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THE EFFECTS OF ASYMMETRIC MOMENTUM ON THE GENESIS OF TROPICAL CYCLONE

Yamei Xu* and Rongsheng Wu
Department of Atmospheric Sciences, Nanjing University, Nanjing, China

1. INTRODUCTION

It has been stated that about 40% of all tropical cyclone are influenced by lower-level trade-wind surges or cross-equatorial surges during their formation stage (Lee, 2002). Although a mature tropical cyclone can be considered as a highly axisymmetric vortex, asymmetric structure is significant in its early stage of development. Low-level asymmetric flow may play an important role in triggering tropical cyclone formation (Lee, 1956; Love,1985; Briegal and Frank, 1997). This current paper attempted to study the direct role of asymmetric momentum on cyclogenesis

2. THEORETICAL ANALYSES

The tangential momentum equation in cylindrical coordinates (r,θ,z) is expressed as

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial r}+v\frac{\partial v}{r\partial\theta}+w\frac{\partial v}{\partial z}= \qquad (1)$$
$$-\frac{1}{\rho}\frac{\partial p}{r\partial\theta}-\frac{vu}{r}-fu+2\Omega\cos\varphi w\sin\theta+F_t,$$

where u and v are the radial and tangential components of horizontal wind. Define an azimuthal mean by overbar and asymmetric perturbation by ph. prime. The rate of change of symmetric tangential velocity can be rewritten as

$$\frac{\partial\bar{v}}{\partial t}=-\overline{u'\eta'}-\overline{w'\frac{\partial v'}{\partial z}}-\bar{u}\bar{\eta}-\bar{w}\frac{\partial\bar{v}}{\partial z}+\bar{F}_t. \qquad (2)$$

Eq.(1) minus (2) derives (3).

$$\frac{\partial v'}{\partial t}=\overline{u'\eta'}+\overline{w'\frac{\partial v'}{\partial z}}-u'\frac{\partial\bar{v}}{\partial r}-u\frac{\partial v'}{\partial r}$$
$$-v\frac{\partial v'}{r\partial\theta}-w'\frac{\partial\bar{v}}{\partial z}-w\frac{\partial v'}{\partial z}-\frac{1}{\rho}\frac{\partial p'}{r\partial\theta}-\frac{v'\bar{u}}{r} \qquad (3)$$
$$-\frac{vu'}{r}-\bar{f}u'-f'u+2\Omega\cos\varphi w\sin\theta+F_t',$$

where

$$\bar{\eta}=\bar{f}+\frac{1}{r}\frac{\partial(r\bar{v})}{\partial r},$$
$$\eta'=f'+\frac{1}{r}\frac{\partial(rv')}{\partial r}-\frac{\partial u'}{r\partial\theta},$$

$\bar{\eta}$ and η' are symmetric and asymmetric absolute vorticity. Although many forcings are responsible for the change of symmetric and asymmetric tangential momentum, we just focus on the first two terms on the right hand of Eq.(2) and (3) because they are exchange terms between asymmetric and tangential symmetric momentum.

The first term on the right side of Eq.(2) is the eddy flux (hereafter EF).

$$EF=-\overline{u'\eta'}$$
$$=-\overline{u'\beta r\sin\theta}-\overline{u'(\frac{v'}{r}+\frac{\partial v'}{\partial r})}. \qquad (4)$$

The second term is refereed as VF.

$$VF=-\overline{w'\frac{\partial v'}{\partial z}}$$
$$=\overline{w'\xi_r'} \qquad (5)$$

where ξ_r' denotes the radial asymmetric vorticity. Apparently, VF is its vertical flux.
u', v' and w' are rewritten as fourier series.

$$\begin{cases}u'=\sum_n U_n(r,z)\cos(n\theta+\theta_{un})\\ v'=\sum_n V_n(r,z)\cos(n\theta+\theta_{vn}),\\ w'=\sum_n W_n(r,z)\cos(n\theta+\theta_{wn})\end{cases} \qquad (6)$$

n is wave number. $U_n(r,z)$, $V_n(r,z)$ and $W_n(r,z)$ are amplitudes. θ_{un}, θ_{un} and θ_{wn} are wave phases at east, which depend on time.

One part of EF is the first term on the right hand side, β- effect of asymmetric flow, which can be expressed as following.

$$-\overline{u'\beta r\sin\theta}=-\frac{U_1}{2}\beta r\sin\theta_{u1}, \qquad (7)$$

Corresponding author address: Yamei Xu, Department of Atmospheric Science, Nanjing University, Nanjing, China;
E-mail: xuym666@yahoo.com.cn

Only wave-1 is effective and its rate of change of symmetric tangential velocity is about 10^{-2}m/s per hour.

Rather than β- effect, the second term on the right hand of Eq.(4) is more important. It can be rewritten as

$$-\overline{u'(\frac{v'}{r}+\frac{\partial v'}{\partial r})}$$
$$=-\sum_n U_n(\frac{V_n}{r}+\frac{\partial V_n}{\partial r})\frac{\cos n(\theta_{un}-\theta_{vn})}{2} \quad (8)$$

We define

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$$EF_n=-U_n(r)(\frac{V_n(r)}{r}+\frac{\partial V_n(r)}{\partial r})\frac{\cos n(\theta_{un}-\theta_{vn})}{2}$$

EF_n is the eddy flux of wave-n. Apparently, if it is positive, symmetric flows are increased and asymmetric flows weaken. Otherwise, if it is negative, symmetric flows are weakened and asymmetric flows increase. EF_n is not only associated with wave-n amplitudes, but also determined by difference between initial wave phases of radial and tangential velocity. While streamline pattern is cyclonic inflow and anticyclonic outflow, $\frac{\pi}{2n}<\theta_{un}-\theta_{vn}<\frac{3\pi}{2n}$, EF_n is positive. Otherwise, $-\frac{\pi}{2n}<\theta_{un}-\theta_{vn}<\frac{\pi}{2n}$, streamline pattern is anticyclonic inflow and cyclonic outflow, EF_n is negative. EF_n is able to trigger the formation of typhoon cyclone, especially initial axisymmetric vortex, while the patterns of θ_{un} and θ_{vn} are appropriate, as the amplitudes in Eq.(8) are significant with evidence of low-level wind surges, such as trade-wind surges and cross-equatorial surges.

The analyses of VF are omitted.

3. A CASE (BILIS 2000)

Tropical cyclone Bilis (2000), which formed in the northwest pacific after cross-equatorial surges, is studied as a case. The evolution of Bilis from a very weak tropical depression into tropical storm and typhoon is successfully simulated using PSU/NCAR nonhydrostatic, two-way interactive, nested grid mesoscale model MM5V3. The model output data are used to diagnose the effect of asymmetric momentum on the genesis of Bilis. It is found that the eddy flux (EF) play a key role in the formation of Bilis, especially the initial axisymmetric vortex, because the asymmetric streamline patterns are cyclonic inflow and anticyclonic outflow during the stage.The asymmetric variables are separate into number-n wave series using Eq.(6). It is found that number-2 wave is more significant than number-1 wave, but number-1 wave plays more important role in eddy flux.

4. CONCLUSIONS

A case study as well as theoretical analyses shows that asymmetric flows may play a key role in tropical cyclone formation, especially the initial axisymmetric vortex. Whether the asymmetric momentum is effective on the genesis of tropical cyclone depends on the asymmetric streamline pattern. When the pattern is cyclonic inflow or anticyclonic outflow, the eddy flux transform momentum from asymmetric to symmetric flow. Asymmetric momentum plays certain role in tropical cyclone formation. Otherwise, its role is negative. There is momentum transport from asymmetric to symmetric flow when the asymmetric streamline pattern is cyclonic outflow or anticyclonic inflow.

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