On the Challenges of Analysis and Design of Turret-Moored FPSOs in Squalls

Arun Duggal
Amir Izadparast
Yu Ding

SNAME OFFSHORE SYMPOSIUM

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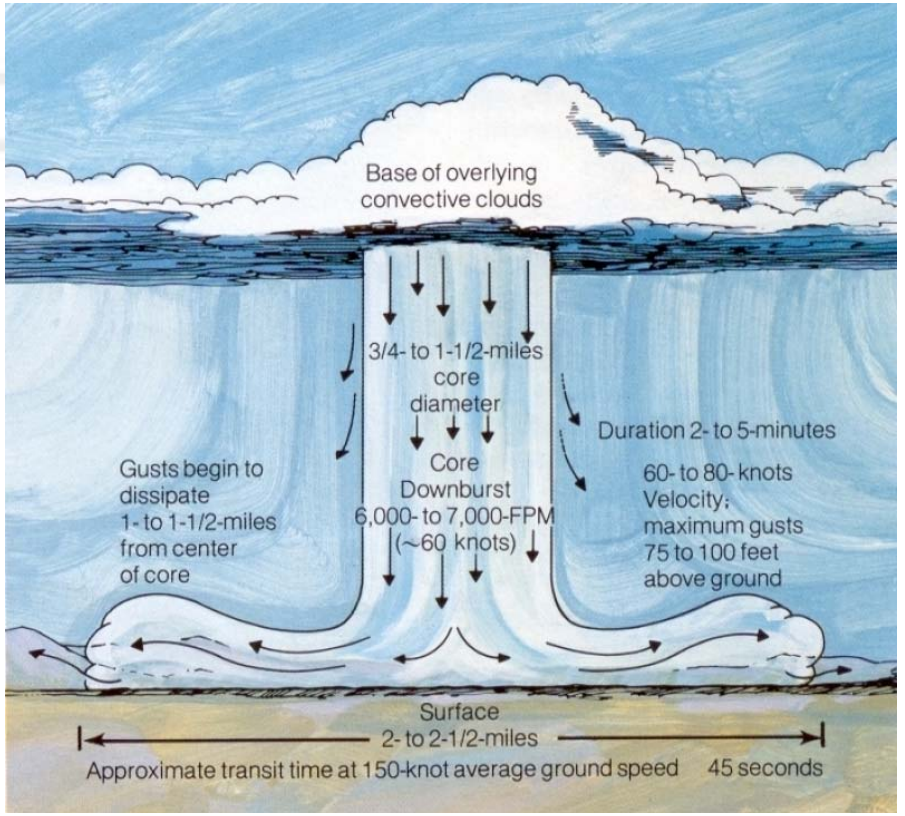
Overview

- Squalls, History & Current “Practice”
- Spread-Moored versus Turret-Moored Systems
- Challenges with Analysis and Design
  - Environmental Loading
  - Numerical Model Development
  - Response Statistics
  - Design Value Estimation
- Proposed Analysis Methodology
- Summary

What is a Squall?

- A sudden on set of Strong Winds with speeds increasing to at least 8 m/s knots and sustained at 11 m/s for at least 1-minute. The Intensity and Duration is longer than that of a Gust.



Objective

- 2006: *“Squall: Nightmare for Designers of Deep Water West African Mooring Systems”*

- 2014: *“Just another Design Environment Load Case…”*

History

- Squalls introduced as a Design Environment off West Africa in the early 2000's
  - 100-year Peak velocities up to 36 m/s
  - Currently many metocean reports for regions all over the world include squalls
- Design Input: Measured Squall Time Histories
- "Scale" to 100-year Design Value
- Use time histories with ambient waves and current to perform global anaysis
  - 2001: 3 to 9 time histories
  - 2009: 17 time histories
  - 2012: 73 time histories
  - 2014: 100+ time histories
- Design Value: Expected maximum, Observed Maximum, ??

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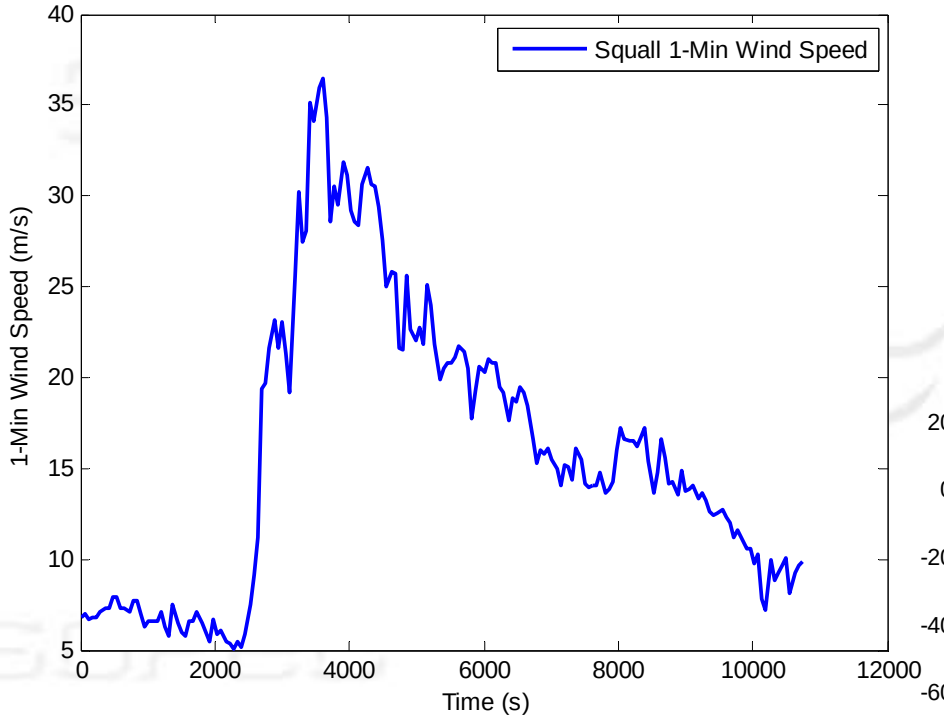
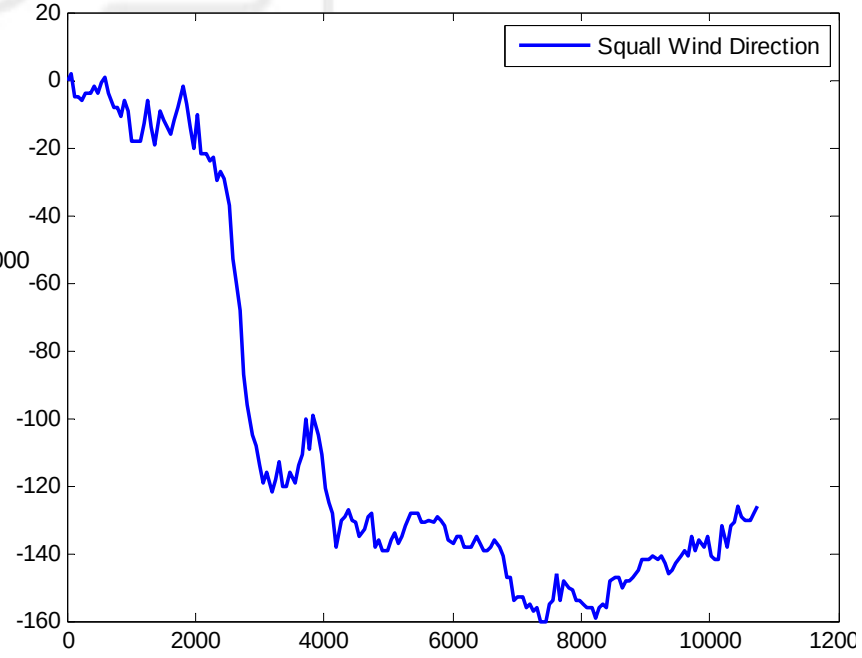
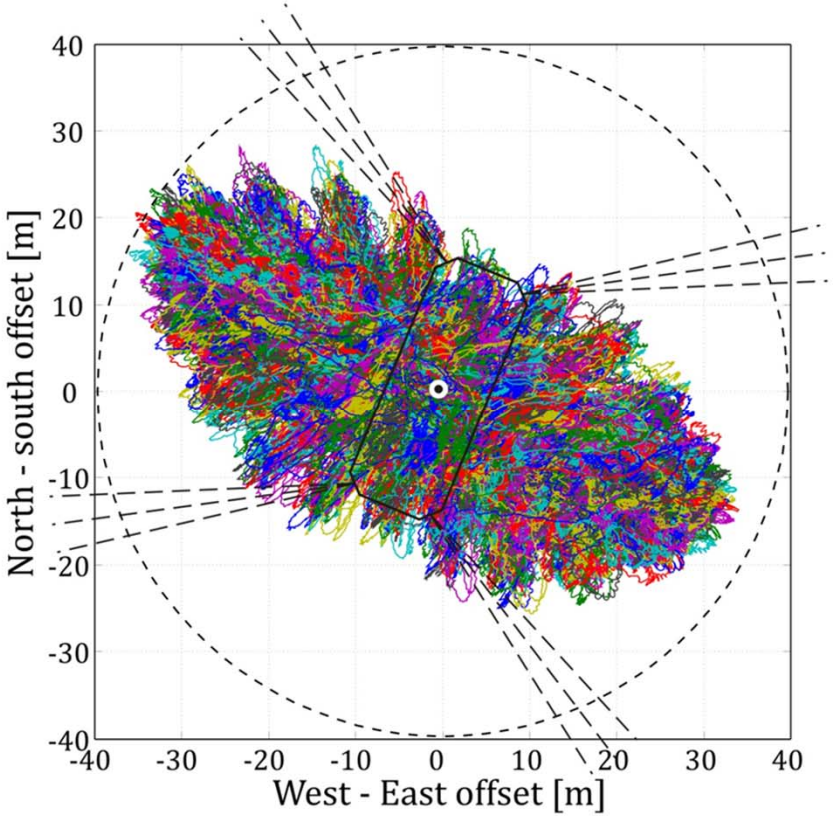
Typical Squall Time History



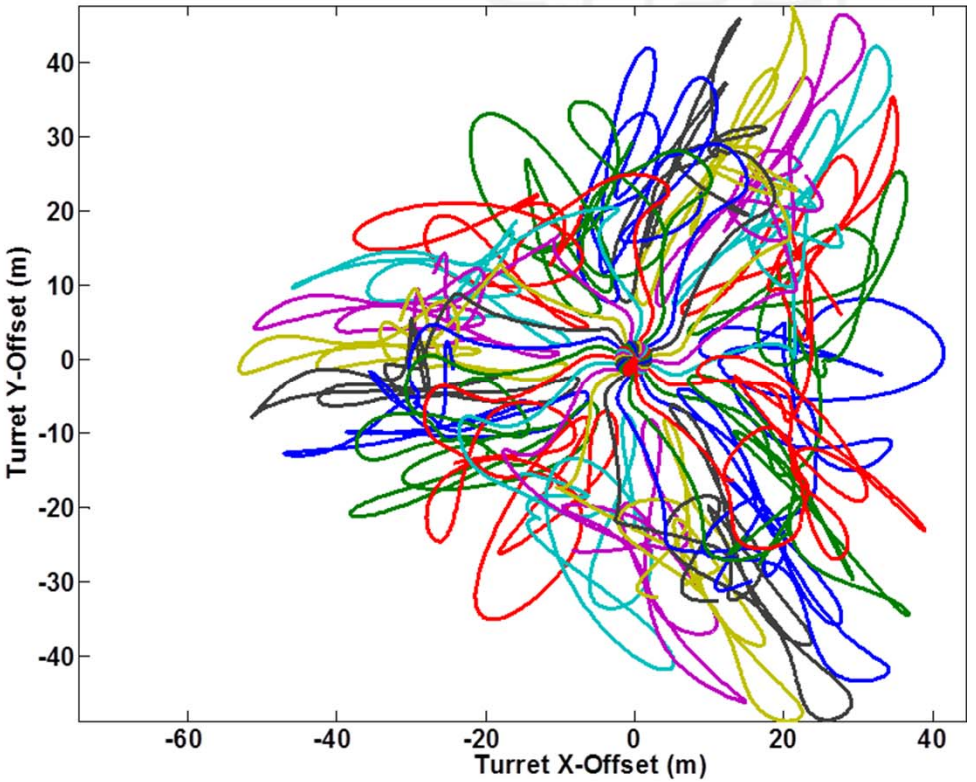


Spread-Moored versus Turret-Moored FPSO Response

Spread-Moored



Turret-Moored



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Wind Data Input:

- **Transient Process – Can we use a Design Methodology aligned with Traditional Stationary Processes?**
- **Amount of available data is "limited"**
- **Squall Time Histories**
  - To scale or not to scale…
  - **How should they be scaled?**
  - **How many are required to provide reasonable design estimates?**
  - **As the database increases can we "select" the most representative set for design?**
- Velocity Profile of Squall Wind Speed
- Wind Speed Coherence over Vessel Length
- What ambient environment to choose?
- …

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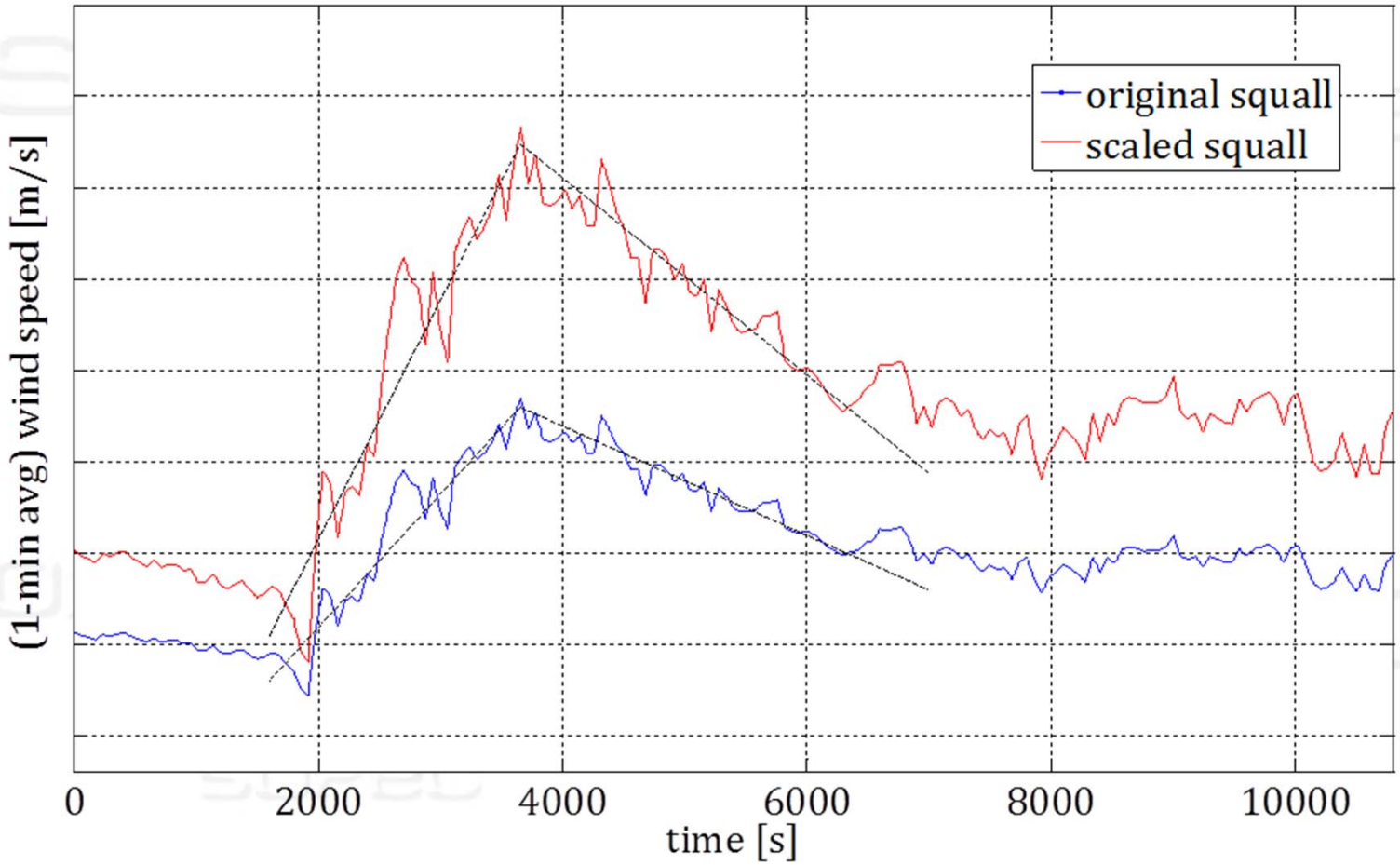
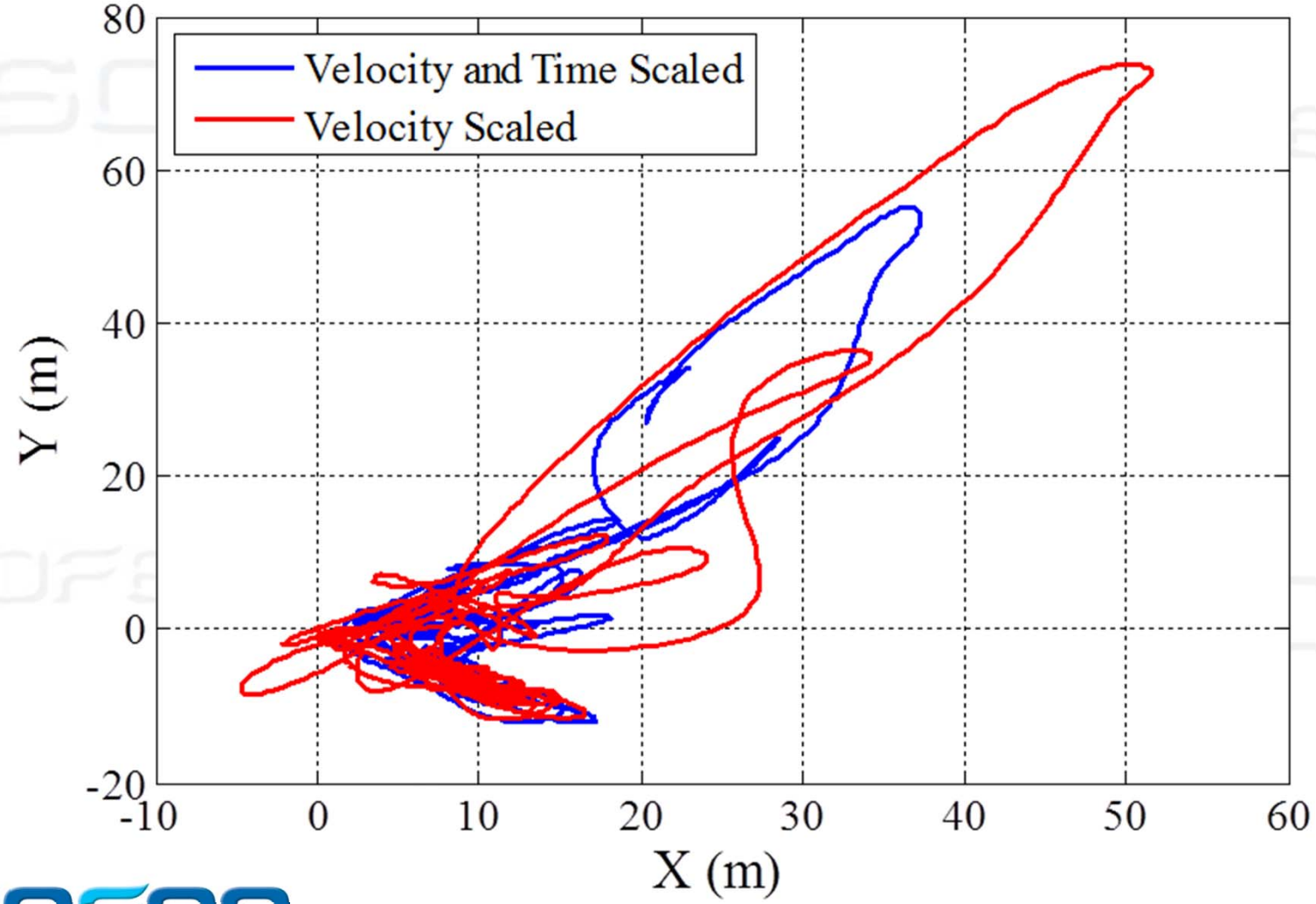
Squall Time History & Scaling



Impact of Squall Scaling Method on Response



Effect of Scaling on Extreme Statistics

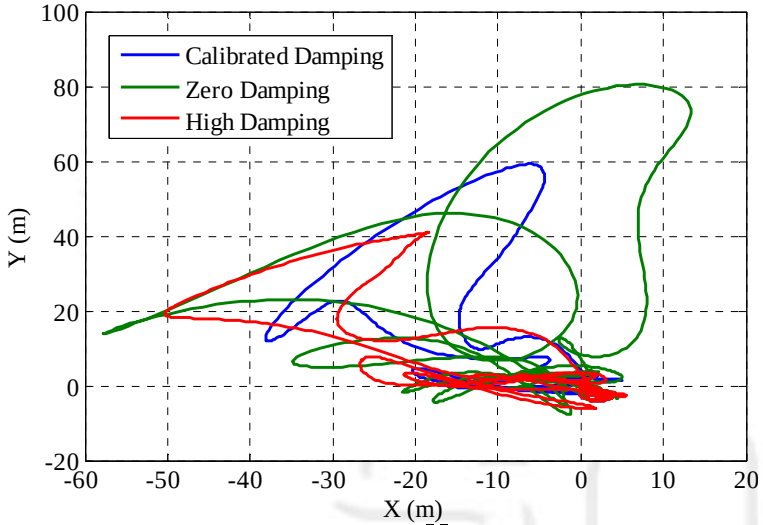
- Large Squall Database provided with Squalls ranging from 11 m/s to 31 m/s
- Ran simulations with 20 squalls with the highest and the lowest scaling factors

Statistics	20 Squalls With Highest Scaling Factor				20 Squalls With Lowest Scaling Factor			
	TIME AND VELOCITY SCALED /VELOCITY SCALED				TIME AND VELOCITY SCALED /VELOCITY SCALED			
	Offset	T (AL1)	T (AL6)	T (AL9)	Offset	T (AL1)	T (AL6)	T (AL9)
Exp Maximum	0.84	0.87	0.86	0.93	0.88	0.90	0.96	0.94
Std Maximum	0.69	0.76	0.74	0.71	0.67	0.69	0.92	0.79
Maximum Observation	0.85	0.84	0.86	0.78	0.74	0.74	1.04	0.82

Numerical Model

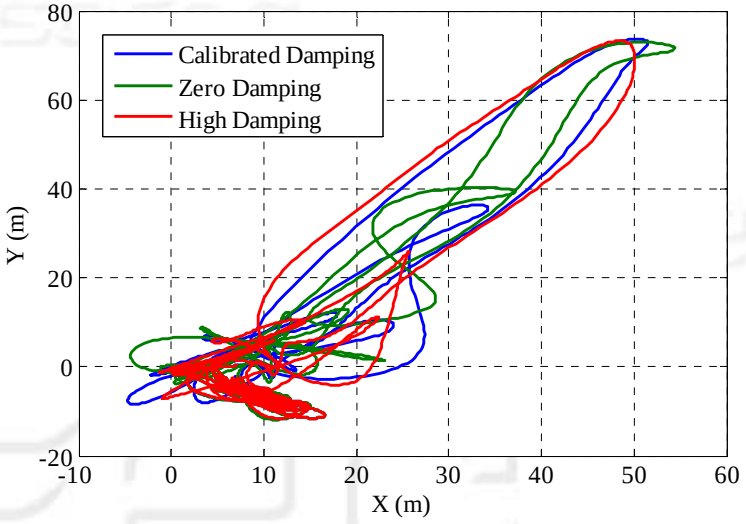
- Wind Load Coefficients
  - Obviously very important
  - Base on accurate topsides arrangement and detail
  - Wind Tunnel Test for accurate coefficients
- **Yaw Rate Damping**
  - Key Parameter for Turret-Moored Systems in Squalls
  - Not commonly used (or important) for Typical Storm Global Analysis

Effect of Yaw Rate Damping



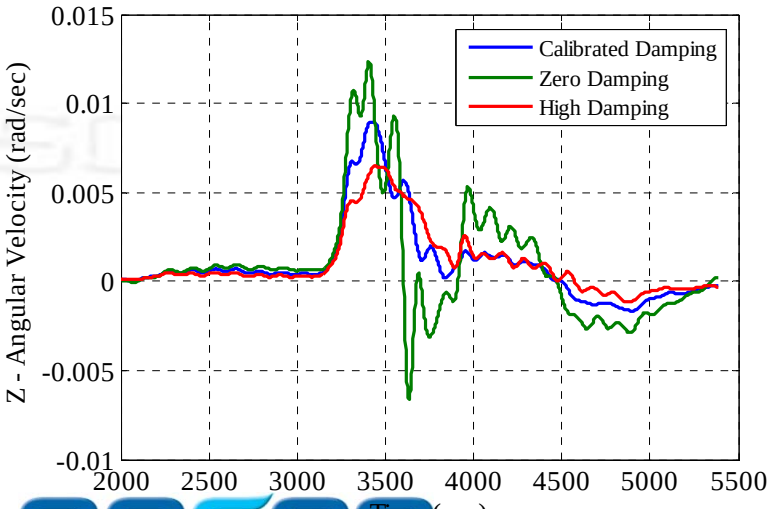
Squall 1

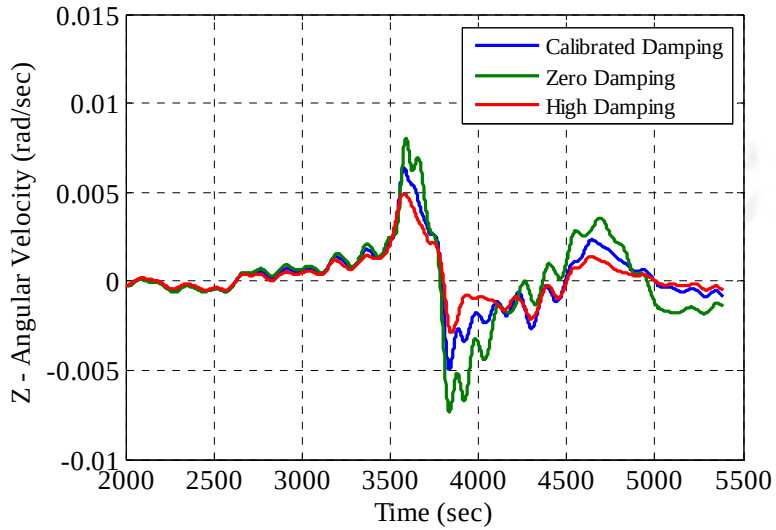
Displacement



Squall 2

Angular Velocity





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Response Statistics and Design Value Estimation

- Stationary versus Non-Stationary (Transient) Processes
- Estimation of the Statistics of Extremes
  - Order Statistics
    - Peaks are independent and Identically distributed
  - Sample of Observed Maxima
    - Individual Observations are generated from independent realizations
- **Can / Should we use a typical Stationary Process Design Value Estimation approach from the Extreme Statistics?**
  - **e.g. Expected Maximum Value or Most Probable Maximum?**

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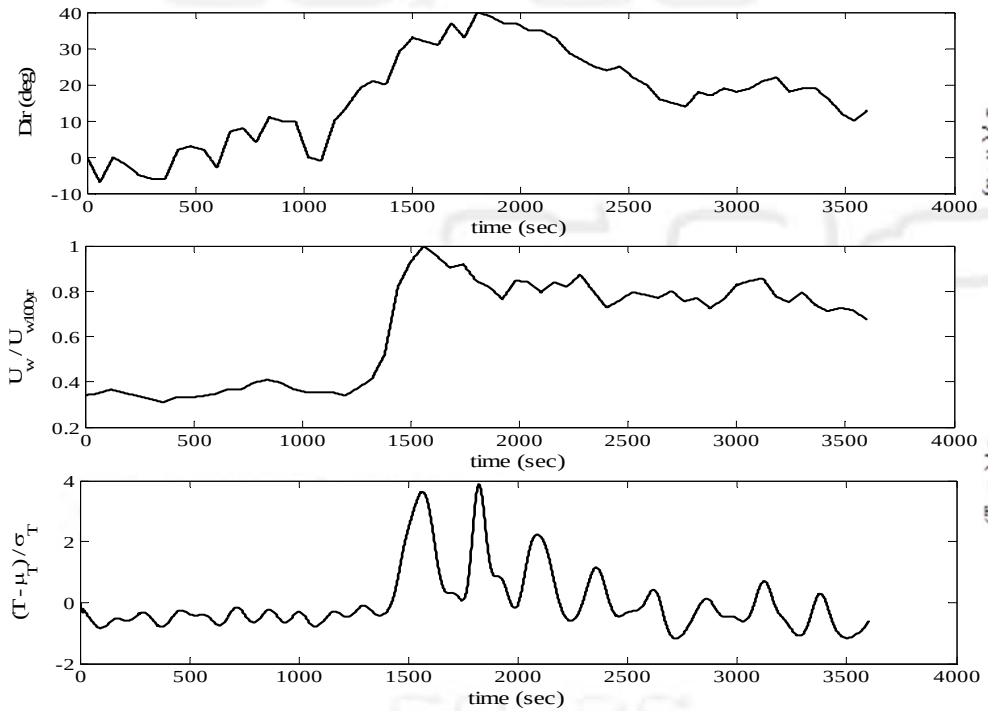
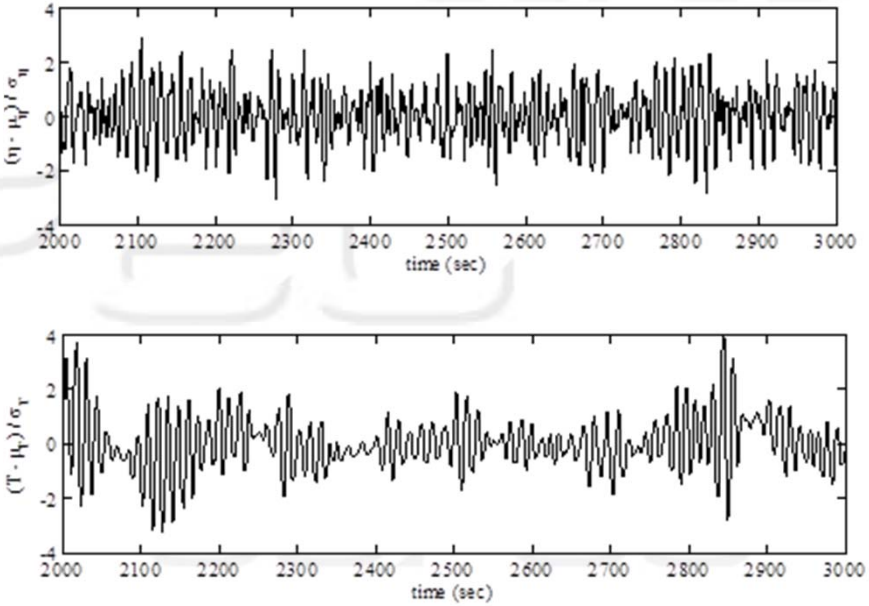
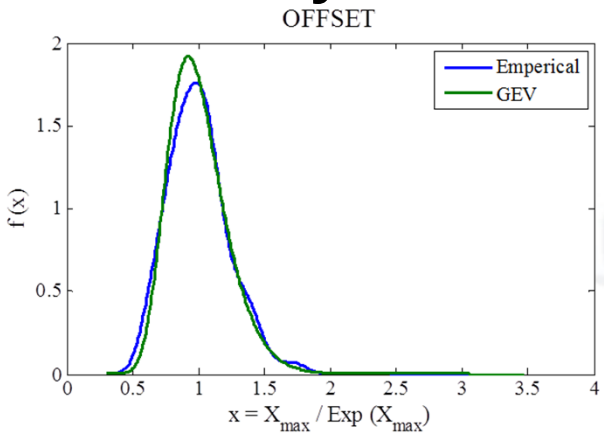
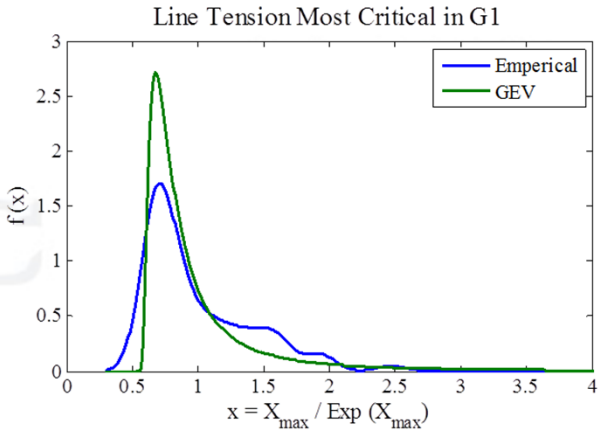
Squall Time History Compared to Typical Storm Environment

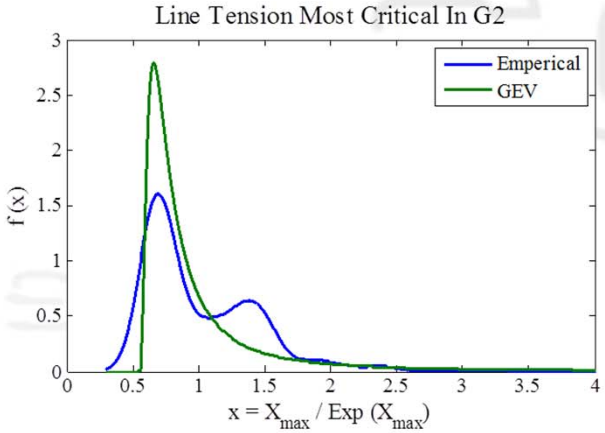


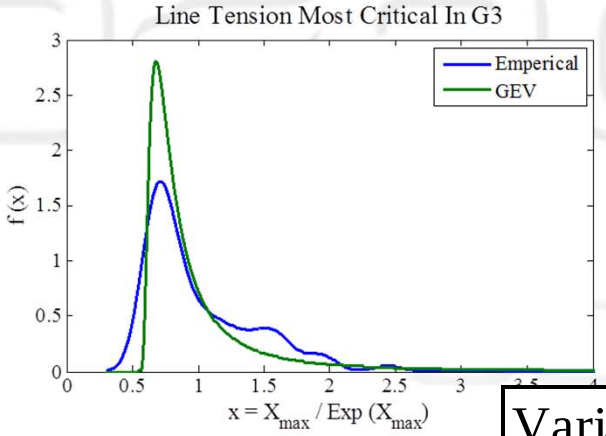


Probability Distribution of Observed Maxima





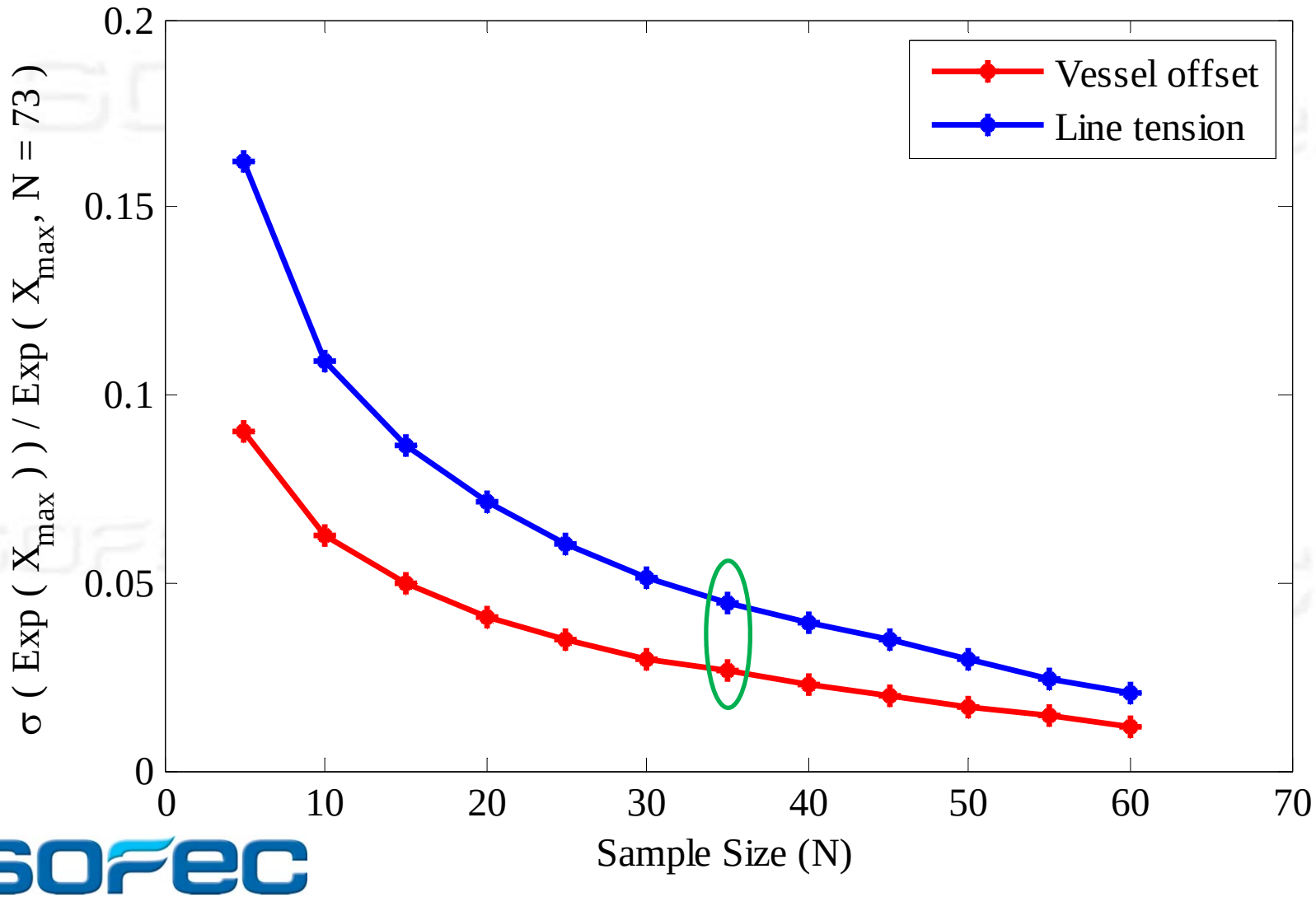




Gumbel: Stationary Process
Expected Maximum ~ 57%ile

Variable	Percentile
Offset	56%
Leg in Group 1	63%
Leg in Group 2	59%
Leg in Group 3	63%

How Many Time Series do we Require?



Proposed Design Guidance

- Environment:
  - 35 realizations should be sufficient for estimation of Expected Maximum
  - Select time series that require minimal “scaling” for desired return period
  - Perform analysis with ambient current and wave environment
    - Expected or 95% non-exceedence values
    - Expected direction
- Numerical Model:
  - Ensure proper wind load coefficients, account for topsides growth!
  - Yaw rate damping is an important parameter
  - Ensure all numerical transients have decayed before starting up squall time history
  - Can terminate simulation a short period after squall peak period

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Proposed Design Guidelines 2

- Extreme Value Estimation:
  - Based on Case Study 35 simulations reduce variability of estimated maximum to less than 5%
- Use the Expected Maximum as a Design Value
  - Can adopt an approach where standard deviation of Observed Maxima is accounted for to provide some margin (e.g. BV-NR 493)

Summary

- Scaling of Measured Squall Time Histories to match 100-year peak velocities strongly affects Turret-Moored FPSO response
- Squall time history database grows it should be culled to provide a smaller set of high quality time histories
  - Performing 100's of realizations for one load case is not required
- Need to involve Metocean Community to refine Design Criteria
- Yaw Rate Damping is shown to have a strong influence on response
- Expected Maximum converges to 5% with 35 simulations
  - Could provide guidance for size of time history dataset
- Design Value should be estimated as is done for other Storm Conditions
  - No evidence that the probability of failure would be very different
- The factor safety should reflect any uncertainty/conservatism
- ***Industry requires a robust, consistent methodology to address Squalls***

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Thank you!

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