Development of Hurricane Hazard Curves and Design Parameters with Atmospheric and Ocean Modeling

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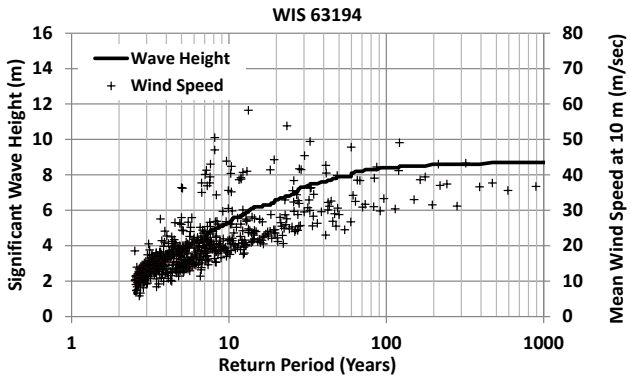
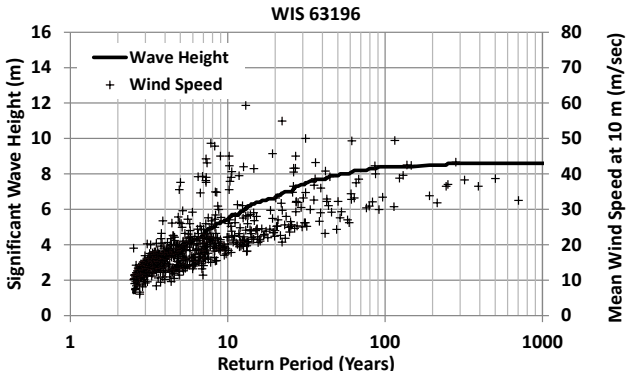
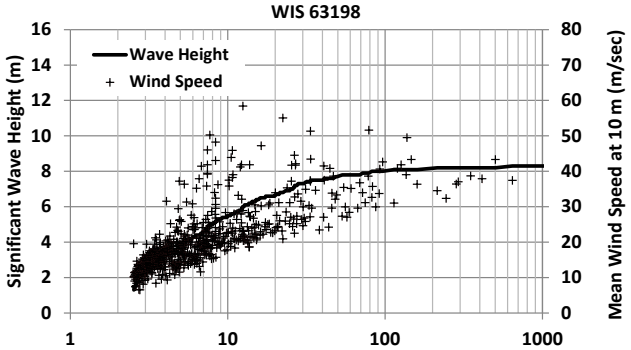
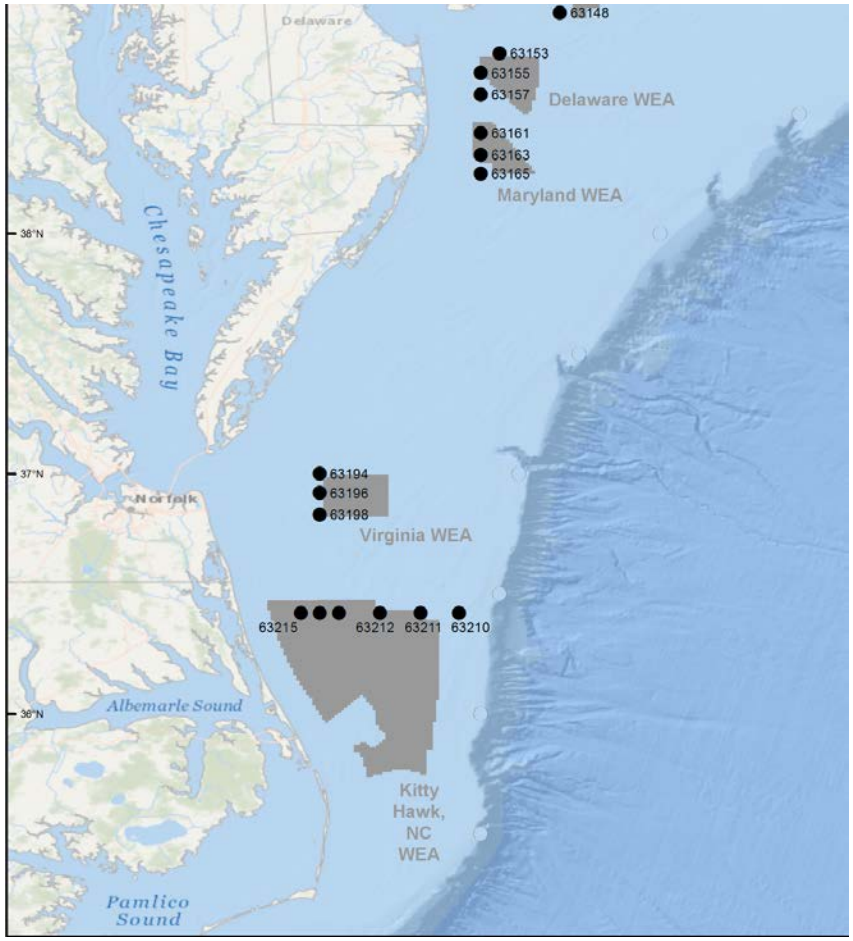
Example Problem: Hurricane Wind-Wave Hazard









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Hurricane Hazard Model Overview

- Two Main Model Components
  - Hurricane hazard simulation model (track, intensity and frequency)
    - Probabilistic models for Radius to maximum winds and the Holland B parameter
  - Wind field and wave models
- Published in the peer reviewed open literature
  - 3 papers in meteorological journals (filling model, B and RMW models, and wind field model)
  - 4 papers in engineering journals (stochastic model methodology and wind field model)
  - First ever track model
  - First model to model B as a random variable
- Wind field model extensively validated
- Used in FEMA coastal flood studies
- Used in FEMA's Hazus loss estimation tool HAZUS

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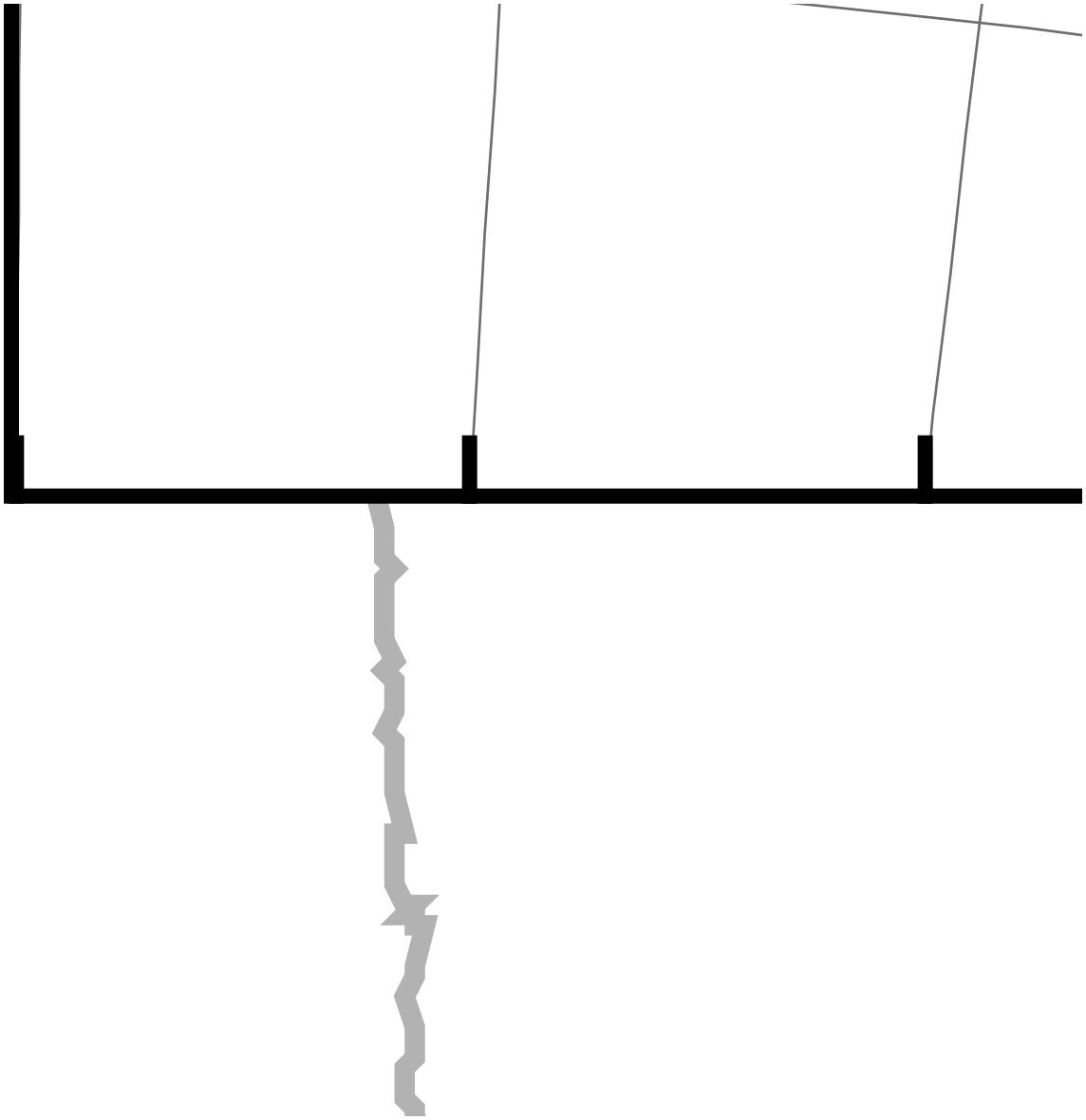
Simulation Methodology



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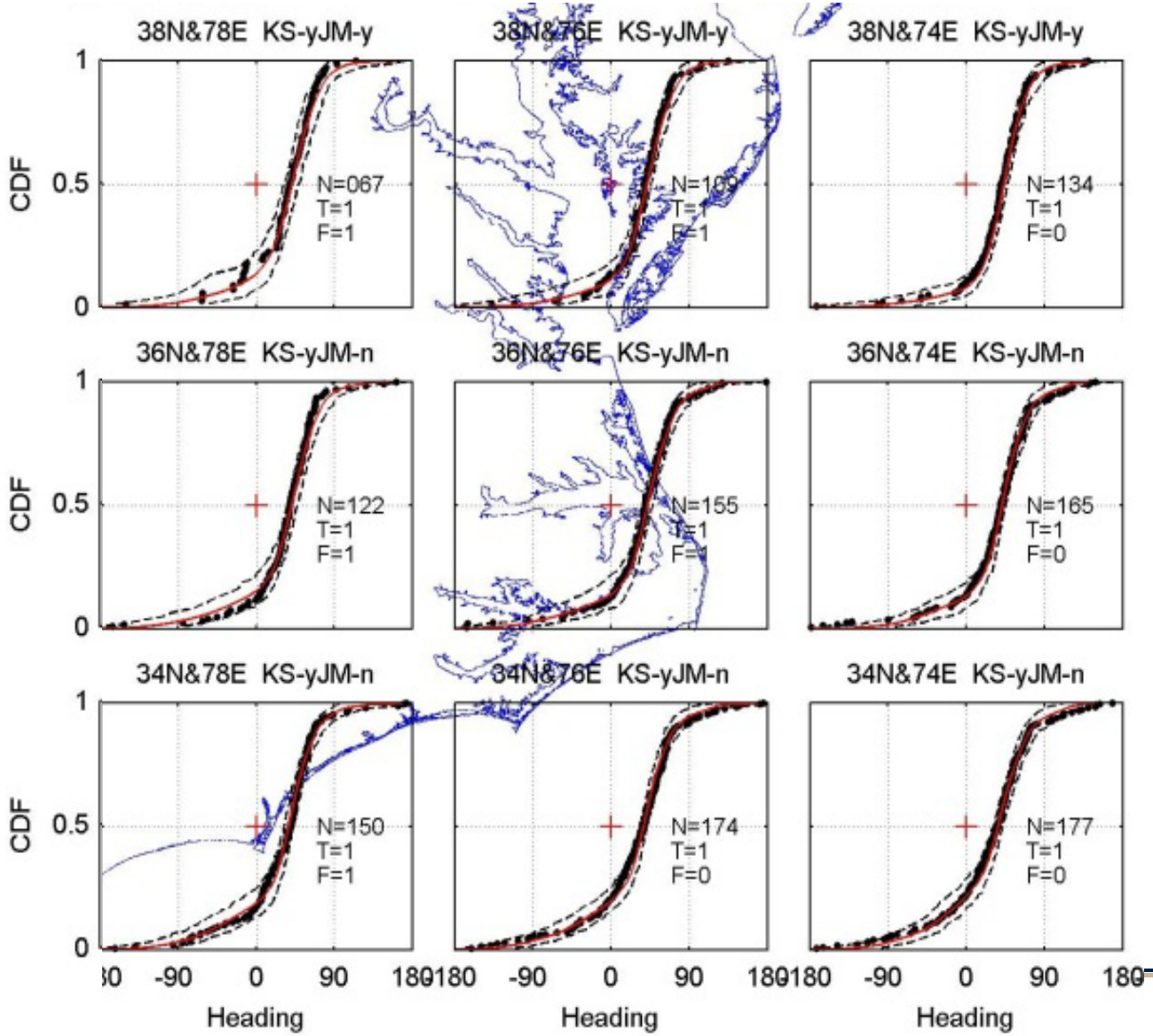
Simulation Model Validation – Storm Heading



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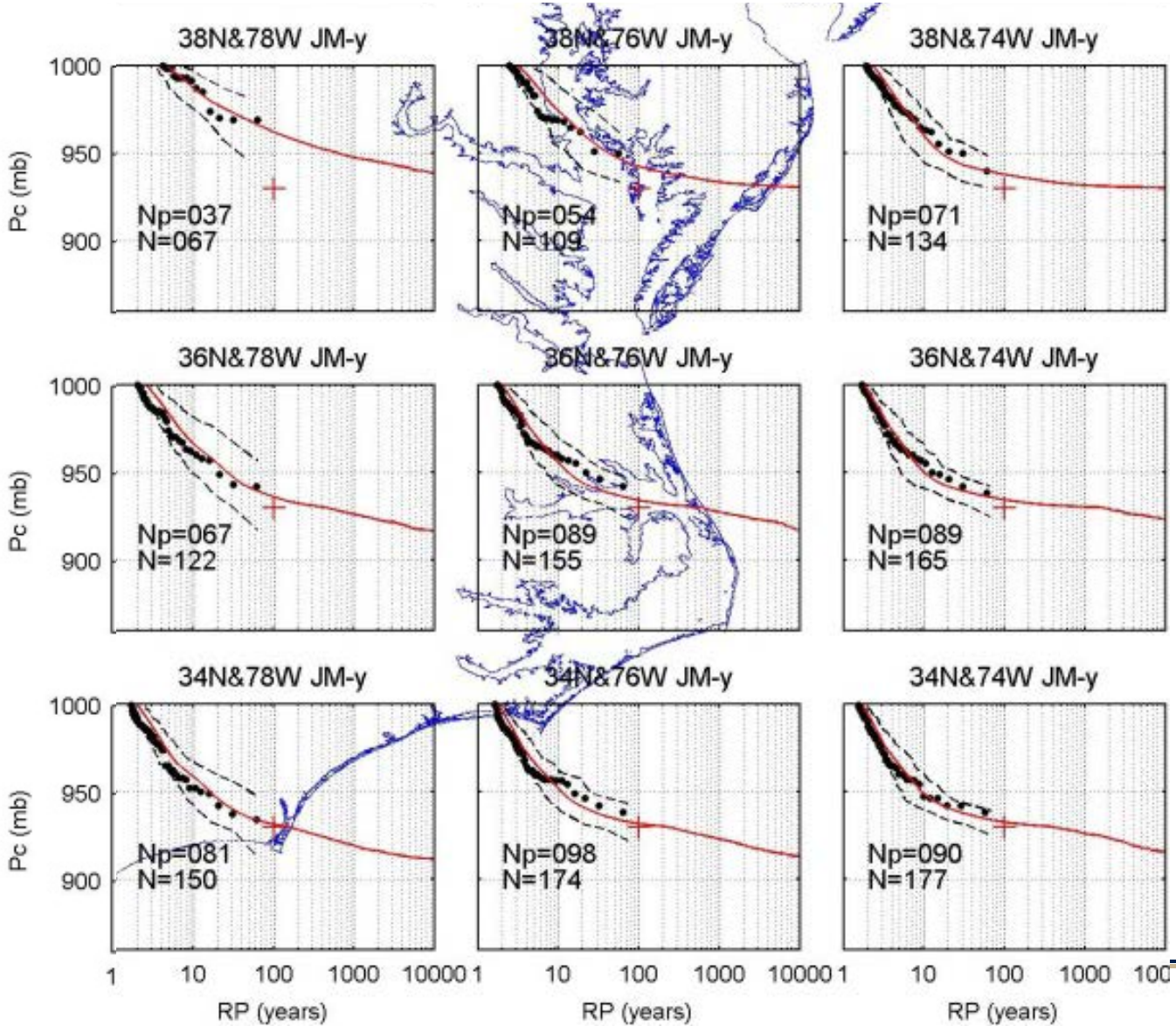
Simulation Model Validation – Intensity and Frequency



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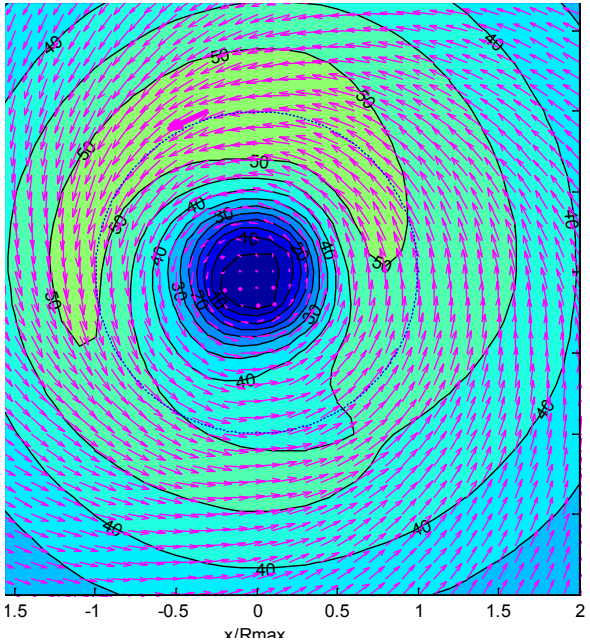
Wind Field Model



- **Wind field:** generated using 2-D numerical slab model representation of the hurricane boundary layer

- **Three step process**:
  - Estimate mean gradient winds
  - Estimate mean surface level winds
  - Apply gust factor and high resolution terrain models to estimate gust, using one minute average surface level winds in a given exposure.

- **Validation:** Wind field model extensively validated against marine and land observations

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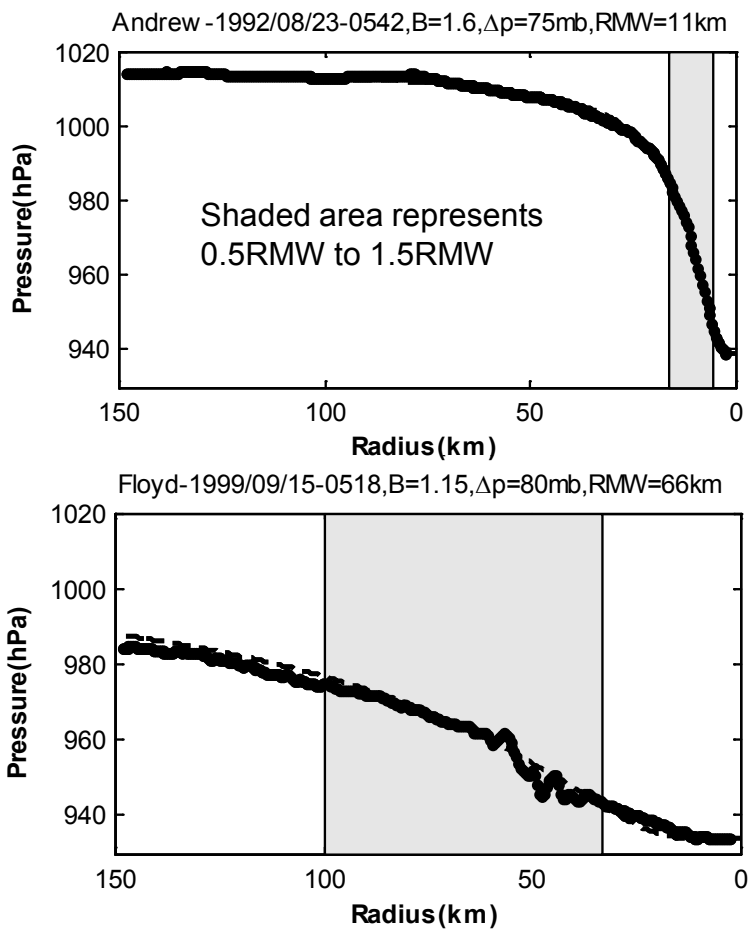
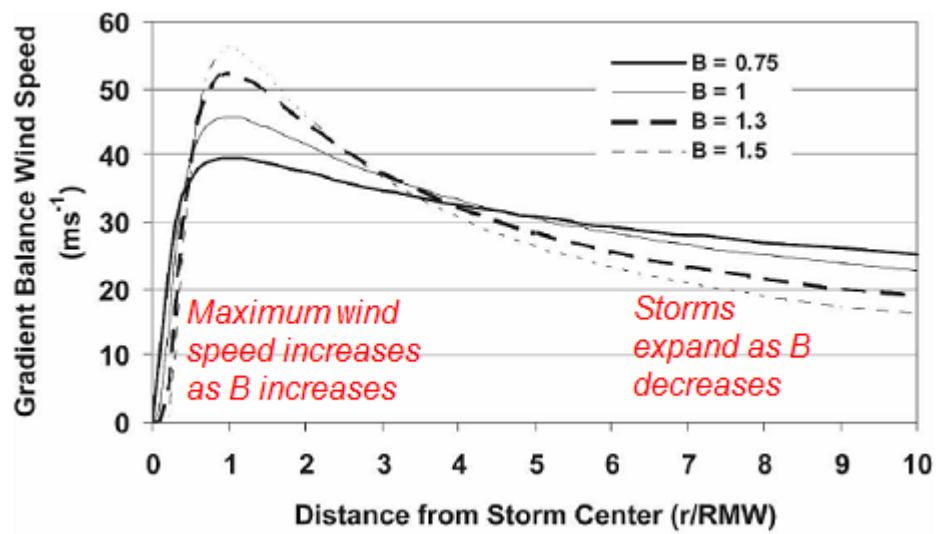
Wind-Pressure Relationships



- An additional parameter beyond central pressure, translation speed and size is needed to model maximum wind speed



B typically ranges between 0.5 and 2.2

$$V_{G\max} \approx \sqrt{\frac{B\Delta p}{e\rho}}$$

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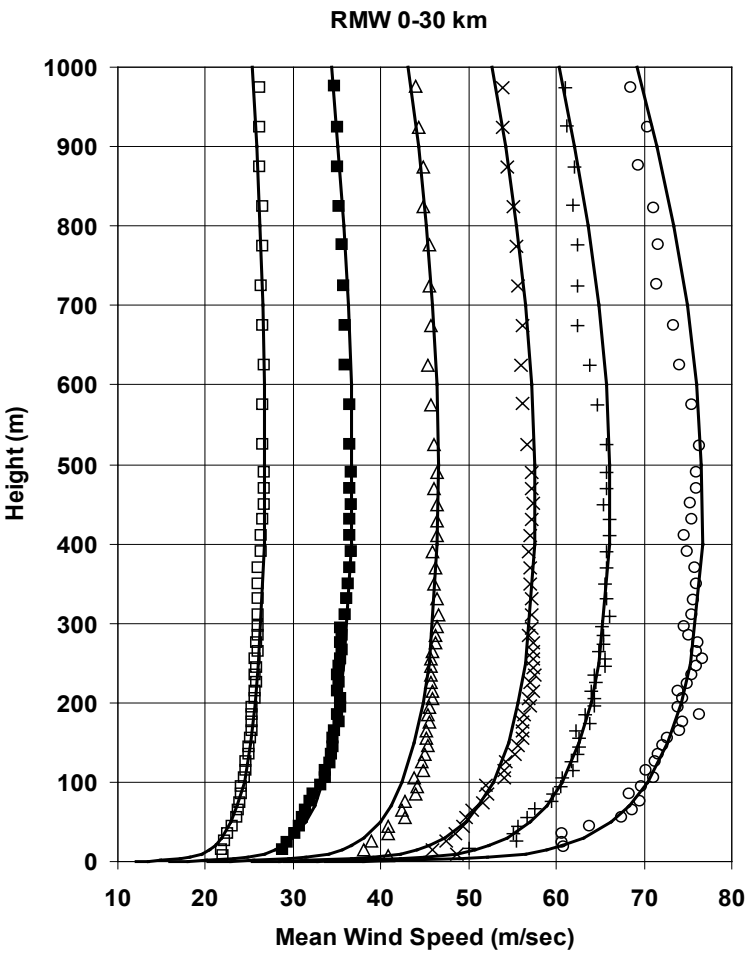
Mean Hurricane Boundary Layer Model



$$U(z) = \frac{u_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - 0.5\left(\frac{z}{H}\right)^2\right]$$

$$z_0 = 10\exp\left[-k/\sqrt{C_{d_{10}}}\right]$$

$$C_{d_{10}} = (0.49 + 0.065|U(3600,10)|)10^{-3}$$
$$C_{d_{10}} \leq C_{d_{max}}$$

$$C_{d_{max}} = (0.0881r + 17.66)10^{-4} \;\; ;$$
$$0.0019 \leq C_{D_{max}} \leq 0.0025$$

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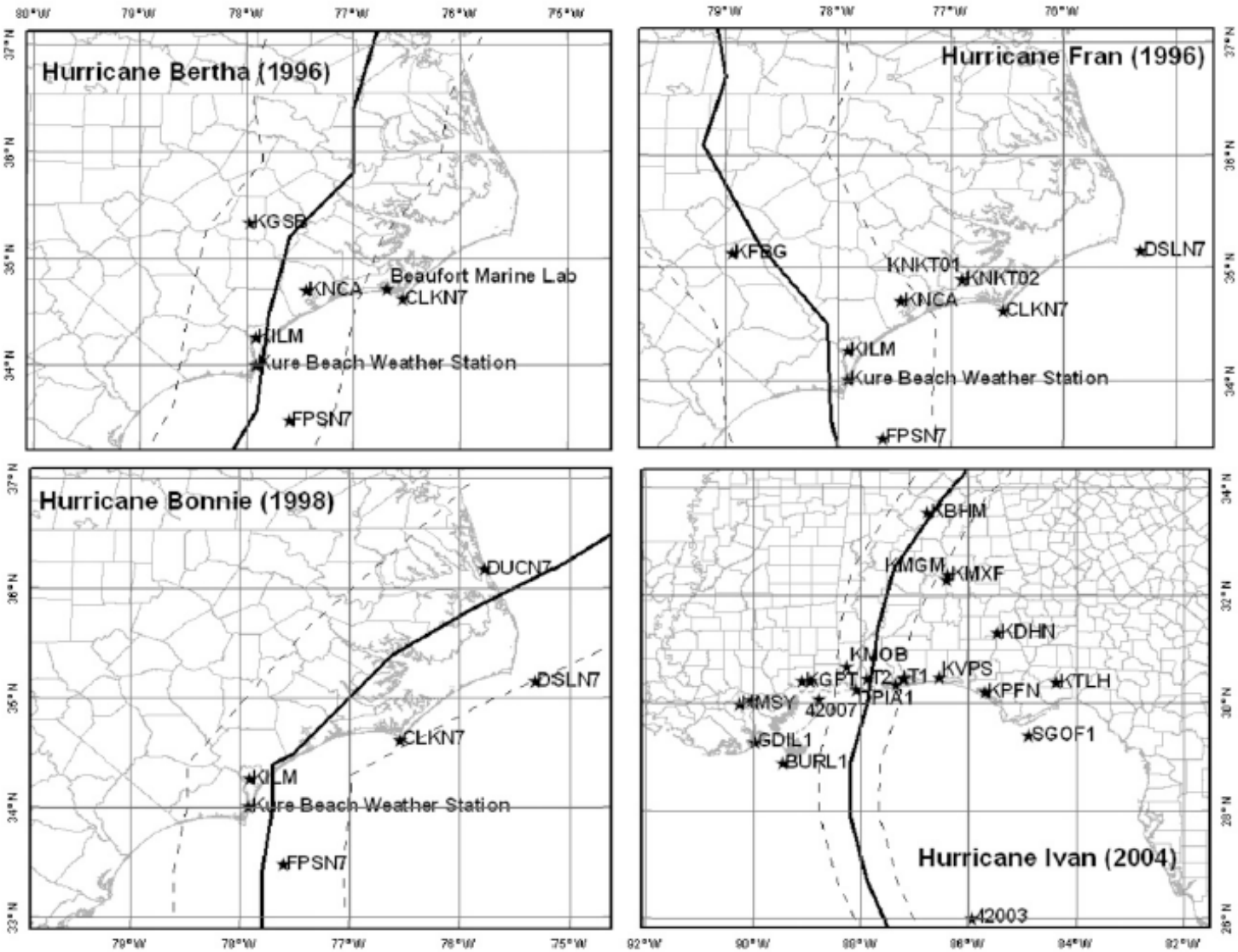
Example Hurricane Validation Study



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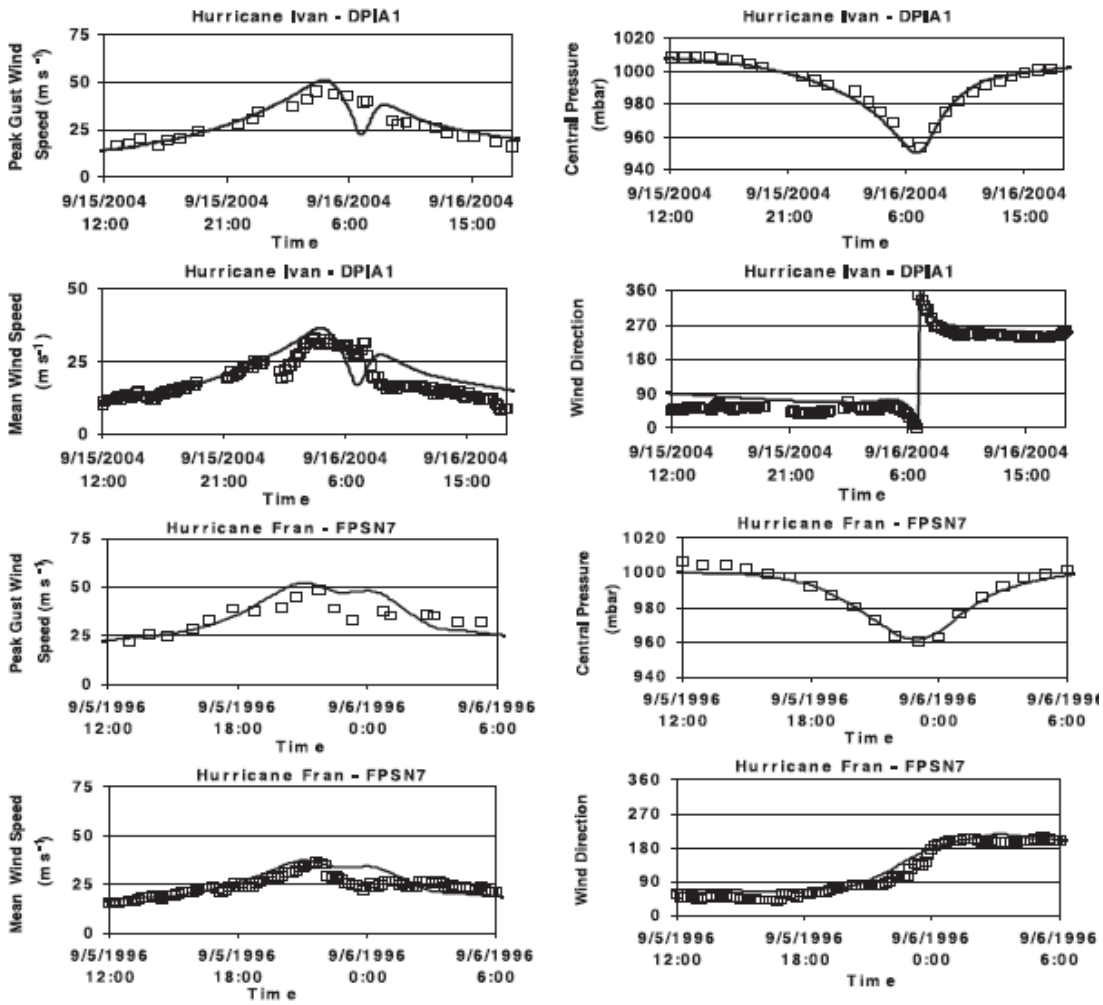
Example Time Series Comparisons



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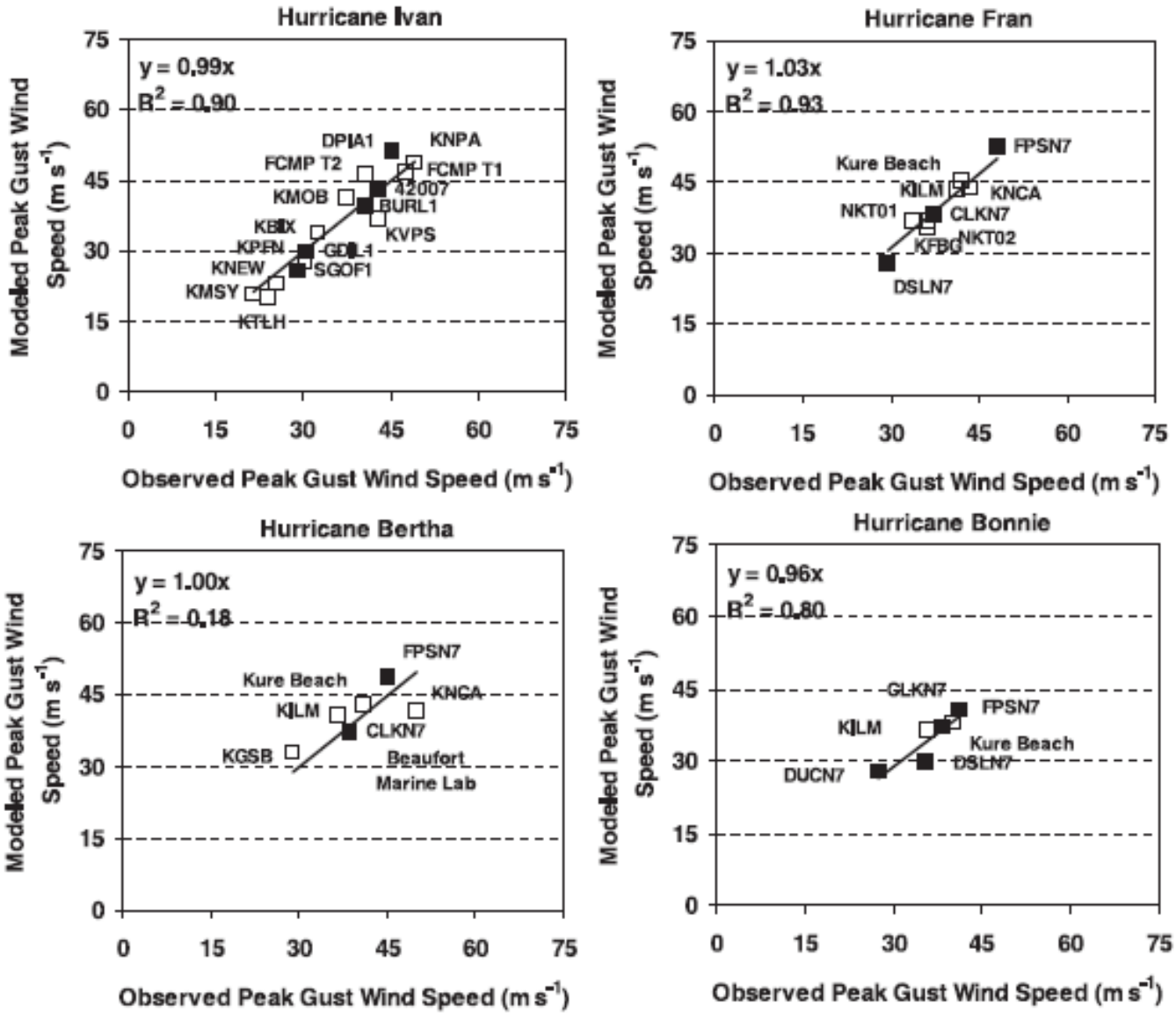
Example Wind Model Validation Summary



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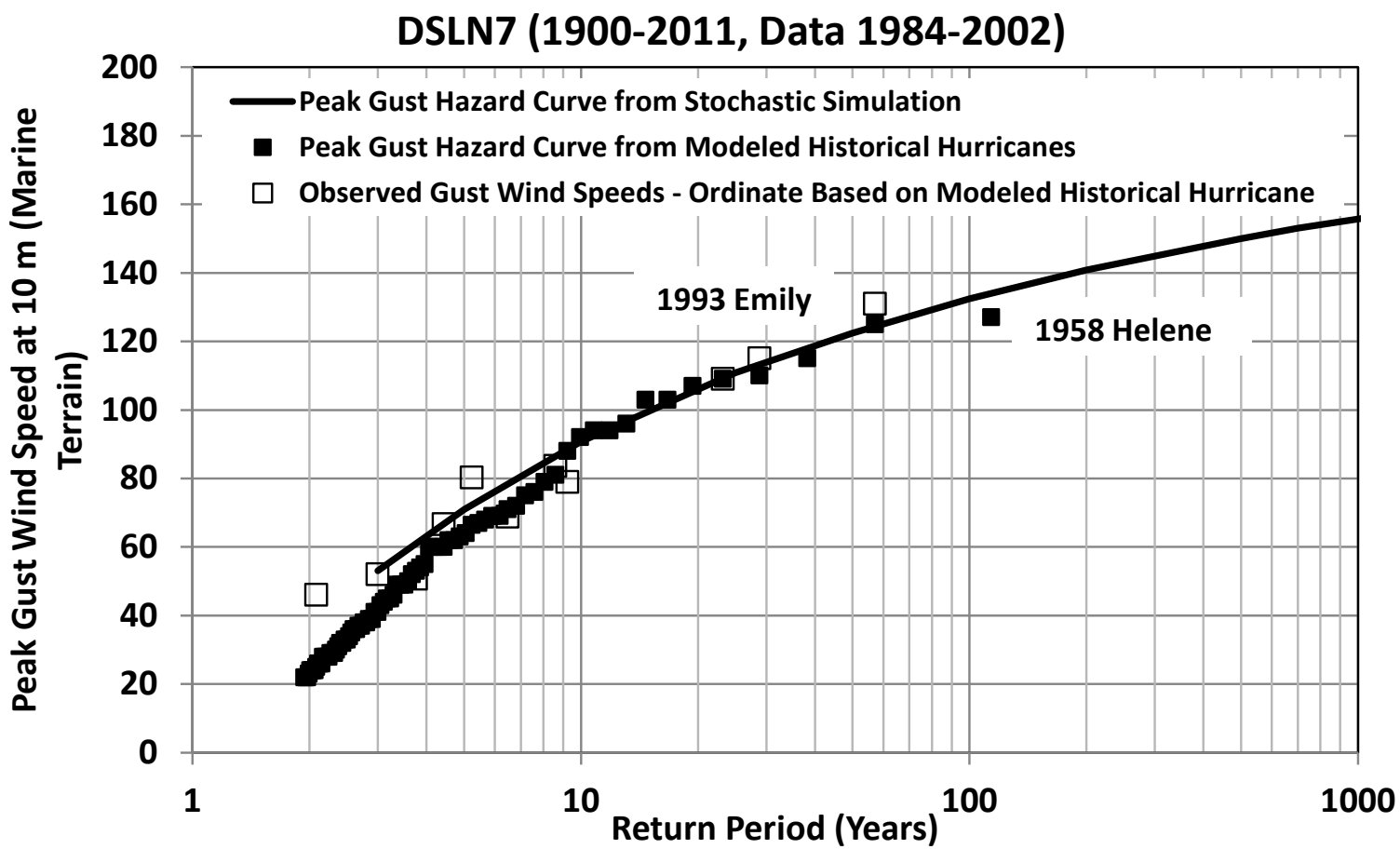
End-to-End Wind Model Validation



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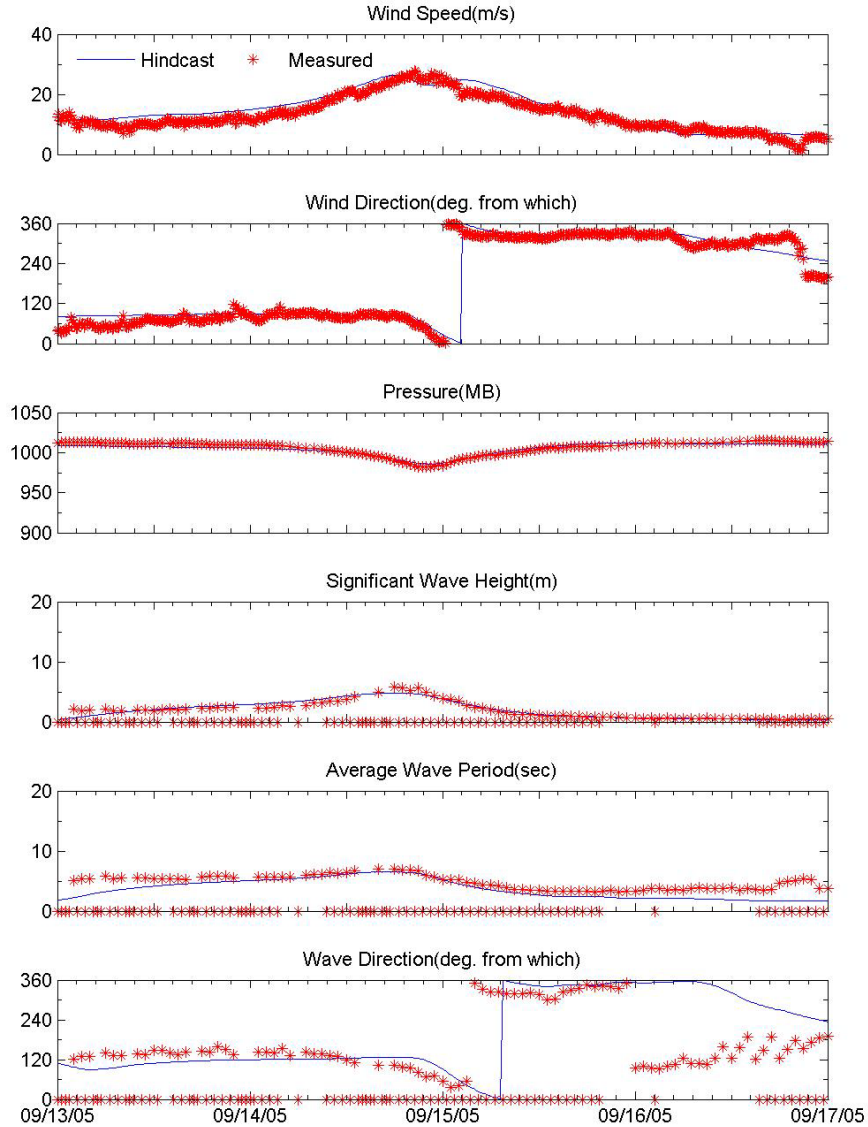
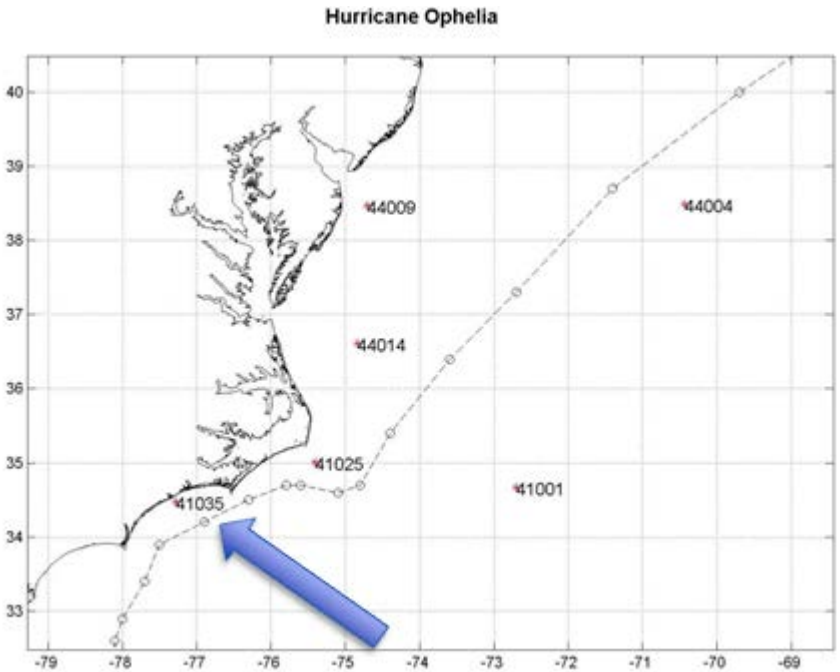
Wind –Wave Model Validation – Hurricane Ophelia

Hurricane Ophelia Hindcast at 41035





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Final Wind-Wave Simulations

- Retained all simulated storms passing north of 35˚ N and west of -70˚ W and pass within 250 km of a site being investigated.
- Resulted in 50,476 tropical cyclones
- Too many ADCIRC-UnSWAN simulations in an acceptable period of time
- Developed a reduced storm set randomly selecting smaller numbers of storms within Saffir Scale storm categories.
- $P_a(p_{Hs} < P_{Hs}) = 1 - exp[-\lambda P(p_{Hs} < P_{Hs})]$
- $P(p_{Hs} < P_{Hs})$ obtained by rank ordering by wind or wave heights and their corresponding rates such that:
- $P(p_{Hs} < P_{Hs}) = 1 - \frac{\sum_{i=1}^{i=i_{Hs}} W_i}{\sum_{i=1}^{i=N} W_i}$

Storm Category	Original Storm Count	Reduced Storm Count	Weight
0	17207	100	172.07
1	17577	110	159.79
2	8516	150	56.77
3	5654	130	43.49
4	1379	130	10.61
5	143	50	2.86
Sum	50476	670	

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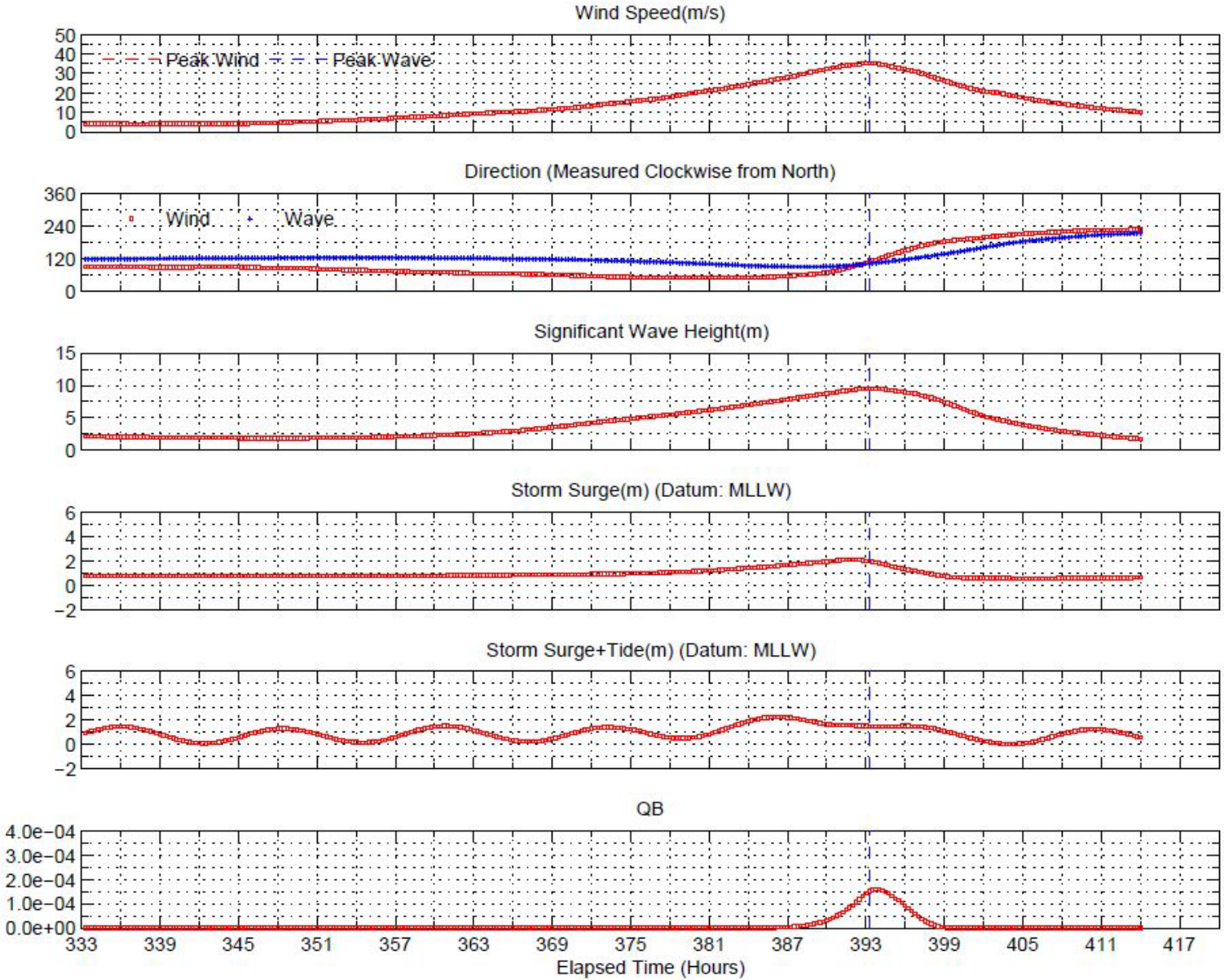
Example Simulation Output



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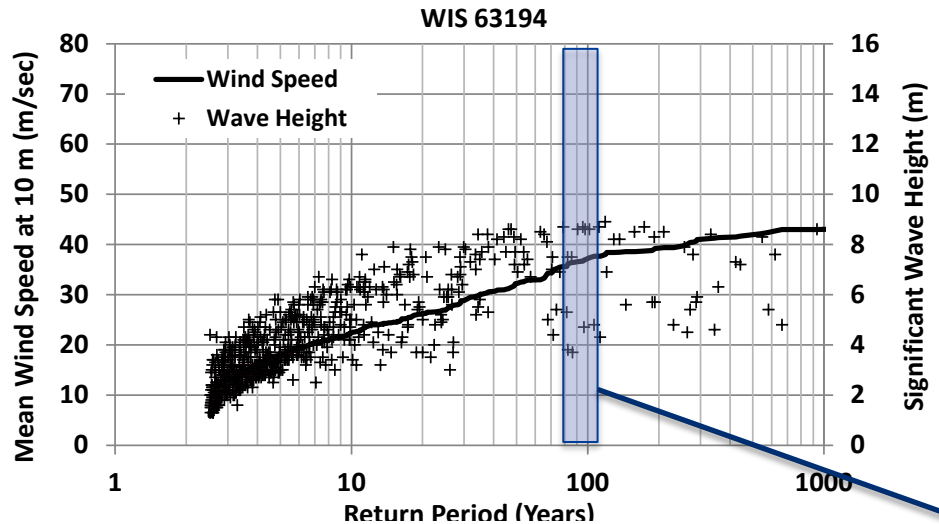
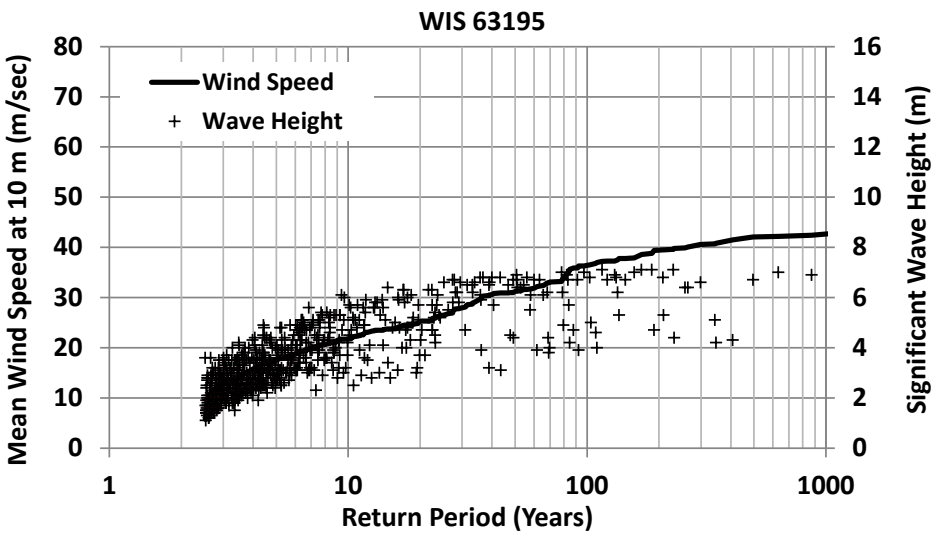
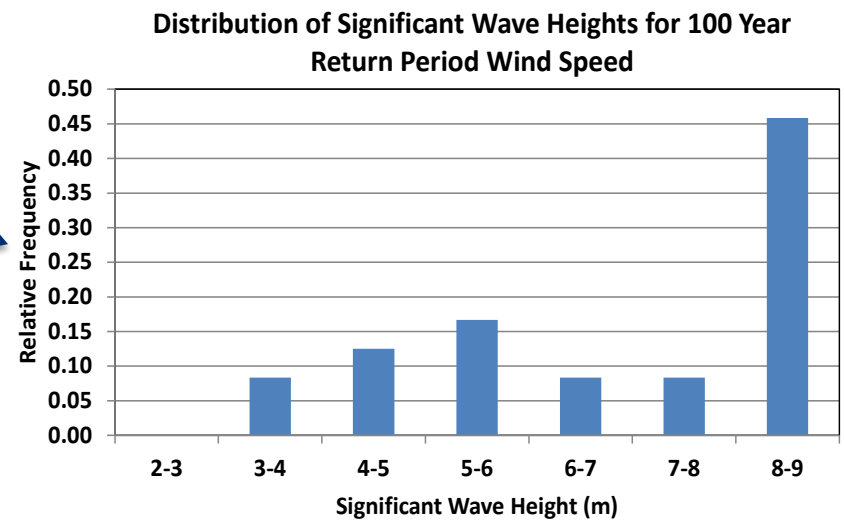
Example Results







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Summary and Conclusions

- The relative scarcity of hurricane wind and wave data renders standard statistical techniques for estimating design conditions uncertain
- Synthetic hurricane simulation models are routinely used in hurricane hazard modeling to solve this problem
- The method essentially allows for multiple (thousands) of realizations of the last 100 years of history providing:
  - Reliable estimates of long return period events
  - Reliable estimates of joint wind-wave statistics

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