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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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GEOPHYSICS

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ON THE PLANETARY DISTRIBUTION OF MAGNETIC-IONOSPHERIC DISTURBANCES AND AURORAS

(Presented by Academician V. V. Shuleikin on 13 III 1957)

We have shown ($^{1-3}$) that the isochrones of the morning maximum of magnetic disturbances in the Arctic constitute a system of spirals emerging from the pole of uniform magnetization and unwinding clockwise. According to Störmer, these are spirals of deposition of solar corpuscles into the Earth' s atmosphere. The use of data on anomalous absorption in the ionosphere has enabled us (^{4}) to extrapolate the spirals of deposition in the western hemisphere down to $\Phi = 50°$. This system of deposition spirals is shown in Fig. 1.

Fig. 1. Isochrones of the morning maximum of magnetic disturbances (universal time): *a*—zone of maximum frequency and intensity of magnetic disturbances and auroras (Fritz zone); *b*—second zone with increased intensity of these phenomena

Störmer gives (^{5}) a theoretically obtained (Fig. 2) spiral of proton deposition for the Arctic, corresponding to protons of a definite rigidity. The magnetic moment of the Earth in the calculations was taken as equal to $M = 8.1 \cdot 10^{25}$ CGSM. An interesting feature of this deposition spiral is the existence in it of four regions where the trajectories of solar protons are most densely concentrated. From Fig. 2 it is seen that these four regions—let us call them regions A, B, V, and G—are centered, respectively: 1) region A at 14 hours local time; 2) region B at 20 hours—the regions A and B are the most distant from the pole of the magnetic dipole; 3) region V at 0-2 hours; 4) region G—the closest to the pole—at 8-9 hours local time.

As the Earth rotates daily, it will pass beneath the spiral of proton deposition associated with the Sun. As a result of this, in the case considered by Störmer of an ideal Earth, for which the axis of rotation coincides with the axis of magnetization, four annular zones (belts) should appear on the Earth' s surface, corresponding to the four regions of concentration of proton trajectories on the deposition spiral (Fig. 2). Evidently, in these four zones one should expect an increase in the intensity of magnetic-ionospheric-

···of disturbances and auroras caused by incursions of solar protons. Under the conditions of the real Earth, the axis of the magnetic dipole and the axis of rotation are separated by 12°. Taking this fact into account in the analysis of magnetic disturbances in the Arctic enabled us ([2]) to conclude that the change in the effective magnetic moment of the Earth, occurring as a result of its rotation, must play a cardinal role with respect to the approaching streams of solar corpuscles. Therefore the four zones mentioned are not regular circles, but have a more complex form.

We have repeatedly ([1–3]) emphasized that the Birkeland–Störmer point of view corresponds most closely to reality, and therefore here as well we shall adhere to this point of view.

Let us find the possible position of Störmer' s four zones with an increased intensity of proton penetration into the Earth' s atmosphere, in which an increased intensity of magnetic-ionospheric disturbances and auroras should likewise be observed; in doing so we shall proceed from the known facts on the geographical distribution of these phenomena.

Analysis of Fig. 1 gives grounds to believe that in the western hemisphere protons may penetrate down to latitude $\varphi = 40^\circ$ ($\Phi = 50^\circ$). Hough ([6]) suggests that in North America the spirals of precipitation may penetrate as far as Tucson ($\varphi = 32.2^\circ$; $\lambda = 249.2^\circ$; $\Phi = 40.4^\circ$). Indeed, from the form of the precipitation spirals (Fig. 1) passing through the western hemisphere and corresponding to 8, 10, and 12 hours of universal time, one may suppose that during these hours favorable conditions are created for the penetration of protons even into the equatorial region of the Earth. From the point of view of generally accepted ideas this supposition seems wholly unacceptable; however, it can be tested if Störmer' s conclusions are considered correct. Thus, from the work of Narayanaswami ([7]) it follows that at Bombay ($\varphi = 18.9^\circ$; $\lambda = 72.8^\circ$; $\Phi = 9.5^\circ$), in the diurnal course of irregular magnetic disturbances, there is a maximum occurring at 14 h local time, which has not yet been explained. If one considers that this maximum corresponds in its nature to region A (the crowding of proton trajectories at 14 h, Fig. 2) on Störmer' s precipitation spiral, then at 14 h local time Bombay must lie on that proton precipitation spiral which corresponds to 10 h universal time. Clearly this can only be a consequence of the fact that precisely in the indicated interval of the day–8, 10, and 12 h universal time–the effective magnetic moment of the Earth reaches an optimum (smallest) value, at which the most favorable conditions are created for protons to break through even to equatorial latitudes. At any other hours of the universal day such conditions for proton penetration to the equator are not realized, and the maximum distance of the proton precipitation spirals from the pole of the

Fig. 2. Theoretical spiral of proton precipitation in the Arctic (after Störmer)

Figure 2: Fig. 2. Theoretical spiral of proton precipitation in the Arctic (after Störmer)

Fig. 3

Figure 3: Fig. 3

terrestrial dipole decreases.

Fig. 2. Theoretical spiral of proton precipitation in the Arctic (after Störmer)

A detailed analysis of the precipitation spirals obtained on the basis of an analysis of experimental data on magnetic-ionospheric disturbances (Fig. 1), and, in particular, from the fact that at 8, 10, and 12 h the precipitation spirals may extend into equatorial latitudes, makes it possible, schematically and in a first approximation, to draw zone A for the entire northern hemisphere. In this zone, approximately at 14-15 h local time, an increased···

new intrusion of protons and, as a consequence, an increased intensity of magneto-ionospheric disturbances and auroras is observed.

Zone A at longitudes 70-90°, as follows from Bombay data, extends to equatorial latitudes. From Fig. 1 it is evident that on the isochrone-spirals from 12 to 17 hr and from 04 to 08 hr, region A must occupy an increasingly northern position. Accordingly, during these hours zone A will rise to ever higher latitudes. The form of the isochrones corresponding to the time from 18 to 03 hr changes comparatively little. This means that region A on each of the spirals in this interval of the day, and consequently the whole of zone A, will be located at approximately the same distance from the dipole pole—at $\Phi = 50–55°$. All this will occur as a result of an increase in the effective magnetic moment of the Earth. The assumed schematic position of zone A as a whole is presented in Fig. 3.

Fig. 3. Geographic distribution in the northern hemisphere of zones A, B, V, and G, in which increased intensity and frequency of magneto-ionospheric disturbances and auroras should be observed; 10_n—the precipitation spiral corresponding to 10 hr universal time

An analogous consideration may be carried out for zones B and V, corresponding to 20 and 02 hr local time. On the 10-hr isochrone, in accordance with Størmer's theoretical precipitation spiral (Fig. 2), the regions B and V can be plotted approximately. Further, analysis of Figs. 1 and 3 shows that at 20 hr protons along the precipitation spirals can penetrate far to the south, down to $\Phi = 10–15°$, only at longitudes 160-180°, and at 02 hr down to $\Phi = 25–30°$ only at longitudes 250-270°. At any universal-time hours other than 9-11 hr, zone B is located closer to the pole, predominantly at $\Phi = 60–62°$, and zone V predominantly at $\Phi = 64–67°$. All these three zones, by their portions of greatest extension toward the equator, are displaced relative to one another by approximately 90° to the east.

The known zone of maximum frequency and intensity of magnetic disturbances and auroras—the Fritz zone—may be regarded as the combined effect of Størmer' s zones B and V.

The fourth zone—zone G, lying closest of all to the dipole pole, in the very circumpolar region of the Arctic, can be delineated in the same way as the three more southerly zones. However, for its exact drawing, it apparently requires the use of local geomagnetic time, since this zone lies in a region where the effects of noncoincidence of the axes of rotation and magnetization of the Earth may manifest themselves most strongly.

There is every reason to assert that the second zone of increased magnetic activity, whose existence we derived ([1,2]) from an analysis of magnetic disturbances in the Arctic, in its physical meaning is nothing other than Størmer' s fourth zone—zone G, located closest to the pole of the magnetic dipole in the Arctic. Therefore, in Fig. 3

we reproduce the second zone we found as Störmer' s zone i. It cannot fail to be noted that this zone as well, constructed by an entirely independent method, is in its form very similar to the three more southerly zones, and the major axis of the second zone is deflected eastward still more, as indeed should be the case according to Störmer' s conclusion (Fig. 2). The major axis of Störmer' s zone Γ should pass approximately along longitudes 340–360°, whereas the second zone has the greatest elongation along the 290° meridian. The discrepancy of 50° is not of fundamental significance and can probably be reduced by a more detailed analysis of the entire complex of questions involved.

Thus, in the case of an ideal Earth, at any point in the Northern Hemisphere four relative maxima should be observed in the daily course of the intensity and frequency of irregular magnetic-ionospheric disturbances and aurorae: at 14, 20, 02, and 08 hours local time. The relative intensity of each of these four maxima would depend on the position of the station with respect to the four annular zones A, , , and Γ. Under the conditions of the real Earth, the geographic distribution of the types of daily variation in the intensity and frequency of irregular magnetic-ionospheric disturbances should be, as is evident from Fig. 3, more complex.

In order to show the correctness of the conclusions drawn, we shall use Fig. 3 to explain certain facts. As is known ([8,9]), radar observations of aurorae carried out at Itaka ($\varphi = 42.4^{\circ}$; $\lambda = 283.5^{\circ}$; $\Phi = 54.0^{\circ}$) and Jodrell Bank ($\varphi = 53.5^{\circ}$; $\lambda = 357.8^{\circ}$; $\Phi = 56.7^{\circ}$) showed that the greatest probability of aurorae occurs at 18–19 hours and 02–03 hours local time. From Fig. 3 it is evident that precisely during these hours the regions and , with which the increased penetration of protons into the Earth' s atmosphere is associated, pass through Itaka and Jodrell Bank.

The question arises whether the increase in magnetic activity at the equator can be explained by the joint influence of protons breaking through to the equator along precipitation spirals from both poles of the Earth' s dipole.

For electrons, by analogy with protons, there should likewise exist four zones: A', $'$, $'$, and Γ'.

In the Southern Hemisphere, in principle, the same pattern should be observed as for the Northern Hemisphere, with the only difference that the precipitation spirals will unwind for protons counterclockwise, and for electrons clockwise.

The zones A, , , and Γ of the most intense penetration of protons into the Earth' s atmosphere in the Northern Hemisphere are plotted in Fig. 3 in a first approximation. It was assumed that the regions A, , , and Γ of proton concentration on the precipitation spirals move uniformly as the Earth rotates. In reality, because the precipitation spirals for different hours of universal time differ somewhat in shape, the zones A, , , and Γ must pass somewhat differently, in particular probably closer to the pole.

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Note: Figure translations are in progress. See original paper for figures.