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# A MODEL STUDY OF HOW SOLAR ACTIVITY AFFECTS THE GLOBAL CIRCULATION OF THE MIDDLE ATMOSPHERE FOR JANUARY CONDITIONS

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**Abstract.** The non-hydrostatic model of the global neutral wind system of the Earth's atmosphere, developed earlier in the Polar Geophysical Institute, is utilized to investigate how solar activity affects the formation of the large-scale global circulation of the mesosphere and lower thermosphere. Simulations are performed for the winter period in the northern hemisphere (16 January) and for two distinct values of solar activity ($F_{10.7}$=101 and 230). The simulation results indicate that solar activity ought to influence considerably on the formation of global neutral wind system in the mesosphere and lower thermosphere. 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 solar activity conditions.

## Introduction

In the Polar Geophysical Institute (PGI), the non-hydrostatic model of the global neutral wind system in the Earth's atmosphere has been developed not long ago [*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 investigate numerically how the horizontal non-uniformity of the neutral gas temperature affects the formation of the middle atmosphere circulation for conditions corresponding to different seasons [*Mingalev et al*., 2007; 2008; 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 [*Mingalev and Mingalev*, 2005; *Mingalev et al*., 2007], how solar activity affects the formation of the large-scale global circulation of the mesosphere and lower thermosphere.

## Mathematical model

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 in the present study. The utilized model produces three-dimensional global distributions of the zonal, meridional, and vertical components of the neutral wind velocity and neutral gas density at the levels of the troposphere, stratosphere, mesosphere, and lower thermosphere. The characteristic feature of the model is that the vertical component of the neutral wind velocity, as well as horizontal components of the neutral wind, is obtained by means of a numerical solution of the appropriate momentum equation for a viscous gas without any simplifications of this equation, with the hydrostatic equation being not used. Moreover, the model does not include the internal energy equation for the neutral gas. Instead, the global temperature field is assumed to be a given distribution obtained from the NRLMSISE-00 empirical model [*Picone et al.*, 2002].

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 model calculations, global distributions of the atmospheric parameters were computed for conditions corresponding to 16 January and for low geomagnetic activity (Kp=1). To investigate the influence of solar activity on the global circulation of the atmosphere, we made calculations for conditions corresponding to two different 10.7-cm solar fluxes: moderate and high, namely, $F_{10.7}$ =101 and 230. 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].

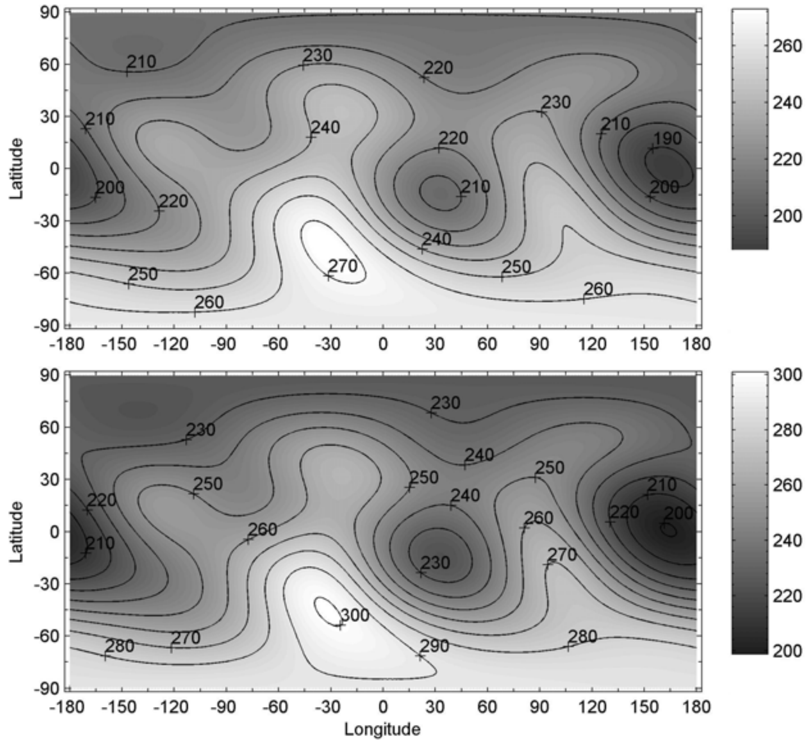


**Fig.1.** The global distributions of the atmospheric temperature (K) at 110 km altitude, obtained from the NRLMSISE-00 empirical model for 16 January, UT=10.30 and calculated for two distinct values of solar activity: $F_{10.7}$ =101 (top panel) and $F_{10.7}$ =230 (bottom panel).

It turns out that atmospheric temperatures, calculated with the help of the NRLMSISE-00 empirical model for two distinct values of solar activity ($F_{10.7}$ =101 and 230), are very similar below approximately 100 km, while, above this altitude, they may be rather different. From Fig. 1, one can see that, at the altitude of 110 km, differences between temperatures, obtained for two considered 10.7-cm solar fluxes, 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 solar 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.

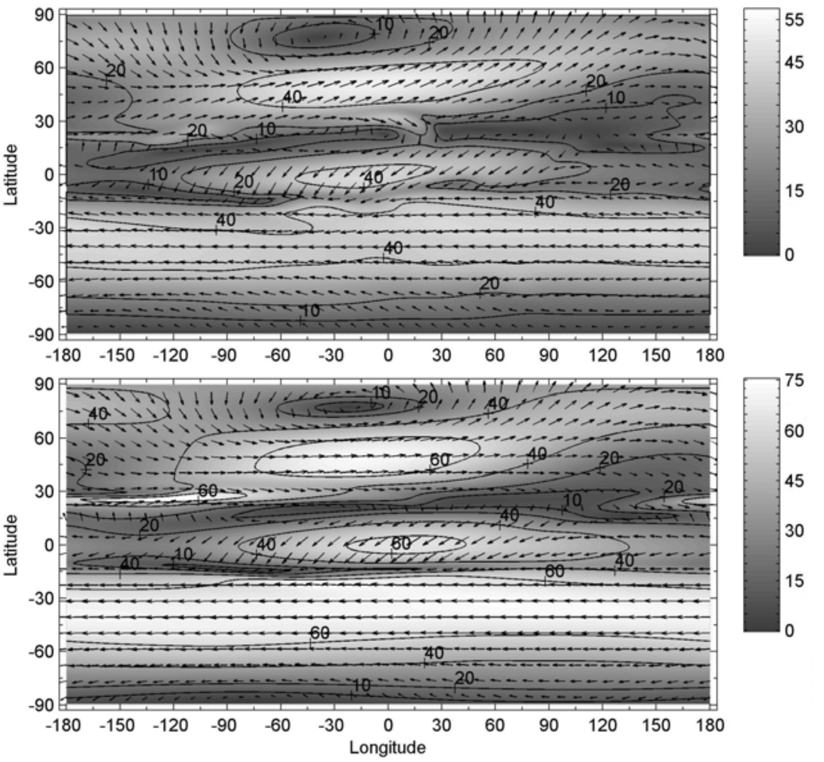


**Fig.2.** The global distributions of the vector of the simulated horizontal component of the neutral wind velocity at the altitude of 50 km, obtained for 16 January and calculated for two distinct values of solar activity: $F_{10.7}$ =101 (top panel) and $F_{10.7}$ =230 (bottom panel). The velocities are given in m/s.

Distributions of the atmospheric parameters, calculated with the help of the mathematical model and obtained for 16 January, are partly shown in Figs. 2-4. The results of modeling illustrate both common characteristic features and distinctions caused by different values of solar 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 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 160 m/s.

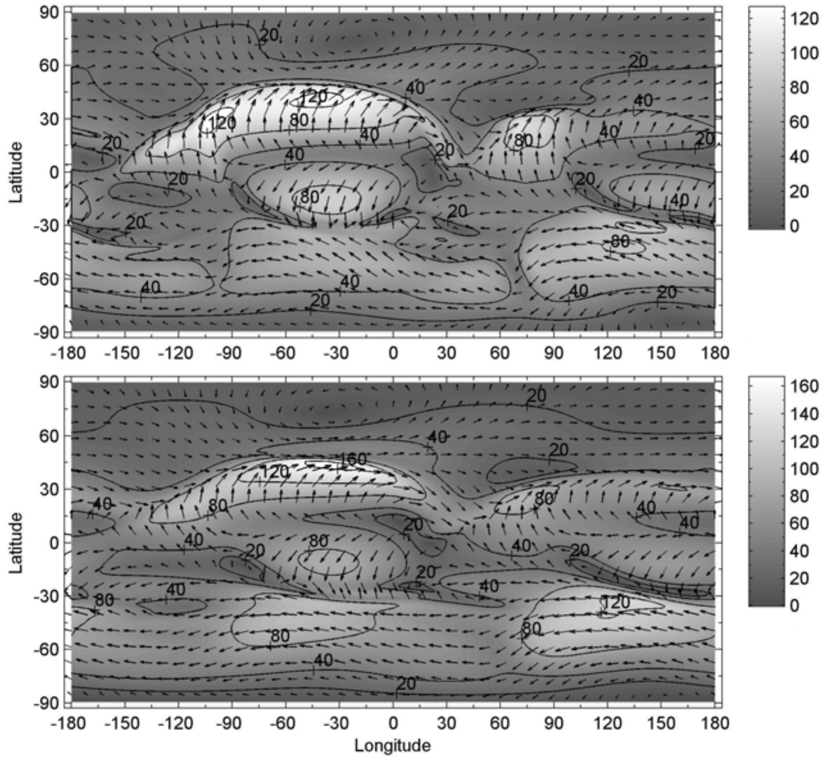


**Fig.3.** The same as in Fig. 2 but at the altitude of 70 km.

From the obtained results, we can see that, for winter period in the northern hemisphere, 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.

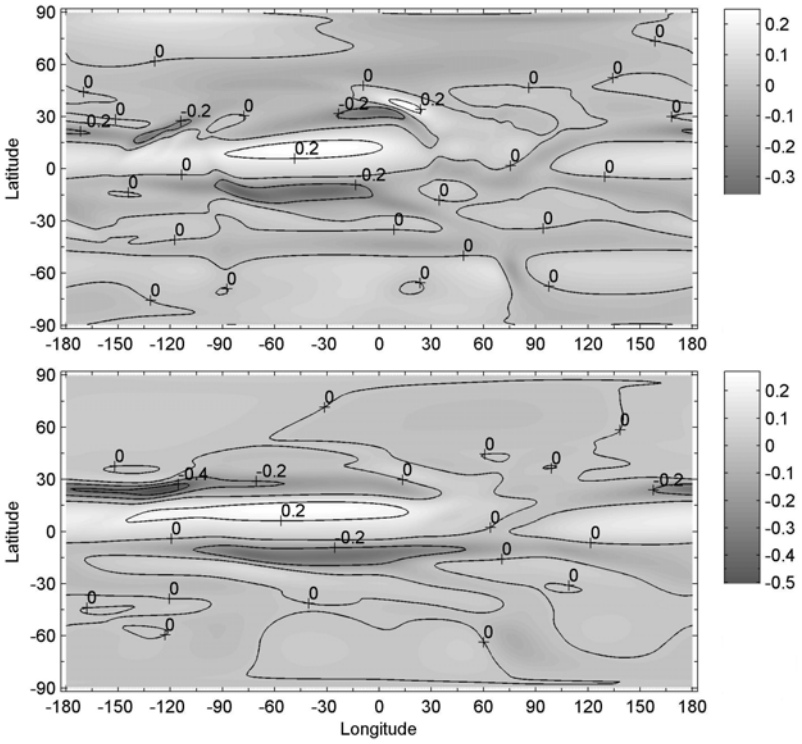


**Fig.4.** The global distributions of the simulated vertical component of the neutral wind velocity at the altitude of 50 km, obtained for 16 January and calculated for two distinct values of solar activity: $F_{10.7}$ =101 (top panel) and $F_{10.7}$ =230 (bottom panel). The velocities are given in m/s, with positive direction of the vertical velocity being upward.

Let us consider simulation results, obtained for distinct values of solar 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 moderate solar activity, is less than that, obtained for high solar activity. Similarly, the horizontal wind velocity in the circumpolar anticyclone of the southern hemisphere, obtained for moderate solar activity, is less than that, obtained for high solar 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 moderate solar activity. On the contrary, for conditions of high solar 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 10.7-cm solar flux below approximately 100 km, the influence of the solar activity level on the global circulation of the stratosphere and mesosphere do 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 solar 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 solar 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 solar activity affects the formation of the large-scale global circulation of the mesosphere and lower thermosphere.

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 10.7-cm solar flux below approximately 100 km. Nevertheless, the effect of solar activity on the global circulation of the atmosphere below 100 km exists. This effect is conditioned by a relationship between global circulations of the thermosphere and middle atmosphere. In this relationship, a vertical motion of air can play a significant role. At altitudes of more than 100 km, the global distributions of the atmospheric temperatures, calculated for distinct 10.7-cm solar fluxes, are different. As a consequence, correspondent global circulations of the atmosphere at these altitudes are different, too, including the vertical wind system. Since the vertical wind can penetrate to low altitudes, the global circulation of the mesosphere and stratosphere may be transformed. In this way, the influence of solar activity on the global circulation of the mesosphere and stratosphere is primarily realized. Incidentally, the utilized mathematical model was able to simulate this influence due to the fact that the model is non-hydrostatic.

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