HIGH RESOLUTION DUAL-DOPPLER OBSERVATIONS OF TROPICAL CYCLONE VORTEX ROSSBY WAVES

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1. INTRODUCTION

- Tropical cyclone (TC) vortex Rossby waves (VRWs) are a topic of debate in the literature. Their existence has been hypothesized via numerical modeling (e.g. Montgomery and Kallenbach 1997; hereafter MK97), but some disagree, suggesting axisymmetrizing waves are actually inertia-gravity waves. VRWs are thought to propagate on the radial gradient of storm vorticity, similar to planetary Rossby waves. They are likely initiated by deep convection within the eyewall.
- Utilizing Shared Mobile Research and Teaching Radar (SMART-R; Biggerstaff et al. 2005) data, we examine the inner core environments of Hurricane Isabel (2003) and Hurricane Irene (2011) via dual-Doppler analysis (DDA).
- Two previous observational studies have been conducted at low spatial and temporal resolution. However, SMART-R deployments have provided the means to examine TC VRWs (see Figure 1) in high temporal and spatial resolution.
- The kinematic structure of TC inner core rainbands (hereafter rainbands) is shown to follow the theory of MK97, suggesting VRW activity as an axisymmetrizing mechanism of tropical cyclone eyewalls. VRWs are also shown to produce deep convection, implying VRWs may be responsible for a majority of the rainfall within the inner core of tropical cyclones.

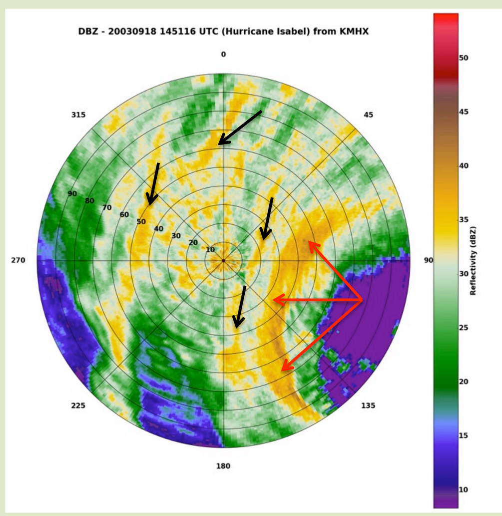


Fig. 1. Plan position indicator (PPI) taken by the WSR-88D in Morehead City, NC (KMHX) during Hurricane Isabel. Range rings are every 10 km and with reflectivity shown (dBZ). Black arrows point to possible VRW activity, seen here as rainbands emanating from the hurricane eyewall (red arrows).

2. METHODS

- SMART-R data from two landfalling hurricanes are examined via DDA utilizing a three-dimensional variational data assimilation technique, shown to be superior to techniques explicitly integrating the continuity equation (e.g. Potvin et al. 2012).
- The spatial and temporal resolution of the analyses to be presented are displayed in the table below. Dual-Doppler pairs are shown in Figure 2.

Hurricane	Interpolation Method	Wind Retrieval Method	Time of Analyses	Time Resolution
Isabel (September 2003)	Natural Neighbor (Δx = 1 km)	3DVAR Dual-Doppler Analysis	1442 – 1456 UTC	2 – 3 min.
Irene (August 2011)	Natural Neighbor (Δx = 500 m)	3DVAR Dual-Doppler Analysis	0936 – 1046 UTC	10 min.

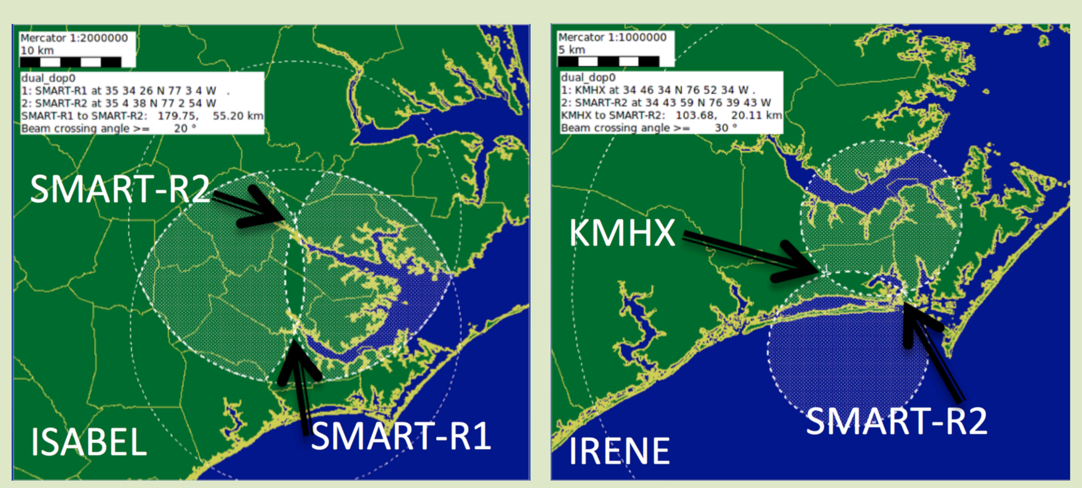
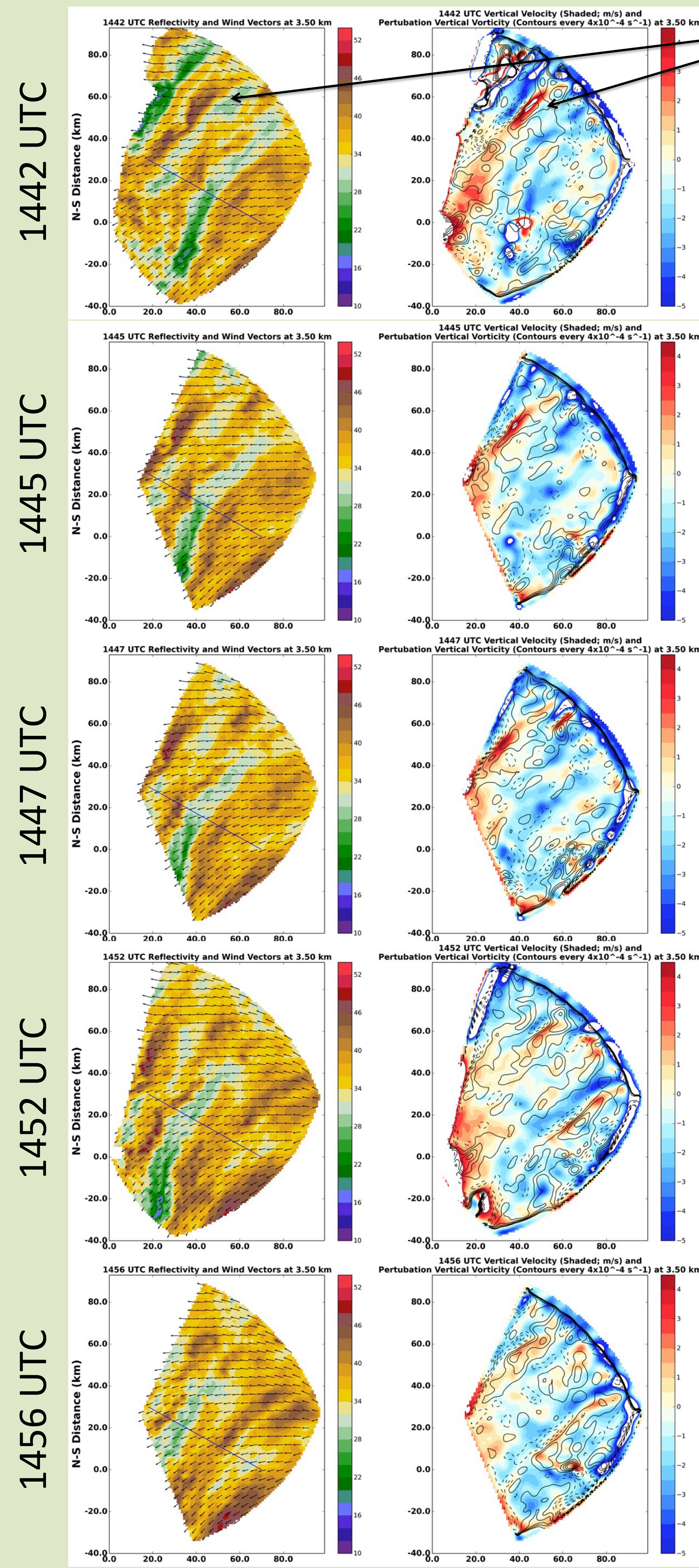


Fig. 2. Dual-Doppler lobes (30° cross-beam angle; white shading) shown for each SMART-R deployment to Isabel (a) and Irene (b). SMART-R2 is used as the origin in Isabel and KMHX in Irene. Radar positions are shown via the black arrows.

3. RESULTS



- Identifiable rainband structures in reflectivity are clearly aligned with elongated vertical vorticity maxima. Rising motion appears to lead the vorticity maxima by a quarter wavelength, consistent with the theory of MK97 and numerical modeling of Wang (2002a; 2002b).
- Examining the vertical structure of a VRW seen at 1452 UTC from Hurricane Isabel, there is a clear increase in reflectivity near 20 km range associated with an updraft (w_{max} = 3 m s^{-1}) extending 8 km above radar level. Slightly lagging the updraft, a positive vertical vorticity perturbation maximum is seen below 6 km. Near the leading (right) edge of the vorticity maximum, the strongest divergence is seen, suggesting the deep vorticity maximum is responsible for inducing the deep convective updraft.
- Hurricane Irene (Figure 4; analyses are preliminary) displays the horizontal distribution of rainfall. Near leading convective bands (VRWs), radar reflectivity is 35-45 dBZ, whereas reflectivity is below 30 dBZ elsewhere. It appears that VRWs contribute disproportionate amounts of rainfall to the inner core region of tropical cyclones. The kinematic structure of a VRW in Isabel displays a WN1 asymmetry in vertical velocity, suggesting the VRW to be the forcing mechanism for deep-convective updrafts in TC inner cores in the absence of buoyancy.
- Finally, using the results shown here an azimuthally averaged vertical vorticity was calculated to examine the radial propagation of these vorticity maxima. Utilizing the theory of MK97, the radial propagation of these wave structures approximately satisfies the dispersion relation for VRWs (Figure 5).

1452 UTC Vertical Cross Section

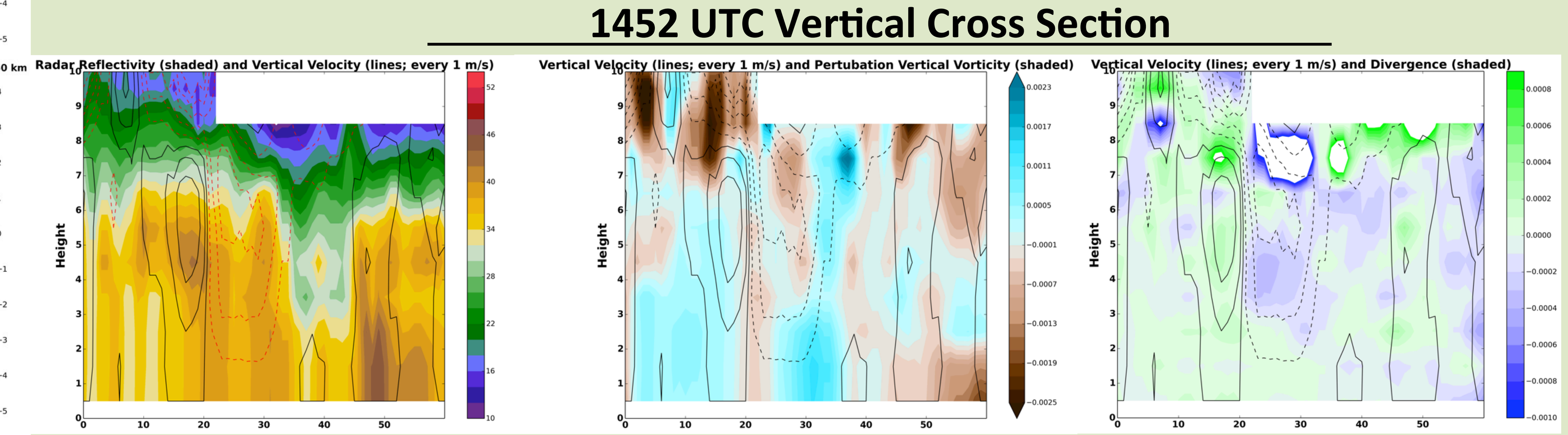
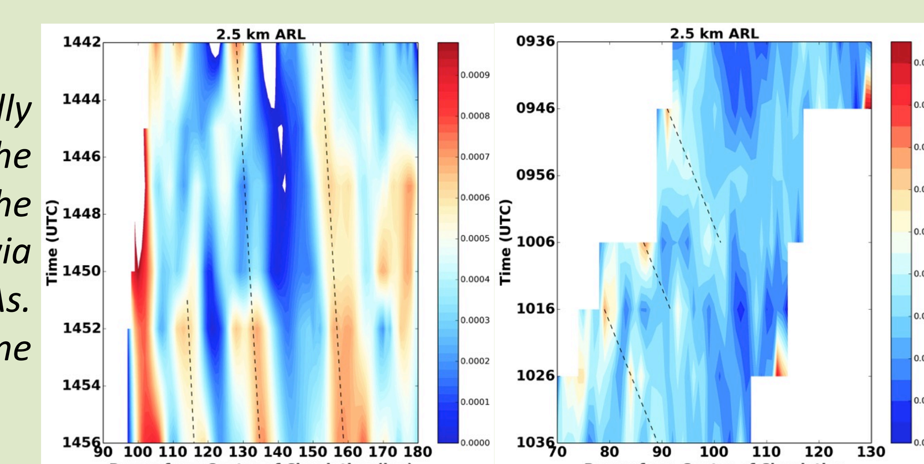


Fig. 3. DDAs during Hurricane Isabel. The left column displays radar reflectivity with overlaid wind vectors. The blue line displays the line through which a vertical cross section was taken (1452 UTC vertical cross section shown). The right column shows vertical velocity (every 0.5 m s^{-1}; shaded) and perturbation vertical vorticity (every 4x10^{-4} s^{-1} starting at ±2x10^{-4} s^{-1}; zero line is omitted). The vertical cross section plots display vertical velocity in each plot (every 1 m s^{-1}; 0 m s^{-1} is the first dashed contour line; positive velocities are solid contours). The filled contours represent radar reflectivity (left plot), perturbation vertical vorticity (middle plot), and total divergence (right plot).

Fig. 5. Hovmoller diagram of azimuthally averaged vertical vorticity (shaded). The dashed lines in the plots represent the theoretical radial phase speed, calculated via MK97 using observations from the DDAs. Hurricane Isabel is the left plot and Hurricane Irene is the right plot.



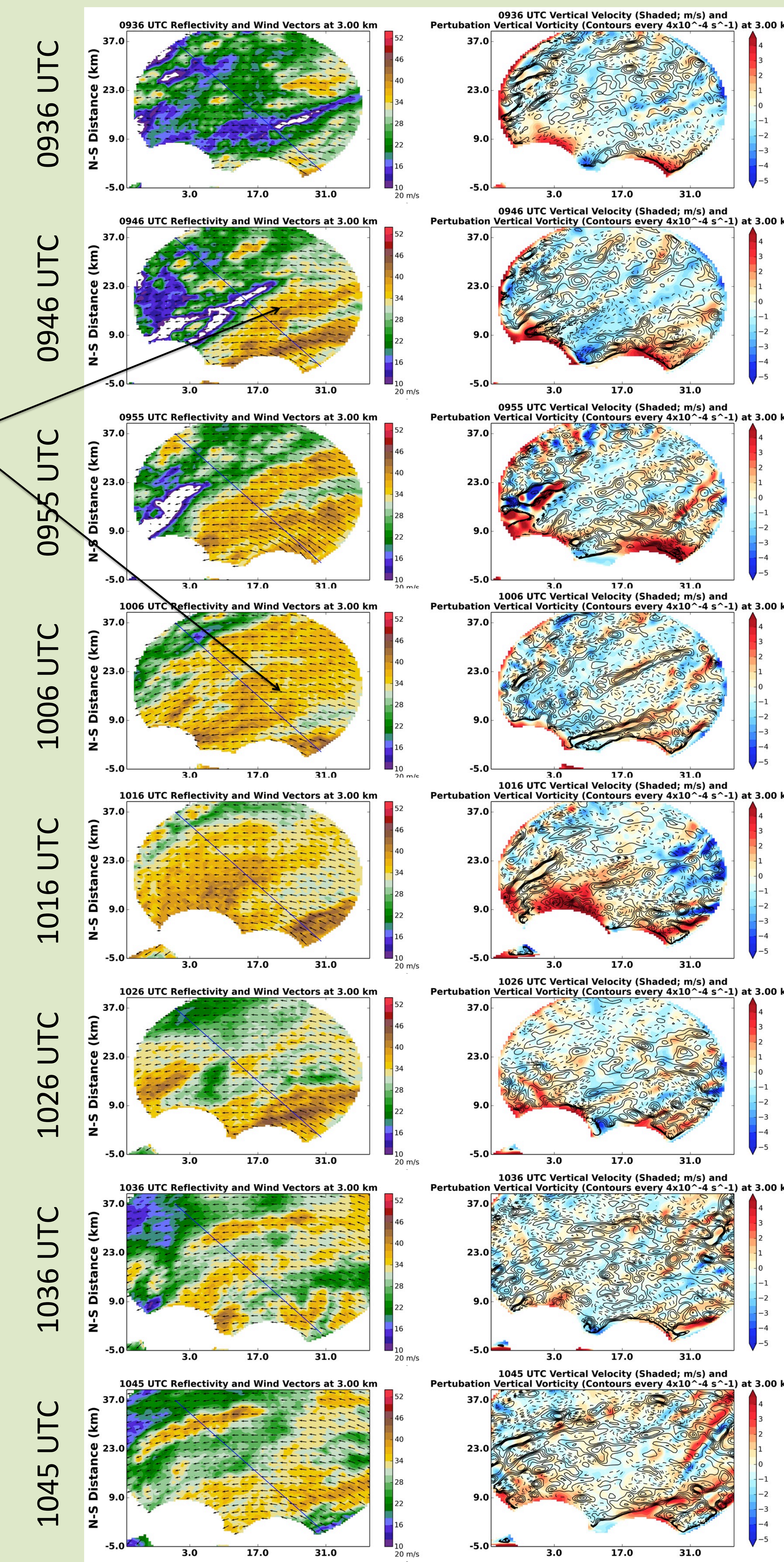


Fig. 4. As in Fig. 3, but for Hurricane Irene. No vertical cross section is displayed.

4. CONCLUSIONS

- The wave structures seen in the inner core of TCs are VRWs, rather than an inertia-gravity wave.
- Consistent with theoretical work, the kinematics of observed VRWs are similar to model VRWs.
- High temporal and spatial resolution observations from the SMART-Rs show that VRWs likely induce inner core spiral rainbands via dynamic processes, rather than that of buoyancy.
- Initial results from Hurricane Irene display VRW-induced rainbands account for a majority of rainfall within the inner core. More work will be needed to conclude this definitively.
- Future work will be focused on quantitatively examining the role VRWs play in the inner core rainfall distribution and assessing VRWs in other SMART-R datasets.

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