New Insight into Secondary Hurricane Eyewall Development from Airborne and Ground Radar

Most intense hurricanes go through at least one eyewall replacement cycle, where an outer, secondary eyewall forms, contracts, and replaces the inner, main eyewall. During these cycles, the overall hurricane intensity and location of peak winds can change dramatically with weakening followed by periods of strengthening. Operational forecasts of these intensity/structure changes are difficult and fraught with errors. In addition, the scientific understanding of the storm metamorphosis, especially during the development of the secondary eyewall, is not fully understood. While several modeling papers have examined this development process, observationally based studies are much more limited.

Radar remote sensing measurements from ground and airborne systems collected in Hurricane Matthew (2016) during the NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) field experiment provided an opportunity to study the secondary eyewall development process. The measurements revealed the presence of ~12–15-km wavelength spiral bands breaking from the inner core eyewall in the down shear-right quadrant of the storm with propagation in the radius and azimuthal directions. The vorticity characteristics and calculations of the intrinsic phase speeds of the bands were shown to be consistent with sheared vortex Rossby waves (VRWs).

The detailed structure of the VRWs were analyzed with three-dimensional (3D) wind retrievals from the NASA High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRP) on the unmanned Global Hawk aircraft. The 3D wind retrievals were computed on a grid with 1-km horizontal and 250-m vertical spacing and validated well with collocated dropsonde profiles. The HIWRAP observations revealed the convectively coupled nature of the VRWs with positive covariances in radial and vertical velocity and often tangential winds.

Flight-level and HIWRAP winds showed the development of tangential wind maxima in the outer core of the storm and the HIWRAP data was used to understand the dynamics of this secondary eyewall formation process. A new angular momen-

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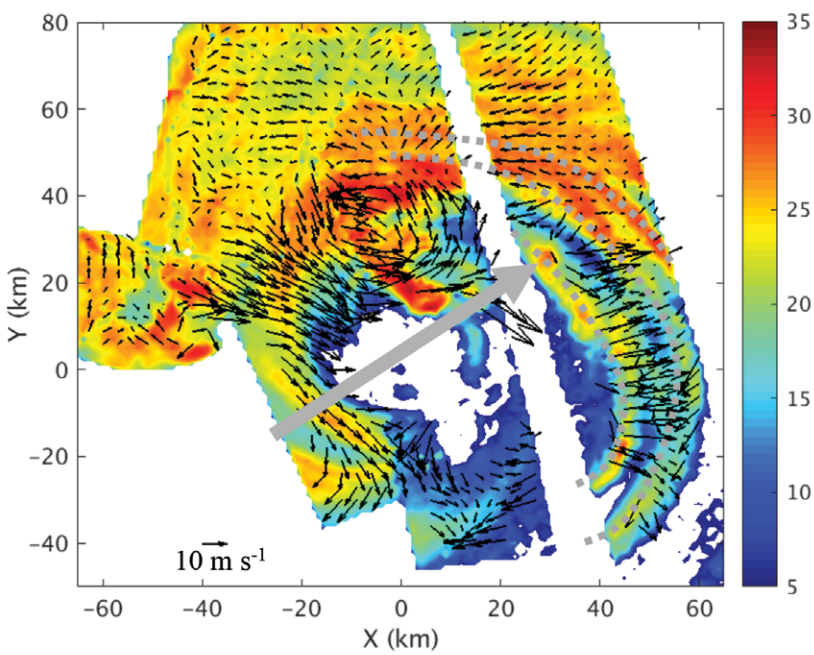

The Inner-Core of Hurricane Matthew. A composite of HIWRAP data in Hurricane Matthew for two overpasses (center crossings at 1811 UTC and 1900 UTC 7 October 2016) averaged between 1–1.5 km height. The shading shows Ku-band radar reflectivity (dBZ) and the arrows denote perturbation wind vectors (m s^{-1}) after removing the azimuthal mean flow. The large gray arrow represents the vertical wind shear vector. Spiral bands of reflectivity breaking from the main eyewall in the down shear-right quadrant with radial wavelengths of ~12–15-km are highlighted with dashed gray lines. The perturbation wind vectors show strong radial outflow of ~20 m s^{-1} where the bands are breaking from the main eyewall along with a closed mesovortex circulation positioned at the eye-eyewall interface in the down shear-left quadrant.

tum budget methodology was designed that allows an understanding of the storm physics, including the interaction of scales, with narrow swath radar measurements.

Overall, the results indicated that the convectively-coupled VRWs are leading to a direct spin-up of the outer core tangential wind field through the projection of wave kinematics, especially the vertical flux of angular momentum, onto the low-wavenumber fields. This is the first observational study to quantify the role of VRWs in the secondary eyewall development process. Future research should analyze the coupling of the boundary layer, including contributions from symmetric and asymmetric dynamics, to the VRW mechanism identified in this paper to develop a more comprehensive understanding of the secondary eyewall formation process. —Stephen R. Guimond (University of Maryland Baltimore County [UMBC] and NASA Goddard Space Flight Center), P. D. Reasor, G. M. Heymsfield and M. McLinden, "The Dynamics of vortex Rossby waves and secondary eyewall development in Hurricane Matthew (2016): New Insights from Radar Measurements," in the July issue of the *Journal of the Atmospheric Sciences*.

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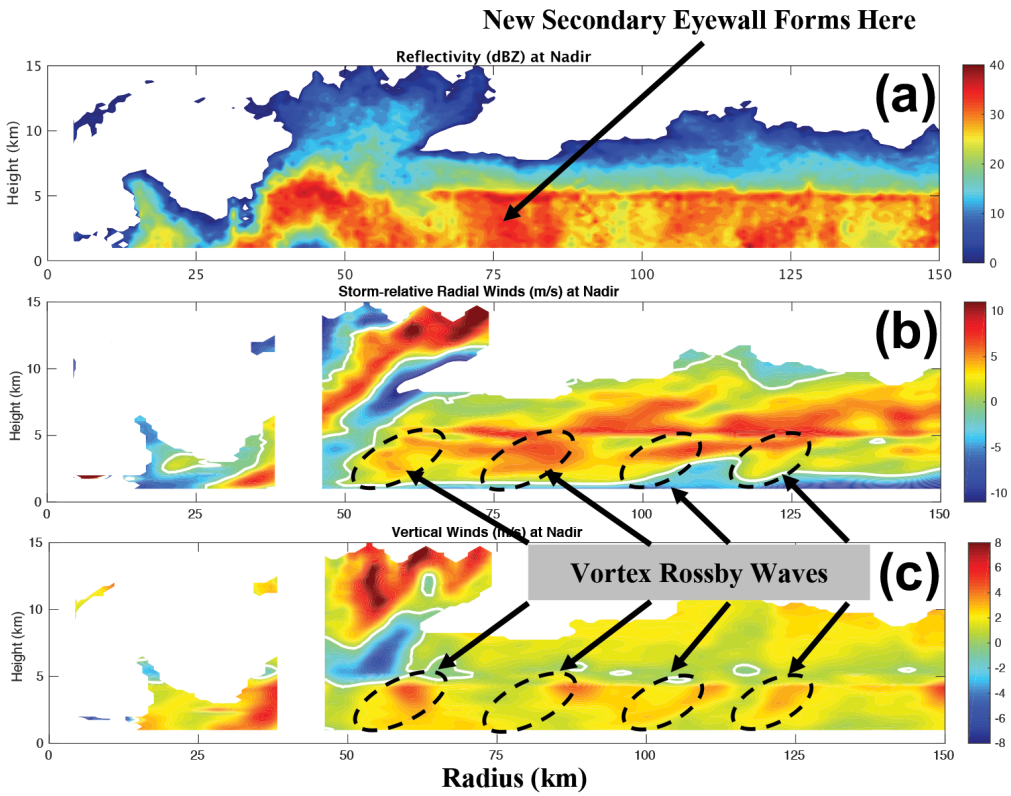

The Vertical Structure of Vortex Rossby Waves (VRWs). HIWRAP Ku-band nadir vertical cross sections of Hurricane Matthew between 1306–1345 UTC 7 October 2016. The panels show (a) reflectivity (dBZ), (b) storm-relative radial winds (m s^{-1}) and (c) vertical winds (m s^{-1}). In panel (a), a remnant eyewall from an earlier eyewall replacement cycle can be seen at a radius of ~20-km, the main eyewall is observed at a radius of ~45-km and the formation of a new secondary eyewall at a radius of ~75-km is denoted with an arrow. In panels (b) and (c), perturbation radial and vertical winds, respectively, associated with the VRWs are highlighted by dashed ovals.