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TIME-DEPENDENT MODELING OF THE INITIAL STAGE OF THE FORMATION OF CYCLONES IN THE INTRATROPICAL CONVERGENCE ZONE OF THE NORTHERN HEMISPHERE

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Abstract. A mathematical model of the neutral wind system of the lower atmosphere, developed recently, is utilized to investigate the initial stage of the formation of cyclones 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. Simulations are performed for the case when this region is intersected by an intratropical convergence zone. The results of modeling indicate that the origin of a convexity of the form of the intratropical convergence zone can lead to the formation of a cyclone.

Introduction

One of the interesting problems of the atmospheric dynamics is a genesis of tropical cyclones and hurricanes. Many of the details of the initial stage of the formation of tropical cyclones and hurricanes, 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 cyclones and hurricanes.

Not long ago, 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.

Moreover, this mathematical model has been used in the study by Belotserkovskii et al. (2009) to investigate another mechanism of cyclone formation. It was shown that cyclones can appear in horizontal stratified shear flows of warm and wet air masses with horizontal direction of gradients of the wind velocity components as a result of small disturbances of pressure which can be produced by Rossby waves.

The purpose of the present paper is to investigate the role of the shape of the intratropical convergence zone on the process of the formation of cyclones by using the regional mathematical model, pointed out previously.

Brief description of the model

In the utilized regional 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).

Thus, the utilized 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 utilized regional model may be found in the studies of Belotserkovskii et al. (2006, 2009).

Simulation results

The important parameters of the utilized regional mathematical model are the boundary conditions and initial distributions of the calculated quantities. To assign the initial and boundary conditions for the present paper, we have studied many results of satellite microwave monitoring of the Earth's atmosphere, obtained in Space Research Institute and included in the electronic collection "GLOBAL-Field" (http://www.iki.rssi.ru/asp). As a consequence of these studies, we have advanced a hypothesis of the important role of the shape of the intratropical convergence zone on the process of the formation of tropical cyclones.

It is known that the 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.

To verify the advanced hypothesis, 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.

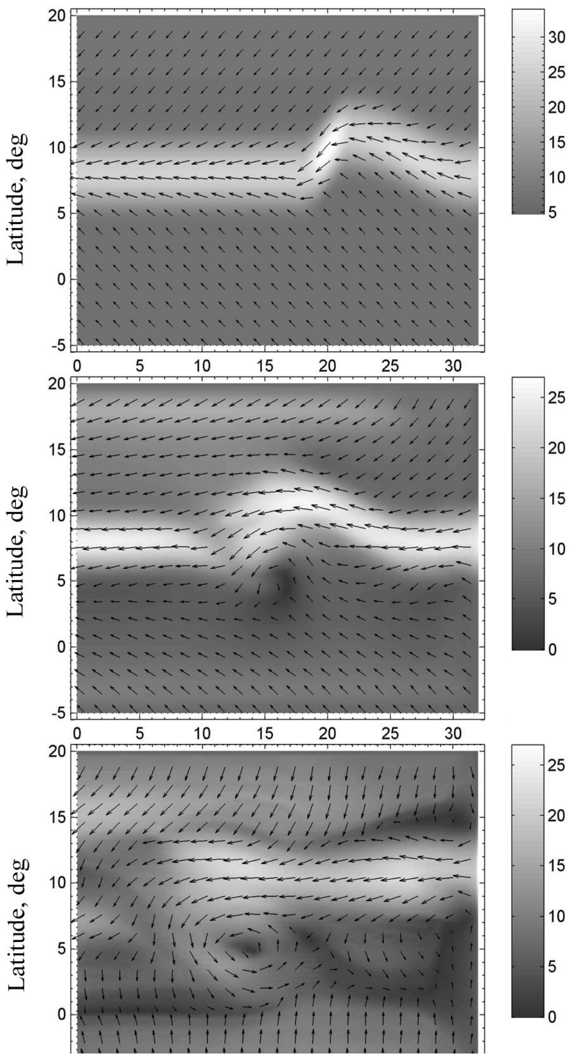

Fig. 1. The distributions of horizontal component of the air velocity (m/s) at the altitude of 600 m, assigned at the initial moment (top panel), computed 12 hours after the beginning of calculations (middle panel), and computed 27 hours after the beginning of calculations (bottom panel). The results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

Initially, let us consider the first case when, at the initial moment, the intratropical convergence zone contains a convexity in the north direction, with the deviation achieving a value of a few hundreds of kilometers. 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 is essential to note that, in the considered first case, the left crook of the convexity is sharp while the right crook of the convexity is gently sloping, 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 cyclonic vortex flow arose whose center is close to the southern edge of the initial intratropical convergence zone. The horizontal wind velocity in this cyclone achieved a value of 20 m/s during the period of twenty seven hours. The radius of this large-scale cyclonic vortex is about 600 km.

In addition, we made simulations for second and third cases when, at the initial moment, the intratropical convergence zone has different configurations. For both cases, the initial forms of the intratropical convergence zone contained the convexities analogous to the convexity of the first case. However, for the second case, the right end of the convexity is situated at more northern latitudes than the left end of the convexity (see top panel of Fig. 2). On the contrary, for the third case, the right end of the convexity is situated at more southern latitudes than the left end of the convexity (see top panel of Fig. 3). The results of time-dependent modeling for second and third cases of the initial configurations of the intratropical convergence zone are partly shown in Figs. 2 and 3. As can be seen from this figures, in the course of time, cyclonic vortex flows arose whose centers are close to the southern edge of the initial intratropical convergence zone. These vortices are analogous to that obtained for the first case.

The simulation results indicate that physical reason of the formation of the calculated tropical cyclones is the origin of a convexity in the configuration of the intratropical convergence zone. 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 large-scale vortex flow arises in the lower atmosphere, with its center being close to the southern edge of the initial intratropical convergence zone. In the course of time, the horizontal wind velocity in the vortex flow increases due to a transformation of energy, emitted owing to phase transitions of water vapor to micro drops of water and ice particles in the upward motion of air, into kinetic energy of the air flow.

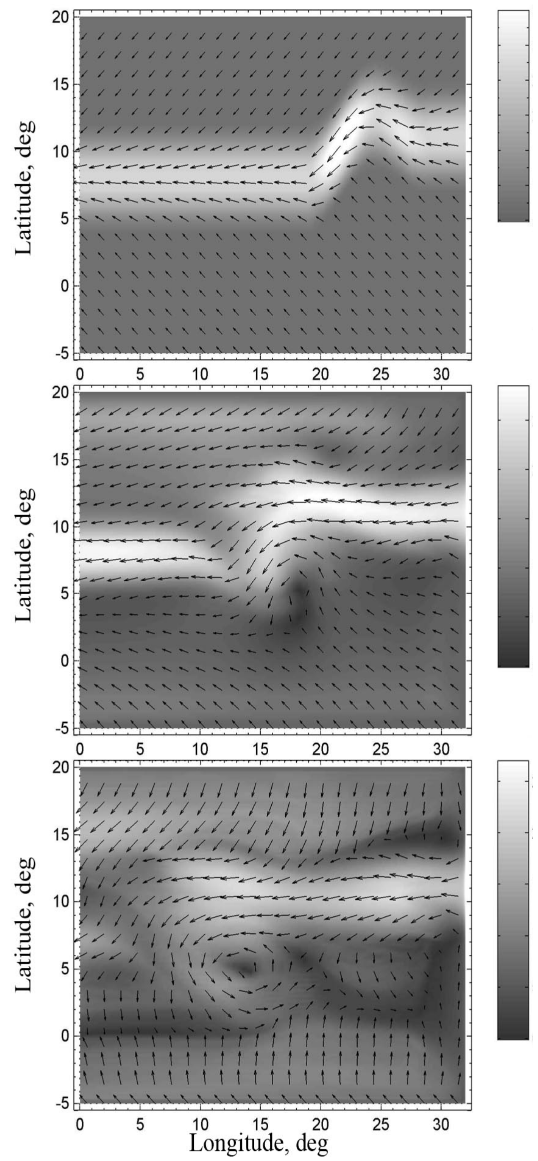

Fig. 2. The same as in Fig. 1, but obtained for the second initial configuration of the intratropical convergence zone.

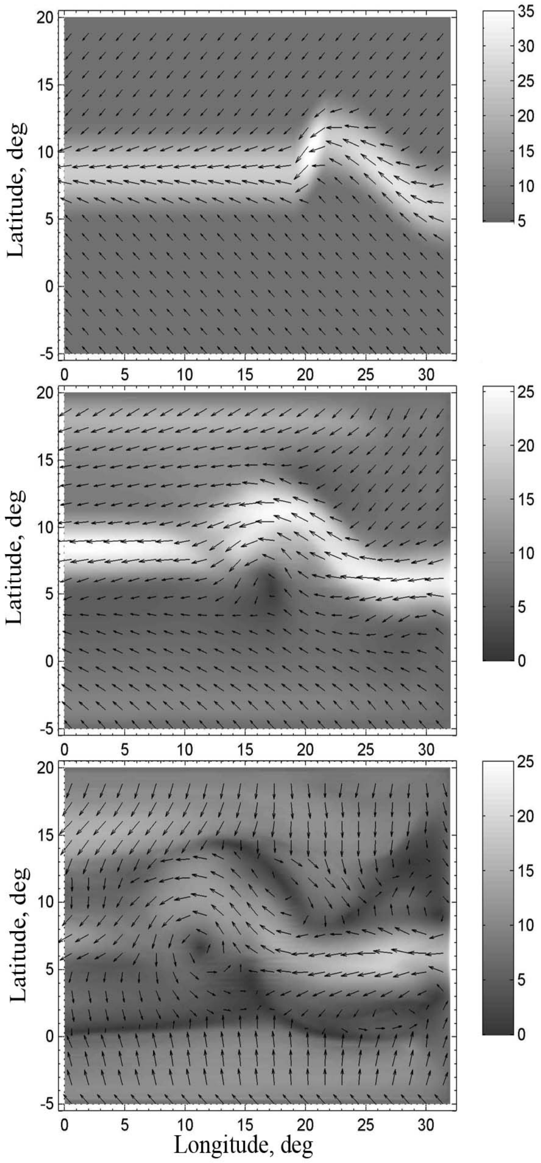

Fig. 3. The same as in Fig. 1, but obtained for the third initial configuration of the intratropical convergence zone.

Conclusions

To simulate the initial stage of the formation of cyclones at tropical latitudes of the northern hemisphere, the regional mathematical model of the neutral wind system of lower atmosphere, developed recently, is applied. The simulation domain covers the altitude range from 0 to 15 km, its dimensions 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. The results of simulations indicated that the origin of a convexity in the configuration of the intratropical convergence zone 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. Physical reason of the cyclone formation is the origin of a convexity in the form of the intratropical convergence zone. The increase of the horizontal wind velocity in the cyclone is due to the transformation of energy, emitted owing to water freezing, into kinetic energy of the air flow.

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