Empirical Estimation of Probability Distribution of Extreme Responses of Turret Moored FPSOs

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Background

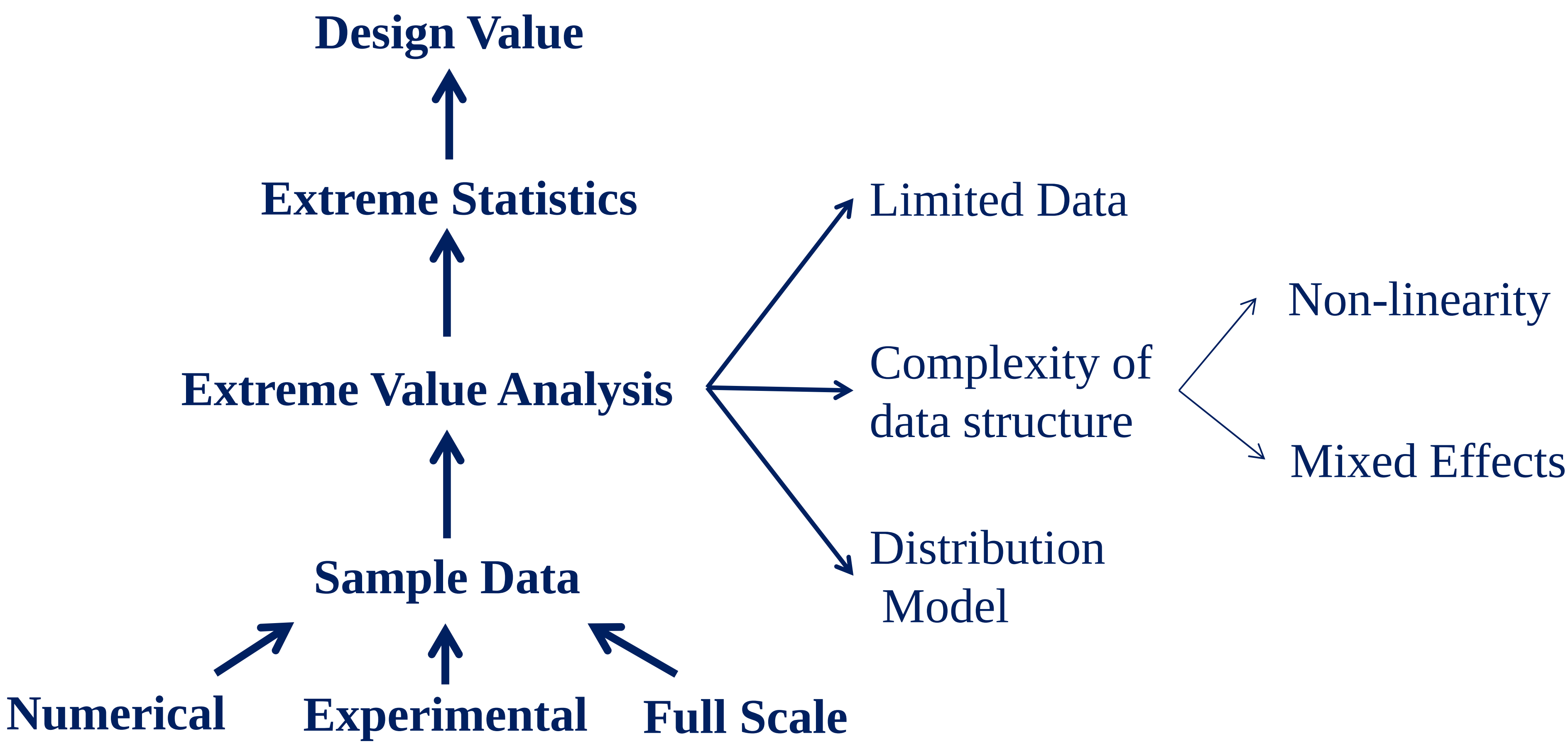

Design Value
Extreme Statistics
Extreme Value Analysis
Sample Data
Numerical
Experimental
Full Scale
Limited Data
Complexity of data structure
Distribution Model
Non-linearity
Mixed Effects

Table of Content

- Non-linear Responses of Turret Moored FPSOs
- Probability Distributions
- Distribution Parameters
- Extreme Statistics
- Case Studies
- Results
- Concluding Remarks

Non-linear Responses of Turret Moored FPSOs

Mooring Leg Tension

- Windward
  - Low-Frequency
  - Wave Frequency
  - Total Tension
- Leeward
  - Low-Frequency
  - Wave Frequency
  - Total Tension

Vessel Offset

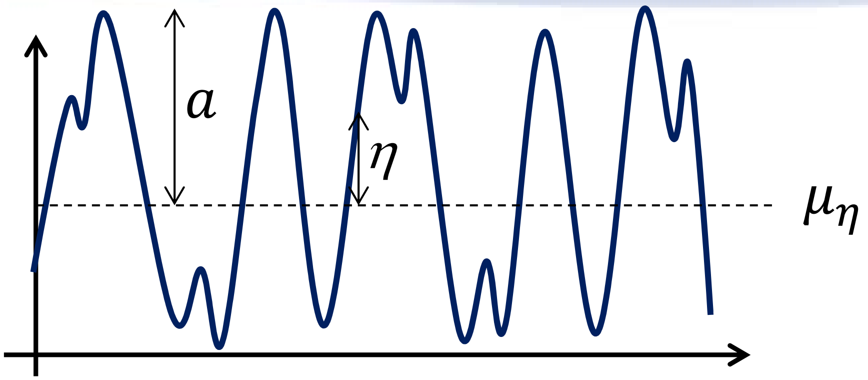
- Along the vessel length (X)
  - Low-Frequency

Sources of Non-linearity

- Mooring System Stiffness
- Loading Nature (low-drift forces, drag, etc.)
- Environmental Condition (steep waves)
- Damping

Probability Distributions

Normalized Random Variable $$\zeta = \frac{a - \mu_\eta}{\sigma_\eta}$$



Model	Transformation	Distribution	
Linear Random Variable (narrow-banded)		$F_\zeta(x) = 1 - \exp\left(-x^2/2\right)$	Rayleigh
Non-Linear Random Variable	$\zeta_n = \dfrac{\zeta^2}{2}$	$F_{\zeta_n}(x) = 1 - \exp(-x)$	Exponential
	$\zeta_n = A\left(\dfrac{\zeta^2}{2} + B\right)$	$F_{\zeta_n}(x) = 1 - \exp\left(-\left(\dfrac{x}{A} - B\right)\right)$	Stansberg
	$\zeta_n = \dfrac{\lambda}{2^{1/\kappa}}\zeta^{2/\kappa} + \rho$	$F_{\zeta_n}(x) = 1 - \exp\left(-\left(\dfrac{(x-\rho)}{\lambda}\right)^\kappa\right)$	Weibull
	$\zeta_n = \alpha\zeta + \beta\zeta^2 + \gamma$	$F_{\zeta_n}(x) = 1 - \exp\left(-\dfrac{(\chi-\alpha)^2}{8\beta^2}\right)$ $\chi = \left(\alpha^2 + 4\beta(x-\gamma)\right)^{1/2}$	3-Par Rayleigh

Distribution Parameters

Model	Distribution	Parameters
Linear Random Variable (narrow-banded)	Rayleigh	μ_η, σ_η
Non-Linear Random Variable	Exponential	μ_η, σ_η
	Stansberg	$\mu_\eta, \sigma_\eta, A, B$
	Weibull	$\mu_\eta, \sigma_\eta, \kappa, \rho, \lambda$
	3-Par Rayleigh	$\mu_\eta, \sigma_\eta, \alpha, \beta, \gamma$

Extreme Statistics

Ordered Value Statistics Theory
(N independent cycles):

$$F_{\zeta_{\max}}(x) = \left[F_{\zeta_n}(x)\right]^N$$

Expected Maximum:

$$E(\zeta_{\max}) = \int_{-\infty}^{+\infty} x\, dF_{\zeta_{\max}}(x)$$

Asymptotic Distribution of Large N (Gumbel)

$$F_{\zeta_{\max}}(x) = \exp\left(-\exp\left(-(x - a_N)/b_N\right)\right)$$

$$E(\zeta_{\max}) = a_N + b_N \gamma_{EM}$$

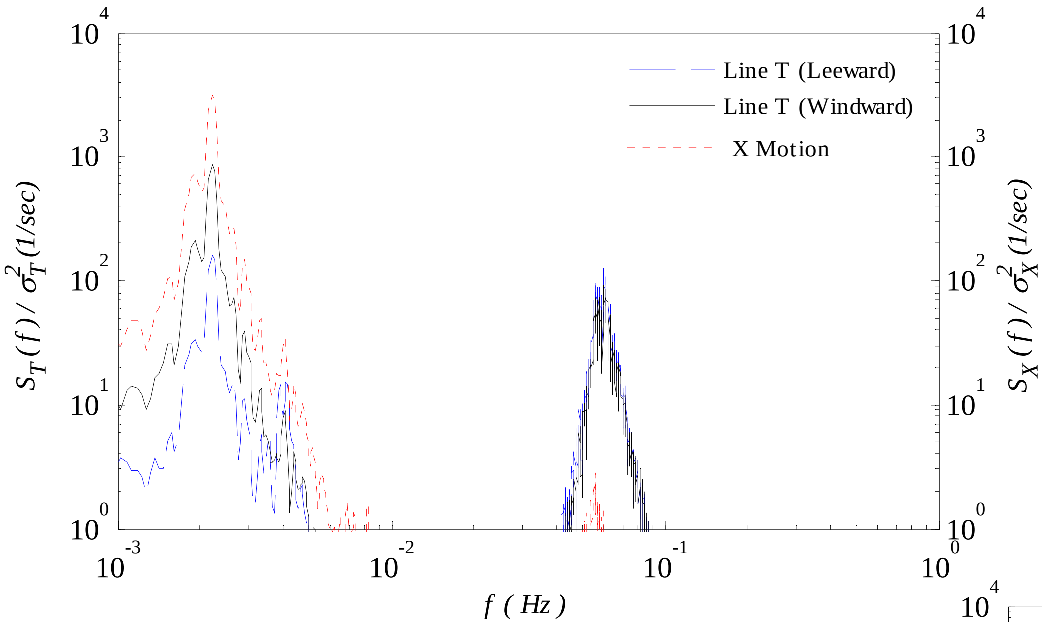
Number of Cycles (N)

Wave frequency	Narrow-banded process →	$N = T_{storm}/T_z$
Low frequency	Non-narrow-banded– Correlation time - Stansberg's formula →	$\tau = 1/2\omega$ ω bandwidth of the spectrum
Combined Process	Difficult to estimate →	Number of observed cycles

Case Studies: General Info

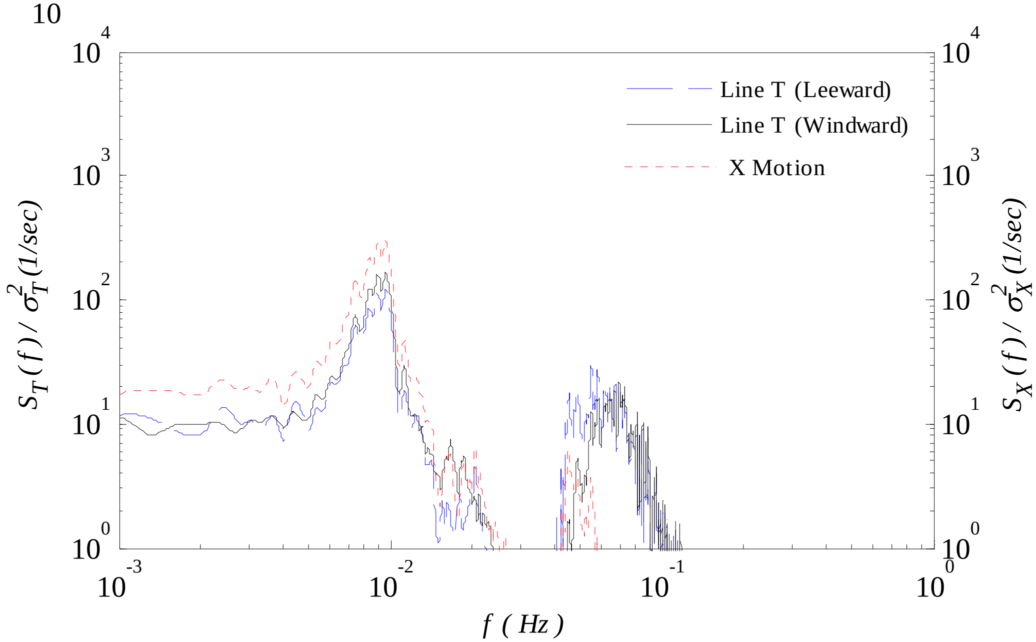
	Deepwater System	Shallow-water System
		
Water depth (m)	~2000m	~45m
Area	West Africa	South East Asia
100Yr Condition	Hs = 4.5m, Tp = 17sec, Ws = 6.3m/sec	Hs = 10m, Tp = 16sec, Ws = 32m/sec
Mooring System	3G*4L Taut mooring legs	4G*3L Catenary mooring legs
Mooring Legs	Chain-Polyester-Chain	Chain-Heavy Chain-Chain

Case Studies: Response Characteristics

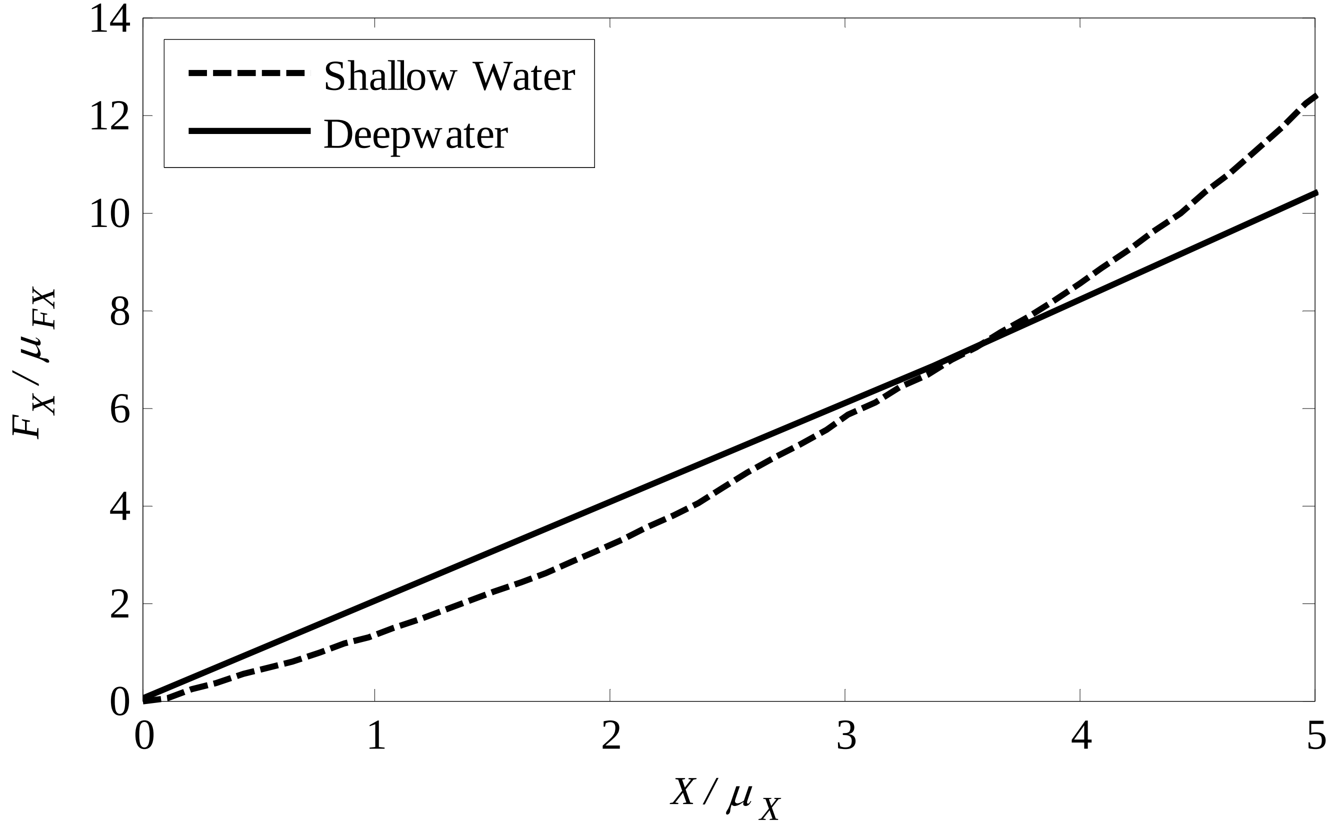


Deepwater System

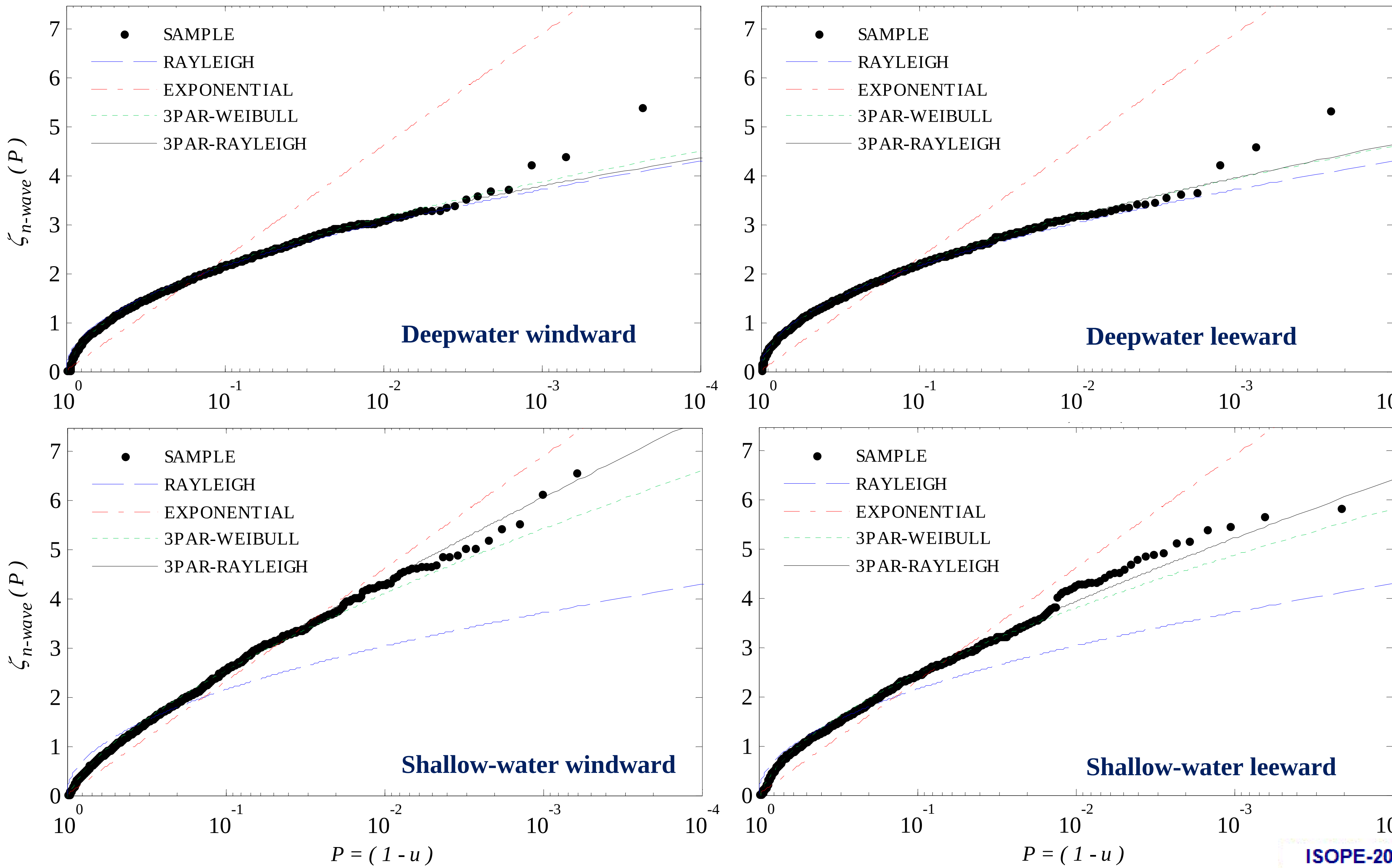
Shallow-water System



Case Studies: Response Characteristics



Results: Wave-Frequency



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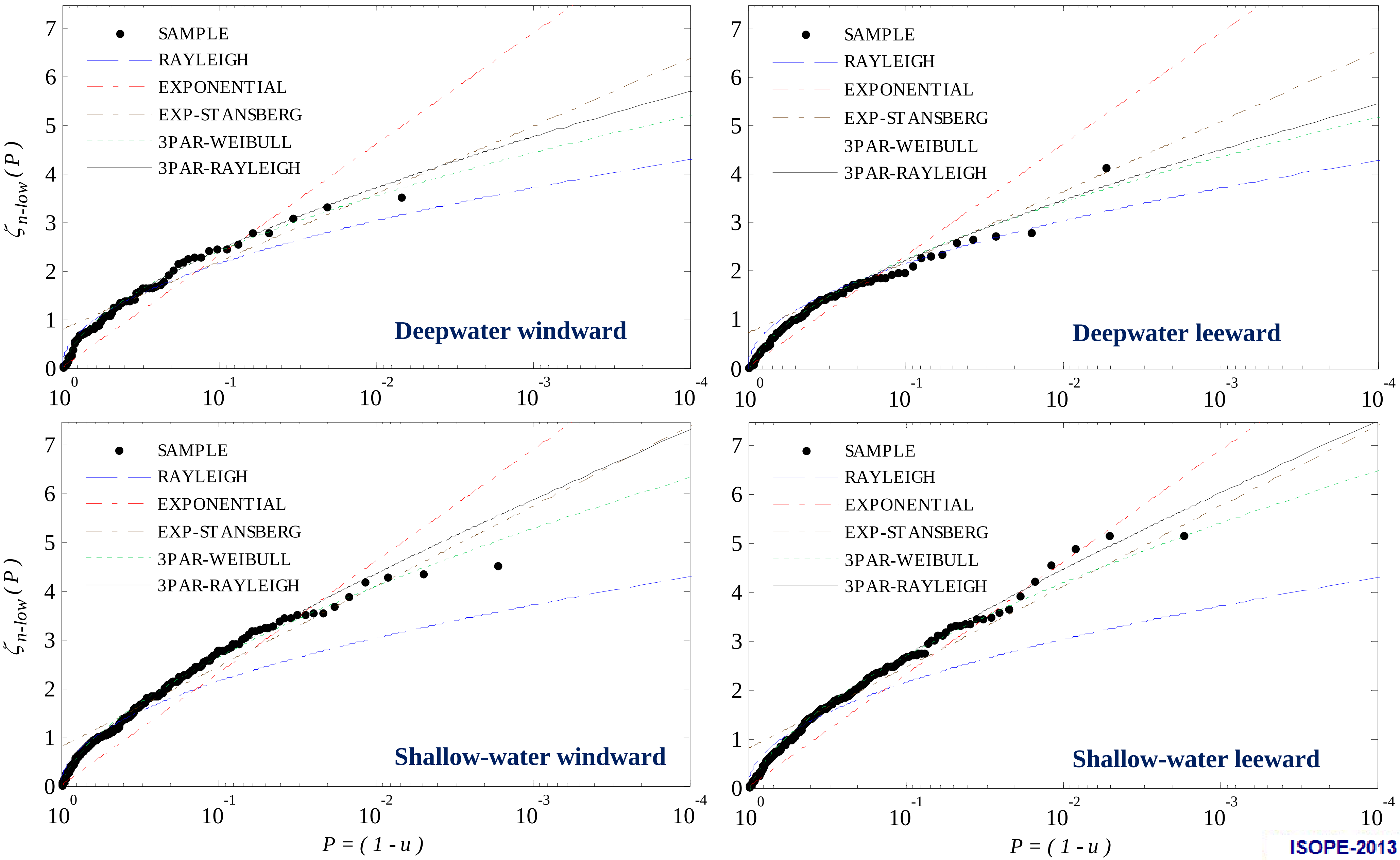
Results: Low-Frequency



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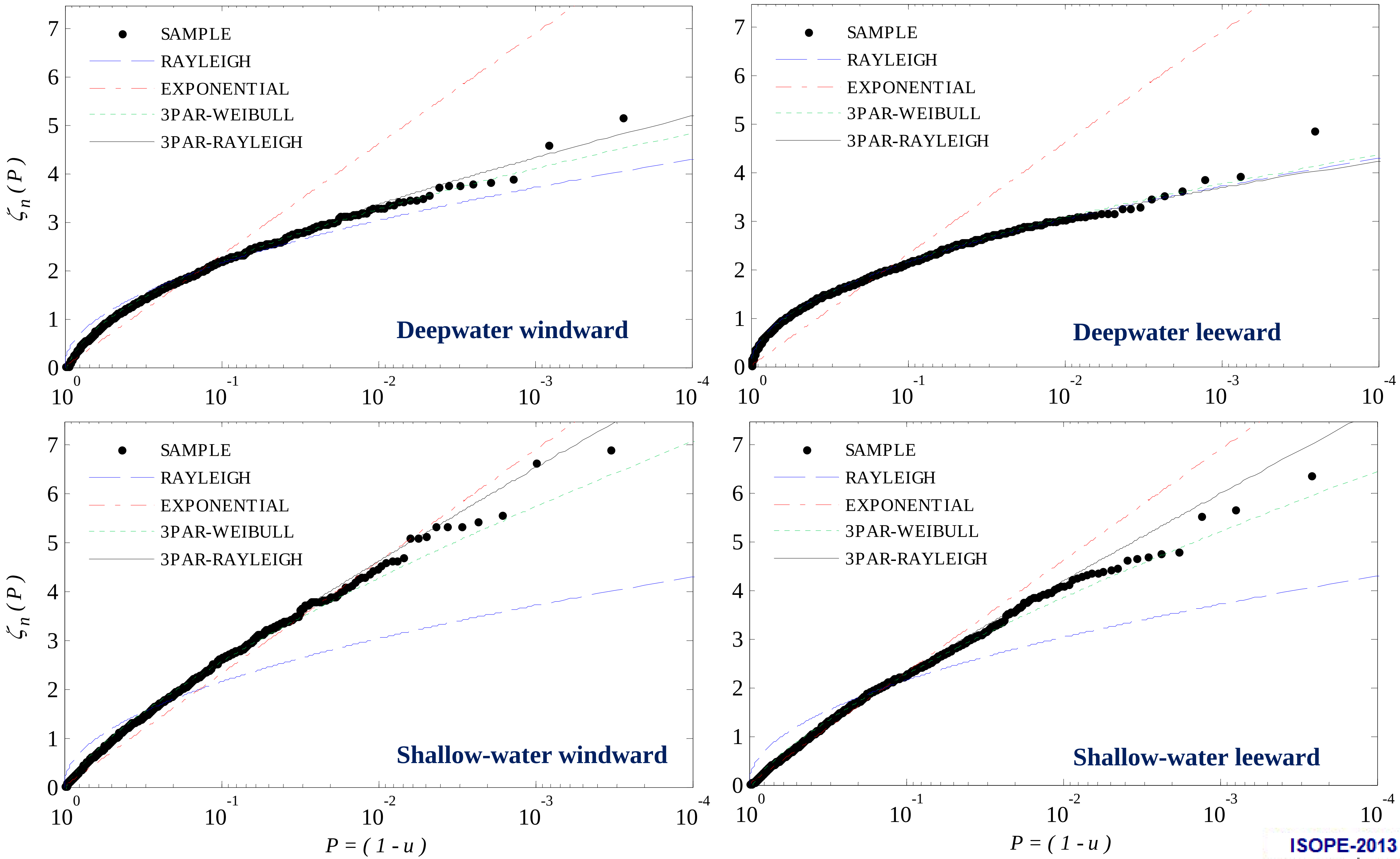
Results: Total



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Results: Extreme Statistics

Deep water →

Model	Windward			Leeward		
	Wave Freq.	Low Freq.	Total	Wave Freq.	Low Freq.	Total
Sample	4.2 (5.4 - 3.3)	3.2 (3.5 - 2.8)	4.2 (5.2 - 3.6)	4.1 (5.3 - 3.4)	3.1 (4.1 - 2.6)	3.9 (4.9 - 3.3)
Rayleigh	3.8	2.7	3.7	3.8	2.8	3.7
Exponential	7.1	3.8	7.0	7.1	4.0	7.1
3-Par. Rayleigh	3.8	3.3	4.3	4.0	3.1	3.7
3-Par. Weibull	3.9	3.1	4.1	4.0	3.1	3.8
Stansberg Exp.	--	3.4	--	--	3.5	--

Shallow water →

Model	Windward			Leeward		
	Wave Freq.	Low Freq.	Total	Wave Freq.	Low Freq.	Total
Sample	5.8 (7.3 - 4.9)	4.1 (4.5 - 3.6)	5.8 (6.9 - 5.1)	5.6 (5.8 - 5.4)	5.0 (5.2 - 4.6)	5.4 (6.4 - 4.4)
Rayleigh	3.8	3.2	3.7	3.8	3.2	3.7
Exponential	7.3	5.2	6.8	7.2	5.2	7.0
3-Par. Rayleigh	6.3	4.7	6.4	5.4	4.8	6.1
3-Par. Weibull	5.6	4.4	5.7	5.0	4.5	5.3
Stansberg Exp.	--	4.5	--	--	4.5	--

Concluding Remarks

- The probability distribution of mooring leg tension and vessel offset in extreme environmental condition were studied.
- Two case studies of shallow water and deepwater turret moored FPSOs are considered.
- The characteristics of probability distribution of wave-frequency, low-frequency, and the combined tension are studied.
- The probability distributions of tension in the windward and leeward lines are studied.
- The performance of widely used distribution models as well as the three-parameter Rayleigh distribution model is evaluated over the experimental data.
- The effect of distribution model on the predicted extreme values is discussed.

Thank You!