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NUMERICAL SIMULATION OF THE INITIAL STAGE OF THE FORMATION OF LARGE-SCALE CYCLONIC VORTICES IN THE VICINITY OF THE INTERTROPICAL CONVERGENCE ZONE

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Abstract. A regional non-hydrostatic mathematical model of the wind system of the lower atmosphere, developed recently in the Polar Geophysical Institute, is utilized to investigate the initial stage of the origin of large-scale vortices at tropical latitudes. 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 intertropical convergence zone, with the horizontal velocity field being asymmetric relatively the centerline of the intertropical convergence zone inside and beyond it. The results of modeling indicate that the origin of a convexity of the intertropical convergence zone, having the specific forms, can lead to the formation of a pair of cyclonic vortices.

Introduction

It is known that severe tropical cyclonic storms and hurricanes can cause tremendous damage and numerous fatalities. Therefore, prediction of tropical cyclone formation is very important problem. 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 vortices.

Recently, a regional mathematical model of the wind system of the lower atmosphere has been developed in the Polar Geophysical Institute (PGI) [*Belotserkovskii et al.*, 2006]. This mathematical model has been applied to verify the hypothesis of the influence of the shape of the intertropical convergence zone (ITCZ) on the process of the formation of tropical cyclones. It was shown that the origin of a convexity in the configuration of the intertropical convergence zone can lead to the formation of a cyclonic vortex during the period for about one day. Its center is close to the southern edge of the initial intertropical convergence zone [*Mingalev et al.*, 2011]. The results of mathematical modeling have indicated that the origin of a convexity of the intertropical convergence zone, having the specific forms, can lead to the formation of not only a single cyclonic vortex but also a cyclonic-anticyclonic pair [*Mingalev et al.*, 2012].

The purpose of the present work is to continue these studies and to investigate numerically, applying the regional mathematical model of the wind system of the lower atmosphere developed in the PGI, the initial stage of the origin of large-scale vortices in the vicinity of the intertropical convergence zone.

Mathematical model

In this study, the regional non-hydrostatic mathematical model of the wind system of the lower atmosphere, developed not long ago at the Polar Geophysical Institute, is applied. In the model, the atmospheric gas is considered as a mixture of air and water vapor, in which two types of precipitating water (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 developed earlier in the PGI [*Mingalev I. and Mingalev V.*, 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 40° 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].

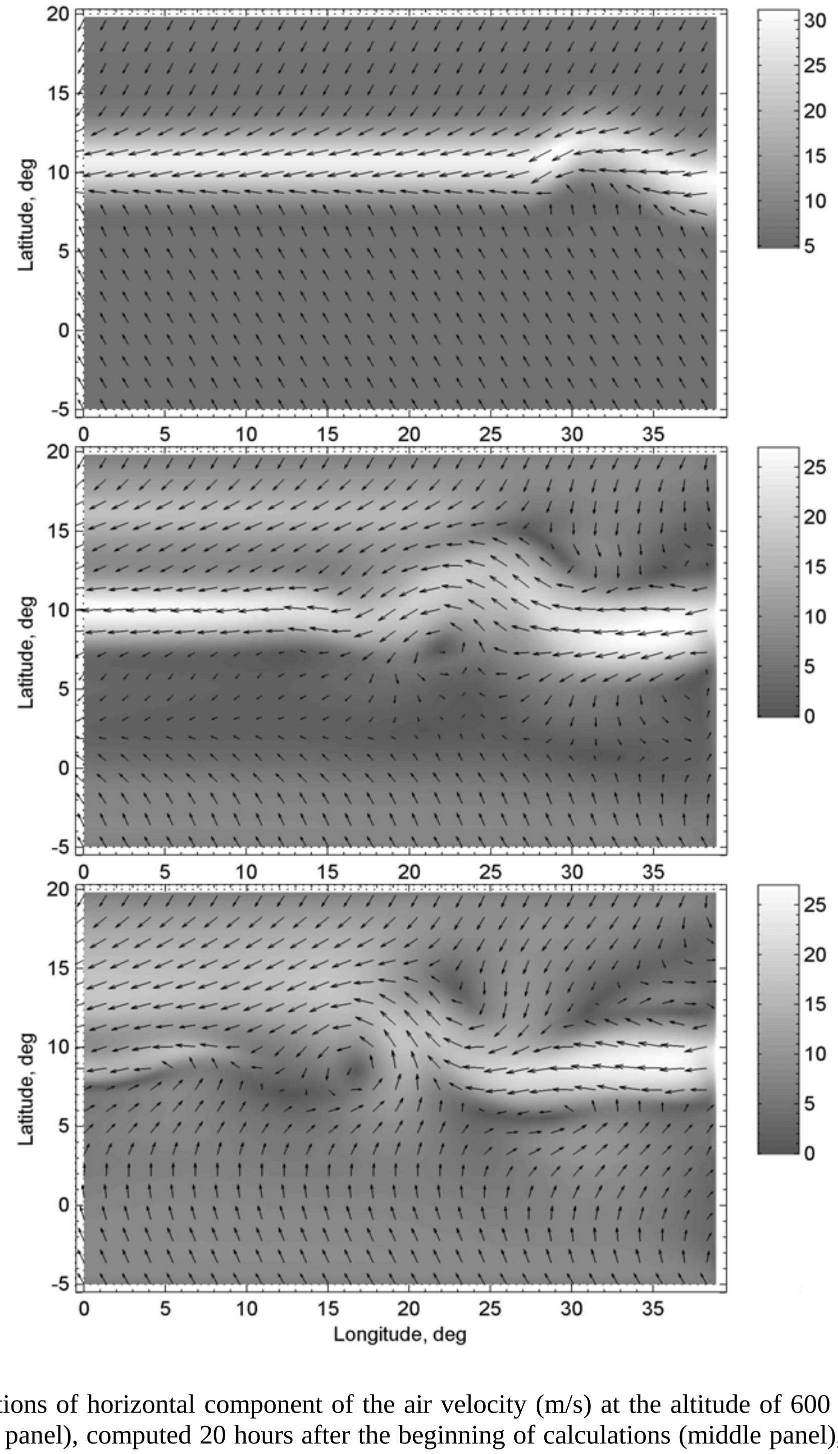

Fig. 1 The distributions of horizontal component of the air velocity (m/s) at the altitude of 600 m, assigned at the initial moment (top panel), computed 20 hours after the beginning of calculations (middle panel), and computed 40 hours after the beginning of calculations (bottom panel). The degree of shadowing of the figures indicates the module of the velocity in m/s.

Simulation results

From observation, it is known that, in an intertropical convergence zone, a zonal flow of air is westward, with the horizontal wind velocity being enhanced inside an intertropical convergence zone. A meridional wind velocity directs towards the centerline of an intertropical convergence zone at levels less than approximately 3 km and directs from the centerline of an intertropical convergence zone at levels higher than approximately 3 km. A vertical wind velocity in an intertropical convergence zone is upward. Therefore, an intertropical convergence zone may be considered as a fluid stream, having enhanced zonal velocities, in the ambient atmospheric gas.

In our calculations, we define the initial and boundary conditions as consistent with the situation when the intertropical convergence zone intersects the simulation domain in the west-east direction. In the present work, we consider a case when, at the initial moment, the horizontal velocity field is asymmetric relatively the centerline of the intertropical convergence zone inside and beyond it. It was supposed that, at the initial moment, the intertropical convergence zone contains a convexity in the north direction, with the zonal wind velocities at more northern latitudes relatively the centerline of the intertropical convergence zone being larger than at more southern latitudes relatively it. The initial form of the intertropical convergence zone may be easy seen from the top panel of the Fig. 1, where it is like a light curved band. It is noted that, in the considered case, the west crook of the convexity is sharp while the east crook of the convexity is gently sloping, with the east end of the convexity being 1^{O} southern than the west crook of it.

It can be noticed that the initial form of the intertropical convergence zone is chosen in accordance with the results of satellite microwave monitoring of the Earth's atmosphere, included in the electron data base "GLOBAL-Field" (*http://www.iki.rssi.ru/asp*), developed in the Space Research Institute of the RAS. This data base contains global radio thermal fields of the Earth at the frequencies containing the information about a moisture and water integral content distribution in a troposphere. The data were obtained from the spacecraft mission, DMSP (Defense Meteorological Satellite Program), with the help of the instrument, SSM/I (Special Sensor Microwave / Imager).

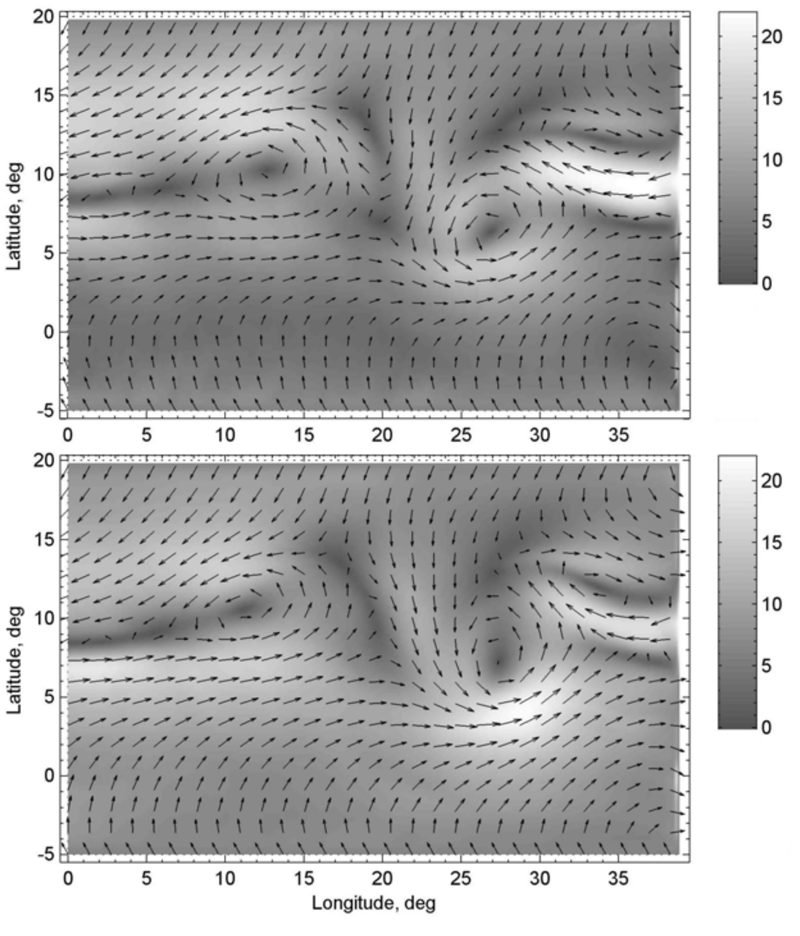

Fig. 2 The same as in Fig. 1, but computed 60 hours after the beginning of calculations (top panel), and computed 70 hours after the beginning of calculations (bottom panel).

Studying results of satellite microwave monitoring of the Earth's atmosphere, included in the electronic data base "GLOBAL-Field", one can see that, sometimes, the Atlantic Ocean is intersected by an intertropical convergence zone stretched from Africa to South America.

The time evolution of model parameters was numerically simulated using the mathematical model during the period for about three days. The results of time-dependent modeling are partly shown in Figs. 1 and 2. As can be seen from these figures, in the course of time, the initial distribution of horizontal component of the air velocity was considerably transformed. To a moment of 20 hours after the beginning of calculations, a cyclonic vortex flow arose whose center is close to the southern edge of the initial intertropical convergence zone. To a moment of 40 hours after the beginning of calculations, this cyclonic vortex has moved in the western direction for about 5 degrees.

To a moment of 60 hours after the beginning of calculations, the rotational center of the formed cyclonic vortex has moved in the north-west direction for a distance of about 600 km. Simultaneously, the second cyclonic vortex arose, with its center being close to the southern edge of the initial intertropical convergence zone.

Thus, to a moment of 70 hours after the beginning of calculations, a pair of cyclonic vortices arose in the vicinity of the intertropical convergence zone. The rotational centers of these cyclonic vortices are situated near the edges of the inetatropical convergence zone. The center of the first cyclonic vortex is close to the northern edge while the center of the second cyclonic vortex is close to the southern edge of the intertropical convergence zone. The horizontal wind velocity in these cyclonic vortices achieved values of 15-20 m/s during the period of seventy hours. The radii of these cyclonic vortices are about 600 km.

It can be noticed that the results of observation of the Earth’s atmosphere indicated a simultaneous origin of twin tropical cyclones sometimes [Chen et al., 2010].

The results of simulation indicate that a key factor in the modeled formation of twin tropical cyclonic vortices is the origin of a convexity in the configuration of the intertropical convergence zone, having the specific form, which is accompanied by asymmetric horizontal velocity field in the vicinity of this zone. The pointed out factors lead to beginning of instability of stream air flow. As a consequence, a pair of cyclonic vortices arises in the lower atmosphere in the course of time. A transformation of energy, emitted due to phase transitions of water vapor to micro drops of water and ice particles in the mixture of air and water vapor moving upward, into kinetic energy of the air flow plays an important role in the increase of the horizontal wind velocity in the course of time.

Conclusions

A regional non-hydrostatic mathematical model of the wind system of the lower atmosphere, developed recently in the Polar Geophysical Institute, was utilized to investigate the initial stage of the origin of large-scale vortices at tropical latitudes. The mathematical 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 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 were performed for the case when this region is intersected by the intertropical convergence zone. It was supposed that, at the initial moment, the intertropical convergence zone contains the convexity in the north direction, moreover, the zonal wind velocities at more northern latitudes relatively the centerline of the intertropical convergence zone are larger than those at more southern latitudes relatively it, with the west crook of the convexity being sharp while the east crook of the convexity being gently sloping. Simulation results indicated that the twin tropical cyclones were formed during the period for about three days. The cyclones were formed one after another in the course of time. The rotational center of the first cyclone is close to the northern edge while the center of the second cyclone is close to the southern edge of the initial intertropical convergence zone to a moment of 70 hours after the beginning of calculations. The radii of these cyclones are about 600 km. The horizontal wind velocity in the cyclones achieved values of 15-20 m/s during the period of about three days.

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