DISTRIBUTION OF AURORAE AND MAGNETIC DISTURBANCES AT HIGH LATITUDES IN RELATION TO THE ASYMMETRIC SHAPE OF THE MAGNETOSPHERE

Ya. I. Fel'dshteyn

ABSTRACT: On the basis of the materials from observations of aurorae at the zenith, with the network of "All-Sky" cameras, during the periods 1957-1959 and 1963-1965, the distribution of the aurorae is shown in relation to the latitude and the local time, for magnetically quiet ($K_p \leq 1$) and magnetically disturbed periods ($K_p \geq 5$).

The position of the auroral zone was obtained for the IGY period on the night and day sides of the Earth, and for the IQSY period on the night side, with $K_p \leq 1$ and $K_p \geq 5$. The presence of a noticeable asymmetry was also shown for magnetically quiet and magnetically disturbed periods. The paper discusses the cyclic changes in the occurrence of aurorae during the night, and the latitude distribution of the mean diurnal values of aurorae-occurrence.

The results of a statistical analysis of the aurorae distribution were supplemented with synoptic maps of the aurorae distribution at fixed moments of Universal Time on December 13 and 23, 1957.

The disturbed solar-diurnal variation S_D of the components H, Z, and D in the geomagnetic field was calculated according to the observational data of geomagnetic-field variations obtained at 24 high-latitude observatories in the Northern Hemisphere. The paper shows that the distribution of the disturbed vector corresponds with the assumption that there is an intensive current in the ionosphere passing along the asymmetric auroral zone in the western direction. The current system of the polar magnetic disturbance (PD) is also presented.

The concept of an oval current zone located at higher latitudes in the day and at lower altitudes during the night correlates well with the ratio between the values of ΔT_{hor} at the stations in Tikhaya Bay and Tromsö, as well as with the distribution of magnetic activity at Canadian stations.

Measurements of the magnetic field by cosmic soundings showed /98
that the lines of force of the geomagnetic field are constricted on the day side of the Earth, and expanded on the night side [1-4]. As a result of the asymmetric shape of the magnetosphere, the corpuscular streams move toward the upper layers of the atmosphere ($H \sim 100$ km). On the day side, they move to higher latitudes than on the night side. Therefore, we should expect that there would be significant diurnal changes in the latitude of the region for the maximum frequency of appearances of aurorae at the zenith and of intensive geomagnetic disturbances. The auroral zone with the coordinates Φ' (corrected, or invariant, geomagnetic latitude) and t_g (local geomagnetic time) has an oval shape with a minimum distance from the geomagnetic pole during the day hours, and a maximum distance during the night hours. Such an oval-shaped zone for visual aurorae was suggested in [5,6], and was further confirmed in [7,10].

Recent satellite observations [11-13] showed that there is a large diurnal variation in the position of the outer boundary of the radiation zone for electrons with energies $\geq$ 40 KeV which are trapped in the atmosphere, and which invade it. In this case, the outer boundary differs insignificantly for the trapped and invading electrons, and is 4-88° closer to the pole during the day hours, in comparison with the night. Theoretical calculations [14-18] showed the possibility of a latitude-dislocation of the charged particles during their drift in the dipolar field formed around the Earth, from the day side to the night. The magnitude of the dislocation depends on the model used for the magnetic field. The zone for the emptying-out of charged particles for the region of the drift currents is found at lower latitudes on the night side than on the day side, because of the inclination of the drift currents toward the plane of the equator [18a].

For a statistical analysis of the frequency of appearance of aurorae, we used the ascaplots of the ascafilms in C-180 cameras which were published in [19] for the period from June 1, 1957 to June 31, 1959, for stations in the Northern Hemisphere. The probability of aurora-apperaances was evaluated by the ratio between the number of half-hour intervals with an aurora at the zenith and the total number of intervals for the observations. The ascaplots were compared according to a single instruction [20] with insignificant types of changes in certain countries. However, the varying quality of the materials obtained, and the difficulties /99
in interpreting the films, lead to a difference in the frequency of appearance of aurorae, in some cases, at near-by stations. Figure 1 shows latitude cross-sections for the probability of aurorae at 0-1, 10-11, and 15-16 local time, in relation to Φ'. Each point corresponds to a separate station. The curves in the Figure characterize the leveled-out change in the probability of appearance of aurorae in relation to the latitude. Those curves were obtained for each hour of a day. The frequency of appearance of aurorae from the leveled-out curves for each degree of corrected geomagnetic

latitude was used in constructing Figure 2, in which the northern polar cap was divided into areas where there was an identical probability of appearance of aurorae. The numbers in the corresponding region signify the frequency of appearance of aurorae. The coordinate system used is the corrected geomagnetic latitude and the local time. A representation of the data in such a system of coordinated is convenient for comparison with the data from satellites. The region with the greatest frequency of appearance of aurorae (shaded region in the Figure) shows significant diurnal displacements from the day hours to the night. When Φ' is less than the latitudes of the oval shaded region, the aurora-distribution is symmetrical in relation to the noon-midnight meridians, while a great symmetry is observed in the circumpolar region in relation to the meridian of ~ 8:00.

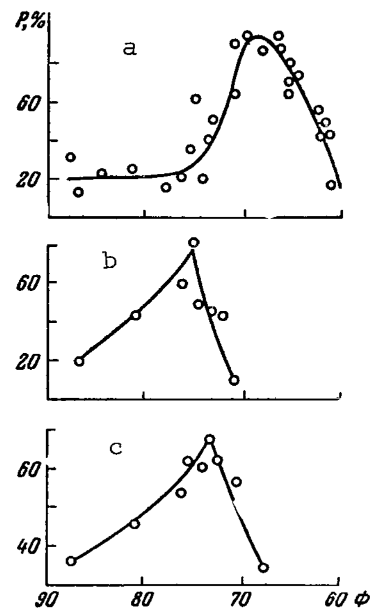


Fig. 1. Frequency of Appearance of Aurorae Versus Φ' at (a) 0:00-1:00, (b) 10:00-11:00; (c) 15:00-16:00, Local Time.

The appearance of visual aurorae is caused, as a rule, by the invasion of electrons with energies of several kilo-electron-volts [21-23]. Therefore, in comparing the aurorae-distributions and the invading particles, it is necessary to make such omparisons with low-energy electrons. However, at the present, the distribution of electrons intruding into high latitudes is known in great detail only for $E \geq 40$ KeV, which, obviously, also reflects to some degree the behavior of electrons with lesser energies.

A comparison of the aurora-distribution with the intensity of the invading electrons with $E \geq 40$ KeV, according to the data of Figure 11 in [13], shows good correspondence in the shape of the outer boundary for the region of the greatest frequency of aurorae at the zenith and the region of the invading particles, while there is displacement from lower latitudes during the night hours to higher latitudes during the day. Thus, the oval zone of the aurorae is located at the latitudes of the outer boundary for the region where electrons, with $E \geq 40$ KeV, intrude.

However, the distribution of the aurorae, and thus that of the invading electrons with energies of 1-10 KeV (which are responsible

for the appearance of the aurorae), differs greatly from that presented in [13]. On the equatorial side of the region where the frequency of aurora-appearances is maximum, there is observed a substantial decrease in the number of aurorae, both during the day hours and during the night. On the day side (Φ'   70°), visual aurorae appear very infrequently. At the same time, the intensity of the electrons with $E \geq 40$ KeV on the day side increases monotonically when Φ' decreases 78 to 70°. Since the outer boundaries for the region of entrapped and intruding electrons with /100
$E \geq 40$ KeV coincide roughly [12, 13], while the intruding electrons are near the high-latitude margin for the region of trapped electrons [24], a decrease in the frequency of appearance of aurorae at lower latitudes is not unexpected.

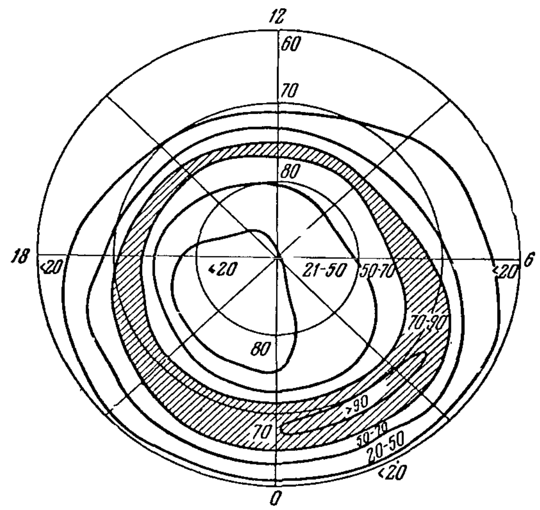


Fig. 2. Frequency of Appearance of Aurorae at the Zenith During the Period 1957-1959 in the Northern Hemisphere, Accoding to Observations on All Days.

It is of interest to examine the latitude distribution of the average diurnal values for the frequency of appearance of aurorae. This problem was first solved in [25], in which the diurnal changes in the frequency of appearance of aurorae at a large number of different stations were used directly. Since the photographic observations were made at these stations with an interruption during the day hours, the diurnal variations in the appearance of aurorae were extrapolated in [25] in order to obtain the average diurnal values. With respect to a certain arbitrariness in the extrapolation, the average diurnal values for the appearance of aurorae were characterized by a significant variance for stations which were located at similar Φ'. Moreover, the varying quality of the ascafilms and the difficulties in interpreting them were also seen in the magnitude of the variance. However, the conclusion was drawn in [25] that the frequency of appearance of aurorae, averaged per day, was maximum at $\Phi \sim 72°$, i.e., at 4-5° in the direction toward the pole from the zone for the nocturnal aurorae.

The leveled-out latitide-distributions we obtained for the frequency of appearance of aurorae for each hour of the day provided for calculating the average diurnal value for the frequency of appearance of aurorae without recourse to extrapolation, in the entire range of high latitudes ($\Phi' > 70°$). South of 70°, we could not avoid extrapolations for several day hours, since, at these latitudes, one station does not conduct 24-hour observations. Extrapolation was necessary within the limits of 4 hours at $\Phi' \sim 70°$, and increases to 7 hours at $\Phi' \sim 65°$.

Figure 3(a) shows the latitude-distribution calculated for the average diurnal values of the rate of appearance of aurorae, and Figure 3(b) shows the diurnal changes in the rate of appearance of aurorae in relation to the oocal time at $\Phi' = 65°$ and three possible means of extrapolation for the day hours. It follows from Figure 3(a) that the average diurnal values fo/ the rate of appearance of aurorae reach maxima within the range of latitudes from 70 to 75^c, i.e., within the range of the oval auroral zone. /101
Within this range, the average frequency of aurorae per day does not change, remaining at a level of 56%. Aurorae appear less frequently in the direction toward the pole and the equator, while the decline around the pole is smoother than that around the equator.

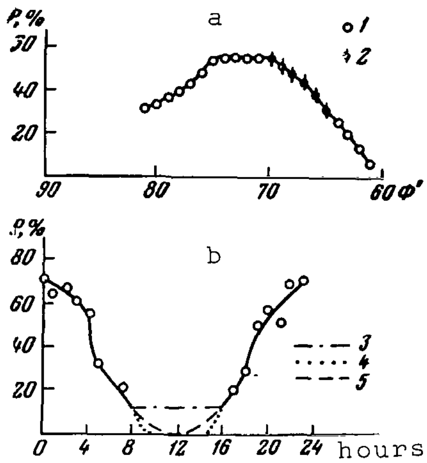


Fig. 3. Latitude-Distribution of the Average Diurnal Values (a) for the Frequency of Appearance of Aurorae (P) and its Diurnal Changes at a Latitude of $\Phi' = 65°$ (b). (1) No Extrapolation for the Day Hours; (2) Upper and Lower Margins for the Average Diurnal Values of P, % by Different Means of Extrapolation; (3) Upper Margin of P, %; (4) Lower Margin of P, %; (5) Average Value of P, %.

The aurorae-distribution shown in Figure 2 was obtained by observation during entire days, without divisions into magnetically quiet and magnetically disturbed periods. Therefore, we examined in greater detail the distribution of aurorae around noon and around midnight, for $K_p = 0\text{-}1$ and $K_p \geq 5$ (Fig. 4). We determined the frequency of appearance of aurorae at the zenith for six hours around noon and three or six hours around midnight. Figure 4 shows the latitude-distribution of aurorae obtained for periods of a maximum in the solar cycle. For a quiet magnetic field, aurorae are observed most frequently during the night hours at $\Phi' = 70°$, and during the day hours at $\Phi' = 79°$. During disturbance periods, the frequency of aurorae at $\Phi' = 70°$ increases somewhat during the night hours, and decreases substantially at $\Phi' = 79°$ during the day hours, but increases at lower latitudes. From the data shown in Figure 4, it follows that, during transition from a magnetically quiet to a magnetically disturbed period, the following occurs.

First of all, the region of the latitudes where aurorae appear frequently at the zenith expands significantly toward the equator during the night hours, while its displacement toward the equator occurs during the day hours. During the hours around midnight, the frequency of appearance of aurorae increases at $\Phi' \sim 75$-$76°$. This shows an expansion of the latitudinal region encompassed by the aurorae on the night side of the Earth, not only toward the equator, but also toward the pole. In examining two storms in October and December, 1961, the conclusion was drawn [26] that the outer boundary for the region of trapped electrons with $E \geq 40$ KeV is displaced toward the equator with an increase in K_p, both during the day hours (October storm) and during the night and morning hours (December storm). This displacement is related to the development of the D_{st}-variation of the magnetic storm. The D_{st}-variation, as a rule, is accompanied at high latitudes with the development of polar magnetic disturbances (*PD*), the value of which also basically determined K_p. The appearance of *PD* is accompanied by a movement of the aurorae, not only toward the equator, but also toward the pole. At the moments of extreme developments of intensive *PD*'s, aurorae on the night side can appear at the zenith all the way to latitudes of $\Phi' \sim 80°$. It was actually found in [12] that the particles penetrate to $\Phi' \sim 80°$ on the night side during a period of magnetic disturbances.

The penetration of electrons to high latitudes during a period of magnetic disturbances was also observed on the satellite "Electron-1" [27].

Secondly, in the circumpolar region with $\Phi' > 80°$, the aurorae appear less frequently, which conforms with well-known data in the literature [28-33, 8, 10]. In this case, the discrete forms of aurorae observed in the circumpolar region before, and at the beginning of, the magnetic storm, disappear as the storm develops [34].

Thirdly, the asymmetric shape of the auroral zone is preserved: /102
during the day hours, the maximum frequency of appearance of aurorae is found at higher latitudes than during the night.

Figure 5, with the coordinates of the corrected geomagnetic latitude and the local time, shows a schematic distribution of the aurorae for $K_p = 0$-1 and $K_p \geq 5$. The latitudinal region where the frequency of appearance of aurorae is greater than 60% is plotted conditionally in the auroral zone. The reason for such a selection was that, during the night hours in the IGY, the southern boundary for the appearance of aurorae at the zenith was found at $\Phi' \sim 66°$ for $K_p = 1$, and at $\Phi' \sim 59.5°$ for $K_p = 6$, at geomagnetic longitudes of 145-190° [35]. The frequency of aurorae-appearances for $K_p = 0$-1 and $K_p \geq 5$ in Figure 4 at these latitudes is $\sim 60\%$ at the zenith. Therefore, the regions of latitudes where the frequency of aurorae at the zenith was 60% were isolated in Figure 5 by the solid lines. This region, during magnetically quiet periods (K_p = 0-1), is an oval zone located during the night hours at Φ' = 67-72°, and at Φ' = 77-80° during the day hours. An asymmetrical shape is characteristic of the inner as well as the outer boundary of the zone. In the circumpolar region, aurorae appear at the zenith rather frequently (from 20 to 40% of the total number of observations). They appear least frequently during the

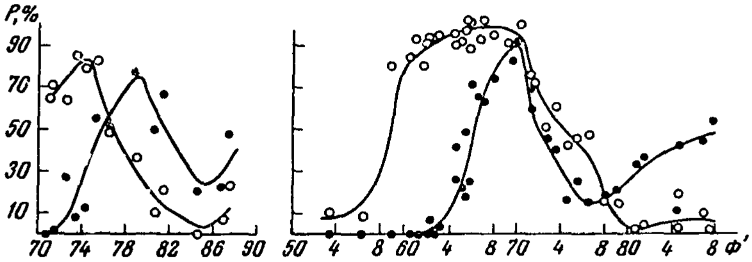


Fig. 4. Latitude-Distribution of the Frequency of Appearance of Aurorae, in Percentages, (a) for the Hours Around Noon, and (b) for the Hours Around Midnight, with K_p = 0-1 (Dark Circles) and $K_p \geq 5$ (Light Circles) During the Period of 1957-1959.

hours around midnight at latitudes of 75-80°. During the disturbed periods ($K \geq 5$), the outer (located closer to the pole) boundary of the auroral zone on the day and night sides is located at an identical distance from the pole (73-76°). The inner boundary on the day side shifts to $\Phi' \sim 70°$, while, on the night side of the Earth, it shifts to $\Phi' \sim 59°$.

Thus, the area over which aurorae appear greatly increases more frequently than in 60% of the cases. The auroral zone remains asymmetrical, since, on the night side, its inner boundary descends to lower latitudes than on the day side. The outer boundary ceases to be asymmetrical, and in this sense, the data presented confirm the results of the study in [8] on the decrease in asymmetry during the period when an elementary aurora develops. The decrease in asymmetry also follows from the theoretical concepts presented in [18a]. Aurorae practically disappear during disturbed periods in the circumpolar region at $\Phi' > 80°$.

For the period of a minimum in the cycle of solar activity, we had only the data for the network of stations in the Soviet Union available. Therefore, we could only obtain the latitude-distribution to $\Phi' < 75°$. For the day hours, the observational materials were very scarce. Therefore, only the data of the hours around midnight are shown in Figure 6. Since the number of "All-Sky" cameras decreased substantially at high latitudes during the period of the ISQY, we included the data of visual observations at the stations in Tiksi, Chelyuskintsky, Vize, and Nagurskaya.

According to the data of the Tiksi and Chelyuskintsky stations, /103
we obtained a conversion factor connecting the frequency of the appearance of aurorae according to visual observations with the data of the "All-Sky" cameras, since, at these stations, the aurorae were photographed simultaneously with the visual observations. This conversion factor was then used for finding the frequency of the appearance of aurorae, according to visual observations at Vize and Nagurskaya, in relation to the data from the cameras. In Figure 6, the values of P for the stations at Vize and Nagurskaya are outlined by a circle.

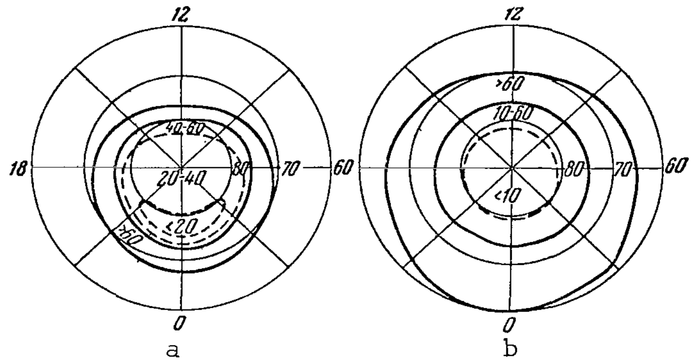


Fig. 5. Frequency of Appearance of Aurorae in the Northern Hemisphere, (a) for K_p = 0-1, and (b) for $K_p \geq 5$.

The years 1963-1965 relate to years with a minimum in the cycle of solar activity. However, in the same way as during the years with a maximum, aurorae are observed practically continuously during the hours around midnight at altitudes of $\sim$ 70°, both during magnetically quiet and magnetically disturbed periods. Thus, at latitudes for the oval auroral zone, during the night hours, no significant decrease is observed in the frequency of appearance of aurorae during a change in the cycle-phase of the solar activity. When the planetary magnetic activity is intensified, the latitudinal region encompassed by the aurorae expands toward the equator and toward the pole. A comparison with the years of maximum solar activity (see Fig. 4) shows that, if the latitude-distributions for K_p = 0-1 practically coincide, then there are definite differences for $K_p \geq 5$. A sharp decrease in the frequency of aurorae occurs at $\Phi' \sim 59°$ during the years of maxima, and at $\Phi' \sim 64°$ during the years of minima. Keeping in mind the fact that, during the years of maximum solar activity, magnetic disturbances are observed very frequently, while quiet periods are found very infrequently, and that, during the years with minima, there is an inverse relationship, the auroral zones which are displaced roughly by 2.5° toward the pole during the years with minima [36] should be traced as a shift of the position of the average statistical maximum in relation to the redistribution of the number of magnetically quiet and magnetically disturbed intervals during the course of the cycle. The fact that, even for relatively identical (in intensity) magnetic disturbances, the region of latitudes encompassed by aurorae on the night side of the Earth expands to lower latitudes during the years with maxima than during those with minima also shas a certain effect.

The data shown in Figures 4-6 on the distribution of aurorae during magnetically quiet and magnetically disturbed periods can be used for a comparison with the distributions of soft electrons invading the upper strata of the atmosphere at high latitudes during periods of various geomagnetic activities.

The conclusions obtained as a result of a statistical analysis of the auroral distribution are confirmed by an analysis of the synoptic maps for the distribution of aurorae at fixed moments of Universal Time on December 13 and 23, 1957. December 23 was /104
one of the quietest days of the winter 1957/1958. The diurnal sum $\Sigma K_p = 8_0$, and K_p did not exceed values of 1_+ throughout all the three-hour intervals. The preceding day, December 22, was also magnetically-quiet. The magnetograms of the observatories located at high latitudes are shown in Figure 7, for December 13 and 23, 1957.

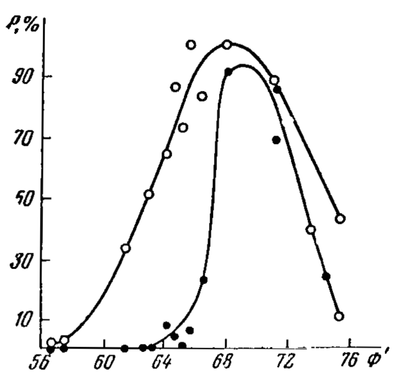


Fig. 6. Latitude-Distribution of the Frequency of Appearance of Aurorae, in Percentages, for the Hours Around Midnight, With K_p = 0-1 (Dark Circles) and $K_p \geq 5$ (Light Circles During the Period of 1963-1965.

December 13 was a moderately-disturbed day, with $\Sigma K_p = 26_+$, from 9:00 to 12:00 and from 15:00 to 18:00 U.T. The K_p was 5_0 and 5_-. During these periods, the polar disturbances at the stations located on the night side of the auroral zone reached values of 500 γ.

During the course of December 23, and during the quiet periods between the disturbances on December 13, the aurorae mainly had extended forms - arcs and bands extended along the oval zone of the aurorae, both on the day side of the Earth and on the night side. On December 23, aurorae were observed continuously at all longitudes along the oval zone, which shows, obviously, the continuous presence of energetic corpuscular streams simultaneously invading the upper strata of the atmosphere along the entire oval auroral zone, even on those days when the magnetic field is quiet. The aurorae during the evening and night hours are characterized by a high intensity which reached a scale of 2-3 on the interplanetary brightness scale, and such aurorae remain in the sky for a long time. The constant presence of bright aurorae along the oval zone suggests the continuous generation of energetic particles, since the supply of electrons in the outer radiation belt is insufficient for prolonged aurorae [24, 37]. Obviously,

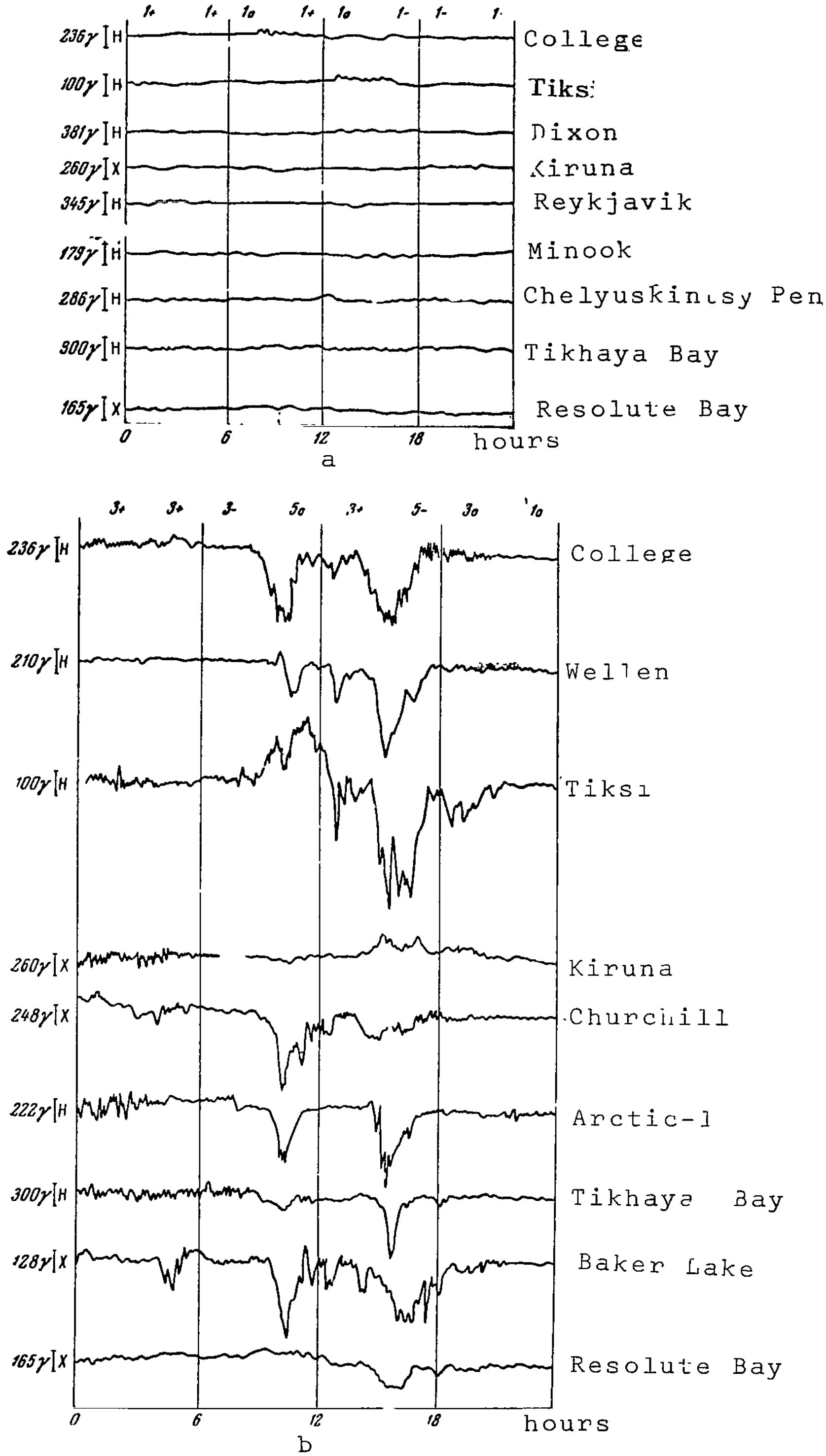


Fig. 7. Changes in the Horizontal Component of the Geomagnetic Field at Observatories Located at High Latitudes. (a) December 13, 1957; (b) December 23, 1957. The Time is Universal.

in the upper strata of the atmosphere, there is a constantly-acting mechanism of acceleration which gives a fairly large number of energetic electrons ($\sim 10^8$-10^{10} particles/cm^2·sec, with an energy of 10 KeV), even during the periods when the magnetic field is quiet. This mechanism should satisfy the following conditions:

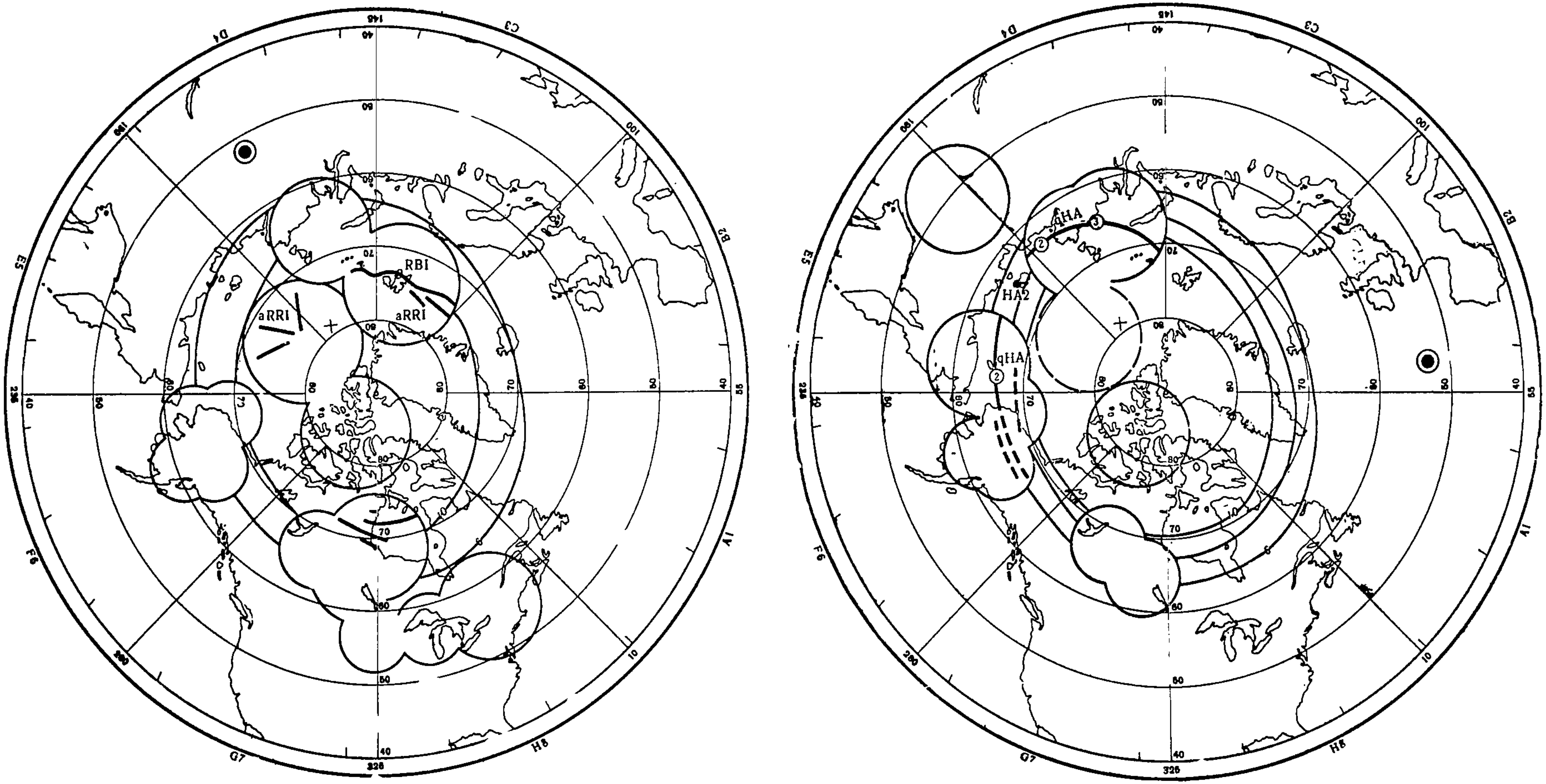
(1) It should act continuously, in time, regardless of the presence of magnetic disturbances;

(2) It should give a large enough flux of energetic particles for excitation of intensive aurorae;

(3) The region in which the acceleration originates should be asymmetrical in relation to the geomagnetic dipole (at greater values of Φ' during the day hours and lesser values during the night hours), and the acceleration should occur at all longitudes along such an asymmetrical zone.

These conditions are satisfied, in particular, by the acceleration mechanism which results from rotation of the lines of force of the geomagnetic field in the deformed magnetosphere. In this case, some of the energy of the aurorae is taken from the energy of the Earth's rotation. A description of such a mechanism is found in Articles [38] and [15]. The presence of a mechanism which continuously accelerates the charged particles in the magnetosphere does not exclude the existence of other accelerating mechanisms acting sporadically and bringing about a sharp increase in the flux of invading electrons per fraction of a second [39]. The appearance of aurorae during magnetically quiet periods also conforms well with the theory of polar drift currents whose particles penetrate the magnetosphere in the vicinity of the neutral points [18a]. Such currents also exist during magnetically quiet periods, while the aurorae are the result of the precipitation of charged particles from the drift currents.

Figure 8 shows maps with the distribution of the aurorae on December 23, 1957, at 5:05 and 13:22 U.T. The field of vision of the "All-Sky" camera is outlined on the map by the circle which corresponds to the zenith distance of 85° for the "All-Sky" camera with 35 mm film, and to 80° for the camera with 16 mm film, on the assumption that the altitudes of the lower boundary of the aurorae are 105 km. For the stations Arctic-2 and Pyramid, the height of the aurorae was assumed to be 150 km during the day hours [40, 28]. The lines for equal values of L related to Φ' by the equation $\cos\Phi' = (1/L)^{\frac{1}{2}}$ [41] are also shown. The position and the shapes of the aurorae are plotted by the arbitrary signs which will also be used for the synoptic maps of the aurora-distribution for the period of the IQSY: a continuous line is an arc, a wavy line is a band, and short lines are rays. The letters over different shapes of aurorae correspond to the international instructions for visual observations of aurorae [42]. The intensity of the aurorae, according to the four-number scale, was determined only for the network /106



a

b

Fig. 8. Synoptic Maps Showing the Position and Nature of the Aurorae on December 23, 1957. (a) 5:05; (b) 13:22. Universal Time. ☉ is the Direction to the Sun.

of cameras in the USSR which met the photometrical standards, and it is indicated in the breaks in the extended shapes of auroraes, or by the order for the ray-designations. The data of visual obser- /107 vations in the region of the Novosibirsk observatories, where the fields of vision of the cameras did not overlap, are plotted in Figure 8. The homogeneous arc of the intensity (scale 2) is shown by the point where, according to the visual observations, the arc was at the zenith. These observations confirm the fact of the continuity of the arc which extends from Franz-Josef Land to the coast of Alaska, and even to Canada. For the stations which photographed the aurorae on 16-mm film, the position of the lower boundary of the aurorae is shown by a dashed line, without designating the shapes of the aurorae.

An examination of the synoptic maps confirms the fact that aurorae appear during magnetically quiet days, both on the day side of the Earth, and on the night side, along the oval zone of the aurorae. During the day hours, the oval zone is found at latitudes of ~ 78°, and during the night hours, it is at ~ 70°. The intensity of the aurorae is rather high during a magnetically quiet day, and quite different shapes of aurorae can be observed at various longitudes along the oval zone. The variability (in time) of the aurorae observed on December 23, particularly during the morning hours and the hours around noon at $\Phi' \geq 75°$, and during the morning hours and around midnight at $\Phi' \sim 70°$, produces the basis on which we can assume that, even during quite magnetically-quiet days, the /108 solar wind (whose pressure leads to the deformation of the magnetosphere) is not homogeneous. The nonuniformities in the density of the solar plasma and its velocity, as well as the changes in intensity of the magnetic field related to this plasma, can bring about continuous movements of the boundary of the magnetosphere, which ultimately affects the effectiveness of the mechanisms for generation of energetic electrons.

On the basis of observations for the aurora on December 23, 1957, and on other magnetically quiet days, we constructed a generalized schematic for the distribution of aurorae in the northern polar cap, for K_p = 0-1 (Fig. 9). The proposed schematic diagram is a certain clarification and development of the distribution of aurorae on magnetically-quiet days presented by Akasofu [43].

The model aurora in Figure 9 encompasses all the longitudes, and various shapes and structures of aurorae are located along the oval zone in relation to the local time. During the hours around noon, there are rays; during the evening hours, there are homogeneous arcs; and during the night and morning hours, there are radial arcs and bands. Several forms of aurorae are frequently observed in the sky. In the circumpolar region, during quiet days, there are observed quickly-disappearing and re-appearing weak lines located along the direction toward the Sun. They differ radically from the aurorae in the oval zone. On the night side, such types of aurora are observed all the way to the latitudes of the Pyramid station ($\Phi' = 75.3°$). Such aurorae are plotted in Figure 9, conditionally, by the wavy lines located along the noon-midnight meridian. The distribution of aurorae, which is described by this model, was fixed in relation to the direction toward the Sun. A change in the shapes of the aurorae at a station located at high geomagnetic latitudes will occur as a result of the Earth's rotation on its axis.

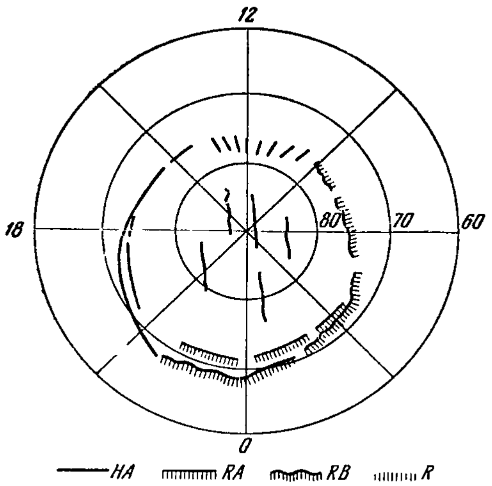
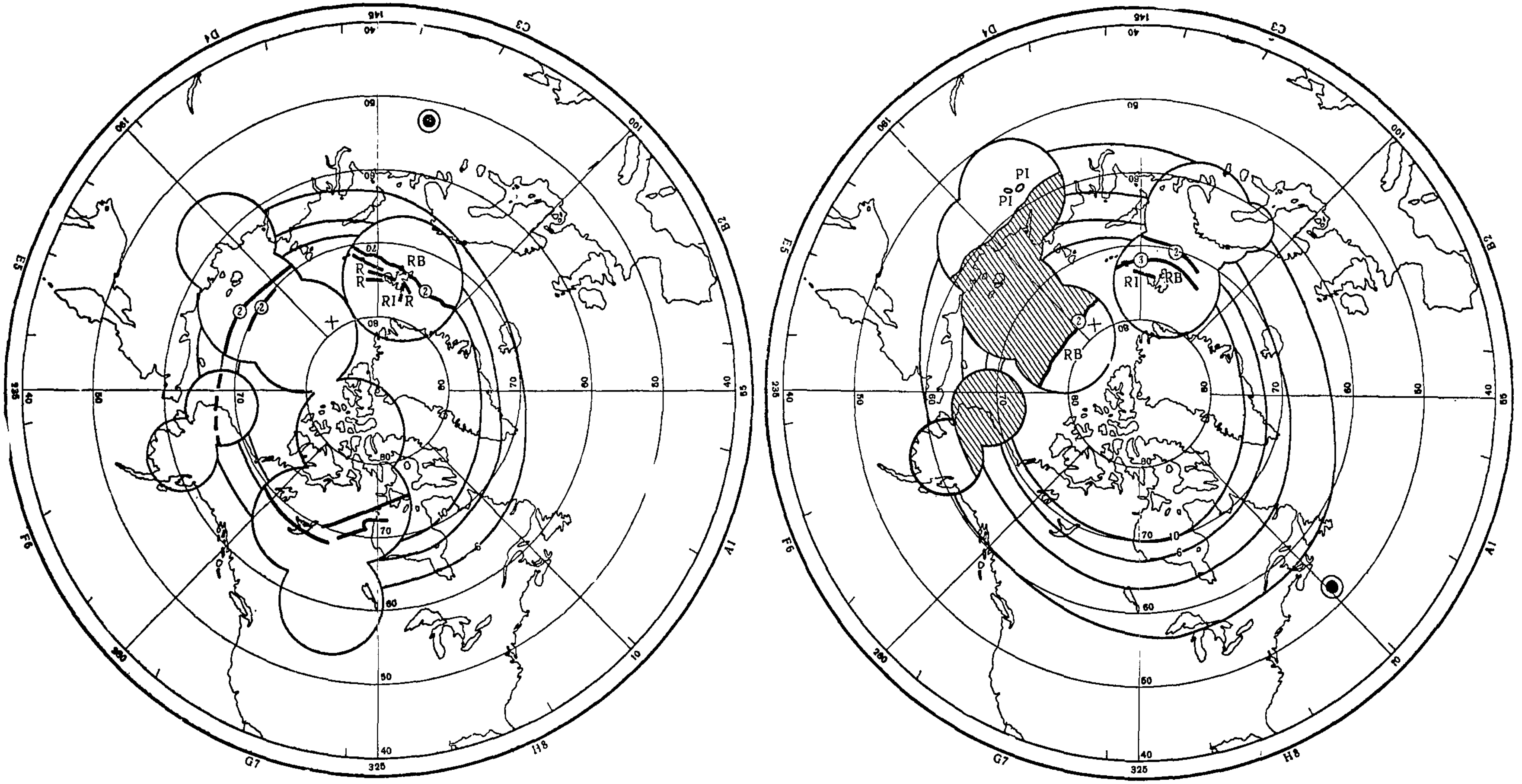


Fig. 9. Generalized Schematic Diagram for the Distribution of the Shapes of Aurorae during Magnetically Quiet Periods, in the Northern Polar Cap.

Figure 10 shows synoptic maps for the distribution of teh aurorae on December 13, 1957. At 8:35, the magnetic field was relatively quiet. The distribution of observed aurorae is characteristic of a quiet period before or after an elementary polar magnetic disturbance. The aurorae are located along the oval zone, with a predominance of radial forms, during the day hours. On the night side, the aurorae are located at the latitudes of the average statistical auroral zone. At 16:00, the intensive negative bay-shaped disturbance reaches a value of $\sim$ 400 λ for the horizontal component (Tiksi Bay). The brightness of the aurorae increases sharply during this period. They appear at the zenith over a large area. In Figure 10(b), the region of intensive emission, according to the data of camera located at stations Arctic-2, Arctic-1, Tiksi, Olenek, Barrow, and Farewell, on the night side of the Earth, is shaded. In this region of the sky, various forms of aurorae are observed. These aurorae move in all possible directions. With respect to the increase in total emission intensity, the ascafilm during this period in total emission intensity, the ascafilm during this period was dark, and this leads to difficulties in plotting different forms of the aurorae on the map. At 16:00, an intensive radial arc coming from the north side of the oval zone is found /109
at the zenith of the Arctic-2 station. This is a rare example of the extension of the aurorae during a period of disturbances to latitudes of $\Phi' \sim 80°$ from the night side of the oval zone. For other moments, the synoptic maps confirmed the shift of the oval zone on the day side to lower latitudes as the magnetic disturbance developed.

The development of polar magnetic storms is closely connected with changes in intensity and position of the aurorae. Therefore, we can expect that the value and direction of the vector of the magnetic disturbance corresponds to the location of the aurorae, and, in particular, to the shape of the auroral zone. It was shown in [44] that, for the winter season of 1957-1958, the direction and value of the vector of the disturbance in the horizontal plane in the northern hemisphere can be explained by the current flowing in the western direction along the oval zone located at $\Phi' \sim 65°$ on the night side of the Earth, and at $\Phi' \sim 76°$ on the day side. The currents in the circumpolar region were assumed to be the result of the cutting-off of some of the current from the evening side of the Earth to the morning side, which occurs along the oval zone of the aurorae. The presence of an oval zone for a thickening of the current lines in the S_D current system was described in [45] for the period of the IGY, from which it follows that the vector of the disturbances in the horizontal plane has a maximum value, while the vertical component changes its sign along three spiral segments. the morning and night spirals are located at the latitudes of the oval zone over which the current flows in the western direction. However, the general appearance of Budro's current system essentially repeats the principal characteristics of the generally-accepted current systems [46-48].

Figure 11 shows the space-time distribution in the northern hemisphere for ΔT and ΔZ, for the period November, 1957-February, 1958, with the coordinates of the corrected geomagnetic latitude and the time of the eccentric dipole [49]. The local time of the eccentric dipole was calculated according to the formulas presented in [50] and [51]: $\Delta T = \sqrt{(\Delta H)^2 + (\Delta D)^2}$. ΔZ was calculated for the three components of the geomagnetic field as the divergences of the field on five international disturbed days from the values for quiet days. The results of the variation-observations of the geomagnetic field at 24 observatories were also used. The data of the minimum number of observatories which provide for clarifying the picture of the distribution of the vector of the disturbance are plotted in Figure 11. The arrows show the direction of the vector of the disturbances in the horizontal plane, and the length of the arrow corresponds to the value of ΔT. The numbers at the base of the arrow are the values of ΔZ, considering the sign for the change in the vertical component. The minus-sign corresponds to the vector of ΔZ directed toward the zenith. The thick solid lines with the numbers 1, 2, and 3 show the relationship between the appearance of maxima in the diurnal variation of ΔT and the geomagnetic latitude. Lines 1 and 2 form an oval located on the night side at latitudes of $\Phi' \sim 62$-$64°$. During the evening hours, the maximum values of ΔT are observed at latitudes of $\Phi' \sim 63°$ (Line 3). Along Lines 1, 2, and 3, the sign of the Z-component of the variation in the geomagnetic field changes. such a distribution of the value and the direction of the vector of disturbances produces the basis on which we can assume that intensive currents flow along these lines. The maximum values of ΔT along the oval are caused by a decrease in the horizontal component, while, during the evening hours, at $\Phi' \sim 63°$, ΔT is determined by the increase



a b

Fig. 10. Synoptic Maps Showing the Position and the Nature of the Aurorae on December 13, 1957. (a) 8:35; (b) 16:00. Universal Time.

in the horizontal component. Such a direction of the vector of the disturbance can be explained if the current along the oval flows in the western direction, while, during the evening hours, at $\Phi' \sim 63°$, it flows in the eastern direction.

In the limited range of latitudes around $\Phi' \sim 70°$, negative changes in the field are mainly observed in the horizontal component [52]. This gives us the basis on which we can assume that, /110 during the disturbed days, no significant cutting-off of the current occurs from the oval auroral zone during the afternoon hours at $\Phi' \sim 65°$. Thus, an increase in the horizontal component at the latitudes of the Fritz zone (the zone of nocturnal aurorae) during the winter season at the evening hours, and a decrease in the horizontal component along the oval zone, are independent geophysical phenomena, although they are closely related. The relationship between both parts of the current system is found in the fact that the intensity of the night and evening vortices change synchronously, although individual exceptions have been observed. An analysis of the changes in the magnetic field at middle latitudes also shows the necessity of separating the evening and night current vortices.

The value and the sign of the vector of the disturbance in the geomagnetic field, shown in Figure 11, were also observed during the disturbed periods on December 13, 1957 (see Fig. 7). At 9:00-12:00, large negative disturbances appeared at the stations in College and Churchill (the night side of the Earth). At the latitudes of the Fritz zone, during the evening hours, positive changes in H were observed (Tiksi Bay); a more intensive decrease in H was observed at the longitude of Tiksi Bay, but at higher latitudes (Arctic-1). During the day hours, at the latitudes of the Fritz zone, the field was quiet (Kiruna). From 15:00 to 18:00 UT, intensive $\Delta H > 0$ during the night and early-morning hours were observed at the lati- /111 tudes of the Fritz zone (College, Uelen, Tiksi); $\Delta H > 0$ during the evening hours (Kiruna), and more intensive $\Delta H < 0$ were observed at the meridian of Kiruna, but closer to the pole (Tiksi Bay). During the afternoon hours, the magnetic field was weakly disturbed at the latitudes of the Fritz zone (Reykjavik).

The current system S_D of the variations for the winter season of the IGY which is shown in Figure 12 takes into account the isolation of the night and evening vortices. The coordinate system is the corrected geomagnetic latitude and the time of the eccentric dipole. The intensity of the currents induced on the Earth were taken into account. The current system was constructed by the approximation method described in [53]. A current of 10,000 amperes flows among the current lines. The intensity of the night current vortex is 180,000 amperes, and that of the evening is 40,000. The greatest intensity of the night vortex is observed during the early-morning hours - a polar electric stream. A definite thickening of the current lines is observed along the oval auroral zone. In the circumpolar region, the currents are the result of the cutting-

off of part of the current from the evening side of the Earth to the morning side, which occurs along the oval auroral zone. On the day side of the Earth, at latitudes of 60-70°, the intensity of the magnetic disturbances is insignificant. At these latitudes, /112
very insignificant currents are found. During the morning hours, at $\Phi' \sim 65°$, the positive changes in the horizontal component are determined by the appearance of relatively weaker evening electric streams which are completely cut-off through the middle latitudes. This leads to negative bay-shaped disturbances during the evening hours at middle latitudes.

Some of the current from the night electric stream is also cut off through the middle latitudes, which leads to the appearance of positive bay-shaped disturbances during the morning and

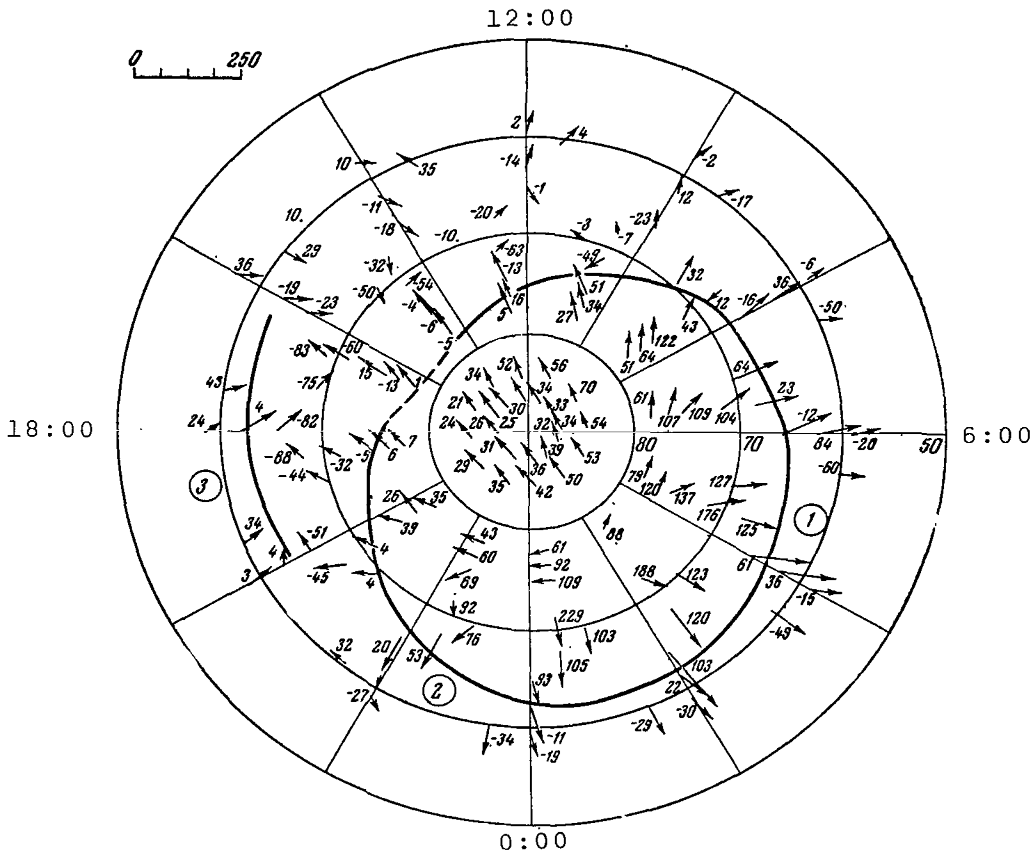


Fig. 11. Space-Time Distribution of the Vectors of a Magnetic Disturbance ΔT and ΔZ, in the Northern Hemisphere, During the Winter Season of the IGY. The Coordinates of the System: Revised Geomagnetic Latitude, Time of the Eccentric Dipole.

night hours. Obviously, the penetration of energetic charged-particles along the oval zone of the aurorae leads to a substantial increase in ionization, and to the appearance of the electric field of the meridional direction toward the equator, which, together with the vertical magnetic field of the Earth, causes the appearance of an intensive current. These electric fields can appear as the result of a separate penetration of protons and electrons into the ionosphere [54]. The changes of the magnetic field in the circumpolar region can be explained by the cutting-off of some of the current from the oval auroral zone, from the evening side to the morning. The increase of the field on the evening side (the positive bay-shaped disturbances), within the framework of the existence of only ionospheric currents, can be explained by the cutting-off of some of the current from the oval auroral zone through lower latitudes, or by the appearance of an electric field directed toward the pole at $\Phi' \sim 63°$ during these hours. It is possible that, within /113

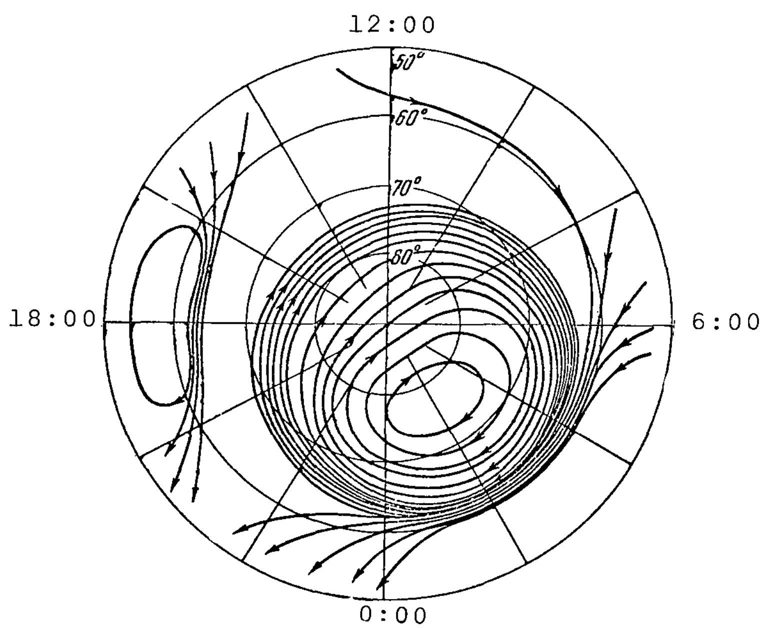


Fig. 12. Current System of the S_D Variation at High Latitudes of the Northern Hemisphere During the Winter Period of the IGY.

the limits of the ionosphere, the current system is not closed off, since the ionospheric currents are part of a more complex system of currents which encompasses the magnetosphere can also be the result of wind movements. These electric fields are transmitted along the lines of force to the Earth's magnetosphere, and, possibly, are the cause of the acceleration of the particles in the magnetosphere [57].

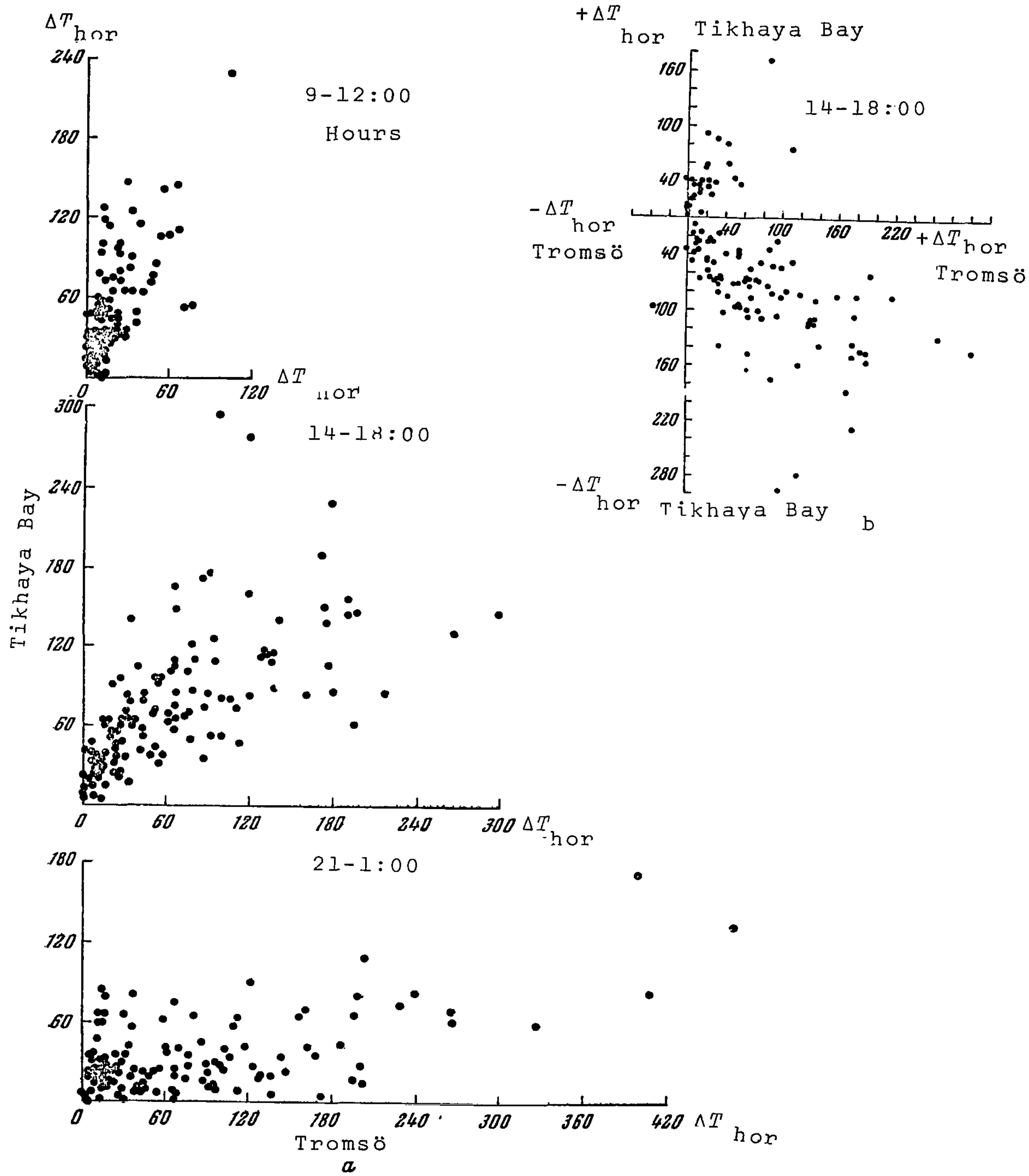


Fig. 13. Relationship Between the Values of ΔT_{hor} at the Stations in Tromsö and in Tikaya Bay, at Different Hours, Universal Time. (a) Without Considering the Sign of the Field; (b) Considering the Sign of ΔT_{hor}.

The distribution of the vector of the disturbance shown in Figures 11 and 12 was obtained by averaging for the entire winter season. It is of interest to examine the instantaneous average hour pictures. However, the construction of a large number of synoptic maps for fixed hours, Universal Time, is very laborious. Therefore, we decided to replace a comparison of the synoptic maps with graphs showing the relationship between the values of ΔT_{hor} at the stations in Tromsö ($\Phi' = 66°$) and Tikhaya Bay ($\Phi' = 74.5°$) for different hours of Universal Time: 9:00-12:00 (the hours around noon, local time), 14:00-18:00 (the period of maximum positive ΔH at Tromsö) and 21:00-1:00 (the hours around midnight). Both stations were located roughly along one geomagnetic meridian, but one was in the Fritz zone, while the other was much farther north. The relationship between the values of ΔT_{hor} at these stations is shown in Figure 13 for all the days of January, 1958. The relationship between the values of ΔT_{hor} at various hours during the day conforms well with the concept of the oval current zone located at higher latitudes during the day and at lower latitudes during the night.

Actually, ΔT_{hor} was greater, as a rule, during the day hours at Tikhaya Bay than at Tromsö, while ΔT_{hor} during the hours around noon was greater at Tromsö than at Tikhaya Bay. At 14:00-18:00 UT, when the large values of ΔT_{hor} at Tromsö were caused by the positive changes in ΔH (the positive ΔH in Tromsö were maximum during these hours), large values of ΔT were also noted at Tikhaya Bay, but they were caused mainly by negative values of ΔH. In this case, between 14:00 and 18:00 UT, the values of ΔT were approximately identical at Tikhaya and at Tromsö, i.e., the value of the disturbance vector in the horizontal plane was identical at the latitudes of the oval zone and the Fritz zone. At the same time, it follows from the latitudinal section for 6:00-18:00 (Figure 3 in [49]) that, at 18:00, the value of ΔT_{hor} at the stations in the Fritz zone were much greater than that at higher latitudes (at which the oval zone of the aurorae is located). It was assumed that the average values of ΔT_{hor} for the winter season, at 18:00, are significantly decreased at the latitudes of the oval zone as a result of the fact that the field vector undergoes significant changes in the orientation of the magnetic meridian during these hours, while, at separate hours, ΔH may even have positive values. Therefore, in averaging the resultant vector, it is much less than ΔT_{hor} in the Fritz zone, where ΔH is always positive. The test conducted showed that this assumption agrees with the actually-observed variations. Figure 13(b) shows ΔT_{hor} at Tikhaya Bay and at Tromsö, for 14:00-1800, during the same period as in Figure 13(a). However, ΔT assumed a plus- or minus-sign in relation to the sign of ΔH. We can see from the data presented in Figure 13 that ΔT is always positive at Tromsö, while, at Tikhaya Bay, in addition to the negative values of ΔT, there are also noted positive values. /115

It was shown in [44] that the region with maximum values of the Q-index of the magnetic activity during the winter season of the IGY is found at higher geomagnetic latitudes on the day side

than on the night side. Such an average distribution of the activity is also confirmed by an analysis of individual cases. Figure 14 shows the latitude-distribution of a number of cases when the magnetic activity at a chain of Canadian stations (Minook, Churchill, Baker Lake, Resolute Bay) and at the circumpolar station in Tula, was maximum at any of these sites. The distribution was constructed only for those hours when the Q-index assumed a value $\geq$ 5, even if this occurred at only one station. This means that, during this hour, there was actually observed a magnetic disturbance, and, moreover, that, from the examination, we could exclude those hours which were characterized by small indices of the magnetic activity, when the error in determining the index was great. We calculated the number of cases (n) when the disturbance at any station was maximum, in comparison with the other stations. The calculations were made on analytical machines. During the winter, in the day, a maximum magnetic disturbance was observed most frequently at the Baker Lake station ($\Phi' = 75°$). It decreased toward the pole and toward the equator. During the night hours, intensive disturbances appeared most frequently at the stations in Minook ($\Phi' = 62.3°$) and Churchill ($\Phi' = 70.2°$). In the circumpolar region, magnetic disturbances appeared quite infrequently at any hour of the day. Thus, both in individual cases and as a rule, a maximum magnetic activity was observed during the day at higher latitudes /116
than during the night, which conforms well with the concept of the oval shape for the region of the maximum magnetic disturbance.

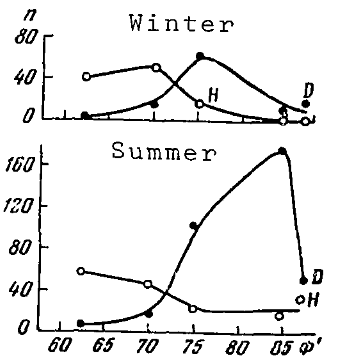


Fig. 14. Latitude-Distribution of the Number of Cases When the Magnetic Activity was Maximum at the Stations Located Along the Geomagnetic Meridian ~ 330°.

During the summer, in the night hours, disturbances were observed most frequently at the latitudes of the Fritz zone. However, during the day, the intensity of the magnetic disturbances in the circumpolar region increased sharply, which has been shown many times in the literature.

Thus, the distribution of aurorae, and the vector of disturbances in the magnetic field and the magnetic activity at high latitudes are combined into a single pattern, and can be clearly explained by the penetration of energetic particles into the oval zone located on the day side at higher latitudes than on the night side. The presence of such an oval zone is explained directly by the asymmetrical shape of the Earth's magnetosphere.

REFERENCES

1. Cahill, L. I. and P. G. Amazeen: The Boundary of the Geomagnetic Field. J. Geophys. Research, Vol. 68, No. 7, p. 1835, 1963. /117
2. Heppner, J. P., N. F. Ness, C. S. Scearce and T. L. Skillman: Explorer X Magnetic Field Measurements. J. Geophys. Res. Vol. 1, No. 1, p. 68, 1963.
3. Ness, N. F., C. S. Scearce and J. B. Seek: Initial Results of the IMPI Magnetic Field Experiment. J. Geophys. Res., Vol. 69, No. 17, p. 3531, 1964.
4. Ness, N. F.: The Earth's Magnetic Tail. J. Geophys. Res., Vol. 70, No. 13, p. 2989, 1965.
5. Fel'dshteyn, Ya. I.: Geograficheskoye raspredeleniye polyarnykh siyaniy i azimuty dug. V sb.: Issledovaniya polyarnykh siyaniy (Geographical Distribution of Aurorae and the Azimuth of the Arcs. In the Collection: Investigations of Aurorae), No. 4, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., 1960, pp. 61-78.
6. Feldstein, J. I.: Auroral Morphology. Tellus, Vol. 16, No. 2, p. 252, 1964.
7. Khorosheva, O. V.: Sutochnyy dreyf zamknutogo kol'tsa polyarnykh siyaniy (The Diurnal Drift of the Closed Ring of Aurorae). Geomagnetizm i Aeronomiya, Vol. 2, No. 5, p. 839, 1962.
8. Akasofu, S. I.: The Development of the Aurorae Substorm. Planet. Space Sci., Vol. 12, No. 4, p. 273, 1964.
9. Malville, J. M.: Diurnal Variation of High-Latitude Auroras. J. Geophys. Res., Vol. 69, No. 7, p. 1285, 1964.
10. Sanford, B. P.: Aurora and Airglow Intensity Variations With Time and Magnetic Activity at Southern High Latitudes. J. Atmos. and Terr. Phys., Vol. 26, p. 749, 1964.
11. O'Brien, B. J.: A Large Diurnal Variation of the Geomagnetically Trapped Radiation. J. Geophys. Res., Vol. 68, No. 4, p. 989, 1963.
12. McDiarmid, I. B. and J. R. Burrows: High-Latitude Boundary of the Outer Radiation Zone at 1000 km. Canad. J. Phys., Vol. 42, No. 4, p. 616, 1964.
13. Frank, L. A., J. A. Van Allen and J. D. Craven: Large Diurnal Variations of Geomagnetically Trapped and of Precipitated Electrons Observed at Low Altitudes. J. Geophys. Res., Vol. 69, No. 15, p. 3155, 1964.
14. Malville, J. M.: The Effect of the Initial Phase of a Magnetic Storm Upon the OUter Van-Allen Belt. J. Geophys. Res., Vol. 65, No. 9, p. 3008, 1960.
15. Hones, E. W.: Motions of Charged Particles Trapped in the Earth's Magnetosphere. J. Geophys. Res., Vol. 68, No. 5, p. 1209, 1963.
16. Fairfield, D. H.: Trapped Particles in a Disturbed Dipole Field. J. Geophys. Res., Vol. 69, No. 19, p. 3919, 1964.

17. Shabanskiy, V. P.: Dvizheniye chastits razlichnykh energiy vo vrashchayushcheysya magneitosfere (The Movement of Particles with Different Energies in the Rotating Magnetosphere). Kosmicheskiye Issledovaniya, Vol. 3, No. 2, p. 221, 1965.
18. Tverskoy, A. B.: Dinamika radiatsionnykh poyasov Zemli (The Dynamics of the Earth's Radiation Belts). Geomagnetizm i Aeronomiya, Vol. 4, No. 2, p. 224, 1964.
18a. Pletnev, V. D., G. A. Skuridin, V. P. Shalimov and I. N. Shvachunov: Dinamika geomagnitnoy lovushki i proiskhozhdeniye radiatsionnykh poyasov Zemli (The Dynamics of the Geomagnetic Trap, and the Origination of the Earth's Radiation Belts). Geomagnetizm i Aeronomiya, Vol. 5, No. 4, p. 626, 1965.
19. Annals of the IGY, Vol. 20, Pt. I, II. Pergamon Press, 1962.
20. Stoffregen, W.: Instruction for Scaling Auroral Ascaplots. 1959.
21. McIlwain, C. E.: Direct Measurement of Protons and Electrons in Visible Aurorae. J. Geophys. Res., Vol. 65, No. 9, pp. 2727-2747, 1960.
22. Davis, L. R., O. E. Berg and L. H. Meredith: Direct Measurements of Particle Fluxes in and Near Auroras. Space Research I. Proc. Internat. Space Sci. Sympos., Nice, p. 721, 1960.
23. McDiarmid, I. B., D. C. Rose and E. Budzinsky: Direct Measurement of Charged Particles Associated with Auroral Radio Absorption. Canad. J. Phys., Vol. 39, p. 1888, 1961.
24. O'Brien, B. J.: Lifetimes of Outer-Zone Electrons and their Precipitation into the Atmosphere. J. Geophys. Res., Vol. 67, No. 10, p. 3687, 1962.
25. Khorosheva, O. V.: Ob izokhazmakh polyarnykh siyaniy. V sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (The Isochasms in Aurorae. In the Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., 1963, pp. 126-132.
26. Maehlum, B. and B. J. O'Brien: Study of Energetic Electrons and their Relationship to Auroral Absorption of Radio Waves. J. Geophys. Res., Vol. 68, No. 4, p. 997, 1963.
27. Bolyunova, A. D., O. L. Vaysberg, Yu. I. Gal'perin, B. P. Potapov, V. V. Temnyy and F. K. Shuyskaya: Predvaritel'nyye rezul'taty issledovaniya korpuskul pri pomoshchi sputnika "Elektron-1". V sb.: Issledovaniya kosmicheskogo prostronstva (Preliminary Results of Examining Corpuscles with the Aid of the Satellite "Electron-1". In the Collection: Investigations of Outer Space), Izdat. "Nauka", 1965, pp. 406-417.
28. Fel'dshteyn, Ya. I.: Magnitno-ionosfernyye vozmushcheniya i polyarnyye siyaniya v okolopolyusnoy oblasti. V sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Magneto-Ionospheric Disturbances and Aurorae in the Circumpolar Region. In the Collection: Aurorae and Airglow), No. 7, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., 1961, pp. 43-50.

29. Fel'dshteyn, Ya. I.: Polyarnyye siyaniya i magnitnaya aktivnost' v pripolyusnoy oblasti (Aurorae and the Magnetic Activity in the Circumpolar Region). Geomagnetizm i Aeronomiya, Vol. 2, No. 5, p. 851, 1962. /118
30. Lassen, K.: Day-Time Aurorae Observed at Godhavn 1954-1956. Publ. Danish Meteosol. Ins., No. 15, 1961.
31. Lassen, K.: Diurnal Variation of High-Latitude Auroral Frequency of Magnetically Quiet and Disturbed Days. Nature, Vol. 192, No. 4800, p. 345, 1961.
32. Davis, T. N.: Negative Correlation Between Polar-Cap Visual Aurora and Magnetic Activity. J. Geophys. Res., Vol. 68, No. 15, p. 4447, 1963.
33. Hamilton, R. A.: Polar Cap Aurora and Magnetic Activity. J. Atmos. and Terr. Phys., Vol. 26, p. 615, 1964.
34. Feldstein, J. I.: Aurora Near Geomagnetic Pole on July, 1959. UGGI, No. 7, p. 126, 1960.
35. Fel'dshteyn, Ya. I. and N. F. Shevnina: Rezul'taty vizual'nykh nablyudeniy za polyarnymi siyaniyami v 1957-1958 gg. V sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (The Results of Visual Observations of Aurorae in 1957-1958. In the Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., 1963, pp. 91-120.
36. Fel'dshteyn, Ya. I.: Izmeneniya v polozhenii zony polyarnykh siyaniy, svyazannyye s tsiklom solnechnoy aktivnosti (The Changes in the Position of the Auroral Zone Related to the Cycle of Solar Activity). Geomagnetizm i Aeronomiya, Vol. 2, No. 3, p. 371, 1962.
37. O'Brien, B. J.: High-Latitude Geophysical Studies with Satellite Injun 3. Precipitation of Electrons into the Atmosphere. J. Geophys. Res., Vol. 69, No. 1, p. 13, 1964.
38. Johnson, F. S.: The Gross Character of the Geomagnetic Field in the Solar Wind. J. Geophys. Res., Vol. 65, No. 10, p. 3049, 1960.
39. Winkler, J. R., P. D. Bhavsar and K. A. Anderson: A Study of the Precipitation of Energetic Electrons from the Geomagnetic Field During Magnetic Storms. J. Geophys. Res., Vol. 67, No. 10, p. 3717, 1962.
40. Yevlashin, L. S.: Polyarnyye siyaniya krasnogo tsveta tipa A v vysokikh shirotakh (Aurorae of a Red Color of Type A at High Latitudes). Geomagnetizm i Aeronomiya, Vol. 1, No. 4, p. 531, 1961.
41. McIllwain, C. E.: Coordinates for Mapping the Distribution of Magnetically Trapped Particles. J. Geophys. Res., Vol. 66, No. 11, p. 3681, 1961.
42. Jacka, F. and J. Paton: IQSY Instruction Manual, Aurora 1963.
43. Akasofu, S. I.: The Dynamical Morphology of the Aurora Polaris. Annals of IGY, Vol. 20, No. III, 1963.
44. Fel'dshteyn, Ya. I.: Morfologiya polyarnykh siyaniy i geomagnetizm. V sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Auroral Morphology and Geomagnetism. In the Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., 1963, pp. 121-125.

45. Budro, O. A.: O sootnoshenii regulyarnykh i neregulyarnykh variatsiy geomagnitnogo polya v vysokikh shirotakh (The Relationship Between the Regular and Non-Regular Changes in the Geomagnetic Field at High Latitudes). Trudy Ark. Nauchnogo In-ta., No. 223, p. 21, 1960.
46. Chapman, S.: The Electric Current-System of Magnetic Storms. Terr. Magn., Vol. 40, No. 4, p. 349, 1935.
47. Vestine, E. H.: The Disturbance-Field of Magnetic Storms. Internat. Assoc. Geom. Aeron. Washington Meeting Bull., No. 11, p. 360, 1940.
48. Ben'kova, N. P.: Magnitnyye buri i sistemy elektricheskikh tokov (Magnetic Storms and the Systems of Electric Currents). Trudy Nauchno-Issled. Inst. Zemnogo Magnetizma, No. 10, p. 20, 1953.
49. Fel'dshteyn, Ya. I.: Vozmushchennyye solnechno-sutochnyye variatsii v vysokikh shirotakh v period MGG (Disturbed Solar-Diurnal Variations at High Latitudes During the IGY Period). Geomagnetizm i Aeronomiya, Vol. 5, No. 3, p. 447, 1965.
50. Cole, K. D.: Eccentric Dipole Coordinates. Austral. J. Phys., Vol. 16, No. 3, p. 423, 1963.
51. Simonov, G. V.: The Geomagnetic Time. Geoph. J. Roy. Astron. Soc., Vol. 8, No. 2, p. 258, 1963.
52. Zhigalova, N. N. and A. I.Ol': Vysokoshirotnyye bukhtoobraznyye vozmushcheniya geomagnitnogo polya (High-Latitude Bay-Shaped Disturbances in the Geomagnetic Field). Problemy Arktiki i Antarktiki, No. 15, p. 69, 1964.
53. Chapman, S. and J. Bartels: Geomagnetism. Oxford Univ. Press, 1940.
54. Krassovsky, V. I.: Polar Auroras. Space Sci. Rev., Vol. 3, No. 2, pp. 232-274, 1964.
55. Cole, K. D.: Motions of the Aurora and Radio-Aurora and their Relationships to Ionospheric Currents. Planet. Space Sci., Vol. 10, pp. 129-163, 1963.
56. Oguti, T.: Magnetospheric General Circulations and Current-Systems of Geomagnetic Disturbances in High Latitudes. Rept. Ionosph. Space Res. Japan, Vol. 18, No. 2, p. 109, 1964.
57. Krasovskiy, V. I.: Nekotoryye problemy fiziki verkhney atmosfery i okolozemnogo prostranstva. V sb.: Issledovaniya kosmicheskogo prostranstva (Some Problems in the Physics of the Upper Atmosphere and the Space Around the Earth. In the Collection: Investigations of Outer Space). Izdat. Nauka, 1965, pp. 11-23.

Translated for the National Aeronautics and Space Administration By:
Aztec School of Languages, Inc.,
Research Translation Division (421)
Acton, Massachusetts.
NASw-1962.