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GEOPHYSICS

Possible Consequences of the Displacement of Magnetic Poles on the Structure and Dynamics of the Earth's Upper Atmosphere

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1. The velocity and acceleration of the North Magnetic Pole (NMP) motion has been increasing sharply since the 1970s and has almost doubled (up to 46 km/yr) in the last 30 yr [1]. During the same period, the velocity of the South Magnetic Pole (SMP) displacement decreased, and its motion has practically stopped since 1986. Wandering in the territory of North Canada gave way to stable, almost rectilinear motion of the Russian Arctic sector with linearly increasing acceleration. Given that the present-day trend continues, extrapolation of the NMP coordinates makes it possible to forecast that the NMP will be located in the Severnaya Zemlya Archipelago region by 2050. Such displacement of the NMP can provoke several physical consequences in the earth's atmosphere and ionosphere.

2. It is known that the existing structure of the earth's ionosphere and thermosphere reflects the dynamic balance between the energy influx with solar radiation depending on the geophysical coordinates and energy input from the magnetosphere with the fluxes of energetic charged particles in the auroral oval zone [2], which depends on the geomagnetic coordinates of the site. The displacement of magnetic poles would influence the following physical processes: (1) the balance of the solar and corpuscular ionization would change; (2) intense increase of ionization in the E layer at mid-latitudes in the auroral zone would directly influence the radiowave propagation; (3) new spatial structure of plasma convection would change the formation and location of the main ionospheric depression; (4) the maximum of Joule heat intensity would displace to mid-latitudes that would influence the distribution of neutral atmosphere parameters, such as temperature, $[O]/[N_2]$ ratio, and vertical wind velocity; and (5) the system of neutral winds and ionospheric response to magnetic storms would change.

Judging from the forecasted location of the NMP, the auroral oval would cover all large Russian cities during magnetic perturbations. In [3], we proposed a 1D model for the influence of the displacement of the pole only on plasma concentration in the ionosphere [4]. It was shown that, as a result of the increase in electron concentration, the critical frequencies of the F layer would exceed the present-day operating frequencies of this layer in summer months at mid-latitudes. Consequently, shortwave radio communication would be practically impossible.

3. The global reconstruction of the structure and dynamics of the earth's upper atmosphere at the displaced magnetic pole was performed using a 3D CTIM coupled ionosphere–thermosphere model [5]. This fully nonlinear model allows us to calculate the winds, concentrations, and temperatures of both neutral and charged components with a resolution of 2° by latitude and 18° by longitude with 15 layers by vertical. Parameterization of auroral precipitations was performed using the TIROS-NOAA model that takes into account the dependence of the oval parameters on magnetic activity. We estimated the NMP coordinates in 2050 as 125° E, 75° N. The SMP position was retained at the position corresponding to 2000 [1]. The current and forecasted locations of the NMP were calculated for four seasons (winter, spring, summer, and autumn) at low magnetic activity ($K_p = 2$) and moderate solar activity (F10.7 = 120). An additional calculation was carried out for winter (December 9) in the case of a strong magnetic storm ($K_p = 7+$) with a duration of 12 h. Figures 1a and 1b show the distribution of NmF2 (electron concentration at the maximum of the F2 ionospheric layer), which is an integral value depending on the sources of ionization, temperature, neutral compo-

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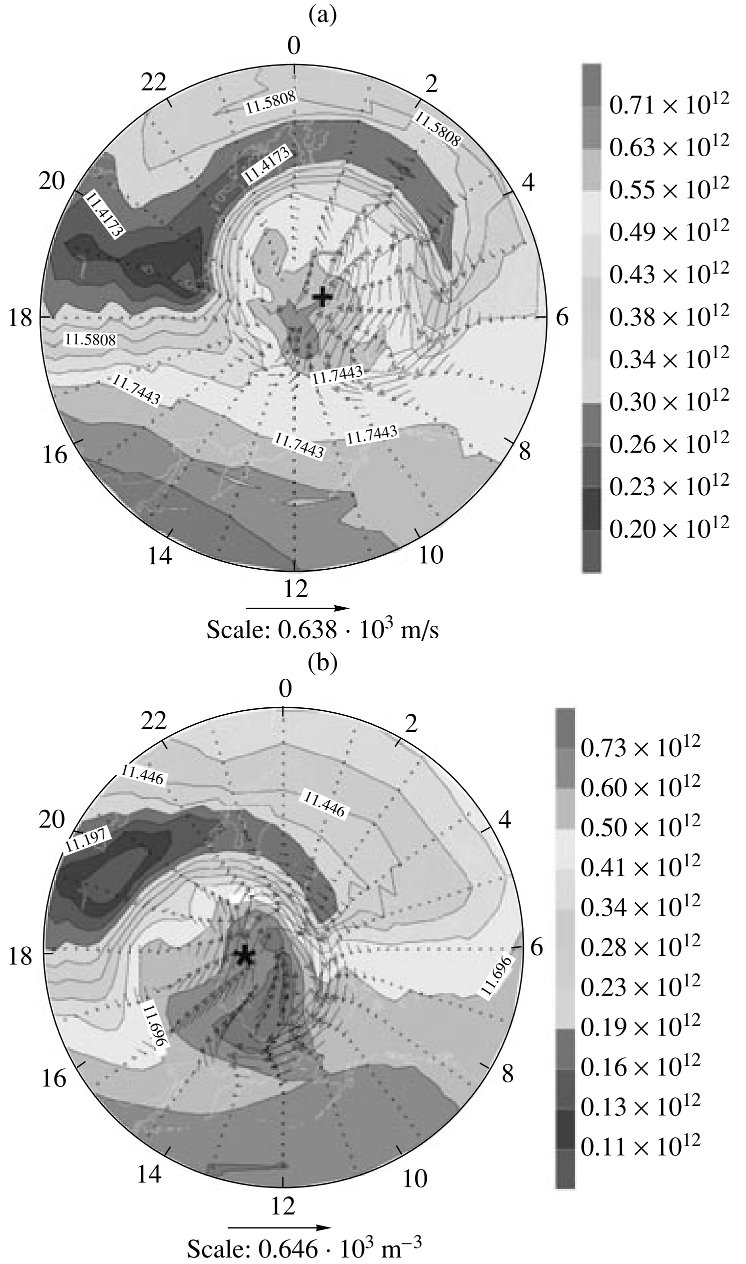

Fig. 1. Electron concentration at the maximum of the F2 layer (NmF2, m^{-3}) at 00:00 UT (spring equinox) and plasma convection speed (m/s) (a) at the current position of the magnetic pole (cross) and (b) position of the magnetic pole in 2050 (asterisk). Numerals on the limb indicate local time.

sition, and wind. Figures 2a and 2b show the distribution of the F2 layer altitude in the Northern Hemisphere during the spring equinox at 00:00 UT. The main convective cell displaces to the daytime side and provokes an additional increase in the electron concentration, while the polar ionosphere merges with the mid-latitude ionosphere. The scheme of ionosphere control by the universal time and formation of the main ionospheric depression would change [6]. The distribution of hmF2 changes qualitatively on the daytime side. In general, the F2 layer ascends by 20–30 km as a result of stronger heating.

A comparison of the results obtained for different seasons and different time moments showed that the pattern is qualitatively reproduced with a shift of approximately 12 h. However, the displacement of the NMP does not lead to a symmetric displacement of the auroral zone to a new location. Owing to a change in the phase shift between the magnetic and solar local time, distributions of the atmospheric parameters differ in terms of quantity and structure, although they are similar in qualitative terms. The difference is maximal in the equinox periods and minimal in summer at least in magnetically calm conditions.

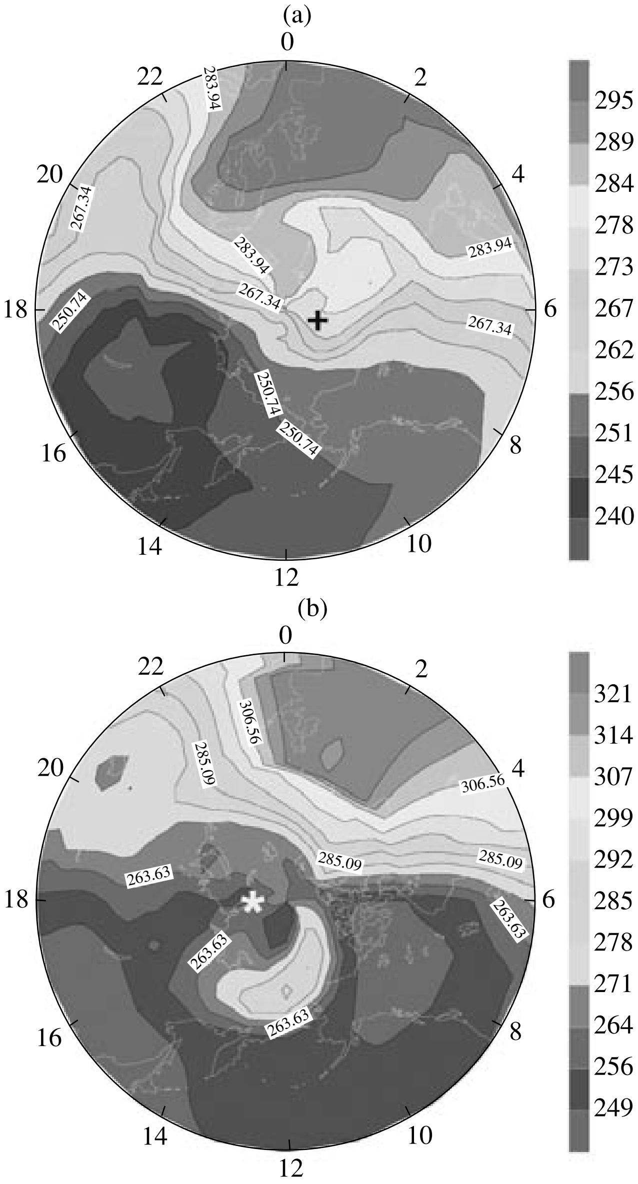

Fig. 2. Altitude of the maximum of the F2 layer (hmF2, km) at 00:00 UT (spring equinox) (a) at the current position of the magnetic pole (cross) and (b) position of the magnetic pole in 2050 (asterisk).

The calculations of the system of currents showed that the strongest currents at the displaced magnetic pole would flow over East Siberia, and they would displace almost to 40° N during magnetic storms.

Modeling of magnetic storm and comparison of the results with those reported in [5] confirmed the change in the response of the ionosphere and thermosphere to magnetic perturbations. In the evening hours, the electron concentration over the northern part of East Siberia would be one order of magnitude greater than the present-day concentration. This zone would be characterized by almost complete disappearance of the F2 layer due to intense heating of the neutral atmosphere and variation in the $[O]/[N_2]$ ratio. Changes in the neutral wind would be maximal at mid-latitudes of North America, over the Atlantic Ocean, and in the southern part of Western Europe. The NMP displacement may completely change shortwave radio communication over the territory of Russia. The operation of satellite navigation systems would be distorted, because they use the algorithms of ionospheric correction based on empirical models that would become inapplicable. It would be necessary to carry out a careful engineering estimate of geomagnetically induced currents in the power networks under conditions of the NMP displacement.

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