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SPIRAL RAINBAND PROPAGATION: VORTEX-ROSSBY WAVES VS. TROPICAL SQUALL LINES

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1. INTRODUCTION

Three hypotheses have been proposed to explain the propagation mechanism of spiral rainbands in tropical cyclones (TCs). Each hypothesis views spiral rainbands as either (1) gravity waves that are generated from rotating convective asymmetries in the eyewall; (2) vortex-Rossby waves (VRWs) that emanate radially outward from the eyewall along the negative potential vorticity (PV) gradient outside the radius of maximum wind; or (3) tropical squall lines where the mechanical lifting along the leading boundaries of spreading dense surface cold pools plays an important role. This study examines how spiral rainbands in a numerical simulation of Hurricane Bill (2009) propagate and makes comparison to the previous hypotheses above.

2. A NUMERICAL SIMULATION OF HURRICANE BILL (2009)

The Weather Research and Forecasting (WRF) model version 3.2.1 is used to simulate Hurricane Bill (2009) for a three-day period when it was a major hurricane. Three domains are used with the horizontal grid spacings of 9 km, 3 km, and 1 km. 60 vertical levels are used, with 19 levels below z = 2 km. The innermost 1-km domain has 624 $\times$ 624 points. Standard parameterizations schemes (WSM6 microphysics, YSU boundary layer, Goddard shortwave, RRTM longwave, 1-D ocean mixed layer) are used. Grell-Devenyi cumulus parameterization is used only in the outermost 9-km domain. GFDL initial and boundary conditions are used. This numerical simulation reproduces the observed track and intensity of Hurricane Bill (2009) remarkably well (Figure 1). 2-minute outputs are produced to examine the propagation of spiral rainbands for a 24-hour period from 18:30 UTC of Aug/19 to 18:30 UTC of Aug/20.

Figure 2 shows horizontal cross sections at z = 3.2 km of reflectivity from 09:00 to 09:20 UTC of Aug/20. During this period, there is an inner rainband that is located southeast of the storm center, and this rainband appears to propagate radially outward with time. The azimuthal wavenumber-two (n = 2) component of reflectivity appears to capture the radial outward propagation of this rainband. How this rainband propagates is now evaluated against previous hypotheses.

3. GRAVITY WAVES

If this rainband propagates like gravity waves (e.g., Kurihara 1976), then this rainband should be collocated in a consistent fashion with positive vertical velocity or pressure anomalies that are typically associated with radially outward-propagating gravity waves. Figure 3 shows that n = 2 reflectivity and n = 2 vertical velocity are not consistently collocated, indicating that this rainband does not propagate like gravity waves.

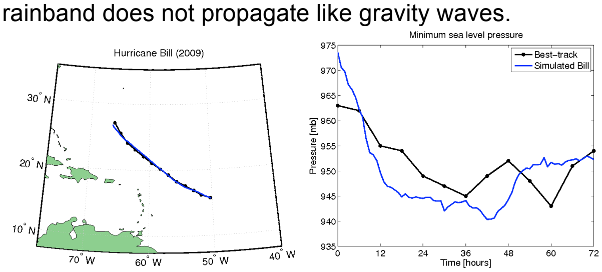

Figure 1: Time evolution of the simulated Hurricane Bill (2009) track and minimum sea level pressure in blue lines. Black lines show the best-track data.

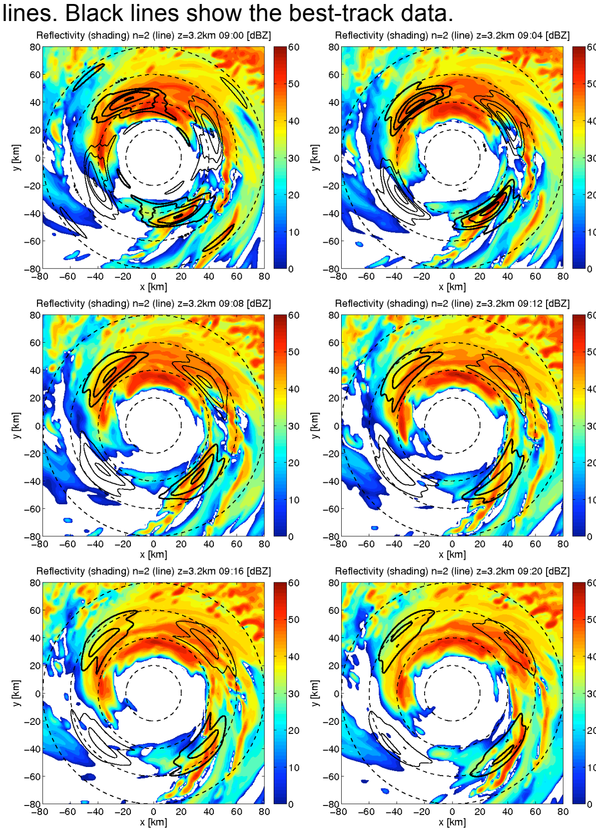

Figure 2: Horizontal cross sections at z = 3.2 km of reflectivity from 09:00 to 09:20 UTC of Aug/20 at 4-minute intervals, with the positive and negative parts of its n = 2 component overlaid as thick and thin black lines (only ± 10, 15, 20, 25 dBZ are shown). Dashed lines are concentric circles at every 20 km radius.

4. VORTEX-ROSSBY WAVES

VRWs are PV bands that propagate radially outward along the sharp negative PV gradient that typically exists just outside the eyewall of TCs (e.g., Montgomery

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and Kallenbach 1997). Chen and Yau (2001) presented evidence that spiral rainbands propagate like VRWs in a numerical simulation of TC. Corbosiero et al. (2006) presented observational evidence that spiral rainbands propagate like VRWs.

Figure 4 shows horizontal cross sections at z = 3.2 km of PV from 09:00 to 09:20 UTC. They suggest that the PV structure associated with this rainband is more like dipoles of PV, not anomalous positive PV bands. Figure 5 shows horizontal cross sections at z = 3.2 km of n = 2 reflectivity and n = 2 PV during the same time. If this rainband propagates like VRWs, then the positive parts of n = 2 reflectivity and n = 2 PV need to be collocated consistently. However, Figure 5 does not show that they are collocated. Instead, dipole structures in n = 2 PV appear to be collocated with the rainband.

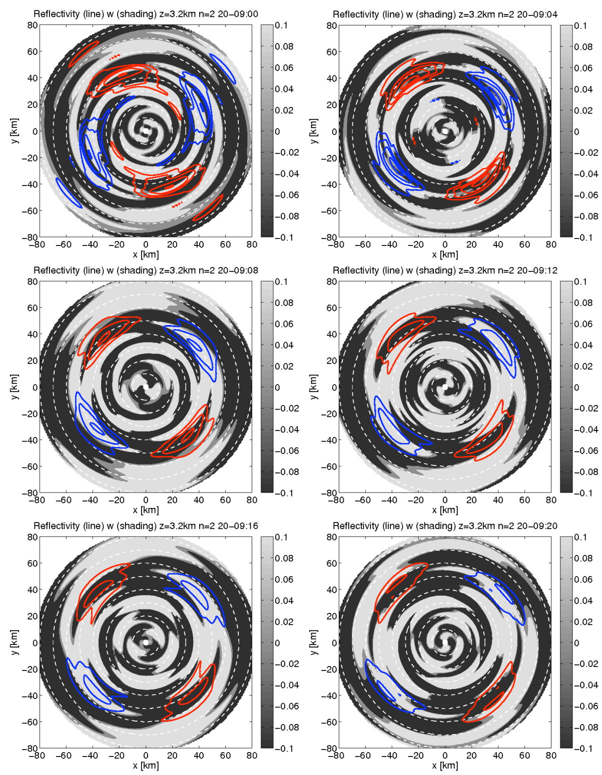

Figure 3: Horizontal cross sections at z = 3.2 km of n = 2 reflectivity in red (positive) and blue (negative) thick lines and n = 2 asymmetric vertical velocity (shaded, in m/s) from 09:00 to 09:20 UTC at 4-minute intervals. Only ± 10, 15, 20, and 25 dBZ lines are shown.

Since spiral rainbands are *trailing* features, it is difficult to determine if they propagate radially outward by examining the real part of n = 2 coefficient (i.e., taking cross sections through it, as done in Corbosiero et al. 2006) as this shows only the *apparent* propagation. Rather, the absolute part of n = 2 will show the *intrinsic* propagation of these trailing rainband features. Figure 6 shows the absolute parts at z =3.2 km of n = 2 reflectivity and n = 2 PV, and yet again they are not collocated with each other. Correlation between n = 2 reflectivity and n = 2 PV does not improve during the 24-hour period examined in this study, nor at z = 2 km or 1 km (not shown).

5. TROPICAL SQUALL LINES

Sawada and Iwasaki (2010) argued that the mechanical lifting occurring along the boundaries of spreading dense surface cold pools plays an important role in how spiral rainbands propagate. If this inner rainband propagates like tropical squall lines through the mechanical lifting mechanism, then it should be collocated with coherent surface cold pool structures. Figure 7 shows horizontal cross sections at z = 0.12 km of potential temperature from 09:00 to 09:20 UTC. Comparison with Figure 2 suggests that this rainband is collocated with a surface cold pool structure, especially after 09:12 UTC. However, the magnitude of its depression is rather very weak (~ 1 K). Horizontal cross sections of other thermodynamic variables (e.g., virtual temperature, equivalent potential temperature) suggest the same (not shown). If this rainband propagates through the mechanical lifting process, then there should be strong rising motions along the leading boundaries of this surface cold pool structure. Figure 8 shows horizontal cross sections at z = 0.65 km of vertical velocity during the same time period. They show that the rainband is collocated with multiple dipoles of positive and negative vertical velocity, instead of rising motion along the leading edges of the surface cold pool structure. It appears unlikely that this rainband propagates through the mechanical lifting mechanism.

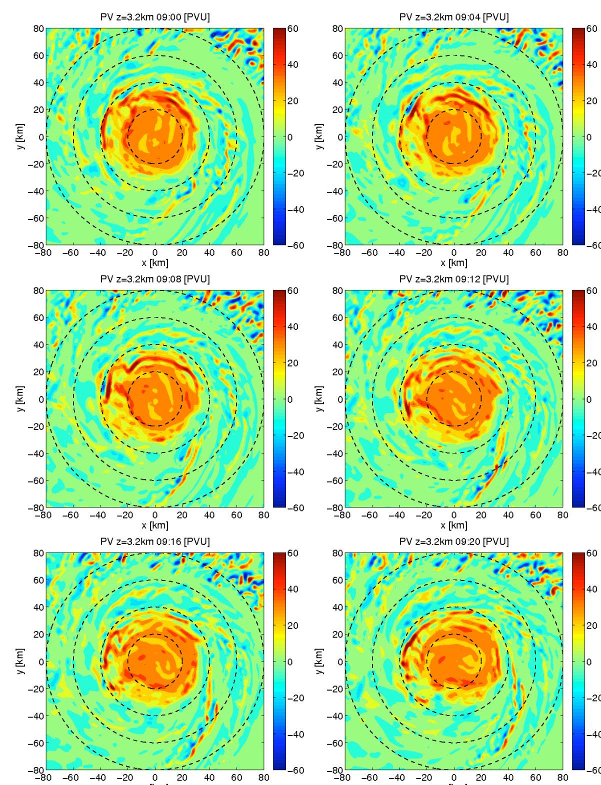

Figure 4: Horizontal cross sections at z = 3.2 km of PV from 09:00 to 09:20 UTC at 4-minute intervals.

6. SUMMARY

The propagation of an inner rainband that is located just outside the eyewall of a numerically simulated Hurricane Bill (2009) is examined by making comparison to previous hypotheses. Results show that the propagation mechanism of this rainband is not consistent with that of gravity waves, vortex-Rossby waves, or tropical squall lines. Preliminary results suggest that the advection by the mean flow and downdrafts generated aloft (z > 6 km) by melting of frozen condensates (e.g., cloud ice) and subsequent evaporative cooling could play an important role in the propagation of this rainband.

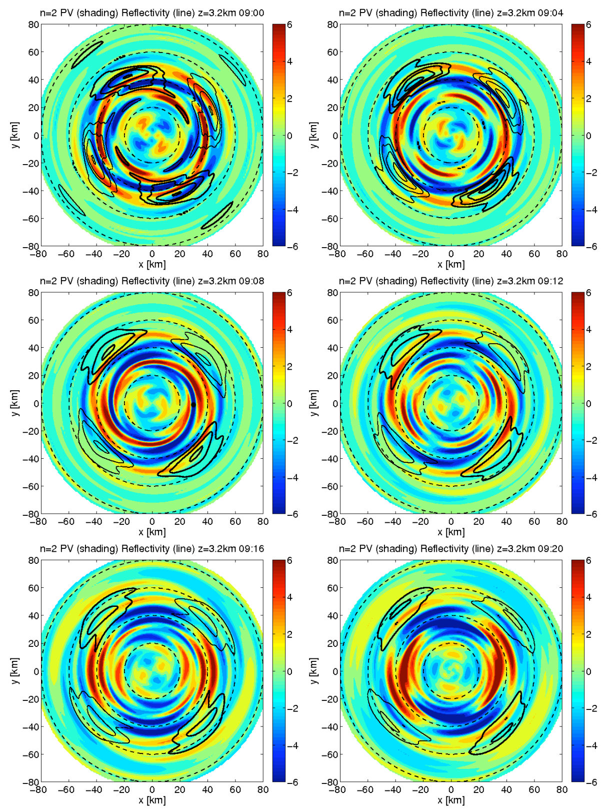

Figure 5: Horizontal cross sections at z = 3.2 km of n = 2 PV in color from 09:00 to 09:20 UTC at 4-minute intervals. The positive and negative parts of n = 2 reflectivity are overlaid as thick and thin solid black lines (only ± 10, 15, 20, 25 dBZ lines are shown).

ACKNOWLEDGEMENT

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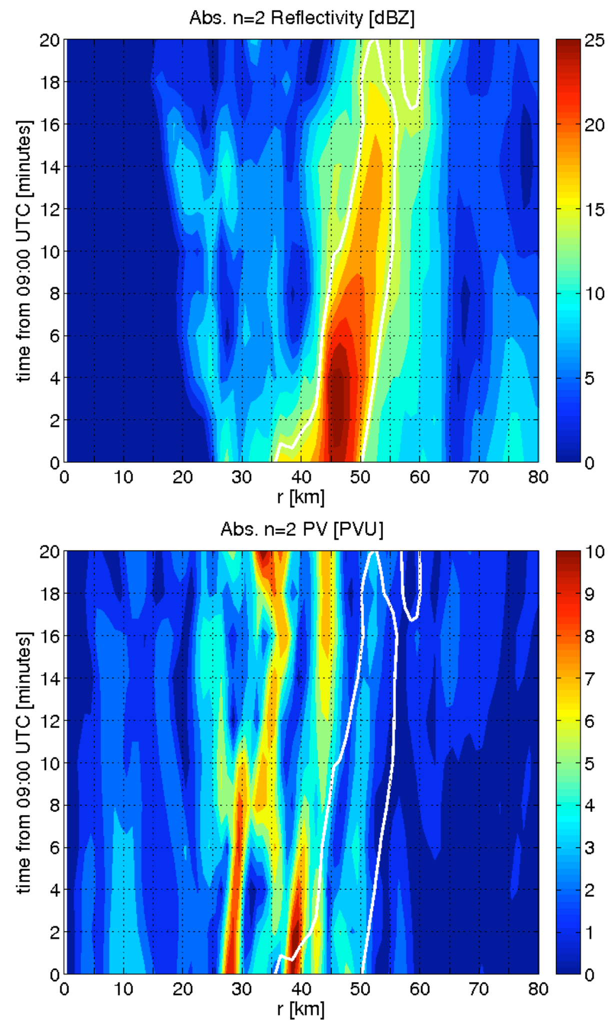

Figure 6: Absolute parts at z = 3.2 km of the n = 2 Fourier decomposition coefficients of (top) reflectivity and (bottom) PV from 09:00 to 09:20 UTC. White line is for 15 dBZ line of the absolute part of the n = 2 reflectivity.

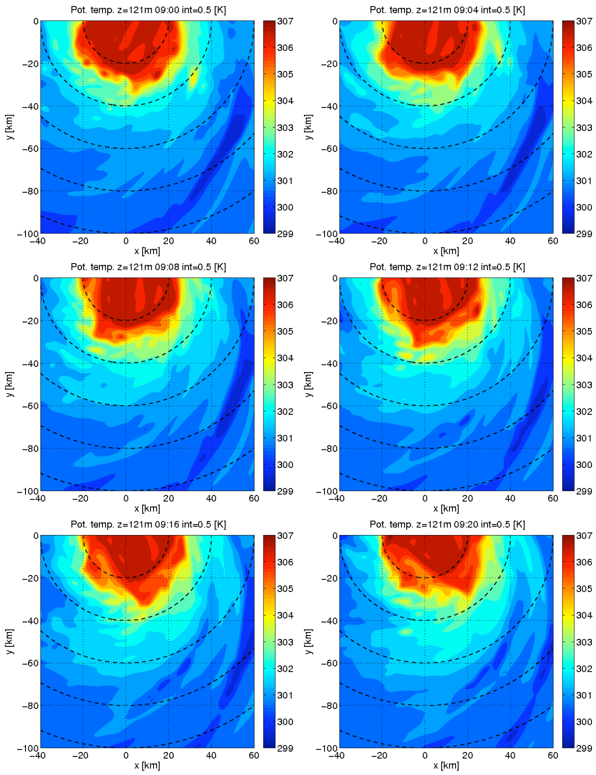

Figure 7: Horizontal cross sections at z = 0.12 km of potential temperature from 09:00 to 09:20 UTC of Aug/20 at 4-minute intervals.

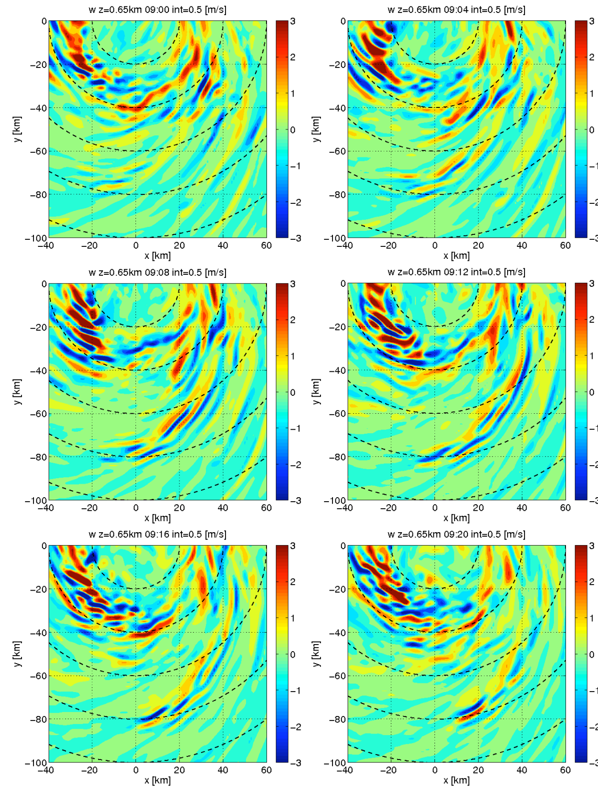

Figure 8: Horizontal cross sections at z = 0.65 km of vertical velocity from 09:00 to 09:20 UTC of Aug/20 at 4-minute intervals.