The Distribution of Helicity and Intense Convection in Tropical Cyclones

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Hurricane Gordon
1720 UTC 9/12
Motivation

- Fall 2001 Morris Weisman convection class project examining CAPE and shear in two highly sheared, but intensifying, convectively active CAMEX4 TCs.

- Hendricks et al. (2004) called buoyant updrafts possessing strong vertical vorticity “vortical hot towers” (VHTs) and linked their axisymmetrization and preconditioning of the environment to the development of nascent TCs.
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Houze et al. (2009)
Motivation

- Molinari & Vollaro (2008, 2010) found significant azimuthal asymmetries in CAPE and helicity in strongly sheared (> 10 m s$^{-1}$) CAMEX TCs.

- They hypothesized that the 30% larger CAPE and double the helicity found in strongly sheared storms lessen the negative impacts of shear on the vortex, but they were lacking inner core (< 75 km) dropsondes and three-dimensional, mesoscale data to fully explore their hypothesis.
Data & Methodology

• NCAR Advanced Hurricane WRF (AHWRF) model initialized from the GFDL model with three, two-way moveable nests at 12, 4 and 1.33 km resolution

• Kain-Fritsch cumulus parameterization (12 km grid only), WSM3 (5) microphysics, YSU planetary boundary layer scheme, drag (Donelan) and surface enthalpy coefficients (Carlson-Boland) for TCs

• Examine fields of most unstable CAPE (MUCAPE), calculated over the 300 hPa layer closest to the ground using virtual temperature, and storm relative helicity:

\[ SRH = \int_0^h \left[ (\mathbf{\nabla} \mathbf{V} - \mathbf{c}) \cdot \left( \hat{k} \times \frac{\partial \mathbf{V}}{\partial z} \right) \right] dz \]

with \( h=6 \) km and cell motion (\( \mathbf{c} \)) estimated following Ramsay and Doswell (2005).
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Katrina rapidly intensified in an environment of weak vertical wind shear and will be compared with the strongly sheared Hurricane Gordon.
The same cannot be said for Hurricane Gordon…
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While the direction of the AHWRF vertical wind shear was consistent with the SHIPS model, the AHWRF shear magnitude was consistently 6-7 m s\(^{-1}\) greater than the true value.

Gordon will thus be considered a strong shear case for study.
Gordon: Precipitable Water and 850 hPa Positive Vorticity

- Shear rotated, 3 hour snapshots out to a radius of 50 km from the center.

- The precipitable water and vorticity are highly variable, but exhibit distinct right of shear and downshear maxima with convective bursts both co-located with, and upstream of, eyewall vorticity maxima.

Figures are plotted from 18 UTC 13 September through 21 UTC 14 September (left to right and top to bottom)
Gordon: 850 hPa Positive Vorticity and Vertical Velocity

- Positive vorticity and upward vertical motion exhibit a clear wavenumber 1 asymmetry maximized to the right of the shear vector.

- Periods of increased symmetry correspond to relative peaks in intensity.

- Evidence for both VHTs and eyewall mesovorticies exist.
Gordon: Storm Relative Helicity and Precipitable Water

- Consistent with Molinari and Vollaro (2008, 2010) helicity values are an order of magnitude larger than in mid-latitude thunderstorms.

- PW and SRH maxima are located to the right of the shear vector.

- Convective cells never propagate into the left of shear semicircle and the simulated storm does not attain a symmetric structure.
Gordon: MUCAPE and Storm Relative Helicity

- **Large CAPE** values are found to the left of shear and upshear of the center outside of the eyewall.

- Modest CAPE values pool into discrete centers in the eye and appear to fuel the strong updrafts right of the shear vector via eye-eyewall mixing associated with mesovorticies.
**Katrina: Precipitable Water and 850 hPa Positive Vorticity**

- Initial right of shear and downshear asymmetries in precipitable water and vorticity are quickly replaced by **large wavenumber 3-5 eyewall mesovorticies** with radially outward and upstream PW maxima.

- The mesovorticies propagate completely around the eyewall, consistent with the weak shear, leading to a more symmetric inner core.

*Figures are plotted from 18 UTC 27 August through 21 UTC 28 August (left to right and top to bottom).*
Katrina: Storm Relative Helicity and Precipitable Water

- A distinct right of shear asymmetry in helicity persists throughout the simulation.
- Extreme values of helicity are found within eyewall convective cells downshear and right of the center.
Katrina: MUCAPE and Storm Relative Helicity

- Very large values of CAPE are found in a 15 km wide ring located along the eye-eyewall interface.

- Distinct cyclonic wave breaking features appear along the interface, mixing high CAPE outward, temporarily reducing the eye CAPE, and fueling strong eyewall convection associated with the mesovorticies.
Summary & Future Work

• Simulated values of CAPE and helicity within the inner 50 km of Hurricanes Gordon and Katrina are consistent with the observational results of Molinari and Vollaro (2008, 2010).

• Evidence of both vortical hot towers and eyewall mesovorticies exist in AHWRF high resolution, real data case simulations.

• Calculate radial profiles of MUCAPE and helicity in each shear rotated quadrant

• Examine a large number of storms embedded in a wide variety of shear environments with a consistent modeling framework, i.e. HFIP storms