Evaluation of the Storm Surge Hazard in Coastal Mississippi

A. Niedoroda, D.Resio, G. Toro;
D. Divoky, H. Das, C. Reed

URS Team

ACKNOWLEDGEMENTS

Project Staff:

Alex Whitworth, Richard Sanborn, Saiduz Zaman, Bikash Saha, Candace Beauvais, Dale Lehman, Lynn Mayo, Darryl Hatheway, Maria Honeycutt, Jonica Gibson, Karen Schuckman, Heather Zhao, William O’Brien, Mark Johnson, David Divoky, Cheryl Johnson, Ki Pak, Vince Cardonne, Andrew Cox, Jeffrey Gangai, Kevin Slover, Elena Drei-Horgan, Kumiko Yamazaki, Darren Rose, Robert Dean, Don Slinn, Robert Weaver, Norm Scheffner, Leon Borgman, Stephen Baig, Gabriel Toro, Peter Vickery, and Todd Walton

FEMA Staff:

Rob Lowe, Dr. Shabbar Saifee, Lynda Charles, Jason Hunter Henrietta Willliams, John LaBrune, Emile Hurst, Doug Bellomo

Companies:

Risk Engineering, Watershed Concepts, Dewberry, Ayres Assoc., Computational Hydraulics,

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MOTIVATION

- New Flood Maps Needed (especially after Hurricane Katrina)
- New Methodology Needed

NEW METHODOLOGY

- **Storm Characterization**
- **Numerical Models**
- JPM – JPM-OS
- Coastal Flood Elevations

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SUMMARY OF CONCLUSIONS

- New working methodology for FEMA Coastal Flood Studies has been developed
- Efficient JPM has been shown to be accurate and efficient
- Wave setup included within the hydrodynamic simulations improves the results
- Results are sensitive to subtle processes
- New efficient methods have been corroborated over related flood study projects

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PROJECT ORGANIZATION

- Characterize the local storm climate
- Develop method of forward projection
- Create surge heights with numerical models
- Analyze recurrence statistics

Characterization

- Storm Parameters
- Period of Record
- Schematic Shoreline
- Optimize the Sample Error/Population Error Trade Off
- Parameter Statistics

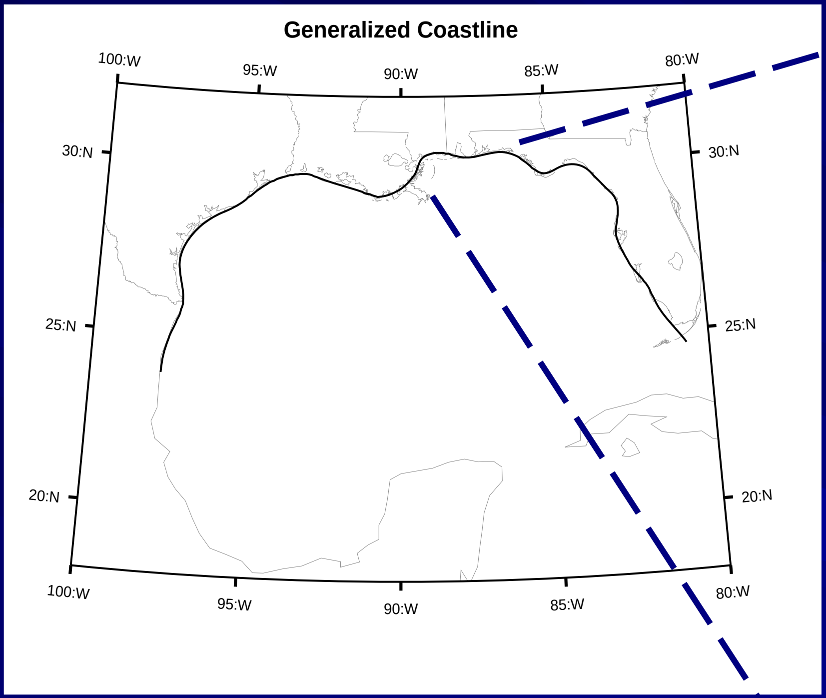
Period of Record

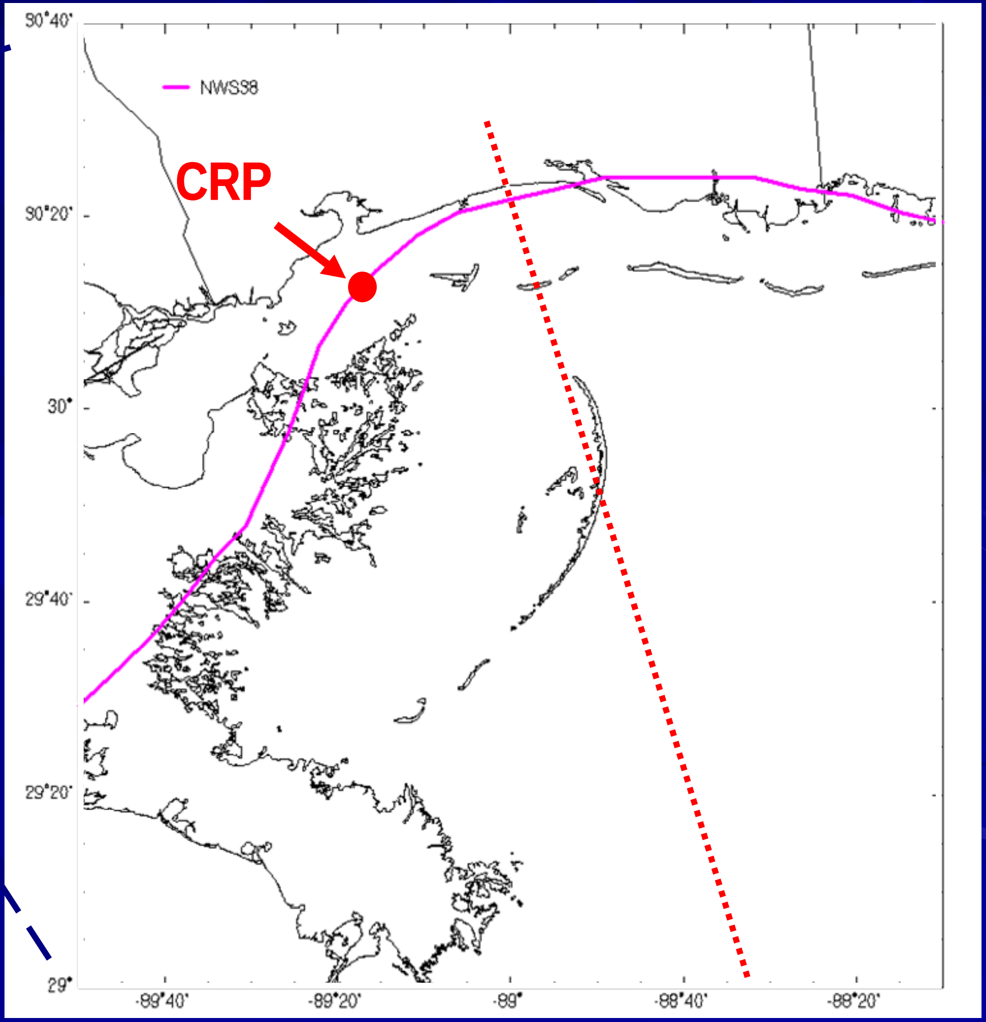
- 1851: Limit of Hurdat
- 1900: Former FEMA Data Limit
- 1940: Offshore Aircraft Observations
- 1960s: Satellites and Data Buoys
- 1990s: Doppler Radar
- 2006: Limit Of Study Data

Period of Record

- 1851: Limit of Hurdat
- 1900: Former FEMA Data Limit
- 1940: Offshore Aircraft Observations
- 1960s: Satellites and Data Buoys
- 1990s: Doppler Radar
- 2006: Limit Of Study data

Schematic Shoreline





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Storm Parameters

- Pressure deficit
- Pressure radius
- Azimuth
- Landfall
- Forward speed
- Holland B
- Astronomical tide
- Track variations
- Wind/Pressure Field Details

- Major Parameters
  - Pressure deficit
  - Pressure radius
  - Azimuth
  - Landfall
  - Forward speed
- Special Parameter
  - Holland B
- Random Parameters
  - Astronomical tide
  - Track variations
  - Wind/pressure field variations
  - Lack of model framework skill

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Optimize Spatial Resolution vs Statistical Precision

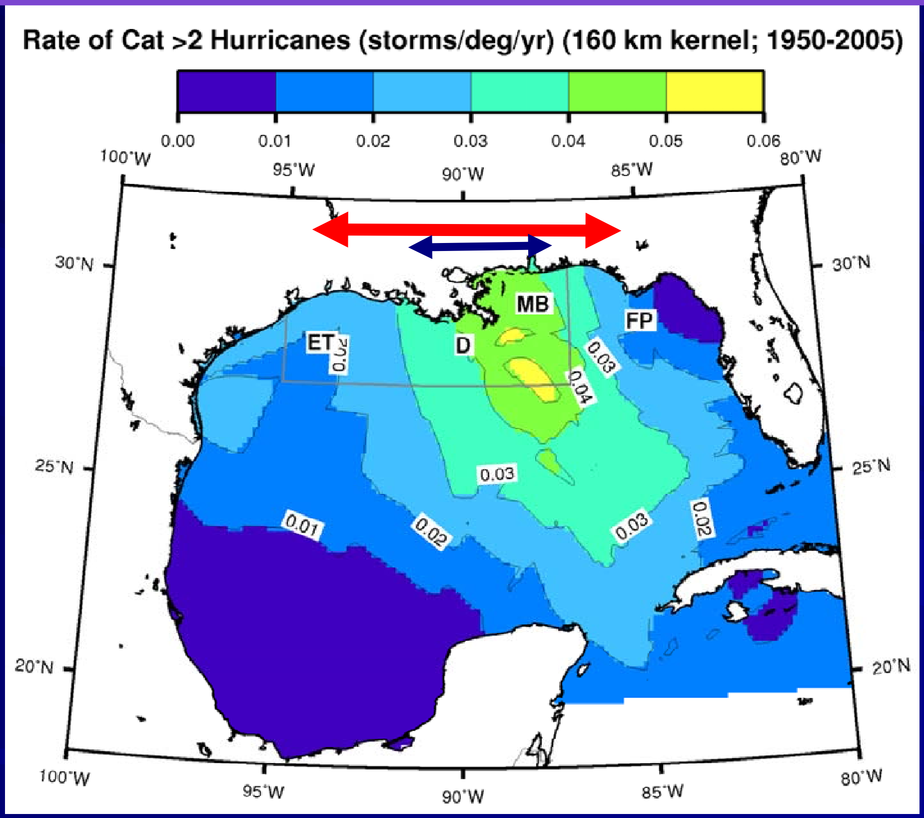

Figure 3-1. Analysis of hurricane frequency from Toro (Risk Engineering) from an analysis using an optimized spatial kernel.

Hurricane frequency (from Toro)

- Optimal kernel – (width 200 km)
- Total of 30 Storms (1940-2006; 85°-95°W)
- Divide: ΔP>48 mb (14);31>ΔP>48 (16)
- Chouinard Method (λ,ΔP,θ)
  - Weights based on track-to-CRP distance
- Conditional Rp | ΔP
- Simple fit for U

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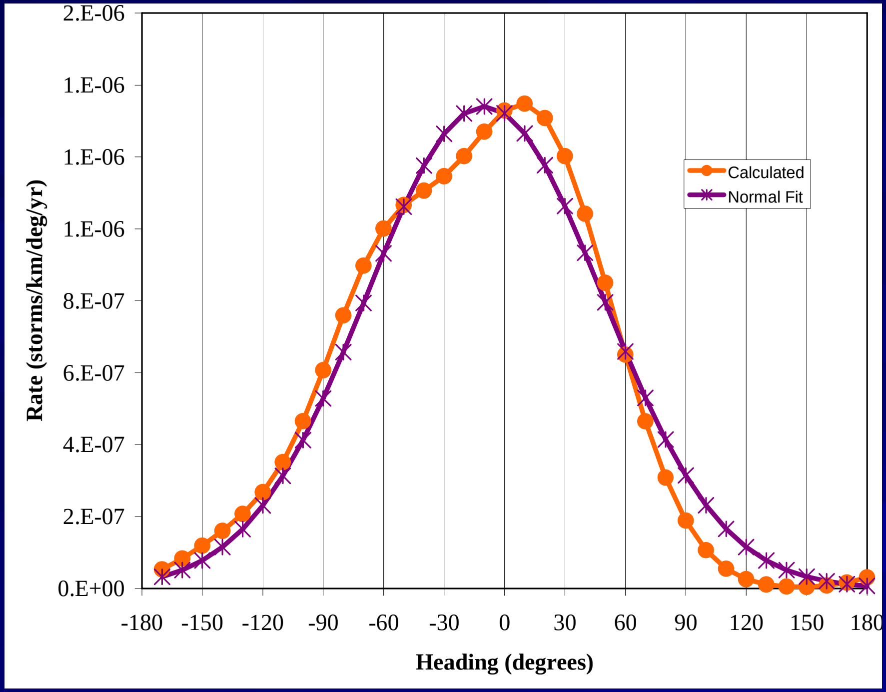
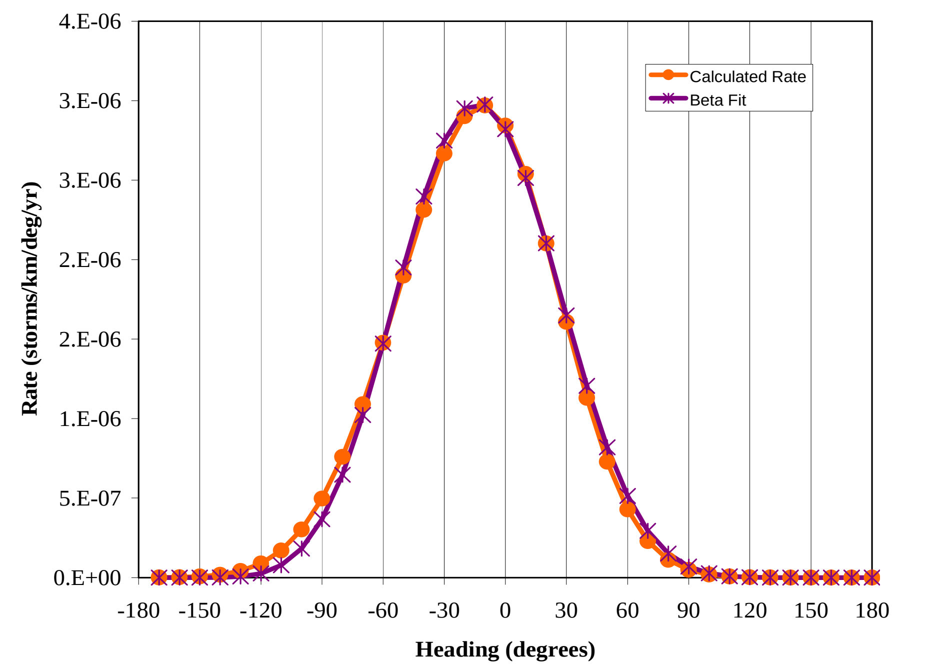
Direction & Rate





Lesser 2.57E-4 storms/km/yr

Greater 2.88E-4 storms/km/yr

Annual Rate 5.45E-4 storms/km/yr

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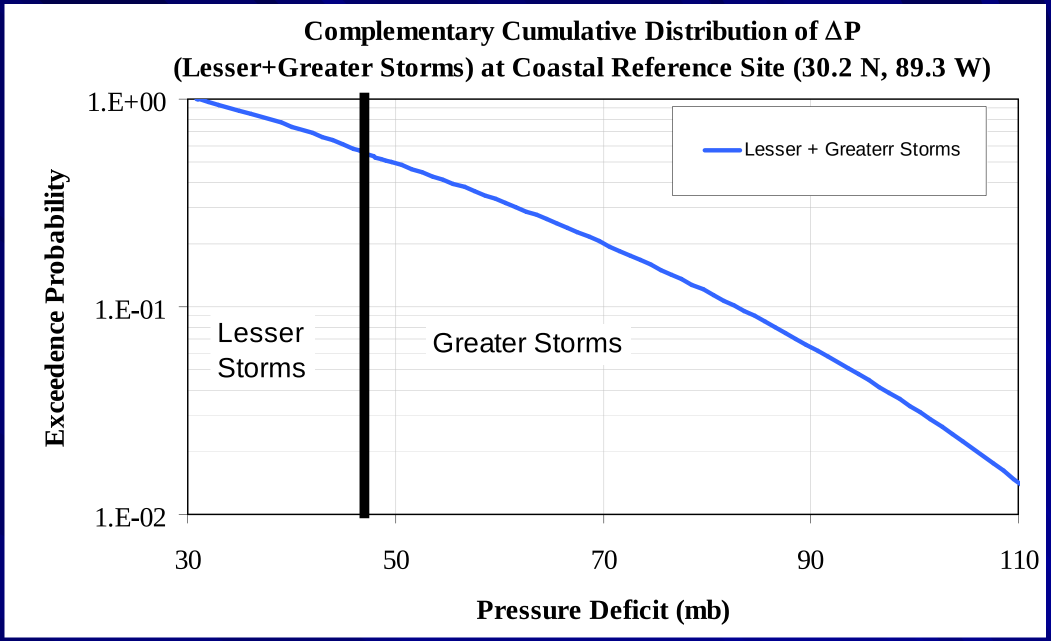
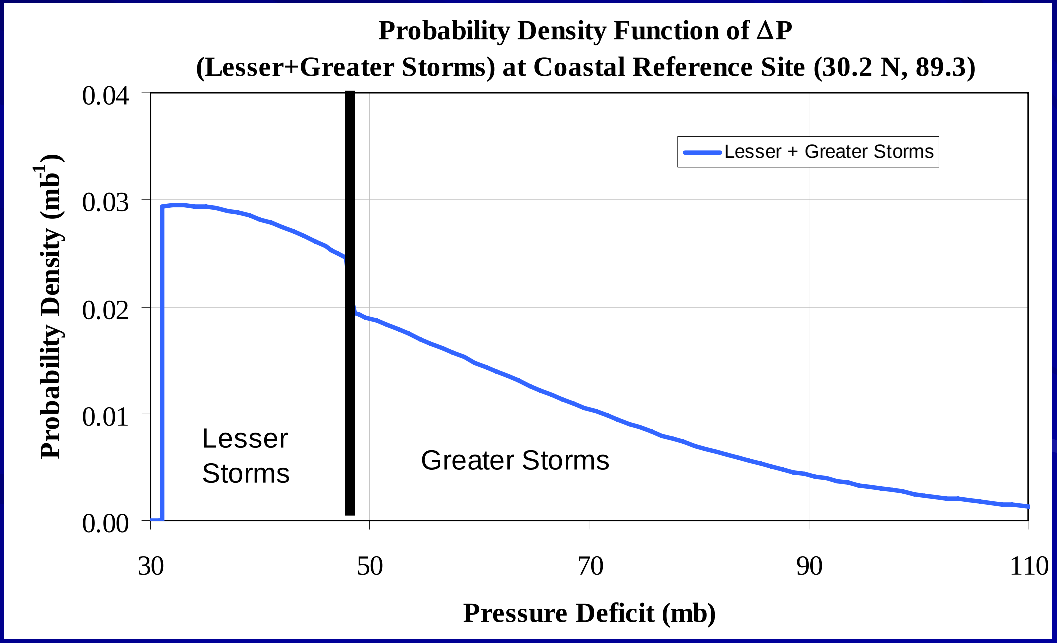
Pressure Deficit





Fitted with a Weibull Distributions

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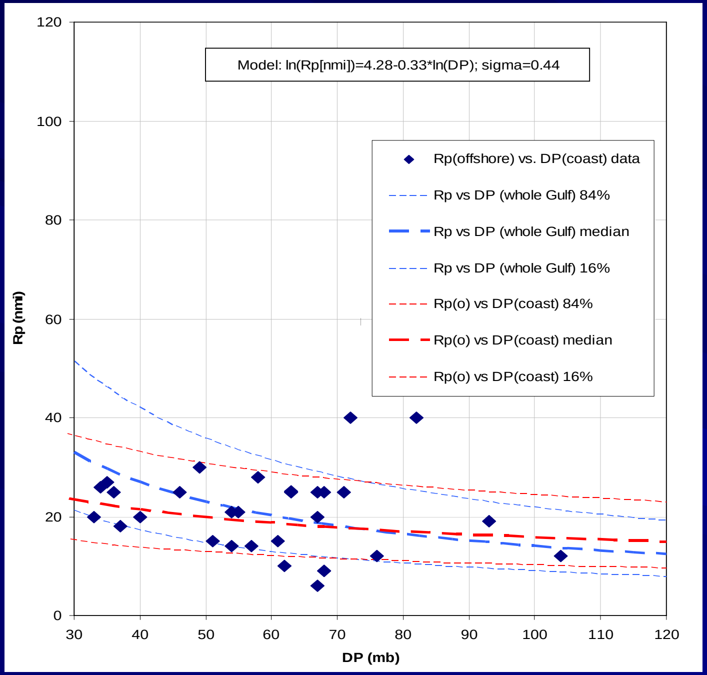
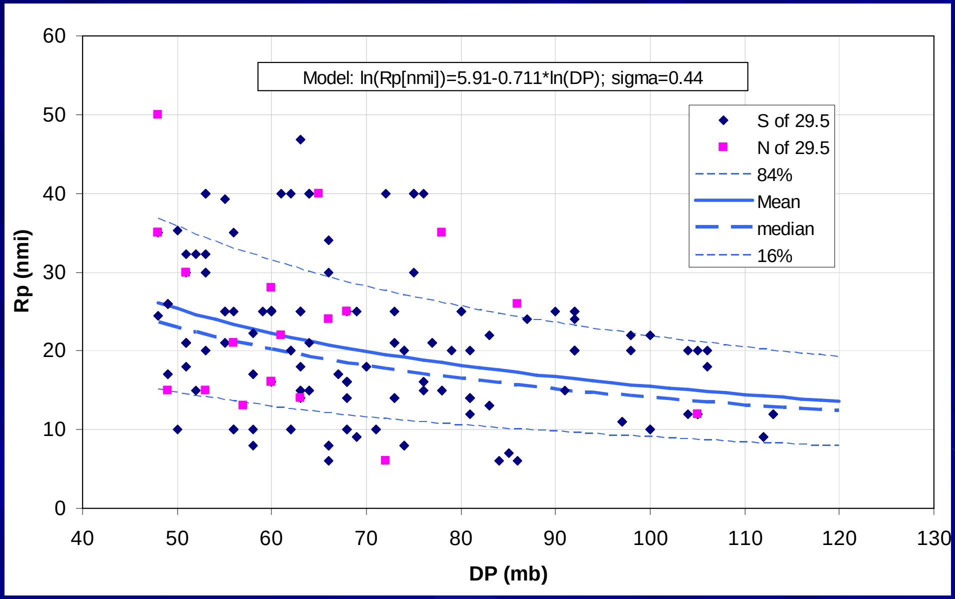
Pressure Radius (depends on ΔP)

LESSER STORMS



DATA FROM WHOLE GULF OF MEXICO (1950-2006)

GREATER STORMS



DATA FROM WHOLE GULF OF MEXICO (1940-2006)

Conditional Distribution Rp|ΔP => lognormal functions

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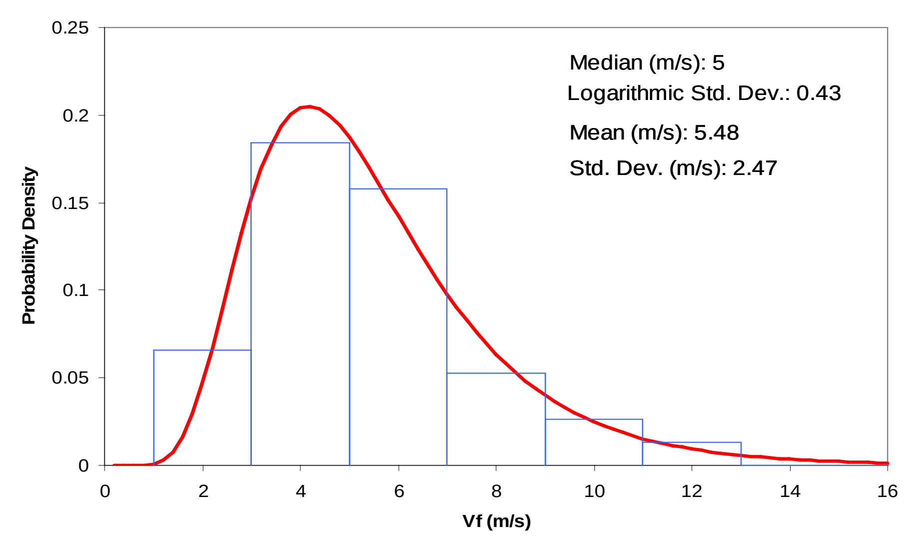
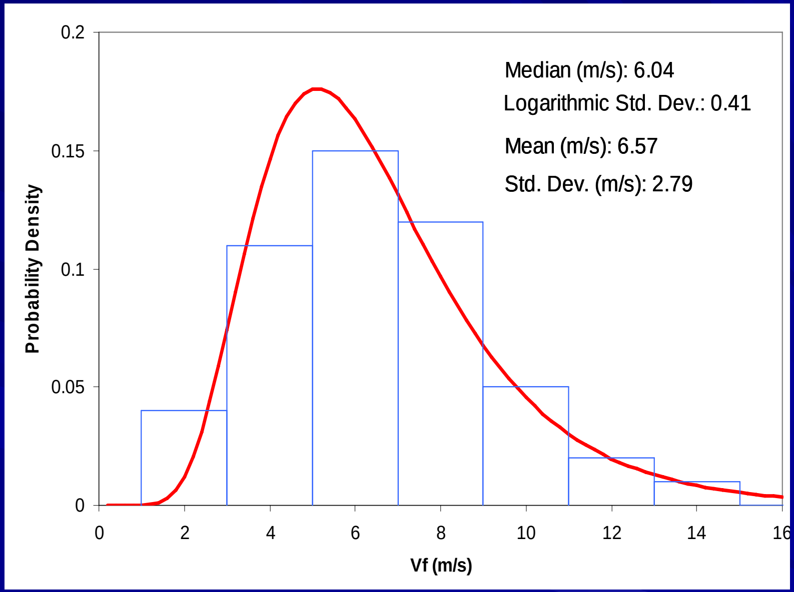
Forward Speed

LESSER STORMS



GREATER STORMS



Forward speed => lognormal function

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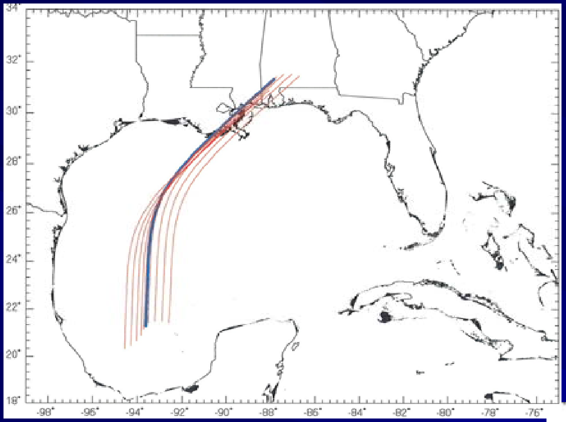
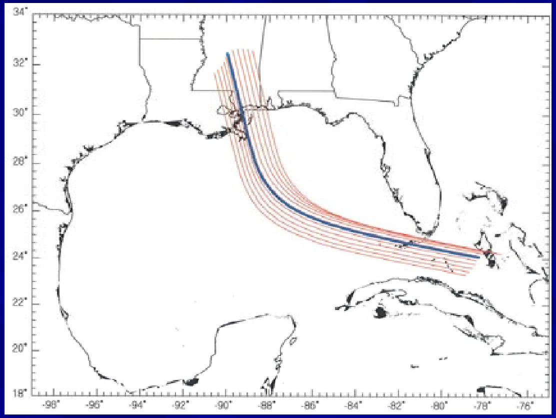
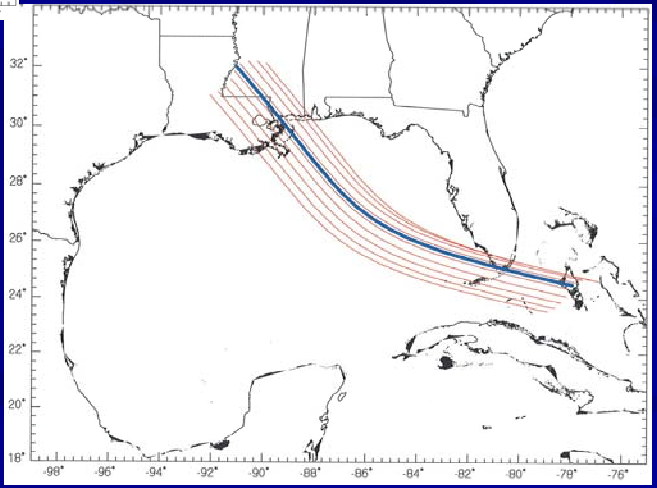
Storm Tracks

Whole Gulf Tracks Curved & Similar to Corps' BRICA







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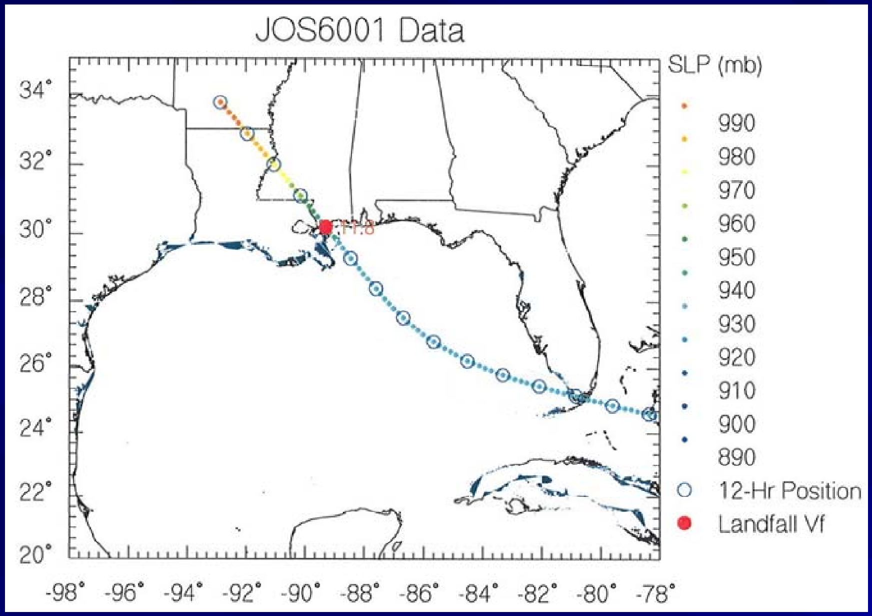
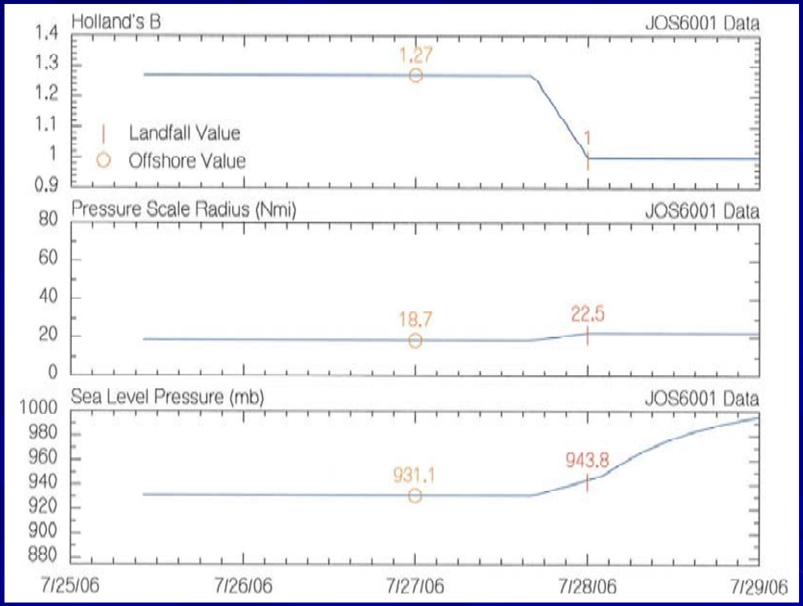
Along-Track Profiles





For storms where Rp > 10 n. mi.

Rp (landfall) = 1.3 * Rp (offshore)

B (landfall) = 1.0   B (offshore) = 1.27

Decrease in ΔP(mb) = Rp (offshore n.mi.) -6

max ΔP = 18 mb, min ΔP = 5 mb

Joint Probability Method (JPM)

$$P[\eta_{\max(1\,yr)} > \eta] = \lambda \int \ldots \int_{\underline{x}} f_{\underline{X}}(\underline{x}) P[\eta(\underline{x}) > \eta] d\underline{x}$$

Annual occurrence rate

From characterization of parameters

Surge from the numerical modeling

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Joint Probability Method (JPM)

$$P[\eta_{\max(1\,yr)} > \eta] = \lambda \int \ldots \int_{\underline{x}} f_{\underline{X}}(\underline{x}) P[\eta(\underline{x}) > \eta] d\underline{x}$$

Commonly approximated by the discrete function:

$$P[\eta_{\max(1\,yr)} > \eta] \approx \sum_{i=1}^{n} \lambda_i P[\eta(\underline{x}_i) > \eta]$$

Rate for each storm

Surge elevation from numerical modeling

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JPM-OS Development Strategy

- SLOSH model sensitivity tests
  - Yields relative importance of parameters
- Create full JPM (Gold Standard) Analysis
  - The 2,967 synthetic storms output at 147 points form a basis of comparison
- Use Bayesian quadrature method to create 4 JMP-OS candidates
  - OS4 = 303 , OS5 = 193, OS6 = 158 and OS7 = 147
- Compare JPM-OS candidates to the Gold Standard (GS) and select “best”
  - OS6 yield least synthetic storms while preserving GS-results

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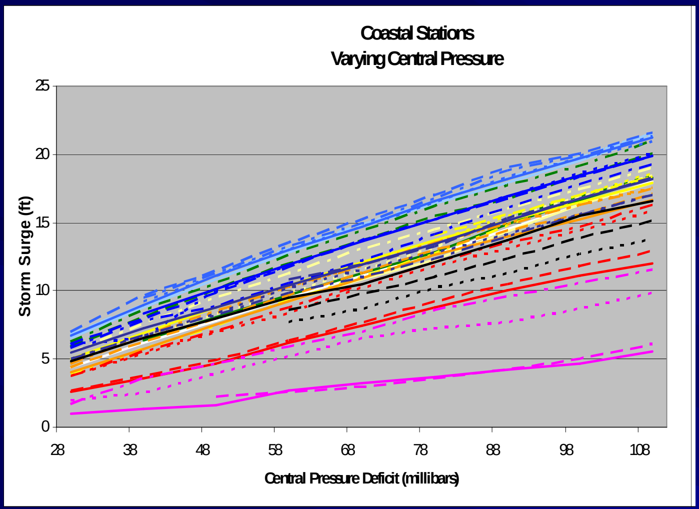
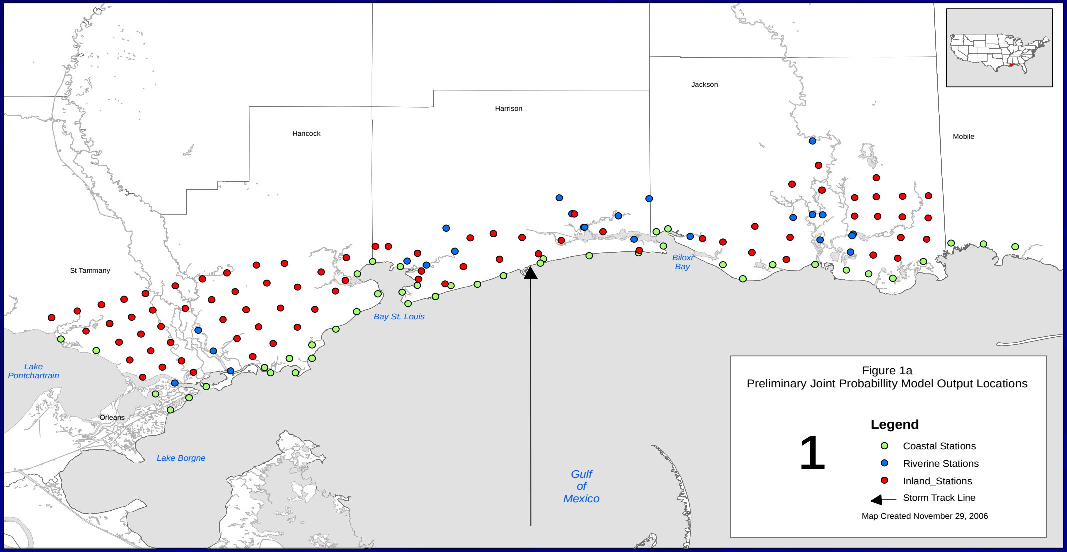
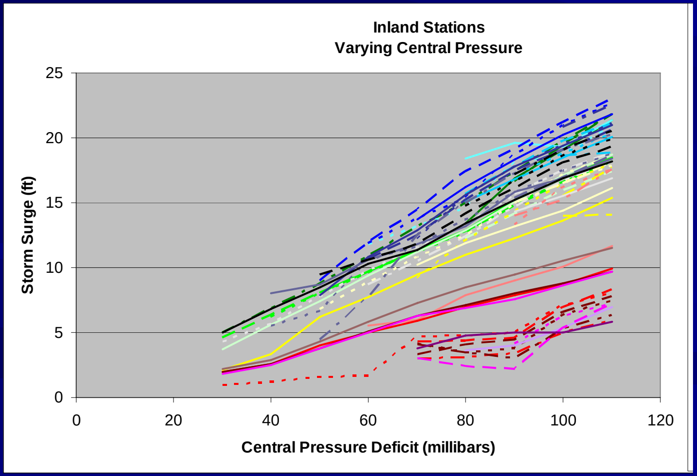
Parameter Sensitivity Tests







Results:

- □ $\Delta P > Rp > \theta > U$
- Track spacing = Rp
- 3 tracks west & 1 east

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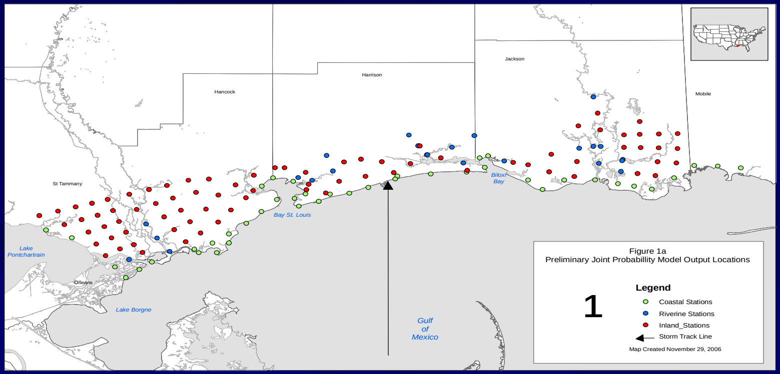
Full JPM ("Gold Standard")



**360 Synthetic storms each on multiple tracks spaced at Rp yields:
2,967 model runs**

	Values of Rp(nmi)					
Central Pressure Deficit (mb)	**Normalized Probability**	0.01100	0.22200	0.53400	0.22200	0.01100
45.6	0.04958	6.94	13.43	24.38	44.28	85.71
48.6	0.16607	6.63	12.84	23.32	42.34	81.96
56.1	0.28435	5.99	11.59	21.05	38.23	74.00
69.1	0.28435	5.16	10.00	18.15	32.96	63.80
87.6	0.16607	4.36	8.44	15.33	27.84	53.88
111.8	0.04957	3.67	7.10	12.89	23.41	45.31

Forward Speed (m/s)	2.99	6.04	12.23
Normalized Probability	0.16667	0.66667	0.16667

Headings (Theta) *	-73.0	-32.7	7.3	49.4
Normalized Probability	0.13299	0.36701	0.36701	0.13299

(direction to; degrees clockwise from North)

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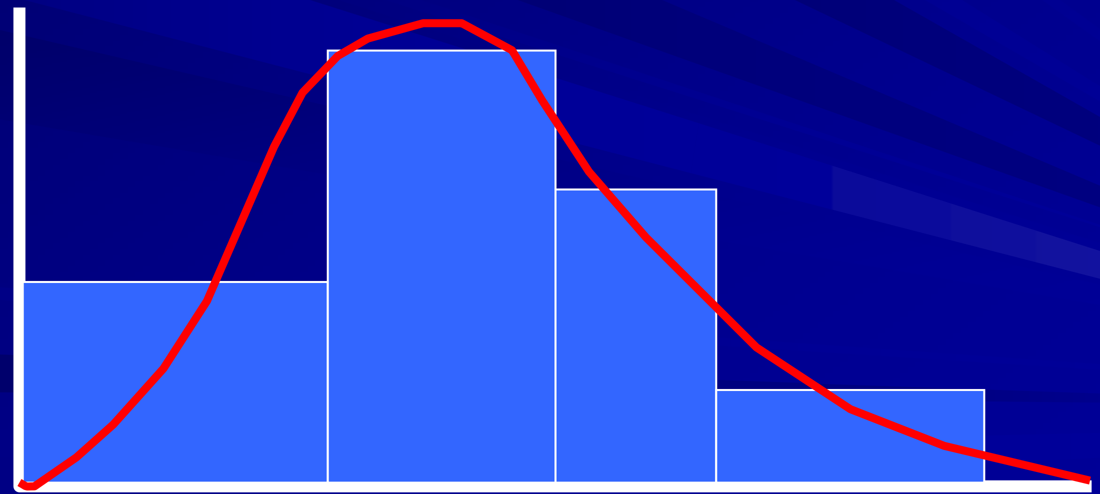
The Bayesian Quadrature Method

$$P[\eta_{\max(1\,yr)} > \eta] = \lambda \int \ldots \int_{\underline{x}} f_{\underline{X}}(\underline{x}) P[\eta(\underline{x}) > \eta] d\underline{x}$$

$$P[\eta_{\max(1\,yr)} > \eta] \approx \sum_{i=1}^{n} \lambda_i P[\eta(\underline{x}_i) > \eta]$$



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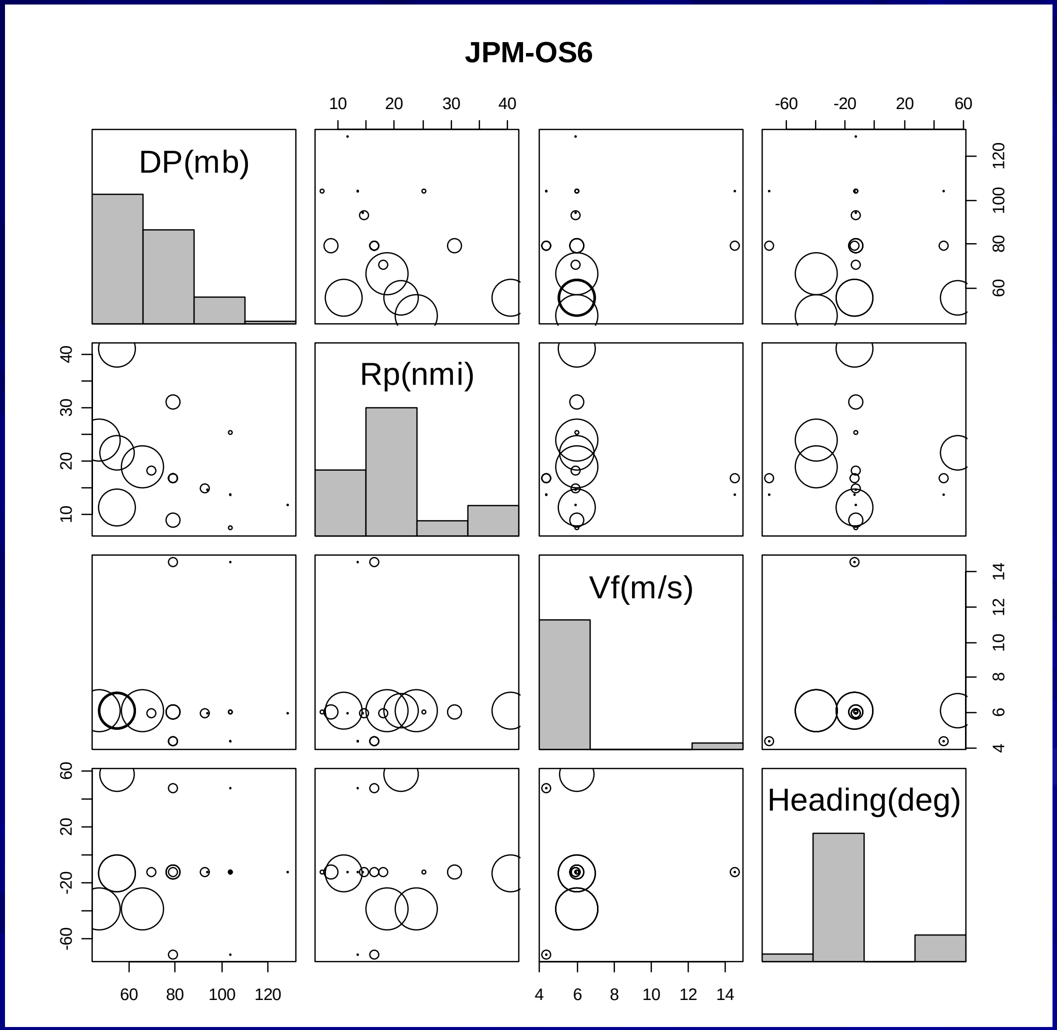
The Bayesian Quadrature Method



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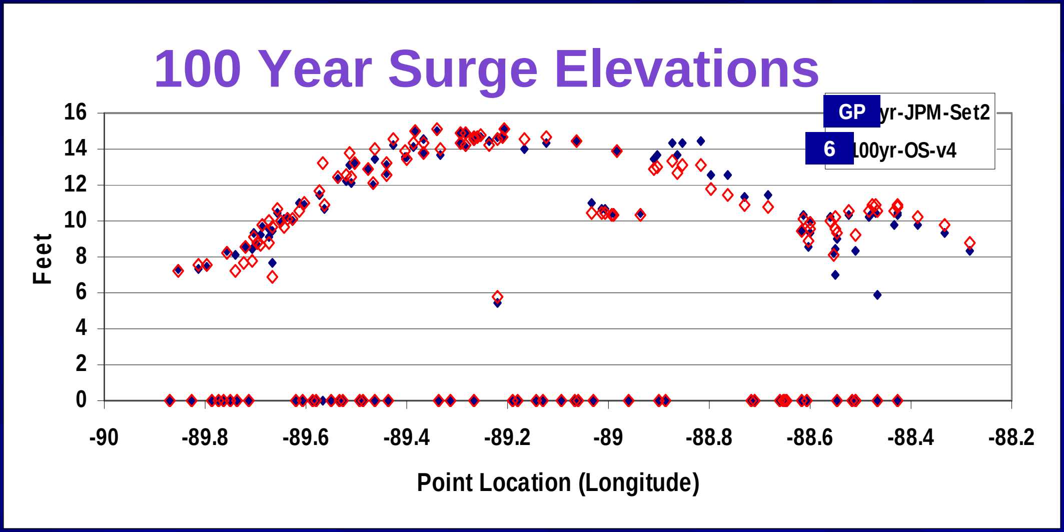
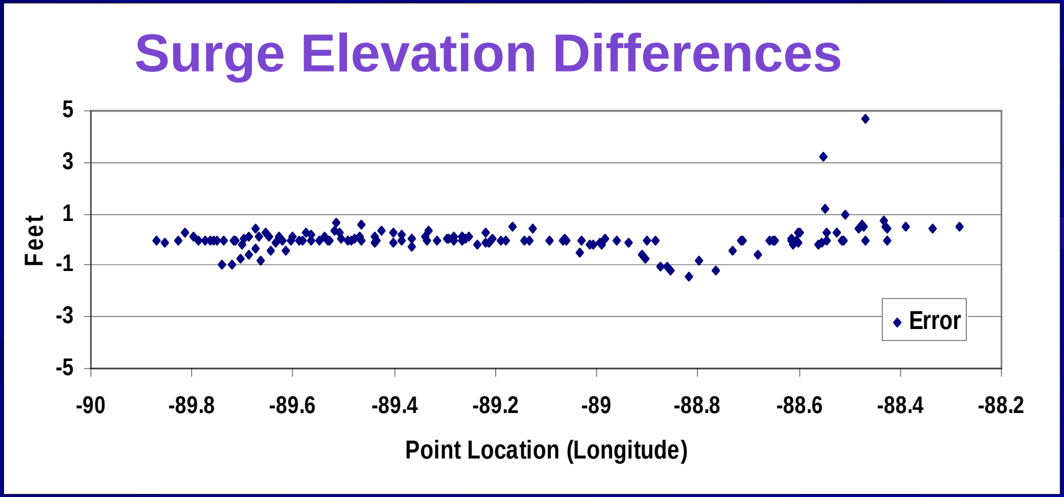
Comparison Of JMP-OS6 & "GS"





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The JPM-OS6 Case

156 Greater Storms

StormID (OWI notation)	dp(mb;coast)	Rp(nmi;offshore)	Vf(m/s)	theta(deg)	Prob.	Annual Rate (each JOS6###% track)
JOS6%	66.69	18.61	6.047	-38.91	1.33E-01	1.32E-03
JOS6%	57.17	39.82	6.047	-13.49	1.20E-01	2.55E-03
JOS6%	49.72	22.93	6.047	-38.92	1.33E-01	1.63E-03
JOS6%	57.17	10.83	6.047	-13.49	1.20E-01	6.94E-04
JOS6%	57.17	20.77	6.047	56.66	1.08E-01	1.19E-03
JOS6%	92.95	14.7	5.943	-12.81	3.42E-02	2.68E-04
JOS6%	78.59	30.8	6.014	-12.82	5.34E-02	8.77E-04
JOS6%	78.59	16.56	4.349	47.33	4.20E-02	3.71E-04
JOS6%	78.59	8.904	6.014	-12.82	5.34E-02	2.54E-04
JOS6%	78.59	16.56	14.54	-12.86	3.49E-02	3.08E-04
JOS6%	70.02	17.98	5.943	-12.82	3.42E-02	3.28E-04
JOS6%	78.59	16.56	4.346	-71.04	4.20E-02	3.71E-04
JOS6%	128.7	11.66	5.943	-12.81	1.06E-02	6.58E-05
JOS6%	103.7	25.3	6.014	-12.82	1.65E-02	2.23E-04
JOS6%	103.7	13.6	4.349	47.33	1.30E-02	9.44E-05
JOS6%	103.7	7.313	6.014	-12.82	1.65E-02	6.44E-05
JOS6%	103.7	13.6	14.54	-12.86	1.08E-02	7.83E-05
JOS6%	94.47	14.53	5.943	-12.82	1.06E-02	8.20E-05
JOS6%	103.7	13.6	4.346	-71.04	1.30E-02	9.43E-05

Notes

1: the Reference storms (e.g., JOS6001) are not assigned any rate. Only JOS6001A, JOS6001B, etc. are used in the probability calculations.

2. The annual rate for each storm is calculated as the storm probability displayed here, times the annual rate of greater storms (2.88E-4 storms/km/yr), times the storm spacing (Rp) in km.

3. The annual rates in column I are the lambda terms in the report text

72 Lesser Storms

StormID (OWI notation)	dp (mb; coast)	Rp (nmi; offshore)	Vf(m/s)	theta (deg)	Prob.	Annual Rate (each *% track)
CAT2001%	46.38	41.59	5.416	8.758	4.74E-02	9.37E-04
CAT2002%	37.75	53.63	2.995	23.55	2.93E-02	7.47E-04
CAT2003%	44.28	21.64	3.4	63.87	7.61E-02	7.83E-04
CAT2004%	40.71	12.72	4.931	-9.324	1.76E-01	1.06E-03
CAT2005%	31.78	44.24	4.881	-11.27	3.92E-02	8.25E-04
CAT2006%	32.11	17.19	6.096	31.22	9.30E-02	7.60E-04
CAT2007%	34.67	24.32	6.941	-71.07	8.75E-02	1.01E-03
CAT2008%	47.53	16.94	4.378	-31.63	6.26E-02	5.04E-04
CAT2009%	42.09	27.82	3.71	-59.19	9.49E-02	1.25E-03
CAT2010%	34.67	24.31	2.458	-5.25	8.75E-02	1.01E-03
CAT2011%	44.28	21.64	10.5	-13.83	7.62E-02	7.83E-04
CAT2012%	37.75	53.63	7.894	-45.75	2.93E-02	7.46E-04
CAT2013%	37.04	29.79	6.644	46.64	1.01E-01	1.44E-03

Notes

1: the Reference storms (e.g., CAT2001) are not assigned any rate. Only CAT2001A, CAT2001B, etc. are used in the probability calculations.

2. The annual rate for each storm is calculated as the storm probability (column H), times the annual rate of storms (2.567E-4 storms/km/yr), times the storm spacing (Rp) in km.

3. The annual rates in column I are the lambda terms in my notes.

Total of 228 Synthetic storms to be modelled

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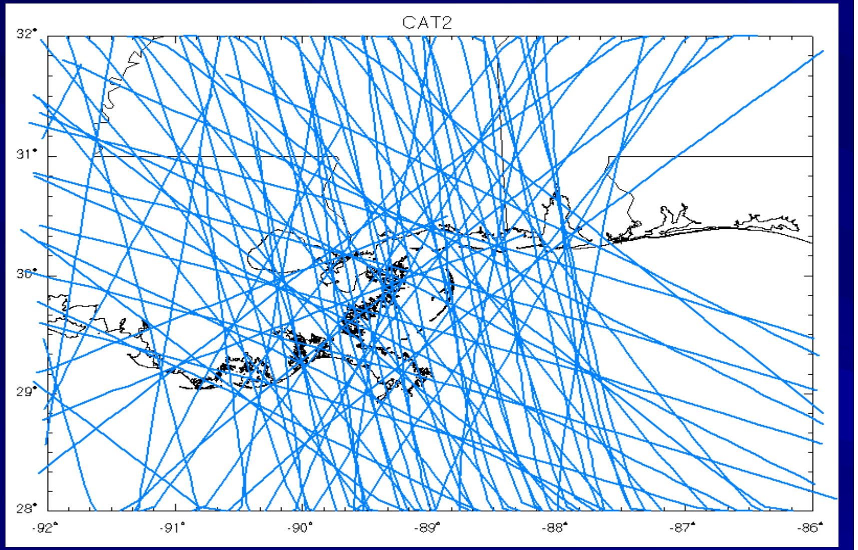
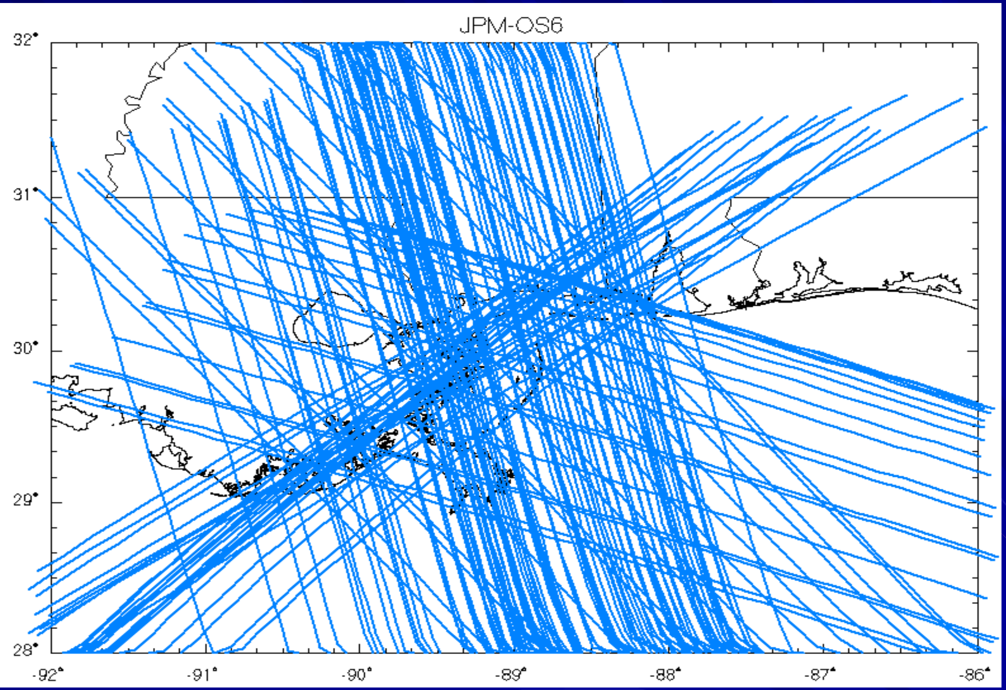
Detailed Tracks

72 LESSER STORMS



152 GREATER STORMS



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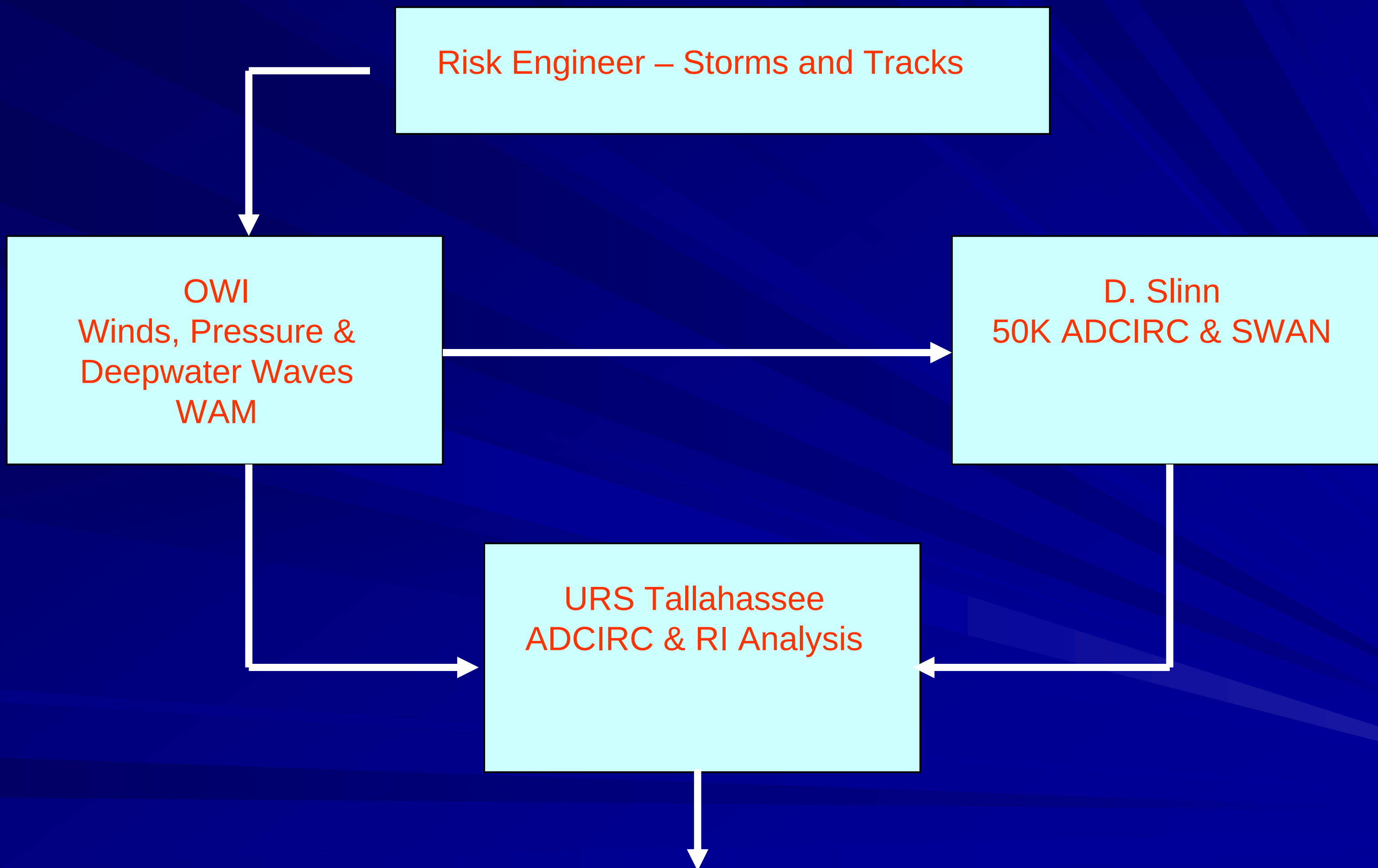
“A Whole Bunch Of Modeling”



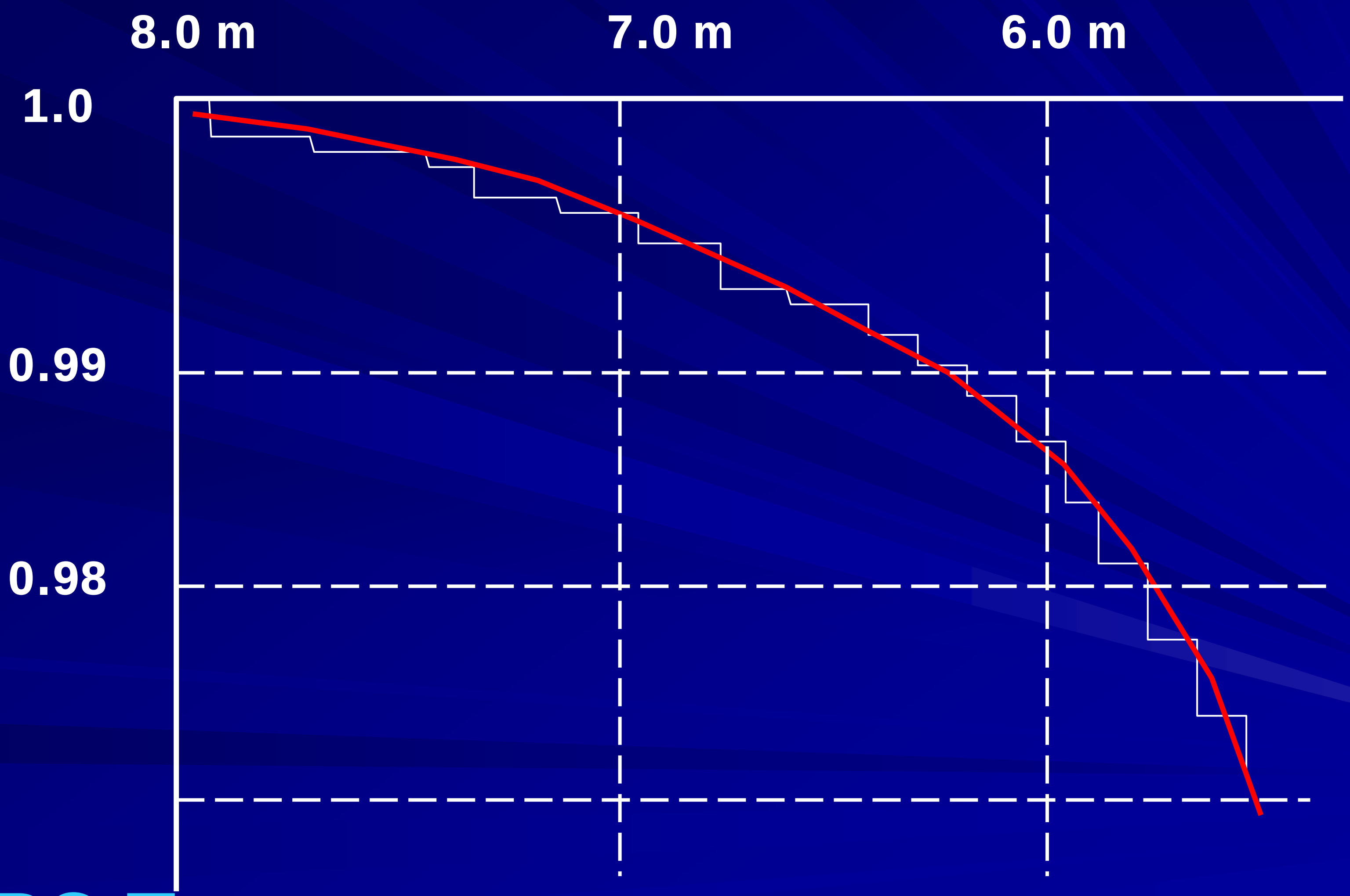
JPM With The “Random Term”

$$P[\eta_{\max(1\,yr)} > \eta] = \lambda \int \ldots \int_{\underline{x}} f_{\underline{X}}(\underline{x}) P[\eta_m(\underline{x}) + \varepsilon > \eta]\, d\underline{x} \approx \sum_{i=1}^{n} \lambda_i P[\eta_m(\underline{x}_i) + \varepsilon > \eta]$$

$$\sigma_\varepsilon = \sqrt{\sigma_{\varepsilon 1}^2 + \sigma_{\varepsilon 2}^2 + \sigma_{\varepsilon 3}^2 + \sigma_{\varepsilon 4}^2}$$

- Astronomical tide $\sigma_{\varepsilon 1}$ = 0.647 feet
- Holland B variations $\sigma_{\varepsilon 2}$ = 0.15 * surge elevation
- Model imprecision $\sigma_{\varepsilon 3}$ = 0.77 feet
- Real storm variability $\sigma_{\varepsilon 4}$ = 1.17 feet

Cumulative Distribution Function



Completion

- Reconcile/combine with MsCIP
- Add WHAFIS Waves
- Prepare DRAFT maps
- Final Digital Maps