The contribution of structure and evolution of potential vorticity tower to the intensity change of Hurricane Wilma (2005)

ZHONG Wei*, LIU Shuang, LU Han-Cheng

Institutes of Meteorology and Oceanography, PLA University of Science and Technology, Nan Jing, 211101

Abstract Observational studies and numerical models reveal that potential vorticity tower (PVT) and its outer PV bands correspond well with eyewall and spiral rainband in hurricanes. Thus, the PVT formation and evolution and its effect on hurricane intensity change have been explored as a new task in international hurricane research. In this study, high-resolution numerical model data is used to conduct dynamic diagnosis and correlation analysis. Dynamic diagnosis is conducted to depict the characteristics and evolution of the PVT in Hurricane Wilma (2005). According to the correlation theory, the structural parameters that can be used to quantitatively describe the PVT structure are redefined and then applied into a real case study. This study aims to reveal the effect of the PVT structure and evolution on the rapid intensification (RI) of Hurricane Wilma (2005).

By comparing the change of physical variables associated with the PV and the intensity change of Wilma, it is determined that the positive PV anomaly in the upper troposphere tends to occur during the pre-RI period. Moreover, the PV anomaly gradually weakens with the subsidence of upper-level warm core during the RI period and disappears at the post-RI period. The temporal evolution of the PV anomaly large centre in the middle and lower troposphere and the intensity change of Wilma are in phase. The appearance of the mid-level positive PV anomaly is closely related to the subsidence of upper tropospheric PV anomaly and the mid-level latent heat release associated with convective activity. Furthermore, the intensity change of the lower-level PV anomaly large centre satisfies the criterion of dynamic instability, which is the necessary condition for hurricane intensification. Thus, it can be seen that the PV intensity and structural change in the inner core of the hurricane mainly depends on the subsidence of the upper-level warm-core, the mid-level latent heat release and the low-level dynamic instability. Hence, the PV intensity and structural change in the inner core of the hurricane is of some importance to the RI of hurricanes.

The vertical and horizontal structures of the PVT at different stages of RI are also diagnosed. Results indicate that the large PV is concentrated in the eye, and the PV structure is characterised by typical monopole PVT (MPVT) in terms of the entire layer during the pre-RI period. As the build-up of hollow PVT (HPVT) under the effect of upper-level warming, latent heat release and vertical mixing of convection during the RI period, the changes of vortex dynamic structure result in meso-scale waves instability and the explosive intensification of Wilma. Subsequently, the large PV is continuously mixed into the eye while the radial PV mixing strengthens. This indicates that the large PV columns on either sides of the eye gradually break down, and the HPVT transforms into the MPVT. Simultaneously, the hurricane begins to stabilise. In conclusion, the transformation between the MPVT and HPVT, which is closely related to the propagation and instability of meso-scale waves, would cause a sharp change in the eyewall and spiral rainbands in hurricanes. The location and intensity of the large PV region change in the process of mutual transformation, so the PV mixing occurs in the horizontal and vertical directions.Meanwhile, the dynamic and thermodynamic factors associated with the PV become anomalous causing the redistribution of momentum, heat and water vapour in the hurricanes, and finally leading to rapid intensity change of hurricanes.

Two theoretical structural parameters, thickness and hollowness, are redefined in the simulated hurricane case so that the structural effect of the PVT on the intensity change of hurricanes could be quantitatively analysed. The correlation analysis of the structural parameters and the intensity change of Wilma (2005) during the RI period show that the coefficients of the structural parameters and the change rate of minimum sea surface central pressure exceed the 99% confidence level, which indicates the high dependency between the PVT structure and the intensity change of hurricanes.
Keywords Tropical Cyclone (TC), potential vorticity tower (PVT), intensity change, instability