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THE FORMATION OF CONCENTRIC VORTICITY STRUCTURES IN TYPHOONS

H.-C. Kuo[(1)], C.-P. Chang[(2)], R. T. Williams[(2)]

[(1)]Department of Atmospheric Sciences National Taiwan University, Taipei, Taiwan

[(2)]Department of Meteorology Naval Postgraduate School, Monterey California

1. INTRODUCTION

Aircraft observations (Black and Willoughby 1992) show that the contraction of the outer tangential wind maximum from a distance of 90 km from the storm center to 60 km in approximately twelve hours in the formation of concentric eyewall structure. Moreover, the core vortex intensity remained approximately the same during the contraction period. An important issue in the formation of concentric eyewalls in a tropical cyclone is the development of a symmetric structure from asymmetric convection.

Dritschel and Waugh (1992) described the general interaction of two barotropic vortices with the parameters of dimensionless gap (separation distance of two vortices divided by a vortex radius) and vortex radius ratio for two equal vorticity strength vortices. The complete straining out regime of the interaction shows a small, weaker vortex being sheared out into thin filaments of vorticity surrounding the large, stronger vortex with no incorporation into the large vortex. The regime resembles the concentric vorticity structure except the filaments are too thin to be called a concentric eyewall. An extension of the complete straining out regime to include a finite-width outer band is needed to explain the interaction of a small and strong vortex (representing the tropical cyclone core) with a large and weaker vortex (representing the vorticity induced by the moist convection outside the central vortex of a tropical cyclone). In radar observations of Typhoon Lekima of 2001 (Kuo et al. 2004), we noticed a huge area of convection outside the core vortex that wraps around the inner eyewall to form the concentric eyewalls in a time scale of 12 hours.

The interaction of a small and strong vortex with a large and weak vortex was not studied by Dritschel and Waugh (1992) as their vortices are of the same strength and their larger vortex was always the ``victor" and the smaller vortex was the one often being partially or totally destroyed. We propose, with the nondivergent barotropic model, that concentric vorticity structures result from the interaction between a small and strong inner vortex and neighboring weak vortices.

Corresponding author address:
H.-C. Kuo, Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan.
E-mail: kuo@lanczos.as.ntu.edu.tw

2. RESULTS AND SUMMARY

Figure 1 gives the vorticity field in the binary vortex experiments for vortex strength ratio 6, radius ratio 1/3, and dimensionless gap 1 (top); and vortex strength ratio 10, radius ratio 1/4, and dimensionless gap 0 (bottom). Figure 2 gives summary of interaction regimes for binary vortices. We have classified the regimes into the C (concentric), T (tripole), M (complete or partial merger regime), and EI (elastic interaction) regimes. With the introduction of a new vorticity strength ratio parameter in the binary vortex interaction problem, we have added the concentric vorticity structure as well as the tripole vortex to the Dritschel-Waugh vortex interaction scheme.

The results highlight the pivotal role of the vorticity strength of the inner core vortex in maintaining itself, and in stretching, organizing and stabilizing the outer vorticity field. Specifically, the core vortex induces a differential rotation across the large and weak vortex to strain out the latter into a vorticity band surrounding the former. The straining out of a large, weak vortex into a concentric vorticity band can also result in the contraction of the outer tangential wind maximum. The stability of the outer band is related to the Fjortoft sufficient condition for stability because the strong inner vortex can cause the wind at the inner edge to be stronger than the outer edge, which allows the vorticity band and therefore the concentric structure to be sustained. Moreover, the inner vortex must possess high vorticity not only to be maintained against any deformation field induced by the outer vortices but also to maintain a smaller enstrophy cascade and to resist the merger process into a monopole. The negative vorticity anomaly in the moat serves as a barrier to the further inward mixing the outer vorticity field. Our binary vortex experiments suggest that the formation of a concentric vorticity structure requires: 1) a very strong core vortex with a vorticity at least six times stronger than the neighboring vortices, 2) a large neighboring vorticity area that is larger than the core vortex, and 3) a separation distance between the neighboring vorticity field and the core vortex that is within three to four times the core vortex radius.

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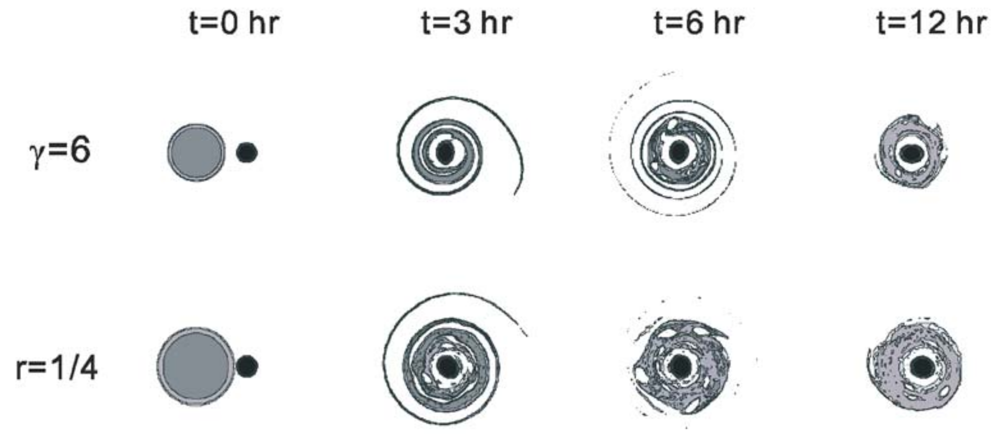

Fig 1. The binary vortex experiments for vortex strength ratio 6, radius ratio 1/3, and dimensionless gap 1 (top); and vortex strength ratio 10, radius ratio 1/4, and dimensionless gap 0 (bottom).

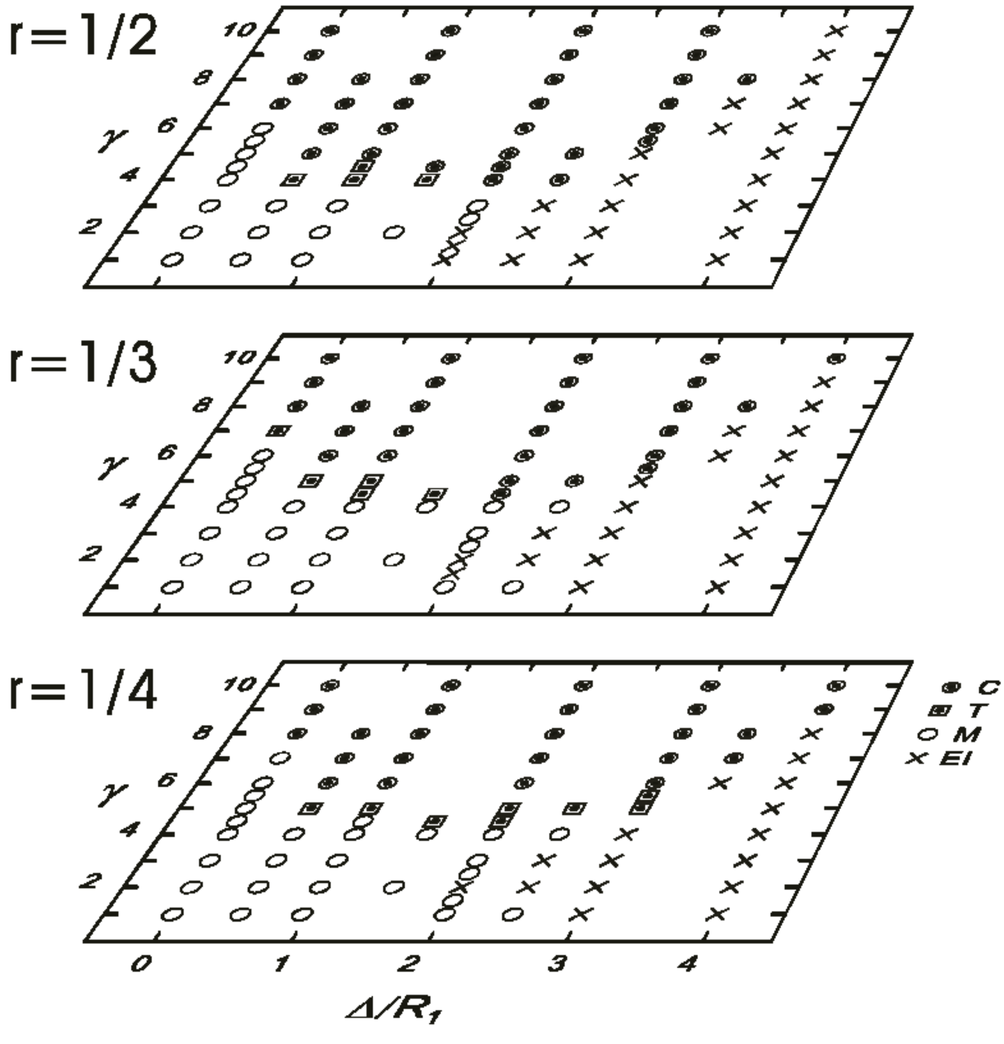

Fig 2. Summary of numerical experiments with the parameters of the vorticity strength ratio (γ), the dimensionless gap Δ/R_1, and the vortex radius ratio r.