Evaluation of Shear-relative Hurricane Structure from the 2012 HWRF Baseline Model

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April 24th, 2013
Background

Zhang and Tao (2013, JAS) found that with increased vertical wind shear comes increased uncertainty in the intensity forecast.

Reasor et al. (2013, MWR) recently documented the shear-relative structure of hurricanes using airborne Doppler-radar composites from NOAA P-3 flights into 18 storms.

As an initial step towards understanding the HWRF model’s challenges in predicting sheared hurricane intensity, a shear-relative analysis of structure, similar to that in Reasor et al., is performed using the 2012 Baseline model.
Methodology

Following Reasor et al. (2013):

- Map storm-relative winds to a cylindrical coord. system centered on the low-level vortex (here, HWRF surface pressure centroid)
- Normalize radial coord. by the 2-km symmetric RMW
- Rotate fields such that the large-scale 850-200-hPa shear vector points due east
- Construct shear-relative structure composites

Focus here only on the domain represented by the radar analyses
Database of Cases

HWRF (6-hourly sampling)  Radar-based
Environment and Vortex Properties

HWRF database

- $S_{850-200} =$ SHIPS deep-layer shear
- SST = Sea surface temperature
- $U_s =$ Storm motion
- $V_{\text{max}} =$ Peak 10-m wind
- $V_{2km} =$ Max. 2-km symm. tang. wind
- $\text{RMW}_{2km} =$ Radius of $V_{2km}$

Radar database

- More low SST cases in HWRF database (higher latitude)
- HWRF-simulated hurricanes have larger eyewalls $\Rightarrow$ Does this enhance resilience?
On average, the HWRF-simulated hurricanes have less (normalized) vorticity at 1.5-3 RMW, but a larger radial gradient of vorticity → Net impact on resilience?
2-7-km Vortex Core Displacement

- Downshear to downshear-left preference for hurricane core tilt
- HWRF database reveals a higher frequency of core tilt values > 5 km

Is this difference an artifact of a bias in the radar database sample?
2-7-km Vortex Core Displacement (Composite)

Note:
- On average, HWRF-simulated hurricane tilts more to the left of large-scale shear
- HWRF-simulated local 2-9-km shear (120-km radius with vortex “removed”) more closely aligns with the large-scale shear
Maximum Convective Area Location

Number of cases in which the peak convective area (defined by the region with 5-km Inner (outer) band $W > 2-2.5$ (1-1.5) ms$^{-1}$) falls within a given octant or quadrant.

Inner band: $0.8 < r^* < 1.2$    Outer band: $1.5 < r^* < 2.5$
Wind, Divergence, and Vorticity (Composite)

HWRF database

- Windspeed (ms⁻¹) + pert. vectors
- div. (±1x10⁻⁴ s⁻¹, contour)
- pert. vort. (10⁻⁴ s⁻¹)

Radar database

- Windspeed (ms⁻¹) + pert. vectors
- div. (±1x10⁻⁴ s⁻¹, contour)
- pert. vort. (10⁻⁴ s⁻¹)
Vertical Velocity and $\theta_e$/dBZ (Composite)

HWRF database
5-km W (contour) and $\theta_e$ (K, shaded)

Radar database
5-km W (contour) and 2-km Refl. (dBZ, shaded)

W contours: 0 (ms$^{-1}$, dashed); 0.5, 1, 1.5, 2 (ms$^{-1}$, solid)
Vertical and Radial Velocity and $\theta_e$/dBZ (Quadrant-Mean Composite)

HWRF database
Vertical wind (-.25,0,.25,.5,1,1.5,2 ms$^{-1}$, black)
radial wind (±1,2,4,6,8,10,15,20 ms$^{-1}$ gray)
$\theta_e$ (K, shaded)

Radar database
Vertical wind (-.25,0,.25,.5,1,1.5,2 ms$^{-1}$, black)
radial wind (±1,2,3,4,5,... ms$^{-1}$, gray)
Refl. (dBZ, shaded)

DSL = Downshear-left  USL = Upshear-left  USR = Upshear-right  DSR = Downshear-right
Summary

Relative to the radar-based study of Reasor et al. (2013), the composite analysis of shear-relative hurricane structure from the 2012 HWRF baseline model reveals:

- Lower (normalized) vorticity outside the RMW, but a greater radial gradient of vorticity there
- Greater tilt of the core, on average, but still a preference for a downshear-left orientation
- Composite eyewall ascent that is more sloped than from observations
- A core-region kinematic asymmetry that is broadly consistent with observations. The pattern of core-region descent and the low-level flow/thermo. structure require further investigation.
Future Work

Include a greater number of storm cases to increase the diversity of the sample.

Extend HWRF diagnostic analyses to a larger domain, and focus more on processes involved in shear-induced intensity change (e.g., transport of low-$\theta_e$ air into HBL).

Recommendations:

1) Test existing and future configurations of the HWRF model within this shear-relative diagnostic framework to ensure consistency with observations.

2) Use the extended HWRF diagnostic analyses to guide future sampling of observed sheared hurricanes.