Outer Vortex Wind Structure Changes during and following Tropical Cyclone Secondary Eyewall Formation in the Atlantic

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Outline

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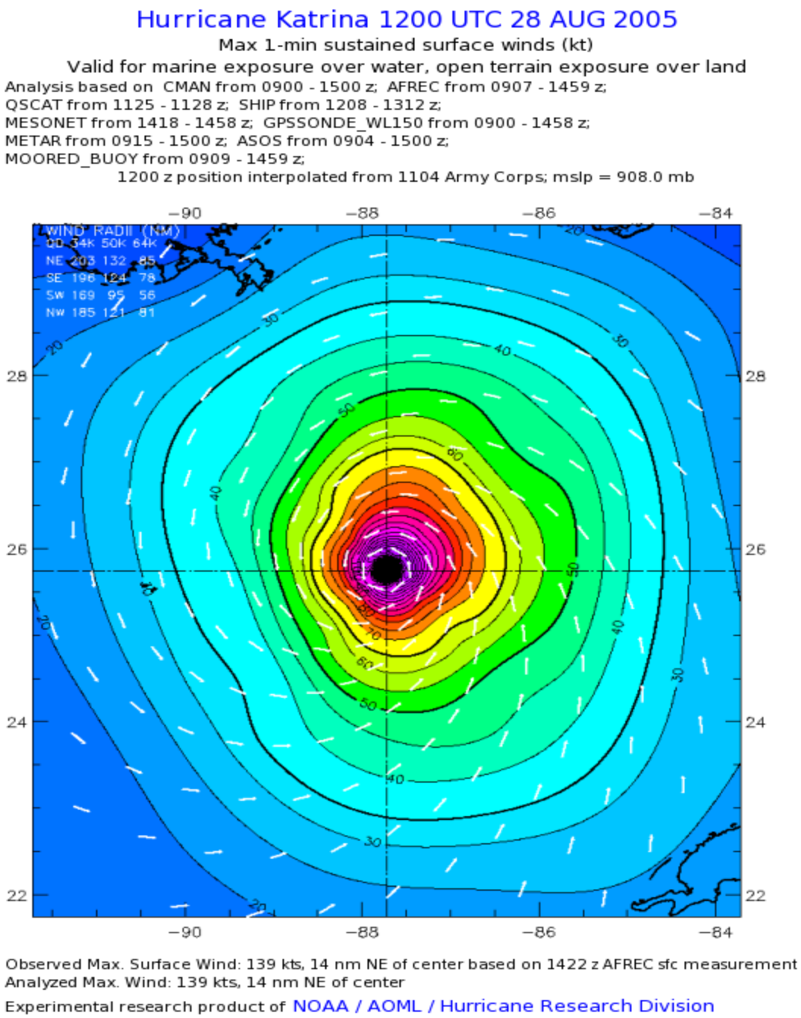
Motivation

- U.S. emergency managers require warnings of arrival of $\geq$34 kt winds (and heavy precipitation)
  - Complete all disaster preparedness activities
  - Complete appropriate evacuations
- Storm surge predictions depend on outer wind profile as well as intensity
  - Hurricane Katrina (2005) surge well to right of the path
- Large size (R_{34}) increases prior to landfall
  - Reduced warning time and delay search/rescue operations
  - E.g., an increase of R_{34} by 100 km for a storm moving 10 km/h will result in 10 h reduced warning time

Methodology

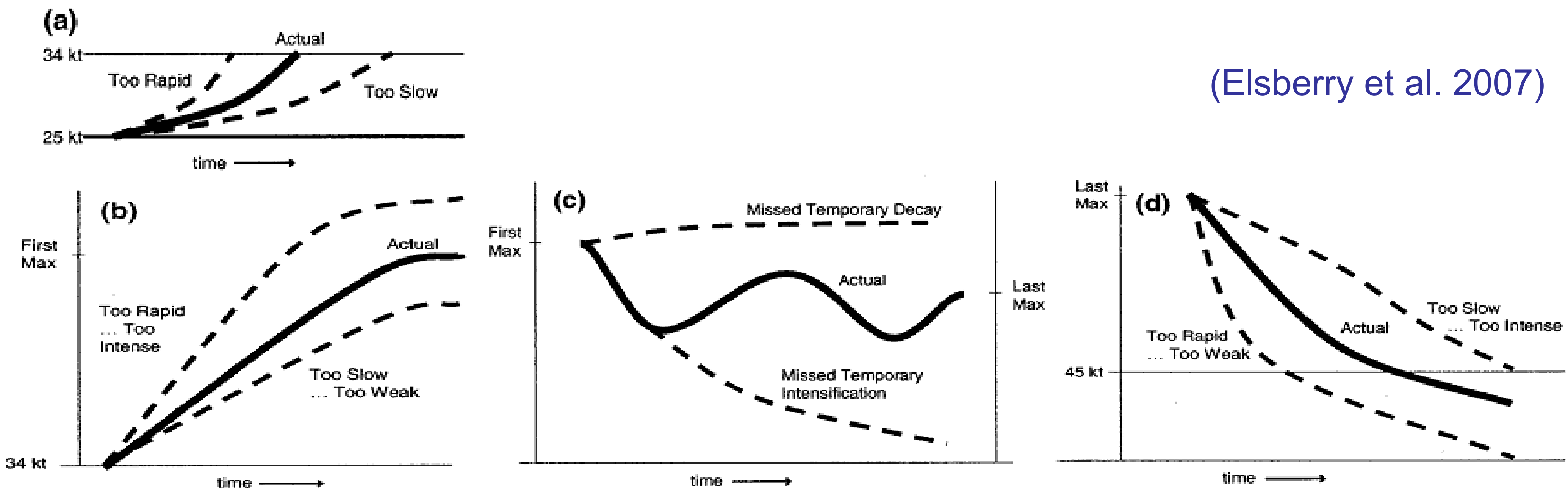
Data Set of Surface Wind Analyses



- NOAA/AOML/Hurricane Research Lab -- Hurricane Wind Analysis System (H*Wind; Powell et al. 1996, 1998)
- Horizontal grid spacing 6 km in 920 km by 920 km domain centered on the storm
- Incorporates all available surface wind observations and dropsondes
- Stepped Frequency Microwave Radiometer (SFMR)
- Reconnaissance aircraft flight-level winds adjusted to the surface
- QuikScat, TRMM, GOES cloud-drift winds

Characterization

Tropical Cyclone Life Cycle Stages



(Elsberry et al. 2007)

Phase	Descriptor	Maximum wind speeds
I	(a) Formation	<34 kt
II	(b) Intensification	34 kt to first intensity peak
IIa	(c) Decay/ Re-intensification	Decay $\geq$10 kt; Re-intensify $\geq$10 kt
III	(d) Decay	Final decay

*Rapid intensification defines as >15 kt in 12 hours

Characterization

H*Wind Dataset

- 35 Atlantic and 3 eastern North Pacific tropical cyclones during 2003-2005
- 564 H*Wind analyses
  - 508 cases with dropsondes
  - 470 cases with recon aircraft flight-level wind reductions (FLR) to surface
  - 135 cases with SFMR observations
- Interpolation on 6 km grid to find values of R_{34}, R_{50}, and R_{64} in four quadrants and azimuthal average

Characterization

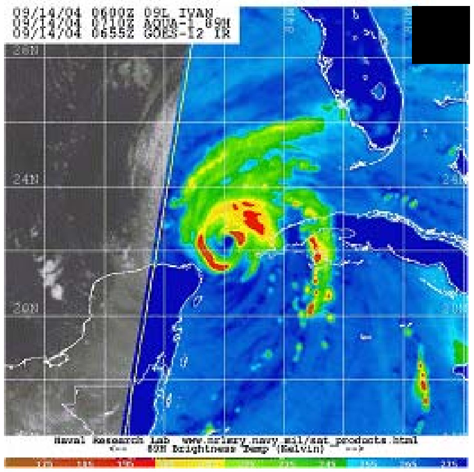
Observed Outer Wind Structure Changes

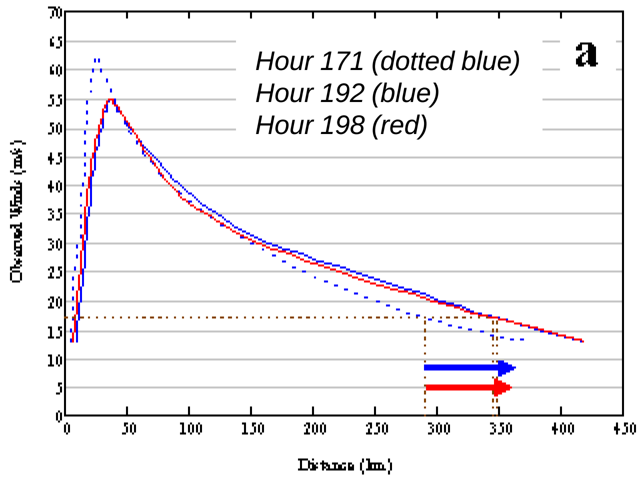
- Axisymmetric wind structure is computed along 24 equally-spaced radial legs interpolated on 6 km grid
- All quadrants in which the 34-kt wind radius intersects land are eliminated
- Hypothesis test is whether axisymmetric R_{34} increases and decreases are directly correlated with intensity increases and decreases during the life cycle stages
- Modified Rankine vortex ($vr^X = constant$) was used as a tool to assess structure change

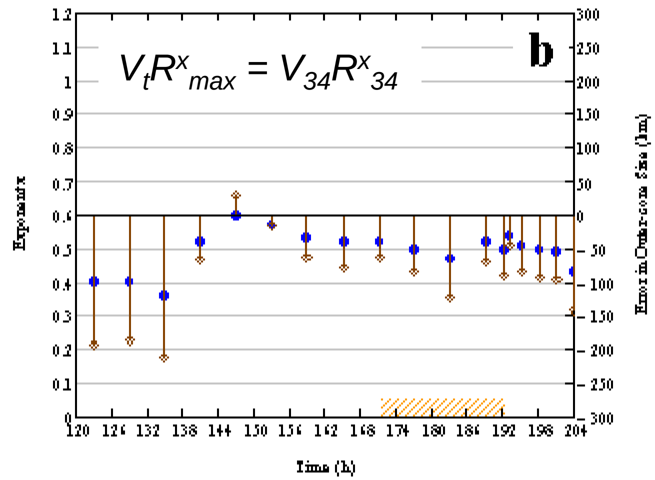
Mechanisms for Structure Change

Mode 1 SEF Example

(Stenger 2013)





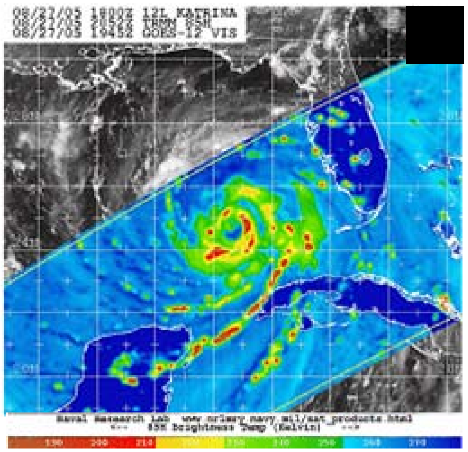


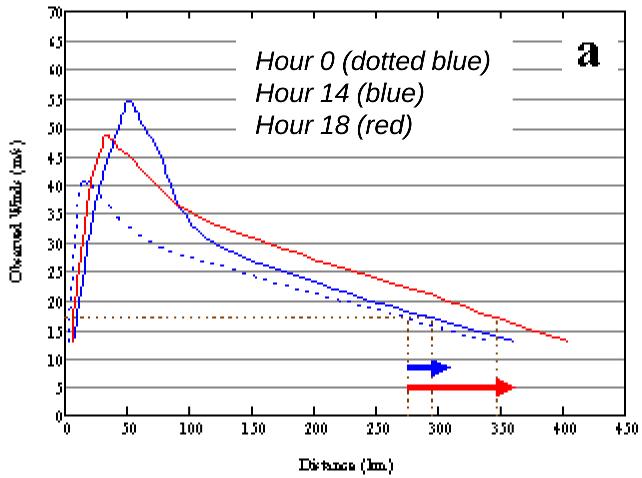
- Mode 1 example – Case of Ivan-4 complete eyewall replacement
- Net R_{max} increase: 20 km
- Net R_{34} increase: 59 km
- Exponent x of modified Rankine vortex: 0.52 → 0.50 → 0.50
- V_t decrease consistent with R_{max} increase
- R_{max} increase offsets V_t decrease for net R_{34} increase

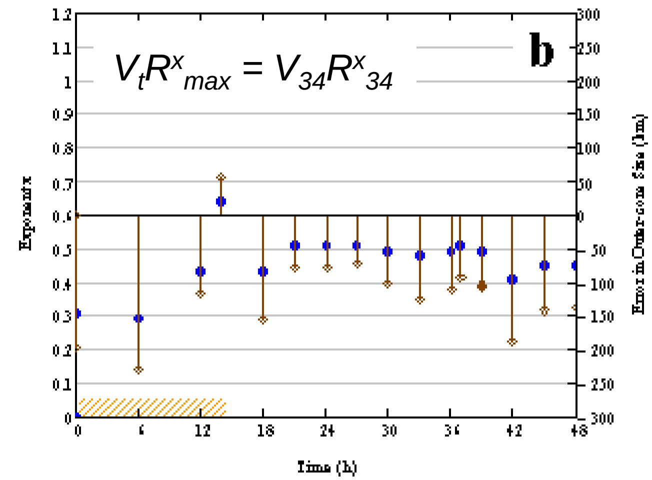
Mechanisms for Structure Change

Mode 2 SEF Example

(Stenger 2013)







- Mode 2 example – Katrina complete eyewall replacement
- Net R_{max} increase: 18 km
- Net R_{34} increase: 71 km
- Exponent *x* of modified Rankine vortex: 0.31 → 0.64 → 0.43
- V_t decrease inconsistent with R_{max} increase
- R_{max} increase and V_t increase result in net R_{34} increase

Mechanisms for Structure Change

Secondary Eyewall Formation

(Stenger 2013; Stenger & Elsberry 2013)

Storm	Pre-SEF				Post-SEF					
	V_{max} (m s^{-1})	R_{max} (km)	x_1	R_{34} (km)	V_{max} (m s^{-1})	R_{max} (km)	x_2	R_{34} (km)	ΔR_{34} (km)	ΔR_{34} (x_2=x_1)
Mode 1										
Ivan-2	53	17	0.46	208	63	18	0.46	307	**99**	109
Wilma	61	6	0.36	220	50	30	0.45	329	**109**	392
Ivan-4	59	25	0.52	289	51	38	0.50	346	**57**	41
Rita	54	18	0.40	321	45	36	0.42	373	**52**	87
Mode 2										
Ivan-3	49	18	0.36	333	58	40	0.57	347	**14**	869
Katrina	42	16	0.31	275	46	34	0.43	346	**71**	547
Fabian	46	26	0.39	321	38	55	0.43	341	**20**	99
Frances	38	18	0.29	271	53	38	0.54	309	**38**	1629

Summary

- Large size changes can occur over a short time period for Mode 1 events which may reduce the time available for disaster mitigation activities
- Whereas the ratio of post-SEF R_{max} to pre-SEF R_{max} is larger for Mode 2 events (2.94 for Mode 2 compared to 1.74 for Mode 1), the outer wind structure increases are notably smaller
- Axisymmetric (and quadrant by quadrant) R_{34} changes are more complicated than simple conceptual model that directly correlates R_{34} changes to intensity changes

Future Work

- Expand the current research results by using the additional H*Wind data since the 2005 hurricane season
  - Funded by Office of Naval Research
- Additional research is required to understand the dynamic and thermodynamic processes leading to the sharpened outer wind profile

Questions

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