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ON THE INFLUENCE OF THE EARTH'S ROTATION ON THE FORMATION OF THE PLANETARY CIRCULATION OF THE LOWER AND MIDDLE ATMOSPHERE

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Abstract. The mathematical model of the global neutral wind system in the lower and middle atmosphere is utilized in order to examine how the Earth's rotation affects the formation of the global circulation of the lower and middle atmosphere. The utilized model produces 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. 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. Numerical modeling is performed at not high solar activity and low geomagnetic activity conditions for summer in the northern hemisphere (10 June). The results indicate that the Earth's rotation ought to influence appreciably on the global distribution of the neutral wind, in particular, on the formation of the large-scale circumpolar vortices.

Introduction

The D region is probably the worst understood portion of the ionosphere. This is due not only to a complicated chemistry of this region but also to scarce information on large-scale circulation in the middle atmosphere. Indeed, a system of transport equations, describing the behaviour of the positive and negative ions and minor and excited neutral constituents at D-region altitudes, contains vertical velocities of the components. It is usually supposed that the vertical velocity of the component consists of three parts: first, a molecular diffusion velocity; second, a velocity given to particles by means of eddy mixing or turbulent processes in the middle atmosphere; third, a mean velocity of atmospheric mass motion in the vertical direction. The later mean velocity is usually assumed to be negligible in simulation studies because of dearth of knowledge of large-scale circulation in the middle atmosphere. It is easy to see that the neglect of the mean velocity of atmospheric mass motion or neutral wind velocity can lead to an inadequacy of the models of the D region. To overcome this obstacle it is necessary to take into consideration the three-dimensional neutral wind system in the middle atmosphere. Unfortunately, an empirical description of the planetary circulation of the middle atmosphere is restricted by an absence of sufficient amount of data, whereas empirical global models of neutral winds in the upper atmosphere do exists, e.g. the model of Hedin et al. [1988] and the HWM-90 model [Hedin et al., 1991]. Although the middle atmosphere is nearer the Earth's surface than the upper atmosphere, it is more difficult to measure individual parameters for the former. Large amounts of satellite data as well ground-based incoherent scatter data have a lower-altitude limit near the mesopause and can not provide a convenient source of information for the middle atmosphere. Therefore, the mathematical models of the global distribution of the atmospheric wind can be useful. It can be noticed that the latter mathematical models may be utilized not only for development of mathematical models of the D region but also for a simulation of a dynamical regime of the middle atmosphere and lower thermosphere, in particular, their large-scale global circulation.

In the present study, the mathematical model of the global neutral wind system in the lower and middle atmosphere is applied in order to investigate mechanisms responsible for the formation of the planetary circulation of the lower and middle atmosphere. In particular, the role of the Earth's rotation on the formation of the lower and middle atmosphere circulation is evaluated.

The mathematical model

In the present study, the mathematical model of the global neutral wind system in the lower and middle atmosphere is utilized which has been developed recently in the PGI [*Mingalev and Mingalev*, 2001]. This model has been applied in order to investigate how the horizontal irregularity of atmospheric temperature affects the formation of circumpolar vortices [*Mingalev and Mingalev,* 2003]. The utilized model differs from existing global circulation models of the atmosphere, on principle. Firstly, the vertical component of the neutral wind velocity is obtained without using 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. The horizontal components of the neutral wind velocity are obtained by means of a numerical solution of the appropriate momentum equations, too. Secondly, the internal energy equation for the neutral gas is not solved. 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. Incidentally, to date, most of the commonly used 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, utilized in existing global circulation models of the lower and middle atmosphere.

In the utilized model, the continuity equation is used for obtaining the neutral gas density. The distributions of the zonal , meridional, and vertical components of the neutral wind and neutral gas density are found in the spherical layer surrounding the Earth globally. This layer stretches from the ground up to the altitude of 120 km. The system of equations, numerical method, boundary conditions, and other details of the model may be found in the study by *Mingalev and Mingalev* [2001].

Numerical experiments

The utilized model can deal with different combinations of the solar cycle, geomagnetic activity level, and seasons. For the present study, the calculations were performed for summer in the northern hemisphere (10 June) and not high solar activity conditions ($F_{10.7}$=101) under 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 the inputs to model corresponding to 10.30 UT.

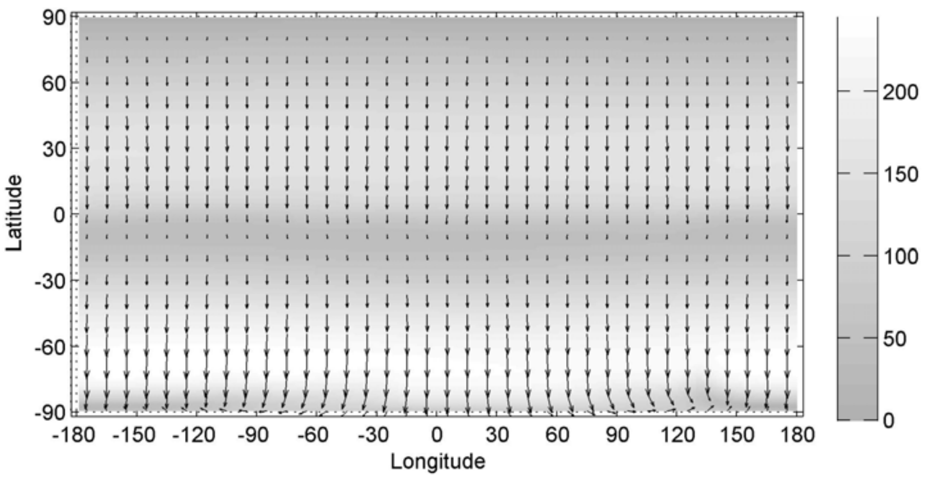

Fig. 1. The distribution of the vector of the horizontal component of the neutral wind velocity as a function of longitude and latitude at the altitude of 50 km, obtained for the case in which both the Coriolis acceleration and acceleration of translation are omitted.

The distribution of the neutral gas temperature is the important input parameter of the utilized model. Simulation results to be presented in this paper were obtained using the temperature distribution derived from the MSISE-90 empirical model [*Hedin*, 1991]. This temperature distribution is inhomogeneous in the vertical and horizontal directions.

The momentum equations of the utilized model contain two kinds of terms conditioned by the Earth's rotation: first, components of the Coriolis acceleration; second, constituents of the acceleration of translation. To evaluate the role of the Earth's rotation on the formation of the atmosphere circulation at levels of the troposphere, stratosphere, mesosphere, and lower thermosphere, we calculated the steady-state distributions of the atmospheric parameters for three distinct cases. The first case corresponds to a situation when the Coriolis acceleration and acceleration of translation are omitted. The second case is consistent with a situation when the Coriolis acceleration is omitted, only, whereas the acceleration of translation is taken into consideration. In the third case, account is taken of the presence of both the Coriolis acceleration and acceleration of translation. The results of simulation of the global neutral wind system, obtained for three distinct cases

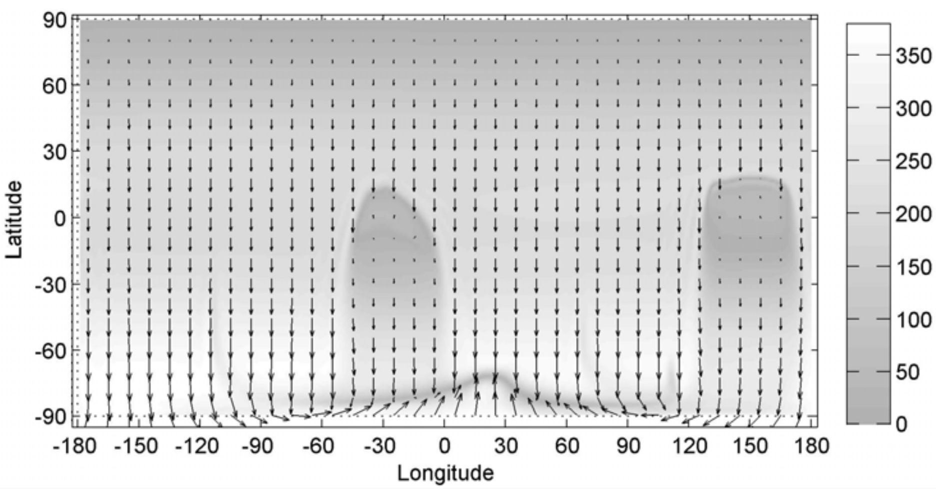

Fig. 2. The same as in Fig. 1 but for the case in which the acceleration of translation is taken into account whereas the Coriolis acceleration is omitted.

described above, are partly shown in Figs. 1-4.

Let us consider the results of model calculations obtained for the first case when the Coriolis acceleration and acceleration of translation are omitted. These results possess the following features. At levels of the troposphere, the horizontal wind ought to be directed northward at all latitudes, that is, from the winter hemisphere to the summer hemisphere. This wind ought to reduce its velocity near the equator where the vertical component of the wind velocity is upward. Near the geographical poles, the vertical component of the wind velocity ought to be directed downward. At levels of the stratosphere and mesosphere (see Fig. 1), the horizontal wind ought to be directed southward at all latitudes, that is, from summer hemisphere to the winter hemisphere. Its velocity ought to be reduced near the equator. The downward vertical component of the wind velocity can achieve a value of 4.5 m/s at 30 km altitude near the south geographical pole. At altitudes above the mesopause, the horizontal and vertical components of the wind velocity can have various directions. These directions may be opposite at the near points of the simulation domain situated at levels of the lower thermosphere.

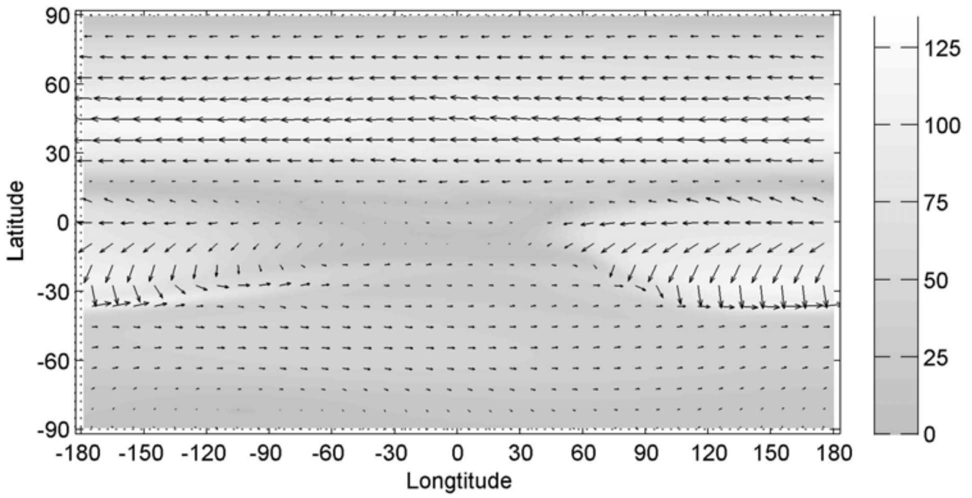

Fig. 3. The same as in Fig. 1 but for the case in which both the acceleration of translation and Coriolis acceleration are taken into account.

Now we consider the simulation results obtained for the second case when the Coriolis acceleration is omitted whereas the acceleration of translation is taken into account. It turns out that the latter simulation results and the results, obtained for the first case, illustrate both common characteristic features and distinctions caused by the action of the acceleration of translation. For both cases, at levels of the troposphere, the horizontal wind ought to be directed northward, mainly. However, near the equator, this wind ought to reduce its velocity for the first case whereas its velocity ought to rise for second case. For both cases at levels of the stratosphere and mesosphere, the horizontal wind ought to be directed southward, primarily, that is, from the summer hemisphere to the winter hemisphere (see Figs.1 and 2). At these levels, the downward vertical component of the wind velocity can achieve values of a few m/s near the south geographical pole. It is obvious that differences between the results, obtained for the first case, and results, obtained for the second case, are conditioned by the action of the acceleration of translation. One of these differences consists in that regions of the opposite direction of the wind velocity arise in morning and evening sectors near the equator at levels of the stratosphere and mesosphere (see Fig.2). At the northern edges of these regions the downward vertical component of the wind velocity can achieve values of a few m/s.

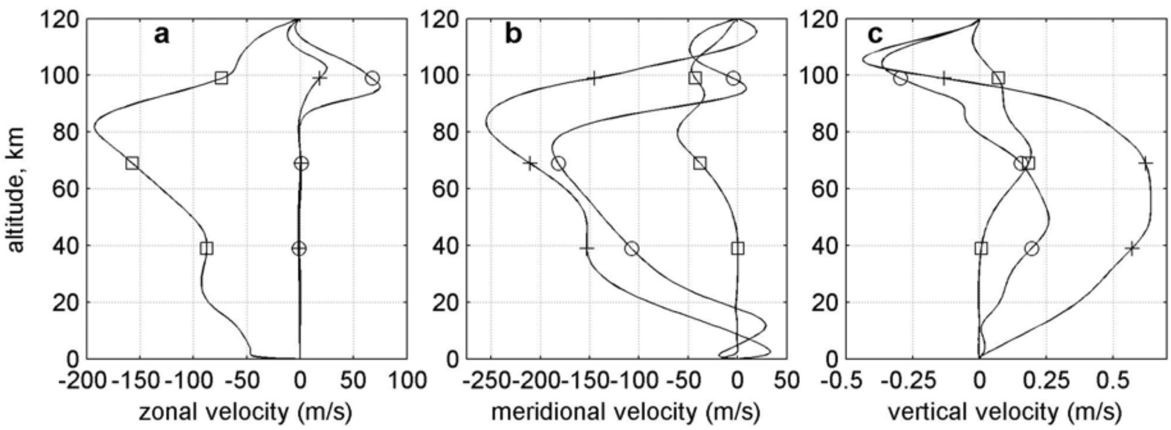

Fig. 4. Altitudinal profiles of (a) the zonal velocity, (b) meridional velocity, (c) vertical velocity at the point of the globe having the geographical coordinates of 45.5°N and 55°W. East, north, and upward directions are assumed to be positive. The circles correspond to results, obtained for the case in which both the acceleration of translation and Coriolis acceleration are omitted. The crosses show the results, obtained for the case in which the acceleration of

translation is taken into account whereas Coriolis acceleration is omitted. The squares show the results, obtained for the case in which both the acceleration of translation and Coriolis acceleration are taken into account.

Let us consider the results of numerical modelling obtained for the third case when both the Coriolis acceleration and acceleration of translation are taken into account. It turns out that these results differ from results obtained for two previous cases significantly. At all altitudes, the horizontal wind velocity changes its direction essentially. At levels of the troposphere, stratosphere, and mesosphere, the direction of the horizontal wind velocity became primarily zonal (see Fig. 3) instead of meridional. In the northern hemisphere, the motion of the neutral gas is westward so a circumpolar anticyclone is formed. On the contrary, in the southern hemisphere, the motion of the neutral gas is eastward so a circumpolar cyclone is formed. It should be emphasized that the circumpolar vortices of the northern and southern hemispheres, obtained using numerical simulation for the case when both the Coriolis acceleration and acceleration of translation are taken into consideration, correspond to the global circulation of the middle atmosphere, obtained from observations. At altitudes above the mesopause, the horizontal wind velocity can have various directions which may be opposite at the near points. At levels of the middle atmosphere and lower thermosphere, there are regions of the opposite direction of the vertical component of the wind velocity. As a rule, the horizontal regions, where the vertical wind velocity is upward, have a great length and large width. Unlike, the horizontal regions, where the vertical wind velocity is downward, have a large length but little width. Usually, the latter regions have a configuration like a long narrow band. As a consequence, maximal absolute values of the vertical component of the wind velocity, directed downward, are more than those, directed upward.

Conclusions

The mathematical model of the global neutral wind system in the lower and middle atmosphere, which enables to calculate three-dimensional planetary 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, was applied to investigate how the Earth's rotation affects the formation of the global circulation of the atmosphere. The steady-state distributions of the atmospheric parameters were calculated for three distinct cases in which taking into account was different of the acceleration of translation and Coriolis acceleration. The calculations were made for June conditions. The simulation results indicated that the global neutral wind system, calculated on condition that the acceleration of translation is taken into account whereas the Coriolis acceleration is omitted, is qualitatively similar to the global circulation of the lower and middle atmosphere, computed under condition that both the acceleration of translation and Coriolis acceleration are omitted. The effect of the Cariolis acceleration on the formation of the lower and middle atmosphere circulation must be much more essential. Taking into account the Coriolis acceleration leads to significant changes of the circulation of the lower and middle atmosphere, with the direction of the horizontal wind becoming primarily zonal instead of meridional. As a consequence, the circumpolar anticyclone is formed in the northern hemishere whereas the circumpolar cyclone is formed in the southern hemisphere. The circumpolar vortices, obtained using numerical simulation, are consistent with the planetary circulation of the middle atmosphere, obtained from observations. Incidentally, this fact manifests the adequacy of the applied mathematical model.

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References

Hedin, A.E., Extension of the MSIS thermosphere model into the middle and lower atmosphere, *J.Geophys.Res.*, 96, No.A2, 1159-1172, 1991.

Hedin, A.E., N.W.Spencer, and T.L.Killeen, Empirical global model of upper thermosphere winds based on Atmosphere and Dynamics Explorer satellite data, *J.Geophys.Res.*, 93, No.A9, 9959-9978, 1988.

Hedin, A.E., M.A.Biondi, R.G.Birnside et al., Revised global model of thermospheric winds using satellite and ground- based observations, *J.Geophys.Res.*, 96, No.A5, 7657-7688, 1991.

Mingalev, I.V., and V.S. Mingalev, A numerical global model of the horizontal and vertical wind in the lower and middle atmosphere, pp.140-143, in *"Physics of Auroral Phenomena", Proc.XXIV Annual Seminar,* Apatity, Kola Science Centre of the RAS, 2001.

Mingalev, I.V., and V.S. Mingalev, Simulation of circumpolar vortex flows in the lower and middle atmosphere for July conditions, pp.239-242, in *"Physics of Auroral Phenomena", Proc.XXVI Annual Seminar,* Apatity, Kola Science Centre of the RAS, 2003.