

# The Study of Auroral Oval Position Changes in Terms of Moving of the Earth's Magnetic Pole



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**Abstract** The auroral oval is actually a natural coordinate system to which theoretically and practically the events of space geophysics in the ionosphere and magnetosphere are attached. The oval was built according to the International Geophysical Year more than 50 years ago and probably is related to the magnetic pole of the Earth, which has shifted over this time by more than 1500 km. It should be expected that the configuration and position of the auroral oval could also change. The purpose of this paper is to study the possible displacement of the auroral oval for various geomagnetic activity under current conditions of the position of the Earth's magnetic pole. The article shows the aurora position relative to the magnetic pole at the present time by analyzing direct optical measurements at the stations of the Kola Peninsula (Lovozero) and Northern Scandinavia (Sodankyla, Kiruna). We have used the model of predicting auroral oval NORUSKA (Svalbard 2) for the comparison of experimental and calculated results. Numerical optical observations from the high apogee satellites during modern time also were used for definition of the oval position. To achieve the goal, precision data and a three-dimensional component model of the Earth's magnetic field of SPbF IZMIRAN were used, taking into account the contribution of magnetic anomalies of the lithosphere in the height range from 80 to 400 km, obtained according to aeromagnetic, marine and aerospace imagery. The paper indicates that the displacement of the auroral oval position follows the displacement of the magnetic pole of the Earth and location of the magnetic anomalies of the lithosphere. These are the first results obtained on a limited number of

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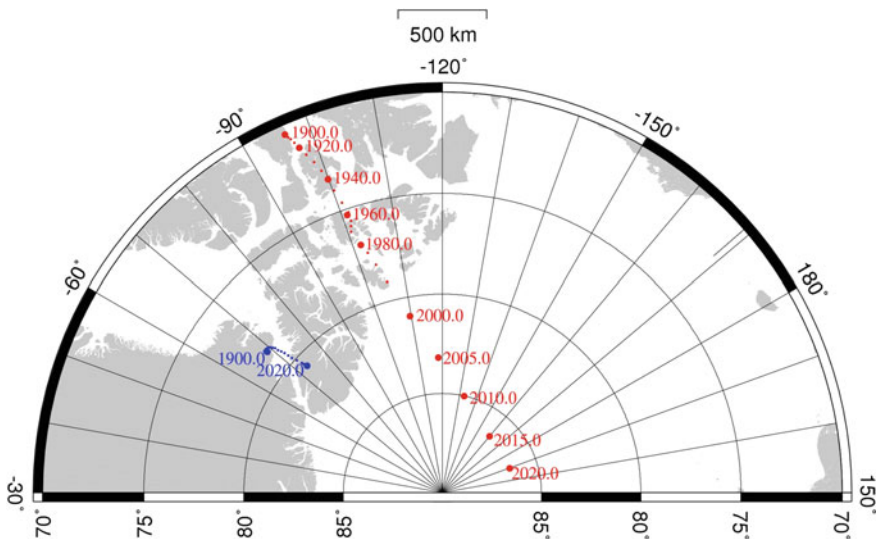
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measurements, and the work should be continued using more significant statistical material on a wide network of optical observation stations.

**Keywords** Displacement of auroral oval · Magnetic anomalies

## 1 Introduction

The auroral oval is actually a natural coordinate system to which theoretically and practically the events of space geophysics in the ionosphere and magnetosphere are attached. The oval was built according to the International Geophysical Year more than 50 years ago [1–3] in geomagnetic coordinates at a time when the difference in the position of the magnetic and geomagnetic poles was small, and in many calculations it could be neglected. In this paper, the following terms are used. Geomagnetic poles are the points where the axis of the magnetic dipole intersects the surface of the Earth. Since the magnetic dipole (Fig. 1, blue points) is only an approximate model of the Earth’s magnetic field, geomagnetic poles differ in their location from the true magnetic poles (Fig. 1, red points), in which the magnetic inclination is  $90^\circ$ . Probably, the oval is related to the magnetic pole of the Earth [4, 5], which shifted during this time to more than 1500 km (Fig. 1). It should be expected that the configuration and position of the auroral oval could also change [6].



**Fig. 1** Positions of the north geomagnetic (blue points) and magnetic (red points—shortest way) poles for 1900–2020 estimated from the 12th Generation IGRF. Image credit the British Geological Survey

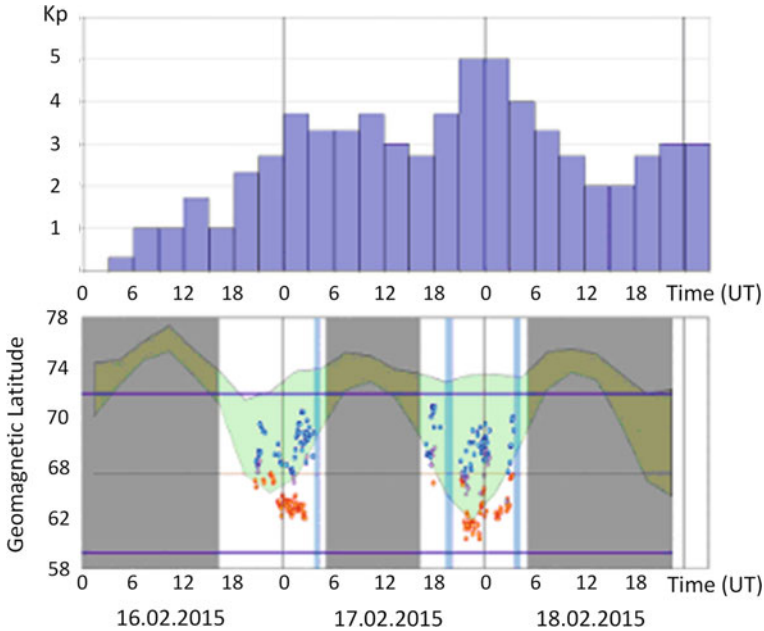
The purpose of this paper is to analyze and to measure directly the position of the auroral oval during the day for various perturbations of the magnetic field under current position of the Earth's magnetic pole.

To achieve the goal, experimental data and a component model of the Earth's magnetic field were used, taking into account the contribution of magnetic anomalies of the lithosphere [7, 8], and direct measurements of the spatial and temporal distribution of auroras by the all-sky camera from observations of individual stations and optical observations of the auroral oval apogee satellites [9]. In addition, we used the aurora forecast model "NORUSCA" based on the data obtained in IZMIRAN and PGI [9–11].

The average position of the auroral oval, obtained mainly according to the International Geophysical Year (1957–1958), was compared with direct measurements of the position of auroras in corrected geomagnetic coordinates during the modern era by analyzing direct optical measurements made by the all-sky cameras at the Observatory of the PGI "Lovozero" on the Kola Peninsula (67.98N, 35.08E) and in the Nordic Observatories Kiruna (Sweden) (67.84N, 20.41E) and Sodankyla (Finland) (67.37N, 26.63E). The equatorial boundary of the auroral oval lies here for Kp values 2–5 which gives the most reliable model of the oval position appropriate for our study. That is why these observatories have been chosen for the analysis.

The position of the auroral oval boundaries at Kiruna Station according to the NORUSCA model [10, 11] based on the Starkov-Feldstein data is shown in Fig. 2 (continuous lines) in Cartesian coordinates: latitude - time together with the position of the equatorial boundary of the oval (redpoints) and the polar boundary of the oval (blue points) according to the all-sky camera [12]. For four days out of seven considered, a situation was observed similar to that shown in Fig. 2. In three other cases, displacements of the oval boundaries also take place, but they are insignificant. Thus, on the basis of comparison of model data and direct measurements, one can assume that the position of the equatorial boundary of the oval during dark nights in the present epoch sometimes is shifted to the southeast by several hundred kilometers in relation to the position of the equatorial boundary calculated using the NORUSCA model based on the International Geophysical Year data.

Since all-sky cameras record the aurora only at night, we see only the night part of the oval. And it would be desirable to know the changes in the position of the oval as a whole. This can be done by modern methods of aurora observation by cameras [9] installed on high-apogee satellites operating in the far ultraviolet region of the spectrum and allowing for round-the-clock photography of auroras. A comparison of the auroral ovals obtained on the basis of the network of all-sky cameras during the International Geophysical Year period and obtained using high-apogee satellites is shown in Figs. 3 and 4 [9–11, 13, 14].



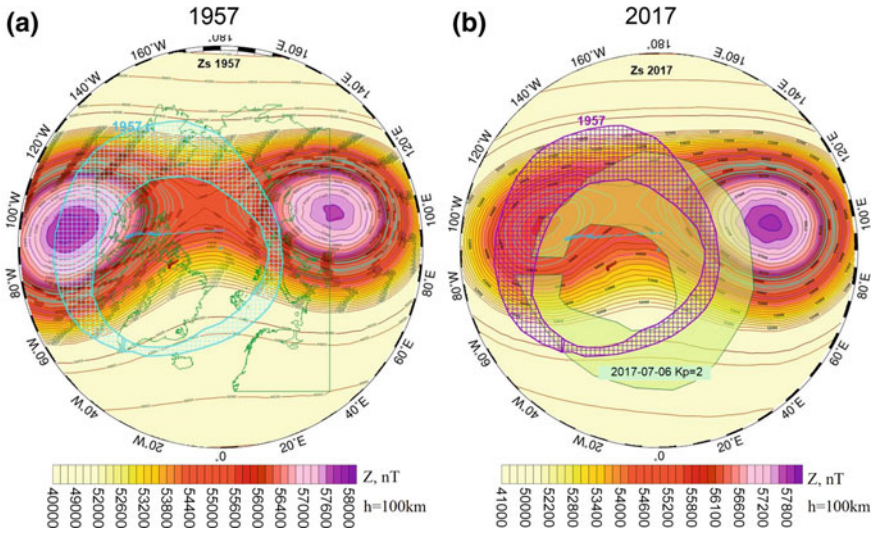
**Fig. 2** The time series of Kp indices (upper panel) and the position of the auroral oval according to the NORUSCA model [10, 11] based on the Starkov-Feldstein data and direct measurements of the oval borders at the Kiruna Observatory (lower panel) on February 16–18, 2018. Model oval borders are designated by lines, direct measurements are marked by blue (Northern border) and red (South border) points. Horizontal straight lines indicate the boundaries of the all-sky camera's field of view at the height of the lower boundary of the discrete auroras

## 2 Features of Changes in the Components of the Induction Vector of the Earth's Magnetic Field at the Heights of the Ionospheric Layers

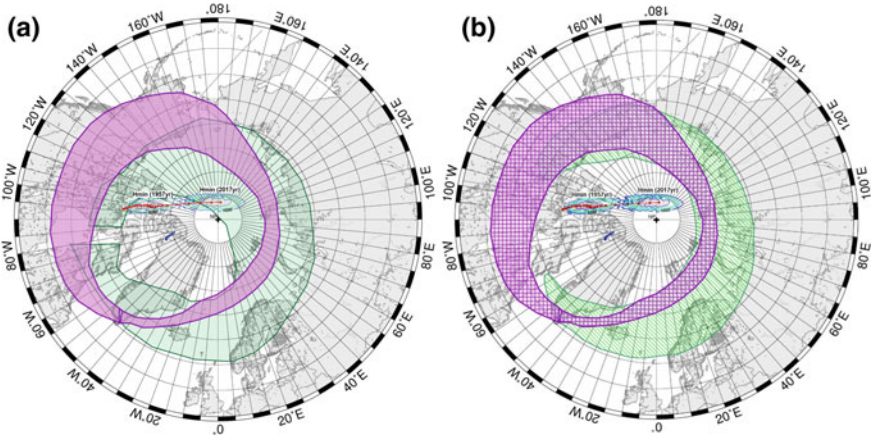
In order to study the configuration of the auroral oval under the Earth's magnetic pole displacement, the features of changes in the induction vector of the Earth's magnetic field (EMF) from 1957 to 2017 were studied.

For this purpose, the values of the vertical, horizontal, northern, and eastern components of EMF, declinations and inclinations obtained using SPbF IZMIRAN component model [7, 8] were calculated within the Polar Cap in the altitude range from 80 to 400 km. The component model is based on the observed and obtained values of the components calculated from the measurements of the modulus near the surface of the Earth. For the most ancient tectonic structures, the influence of the structure of magnetic anomalies of the lithosphere at the heights of the ionospheric layers manifests in the full values of EMF components.

Analysis of changes in the configuration of the auroral oval for the period from 1957 to 2017 was carried out on the basis of a comparison of the position of the oval



**Fig. 3** Position of the auroral oval and distribution of the Z-component isolines of the Earth's magnetic field at 100 km in 1957 (a) and in 2017 (b). For comparison, Figure (b) shows the position of the auroral oval in 1957



**Fig. 4** Offset of the auroral oval against the displacement of the magnetic pole at 100 km for different values of Kp in 2017: Kp = 2 (a); Kp = 5 (b). The figures depict the ovals of the aurora in 1957 (violet grid) and 2017 (green hatching) and the movement of the H-component minima (red line) over this period

at different  $K_p$  values between 2 and 9 for 16–18 Universal Time (UT) sector [1, 2, 9–11]. This made it possible to estimate the nature of the shift of the center of the auroral oval relative to the line of movement of the north magnetic pole for the period studied (Figs. 3 and 4).

The most significant changes occurred in the vertical  $Z$ -component (Fig. 3) from 1957 to 2017. The Canadian magnetic anomaly, to the center of which the auroral oval was timed, reached the value of 61200 nT in  $Z$ -component in 1957, which decreased to 58000 nT by 2017. At the same time, the auroral oval in 2017 [9–11] moved from the center of the Canadian Magnetic Anomaly towards the center of the Siberian Magnetic Anomaly, which for 60 years has not changed its maximum values in the  $Z$ -component (about 61000 nT). In addition, while the Canadian Magnetic Anomaly, having decreased in size, expanded to the North in the sector from  $80^\circ\text{W}$  to almost  $85^\circ\text{W}$ , the Siberian Magnetic Anomaly has descended from the  $100^\circ\text{E}$  meridian to almost  $82^\circ\text{E}$ . Auroral oval followed the collinear displacement of the Siberian Magnetic Anomaly in 2017. For  $K_p$  indices 2–5, the southern edge of the auroral oval descended from Iceland, where it was in 1957, to the south of Norway (Figs. 3 and 4).

From 1957 to 2017 there was a shift of the  $Z = 58000$  nT isoline of the Siberian Magnetic Anomaly to the south by  $L = 600$  km. At the same time, the auroral oval shift to the south for 1957–2017 amounted the same value ( $L = 600$  km), for analyzed  $K_p$  values from 2 to 5 (Fig. 4) taken from [9, 10].

Migration of the magnetic pole for the period from 1957 to 2017 may be depicted by the displacement of the minimum horizontal  $H$ -component region ( $H \leq 1000$  nT) (Fig. 4) and the maximum inclination region ( $I \geq 89^\circ$ ). For 60 years, both of these areas have moved eastward by the distance  $L \sim 1600$  km from the islands of the Canadian Arctic Archipelago towards the Siberian Magnetic Anomaly. At the same time, the shift of the eastern edge of the auroral oval for 1957–2017 to the east was  $L = 1050$  km.

There was a spatial shift of the auroral oval during 1957–2017:

- in the south direction by 600 km, together with the shift of the  $Z$  isoline;
- in the east direction by more than 1000 km, collinear to the displacement of the magnetic pole, identical to the region of the minimum of the  $H$ -component ( $H \leq 1000$  nT) and of maximum inclination ( $I \geq 89^\circ$ ).

Based on experimental data from 2013 to 2017, we concluded that there was a spatial shift of the auroral oval during 1957–2017.

As a result, for the analyzed period, the auroral oval shifted in the south-east direction from the center of the Canadian magnetic anomaly towards the Siberian magnetic anomaly.

### 3 Discussion and Conclusions

Based on experimental data, the present work indicates that the displacement of the position of the auroral oval occurred during the displacement of the magnetic pole and changes in the magnitude and configuration of the Z-component in the centers of the Canadian and Siberian magnetic anomalies.

These are the first results obtained on a limited number of measurements, and the work should be continued using more significant statistical material on a wide network of optical observation stations.

Probably the cause of the detected shift of the auroral oval is the significant decrease in the power of the source supporting the Canadian magnetic anomaly over the past 50 years.

The practical value of this study lies in the fact that in some cases, when calculating and forming models of the Earth's magnetic field, it is necessary to use not only the data of high-altitude satellite measurements and the analytical description by Gauss series, which allow to calculate the components of the main geomagnetic field only. It is necessary to apply more realistic values of the surface magnetic field measurements taking into account the contribution of magnetic anomalies of the lithosphere, which is considerable up to a height of 400 km.

It is also obvious that charged particles precipitate to the lower layers of the ionosphere along the real magnetic field lines. Thus, the uselessness of computational models taking into account the characteristics of the oval for magnetospheric particles precipitation studies [3] may be true. But this is not right for modern ionospheric studies. For example, consideration of the modern configuration of the auroral oval and the forecast of its further displacement will give us a necessary link for the operation of space-based navigation systems [13, 14]. And it gives a new life for the auroral oval.

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