Theory and Computation of Wavenumber-2 Vortex Rossby Wave Instabilities in Hurricane-like Vortices

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The appearance of polygonal eyewalls in hurricanes is thought to be caused by quasi-two-dimensional Vortex Rossby Waves (VRWs) that live on the radial vorticity gradients of the hurricane. VRWs have been studied theoretically and numerically using both discrete and continuous models. The discontinuous, barotropic, three-region vortex model analyzed by *Schubert et al.* [1], successfully elucidates the archetypal behavior of two phase-locked, counter-propagating VRWs that live on the inner and outer vorticity gradients of the eyewall and grow exponentially in time. Despite the success of *Schubert et al.*, this analytic theory is considered to be unsatisfactory [2] because it does not predict a wavenumber-2 instability when the hurricane vorticity is non-negative and compact. Yet wavenumber-2 instabilities are prominently observed in experimental, observational and numerical studies of hurricanes [2] with compact positive vorticity.

We present computational results—and supporting analytic theory—for a class of three-dimensional, baroclinic, wavenumber-2 exponential instabilities that live on hurricane-like vortices with compact, non-negative potential vorticity. For a set of base-vortex states with vorticity profiles that range from linear to Gaussian in the inner-eye region, this new class of VRW instability exhibits the following fundamental features.

- These wavenumber-2 instabilities are hydrostatic, baroclinic, and three-dimensional, and exist for Froude numbers greater than ≈ 4.
- The instability is generated by two counter-rotating VRWs. The hurricane angular momentum at the inner location, r_1, of the inner VRW is about 75% of that at the outer location, r_2. We find r_1 in the range 0.1–0.6 and r_2 in 1.3–1.8, where all distances are normalized by the location of maximum hurricane wind.
- The oscillation frequency of the VRWs is $\approx 35\%$ of the maximum hurricane vorticity; maximum growth rates are near the Coriolis frequency.
- These instabilities are associated with vertical convection in the hurricane eyewall and the generation of azimuthal rolls, reminiscent of symmetric instability, in the inner and outer eyewall. Vertical vorticity stretching plays an essential role.

We compare these results with a three-dimensional extension of the *Schubert et al.* three-region vortex model that predicts exponential wavenumber-2 instability and highlights the salient features of these VRWs. Implications for hurricane intensification are discussed.