Improved Understanding and Diagnosis of Tropical Cyclone Structure and Structure Changes

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Project Goals

TC Location: Multiple spectral bands and lightning information will be used to improve and automate TC center location estimation. This will be done using Red-Green-Blue (RGB) image combinations along with lightning overlays; accounting for satellite view angles and parallax.

TC Size: With the goal of producing a uniform record of TC size, we propose that an objective technique using IR imagery to estimate azimuthally-averaged tangential winds at a fixed radius.

RMW and TC Wind Structure: To better understand the climatological variations of radius of maximum wind (RMW), we propose to redevelop previous relationships developed from extended best track RMW estimates using aircraft-based eye diameter estimates. These climatologies may be extended with satellite-based RMW estimate methods. Additionally we propose to use these climatologies to revise existing IR-based methods and develop new tools that utilize lightning information to better diagnose RMW. The motion-induced TC wind asymmetry at flight-levels will also be reexamined using larger and more systematic satellite, flight-level, and surface wind speed datasets.

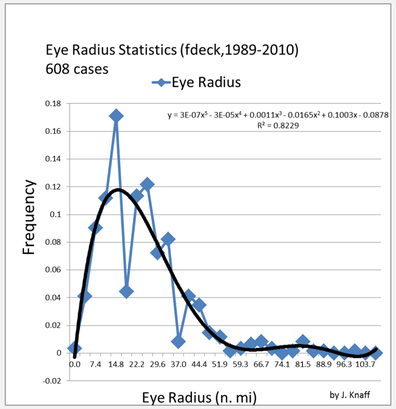
Variations of TC Structure: We also seek to elucidate how TC structure evolves subject to varying parameters characterizing the environment (e.g. moisture, vertical shear) and other aspects of the TC's structure. Two distinct topics will be investigated using numerical weather prediction models: 1) latent heating structure (rainbands, hot towers, etc.) and its role in TC intensification, and 2) the purported influences of dry environmental air on TC size found in NWP simulations. The latter topic will also be investigated using the NESDIS blended total perceptible water (TPW) to infer moisture influences on TC size.

Statistical-Dynamical Models (optional YEAR 3): We envision the development and testing of a statistical-dynamical model that can forecast changes in TC structure (RMW, Radii or 34, 50, and 64 kt winds) and MSLP in the third year of this project.

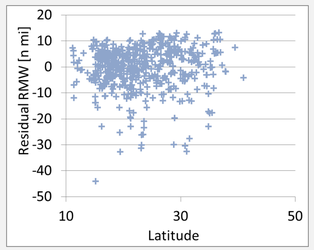
Achieved Accomplishments

RMW Climatologies:

Thus far work has concentrated on aircraft-based observations. We find that the often used extended best track RMW estimates are in error; tending to be too large and strongly dependent on intensity. We find that the eye radius and thus the radius of maximum wind is best related to latitudinal variations and is only weakly related to intensity. RMW sizes also tend to be rather small and confined largely to a small range of values with 57 % of eye radii falling below 25 nautical miles as shown below.



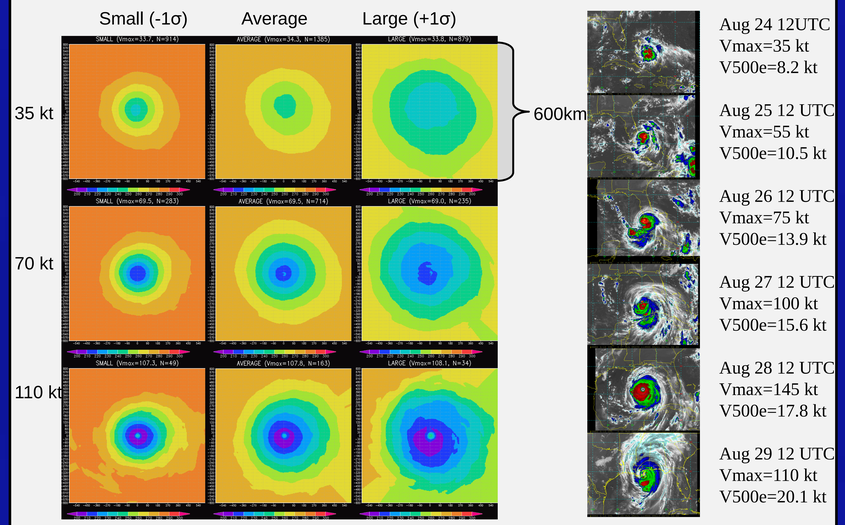
From these data a simple climatological relationship can be developed where $RMW[n\ mi] \cong e^{(1.777+0.0261\varphi+0.00282v)}$, where φ is latitude and v is the maximum sustained winds. The residual plot as a function of latitude is shown below



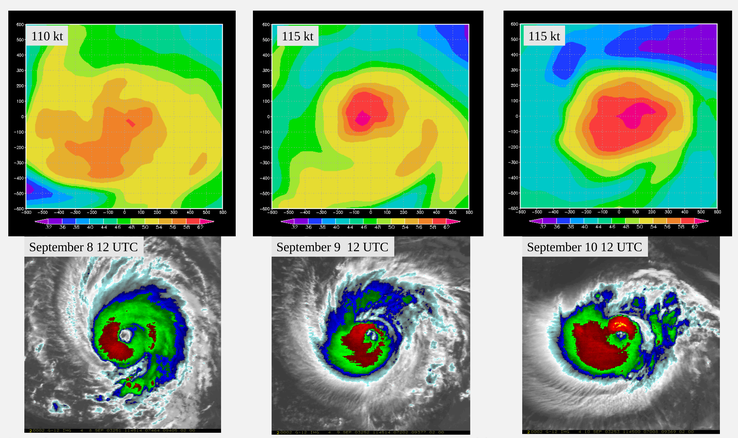
Satellite-based, Objective Tropical Cyclone Size Estimates:

This year we have developed an objective method to estimate tropical cyclone size (i.e., the areal extent of the cyclonic circulation). For the development of the technique TC size was assumed to be well related to the azimuthally averaged tangential wind at 500 km (V500) radius following Merrill (1984) and Weatherford and Gray (1988), which is the predictor. This quantity is also easily estimated by global model analyses. Storm-centered infrared imagery was simplified by azimuthally averaging brightness temperatures and then calculating the empirical orthogonal functions and estimating the principle components.

The objective tropical cyclone size estimates are a function of latitude, intensity, intensity squared and the first three 1-dimentional IR principle components. Composites based on this objective technique are shown below for three intensity ranges and three size categories. An example of images and IR-based size estimates (V500e) of Hurricane Katrina are also shown.



Tropical Cyclone-Relative Total Precipitable Water (TPW) Database:

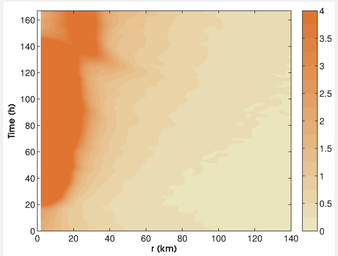


Caption: *Total precipitable water images (Top) and infrared images (Bottom) of Hurricane Isabel (2003) on September 8, 9, and 10. Isabel had just completed rapid intensification on the 8th and was in the process of an eyewall replacement cycle on the 9th and 10th. Following this time Isabel rapidly intensified to 145 kt. TPW imagery is being created for all Atlantic and East pacific Cases (1995-2011) to study relationships between TPW and TC structure changes.*

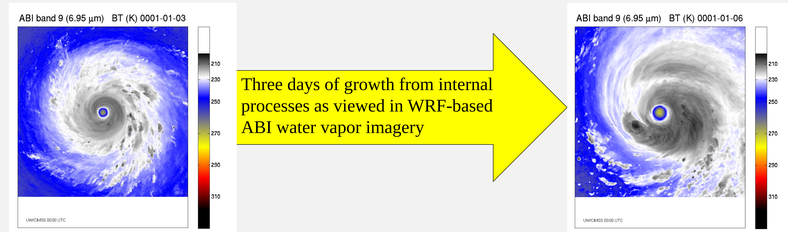
Modeling Structure Change with the Weather Research and Forecast (WRF) Model:

WRF Model Configuration/Set-up:

- β-plane (at 20°N), motionless background flow, and homogeneous thermodynamic environment
- 3 nested grids:
  - 10800 x 10800 (Δx = 9 km)
  - 1620 x 1620 (Δx = 3 km)
  - 1000 x 1000 (Δx = 1 km)
  - 35 vertical levels with 0.6-km spacing near the surface
- No cumulus parameterization, WSM6 microphysics, no radiation, YSU PBL
- Axisymmetric vortex initialization



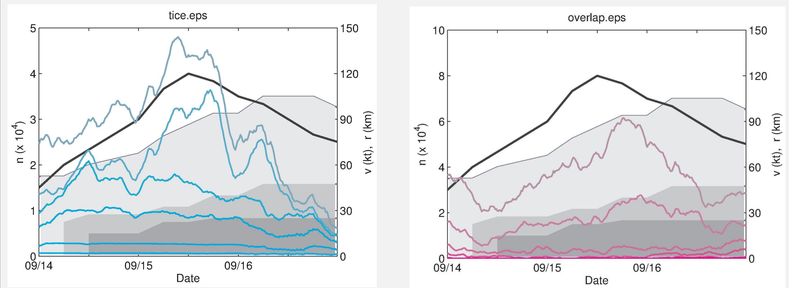
Caption: *Azimuthally average inertial stability (1 x 10^{-3} s^{-1}) as a function of time in a constant environment. Shows that TC growth can be due entirely to internal processes (rainband activity, eyewall cycling etc..) that act over time.*



Modeling Accomplishments and Findings Thus far:

- The model dataset confirms diabatic heating associated with rainband activity converges angular momentum outside of the TC inner core and leads to the growth and strengthening of the wind field there.
- As the wind field expands outward, intense low-level frictional inflow and boundary layer Ekman pumping expand outward as well.
- Subsequent rainband activity and attendant diabatic heating becomes increasingly efficient at increasing the outer wind field as the TC grows.
- These results, and the relationship between secondary eyewall formation and storm growth mechanisms, are reported upon in Rozoff et al. (2012; *J. Atmos. Sci.*, in press)

A Case study of Hurricane Julia (2010) shows the potential importance of the outer rainband activity.



Caption: *Julia's (2010) intensity (kt) (black) (from best track data), the radius (km) of 34-kt (light gray shading), 50-kt (medium gray), and 64-kt (dark gray shading) winds (from ATCF data), along with (a) the number of MSG-SEVIRI-based thick ice pixels within 50, 100, 200, 300, 500, and 1000 km of center (bright to dull blue), and (b) the number of MSG-SEVIRI-based overlap cloud type pixels within 50, 100, 200, 300, 500, and 1000 km of center (bright to dull magenta).*