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SIMULATION STUDY OF THE INITIAL STAGE OF THE ORIGIN OF CYCLONIC AND ANTICYCLONIC PAIRS IN THE INTRATROPICAL CONVERGENCE ZONE

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Abstract. To investigate the initial stage of the formation of large-scale vortexes at tropical latitudes of the northern hemisphere, the regional mathematical model of the neutral wind system of the lower atmosphere, developed recently in the PGI, is applied. The model produces three-dimensional distributions of the atmospheric parameters in the height range from 0 to 15 km over a limited region of the Earth's surface. Simulations are performed for the case when this region is intersected by an intratropical convergence zone. Calculations were made for various cases in which the initial forms of the intratropical convergence zone were different and contained convexities with distinct shapes. The results of modeling indicate that the origin of a convexity of the intratropical convergence zone, having the specific forms, can lead to the formation of a pair of cyclonic and anticyclonic vortexes.

Introduction

A genesis of tropical large-scale vortexes, in particular cyclones, is one of the interesting problems of the atmospheric dynamics. Many of the details of the initial stage of the formation of tropical large-scale vortexes, however, are still unresolved. Mathematical models have the potential to make significant contributions to our knowledge of the processes responsible for the formation of tropical large-scale vortexes.

Recently, a regional mathematical model of the neutral wind system of the lower atmosphere has been developed in the Polar Geophysical Institute (Belotserkovskii et al., 2006). In the above pointed out study, this model was applied to investigate the formation mechanisms of a large-scale vortex over a warm water band on the ocean surface. The results of modeling have allowed the authors to distinguish one of the formation mechanisms of moderate cyclones over the ocean.

Another formation mechanism of a cyclone was investigated, using this mathematical model, in the study by Belotserkovskii et al. (2009). It was shown that cyclones can appear in horizontally stratified shear flows of warm and wet air masses with a meridional direction of gradients of the wind velocity components as a result of small disturbances of pressure which can be produced by Rossby waves.

Besides, this mathematical model has been used in the study by Mingalev et al. (2011) to investigate a mechanism of the cyclone formation in the vicinity of the intratropical convergence zone. The results of modeling have indicated that the origin of a convexity of the form of the intratropical convergence zone can lead to the formation of a cyclone.

The present paper is intended to investigate the role of the shape of the convexity of the intratropical convergence zone on the process of the formation of a pair of cyclonic and anticyclonic vortexes by using the regional mathematical model, pointed out previously.

Mathematical model

In the applied mathematical model, the atmospheric gas is considered as a mixture of air and water vapor, in which two types of aerosols (namely, water microdrops and ice microparticles) can exist. The model is based on the numerical solution of the system of transport equations containing the equations of continuity for air and for the total water content in all phase states, momentum equations for the zonal, meridional, and vertical components of the air velocity, and energy equation. The characteristic feature of the model is that the vertical component of the air velocity is calculated without using the hydrostatic equation. Instead, the vertical component of the air velocity is obtained by means of a numerical solution of the appropriate momentum equation, with whatever simplifications of this equation being absent. In the momentum equations for all components of the air velocity, the effect of the turbulence on the mean flow is taken into account by using an empirical subgrid-scale parameterization similarly to the global circulation model of the Earth's atmosphere (Mingalev and Mingalev, 2005; Mingalev et al., 2007).

In essence, the applied regional mathematical model is based on numerical solving of non-simplified gas dynamic equations and produces three-dimensional distributions of the wind components, temperature, air density, water vapor density, concentration of micro drops of water, and concentration of ice particles in the height range from 0 to 15 km over a limited region of the Earth's surface. The dimensions of this region in longitudinal and latitudinal directions are 32° and 25°, respectively. The model takes into account heating / cooling of the air due to

absorption / emission of infrared radiation, as well as due to phase transitions of water vapor to micro drops of water and ice particles, which play an important role. The finite-difference method and explicit scheme are applied for solving the system of governing equations. The calculated parameters are determined on a uniform grid. The latitude step and longitude step are equal to 0.08°, and height step is equal to 200 m. More complete details of the applied regional mathematical model may be found in the studies of Belotserkovskii et al. (2006, 2009).

Simulation results

It may be recalled that an intratropical convergence zone is similar to a band, in which zonal westward flow of air predominates, with the air velocity being abnormally high. The width of the intratropical convergence zone can achieve a value of some hundreds of kilometers.

As pointed out previously, it was established in the study of Mingalev et al. (2011) that the origin of a convexity in the configuration of the intratropical convergence zone, having the dimension of 800-1000 km, can lead to the formation of a cyclone. However, in the study of Mingalev et al. (2011), calculations were made for three cases in which the initial forms of the intratropical convergence zone were different and contained convexities with distinct shapes. The common feature of these shapes is that the left crook of the convexity is sharp while the right crook of the convexity is gently sloping, with the deviation of the convexity in the north direction achieving a value of a few hundreds of kilometers. The distinction of their shapes is that the right end of the convexity may be both at the same latitude as the left end of the convexity and at more northern or at more southern latitudes than the left end of the convexity. The results of modeling have indicated that the origin of a convexity of the intratropical convergence zone, having three considered shapes, can lead to the formation of a cyclone during the period for about one day. Its center is close to the southern edge of the initial intratropical convergence zone. The horizontal wind velocity in this cyclone can achieve a value of 20 m/s during the period of 27 hours. The cyclone has a horizontal extent of about 600 km.

In the present study, we disposed the south boundary of the simulation domain in the vicinity of the equator. It was supposed that, at the initial moment, distributions of zonal, meridional and vertical components of the wind were consistent with the situation when the intratropical convergence zone intersects the simulation domain in the west-east direction. Calculations were made for various cases in which the initial forms of the intratropical convergence zone were different and contained convexities with distinct shapes.

Initially, let us consider the first case when, at the initial moment, the intratropical convergence zone contains a convexity in the north direction. The initial form of the intratropical convergence zone may be easy seen from the top panel of the Fig.1, where it is like a light curved band. It can be noticed that, in the first case, the left crook of the convexity is sharp and the right crook of the convexity is sharp too, with the left and right ends of the convexity being at the same latitudes. The time evolution of model parameters was numerically simulated using the mathematical model during the period for about one day. The results of time-dependent modeling are partly shown in Fig.1. As can be seen from this figure, in the course of time, the initial distribution of horizontal component of the air velocity was considerably transformed. A pair of cyclonic and anticyclonic vortexes arose in the vicinity of the initial intratropical convergence zone. A cyclonic vortex arose whose center is close to the southern edge of the initial intratropical convergence zone and an anticyclonic vortex arose whose center is close to the northern edge of the initial intratropical convergence zone. The horizontal wind velocity in these vortexes achieved a value of 20 m/s during the period of twenty seven hours. The radii of these large-scale vortexes are about 400 km.

It should be emphasized that the results of satellite monitoring of the Earth's atmosphere often indicated a simultaneous origin of a cyclone-anticyclone pair. Naturally, a formation of a single cyclone or a single anticyclone was observed by satellites repeatedly. It can be noticed that, according to observations, an initially originated single cyclonic or anticyclonic vortex as well as one of vortexes, belonging to a cyclone-anticyclone pair, as well as both vortexes, belonging to a cyclone-anticyclone pair, sometimes can be attenuated in the course of time and will not achieve a status of the long-live large-scale atmospheric vortexes.

Let us consider the second case when, at the initial moment, the intratropical convergence zone contains a convexity, analogous to the convexity of the first case, but deviated in the south direction. The initial form of the intratropical convergence zone may be easy seen from the top panel of the Fig.2, where it is like a light curved band. The results of time-dependent modeling for second case of the initial configurations of the intratropical convergence zone are partly shown in Fig.2. As can be seen from this figure, in the course of time, a pair of cyclonic and anticyclonic vortexes arose in the vicinity of the initial intratropical convergence zone. These vortices are analogous to those obtained for the first case.

The results of simulation indicate that physical reason of the formation of the calculated pair of cyclonic and anticyclonic vortexes is the origin of a convexity in the configuration of the intratropical convergence zone, having the specific forms. As a rule, such convexities are observed during the periods of rebuilding of the global circulation of the atmosphere. The origin of a convexity of the intratropical convergence zone leads to beginning of an instability of air flow. As a consequence, a pair of cyclonic and anticyclonic vortexes arise in the lower atmosphere. In the course of time, the horizontal wind velocity in the vortexes increases due to a transformation of energy,

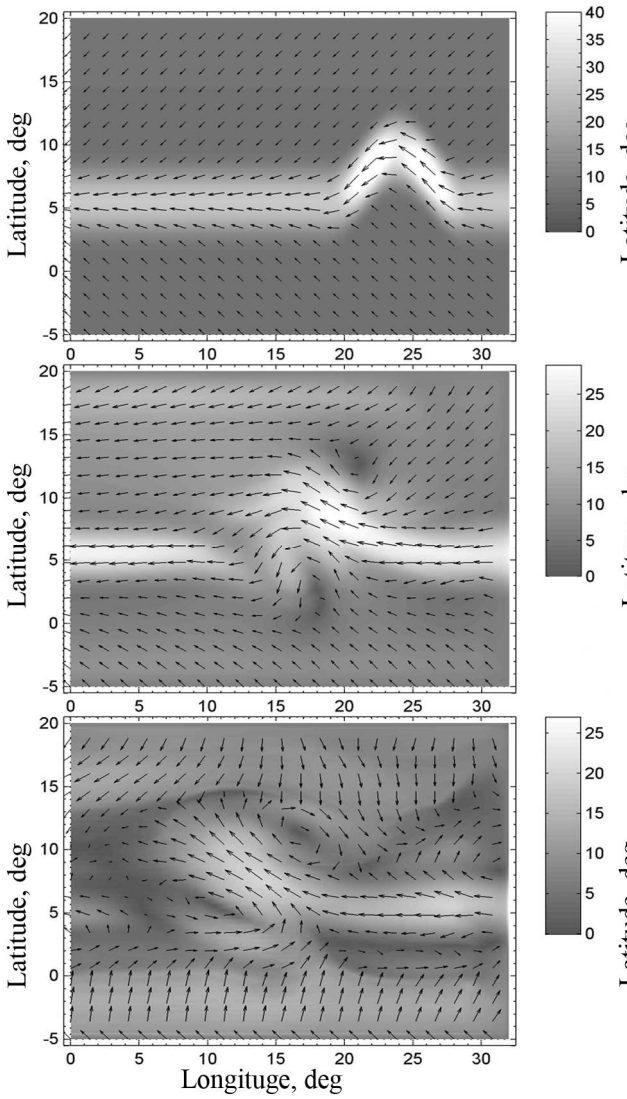

Fig. 1. The distributions of horizontal component of the air velocity (m/s) at the altitude of 600 m, assigned at the initial moment (top panel), computed 12 hours after the beginning of calculations (middle panel), and computed 27 hours after the beginning of calculations (bottom panel). The results are obtained for the first initial configuration of the intratropical convergence zone.

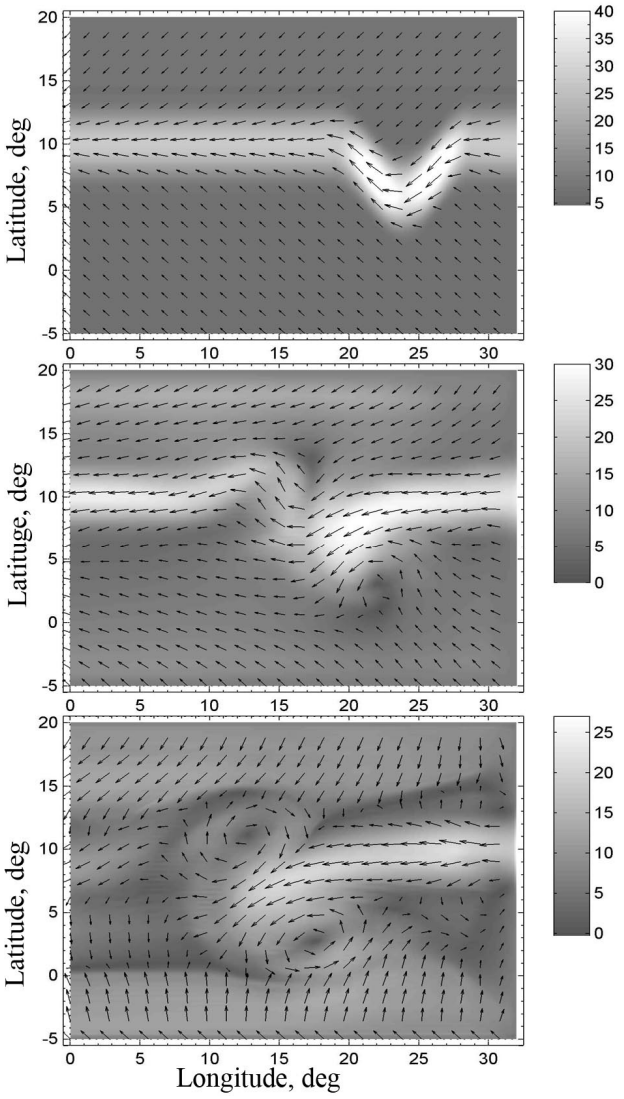

Fig. 2. The same as in Fig. 1, but obtained for the second initial configuration of the intratropical convergence zone.

emitted owing to phase transitions of water vapor to micro drops of water and ice particles due to the upward motion of air, into kinetic energy of the air flow.

Conclusions

A regional mathematical model of the neutral wind system of the lower atmosphere, developed recently in the Polar Geophysical Institute, was utilized to investigate the initial stage of the origin of cyclonic and anticyclonic vortexes at tropical latitudes of the northern hemisphere. The model produces three-dimensional distributions of the atmospheric parameters in the height range from 0 to 15 km over a limited region of the Earth's surface. The dimensions of the simulation domain in longitudinal and latitudinal directions are 32° and 25°, respectively. Calculations were performed for the cases when the simulation domain is intersected by the intratropical convergence zones with different configurations. Calculations were made for various cases in which the initial forms

of the intratropical convergence zone were different and contained convexities with distinct shapes. It was found the specific initial shapes of the intratropical convergence zone convexity which, during the period for about one day, bring forth a pair of cyclonic and anticyclonic vortexes. The common feature of these initial shapes is that the left crook of the convexity is sharp and the right crook of the convexity is sharp too, with the left and right ends of the convexity being at the same latitudes. At the initial moment, the convexity may be deviated either in the north direction or in the south direction. In both cases, a cyclone-anticyclone pair arose in the vicinity of the initial intratropical convergence zone. The cyclonic vortex arose whose center is close to the southern edge of the initial intratropical convergence zone and the anticyclonic vortex arose whose center is close to the northern edge of the initial intratropical convergence zone. The radii of these large-scale vortexes are about 400 km. The horizontal wind velocity in these vortexes achieved a value of 20 m/s during the period of twenty seven hours.

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