $r_c$ and $r_s$. The three-hourly values descend from $r_{c0} \approx 14{,}9\ R_E$ and $r_{s0} \approx 18{,}2\ R_E$ ($r_{c(80)} \approx 26{,}7\ R_E$ and $r_{s(80)} \approx$ $\approx 31{,}5\ R_E$), having taken place on 11 September at 0900-1200 hrs UT, when $p_1 \approx$ $\approx 0117\ 10^{-8}$ dyne/cm$^2$, $M_s \approx 12{,}4$, $M_A \approx 3{,}8$, $M_{Ms} \approx 3{,}6$, till $r_{c0} \approx 7{,}8\ R_E$ and $r_{s0} \approx 9{,}2\ R_E$ ($r_{c(80)} \approx 14{,}0\ R_E$ and $r_{s(80)} \approx 15{,}8\ R_E$), having taken place on 12 September at 0300-0600 hours UT, when $p_1 \approx 7{,}68 \cdot 10^{-8}$ dyne/cm$^2$, $M_s \approx 12{,}8$, $M_A \approx 16{,}9$ and $M_{Ms} \approx 5{,}0$ [3]. Thus, at dynamic pressure drop $\Delta p_1 \approx 7{,}5 \cdot 10^{-8}$ dyne/cm variation of $\Delta r_{c0} \approx 7\ R_E$ and $\Delta r_{s0} \approx 9\ R_E$ ($\Delta r_{c(80)} \approx 13\ R_E$ and $\Delta r_{s(80)} \approx 15{,}7\ R_E$) was observed. For daily values $\Delta p_1 \approx 3{,}9 \cdot 10^{-8}$ dyne/cm$^2$ corresponded $\Delta r_{s0} \approx 3{,}7\ R_E$ and $\Delta r_{s0} \approx 4{,}8\ R_E$ ($\Delta r_{c(80)} \approx 6{,}7\ R_E$ and $\Delta r_{s(80)} \approx 8{,}6\ R_E$). Let us note that the limits of three-hourly

(*) (t. e. $\psi = 80° \leftrightarrow \varphi \approx 115–120°$).

values of $r_c$ and $r_s$ variation are greater than the corresponding thresholds for the daily values, though $\overline{r}_c$ and $\overline{r}_s$ nearly coincide for both periods of averaging.

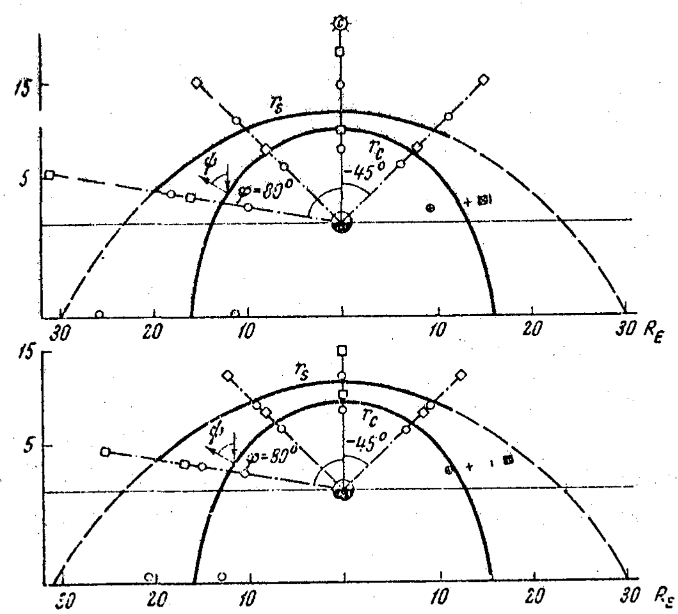

Fig.3

The period of $r_c$ and $r_s$ variations change within broad limits, from 3 hrs to ~ 10-15 days. Particularly notworthy is the variation with period of ~ 10-15 days (see Fig.1), whose minima take place near the boundaries of the sectors of interplanetary magnetic fields of opposite polarity [20], when $\beta = 8\pi nkT/H^2 > 1$ and $M_{M3}$ are greater. The maxima of $r_c$ and $r_s$ are observed for $\beta < 1$ and $M_{M3}$ low. Let us point to the synchronous behavior of $r_c$ and $r_s$. There is a visible tendency to back coupling of $p_1$ with $r_c$ and $r_s$, which speaks of prevailing influence of $p_1$. The back coupling is noticed between $r_s$ and $M_{M3}$, which should have been expected on the basis of the gas dynamics principle.

Comparison of $r_c$ and $r_s$ with $r_c^e$ and $r_s^e$ has shown that there are sufficient V, n, T and H variations for the explanation of the greater part of $r_c^e$ and $r_s^e$ variability that was observed on satllites [5 - 9]. This is particularly well seen when comparing with $r_c^e$ and $r_s^e$ obtained on Explorer-14 on 7 and 19 October 1962 for $\phi \approx -(79 - 90°)$, when sharp variations of n, V, T, H were observed on Mariner-2 [1, 2, 6, 7], while SC and SI were registered on the ground on 7 September; ${}^{\varphi}r^{0}_{c80} \approx 13{,}5\,R_E$ and $r^{0}_{s(80)} \approx 15-16\,R_E$ (this corresponds in Fig.3 to respectively a cross and a stroke), while the three-hourly ${}^{\varphi}r_{c117} \approx$ $\approx 13{,}4\,R_E$, ${}^{\varphi}r_{c80} \approx 9{,}3\,R_E$ and $r_{s(80)} \approx 15{,}0\,R_E$ (in Fig.3 these are circles and squares with crosses, i. e. the agreement is very good (in truth, on 19 October the agreement is satisfactory).

For the considered period $r_{s(+45)}$ is only insignificantly greater than $r_{s(-45)}$, i. e. $\theta'$ is feebly influencing $r_s$, which justifies the direction og $\vec{H}$ fixed by us. Moreover, $r_{s_0} - r_{c0} < \Delta r_0$, but by very little.

Let us examine the shape of the magnetopause and of the shock wave, constructed by $\overline{r}_c$ and $\overline{r}_s$ (Fig.3). In the initial period of its operation, the satellite EXPLORER-14 ($\phi = -80°$) cross the boundary of the magnetosphere only at times, but, as a rule, it was situated beyond ~ 16.5 $R_E$, which agrees well with $\overline{r}_{c(80)} \approx 17.6\ R_E$ and somewhat worse with $r_{c80} \approx 12.13\ R_E$. Within the limits $\phi = 0 - 45°$ for EXPLORER-14, having flown one year earlier than MARINER-2, $\overline{r}_c^{e} \approx 10.7\ R_E$ [5], while $(\bar{r}_{c0} + \bar{r}_{c(45)})/2 = 10{,}4\,R_E$, i.e. the coincidence is good. The shape of $\overline{r}_c$ and $\overline{r}_s$ agrees satisfactorily with the shape constructed according to data of IMP-1, altough $\bar{r}_{s0}{}^{i} > \bar{r}_{s0}$. $\bar{r}_{s0} < \bar{r}_{s0}{}^{i}$ may be explained either by parameter variation of interplanetary medium (in particular, by the decrease of $M_{M3+}$), or by the fact that in our case $r_{s0}$ are underrated, i. e. the utilized formula for $r_{s0}$ from [13] reflects insufficiently well the pattern of the subsolar region.

The factors influencing $r_c$ and $r_s$ may be roughly subdivided into the outer, linked with the parameters of the interplanetary medium, and the inner, linked with the parameters and the state of the magnetosphere. Related to the latter are: the inflation (bulb) of the magnetosphere [14] during the intrusion of solar plasma [15], the expansion of the magnetosphere at heating of its matter by shock waves [16], the influence of the nondipole part of the geomagnetic field [17], the resonance properties of the magnetosphere resulting in the oscillations of the magnetopause. Apparently, the determining factors are the external ones, though in isolated cases, and in particular in the main phase and in the phase period of magnetic storm recovery, the expansion of the magnetosphere at the expense of inner factors may result to be more substantial [5,14].

According to [18],

$$X = 0.0305\sqrt{n}V \cdot \sin\theta, \qquad (8)$$

From the results of computations (Figs 1, a, Table 1) one may see first of all the substantial variability of X. The maximum variation of two consecutive daily values of X (11 and 12 September), $\Delta X \approx 30\gamma$. For the three-hourly values during the period 29 August- 12 September, $\Delta X \approx 55\gamma$ for $\Delta p_1 \approx 7.5\ 10^{-8}$ dyne/cm$^2$. The maximum variation of two consecutive three-hourly values (12 September) constituted $\Delta X \approx 27\gamma$ for $\Delta p_1 \approx 5\ 10^{-8}$ dyne/cm$^2$.

The data considered relative to X corroborate the correctness of the earlier obtained deductions that SC magnetic storms, sudden impulses SI and to a significant degree the initial phase of a magnetic storm can be explained by the magnetopause current field [18, 19]. It seems to us that these effects may diminish the lowering of the field in the period of the main phase of a storm and contribute specifically to $D_i$.

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