"Physics of Auroral Phenomena", Proc. XXXVII Annual Seminar, Apatity, pp. 113-116, 2014

Polar Geophysical Institute

NUMERICAL MODELING OF THE INITIAL STAGE OF THE ORIGIN OF CYCLONIC VORTICES IN THE VICINITY OF THE INTERTROPICAL CONVERGENCE ZONE

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Abstract. To investigate the initial stage of the origin of large-scale vortices at tropical latitudes a regional non-hydrostatic mathematical model of the wind system of the lower atmosphere, developed recently in the Polar Geophysical Institute, is utilized. 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 are produced by the utilized model. Simulations are performed for the case when the limited three-dimensional simulation domain is intersected by an intertropical convergence zone in the west-east direction. It was supposed that, at the initial moment, the intertropical convergence zone contains two convexities in the north direction. Time-dependent modeling was performed during the period of about four days. Simulation results indicated that three tropical cyclones were formed in the vicinity of the initial intertropical convergence zone in the course of time.

Introduction

It is known that the physical theory of tropical cyclone formation is still far from completion. Nevertheless, some aspects of tropical cyclogenesis are commonly understood, in particular, in the late stages of formation as well as in a fully developed stage [*Emanuel, 1986; Montgomery and Farrell, 1993; Kieu and Zhang, 2008; Mao and Wu, 2011 and references therein*]. However, the important details of the initial stage of the formation of tropical large-scale vortexes are still unresolved. To investigate physical mechanisms responsible for the tropical cyclone formation, mathematical models may be utilized.

Not long ago, in the Polar Geophysical Institute (PGI), a regional mathematical model of the wind system of the lower atmosphere has been developed [*Belotserkovskii et al., 2006*]. With the help of this model, 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, with the cyclonic center being close to the southern edge of the initial intertropical convergence zone [*Mingalev et al., 2011*]. Moreover, 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*] and pair of cyclonic vortices [*Mingalev et al., 2013*], during the period not longer than three days.

The purpose of the present work is to continue these studies, applying the regional mathematical model of the wind system of the lower atmosphere developed in the PGI, and to investigate numerically how the origin of convexities in the form of the intertropical convergence zone influence on the formation of the large-scale vortices.

Mathematical model

A regional mathematical model of the wind system of the lower atmosphere, applied in the present study, has been developed in the Polar Geophysical Institute [*Belotserkovskii et al., 2006*] not long ago. In this 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 peculiarity 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.

Thus, the utilized mathematical model is based on numerical solving of non-simplified gas dynamic equations and produces three-dimensional time-dependent distributions of the wind components, temperature, air density, water vapor density, concentration of micro drops of water, and concentration of ice particles. 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 in energetic balance. The three-dimensional simulation domain of the model is a part of a spherical layer stretching from land and ocean surface up to the altitude of 15 km over a limited region of the Earth's surface. In the present study, the dimensions of this region in longitudinal and latitudinal directions are 75° and 25°, respectively. The finitedifference method and explicit scheme are applied for solving the system of governing equations. The calculated parameters are determined on a uniform grid. The latitude and longitude steps are equal to 0.08°, and height step is equal to 200 m. 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*]. More complete details of the applied regional mathematical model may be found in the studies of *Belotserkovskii et al.* [2006] and [*Mingalev et al., 2013*].

Simulation results

In the present study, simulations are performed for the case when the three-dimensional simulation domain is intersected by an intertropical convergence zone in the west-east direction. It is known that an intertropical convergence zone may be considered as a fluid stream, having enhanced zonal velocities, in the ambient atmospheric gas, with a zonal flow of air being westward. 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.

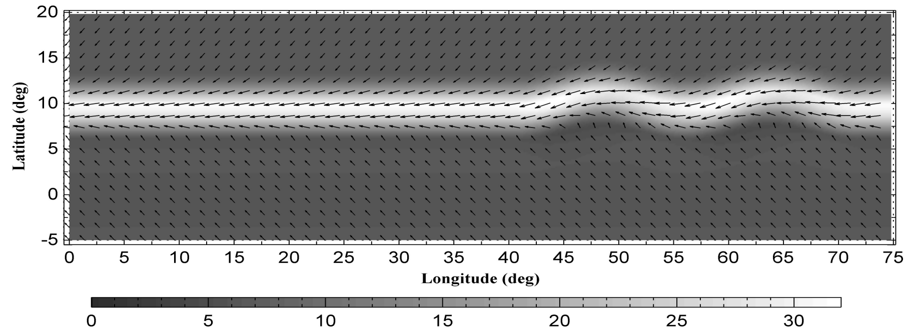

Figure 1. The distribution of horizontal component of the air velocity (m/s) at the altitude of 600 m, assigned at the initial moment. The degree of shadowing of the figure indicates the module of the velocity in m/s.

In the earlier studies of *Mingalev et al*., [2012 and 2013], it was shown that the origin of convexities in the form of the intertropical convergence zone, having distinct configurations, can lead to the formation of different large-scale vortices, in particular, a cyclonic vortex, pair of cyclonic-anticyclonic vortices, and pair of cyclonic vortices, during the period not longer than three days.

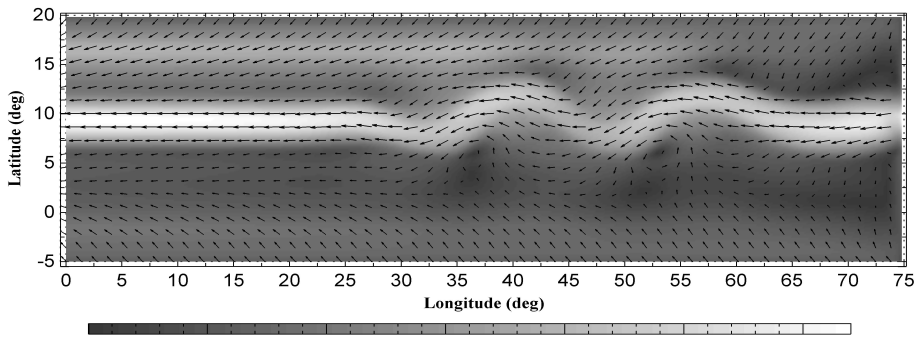

Figure 2. The distribution of horizontal component of the air velocity (m/s) at the altitude of 600 m, computed 20 hours after the beginning of calculations. The degree of shadowing of the figure indicates the module of the velocity in m/s.

In the present work, simulations are performed for the case when the simulation domain is intersected by the intertropical convergence zone having the specific configuration. It was supposed that, at the initial moment, the intertropical convergence zone contains two convexities in the north direction, with the deviations achieving a value of a few hundreds of kilometers. The initial form of the intertropical convergence zone may be easy seen from the Figure 1. The time evolution of model parameters was numerically simulated using the mathematical model during the period for about four days. The results of time-dependent modeling are shown in Figures 2 and 3.

The results of simulation indicate that, in the course of time, the initial distribution of horizontal component of the air velocity was considerably transformed. In a moment of 20 hours after the beginning of calculations, a pair of tropical cyclonic vortices arose. Their centers are close to the southern edge of the initial intertropical convergence zone. Approximately 30 hours later, third tropical cyclone arose whose center is close to the southern edge of the initial intertropical convergence zone. The arisen cyclonic vortices have moved in the western direction. The radii of these three cyclones are about 800 km. The horizontal wind velocity in the cyclones can achieve values of 15-20 m/s in the course of time.

The simulation results indicate that a key factor in the modeled formation of the triplet of tropical cyclonic vortices is the origin of convexities in the configuration of the intertropical convergence zone. The origin of these convexities leads to beginning of instability of stream air flow. This instability leads to considerable transformation of the wind field. As a consequence, the triplet of tropical cyclonic vortices arises in the lower atmosphere in the course of time. In addition to that, the initial intertropical convergence zone is broken down.

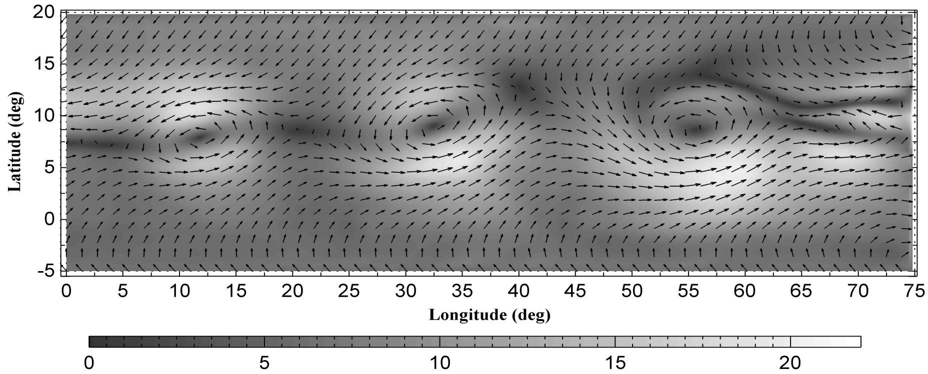

Figure 3. The distribution of horizontal component of the air velocity (m/s) at the altitude of 600 m, computed 90 hours after the beginning of calculations. The degree of shadowing of the figure indicates the module of the velocity in m/s.

It can be noticed that, according to observations, not each cyclonic vortex, arisen in the lower atmosphere, has the potential to grow up to the long-live large-scale atmospheric vortex. It is known that, sometimes, a vortex, initially arisen in the lower atmosphere, can be attenuated in the course of time and will not achieve a status of the long-live large-scale atmospheric vortex. This peculiarity may take place for the large-scale vortices arisen in the calculations of the present study, which were limited by the time intervals not longer than four days. Unfortunately, more prolonged time intervals are impossible for the utilized mathematical model because of limited sizes of its simulation domain and owing to tendency of the modeled vortices to move and to abandon the simulation domain in the course of time.

Conclusions

In earlier studies by the authors of the present work, the idea has been advanced that the transformation of the shape of the intertropical convergence zone can influence the process of the formation of tropical cyclones [*Mingalev et al., 2013 and references therein*]. The present work is the continuation of the investigation of the initial stage of the origin of large-scale vortices at tropical latitudes. For this investigation, a regional non-hydrostatic mathematical model of the wind system of the lower atmosphere, developed recently in the Polar Geophysical Institute, is utilized. 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 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 the intertropical convergence zone having the specific configuration. It was supposed that, at the initial moment, the intertropical convergence zone contains two convexities in the north direction, with the deviations achieving a value of a few hundreds of kilometers. The simulation results indicated that the twin tropical cyclones were formed during the period for about 20 hours. Their centers are close to the southern edge of the initial intertropical convergence zone. Besides, to a moment of approximately 50 hours after the beginning of calculations, third tropical cyclone arose whose center is close to the southern edge of the initial intertropical convergence zone, too. The arisen triplet of tropical cyclonic vortices has moved in the western direction. The radii of these three cyclones are about 800 km. The horizontal wind velocity in the cyclones can achieve values of 15-20 m/s in the course of time.

Acknowledgments. This work was partly supported by Grant No. 13-01-00063 from the Russian Foundation for Basic Research.

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