HELICAL SCENARIO OF TROPICAL CYCLONE GENESIS AND INTENSIFICATION

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Summary A helical scenario of tropical cyclogenesis and further vortex intensification is proposed which is based on results of direct numerical simulation of atmospheric flows. The main idea of the scenario consists in a specific topology of helical flows which are characterized by the linkage of vortex lines. Velocity fields resulted from a high resolution numerical simulation by Regional Atmospheric Modeling System (RAMS) are used to calculate helical and integral characteristics during a tropical cyclone formation. It is shown how non-zero mean helicity is generated by moist convective atmospheric turbulence, which implies a new flow topology with linked vortex lines. A possible role of vortical hot towers (VHTs) is discussed in generating the linkage. It is shown that the linkage results in a positive feedback between the horizontal and vertical circulation in the formation of a larger-scale vortex and contributes to the instability of the macro vortex.

In 2006, Montgomery and co-authors \cite{Montgomery2006} proposed a new scenario of tropical cyclogenesis within a kinematically and thermodynamically favorable environment of a mesoscale convective vortex. Using near-cloud-resolving simulations, the work demonstrated how a mesoscale tropical depression (TD) vortex could develop from cumulonimbus convection as a result of system-scale convergence and upscale vorticity growth. Within the cyclonic vorticity-rich environment of the mesoscale convective vortex (MCV) embryo, the numerical simulations indicated that deep cumulonimbus towers possessing intense cyclonic vorticity in their cores (“vortical” hot towers, VHTs) emerged as the preferred coherent structures. The VHTs acquired their vertical vorticity through a combination of tilting of MCV-horizontal vorticity and stretching of MCV and VHT-generated vertical vorticity. Horizontally localized and exhibiting convective lifetimes on the order of one hour, VHTs overcame the detrimental effects of downdrafts by consuming convective available potential energy in their local environment, humidifying the middle and upper troposphere, and undergoing diabatic vortex merger with neighboring towers. In those simulations the growth of flow scales occurred by both system convergence and multiple diabatic vortex mergers alongside the more familiar dry adiabatic vortex merger of convectively generated remnants. The generated VHTs, each of 10-30 km horizontal scale, eventually resulted in an intense helical vortex (TD) on the atmospheric mesoscale. Meanwhile, during all subsequent stages of vortex intensification from the TD up to the mature hurricane strength, a number of VHTs of different scale and strength were always observed within the vortex circulation.

In paper \cite{Levina2011} the first investigation of tropical cyclone genesis and intensification was conducted from the perspective of helical features of atmospheric flows of different scales, which contributed to the organization of the cyclone. Using the data \cite{Montgomery2006}, helical characteristics of the velocity field were calculated and analyzed. It has been discovered that the process of hurricane formation is accompanied by the generation of nonzero mean helicity in moist convective atmospheric turbulence that implies a new topology of the flow when it is characterized by linked vortex lines \cite{Moffatt1969}.

It is important to point out that no external assumptions were imposed on the fluid motions here, i.e., no external forcing terms were imposed to mimic a “helical alpha effect”. In other words, the current results are the outcome of a direct numerical simulation subject to the usual caveats of a sub-grid scale closure that is used to remove small scale motions at the horizontal grid scales of the model (∼3km).

In this work we examine from “the helical perspective” three numerical experiments from paper \cite{Montgomery2006}, which resulted in the hurricane strength vortex (successful case), tropical depression (intermediate case), and that of no surface vortex development whatsoever (unsuccessful case). We use the velocity fields obtained in \cite{Montgomery2006} to calculate and analyze helical and integral characteristics of the cyclogenesis and intensification process for the problem as posed by \cite{Montgomery2006}. We consider a set of characteristics recommended in paper \cite{Levina2006} for diagnosing a positive helical feedback between the horizontal and vertical circulation in a forming large-scale vortex structure. Using this framework we discuss how the feedback works. We analyze the pivotal role of vortical hot towers in generating and sustaining the feedback at different stages of the vortex evolution. Helical and integral characteristics for the successful, intermediate and unsuccessful numerical experiments are compared to pinpoint the significance of HELICAL flow topology in tropical cyclone genesis and intensification.

References