Conversion from Shear to Curvature Vorticity, Organization of Convection, and Hurricane Genesis

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Introduction

The objective of this study is to provide a solution to the hurricane intensity issue as it pertains to tropical cyclone genesis. The motivation for this work is found in past studies that have indicated the importance of barotropic processes in the evolution of AEWs (Krishnamurti, 1986; Norquist, 1977). These waves serve as seedlings for many tropical cyclones and play a crucial role in influencing hurricane activity in the Atlantic Ocean (Thorncroft and Hodges, 2001). The following study uses shear and curvature vorticity in the framework of barotropic dynamics to predict the development of tropical cyclones from African Easterly Waves (AEWs).

Shear to Curvature Vorticity Exchanges and the Organization of Convection

The derivation of the curvature and shear vorticity tendency equations in natural coordinates is found in Bell and Keyser (1993). The equations for curvature and shear vorticity as derived from the frictionless, horizontal momentum equations in isobaric coordinates are as follows:

$$\frac{d}{dt}(f+V\frac{\partial\alpha}{\partial s})=-\frac{\partial V}{\partial s}\frac{d\alpha}{dt}-\frac{\partial}{\partial n}(\frac{\partial\phi}{\partial s})-(f+V\frac{\partial\alpha}{\partial s})\nabla_p\bullet\vec{V}-\vec{V}\frac{\partial\omega}{\partial s}\frac{\partial\alpha}{\partial p}$$

$$\frac{d}{dt}(-\frac{\partial V}{\partial n})=\frac{\partial V}{\partial s}\frac{d\alpha}{dt}+\frac{\partial}{\partial n}(\frac{\partial\phi}{\partial s})-(-\frac{\partial V}{\partial n})\nabla_p\bullet\vec{V}-\vec{V}\frac{\partial\omega}{\partial n}\frac{\partial V}{\partial p}$$

The first two terms on the right hand side are the conversion terms which can be represented as an expression for shear to curvature exchanges:

$$<S\cdot C>=-\frac{\partial V}{\partial s}\frac{d\alpha}{dt}-\frac{\partial}{\partial n}(\frac{\partial\phi}{\partial s})$$

where positive values represent a transfer from shear to curvature vorticity.

In this study, it is hypothesized that dynamics, specifically barotropic dynamics, is critical to the genesis of tropical cyclones. In a barotropic system, absolute vorticity is materially conserved. Any changes in the vorticity budget are due to transfers among curvature, shear, and planetary vorticity. A weak AEW is associated with relatively high magnitudes of shear vorticity in comparison to curvature and planetary vorticity. Assuming purely westward motion, increasing curvature vorticity associated with the development of a tropical cyclone is due to shear vorticity being converted into curvature vorticity via horizontal shear instabilities. As shear goes into curvature, the radius of flows will decrease causing convection to concentrate around the center of circulation. Once enough convection has amassed around the center of the storm, baroclinic based convective processes will begin to dominate.

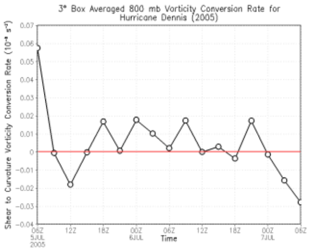

Figure 1: Average shear to curvature conversion per grid point over a 3^0 by 3^0 box centered over the storm. Positive values represent shear being converted into curvature.

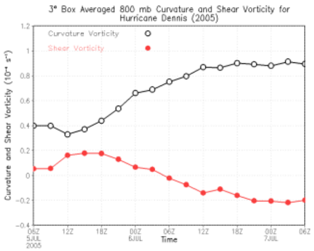

Figure 2: Average curvature vorticity and shear vorticity per grid point calculated over a 3^0 by 3^0 box centered over the storm.

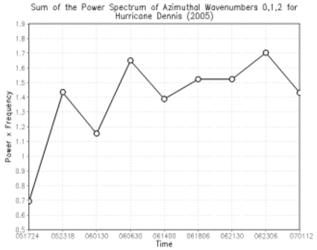

Figure 3: Sum of the power spectrum of azimuthal wavenumbers 0, 1, and 2 at a radius of 100 km from the center of the storm. The first two numbers for the x-axis label are the day and the last four numbers are the time.

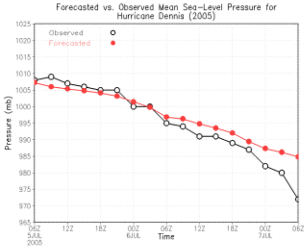

Figure 4: Mean sea-level pressure for forecasted and observed storms for Hurricane Dennis (2005).

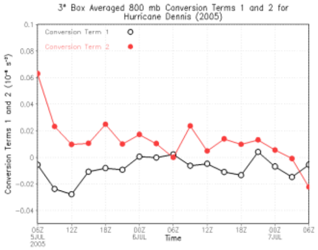

Figure 5: Average values for the two conversion terms per grid point over a 3^0 by 3^0 box centered over the storm.

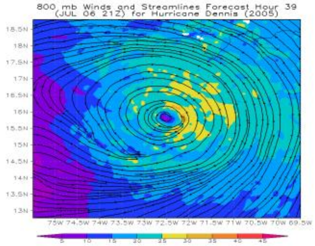

Figure 6: Winds and streamlines for Hurricane Dennis during hour 39 of the forecast. Winds are in m/s.

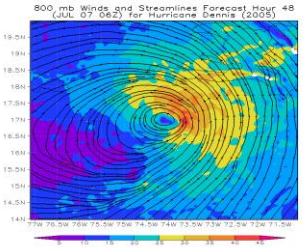

Figure 7: Same as figure 6 but 9 hours later. Notice the asymmetry that has developed in the wind field over 9 hours.

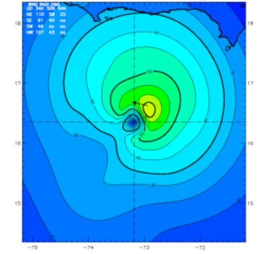

Figure 8: H*Wind Analysis for Hurricane Dennis at 0130Z on July 07, 2005. Notice the similarities to the forecasted wind structure in the previous figure.

Methodology

Hurricane Dennis (2005) is the only case that has been examined up to this point. Organization of convection is estimated by computing the power spectrum of the azimuthal wavenumber structure of cloud liquid water (Wentz, 1997). The power spectrum is computed by taking the Fourier Transform of satellite derived cloud liquid water at radii of 25, 50, 75, 100, and 125 km from the center of the storm.

The data necessary to calculate shear to curvature vorticity exchanges is obtained from a simulation involving the MM5. The innermost domain was run for a period of 48 hours at a resolution of 3 km.

Results

Shear vorticity is converted into curvature vorticity at the beginning of the forecast leading to an increase in curvature vorticity and a decrease in shear vorticity. The second conversion term is the more dominant term of the two for the majority of the forecast. Power spectrum data indicates that an organization of convection is occurring at radii between 75 and 125 km as evidenced by an increase in the magnitude of the wavenumbers on the hurricane scales (0, 1, 2). The simulated storm begins to steadily intensify only after positive transfers begin to take place. The curvature to shear exchanges that occur during the last 6 hours of the forecast are the result of asymmetries that develop in the wind field. These changes in the wind structure due to the intensification of the storm are a negative feedback that causes the cessation of shear to curvature vorticity conversions. H*Wind data corroborates the existence of a similar asymmetry at this time.

Conclusions

The results from this case study support the hypothesis that shear to curvature vorticity exchanges are an important kinematic factor in cyclogenesis and lead to an organization of convection. Parameters derived from the forecast strongly indicate that vorticity conversions play a key role in wave development. The correlation of observational data with the forecast is not merely coincidental as storm structure and organization are what would be expected. Future work will consist of conducting more case studies and isolating the primary dynamics of shear to curvature conversions.

Acknowledgements

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