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# A MODEL STUDY OF THE TRANSFORMATION OF THE GLOBAL CIRCULATION OF THE LOWER AND MIDDLE ATMOSPHERE DURING THE PERIOD FROM JUNE TO DECEMBER

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**Abstract.** A mathematical model of the global neutral wind system of the lower and middle atmosphere, developed earlier in the Polar Geophysical Institute, is utilized to simulate global distributions of the horizontal and vertical wind for conditions corresponding to seven dates, which belong to seven different months beginning from June. Simulations enable to investigate how the horizontal non-uniformity of the atmospheric temperature affects the formation of the lower and middle atmosphere circulation, in particular, the large-scale circumpolar vortices.

## Introduction

Not long ago, a mathematical model of the global neutral wind system in the Earth's atmosphere has been developed in the Polar Geophysical Institute [*Mingalev and Mingalev*, 2005; *Mingalev et al.*, 2007a]. This model allows to calculate three-dimensional global distributions of the zonal, meridional, and vertical components of the neutral wind and neutral gas density 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 study how the horizontal non-uniformity of the atmospheric temperature affects the formation of circumpolar vortices under conditions corresponding to four different seasons [*Mingalev and Mingalev*, 2005; *Mingalev et al.*, 2007a; *Mingalev et al.*, 2007b]. In the present study, the model is applied to simulate the global distributions of the atmospheric parameters in the lower and middle atmosphere for conditions corresponding to seven dates, which belong to seven different months beginning from June.

## Numerical model

The utilized model differs from existing global circulation models of the atmosphere, on principle. Firstly, the model does not include the pressure coordinate equations of atmospheric dynamic meteorology, in particular, the hydrostatic equation. Instead, the vertical component of the neutral wind velocity is obtained by means of a numerical solution of the appropriate momentum equation, with whatever simplifications of this equation being absent. Thus, three components of the neutral wind velocity are obtained by means of a numerical solution of the generalized Navier-Stokes equation. Therefore, the model has the potential to describe the global neutral wind system under disturbed conditions when the vertical component of the neutral wind velocity at the levels of the lower thermosphere can be as large as several tens of meters per second [*Wardill and Jacka*, 1986; *Crickmore et al.*, 1991; *Ishii*, 2005]. Secondly, 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. This peculiarity proceeds from complexity and uncertainty in various chemical-radiational heating and cooling rates, resulting in a discrepancy between the calculated and observed distributions of the atmospheric temperature. On the other hand, over the last years empirical models of the global atmospheric temperature field have been successfully developed. In the present study, we take the global temperature distribution from the NRLMSISE-00 empirical model [*Picone et al.*, 2002] and consider it to be an input parameter of the model. 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. 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. The finite-difference method is applied in the numerical model. The calculated parameters are determined on a $1^O$ grid in both longitude and latitude. The height step is non-uniform and does not exceed the value of 1 km. The details of the model may be found in the studies by *Mingalev and Mingalev* [2005] and *Mingalev et al.* [2007a].

## Simulation results

The applied mathematical model of the global neutral wind system can be used for different geomagnetic, solar cycle and seasonal conditions. In the present study, calculation were performed for conditions corresponding to seven different dates, namely, 16 June, 16 July, 16 August, 16 September, 16 October, 16 November, and 16 December, which belong to seven different months beginning from summer to winter in the northern hemisphere. Calculations were made for moderate solar activity ($F_{10.7} = 101$) and low geomagnetic activity (Kp = 1). The variations of the atmospheric parameters with time were calculated until they become stationary. The steady-state

distributions of the atmospheric parameters were obtained for seven considered dates on condition that inputs to the model correspond to 10.30 UT for each day.
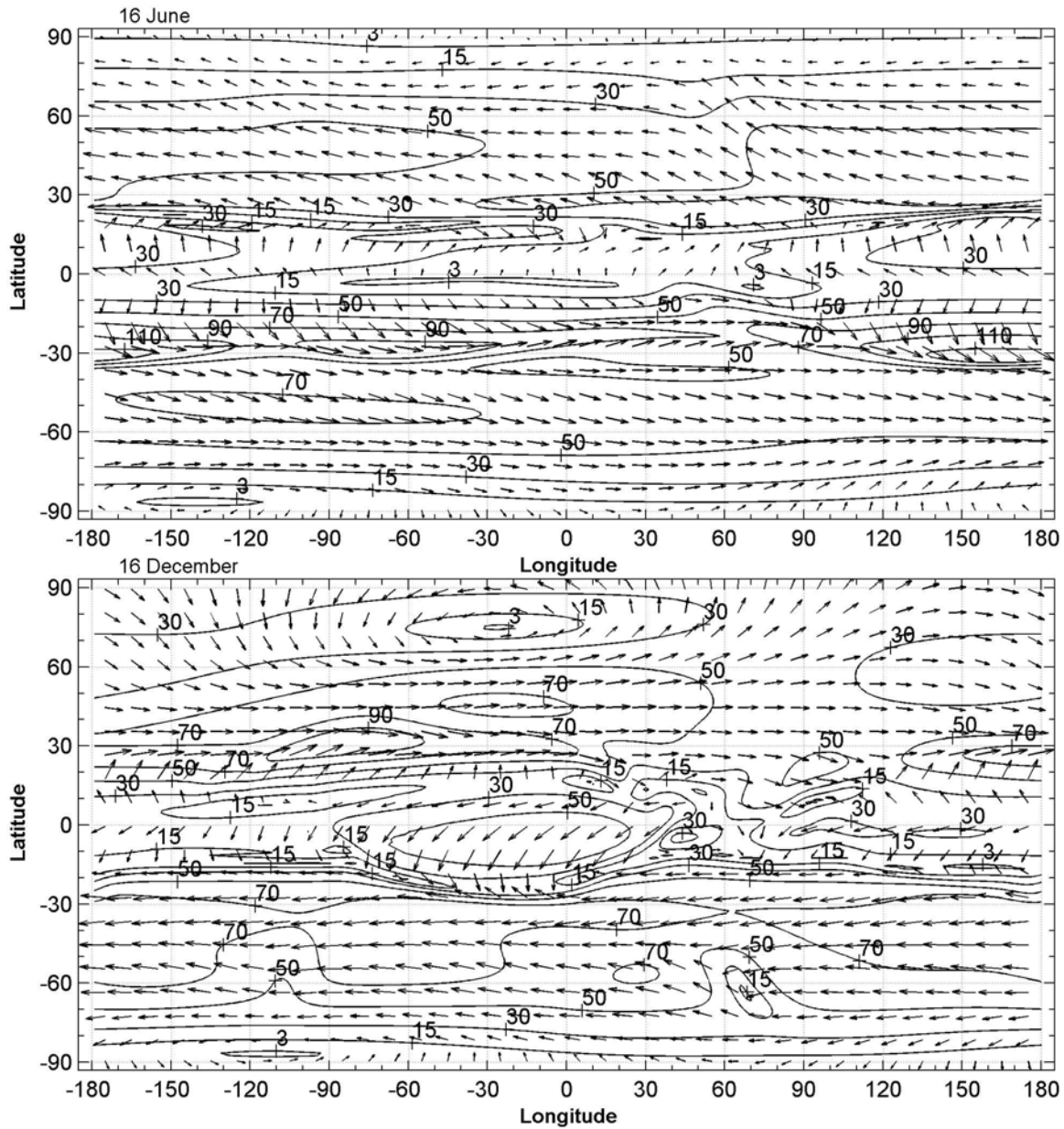


**Fig.1.** The distributions of the vector of the calculated horizontal component of the neutral wind velocity (m\s) as functions of longitude and latitude at the altitude of 60 km, obtained for 16 June (top panel) and 16 December (bottom panel).

In Figs.1-3, simulation results, obtained on condition that the inputs to the model and boundary conditions are time-independent, are partly shown. Three-dimensional global distributions of the horizontal and vertical components of the neutral wind velocity, calculated with the help of the mathematical model, illustrate both common characteristic features and distinctions caused by various conditions of solar illumination. It is seen from simulation results that the horizontal component of the wind velocity is changeable function of latitude, longitude, and altitude. The horizontal wind velocity can have various directions which may be opposite at the near points. It appears that, close to these points, the vertical wind velocity, as a rule, has enhanced magnitudes which can achieve values of a few m/s. Maximal absolute values of the horizontal and vertical components of the wind velocity are larger at higher altitudes.

It is clear that the circulations of the lower and middle atmosphere, obtained for different months, are completely conditioned by the horizontal non-uniformity of the temperature in the rotatable atmosphere. It is obvious that horizontal non-uniformity of the atmospheric temperature, which is distinct in different months, influences

considerably on the transformation of global circulation of the lower and middle atmosphere during the period from June to December.

It is know that the global atmospheric circulation can contain sometimes so called circumpolar vortices that are the largest scale inhomogeneities in the global neutral wind system. Their extent can be very large, sometimes reaching the latitudes close to the equator. It is well known from numerous observations that circumpolar vortices are formed at heights of the stratosphere and mesosphere in the periods close to summer and winter solstices, when there is no rebuilding of the atmosphere. The circumpolar anticyclone arises in the northern hemisphere under summer conditions, while the circumpolar cyclone arises in the southern hemisphere under winter conditions. On the contrary, the circumpolar cyclone arises in the northern hemisphere under winter conditions, while the circumpolar anticyclone arises in the southern hemisphere under summer conditions.
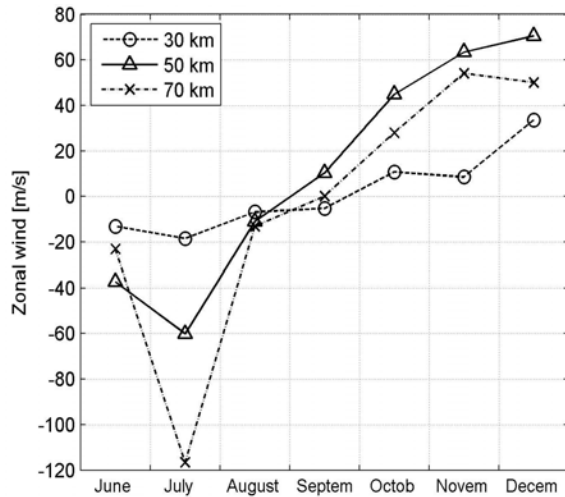


**Fig.2.** The temporal evolution of the zonal component of the neutral wind derived from simulation results for the point of the glob having the geographical coordinates of $45^O$N and $22,5^O$E (northern hemisphere, noon meridian) at three altitudes: 30, 50, and 70 km.

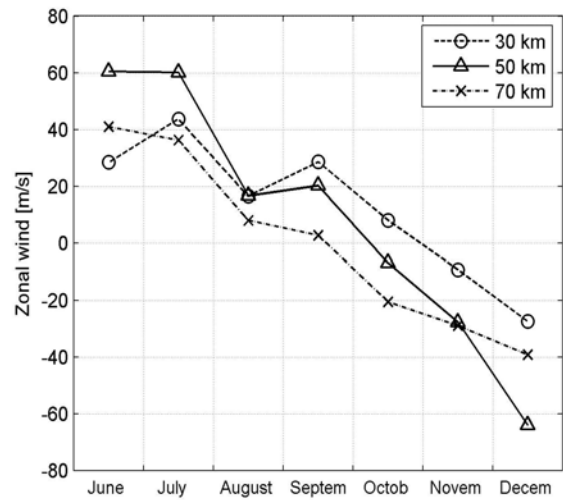**Fig.3.** The same as in Fig.2 but obtained for the point of the glob having the geographical coordinates of $45^O$S and $22,5^O$E (southern hemisphere, noon meridian).

From simulation results, we can see that the global distributions of the neutral wind, calculated for June conditions, in particular, the large-scale circumpolar vortices, are consistent with the planetary circulation of the atmosphere, obtained from observations. We can see that, for December conditions, at levels of the middle atmosphere, 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 is displaced from the pole for a distance corresponding to approximately $10^O$ of latitude. Simultaneously, the motion of the neutral gas is primarily westward in the southern hemisphere at levels of the middle atmosphere, so a circumpolar anticyclone is formed. It can be seen that the circumpolar vortices of the northern and southern hemispheres, simulated at levels of the lower and middle atmosphere for June and December conditions, correspond qualitatively to the global circulation, obtained from observations.

Let us consider the process of transformation of the global circulation of the lower and middle atmosphere during the period from June to December. Simulation results indicated that the global distributions of the neutral wind, calculated for July conditions, are similar to those, calculated for June conditions. The global atmospheric circulation, computed for August conditions, is similar to that, calculated for June conditions too, with maximal absolute values of the horizontal component of the wind velocity being less in August than in July.

In the northern hemisphere, in September, at the levels of stratosphere and mesosphere, the module of the neutral gas velocity is reduced but the direction of the flow remains just the same (circumpolar anticyclone).Unlike, at the levels close to the stratopause (approximately 50 km), the direction of the flow becomes contrary (circumpolar cyclone). In October, in the northern hemisphere, at the levels close to the stratopause, the circumpolar cyclone increases; at the levels of stratosphere and mesosphere the direction of the flow becomes opposite, with the circumpolar cyclone arising. Thus, during September, in the northern hemisphere, at the levels of stratosphere and mesosphere, circumpolar vortices of the atmosphere changes significantly, with the direction of the flow becoming opposite.

In the southern hemisphere, the period of rebuilding of circumpolar vortices begins in September and lasts during October, with the process starting in the mesosphere and continuing in the stratosphere.

In November, in both hemispheres, the circumpolar vortices increase and, to December, they become analogous to those observed usually in the period close to the solstice.

During the period from June to December, at the levels of 60 km, maximal absolute value of the horizontal component of the wind velocity in both hemispheres ought to be biggest in July, and that ought to be least in August.

## Conclusion

The mathematical model of the global neutral wind system of the lower and middle atmosphere was utilized to simulate global distributions of the horizontal and vertical wind for conditions corresponding to seven dates, which belong seven different months beginning from June. Simulation results indicate that the horizontal non-uniformity of the neutral gas temperature, which is distinct in different months, influences considerably on the transformation of global circulation of the lower and middle atmosphere.

The results of simulation indicated that the process of transformation of the global circulation of the lower and middle atmosphere during the period from June to December possesses the following peculiarities. In the northern hemisphere, the circulation, characteristic for period close to summer solstice, ought to exist up to September. During September this circulation is weakened and a circulation, characteristic for period close to winter solstice, arises. This transformation ought to begin from the level of the stratopause and then to propagate upward and downward. An analogous transformation takes place in the southern hemisphere during the past half of September and October. This transformation ought to begin from the level of the mesosphere and then to propagate downward. From November to December, the arisen circulations ought to increase.

It can be noticed that the circumpolar vortices of the northern and southern hemispheres, obtained using the applied mathematical model at levels of the lower and middle atmosphere, are consistent with existing observational data, in particular, for winter and summer periods. Incidentally, this fact manifests the adequacy of the distributions of the atmospheric temperature, calculated with the help of the NRLMSISE-00 empirical model [*Picone et al.*, 2002] and utilized in our simulations.

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