8C.6

INTERMITTENTLY FORCED VORTEX ROSSBY WAVES

Amaryllis Cotto and Hugh E. Willoughby *
Florida International University, Miami, Florida

Wavelike asymmetries are an intriguing aspect of Tropical Cyclone (TC) dynamics. Previous work hypothesized that some of them are Vortex Rossby Waves (VRWs) that propagate on the radial gradient of mean-flow relative vorticity (e.g., Guinn and Schubert, 1993, Montgomery and Kallenbach 1997, Montgomery and Enagonio 1998, Möller and Montgomery 1999).

MacDonald (1968) first proposed that spiral rain bands in hurricanes are Rossby waves. They rotate cyclonically within the hurricane and wrap around the vortex. Depending upon the size of the vortex itself, these bands can extend hundreds of kilometers from the eyewall (Romine and Wilhelmson 2006). They appear to propagate outward as they are advected cyclonically downwind by the axially symmetric mean flow with velocities lower than the mean tangential wind. One theory of their genesis is linked to energy released by the exchange of potential vorticity anomalies within the symmetric vortex (Guinn and Schubert 1993). Accordingly, spiral bands can be interpreted as Vortex Rossby Waves.

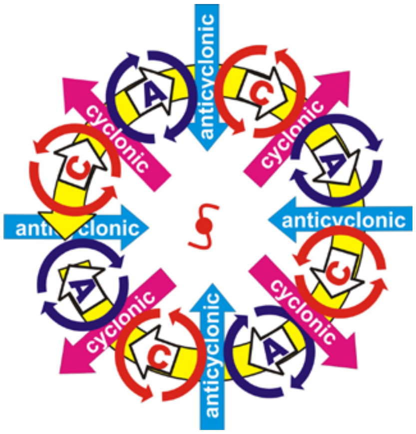

Figure 1: Simulation of Cyclonic and Anticyclonic Vortices in Tropical Cyclones.

The purpose of this research is to offer a different perspective and present a computationally and conceptually simpler formulation. The simulated VRWs resemble spiral rain bands observed in Tropical Cyclones, for example in Eastern Pacific Hurricane Olivia 1994 (Black et al. 2002).

In this theory VRWs are initiated by convection in the TC eyewall, propagate wave energy outward, and converge angular momentum inward at the locus of forcing. The VRWs thus "pump" cyclonic angular momentum into the eyewall wind maximum (Figure 1). Because of their slow tangential phase velocity and the narrow interval between the Rossby-wave cut-off frequency where the radial wavenumber is locally zero and zero frequency where it is locally infinite, their radial propagation is limited to a relatively narrow annular waveguide (Figure 2).

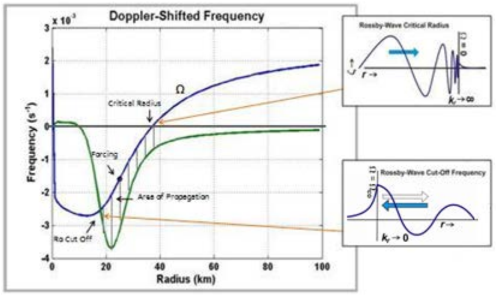

Figure 2: Wave Propagation. The left diagram displays the Doppler shifted frequencies (blue line) and the apparent frequency (green line). The forcing (black dot) is placed at *r* = 25km. The shaded area defines the waveguide where Rossby waves can propagate. The upper right diagram shows the propagation as the waves approach the Rossby wave critical radius. Here, the waves are tightly filamented and absorbed. The lower right diagram illustrates the propagation as the waves approach the Rossby Waves cut-off frequency where they are reflected.

Their wave energy is absorbed at an outer critical radius where their Doppler-shifted frequency approaches zero. Angular momentum flux divergence and vorticity convergence at the critical radius decelerate the mean flow there. The waves converge angular momentum

---

* *Corresponding author address*: Hugh E. Willoughby, Florida International Univ., Dept. of Earth and Environment, Miami, FL 33199; email: willough@fiu.edu.

from the critical radius to the locus of forcing and accelerate the mean flow there. The vorticity perturbations that accumulate near the critical radius stretch into narrow cyclonic and anticyclonic bands that become filamented as they wrap around the vortex (Figure 3). This mechanism may initiate outer wind maxima by weakening the mean swirling flow just inside the critical radius (e.g., Qiu et al. 2010).

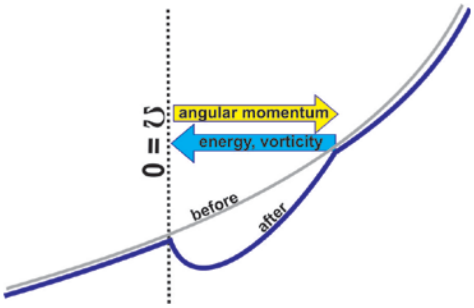

Figure 3: Wave energy and momentum transport at the zero Doppler shifted frequency.

In the present simulations, the VRWs are forced intermittently so that wave energy accumulates near the critical radius where the waves become filamented and are ultimately absorbed.

REFERENCES

Black, M.L., J.F. Gamache, F.D. Marks, Jr, C.E. Samsury, and H.E.Willoughby, 2002: Eastern–Pacific Hurricanes Jimena of 1991 and Olivia of 1994: The effects of vertical shear on structure and intensity. *Mon. Wea. Rev.*, **130**, 2291-2312.

Guinn, T.A., and W.H. Schubert, 1993: Hurricane Spiral Bands. *J. Atmos. Sci.*, **50 (20)**, 3380-3403.

MacDonald, N.J., 1968: The Evidence for the Existence of Rossby-like Waves in the Hurricane Vortex. *Tellus XX (196S)*, **1**, 138-150.

Möller, J. D., and M. T. Montgomery, 1999: Vortex Rossby waves and Hurricane Intensification in a Barotropic Model. *J. Atmos. Sci.,* **56,** 1674-1687.

Montgomery, M. T., and J. Enagonio, 1998: Tropical cyclogenesis via convectively forced vortex Rossby waves in a three-dimensional quasigeostrophic model. *J. Atmos. Sci.*, **55**, 3176-3207***.***

Montgomery, M. T., and R. J. Kallenbach, 1997: A Theory for Vortex Rossby Waves and its Application to Spiral Bands and Intensity Changes in Hurricanes. *Quart. J. Roy. Meteor. Soc.*, **123**, 435-465***.***

Romine, G.S. and R.B. Wilhelmson, 2006: Finescale Spiral Band Features within a Numerical Simulation of Hurricane Opal (1995). *American Meteor. Soc.*, **134**, 1121-1139.

Qiu, X., Z. Tan, and Q. Xiao, 2010: The Roles of Vortex Rossby Waves in Hurricane Secondary Eyewall Formation. *Mon. Wea. Rev.*, **138**, 2092–2109. DOI: 10.1175/2010MWR3161.1.