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MODEL SIMULATION OF CIRCUMPOLAR VORTEX FLOWS IN THE EARTH'S ATMOSPHERE FOR DIFFERENT SEASONS

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Abstract. A mathematical model of the global neutral wind system of the lower and middle atmosphere, developed earlier, is utilized to simulate global distributions of the horizontal and vertical wind for conditions of different seasons. Simulations enable to investigate how the horizontal non-uniformity of the atmospheric temperature affects the formation of the atmosphere circulation, in particular, the large-scale circumpolar vortices at levels of middle atmosphere.

Introduction

A mathematical model of the global neutral wind system in the Earth's atmosphere has been recently developed in the Polar Geophysical Institute [*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 study how the horizontal non-uniformity of the atmospheric temperature affects the formation of circumpolar vortices under conditions corresponding to summer in the northern hemisphere [*Mingalev and Mingalev*, 2005; *Mingalev et al.*, 2007]. In the present study, the model is applied to simulate the global distributions of the atmospheric parameters in the middle atmosphere for conditions corresponding to four different seasons.

Mathematical model

There are principal distinctions of the applied mathematical model from other existing global atmospheric circulation model. Firstly, the vertical component of the neutral wind velocity is calculated without using the pressure coordinate equations of atmospheric dynamic meteorology, in particular, the hydrostatic equation. To calculate the vertical component of the neutral wind velocity the appropriate momentum equation is used, with whatever simplification of this equation being absent. The horizontal components of the neutral wind velocity are obtained by means of a numerical solution of commonly used momentum equations. Thus, three components of the neutral wind velocity are obtained by means of a numerical solution of generalized Navier-Stokes equation for compressible gas. As a consequence, the applied mathematical model has the potential to describe the global neutral wind system under disturbed conditions when the vertical component of the neutral wind velocity at 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, an internal energy equation for the neutral gas is not included in the applied mathematical model. Instead, the global temperature field is assumed to be a given distribution, i.e. the input parameter of the model, and obtained from one of the existing empirical models. It can be noticed that, to date, most of the existing global circulation models of the atmosphere produce temperature distributions which correspond to reality worse than the temperature fields, obtained from modern empirical models, at altitudes below the mesopause. This is a consequence of complexities and uncertainties in various chemical-radiational heating and cooling rates, used in global circulation models of the lower and middle atmosphere. In the present study, the global temperature distributions are taken from the NRLMSISE-00 empirical model [*Picone et al.*, 2002]. The simulation domain is the layer surrounding the Earth globally and stretching from the ground up to the altitude of 120 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. In the mathematical model, the finite-difference method is used. The calculated parameters are determined on a 1° 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 applied mathematical model may by found in the studies by Mingalev and Mingalev [2005] and Mingalev et al. [2007].

Simulation results

The applied mathematical model of the global neutral wind system can be utilized for different geomagnetic, solar cycle and seasonal conditions. In the present study, calculation were performed for conditions corresponding to four different dates, namely, 16 January, 16 April, 16 July, and 16 October, which belong to winter, spring, summer, and autumn in the northern hemisphere, respectively. Calculations were made for moderate solar activity ($F_{10.7}$ = 101) and low geomagnetic activity (K_p = 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 four considered dates on condition that inputs to the model correspond to 10.30 UT for each day.

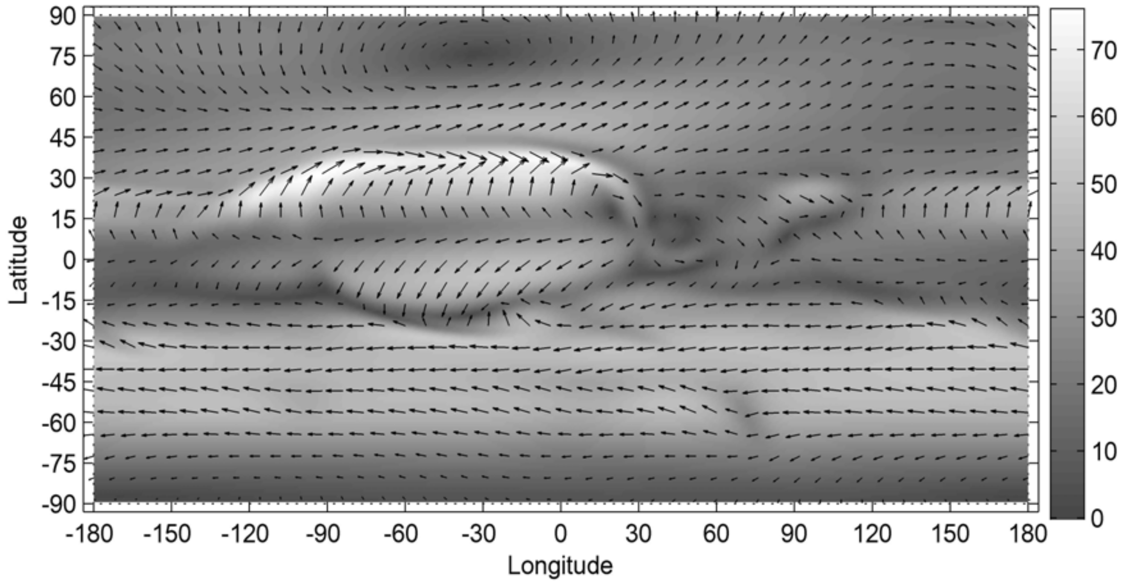

Fig.1. The distribution of the vector of the calculated horizontal component of the neutral wind velocity (m\s) as a function of longitude and latitude at the altitude of 60 km, obtained for 16 January.

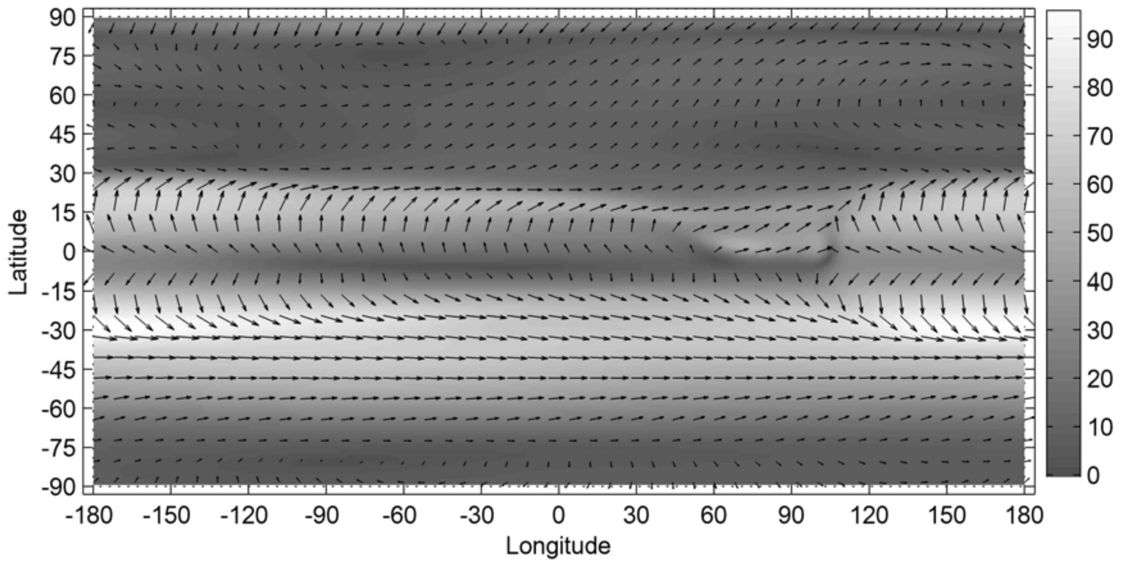

Fig.2. The same as in Fig.1 but obtained for 16 April.

Simulation results, obtained on condition that the inputs to the model and boundary conditions are time-independent, are partly shown in Figs. 1-4. From simulation results, it is seen that the horizontal component of the wind velocity is changeable function of latitude and longitude. 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. The horizontal and vertical components of the wind velocity are changeable functions not only of latitude and longitude but also of altitude. 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 middle atmosphere, obtained for different seasons, 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 seasons, influences significantly on the formation of the atmospheric circulation at levels of the troposphere, stratosphere, mesosphere, and lower thermosphere, in particular, on the formation of the circumpolar vortices. It is know that the circumpolar

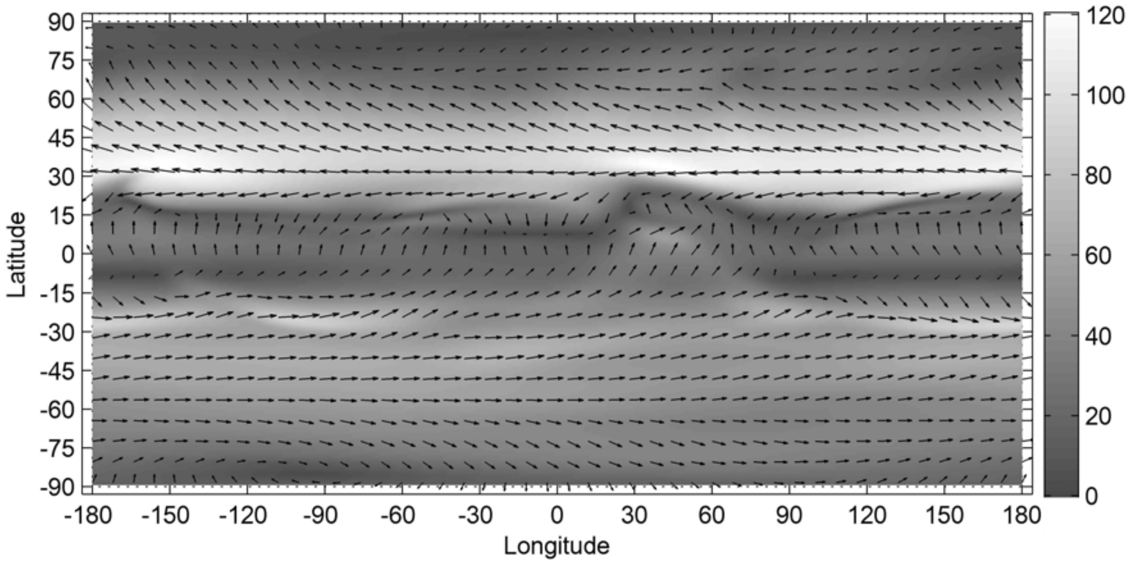

Fig.3. The same as in Fig.1 but obtained for 16 July.

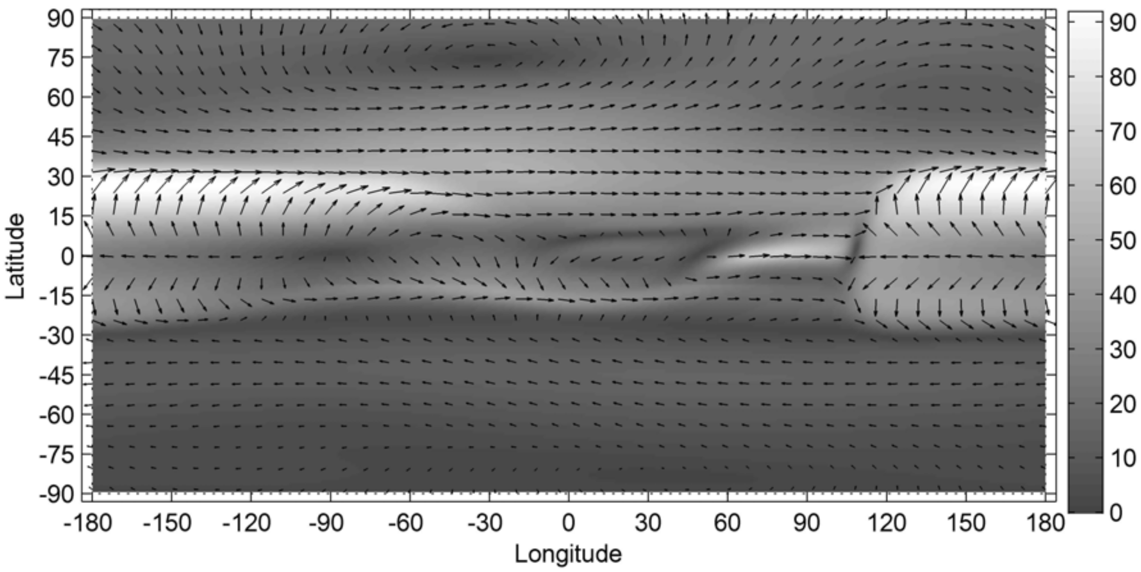

Fig.4. The same as in Fig.1 but obtained for 16 October.

vortices 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. Let us compare these experimental data with the simulation results.

From Fig. 1 one can see that, for winter period in the northern hemisphere, the motion of the neutral gas in the northern hemisphere is primarily eastward so a circumpolar cyclone is formed, and this motion in the southern hemisphere is primarily westward so a circumpolar anticyclone is formed. From Fig. 3 one can see that, for summer period in the northern hemisphere, the directions of these motions are opposite, therefore, the circumpolar anticyclone is formed in the northern hemisphere and the circumpolar cyclone is formed in the southern hemisphere. It is easy to see that the circumpolar vortices of the northern and southern hemispheres, obtained using the mathematical model at the level of mesosphere for January and July conditions, correspond to the global circulation, obtained from observations.

Let us consider simulation results, obtained for spring period in the northern hemisphere (Fig. 2). The atmospheric circulation, presented if Fig. 2, does not coincide with the distributions, shown neither in Fig. 1 (January) nor in Fig 3 (July). From Fig. 2 one can see that the motion of the neutral gas in the northern hemisphere in spring (16 April) is analogous to January circulation (Fig. 1), and a weakened winter circumpolar cyclone continues to exist in April. On the contrary, the motion of the neutral gas in the southern hemisphere in the spring (Fig. 2) is opposite to that, obtained for January conditions (Fig. 1). Thus, in the southern hemisphere to April, the January circumpolar anticyclone is destroyed and circumpolar cyclone arises which continues to exist up to July.

Now, let us consider simulation results, obtained for autumn period in the northern hemisphere (Fig. 4). It is easy to see that the primary directions of the neutral gas motions in the northern and southern hemispheres in October are opposite to those, obtained for July conditions (Fig. 3). It turns out that, to October, the July atmospheric circulation is destroyed in both hemispheres and a new wind system arises which is analogous to atmospheric flow characteristic to January conditions (Fig. 1). The arisen new wind system is enhanced during the period from October to January, especially, in the southern hemisphere.

Conclusion

To investigate how the different conditions, corresponding to four distinct seasons, affect the formation of the middle atmosphere circulation, the mathematical model of the global neutral wind system in the Earth's atmosphere, developed earlier, was applied. The applied model enables to calculate three-dimensional planetary distributions of the zonal, meridional, and vertical components of the neutral wind and neutral gas density without any restrictions on the vertical transport of the neutral gas. In the mathematical model, the global temperature distribution from the NRLMSISE-00 empirical model is utilized in the capacity of the input parameter. The steady-state distributions of the calculated parameters were obtained for conditions corresponding to four different dates, namely, 16 January, 16 April, 16 July, and 16 October. The results of simulation indicated that the horizontal non-uniformity of the neutral gas temperature affects considerably the formation of the global neutral wind system in the lower and middle atmosphere, in particular, the large-scale circumpolar vortices. It turned out that, in the northern hemisphere, the circumpolar cyclone is formed under winter conditions, and the circumpolar anticyclone is formed under summer conditions. In the southern hemisphere, the circumpolar anticyclone is formed in January, and the circumpolar cyclone is formed in July. In spring period (April), the flow of the neutral gas in the northern hemisphere is analogous to January circulation and the motion in the southern hemisphere is analogous to July circulation. In autumn period (October), the atmospheric circulations in both hemispheres at levels of mesosphere are analogous to those, obtained for January conditions. It can be noticed that the circumpolar vortices of the northern and southern hemispheres, obtained using the applied mathematical model at levels of middle atmosphere, are consistent with existing observational data, in particular, for winter and summer periods.

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