11D.6 A POSSIBLE MECHANISM OF THE FORMATION OF THE CONCENTRIC EYEWALLS: GRADIENT ADJUSTMENT PROCESS

Jia-Yi Peng* and Ben Jong-Dao Jou
Department of Atmospheric Sciences, National Taiwan University, Taipei 106

1. INTRODUCTION[1]

The concentric eyewall structure often displays in the strong tropical cyclones, such as hurricane "Gilbert" occurred in the Atlantic basin in 1988. The analyses of hurricane "Gilbert" (Black and Willoughby, 1992) showed that the primary eyewall appeared first, and then the outer eyewall formed. Later on, the outer eyewall strengthened and contracted while the inner eyewall showed sign of weakening. Finally, the outer eyewall completely replaced the inner eyewall.

Currently, two main theories have been proposed to explain the formation physics of the concentric eyewalls. The first speculates that symmetric instability plays an important role in the formation of the outer eyewall (Willoughby et al., 1984, 1988). The second theory provides simple formulae for phase and group velocities that may be used in distinguishing vortex Rossby-wave from gravity-inertia waves in observational data (Montgomery and Kallenbach, 1997). The theory also speculates a remarkable wave-mean-flow interaction during the formation of a secondary eyewall. However, the above mentioned formation mechanism could not illustrate the location of the outer eyewall. Furthermore, the formation of the symmetrically unstable in the upper tropospheric outflow layer for the former mechanism (Willoughby et al., 1984) and the wave-mean-flow interaction mechanism for the latter one (Montgomery and Kallenbach, 1997) are not revealed clearly. So it is worth to get insight into the physical process of the formation of the double eyewalls. On the contrary, it is evident that the outer eyewall formation of hurricane "Gilbert" is associated with the external forcing. Consequently, this paper will focus on the tropical cyclone's response to external source forcing with the aid of gradient adjustment theory in order to provide another possible formation mechanism of the concentric eyewalls.

2.GOVERNING EQUATIONS

The response of an axisymmetric vortex to the external cold source $Q\ (r,t)$ is discussed in this paper. By using cylindrical coordinates in the horizontal and pressure in the vertical, the axisymmetric form of the primitive equations can be written as follows:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+\omega\frac{\partial u}{\partial p}-(f+\frac{v}{r})v+\frac{\partial \phi}{\partial r}=0\text{ , (1)}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial r}+\omega\frac{\partial v}{\partial p}+(f+\frac{v}{r})u=0\text{ ,} \qquad (2)$$

$$\frac{\partial ru}{r\partial r}+\frac{\partial \omega}{\partial p}=0\text{ ,} \qquad (3)$$

$$\frac{\partial}{\partial t}\left(-\frac{\partial \phi}{\partial p}\right)+u\frac{\partial}{\partial r}\left(-\frac{\partial \phi}{\partial p}\right)-\sigma\omega=\frac{R}{C_p p}Q(r,t)\text{ ,(4)}$$

where u is the radial component of velocity, v the tangential component, ω the vertical P velocity $(\omega = dp/dt)$, ϕ the geopotential, f the constant Coriolis parameter, and σ the static stability defined by $\sigma = -\rho^{-1}(\partial \ln\theta/\partial p)$.

In order to simplify the vertical structure of this system as much as possible, we follow the geostrophic adjustment study of Paegle(1978) and Schubert et al.(1980) by considering the standard two-layer model version of (1)-(4). In addition, we restrict our attention to small perturbations about a basic state of gradient balance, i.e., $\overline{u}=\overline{\omega}=0$ and $(f+\overline{v}/r)\overline{v}=\partial\overline{\phi}/\partial r$ with $\overline{v}$ assumed to

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*Corresponding author permanent address: Jia-Yi Peng, Department of Atmospheric Sciences, Nanjing Institute of Meteorology, Nanjing 210044; e-mail: Jiaypeng@hp735.as.ntu.edu.tw be a function of r but not of p. With (1)-(3) applied at level 1 (250hPa) and level 3 (750hPa), and (4) applied at level 2 (500hPa), and requiring that $\omega = 0$ at the top (0hPa) and bottom pressure surfaces (1000hPa). (1)-(4) reduce to six equations. It is convenient to convert these equations into non-dimensional form by choosing units of time, horizontal distance and velocity as $1/f$, c/f and c. Here $c^2 = (1/2)\overline{\sigma}_2(\Delta p)^2$ is the square of the phase speed of a pure internal gravity wave. Then we get the next equation:

$$\frac{\partial^2 \hat{v}}{\partial t^2} + \left(1 + \overline{\zeta} + \frac{2\overline{v}}{r} + \overline{\zeta}\,\frac{2\overline{v}}{r} + \frac{1}{r^2}\right)\hat{v} - \frac{1}{r}\frac{\partial \hat{v}}{\partial r} - \frac{\partial^2 \hat{v}}{\partial r^2} \cdot = \int_0^t \frac{\partial Q(r,\tau)}{\partial r} d\tau \qquad (5)$$

in which $\hat{v} = \frac{v_d}{1+\overline{\zeta}}$, $\overline{\zeta} = \frac{\partial r\overline{v}}{r\partial r}$ is the basic state relative vorticity, v_d indicates the shear of wind between the upper and lower levels. Eq.(5) can be regarded as a concise mathematical description of the time- and space- variation of the perturbation $\hat{v}$ during the adjustment process of the initial balance vortex to the external forcing. Because it is hard to get the analytical solution, here we take the numerical solution by the use of time and space centred finite difference.

3.CONCLUSIONS

In the context of a linearized two-layer model, the gradient adjustment process of the initial balance vortex forced by a cold source is discussed in this paper. It turns out that owing to the forcing of the external cold source, the thickness of the vortex system become thinner with the low-level pressure ascent, which results in that the pressure force could not balance with coriolis force and centrifugal force, and then the outflow is produced. The outflow speed is intimately related with the cold source distribution with the maximum outflow located at the position of the remarkable radial variation of the cold source. As a sequel of the rotation of the earth and the vortex, the outflow will induce the tangential wind perturbations that are opposite to the basic state tangential wind, with its speed associated not only with the cold source but also the relative vorticity distribution of the initial vortex. Because the radial distribution of the perturbation of the tangential wind is heterogeneous, and when the basic state tangential wind are overlapped with the perturbations, the total tangential wind will displays two-peak tangential wind distribution analogous to that of concentric double eye-walls typhoon. Therefore, the gradient adjustment process of the initial vortex forced by a cold source may be another mechanism of the formation of the concentric eye-walls typhoon.

REFERENCES

Black, M. L. and H. E. Willoughby, 1992: The concentric eyewall cycle of hurricane Gilbert. Mon. Wea. Rev., **120**, 947-957.

Montgomery, M. T. and R. J. Kallenbach, 1997: A theory for vortex Rossby-waves and its application to spriral bands and intensity changes in hurricanes. Q. J. R. Meteorol. Soc., **123**, 435-465.

Paegle, J., 1978: The transient mass flow adjustment of heated atmospheric circulation. J. Atmos., Sci., **35**, 1678-1688.

Schubert, W. H., J. J. Hack, P. L. Silva Dias and S. R. Fulton, 1980: Geostrophic adjustment in an axisymmetric vortex. J. Atmos. Sci., **37**, 1464-1483.

Willoughby, H. E., H. L. Jin, Stephen J. Lord, and Jacqueline M. Piotrowicz, 1984: Hurricane structure and evolution on simulated by an axisymmetric nonhydrostatic numerical model. J. Atmos. Sci., **41**,1169-1185.

Willoughby, H. E., 1988: The dynamics of the tropical cyclone core. Aust. Met. Mag., **36**, 183-191