Classification of Radial Wind Profiles for Gulf of Mexico Tropical Cyclones

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Overview

1. Approach to the analysis of tropical cyclone winds for ocean response models
2. Model inputs for fitting the radial wind and pressure profile
3. Prior work on storm classification
4. Classification system for radial wind profiles
5. Summary of results

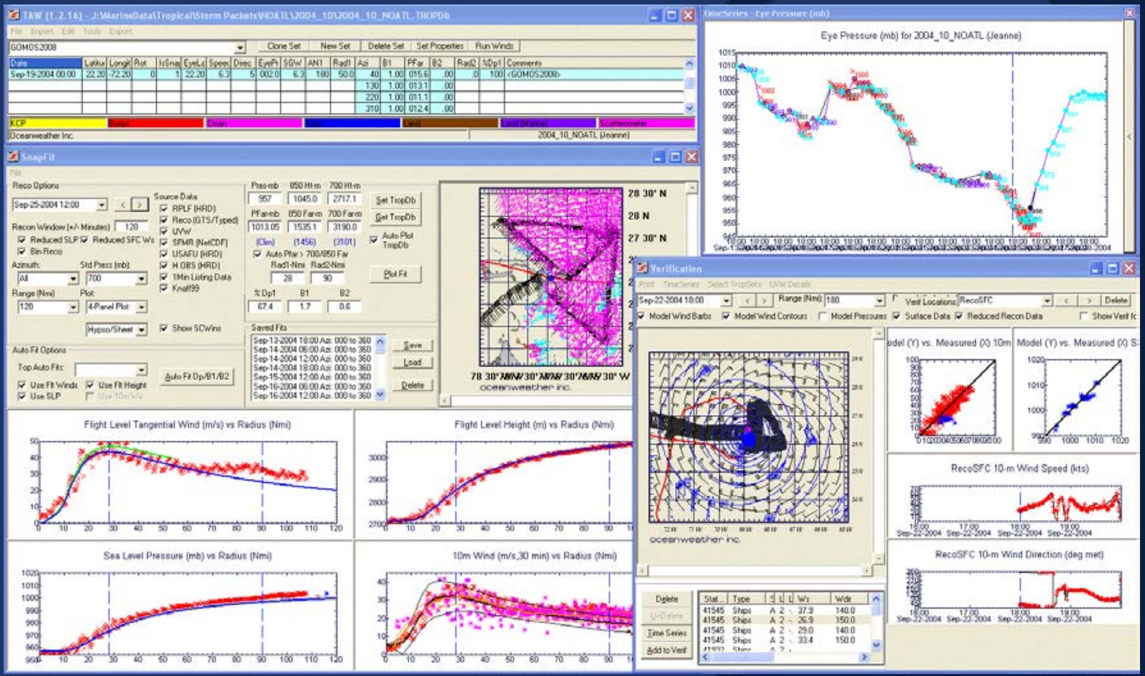
Approach to the analysis of tropical cyclone winds for ocean response models

Analysis of tropical cyclone wind and pressure fields applies a GUI interface to the OWI Tropical Planetary Boundary Layer Model

Available track/intensity, fix data, aircraft reconnaissance, in-situ and satellite data are applied in the determination of model inputs and validation of results

Basic steps:

1. Evaluation of basic storm parameters: track, intensity, speed/direction, environmental conditions
2. Fitting of radial pressure profiles at snapshot times
3. Review 10 m wind output with available validation data
4. Repeat process and impose time continuity in model inputs



TAWS – Tropical Analyst WorkStation

OWI Tropical PBL Inputs

Pressure field is prescribed with a Holland profile

$$P(r) = Po + \sum_{i=2}^{n} dp_i e^{-\left(\frac{R_{pi}}{r}\right)^{Bi}}$$

Storm Position – Latitude/Longitude

Storm Motion – Speed/Direction

Po - Central Pressure of Storm

Available from standard sources such as HURDAT but we reexamine these as well

Rp_i – Scale Pressure Radius

Related to the Radius of Maximum Wind (RMW) expressed as an inner and outer radii

Dp_i – Total Pressure Drop (*Pfar-Po*)

Pfar may be derived from synoptic maps or atmospheric model output, however the % associated with each Rp_i must be determined

B_i – Holland's B associated with each Rp_i

Controls the peakedness of the pressure and resultant wind profile

Specification of a single Rp1/B1 combination can work for many storm wind/pressure profiles, but cannot describe more complex shapes

Figures to the right depict flight level tangential winds and estimated sea level pressure data (red) measured during Katrina 2005 on Aug-28-2005 12:00 UTC

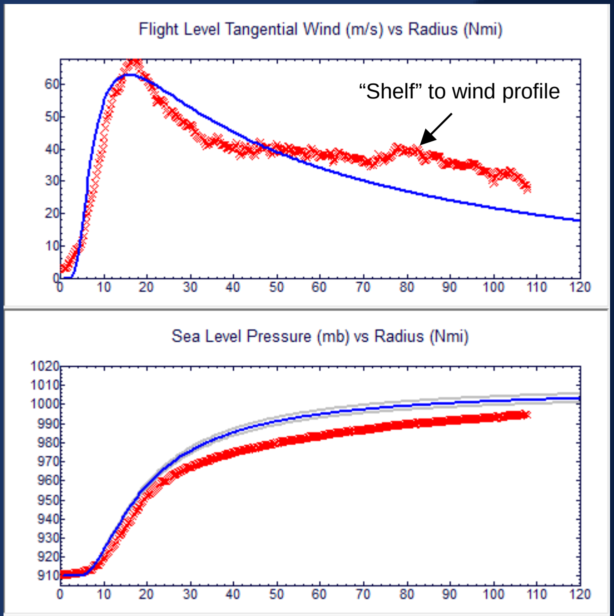
Model fits using a single exponential profile (top) and double exponential profile are shown in blue – both result in the same maximum wind and radius of maximum winds but the resultant wind profiles differ greatly

Cp=910, Pfar=1010,

Dp1=100 mb

Rp1=16 Nmi

B1=1.45

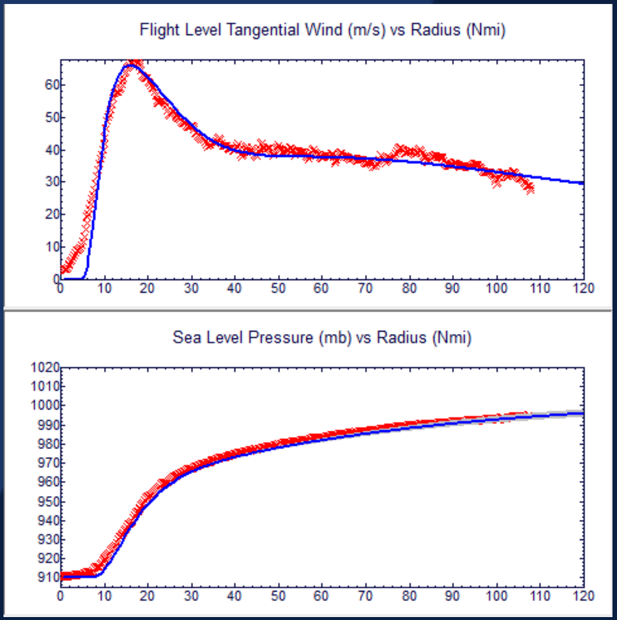


Cp=910, Pfar=1010,

Dp1=70 mb Dp2=30 mb

Rp1=16 Nmi Rp2=80 Nmi

B1=2.1 B2 = 1.7

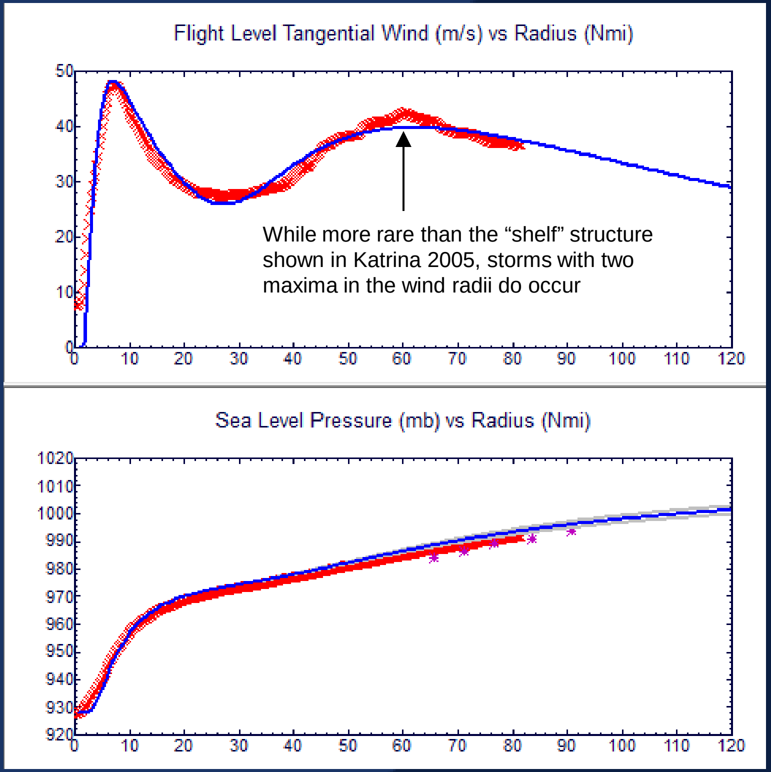


While application of the double exponential fit can better describe complex wind profiles – including those with two wind maxima like Allen 1980 (right) – it increases the number of model parameters from 3 (Dp1, Rp1 and B1) to 6 (Dp1, Dp2, Rp1, Rp2, B1, B2)

In Joint Probability Method (JPM) or synthetic storm generation the increased number of parameters can lead to a large set of storms to be run, plus statistical relationships applied for Rp1/B1 are even more difficult for the expanded parameter set

Can this complexity be better described through an analysis of the resultant wind profile rather than in the raw model inputs?

The Gulf of Mexico Meteorological and Oceanographic (GOMOS) hindcast provides over 4,000 profile fits in 396 storms for the period 1900-2011 to evaluate tropical radial wind profiles in the Gulf of Mexico



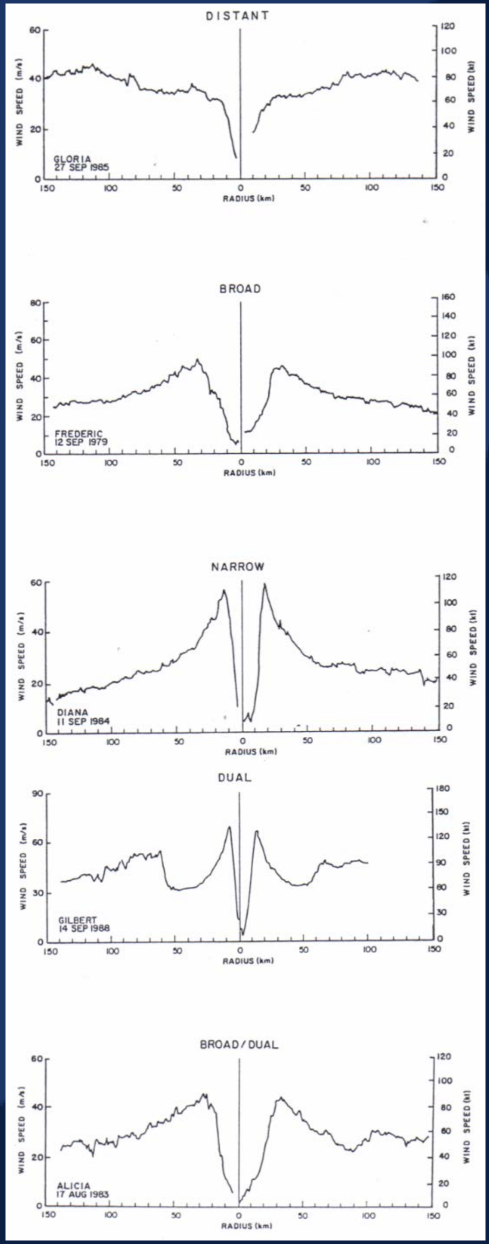
Wind/Pressure profile measurements (red) and model fit (blue) during Allen 1980

Prior Classifications for Profile Shape

Descriptions of the radial wind profile are not new!

- Colon (1963) describes wind profiles as resembling Daisy 1958 (small eye, narrow) or Helene 1958 (large eye, broad)
- Merrill (1984) looked at tropical cyclone size in North Atlantic and North Pacific storms
- Samsury and Rappaport (1991) developed a five class wind profile classification system (figure, right)
- Chen (2010) developed a size index for North Pacific typhoons in which systems were deemed “compact” or “incompact”

The goal of most of the prior work was to relate cyclone size to intensity changes to aid in forecasting



From Samsury and Rappaport (1991)

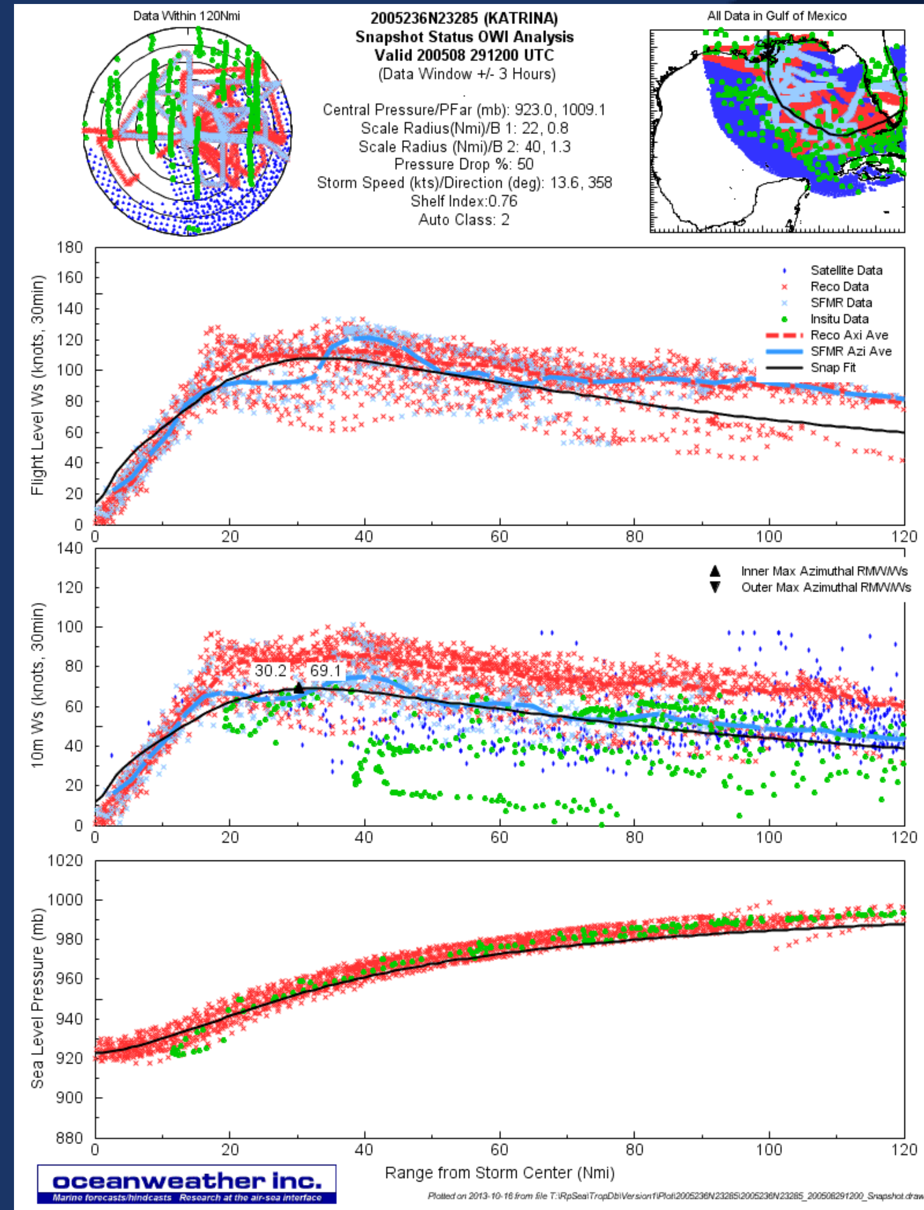
Diagnostic Plots for All Profile Fits

To aid in the development of wind profile classes diagnostic plots of the PBL inputs, measured data, and resultant model fit were produced.

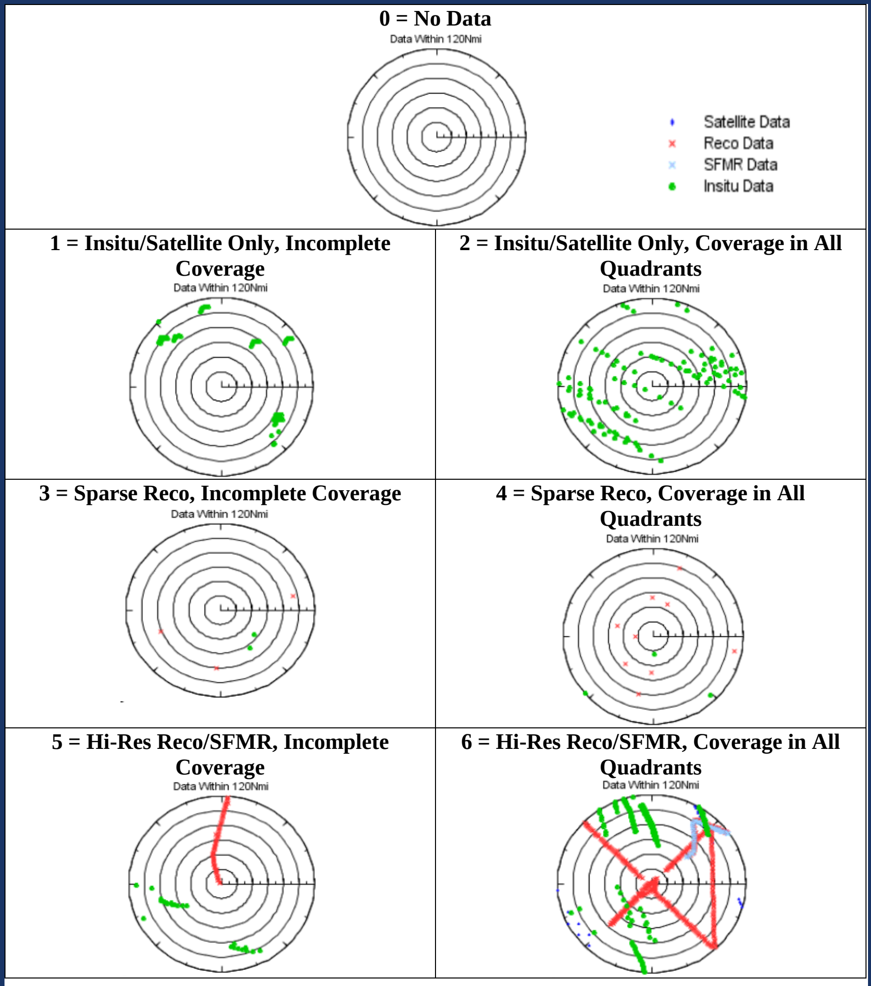
This figure is during Katrina 2005 valid on Aug-29-2005 at 12:00 UTC

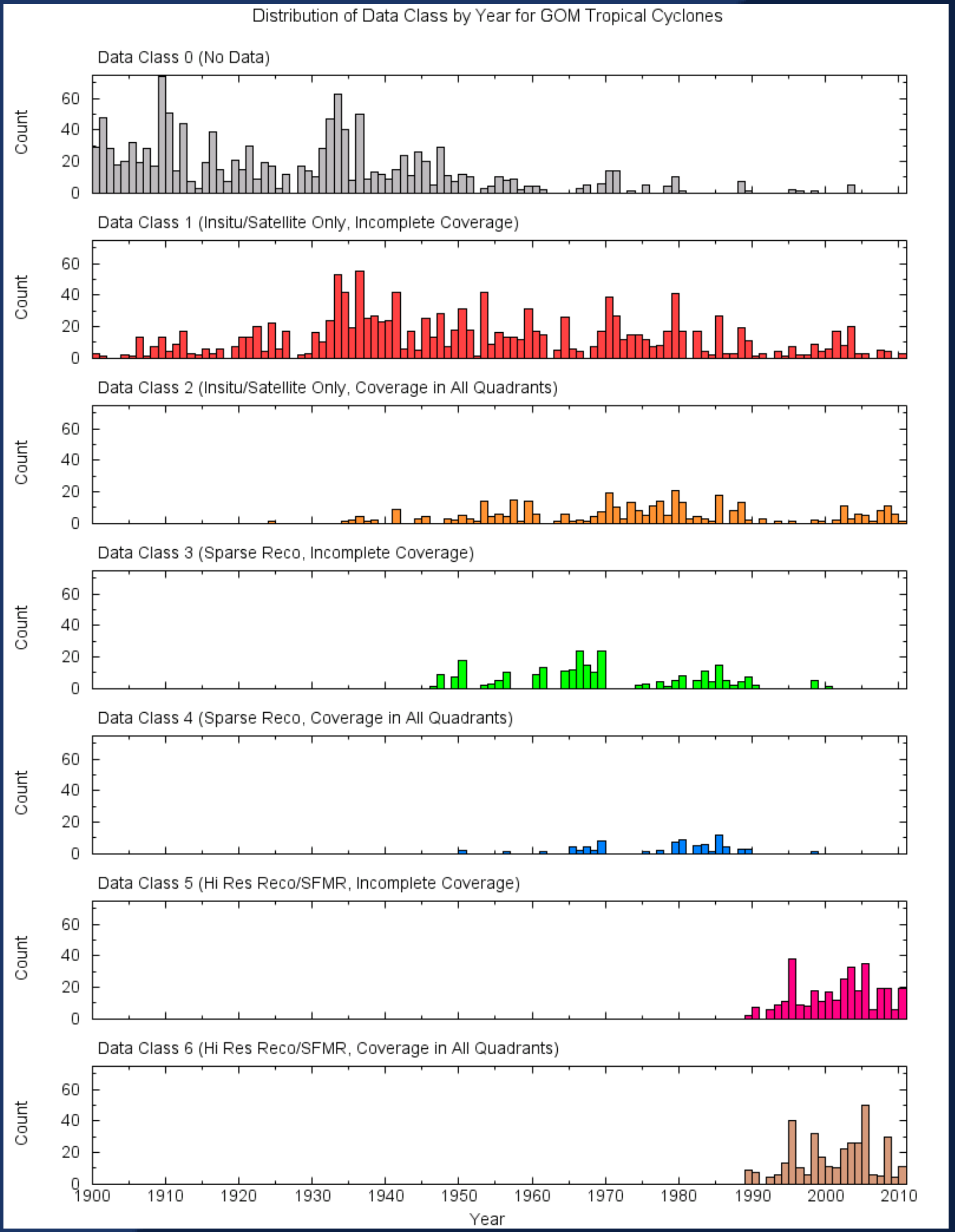
Analyzed model data are shown as azimuthally averaged black lines and can be directly compared to azimuthally averaged Aircraft/SFMR dashed lines

Other data (satellite, recon, in-situ) are not azimuthally averaged and show the variation of the measurements by quadrant of the storm



Data availability over time for use in tropical wind profile analysis





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The “Shelfy” Index

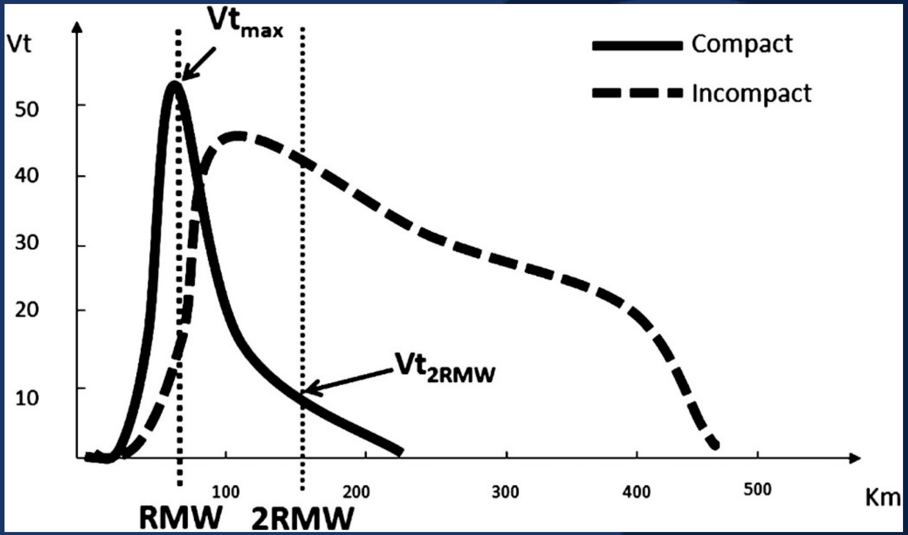
Manual inspection of diagnostic profiles indicated that a classification on just the tropical inputs (Rp 1/2, B 1/2, Dp) would be difficult – a descriptor of the shape of the wind profile was needed

Chen (2010) applied a simple structure parameter *S* which was the ratio of the tangential wind speed at twice the RMW to the average value. Values of S < 1 were deemed “incompact” and S>1 “compact”

This led to the development of S_{GOM} parameter which applied the ratio of RMW and pressure deficit to the average GOM storm (45 mb).

$$S = \frac{Vt_{2RMW}RMW}{(Vt_{2RMW}RMW)_{ave}}$$

Chen (2010) Structure Parameter



$$S_{GOM} = \frac{Vt_{4RMW}}{Vt_{RMW}} \; x \; \sqrt{\frac{\Delta p}{\Delta p_{ave}}}$$

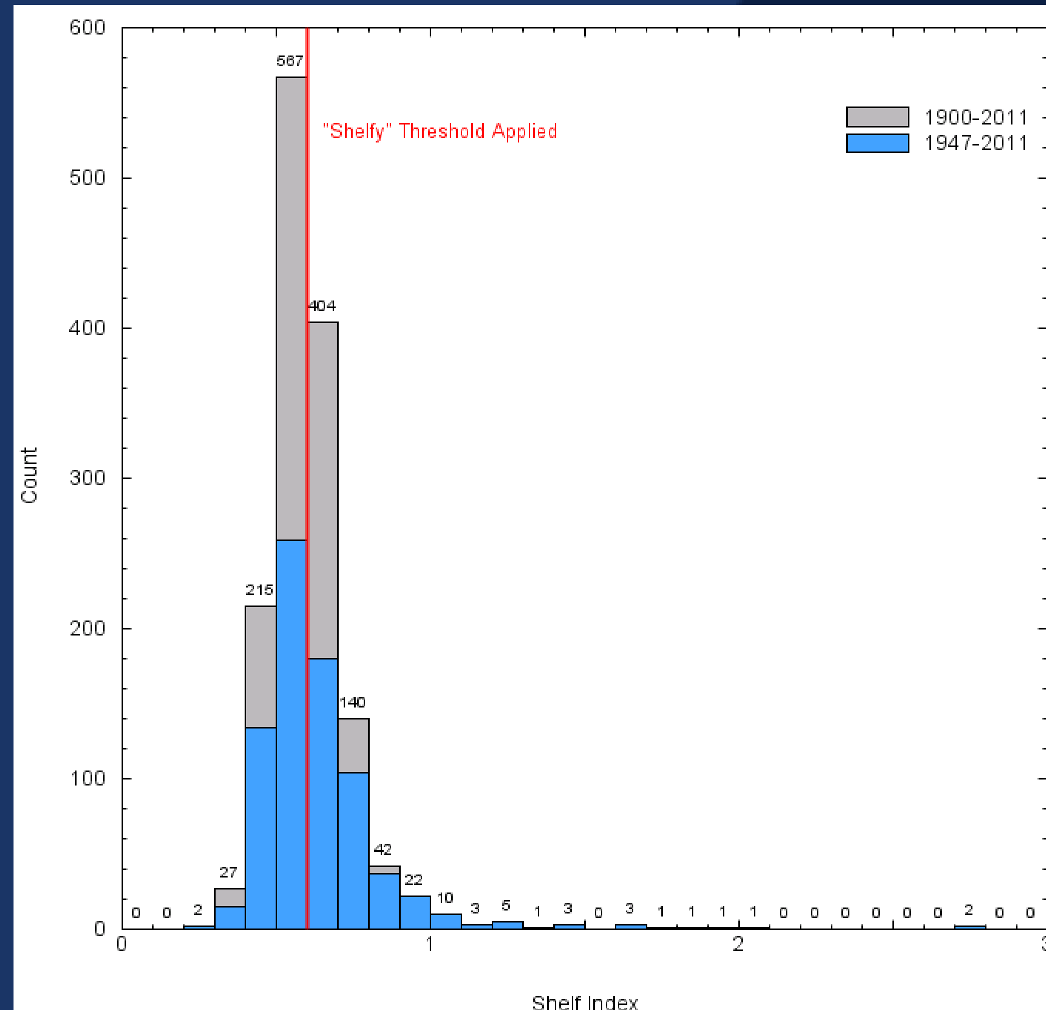
Gulf of Mexico Shelf Index

The "Shelfy" Index

A S_{GOM} index of 0.6 was found to be a good threshold between simple profiles and those with shelf or dual radii structure

Population of GOM snapshots show are near even split of storms 56% below and 44% above

Nearly all fits with high S_{GOM} (large shelf or dual radii) are from the post 1947 period which indicates the need for in-situ data to fit properly



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Using S_{GOM} and a subset of model inputs, a profile classification system was developed and applied in 4,043 snapshots from GOM storms 1900-2011 in 396 individual storms

Class	Description	S_{GOM}	Radius Criteria	B Criteria
1 CSPN	Compact Single Peaked Negligible Shelfiness	≤0.6	RMW<24	B1 > 1
2 CSPS	Compact Single Peaked Shelfy Outer Core	>0.6	RMW<24	-
3 BSPN	Broad Single Peaked Negligible Shelfiness	≤0.6	RMW≥24	-
4 BSPS	Broad Single Peaked Shelfy Outer Core	>0.6	RMW≥24	-
5 MPID	Multi Peaked – Inner Dominant	RMW_In_Ws ≥ RMW_Out_Ws		
6 MPOD	Multi Peaked – Outer Dominant	RMW_In_Ws < RMW_Out_Ws		
7 SDNP	Shelf Dominant No Peaks	Flat Profile – Manually Determined		

Class #1 CSPN

Compact Single Peaked Negligible Shelfiness

Class conforms most closely to Colon's "Daisy" type and S&R's "Narrow" type

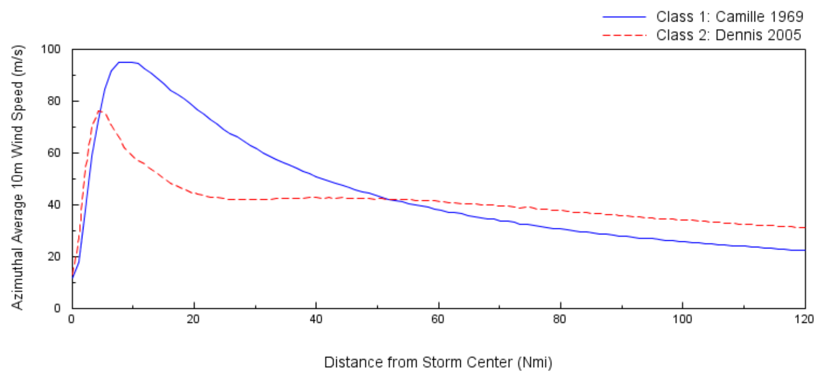
Notable example: Camille 1969

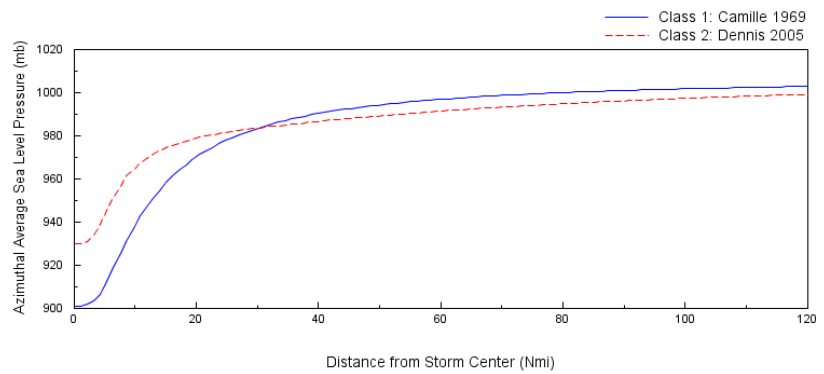
Class #2 CSPS

Compact Single Peaked Shelfy Outer Core

Stronger (954/945mb) on average than CSPN (980/977 mb)

Notable example: Dennis 2005





Profile Class	Exponential Fit	Count	Average EyePres (mb)	Average Rad1 (Nm)	Average Rad2 (Nm)	Average Dp%	Average B1	Average B2	Average Pfar	Average Shelf Index
1 (CSPN)	Single	362	980	19		100	1.10		1013	0.54
	Double	42	977	16	49	58	1.70	1.30	1014	0.50
2 (CSPS)	Single	293	954	18		100	1.20		1012	0.68
	Double	109	945	16	65	66	1.80	1.30	1013	0.77
3 (BSPN)	Single	384	979	31		100	1.20		1013	0.50
	Double	35	972	32	82	66	1.50	1.50	1012	0.52
4 (BSPS)	Single	96	956	33		100	1.20		1013	0.71
	Double	26	955	31	96	69	1.40	1.30	1012	0.70
5 (MPID)	Single	0								
	Double	42	946	11	85	63	1.80	1.50	1012	0.78
6 (MPOD)	Single	0								
	Double	39	968	15	63	50	1.10	1.80	1012	0.94
7 (SDNP)	Single	10	988	144		100	1.10		1011	0.81
	Double	12	981	25	100	53	0.70	0.70	1010	0.65

Class #3 BSPN

Broad Single Peaked Negligible Shelfiness

Class conforms most closely to Colon’s “Helene” type and S&R’s “Broad” type

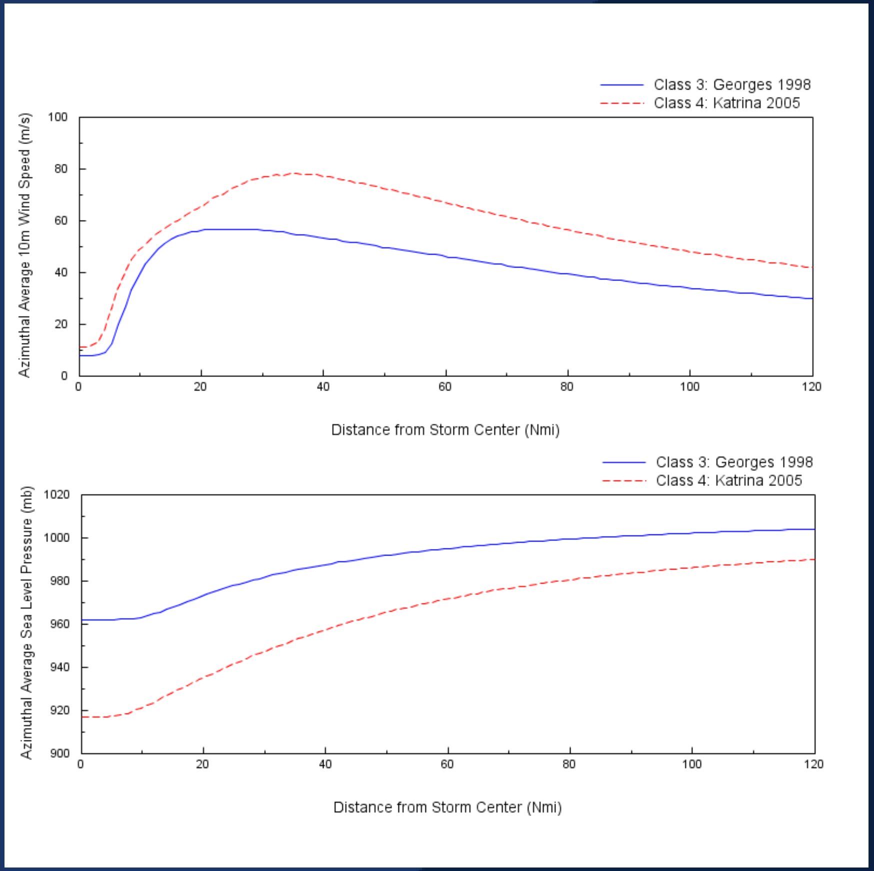
Notable example: Georges 1998

Class #4 BSPS

Broad Single Peaked Shelfy Outer Core

The shelfy counter part to BSPN –stronger (956/955mb) on average than BSPN (979/972 mb)

Notable example: Katrina 2005



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Class #5 MPID

Multi Peaked Inner Dominant

Two wind maxima seen in wind profile – inner maxima stronger, can only be fit using double exponential

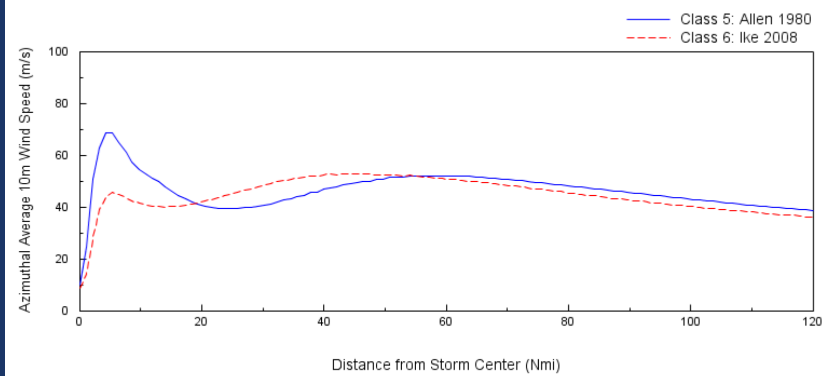
Notable example: Allen 1980

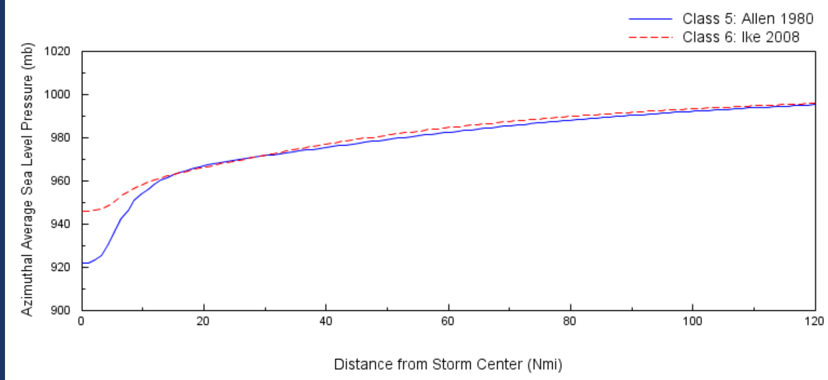
Class #6 MPOD

Multi Peaked Outer Dominant

Two wind maxima seen in wind profile – outer maxima stronger, can only be fit using double exponential

Notable example: Ike 2008





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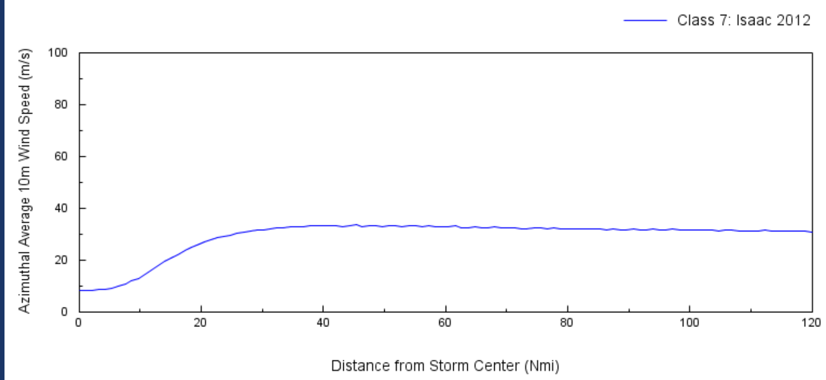
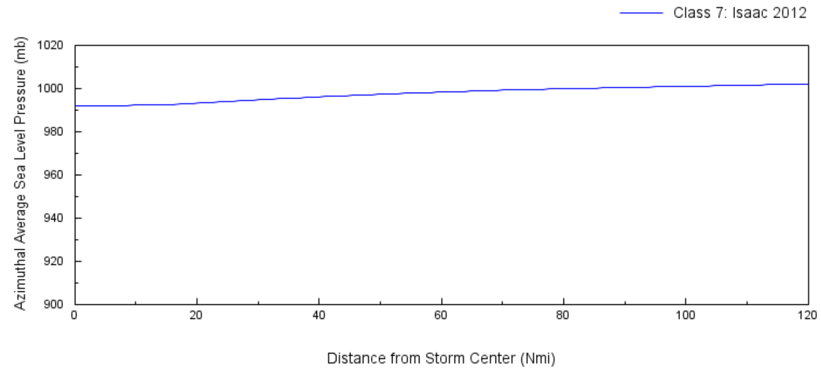
Class #7 SDNP

Shelf Dominant No Peak

Flat wind profile associated with weakest storm class

Notable example: Isaac 2012





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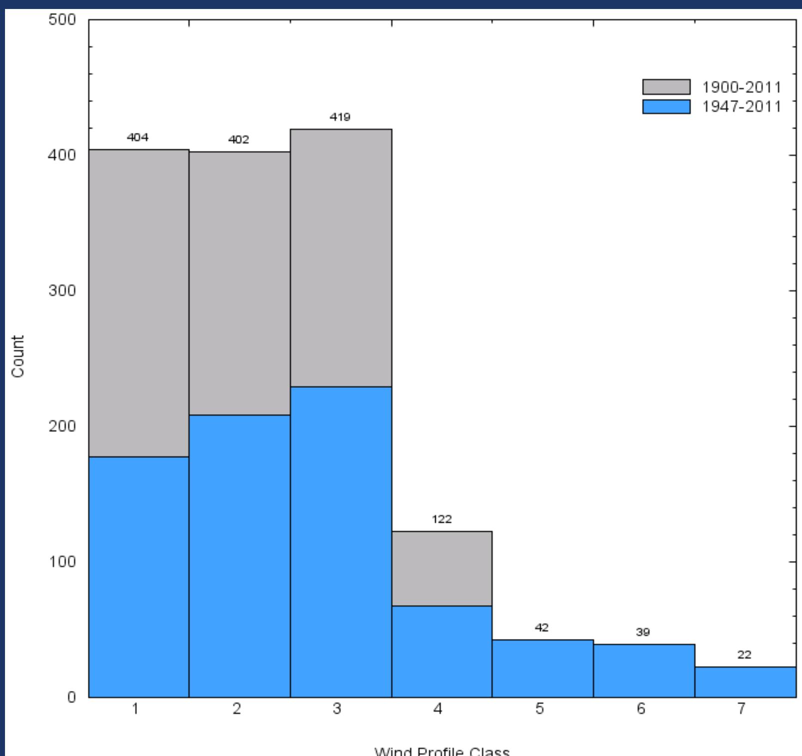
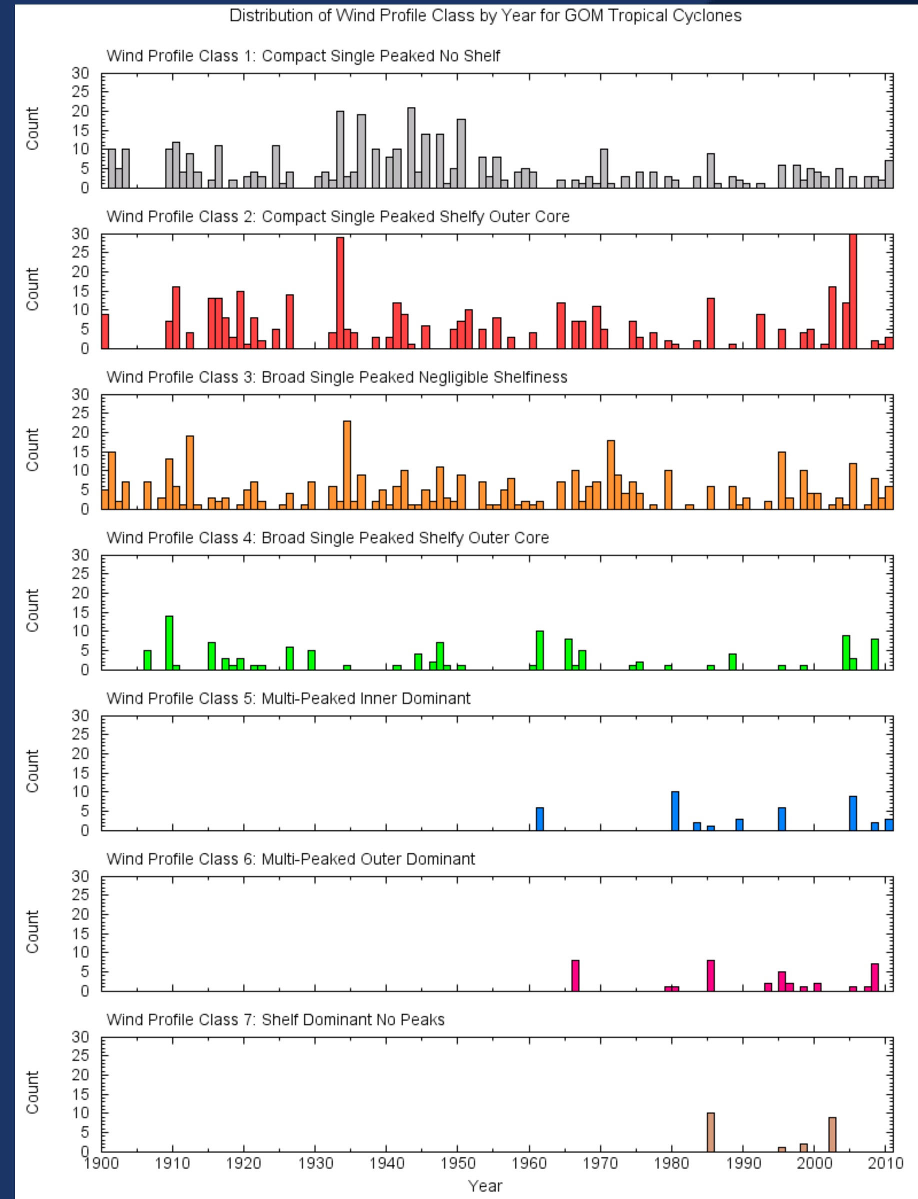
Distribution of storm profile classes

Single wind peak Class 1-4 found throughout time period

Double wind peak Classes 5/6 and shelf dominant Class 7 storms only analyzed when reconnaissance is available





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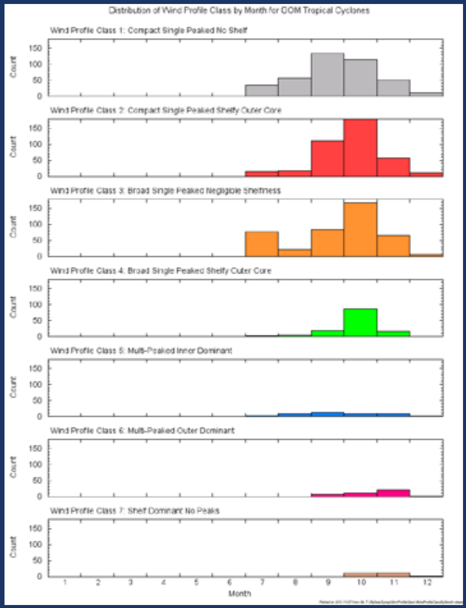
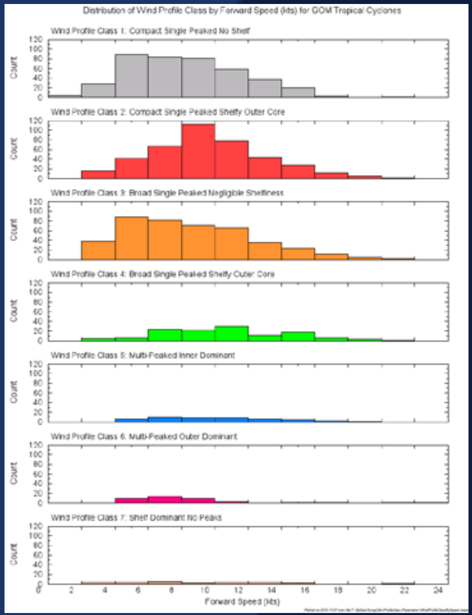
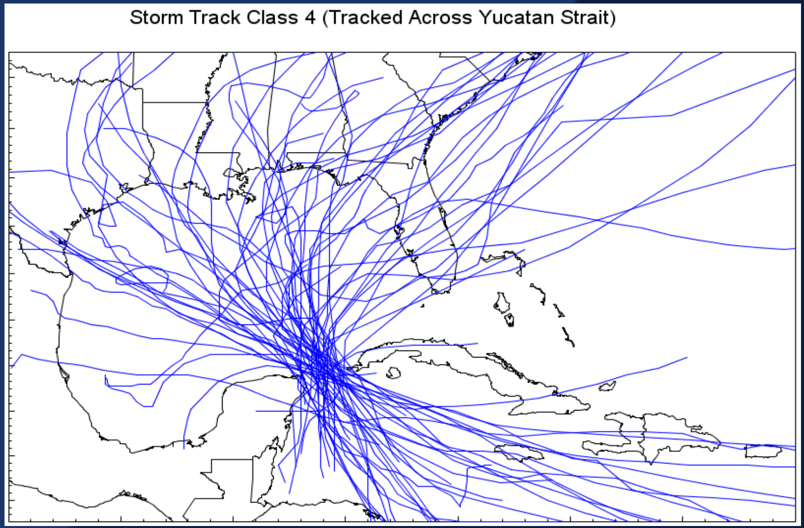
Other relationships explored

- Seasonal dependence on profile class?
- Dependence on other model inputs (Vf)?
- Association with track history/origin of storm in Gulf of Mexico?
- How long does a storm maintain a single profile class? Are there preferences from one class to another?







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Synoptic Classification – Notable Results

- Storms which depict a shelf like structure (S_{gom} >= 0.6) to the radial wind profile make up 44% of the storm population 1900-2011 and 48% of the population during the aircraft recon period of 1947-2011
- Most "shelfy" storms exhibit a single wind maxima in the radial wind profile. Storms with a second radial wind maxima (Class 5/6) make up just 5.6% of the total population
- While "shelfy" storms are found in the full 1900-2011 storm population, storms with a second radial wind maxima (Class 5/6) were only analyzed post 1960 – highlighting the need for aircraft recon to diagnose
- Storms which form in the GOM have the highest occurrence (77%) of wind profile classes associated with negligible shelfiness (Class 1 & 3)
- The strongest storms were typically analyzed with a double exponential pressure profile fit in Class 2 (Compact with Shelf, 945mb/16Nmi average central pressure/RMW) and Class 5 (Multiple Peak Inner Dominant, 946mb/11Nmi average central pressure/RMW)
- 58% of storms exhibited multiple wind profile classes while in the GOM. Wind profile classes associated with no shelf (Class 1 CSPN) or negligible shelfiness (Class 3) were the most likely to retain a single wind profile class for the entire GOM lifetime
- On average, storms retained the same wind profile 70-85% of the time for adjacent 6-hourly synoptic snapshots. When the wind profile class does change, some classes exhibit preferences. For instance, Class 5 storms (Multiple Peaks) had zero occurrences of transitioning to a Class 1 (Compact Single) profile.

Summary

Synoptic classification was performed as part of a Research Partnership to Secure Energy for America (RpSea) project 10121-4801-01 - Ultra-Deepwater Synthetic Hurricane Risk Model for Gulf of Mexico

More information:
http://www.rpsea.org/projects/10121-4801-01/

Primary Contractor: Applied Research Associates (Peter Vickery and Lauren Mudd)
Sub-Contractors: Oceanweather Inc. and UCAR (James Done and Greg Holland)

Work is underway on the application of the double exponential fits in a synthetic hurricane generation model

Questions?