17B.1

THE EFFECTS OF THE FULL CORIOLIS FORCE ON THE STRUCTURE AND MOTION OF A TROPICAL CYCLONE PART I: EFFECTS DUE TO VERTICAL MOTION

Xudong Liang[1*], Johnny C L Chan[2] and Yihong Duan[1]
[1]*Shanghai Typhoon Institute, China*
[2]*Laboratory for Atmospheric Research, Dept. of Physics and Mat. Sci., City University of Hong Kong*

1. INTRODUCTION

A scale analysis of synoptic-scale phenomena (Holton 1992) suggests that the only significant contribution of the Coriolis force to the atmospheric flow is the Coriolis parameter f (= $2\Omega\sin\phi$, where Ω is the magnitude of the angular velocity of the earth and ϕ the latitude) multiplied by the horizontal wind vector, and only in the horizontal momentum equation. In addition to f, the full Coriolis force consists of two other terms: (1) f_w (= $2\Omega w\cos\phi$), the Coriolis force in the x-momentum equation due to the vertical motion w, and (2) w_f (= $2\Omega u\cos\phi$) the Coriolis force in the vertical momentum equation due to the zonal wind u. Holton (1992) suggested that since for synoptic-scale weather systems, w is ~ 1 cm s^{-1}, f_w ~ 10^{-6} s^{-1} and can therefore be neglected when compared with the other terms in the x-momentum equation. However, in a TC, and especially near the eyewall, w can be very large, up to 10 m s^{-1} so that f_w ~10^{-4} to 10^{-3} s^{-1}, which will then be comparable to the acceleration term and should therefore be included. In nonhydrostatic numerical models and in the real atmosphere, vertical acceleration exists, and, near the eyewall, could be as large as ~ 10^{-4} s^{-1}, which is therefore of the same order of magnitude as that of w_f. Thus, it appears that these two extra terms should be included in numerical simulations related to TC studies.

The objective of this study is to investigate the effects of one of these two terms, f_w, on the simulated structure and motion of TCs based on an analytical analysis, a barotropic and a baroclinic model.

2. BAROCLINIC SIMULATION

Two experiments are carried out using MM5, one on f plane only (control run) and the other on an f plane with the f_w term. With the inclusion of f_w, the rainfall in the eastern section of a TC is enhanced but weakened in the west (Fig. 1a). The asymmetric parts account for 20~30% of the symmetric parts. In addition, the inclusion of f_w leads to a 35 km southwestward displacement in 48 h (Fig. 1b).

3. ANALYTICAL ANALYSIS

Introduction of the term f_w leads to the following form of the shallow water equations

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv+ew=-\frac{\partial \phi}{\partial x} \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu=-\frac{\partial \phi}{\partial y} \quad (2)$$

$$\frac{\partial \phi}{\partial t}+u\frac{\partial \phi}{\partial x}+v\frac{\partial \phi}{\partial y}+\phi\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)=0 \quad (3)$$

where u, v are the wind in the x and y directions, f the Coriolis parameter and e (=$2\Omega\cos\varphi$) the parameter of the horizontal component of Coriolis force. Combining (1), (2) and (3) gives

$$\frac{d}{dt}\left(\frac{\zeta+f}{\phi}\right)=\frac{1}{\phi}\left(e\frac{\partial w}{\partial y}\right) \quad (4)$$

Equation (4) suggests that if f_w is included, the vertical potential vorticity in a barotropic atmosphere is not conserved following the motion. When $\partial w/\partial y < 0$, such as north of the northern section of the eyewall (i.e. out of the eye) and north of southern section of the eyewall (i.e. in the eye), $d/dt\,\{(\zeta + f)/\phi\} < 0$, then ζ (ϕ) will decrease (increase). The reverse situation occurs in the eye near the northern section of the eyewall and out of the eye nearthe southern section. This anomalous changes in geopotential height and vorticity would then lead to a southward displacement of TC center. Geostrophic adjustment would also produce easterly winds cross the TC center, which would lead to a westward movement. As a result, inclusion f_w will result in a southwest displacement.

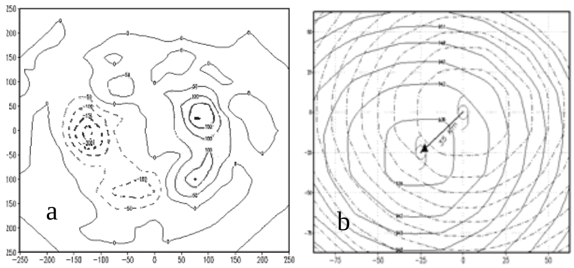

Fig. 1. Results with the inclusion of the f_w term. (a) Asymmetric precipitation (mm) after 48 h; solid (dashed) lines representing positive (negative) values. (b) Initial (solid) and 48-h (dot-dashed) sea-level pressure distribution (hPa, contour interval: 3 hPa); typhoon symbols indicate vortex center; arrow indicates 48-h displacement of the TC center. X and y axes are distances relative to initial TC center.

4. BAROTROPIC MODEL EXPERIMENTS

Two sets of experiments with a barotropic model based on (1)-(3) are described here. The rest will be presented at the conference.

[*]*Corresponding author address:* Xudong Liang, Shanghai Typhoon Institute, Shanghai, China; e-mail: liangxd@mail.typhoon.gov.cn

In the first experiment, the initial conditions consist of a symmetric vertical motion profile similar to that of a TC eyewall but without the TC vortex. Integration of the model gives a positive (negative) geopotential height anomaly to the north (south) (Fig. 2a). The relative vorticity and divergence anomaly distributions are just the opposite (Fig. 2b). These results are to be expected from the analytical analysis discussed in section 3.

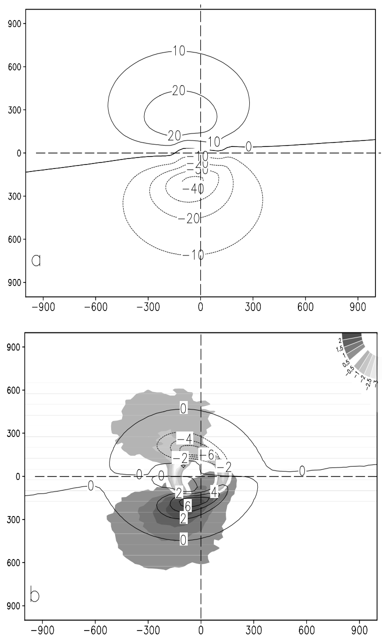

Fig. 2. Asymmetric (a) geopotential height (unit: gpm) and (b) relative vorticity (contour, unit: 10^{-5} s^{-1}) and divergence (shading, unit: 10^{-7} s^{-1}) after 48 h of integration of the barotropic model in an experiment with only a symmetric vertical motion forcing.

In the second experiment, the TC flow is included. In this case, the geopotential height and relative vorticity distributions of the vortex will dominate. Nevertheless, the asymmetric patterns can still be clearly identified. In particular, a high exists to the north to northwest (Fig. 3a) and the vortex is displaced to the southwest, as can be seen from both the geopotential height and relative vorticity distributions (Fig. 3b).

As a result of these distributions, the vertical motion also possesses an asymmetry (Fig. 4) such that stronger rising motion exists to the southeast of the vortex, which is very similar to the result from the baroclinic simulation (see Fig. 1). This asymmetry is due to the stronger convergence in the south and east of the vortex (see Fig. 3b).

5. SUMMARY AND CONCLUSION

To summarize, this study has shown that in the modeling of TCs, the other term of the Coriolis force should not be neglected, especially in the study of the structure and motion of TCs. The effects of the term f_w include:

a) a complex eye structure with a wavenumber one distribution of the anomaly fields,
b) intensified (weakened) structure in the southeastern (northwestern) section in the outer areas, and
c) a southwestward displacement.

Acknowledgments. This research is sponsored by the National Natural Science Foundation of China Grant 40275018.

Reference

Holton, J. R., 1992: *An Introduction to Dynamic Meteorology.* 3rd Edition, Academic Press, 511pp.

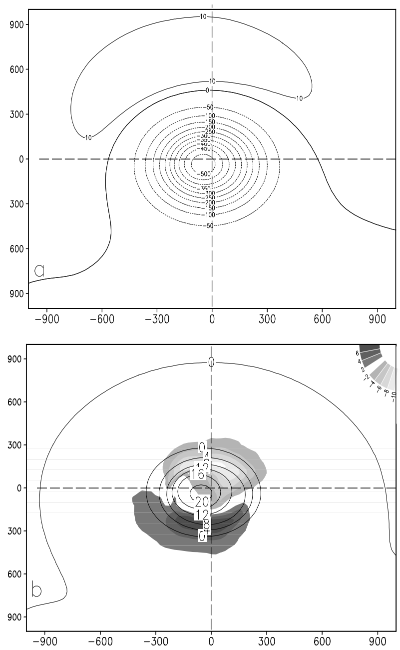

Fig. 3. As in Fig. 2 except with the inclusion of the vortex flow in the initial conditions.

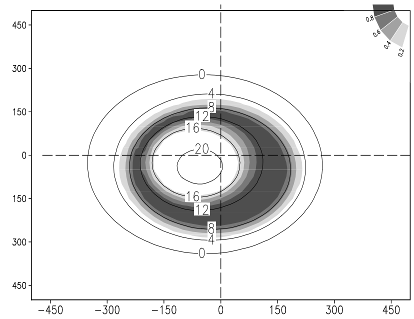

Fig. 4. Asymmetric vertical motion (unit: m s^{-1}) and relative vorticity (contour, unit: 10^{-5} s^{-1}) after 48 h of integration of the barotropic model in an experiment with the inclusion of the vortex flow in the initial conditions.