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ON THE EFFECT OF INTERNALLY GENERATED ASYMETRIC STRUCTURE ON TROPICAL CYCLONE INTENSITY

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1. INTRODUCTION

Previous theoretical studies of tropical cyclone TC) intensity have primarily focused on the maximum potential intensity (MPI) that a TC could achieve (Emanuel 1995). The statistic analysis of Atlantic TCs by DeMaria and Kaplan (1994) revealed that most storms reached only 55% of their MPI. The question arises as to what factors affect TC intensification and prevent a TC from achieving its MPI. So far several factors have been considered, including the environmental flow, vertical shear, and the negative feedback from the underlying ocean (see a review by Wang and Wu 2004). A common finding in previous studies is that the external forcing (except for the ocean feedback) generates asymmetric structure in the TC core, reducing the TC intensity. The current MPI theories have assumed axisymmetric structure of a TC. It is not clear how the asymmetric structure, which may result from external forcing or internal dynamics, affects the TC intensity. As a first step toward a further understanding, in this study, we first investigate the potential effect of the internally generated asymmetric structure on TC intensity through a comparative study between a 3D TC model and its axisymmetric version.

2. EXPERIMENT DESIGN

The triply nested moveable mesh 3-D TC model TCM3 (Wang 2001) and its axisymmetric version are used in this study. Both 3-D (CTL) and axisymmetric (SYM) models have identical model structure and model physics and are integrated from the same initial condition up to 10 days. A horizontally uniform sea surface temperature of 29^{o}C and an *f*-plane at 18^{o}N are assumed. Since our focus is on the effect of asymmetric structure generated by the internal dynamics, an environment at rest is assumed to exclude any environmental flow effect on the simulated TC.

3. RESULTS

The results show that the TC from the 3-D experiment is about 10% weak than that from the symmetric experiment (not shown), indicating that the internally generated asymmetric structure, which is dominated by vortex Rossby waves (Wang 2001, 2002), reduces TC intensity. Consistent with the results of Wang (2002), the asymmetric eddies in the inner core region of the TC in CTL play an important role in mixing the PV between the eye and the eyewall, resulting in a monotonic PV distribution decreasing outward in the mid-upper troposphere where the inertial stability is much weaker than in the lower levels (Fig. 1b), while the PV in SYM has a annular tower in the eyewall throughout the troposphere (Fig. 1a).

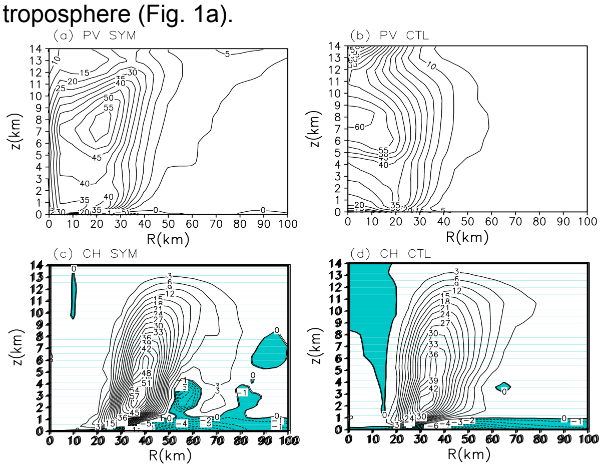

Fig.1 Composite (180-240hr mean) symmetric profile for PV (a) SYM (b) CTL, and condensational heating rate (c) SYM (d) CTL. The Unit for PV is PVU ($10^{-6} Km^2 kg^{-1} s^{-1}$) and the unit for condensational heating rate is K hr^{-1}.

The consequence of inward PV mixing in CTL by eddies is a less outward tilt of the eyewall than that in SYM, as seen from the condensational heating rate given in Figs. 1c,d. Evaporative cooling under the

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titled eyewall originating from the middle troposphere in SYM (Fig. 1c) is responsible for generating downdrafts, thus cools and dries the subcloud-layer (not shown). This increases entropy deficit between the ocean surface and the boundary layer air under the titled eyewall, and thus increasing the entropy flux at the ocean surface under the eyewall. On the contrary, this effect is less significant in CTL where the eyewall is more erect (Fig. 1d). The Emanuel's (1995) MPI theory predicts a strong dependency of the MPI upon the entropy deficit at the ocean surface under the eyewall. Our results are thus in agreement with the Emauel's MPI theory. Note that an oppose argument is that the drying and cooling due to downdrafts may reduce the buoyancy in the eyewall, weakening the eyewall convection. This effect, however, seems to be secondary for our simulated TC at the mature stage.

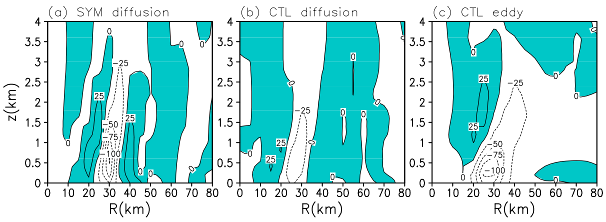

Fig. 2. The parameterized horizontal diffusion in the azimuthal mean angular momentum budget in SYM (a) and CTL (b). (c) shows the model resolved eddy diffusion of the azimuthal mean angular momentum in CTL.

In addition to the thermodynamic effect discussed above, there is a fundamental dynamical difference between the storms simulated in CTL and SYM. At the resolution of 5 km used in the model, the parameterized horizontal diffusion becomes less important in the angular momentum budget for the asymmetric vortex, while the explicit eddy diffusion term becomes dominant (Figs. 2b,c). The sum of the implicit and explicit diffusion of angular momentum in CTL is about 20% larger than implicit horizontal diffusion in SYM (Fig. 2a). Since the horizontal eddy diffusion (both parameterized and model resolved) has a tendency to reduce the angular momentum under the eyewall in the lower troposphere, larger horizontal diffusion in CTL infers stronger dissipation of angular momentum by the eddies. As a result, this dynamical effect also reduces the TC intensity in CTL.

4. CONCLUSIONS

We have shown the possible effect of internally generated inner core asymmetric structure on TC intensity. In general the asymmetric eddies reduces the TC intensity by about 10% through both dynamical and thermodynamic effects. The resolved eddies in the eyewall produces eddy diffusion to the azimuthal mean angular momentum, reducing the maximum tangential wind and thus TC intensity. The resolved eddies also play an important role in mixing the PV inward to the eye from the eyewall region, reducing the outward vertical tilt of the eyewall. This limits the drying and cooling effects under the eyewall due to downdrafts, which might otherwise increase the entropy deficit between the ocean surface and the boundary layer air under the eyewall. This thermodynamic effect also limits the TC intensity, consistent with the Emanuel's MPI theory. These findings need to be confirmed further using higher resolution, nonhydrostatic simulations since the resolved eddies would become stronger at higher resolutions.

ACKNOWLEDGMENTS: This study has been partly supported by the U. S. office of Navy research under grant N-00014-021-0532.

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