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TROPICAL CYCLONE INTENSITY CHANGE IN A UNIFORM FLOW

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1. INTRODUCTION

The effect of a uniform flow on tropical cyclone (TC) intensity change is unclear even in an *f* plane situation. For example, Frank and Ritchie (2001) found that a TC in a 3.5 m s^{-1} uniform background flow slightly intensifies compared with a no-flow case. However, in an earlier modeling study, Peng et al. (1999) showed that a TC weakens in a uniform flow of 5 m s^{-1}. The mechanisms that affect TC intensity under a uniform flow have therefore yet to be clearly identified. In other words, it is necessary to re-consider TC structure and intensity changes in the simplest case of a uniform flow on an *f* plane, which is the objective of the present study.

2. EXPERIMENTAL DESIGN

The Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model Version 5 (MM5) is used in this study. The model domain consists of 301 x 301 grid points with a grid size of 15 km and 24 full sigma levels. The Betts-Miller cumulus parameterization scheme (Betts and Miller 1986) and the simple ice explicit moisture scheme are selected as the cumulus physics. Experiments are performed on the *f* plane. The control vortex (CTRL) is the one without any background flow while the uniform flows from different directions are imposed to the vortex after spun up.

3. BASIC EXPERIMENTAL RESULTS

3.1 Intensity of bogus TCs

The intensity trends (Fig. 1) of all the TCs are almost identical. In addition, their trends follow closely to that of the control vortex in the first 57 h of the simulation time (33 h after imposing the uniform flow). At t = 57 h, the intensities of CTRL and the TCs under uniform flow are 929 and 930 hPa respectively. From t = 57 h to the end of simulation (t = 72 h), the CTRL vortex steadily intensifies to 918 hPa while the intensities of the vortices under a mean flow stay at values between 925 to 928 hPa. Throughout the simulation, the intensity of the no-flow case is stronger than the mean flow cases, and the intensity difference is more noticeable after 51 h. In other words, the intensification of the vortices is not halted immediately after the flow has been imposed.

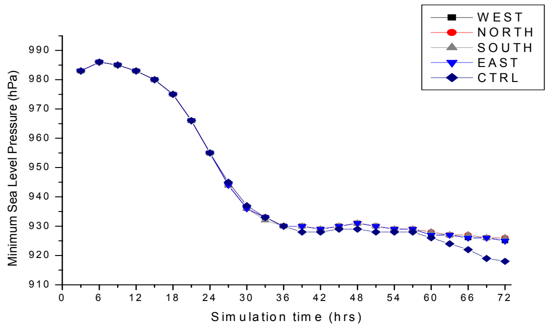

Fig. 1. Temporal intensity variations of the CTRL vortex and those different under uniform flows.

3.2 Upper level flow and asymmetric convergence

The upper level flow pattern shows that when a westerly uniform flow is applied, an anticyclone blocks the southern and the southwestern parts of the outflow channels. Since the upper-level flow of a TC is anticyclonic, an anticyclonic gyre will be formed subsequent to the interactions between the uniform flow and the outflow (Fig. 2), which occurs at the position where the uniform flow encounters the TC.

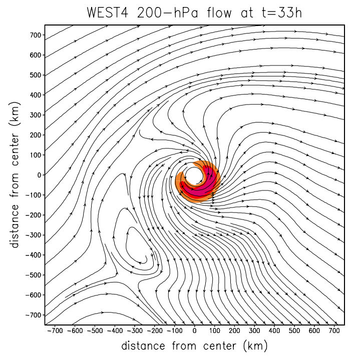

Fig. 2. 200-hPa flow patterns at t = 57 h of the vortex under a westerly uniform flow. Light and dark shadings denote isotachs > 30 m s^{-1} and >40 m s^{-1} respectively.

Consequently, the TC is not intensifying as much as the control vortex due to a stifling of the outflow channel. Kimball and Evans (2002) suggested that when TCs interact with a shallow trough (200-300

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hPa), TC intensification would be delayed and reduced due to the deformed trough preventing an outflow channel from developing on the eastern side of the TCs. The current results are therefore similar and consistent with theirs.

When a uniform flow is imposed, a structural asymmetry of the TC starts to develop. Rising motion dominates in the front part of the TC along the direction of the uniform flow (Fig. 3). In addition, stronger surface wind convergence also occurs in the front part of the TC (not shown). The vertical motion asymmetry is apparently caused by the difference in surface wind convergence between the front and rear parts of the translating vortex. It should be noted that the convergence of the CTRL case is comparably stronger than that of the westerly flow case especially in the western part of the vortex. As a whole, the low-level convergence is stronger in the CTRL case, which may explain why the intensity of the uniform flow case is weaker. Previous studies by Shapiro (1983) and Bender (1997) found that a translating vortex with a constant basic flow exhibited increased convergence in the boundary layer in front of the moving TC, which is consistent with the current result.

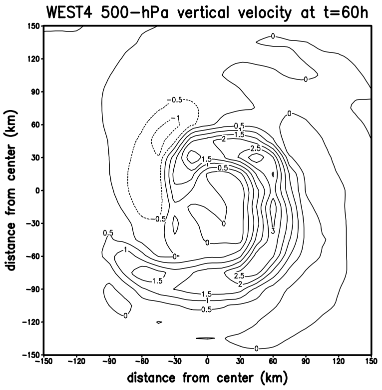

Fig. 3. 500-hPa vertical velocity (unit: m s^{-1}) of the vortex under westerly flow at t = 60 h. Contour interval: 0.5 m s^{-1}. Negative contours are dashed.

4. ANGULAR MOMENTUM FLUX

In the angular momentum flux (AMF) analysis, the 200-hPa eddy flux of the TC under a uniform flow has a larger export than the no-flow case, the difference of which is mainly negative (Fig. 4), while very little difference is observed at the lower levels. The eddy flux export contributes directly towards the total upper-level AMF export. While similar amounts of total AMF import are found at the lower levels, the vortex under the uniform flow has a larger upper-level AMF export than the control vortex, so that the net loss of total AMF is larger in the former, which is apparently responsible for the halt of intensification of the vortex.

5. DISCUSSION

Results of this study suggest that the uniform flow actually suppresses the intensification of a TC rather than weakening, and the mechanism includes the asymmetric convergence and its subsequent reduction in vertical motion in the rear part of the TC, the development of the upper-level anticyclone and the enhancement of the net angular momentum export, all of which would inhibit the TC intensification process.

If a uniform flow generates such asymmetry to the horizontal TC structure, a horizontal wind shear should enhance the asymmetry. Thus, the effect of horizontal wind shear on the TC structure and intensity changes should be examined. Furthermore, future experiments need to be performed on a beta plane since the dynamic processes on *f* and beta plane behave differently as discussed by Peng et al. (1999). They suggested that westerly flows are more favorable for TC intensification than easterly flow. Apart from the zonal flow, the effect of uniform flow in meridional directions should also be explored.

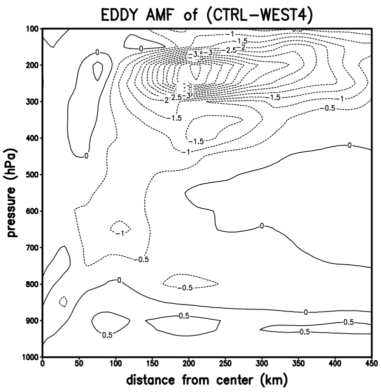

Fig. 4. Time averaged (from 33 to 72 h) eddy flux of angular momentum for the vortex under westerly flow subtracted from that of the control vortex. Unit: 10^6 m^3s^{-2}, contour interval: 0.5; negative contours dashed.

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REFERENCES

Bender, M. A., 1997: The effect of relative flow on the asymmetric structure if the interior of hurricanes. *J. Atmos. Sci.,* **54**, 703-724.

Betts, A.K. and M. J. Miller, 1986: A new convective adjustment scheme. Part II: Single column tests using GATE wave, BOMEX, ATEX and arctic air-mass data sets. *Quart. J. Roy. Meteor. Soc.,* **112,** 693-709.

Frank, W. M., and E. A. Ritchie, 2001: Effects of vertical wind shear on the intensity and structure of numerically simulated hurricanes. *Mon. Wea. Rev.,* **129,** 2249-2269.

Kimball, S. K., and J. L. Evans, 2002: Idealized numerical simulations of hurricane–trough interaction. *Mon. Wea. Rev.,* **130,** 2210–2227.

Peng, M. S., B. F. Jeng, and R. T. Williams, 1999: A numerical study on tropical cyclone intensification. Part I: Beta effect and mean flow effect. *J. Atmos. Sci.,* **56**, 1404-1423.

Shapiro, L. J. 1983: The asymmetric boundary layer flow under a translating hurricane. *J. Atmos. Sci.,* **40**, 1984-1998.