



# NUMERICAL MODELING OF THE INFLUENCE OF GEOMAGNETIC ACTIVITY ON THE GLOBAL CIRCULATION OF THE EARTH'S ATMOSPHERE FOR JULY CONDITIONS

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**Abstract.** The effect of geomagnetic activity on the global circulation in the Earth's atmosphere is studied with the help of the non-hydrostatic mathematical model, developed earlier in the Polar Geophysical Institute. The model produces three-dimensional distributions of the zonal, meridional, and vertical components of the neutral wind and neutral gas density in the layer surrounding the Earth globally and stretching from the ground up to the altitude of 126 km. Simulations are performed for the summer period in the northern hemisphere (16 July) and for three distinct values of geomagnetic activity ( $K_p=1, 4$  and  $7$ ). The simulation results indicate that the global neutral wind system may be rather different under distinct geomagnetic activity conditions not only in the lower thermosphere but also in the mesosphere and stratosphere. The influence of geomagnetic activity on the global neutral wind system in the mesosphere and stratosphere is conditioned by the vertical transport of the air which may be noticeably different under distinct geomagnetic activity conditions.

## Introduction

Computational studies may be successfully applied to investigate the planetary wind system of the Earth's atmosphere. Earlier, in the Polar Geophysical Institute, the non-hydrostatic mathematical model of the global circulation in the Earth's atmosphere has been developed [Mingalev and Mingalev, 2005; Mingalev et al., 2007]. This model enables to calculate three-dimensional global distributions of the zonal, meridional, and vertical components of the neutral wind at levels of the troposphere, stratosphere, mesosphere, and lower thermosphere. This non-hydrostatic mathematical model has been utilized in order to investigate numerically how solar activity and horizontal non-uniformity of the atmospheric gas temperature affects the formation of the atmosphere global circulation [Mingalev et al., 2014 and references therein]. Also, this model has been utilized in order to investigate numerically how geomagnetic activity affects the formation of the large-scale global circulation of the mesosphere and lower thermosphere under January conditions when the winter period is in the northern hemisphere [Mingalev et al., 2013]. It is known that solar radiation, reaching the Earth's surface, is distinct in different months due to the tilt of rotational axis of the Earth. Therefore, it may be expected that the effect of geomagnetic activity on the global circulation in the Earth's atmosphere is different in the periods, corresponding to various seasons, as a consequence of different positions of the Earth along its trajectory around the Sun.

The purpose of the present work is to investigate numerically, using the non-hydrostatic model of the global neutral wind system, developed earlier in the Polar Geophysical Institute, how geomagnetic activity affects the formation of the large-scale global circulation of the stratosphere, mesosphere, and lower thermosphere under July conditions when the summer period is in the northern hemisphere.

## Mathematical model

The non-hydrostatic model of the global wind system of the atmosphere, developed earlier in the Polar Geophysical Institute, is utilized in the present work [Mingalev and Mingalev, 2005; Mingalev et al., 2007]. The model produces three-dimensional global distributions of the zonal, meridional, and vertical components of the neutral wind and neutral gas density in the troposphere, stratosphere, mesosphere, and lower thermosphere. The peculiarity of the utilized model consists in that the internal energy equation for the neutral gas is not solved in the model calculations. Instead, the global temperature field is assumed to be a given distribution, i.e. the input parameter of the model, and obtained from the NRLMSISE-00 empirical model [Picone et al., 2002]. Moreover, the model is non-hydrostatic, that is, not only the horizontal components but also the vertical component of the neutral wind velocity is obtained by means of a numerical solution of a generalized Navier-Stokes equation for compressible gas.

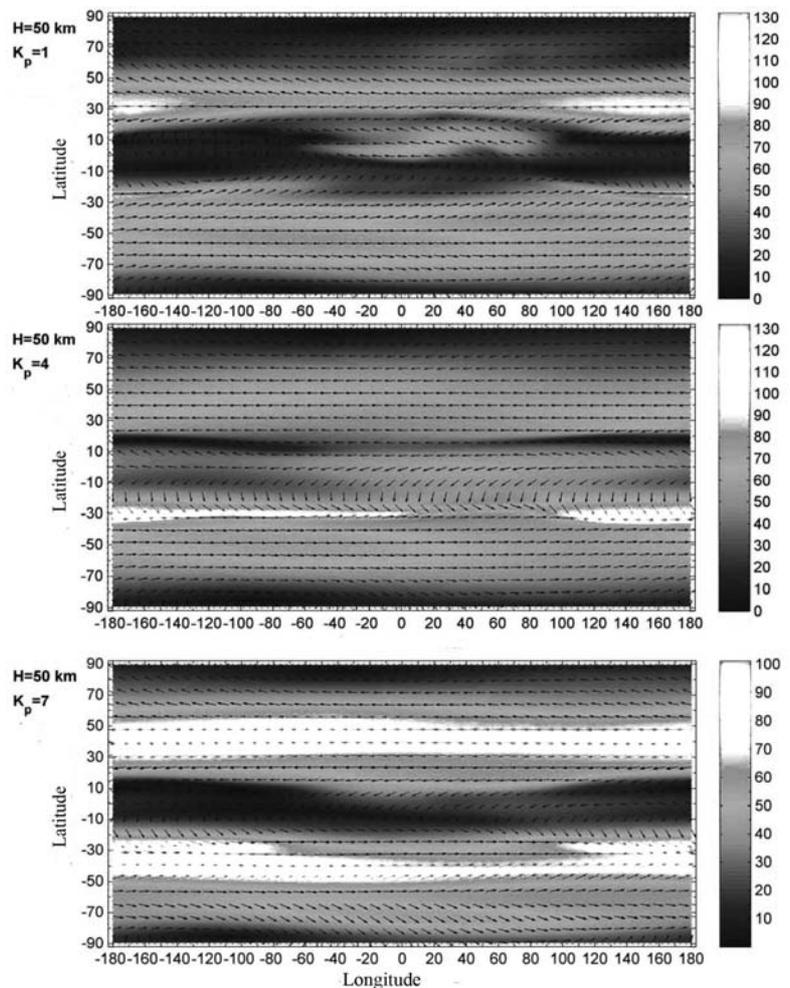
The mathematical model, utilized in the present study, is based on the numerical solution of the system of equations containing the dynamical equation and continuity equation for the neutral gas. The finite-difference method is applied for solving the system of equations. The calculated parameters are determined on a uniform grid, with the latitude and longitude steps being equal to  $1^\circ$ . A height step is non-uniform and does not exceed the value of 1 km. The simulation domain is the layer surrounding the Earth globally. This layer stretches from the ground up to the altitude of 126 km at the equator. The Earth's surface is supposed to coincide approximately with an oblate

spheroid whose radius at the equator is more than that at the pole. Upper boundary conditions provide the conservation law of mass in the simulation domain. More complete details of the utilized model may be found in the studies of *Mingalev and Mingalev [2005]* and *Mingalev et al. [2007]*.

## Simulation results

Simulation results to be presented in this work were obtained for the summer period in the northern hemisphere (16 July) and for conditions corresponding to moderate 10.7-cm solar flux ( $F_{10.7}=101$ ). Calculations were made for three distinct values of geomagnetic activity ( $K_p=1, 4,$  and  $7$ ). The steady-state distributions of the atmospheric parameters were obtained, using the method of establishment, that is, the variations of the atmospheric parameters with time were calculated until they become stationary on condition that inputs to the model and boundary conditions correspond to the fixed moment, namely, 10.30 UT. The temperature distributions, corresponding to this moment, were taken from the NRLMSISE-00 empirical model [*Picone et al., 2002*]. Analyzing these temperature distributions, obtained for three distinct values of geomagnetic activity ( $K_p=1,4,$  and  $7$ ), we can see that they are very similar below approximately 80 km, whereas, above this altitude, they may be rather different. Thus, it can be seen from the NRLMSISE-00 empirical model that the influence of level of geomagnetic activity on the global distribution of the atmospheric temperature ought to be absent at altitudes of the troposphere, stratosphere, and mesosphere, while this influence ought to be appreciable at altitudes of the lower thermosphere for the summer period in the northern hemisphere.

**Figure 1.** The global distributions of the vector of the simulated horizontal component of the neutral wind velocity at the altitude of 50 km, obtained for 16 July and calculated for three distinct values of geomagnetic activity:  $K_p=1$  (top panel),  $K_p=4$  (middle panel), and  $K_p=7$  (bottom panel). The degree of shadowing of the figures indicates the module of the velocity in m/s.

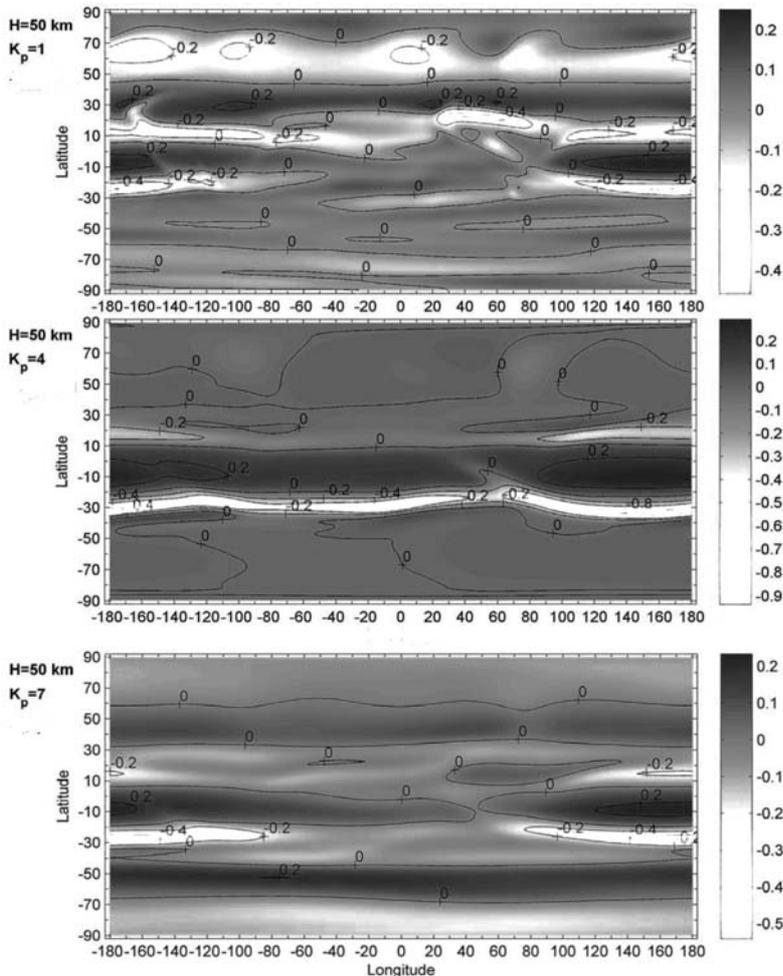


The global distributions of the vector of the simulated horizontal component of the neutral wind velocity at the altitude of 50 km, calculated with the help of the mathematical model and obtained for three distinct values of geomagnetic activity ( $K_p=1, 4,$  and  $7$ ), are shown in Fig. 1. The global distributions of the simulated vertical component of the neutral wind velocity at 50 km altitude, calculated for three distinct values of geomagnetic activity ( $K_p=1, 4,$  and  $7$ ), are shown in Fig. 2. It turns out that distributions of the atmospheric parameters, calculated with the help of the mathematical model, illustrate both common characteristic features and distinctions caused by different values of geomagnetic activity.

Let us consider common features of the simulation results. The horizontal and vertical components of the wind velocity are changeable functions not only of the altitude but also of latitude and longitude. At levels of the troposphere, stratosphere, mesosphere, and lower thermosphere, maximal absolute values of the horizontal and vertical components of the wind velocity are larger at higher altitudes. At altitudes of the mesosphere and lower thermosphere, the horizontal domains exist where the steep gradients in the horizontal velocity field take place. At the near points, the horizontal wind velocity can have various directions which may be opposite. Also, the horizontal domains exist in which the vertical neutral wind component has opposite directions. The horizontal wind velocity

can achieve values of more than 130 m/s at levels of the mesosphere. In the horizontal domains, having a configuration like a limited narrow band, the vertical wind velocity can achieve values of more than 1 m/s at levels of the mesosphere. At these levels, maximal module of the upward vertical wind component is less than the maximal absolute values of the downward vertical wind component.

It can be noticed that, from numerous observations, it is known that the global atmospheric circulation can contain sometimes so called circumpolar vortices. In the planetary neutral wind system, these vortices are the largest scale inhomogeneities which are formed at heights of the stratosphere and mesosphere in the periods close to summer and winter solstices. It is known that, in the northern hemisphere, the circumpolar anticyclone arises under summer conditions, whereas, in the southern hemisphere, the circumpolar cyclone arises under winter conditions.



**Figure 2.** The global distributions of the simulated vertical component of the neutral wind velocity at the altitude of 50 km, obtained for 16 July and calculated for three distinct values of geomagnetic activity:  $K_p=1$  (top panel),  $K_p=4$  (middle panel), and  $K_p=7$  (bottom panel). The degree of shadowing of the figures indicates the velocity in m/s, with positive direction of the vertical velocity being upward.

Let us compare these observational data with the simulation results, obtained in the present study for July conditions. From the numerically obtained results for summer period in the northern hemisphere, we can see that at levels of the stratosphere and mesosphere, the motion of the neutral gas in the northern hemisphere is primarily westward (Fig. 1), so a circumpolar anticyclone is formed. Simultaneously, the motion of the

neutral gas is primarily eastward in the southern hemisphere at levels of the stratosphere and mesosphere (Fig.1), so a circumpolar cyclone is formed for winter period of the southern hemisphere. Thus, the circumpolar vortices of the northern and southern hemispheres, calculated in the present study, correspond well to the global circulation of the stratosphere and mesosphere, obtained from observations for July conditions.

Let us consider simulation results, obtained for different values of geomagnetic activity, and their distinctions. It can be seen that the global distributions of the vector of the simulated horizontal component of the neutral wind velocity, calculated for three different values of geomagnetic activity ( $K_p=1, 4,$  and  $7$ ), are rather distinct. In particular, the maximal absolute values of the horizontal wind velocity, obtained for three different values of geomagnetic activity ( $K_p=1, 4,$  and  $7$ ), are perceptibly distinct. Incidentally, the lower the value of geomagnetic activity is, the higher the maximal absolute values of the horizontal wind velocity ought to be (Fig. 1).

It is clear that the dependence of the global neutral wind system on the geomagnetic activity, obtained in the model calculations at levels of the lower thermosphere, is conditioned by the distinctions of the planetary distributions of the atmospheric temperature, which take place at these levels. From the results shown in Fig. 1, we can see that the global distributions of the vector of the simulated horizontal component of the neutral wind velocity at the altitude of 50 km, calculated for three different values of geomagnetic activity ( $K_p=1,4,$  and  $7$ ), are perceptibly distinct. This fact can not be explained by the distinctions of the planetary distributions of the atmospheric temperature because of the absence of these distinctions below approximately 80 km, as was noted earlier. Thus, simulation results, obtained for July conditions, indicate that, despite of independence of the

atmospheric temperature on the geomagnetic activity below approximately 80 km, the influence of the geomagnetic activity level on the global circulation of the stratosphere and mesosphere do exist.

To explain this fact, let us consider the global distributions of the simulated vertical component of the neutral wind velocity, calculated for three distinct values of geomagnetic activity. It turns out that these distributions are rather distinct not only at levels of the lower thermosphere but also at levels of the stratosphere and mesosphere (Fig. 2). Consequently, the vertical transport exists of the air from the lower thermosphere to the mesosphere and stratosphere and vice versa. This transport is influenced by geomagnetic activity conditions. Thus, the influence of geomagnetic activity on the global circulation in the Earth's stratosphere and mesosphere for July conditions may be explained by the vertical transport of the air which may be noticeably different under distinct geomagnetic activity conditions.

The simulation results, obtained in the present study for July conditions, are similar to the results of simulation, obtained earlier for January conditions, as for the cause of the influence of geomagnetic activity on the global circulation in the Earth's stratosphere and mesosphere.

## Conclusion

The non-hydrostatic model of the global neutral wind system of the Earth's atmosphere, developed earlier in the Polar Geophysical Institute, was utilized to investigate how geomagnetic activity affects the global circulation of the atmosphere for July conditions. The model produces three-dimensional distributions of the zonal, meridional, and vertical components of the neutral wind and neutral gas density in the layer surrounding the Earth globally and stretching from the ground up to the altitude of 126 km. The peculiarity of the utilized model consists in that the internal energy equation for the neutral gas is not solved in the model calculations. Instead, the global temperature field is assumed to be a given distribution, i.e. the input parameter of the model, and obtained from the NRLMSISE-00 empirical model. Simulations are performed for three distinct values of geomagnetic activity ( $K_p=1, 4, \text{ and } 7$ ).

The simulation results indicate that, in the lower thermosphere, geomagnetic activity ought to influence considerably on the formation of global neutral wind system as a consequence of variations of the atmospheric temperature distributions due to geomagnetic activity changes. At levels of the stratosphere and mesosphere, the influence of geomagnetic activity on the global distribution of the atmospheric temperature ought to be absent, nevertheless, the effect of geomagnetic activity on the global circulation of the atmosphere exists at these levels. The influence of geomagnetic activity on the global neutral wind system in the stratosphere and mesosphere is conditioned by the vertical transport of the air which may be noticeably different under distinct geomagnetic activity conditions. The explanation of the influence of geomagnetic activity on the global circulation in the Earth's stratosphere and mesosphere, propounded in the present study for July conditions, is similar to the elucidation, given earlier for January conditions. It can be emphasized that the applied mathematical model was able to simulate this effect due to the fact that the model is non-hydrostatic.

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