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SIMULATION OF CIRCUMPOLAR VORTEX FLOWS IN THE LOWER AND MIDDLE ATMOSPHERE FOR JULY CONDITIONS

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Abstract. The mathematical model of the global neutral wind system in the lower and middle atmosphere is applied in order to investigate how horizontal non-uniformity of the atmospheric temperature affects the formation of circumpolar vortices. The applied model reproduces 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. A peculiarity of the applied model is that the equation for the neutral gas internal energy is not solved. Instead, the global temperature is assumed to have a given distribution, being an input parameter of the model. Simulations are performed for two distinct distributions of the neutral gas temperature, corresponding to July conditions. The results indicate that horizontal non-uniformity of the atmospheric temperature influences noticeably the global distribution of the neutral wind, in particular, the formation of the large-scale circumpolar vortices.

Introduction

From numerous observations, it is well known that large-scale 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. The circumpolar 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. There is a widely accepted viewpoint that at the levels of the stratosphere and mesosphere the circumpolar vortices are generated due to the temperature horizontal irregularity, e.g. temperature gradients in the meridional direction The purpose of this paper is to examine the above suggestion. The examination is performed with the use of the mathematical model of the global neutral wind system, which has been recently developed in the Polar Geophysical Institute.

Mathematical model

Not long ago we have developed the mathematical model of the global neutral wind system [*Mingalev and Mingalev,* 2001], which is applied in the present study. The model allows us to calculate three-dimensional global distributions of the zonal, meridional, and vertical components of the neutral wind and neutral gas density at the levels of the troposphere, stratosphere, mesosphere, and lower thermosphere. There are principal distinctions of our model from other global atmospheric circulation models so far developed. Firstly, we do not use the pressure coordinate equations of atmospheric dynamic meteorology, in particular, the hydrostatic equation. Instead, the vertical component of the neutral wind velocity is obtained through numerical solution of the corresponding momentum equation without any simplifying suggestions. That is, all three components of the neutral wind velocity are obtained from numerical solution of the Navier- Stokes equation. This is of principle importance for 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; *Leontyev,* 2001]. Secondly, our model does not include the equation for the neutral gas internal energy. Instead, the global temperature is assumed to have 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. Here we take the global temperature distribution from the MSISE-90 empirical model [*Hedin,* 1991] and consider it to be an input parameter of the model being developed.

To obtain the neutral gas density we use the continuity equation, the distributions of the zonal, meridional, and vertical components of the neutral wind and neutral gas density being found in a spherical layer around the Earth, extending from the ground up to the altitude of 120 km. The system of equations, numerical method, boundary conditions, and other details of the model can be found in the study of *Mingalev and Mingalev* [2001].

Computer simulation

The mathematical model of the global neutral wind system can be applied for different geomagnetic, solar cycle and seasonal conditions. In the present study the calculations were performed for summer period in the northern hemisphere (16 July) under moderate solar activity ($F_{10.7}$=101) and low geomagnetic activity (K_p=1). The time variations of the atmospheric parameters were reproduced until the steady state was reached. The steady-state distributions were obtained for the input parameters corresponding to 10.30 UT. To examine the role of the temperature horizontal gradients in the formation of large-scale circumpolar vortices, we calculated the steady-state distributions of, e.g., the global neutral wind system under two different distributions of the neutral gas temperature, both being non-uniform in the vertical direction. One distribution, which is depicted in Fig.1 for the altitude of 50 km, was assumed to be horizontally non-uniform and taken from the MSISE-90 empirical model [*Hedin*, 1991]. The other distribution was horizontally uniform, with the temperature altitude dependence being identical for each point and taken in such a manner as to reproduce that obtained from the MSISE-90 model at the point with the geographical coordinates of 44.5^{o}N and 55^{o}W, corresponding to the middle latitude in the morning sector. The altitudinal profile of the temperature calculated for this point of the globe is presented in Fig.2.

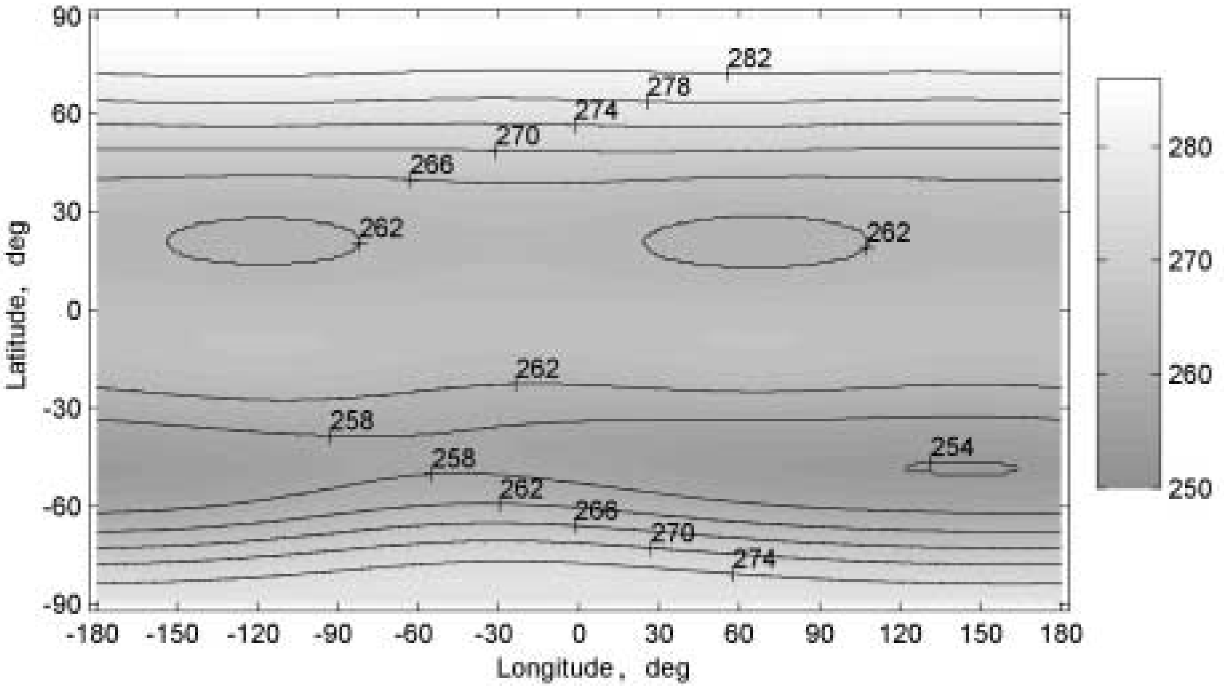

Fig. 1. Non-uniform distribution of the neutral gas temperature over longitude and latitude at the altitude of 50 km according to the MSISE-90 empirical model.

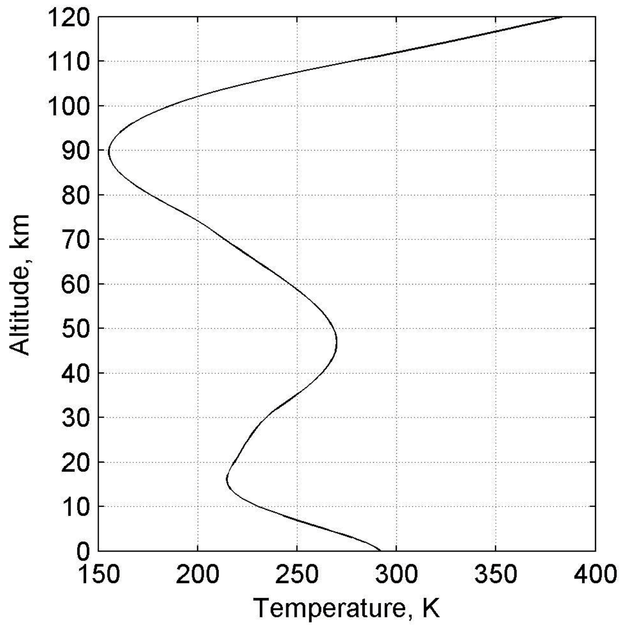

Fig. 2. The altitudinal profile of the given neutral gas temperature obtained from the MSISE-90 empirical model at the point of the glob having the geographical coordinates of 44.5^{o}N and 55^{o}W.

Some of the simulation results for the global neutral wind system, obtained under above distributions of the neutral gas temperature are shown in Fig. 3 and Fig. 4. From Fig.3 we can see that large-scale circumpolar vortices arise at the mesosphere level for the horizontally non-uniform distribution of the neutral gas temperature. It is seen that a circumpolar anticyclone is formed in the northern hemisphere under summer conditions, with the neutral gas moving westward. At the same time, a circumpolar cyclone is formed in the southern hemisphere when there is winter, the motion of the neutral gas being eastward. The large-scale circumpolar vortices obtained from our calculations are evidently consistent with those observed in global circulation of the middle atmosphere, which proves that the applied mathematical model of the global neutral wind system is adequate

Now we consider the simulation results for the case when the neutral gas temperature distribution is horizontally uniform. From Fig.4 one can see that in the northern hemisphere under summer conditions, a circumpolar anticyclone is formed similarly to the one shown in Fig.3. Thus both for horizontally uniform and non-uniform distribution of the neutral gas temperature to be given, the circumpolar anticyclone is formed in the northern hemisphere under summer conditions. Consequently, the suggestion of a principal role of temperature horizontal gradients in the formation of the circumpolar vortex is not confirmed in this case.

On the other hand, from Fig.4 we can see that in the southern hemisphere under winter conditions a circumpolar anticyclone is formed which is opposite to the circumpolar vortex shown in Fig.3 for non-uniform distribution of the neutral gas temperature. We note that this feature is experimentally observed. Thus, the suggestion of a principal role of the horizontally non-uniform atmospheric temperature distribution in the formation of the circumpolar vortex in the southern hemisphere under winter conditions is fully confirmed by our simulation.

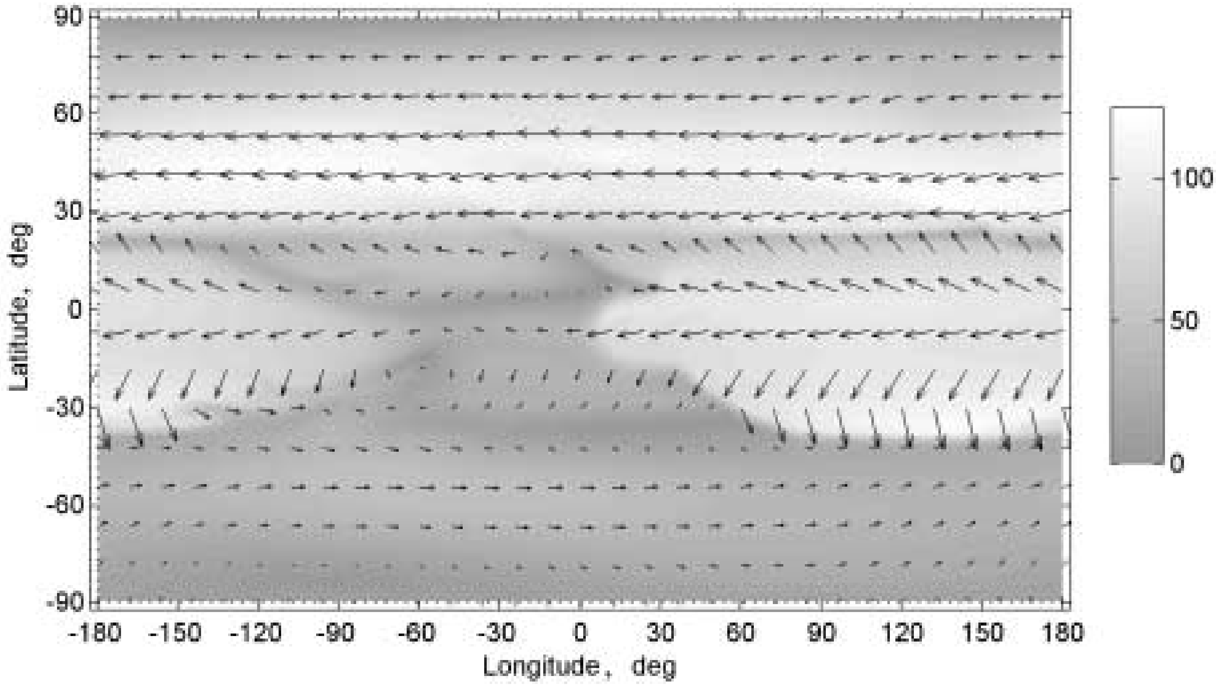

Fig. 3. The distribution of the vectors of the neutral wind horizontal velocity over longitude and latitude at the altitude of 50 km, as obtained under horizontally non-uniform distribution of the neutral gas temperature.

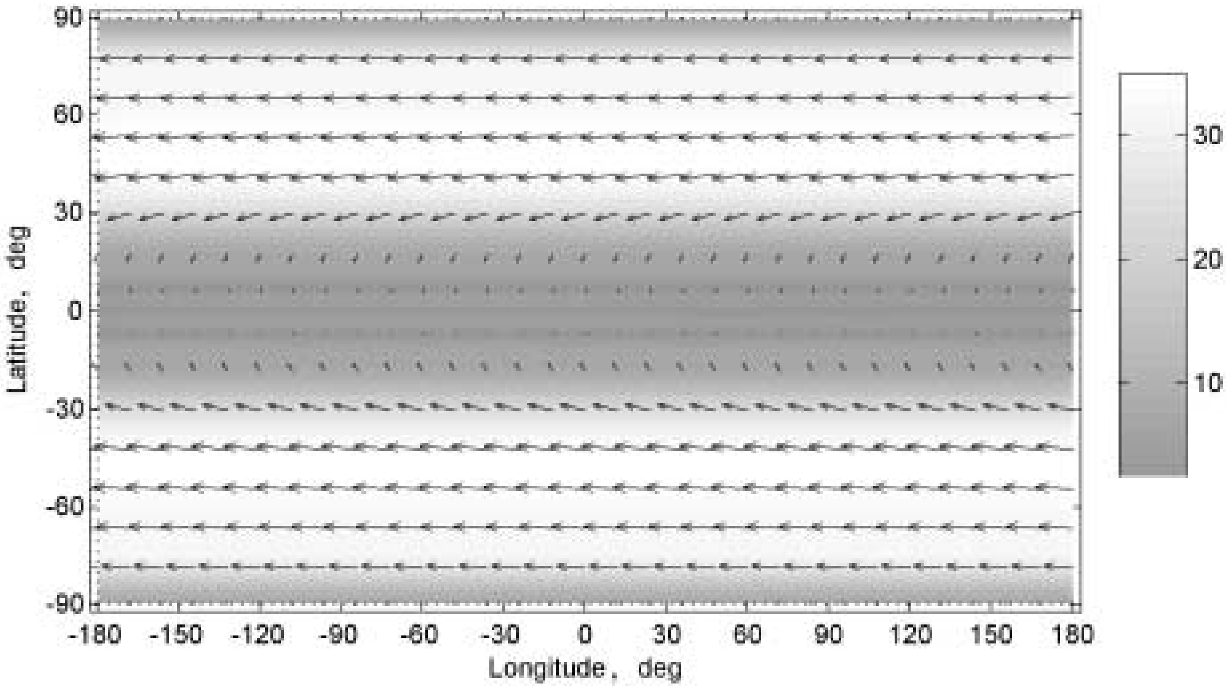

Fig. 4. The same as in Fig. 3, but for horizontally uniform distribution of the neutral gas temperature.

Conclusions

The suggestion of a principal role of the horizontally non-uniform atmospheric temperature distribution in the formation of the circumpolar vortices at stratosphere and mesosphere heights in the periods close to the solstices has been examined through numerical simulations. The mathematical model of the global neutral wind system developed recently in the PGI was applied. A distinct feature of this model is that the equation for the neutral gas internal energy is not solved. Instead, the global temperature distribution is given as an input parameter of the model. Another peculiarity is that the vertical component of the neutral wind velocity is found from the Navier-Stokes equation rather than from the hydrostatic equation, the latter being typically used in the existing models of global atmospheric circulation. The model calculations were performed for July conditions, under two given distributions of the neutral gas temperature. The first distribution was horizontally non-uniform and taken from the MSISE-90 empirical model. The second one was horizontally uniform. Both distributions were height-dependent. The simulation results indicate that the suggestion being examined is confirmed only partly. Specifically, formation of the circumpolar cyclone in the southern hemisphere under winter conditions is associated with temperature horizontal gradient. On the contrary, formation of the circumpolar anticyclone in the northern hemisphere under summer conditions cannot be interpreted within this framework.

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