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NUMERICAL MODELING OF THE INFLUENCE OF MAGNETIC ACTIVITY ON THE GLOBAL CIRCULATION OF THE MIDDLE ATMOSPHERE FOR JANUARY CONDITIONS

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Abstract

To investigate how magnetic activity affects the formation of the large-scale global circulation of the stratosphere, mesosphere, and lower thermosphere, the non-hydrostatic model of the global neutral wind system of the Earth's atmosphere, developed earlier in the Polar Geophysical Institute, is utilized. Simulations are performed for the winter period in the northern hemisphere (16 January) and for two distinct values of magnetic activity (Kp=1 and Kp=4). The simulation results indicate that magnetic activity ought to influence considerably on the formation of global neutral wind system not only in the lower thermosphere but also in the mesosphere and stratosphere. The influence on the middle atmosphere is conditioned by the vertical transport of air from the lower thermosphere to the mesosphere and stratosphere. This transport may be rather different under distinct magnetic activity conditions.

Introduction

Not long ago, in the Polar Geophysical Institute (PGI), the non-hydrostatic model of the global neutral wind system 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, with whatever restrictions on the vertical transport of the neutral gas being absent. This model has been utilized in order to simulate the global circulation of the middle atmosphere for conditions corresponding to different seasons [*Mingalev et al*., 2007; 2012] and to investigate numerically how solar activity affects the formation of the large-scale global circulation of the mesosphere and lower thermosphere [*Mingalev and Mingalev*, 2012]. The purpose of the present work is to continuer these studies and to investigate numerically, using the non-hydrostatic model of the global neutral wind system, developed earlier in the Polar Geophysical Institute, how magnetic activity affects the formation of the large-scale global circulation of the stratosphere, mesosphere, and lower thermosphere.

Mathematical model

In the present study, the non-hydrostatic model of the global neutral wind system in the Earth's atmosphere, developed earlier in the PGI [*Mingalev and Mingalev*, 2005; *Mingalev et al*., 2007], is utilized. This 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, in the model calculations, 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, so the model is non-hydrostatic.

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. For solving the system of equations, the finite-difference method is applied. The steps of the finite-difference approximations in the latitude and longitude directions are identical and equal to 1 degree. 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 and stretching from the ground up to the altitude of 126 km at the equator. Upper boundary conditions provide the conservation law of mass in the simulation domain. 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. 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

In the present study, simulations are performed for the winter period in the northern hemisphere (16 January) and for conditions corresponding to moderate 10.7-cm solar flux ($F_{10.7}$ =101). To investigate the influence of magnetic activity on the global circulation of the atmosphere, we made calculations for conditions corresponding to two different values of magnetic activity: low and considerable, namely, Kp=1 and Kp=4. The variations of the atmospheric parameters with time were calculated until they become stationary. The steady-state distributions of the atmospheric parameters were obtained on condition that inputs to the model and boundary conditions correspond to 10.30 UT. The temperature distributions, corresponding to this moment, were taken from the NRLMSISE-00 empirical model [*Picone et al.,* 2002].

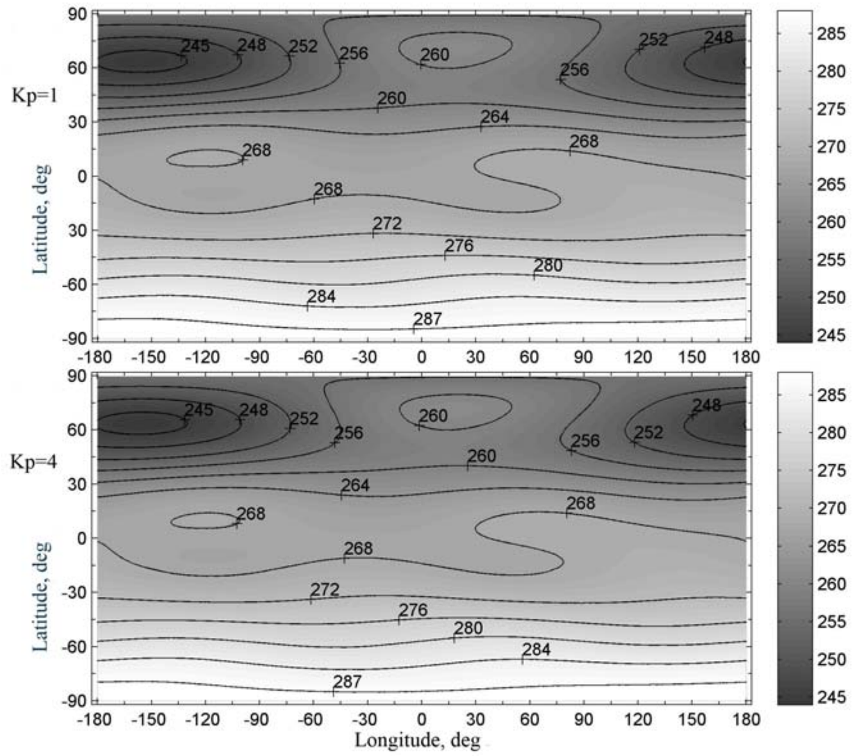

Fig. 1 The global distributions of the atmospheric temperature (K) at 50 km altitude, obtained from the NRLMSISE-00 empirical model for 16 January, UT=10.30 and calculated for two distinct values of magnetic activity: Kp=1 (top panel) and Kp=4 (bottom panel).

It turns out that atmospheric temperatures, calculated with the help of the NRLMSISE-00 empirical model for two distinct values of magnetic activity (Kp=1 and Kp=4), are very similar below approximately 80 km, while, above this altitude, they may be rather different. Fig. 1 shows the global distributions of the atmospheric temperature at 50 km altitude, obtained from the NRLMSISE-00 empirical model for 16 January, UT=10.30 and calculated for two distinct values of geomagnetic activity: Kp=1 and Kp=4. It is seen no distinctions between the results obtained for two different values of geomagnetic activity. Above 80 km, for example, at the altitude of 110 km, differences between temperatures, obtained for two considered values of magnetic activity, can achieve a few tens of degrees at identical points of the globe. Thus, the application of the NRLMSISE-00 empirical model shows that the influence of level of magnetic 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 winter period in the northern hemisphere.

Distributions of the atmospheric parameters, calculated with the help of the mathematical model and obtained for 16 January, are partly shown in Figs. 2 and 3. The results of modeling illustrate both common characteristic features and distinctions caused by different values of magnetic activity. The calculated global distributions of the atmospheric parameters display the following common features. The horizontal and vertical components of the wind velocity are changeable functions of latitude and longitude at levels of the stratosphere, mesosphere, and lower thermosphere. The horizontal domains exist where the steep gradients in the horizontal velocity field take place. The horizontal wind velocity can have various directions which may be opposite at the near points. Moreover, the horizontal domains exist in which the vertical neutral wind component has opposite directions. Maximal absolute values of the horizontal and vertical components of the wind velocity are larger at higher altitudes. At levels of the mesosphere, the horizontal wind velocity can achieve values of more than 150 m/s.

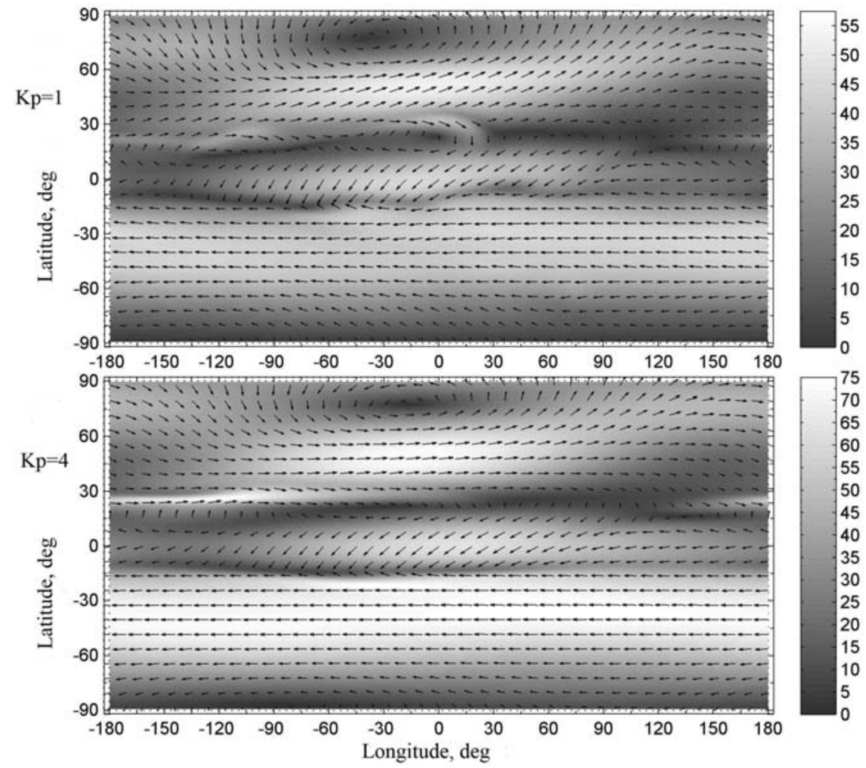

Fig. 2 The global distributions of the vector of the simulated horizontal component of the neutral wind velocity at the altitude of 50 km, obtained for 16 January and calculated for two distinct values of magnetic activity: Kp=1 (top panel) and Kp=4 (bottom panel). The degree of shadowing of the figures indicates the module of the velocity in m/s.

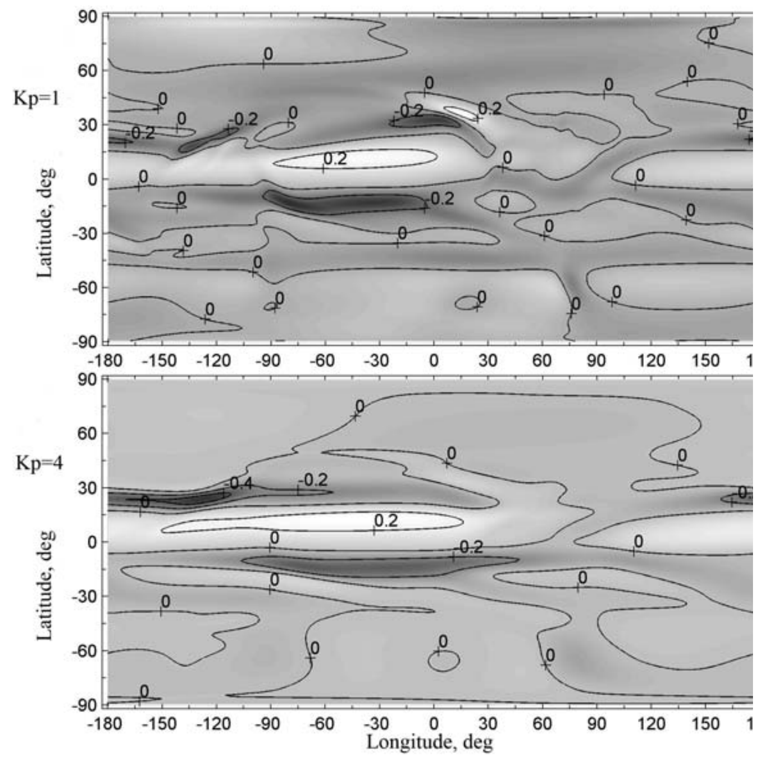

Fig. 3 The global distributions of the simulated vertical component of the neutral wind velocity at the altitude of 50 km, obtained for 16 January and calculated for two distinct values of magnetic activity: Kp=1 (top panel) and Kp=4 (bottom panel). The velocities are given in m/s, with positive direction of the vertical velocity being upward.

From the obtained results for winter 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 eastward, so a circumpolar cyclone is formed. It can be noticed that the center of the northern cyclone may be displaced from the pole. Simultaneously, the motion of the neutral gas is primarily westward in the southern hemisphere at levels of the stratosphere and mesosphere, so a circumpolar anticyclone is formed for summer period of the southern hemisphere.

Let us consider simulation results, obtained for distinct values of magnetic activity, and their distinctions. From the obtained results, one can see that the horizontal wind velocity in the circumpolar cyclone of the northern hemisphere, obtained for low magnetic activity, is less than that, obtained for considerable magnetic activity. Similarly, the horizontal wind velocity in the circumpolar anticyclone of the southern hemisphere, obtained for low magnetic activity, is less than that, obtained for considerable magnetic activity.

From the obtained results, we can see that, for winter period in the northern hemisphere, at levels of the mesosphere, the vertical wind velocity can have opposite directions in the horizontal domains having different configurations. Maximal absolute values of the downward vertical wind component are commensurable with the maximal module of the upward vertical wind component for conditions of low magnetic activity. On the contrary, for conditions of considerable magnetic activity, maximal absolute values of the downward and upward vertical wind components can be rather different.

Simulation results, obtained for January conditions, indicate that, despite of independence of the atmospheric temperature on the magnetic activity below approximately 80 km, the influence of the magnetic activity level on the global circulation of the stratosphere and mesosphere does exist. This influence is a consequence of a relationship between large-scale circulations of the middle atmosphere and thermosphere, with the thermospheric circulation being dependent on the magnetic activity level, undoubtedly. The influence is conditioned by the vertical transport of air from the lower thermosphere to the mesosphere and stratosphere. This transport may be rather different under distinct magnetic activity conditions.

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 magnetic activity affects the formation of the large-scale global circulation of the stratosphere, mesosphere, and lower thermosphere for January conditions.

The simulation results indicate that magnetic activity ought to influence considerably on the formation of global neutral wind system in the stratosphere, mesosphere, and lower thermosphere. However, this influence is not straightforward. Undoubtedly, at levels of the lower thermosphere, this influence is conditioned by the differences of the temperature distributions, obtained for various values of geomagnetic activity at these levels. However, from the simulation results obtained, we can see that the atmospheric temperature, calculated with the help of the NRLMSISE-00 empirical model, does not depend on the geomagnetic activity below approximately 80 km. Nevertheless, the effect of geomagnetic activity on the global circulation of the atmosphere below 80 km exists. This effect is conditioned by the vertical transport of air from the lower thermosphere to the mesosphere, stratosphere, and upper troposphere, eventually, and vice versa. The simulation results indicate that this vertical transport may be rather distinct under different geomagnetic activity conditions. It can be noticed that the utilized mathematical model was able to simulate this effect due to the fact that the model is non-hydrostatic.

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