Auroral morphology, I. The location of the auroral zone

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ABSTRACT

An analysis of aurora distribution in the northern and southern hemispheres has been made according to results of photo-observations for aurorae. The auroral zone is of an oval form, approaching the geomagnetic pole ($\phi' \sim 78°$) at day hours and withdrawing from the pole ($\phi' \sim 68°$) at night hours. The location of auroral zones in the northern and southern hemispheres at day and night hours are given.

1. The form of auroral zone at a definite moment of time (universal time)

The establishment by FRITZ (1881) of the fact of the auroral zone existence is of great importance to all geophysics. None of the theories on aurora and magnetic storms could be considered complete, if they do not give explanations to the existence of the zone of maximum frequency of aurora appearance and maximum intensity of geomagnetic disturbances. VESTINE (1944) with the data of visual observations made at about 100 stations defined more exactly the location of the Fritz auroral zone.

Both investigators estimated the frequency of aurora appearance at a given station by relation of the number of nights with aurora, appearing at any part of the sky, to the general number of observation nights.

A correction was given to account for meteorological conditions, as well as the duration of dark time during which it is possible to carry out observations of aurorae. However, the difference of daily variation in the frequency of aurora appearance at different latitudes was not taken into account.

One of the purposes of the International Geophysical Year in the field of aurora investigations was the definition of the probability of aurora appearance in the zenith as a function of coordinates on the surface of the Earth. Continuous photo-observations during the IGY allowed to use a more accurate index of aurora activity for estimating aurora appearance frequency as well as to take into account more carefully the influence of light time and unfavourable meteorological conditions.

The ascaplots of ascafilms of the southern and northern hemisphere stations, published in the Annals of the IGY (1962) for the period from July 1 1957, to June 31, 1958, served as the initial data for this paper as well as for the articles by FELDSTEIN (1960), and FELDSTEIN & SOLOMATINA (1961*a*). The present investigation estimated the probability of aurora appearance by the relation of the number of half an hour intervals with the aurora in the zenith to the general number of these intervals.

FELDSTEIN (1960) showed that the frequency of aurora appearance in the zenith changes during 24 hours: at geomagnetic latitudes $\sim 65°$ aurorae appear more often in the zenith at near-midnight hours and at the latitudes $\sim 78°$ —at near-midday hours. The frequency of aurora appearances in midday at the latitudes $\sim 78°$ is the same as at midnight hours at the latitude $\sim 65°$. At the latitudes between 65° and 78° one observes two maxima in daily variations of appearance frequency—one at the evening hours, the second—at the morning hours. If the time dependence of the two maxima in daily variations of aurora frequency is compiled in polar coordinates (geomagnetic latitude—geomagnetic time) then we shall get a figure, consisting of two cuts of the spiral. The figure looks like an oval with the minimum distance from the geomagnetic pole at day hours and with the maximum distance at night hours. A part of the oval, corresponding to the spiral cut at evening hours for the southern hemisphere, was obtained by MALVILLE (1959), the

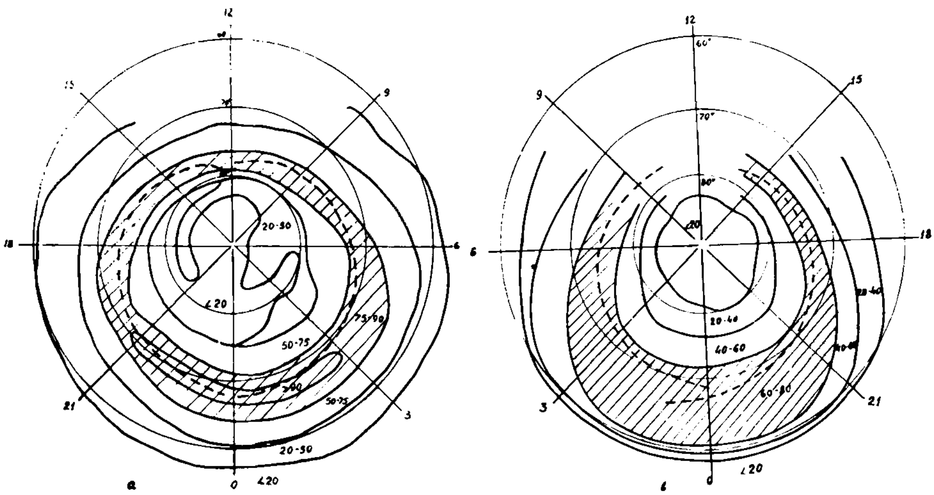


FIG. 1. The aurora oval zone in the northern (*a*) and the southern (*b*) hemisphere. The numbers give in per cent the frequency of aurora appearance in the zenith. The dashed line—the morning and night cuts of the spiral. The hatched area—the oval zone of aurorae. The coordinate system—the corrected geomagnetic latitude and the geomagnetic time.

complete oval for the northern and southern hemispheres is given by FELDSTEIN (1960), and by FELDSTEIN & SOLOMATINA (1961*b*). As the aurorae appear in the zenith more often at the given geomagnetic latitude near this oval, this oval is the auroral zone at the fixed moment of time.

If the auroral zone at the fixed moment of time has the form of the oval, then the isolines of the frequency of the aurora appearance in the zenith (izoaurorae) should go up from lower geomagnetic latitudes at night hours to higher latitudes at day hours. In Fig. 1 according to the data of 24 stations of the northern hemisphere and 17 stations of the southern hemisphere given in Table 1, the northern and southern polar caps are divided into a number of regions. Fig. 1 shows that the regions of aurora appearance of equal frequency are situated at the latitudes more to the south on the night side of the Earth and more to the north on the day side of the Earth. The aurora zone is the hatched part with the frequency of aurora appearance with more than 75 % in the northern hemisphere and more than 60 % in the southern. This region with $\varphi' \sim 68°$ on the night side goes up to $\varphi' \sim 78°$ on the day side. The aurora zone of the oval form, consisting of two spiral cuts, is given by the dashed line. For the southern hemisphere the isolines on the day side in high latitudes could not be closed due to the absence of reliable data on the frequency of aurora appearances in the zenith at day hours at the latitudes 70–83°.

The chart of aurora appearance frequency in the zenith for the northern hemisphere according to the data of aurora photo-observations in Alaska and Canada (in the coordinates geomagnetic latitude-approximate geomagnetic time) was compiled by DAVIS (1961, Fig. 40). According to Davis aurorae most often appear at the latitudes $\sim 67°$ at near-midnight hours. Davis did not mention aurora appearance at day hours at the geomagnetic latitudes 70–80°. One should bear in mind, that the territory of Canada, which is at such high geomagnetic latitudes, is situated at rather low geographic latitudes. Because of this it is impossible to carry out aurora observations even in the middle of the winter during 24 hours due to long duration of light time. High-latitudinal stations of the eastern hemisphere (Murchison-Bay, Pyramida, Arctica I) and partially the Greenland stations as Godhavn and Nord allow to follow aurora appearance at nearmidday and early-morning hours. On the basis of the observation data of these stations one has managed to find out that the aurorae often appear on the day side of the Earth at high latitudes. KHOROSHEVA (1961) by the simultaneous photos of the aurorae with all-sky camera found that the aurorae, simultaneously observed at different longitudes,

TABLE 1.

No.	Station	Goem. coord. Lat.	Long.	No.	Station	Geom. coord. Lat.	Long.
1.	Thule	88.1	1.1	22.	Verkhoyansk	56.6	195.6
2.	Resolute Bay	83.1	287.1	23.	Ithaca	53.8	350.6
3.	Nord	80.8	133.3	24.	Delawre	51.6	349.6
4.	Godhavn	79.8	32.5	25.	Vostok	90	71.8
5.	Arctica II	77.5	199	26.	Scott Base	79	294.4
6.	Scoresbysund	75.6	81.8	27.	Amundsen-Scott	78.5	0
7.	Murchison Bay	75.3	137.3	28.	Oasis	77.3	161.0
8.	Pyramida	74.5	130.8	29.	Mirny	77.0	146.6
9.	Baker Lake	73.7	315.1	30.	Davis	76.9	121.9
10.	Julianehab	70.8	35.4	31.	Dumont-D'Urville	75.0	230.0
11.	Aklavik	70.1	263.7	32.	Hallet	74.7	278.2
12.	Arctica I	69	201	33.	Little America	74.0	311
13.	Point Barrow	68.6	241.2	34.	Mawson	73.3	104.5
14.	Abisko	66.1	115	35.	Ellsworth	67.9	13.9
15.	Wrangel Is.	64.7	226.2	36.	General Belgrano	67.5	16.0
16.	College	64.7	256.5	37.	Halley Bay	65.8	24.3
17.	Murmansk	64.1	126.5	38.	Norway Station	64.0	44.6
18.	Dixon	63.0	161.5	39.	Campball Is.	57.3	253.0
19.	Kristineberg	63.0	111.9	40.	Kergelen	56.1	127.2
20.	Farewell	61.4	253.4	41.	Awarua	51.1	249.2
21.	Arkhangelsk	59.0	128.4				

present an indivisible, physically-connected band that changes its brightness and width synchronically along its length. The location of the aurora band on the Earth's surface in the Eastern hemisphere at concrete moments of time well corresponds to the oval zone of aurorae. In making such comparisons one should bear in mind that in individual cases the aurora band location may somewhat differ from the location of the aurora oval zone, obtained statistically and presenting an average location of the zone. Probably, the form of oval, its radius and the interval of the latitudes with the aurorae change depending on the level of magnetic activity. The differences in the latitudinal distributions of aurora appearance frequency on planetary magnetic-disturbed and magnetic-quiet days testify it. KHOROSHEVA (1962) showed, that the aurorae simultaneously appear in the ring, embracing all the Earth and locating above the geomagnetic latitudes 60–65° on the night-side of the Earth and 75–80° on the day-side of the Earth.

The aurora zone of the oval form given in Fig. 1, explains daily variations of the location of hydrogen emission in the aurorae (REES, REID, 1959] as well as analogical daily variations in the aurora location at the geomagnetic latitudes 63–68°. On the basis of a detailed analysis of daily aurora drifts in the meridional direction at a great number of stations in Arctica and Antarctica, DZUBENKO (1963) has also arrived at a conclusion about the oval form of the aurora zone (the zone comes nearer to the geomagnetic pole at day hours and withdraws from the pole at night hours).

The existence of the aurora zone of the oval form may be explained by the deformation of the Earth's magnetic field by the "solar wind". The observations on rockets and satellites showed that the boundary of the geomagnetic field in the equatorial plane is located at the distance of 10 radii of the Earth on the day-side and of 20 radii on the night-side. (CAHILL, AMAZEEN, 1963; HEPPNER *et al.*, 1963). The calculations, made by REES & REID (1959) confirmed, that the compression of the force lines of the geomagnetic field on the day-side may bring to the latitudinal drift of the aurora zone to 10°. More accurate calculations, made by MALVILLE (1960) showed that due to the compression of the geomagnetic field on the day-side the latitudinal drift cannot be more than 2°. The latitudinal drift will substantially increase, if simultaneously with the field compression on the day-side an extension of magnetic force lines occurs on the night-side of the Earth. The explanation to the appearance of the two spiral distributions in aurorae is also given by CHAMBERLEIN, KERN & VESTINE (1960). They use the theory of adiabatic invariants of a charged particle movement in the field of the dipole, supposing its simultaneous acceleration.

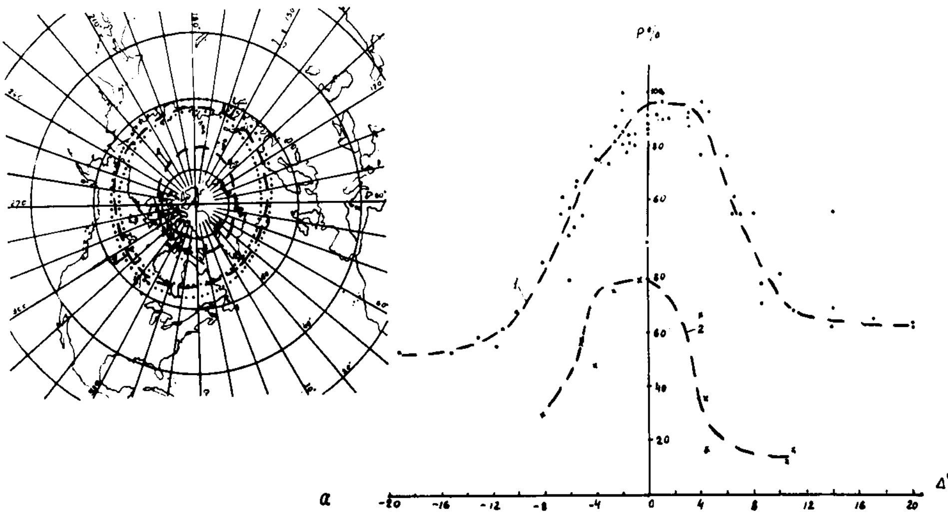
2. Aurora zones during the night and day hours

The oval zone of aurorae is oriented in a certain way to the Sun. The Earth rotates under it, making one revolution in 24 hours. In consequence of such rotation, the aurorae, appearing on the night side of the Earth, draw a band (a zone) on the Earth's surface, the distance of which from the geomagnetic pole is essentially greater than for morning and day aurorae. FELDSTEIN, SOLOMATINA (1961*a*) gave the location of the zone of the largest frequency of aurora appearance during the night and morning hours. The band drawn on the Earth's surface by the aurorae on the night side very well corresponds by its location to the Fritz aurora zone ($\varphi \equiv 63$–$67°$), and the line, drawn by the morning aurorae, forms the second high-latitudinal zone of aurorae, situated in the western hemisphere at the latitudes $\varphi \sim 78$–$80°$, and in the eastern hemisphere at $\varphi \sim 74$–$76°$. KHOROSHEVA (1962) presents a model of aurora band, and considering this model one sees that both aurora zones—the Fritz zone and the inner zone—should be considered as situated on the Earth's surface and as enveloping the locations of indivisible ring of aurorae at definite moments of time.

For the precise definition of the location of the zone of night and day aurorae the results of photo-observations of 60 stations of the northern hemisphere and 22 stations of the southern were used. This number includes all the stations, situated at the near-polar side from the line, passing at 5° to the Equator from the zone for night aurorae. The frequency of the aurora appearance in the zenith at night hours was counted up for 6 hours, centered to the local midnight, and at day hours for twelve near-midday hours. In defining the zone location for day aurorae preferably the observations of the stations, at which in the period of winter solstice it is possible to make observations through all 24 hours, should be taken into account.

In Fig. 2 the dashed lines present the zones for night and day aurorae in the northern and southern hemispheres. The projections of the two circles in the geomagnetic equatorial plane on the Earth's surface are drawn by dots in projecting along magnetic force lines by HULTQVIST (1958, 1961*a*). The distance of the circles from the dipole centre is 5.6 and 7.1 radii of the Earth. For the northern as well as for the southern hemisphere the zones for night aurorae go well along the theoretical curves. The zone location for night aurorae also corresponds well to the izoline of the integral adiabatic invariant $J = 15.7$, calculated by VESTINE & SIBLEY (1960). Therefore, one can conclude that the night aurorae are formed by the charged particles, making oscillation movements on the night side of the Earth along the magnetic force lines between the northern and southern hemisphere at the distance of about 6 radii of the Earth (in the equatorial plane). During the rotation of the Earth under the aurora oval zone the zone for night aurorae on the Earth's surface is defined by the real magnetic field of the Earth. In connection with this the aurorae more often appear at near-midnight hours along the line which differs from the geomagnetic parallel and agrees with the calculations of HULTQVIST (1961*a*) and VESTINE & SIBLEY (1960).

The accuracy of the aurora zone location definition on the Earth's surface may be estimated by considering the latitudinal distribution of the aurora appearance frequency in the zenith, given in Fig. 2. For the night aurorae in the northern hemisphere the data of the two stations Reykjavic and Arctic Ice Flow and in the southern hemisphere the data of Byrd and Wilkes do not agree with the latitudinal distribution. No permissible changes in the aurora zone location could make the data of these stations agree with the latitudinal distribution. At the same time 1° change of the zone location for the night aurorae from the given in Fig. 2 sharply increases point dispersion. One can presume that the error in defining the zone location for night aurorae does not exceed 1° along the latitude. For day aurorae the available data are rather limited, because the observations for 24 hours were possible only in very few points. Therefore the



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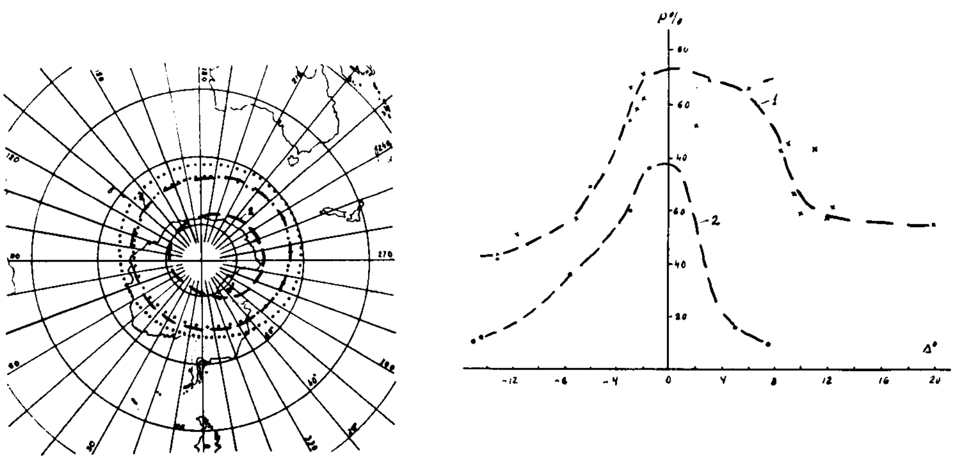

b

2 *b*

FIG. 2. The zones for night (1) and day (2) aurorae in the northern (*a*) and the southern (*b*) hemispheres (a dashed line). The dots—the projections of circles by Hultqvist. The latitudinal distribution of the frequency of the aurora appearance in per cent for night (1) and day (2) hours, depending on the distance to the corresponding aurora zones (Δ—in degrees of latitude: positive—to the pole, negative— to the equator).

error in the zone location is bigger, but does not exceed 2°–3° of the latitude.

For the frequency of aurora appearance in the zenith, calculated by the ascoplots of the U.S.A. stations in Antarctica, it is necessary to introduce a correction coefficient. The introduction of such a coefficient will somewhat change the latitudinal distribution for the southern hemisphere (Fig. 2). The frequency of aurora appearance at near-midnight hours will more rapidly decrease in approaching the pole, and the maximum frequency of aurora appearance at day hours will decrease. The zone for day aurorae at the geomagnetic meridians 0° and 330° will be 2° shifted to the equator isolines.

The oval form of the aurora zone, causing different distribution of aurorae at night and day hours, allows to interpret the charts of FRITZ

(1881) and Vestine (1944) isochasms from a new point of view. It was shown above that at day hours the aurorae more often appear at the corrected geomagnetic latitudes $\sim 78°$, and at night hours at the latitudes $\sim 68°$. The estimation of the aurora appearance frequency by Vestine's method results in a noticeable decrease of the aurora appearance frequency at the latitudes where aurorae more often appear at day hours. Really in high latitudes the observations of aurorae can be made almost 24 hours during the period of the winter solstice. While approaching the equinox due to the decrease of dark time the day hours fall out of observation. At the latitudes $\sim 68°$ such change in the observation period duration does not influence the frequency of aurora appearance, defined by Vestine's method. At the latitudes $\sim 78°$ the aurora appearance frequency sharply decreases because those hours will fall out of observations when aurorae appear more often. Therefore Fritz' and Vestine's isochasm charts *mainly show a geographical distribution* of night aurorae. The zone location for the zenith forms of aurorae, found by Feldstein (1960), with the account of observations during all 24 hours also well agrees with the zone for night aurorae.

3. Conclusion

1. The auroral zone, in which the aurorae appear more often in the zenith, is of an oval form at a definite moment of universal time. A spiral distribution of the maximum frequency of aurora appearance in the zenith coincides with the oval zone. The zone approaches the geomagnetic pole ($\varphi' \sim 78°$) at day hours and withdraws from the pole ($\varphi' \sim 68°$) at night hours.

2. The aurora distribution on the Earth's surface at near-midnight and near-midday hours can be explained by the rotation of the Earth under the oval zone of aurorae. The aurora distribution at near-midnight hours well agrees with the theoretical calculations, where one takes into account the difference of the Earth's magnetic field from the dipole field.

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