Uncertainties assessment in Real-Time Hybrid Model for ocean basin testing of a Floating Offshore Wind Turbine

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Motivation

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MOTIVATION

Limitations typically given by scaled problems:

- Reynolds scale at the wind tunnel which limits the hydrodynamic problem.

$$Re = \frac{uD}{\nu}$$

- Froude scale at the wave basin which limits the aerodynamic problem.

$$Fr = \frac{u^2}{gD}$$

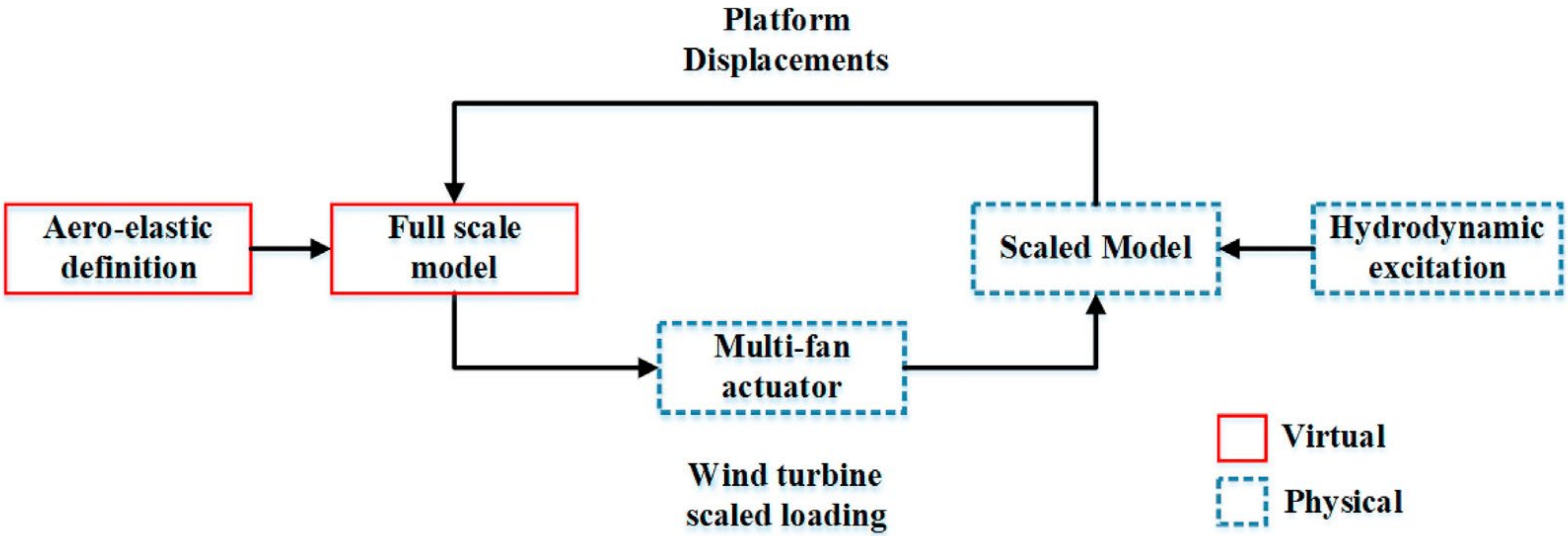
$$\lambda = \frac{D_p}{D_m} \qquad \lambda^{3/2} = \frac{Re_p}{Re_m}$$

While Re deviation may be neglected in water, leads to a consistent change in the associated aerodynamic thrust acting on the rotor.

Real-time hybrid testing overcomes this issue by performing scale model testing only on a subpart of the whole structure, the aerodynamic loads being simulated numerically.

$$\lambda^{1/2} = \frac{t_p}{t_m} \qquad \lambda^3 \frac{\rho_m}{\rho_p} = \frac{F_p}{F_m}$$

MOTIVATION



(Battistella, et al., 2018) made possible the reproduction of the most important aerodynamic loads by using a multi-fan system as actuators at the hub height of the physical model.

By simulating errors in the hybrid coupling system, the sensitivity of the floating wind turbine response to coupling quality can be quantified.

Motivation

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OBJECTIVES

To resume the uncertainties included in scaled model tests of FOWTs in wave tank layouts, focusing on the

- Identification
- Quantification
- Propagation

of the uncertainties related with the implementation and application of the HIL strategies.

To set the uncertainty bounds on the response metrics of interest, evaluating the accuracy of modelling tools and the levels of the test reliability.

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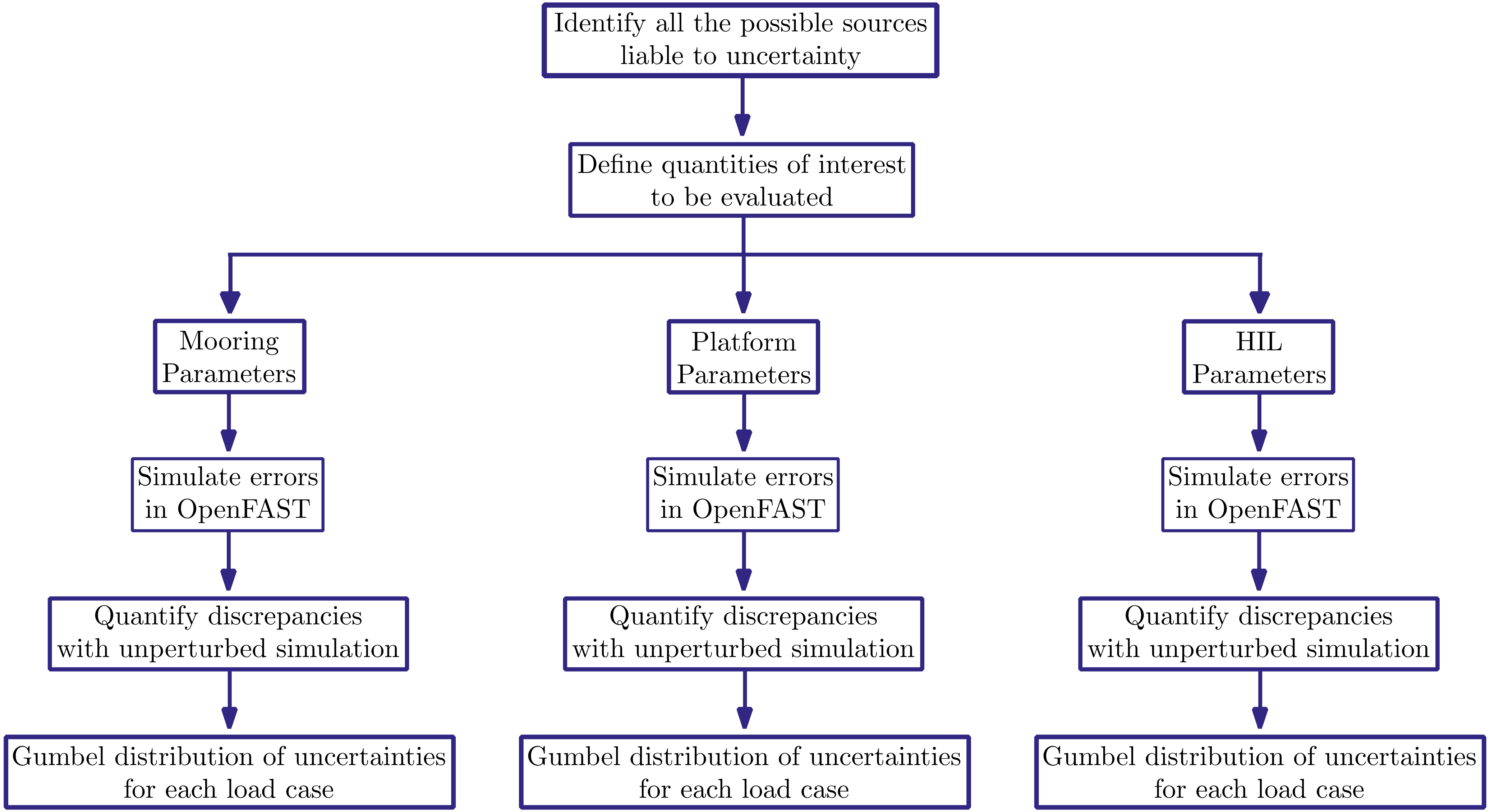
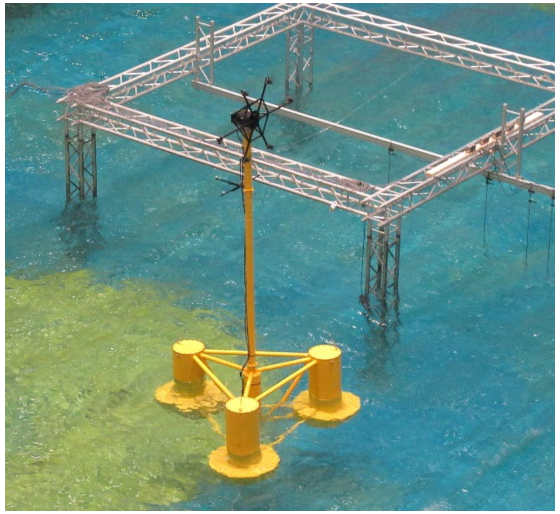
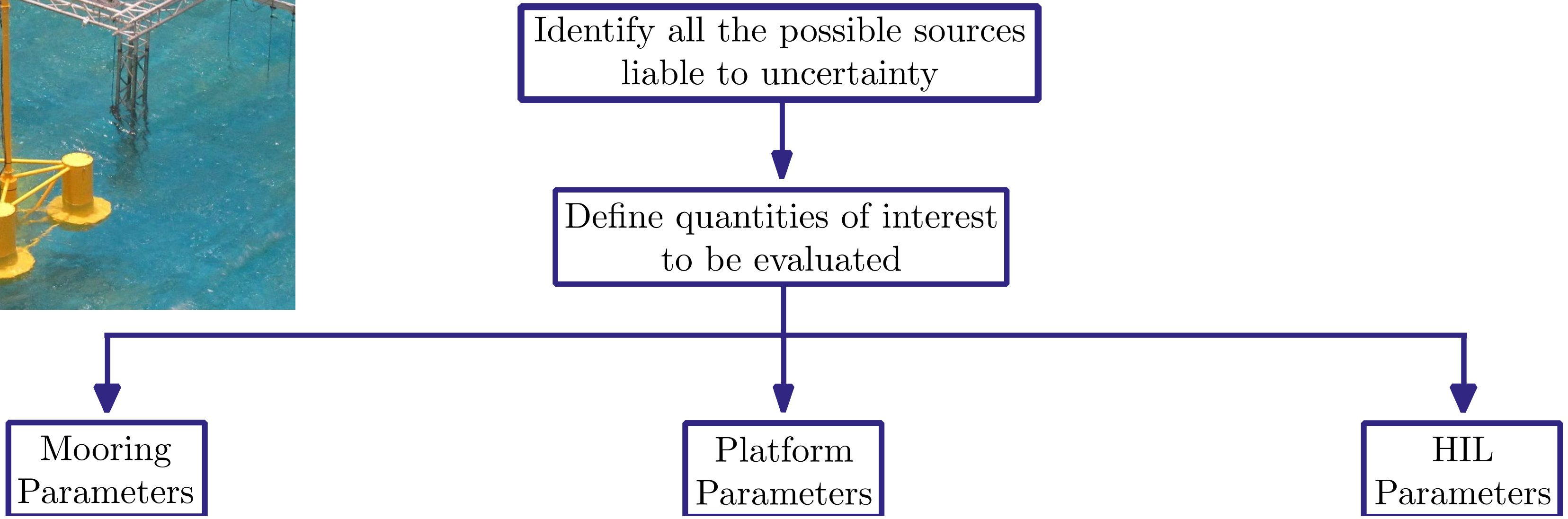
Methodology for uncertainty analysis

METHODOLOGY FOR UNCERTAINTY ANALYSIS





METHODOLOGY FOR UNCERTAINTY ANALYSIS



Identify all the possible sources liable to uncertainty:

- ➢ Hybrid system is modelled by means of the combination of a numerical simulation, sensors, actuators and control software.

Define quantities of interest to be evaluated:

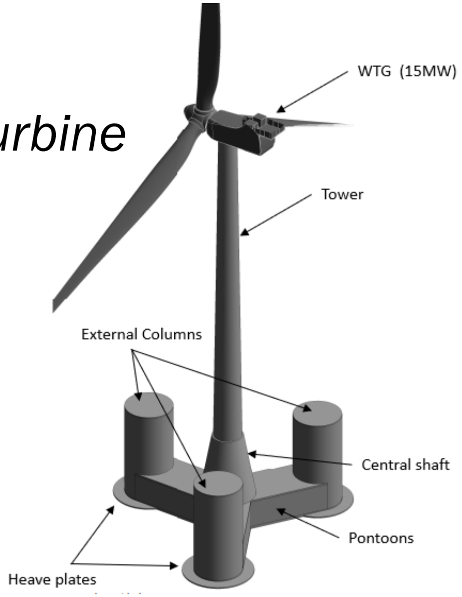
- ➢ The variable selection planned to focus on the more significative sources of uncertainty and limit the number of simulations.

METHODOLOGY FOR UNCERTAINTY ANALYSIS

Simulate in OpenFAST:

- 5400 s for various noise levels defined by Normal distributions of each QOI measurement.

*COREWIND D1.3: Public design and FAST model of the 15MW **ActiveFloat** floater-turbine concept and WP2 outcomes for mooring design.*



Mooring Parameters → Simulate errors in OpenFAST → Quantify discrepancies with unperturbed simulation

Platform Parameters → Simulate errors in OpenFAST → Quantify discrepancies with unperturbed simulation

HIL Parameters → Simulate errors in OpenFAST → Quantify discrepancies with unperturbed simulation

Quantify discrepancies:

- By taking the absolute difference between the mean of the time-series output of perturbed and baseline simulation.

METHODOLOGY FOR UNCERTAINTY ANALYSIS

Gumbel distribution for each load case:

- Fitted with the resulting Mean discrepancy level averaged for various levels of noise in each QOI evaluated.

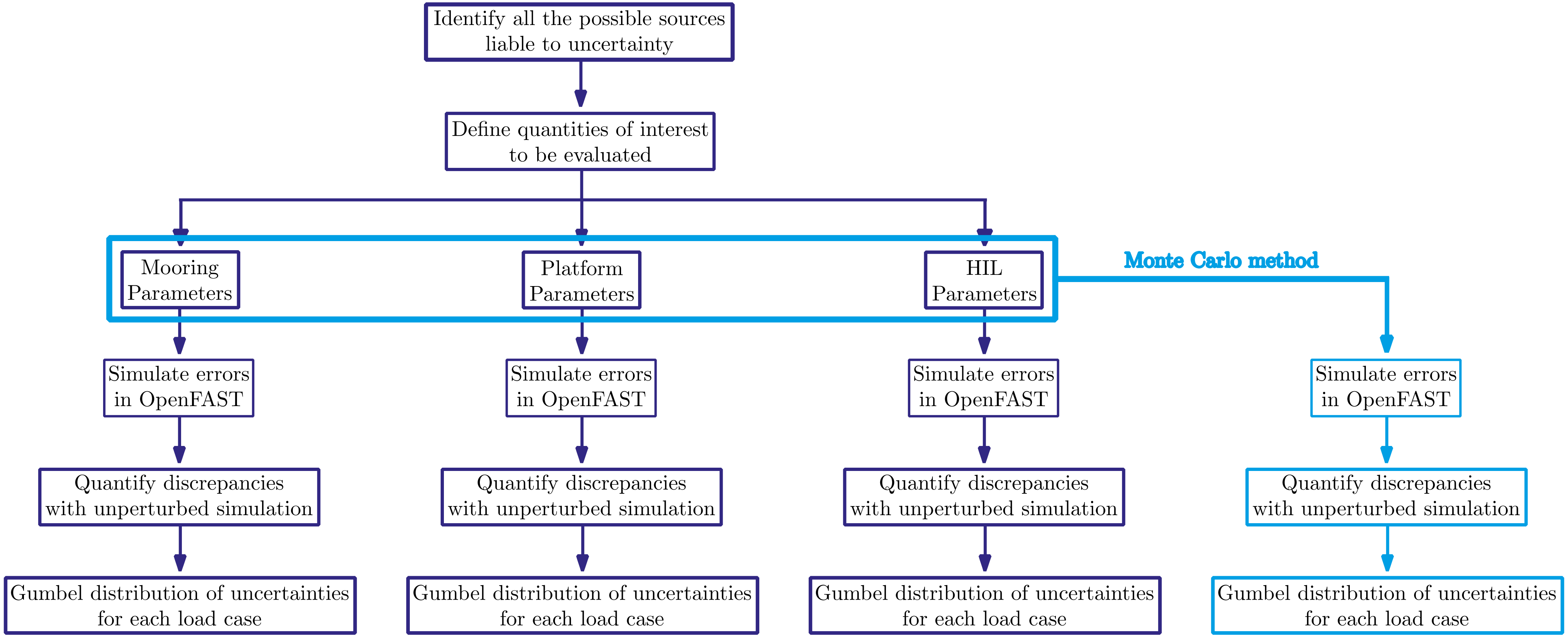
$$Mean\ dicrepancy = \left| \frac{\sum_{i=1}^{n} x_i'}{n} - \frac{\sum_{i=1}^{n} x_i}{n} \right|$$

Mooring Parameters → Simulate errors in OpenFAST → Quantify discrepancies with unperturbed simulation → Gumbel distribution of uncertainties for each load case

Platform Parameters → Simulate errors in OpenFAST → Quantify discrepancies with unperturbed simulation → Gumbel distribution of uncertainties for each load case

HIL Parameters → Simulate errors in OpenFAST → Quantify discrepancies with unperturbed simulation → Gumbel distribution of uncertainties for each load case

METHODOLOGY FOR UNCERTAINTY ANALYSIS



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Extremal load cases

EXTREMAL LOAD CASES

Name	Duration [s]	Waves	Wind [m/s]	Turbine
DLC1.3	5400	Irregular; Hs=2m, Tp=6s	Turbulent ETM; 10.5 m/s	Operational Active control
	5400	-	Turbulent ETM; 10.5 m/s	Operational Active control
DLC1.6	5400	Irregular; Hs=5.11m, Tp=9s	Turbulent NTM; 10.5 m/s	Operational Active control
	5400	Irregular; Hs=5.11m, Tp=9s	-	Operational Active control
DLC6.1	5400	Irregular; Hs=5.11m, Tp=9s	Turbulent EWM50; 41.2 m/s	Idling Active control
	5400	-	Turbulent EWM50; 41.2 m/s	Idling Active control

*COREWIND D1.2: Design load basis at **Gran Canaria Island** (SPAIN).*

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Identification of uncertainty sources

IDENTIFICATION OF UNCERTAINTY SOURCES

Neglect inaccuracies:

- In the numerical sub-model.
- In the sea state characterization.
- In the Qualisys Track Manager.

Uncertainties in the fabrication of the scale model:

- Mooring parameters:
  - Mooring length
  - Mooring weight
- Platform parameters:
  - Metacentric height (GM)
  - Inertia for pitch tilt rotation about the centre of mass (Iyy)

Uncertainties in the multi-fan system:

- Limited force actuation bandwidth
- Latency in the overall coupling system's response

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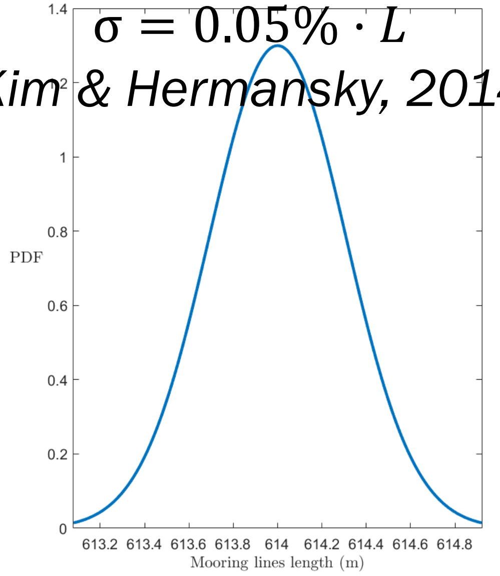
UNCERTAINTY QUANTIFICATION

Mooring parameters

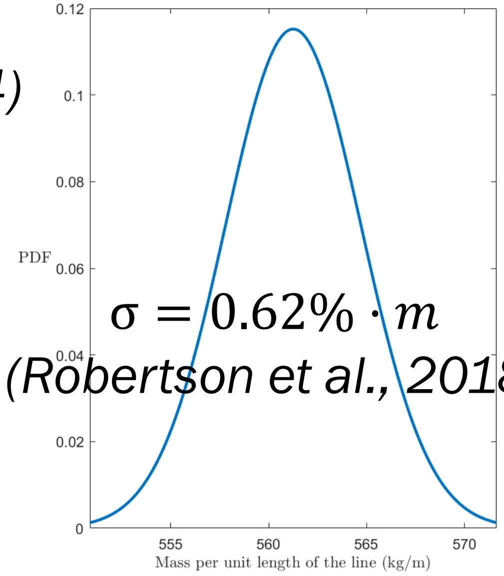
$\sigma = 0.05\% \cdot L$

(Kim & Hermansky, 2014)



$\sigma = 0.62\% \cdot m$

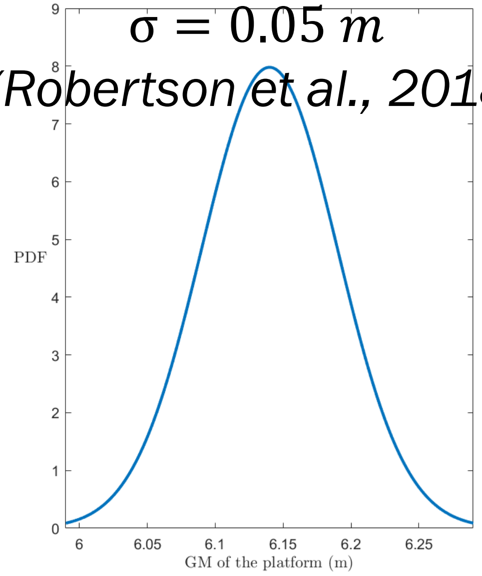
(Robertson et al., 2018)



Platform parameters

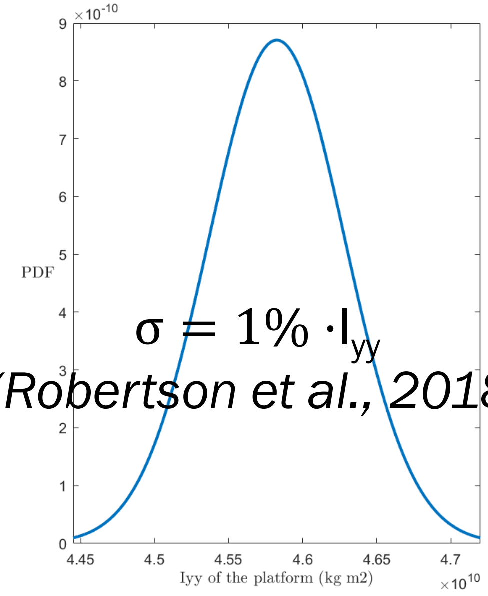
$\sigma = 0.05\ m$

(Robertson et al., 2018)



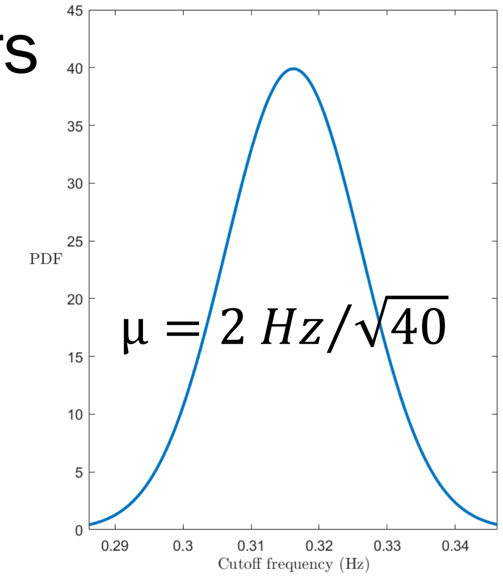
$\sigma = 1\% \cdot I_{yy}$

(Robertson et al., 2018)

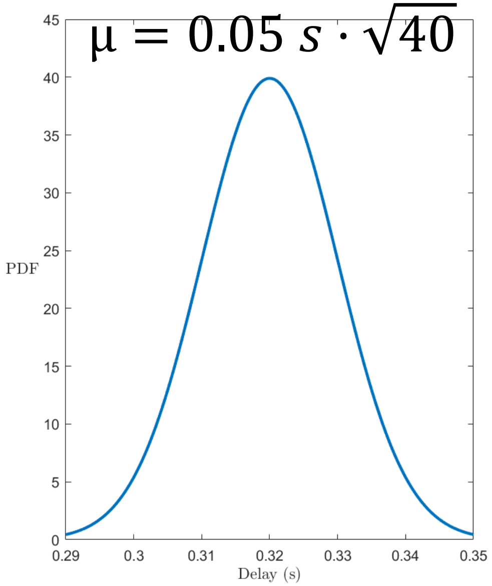


HIL parameters

$\mu = 2\ Hz/\sqrt{40}$



$\mu = 0.05\ s \cdot \sqrt{40}$



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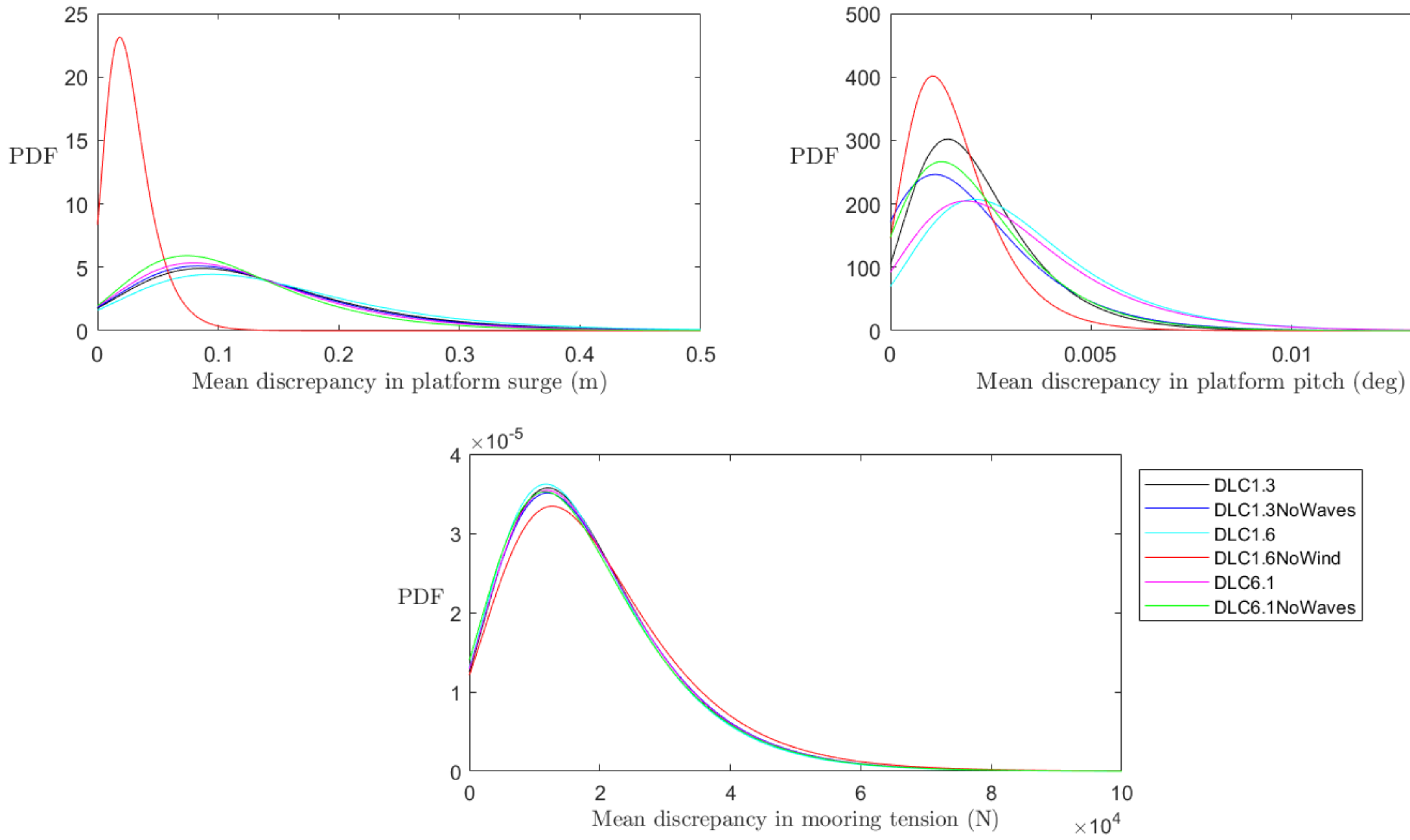
UNCERTAINTY PROPAGATION

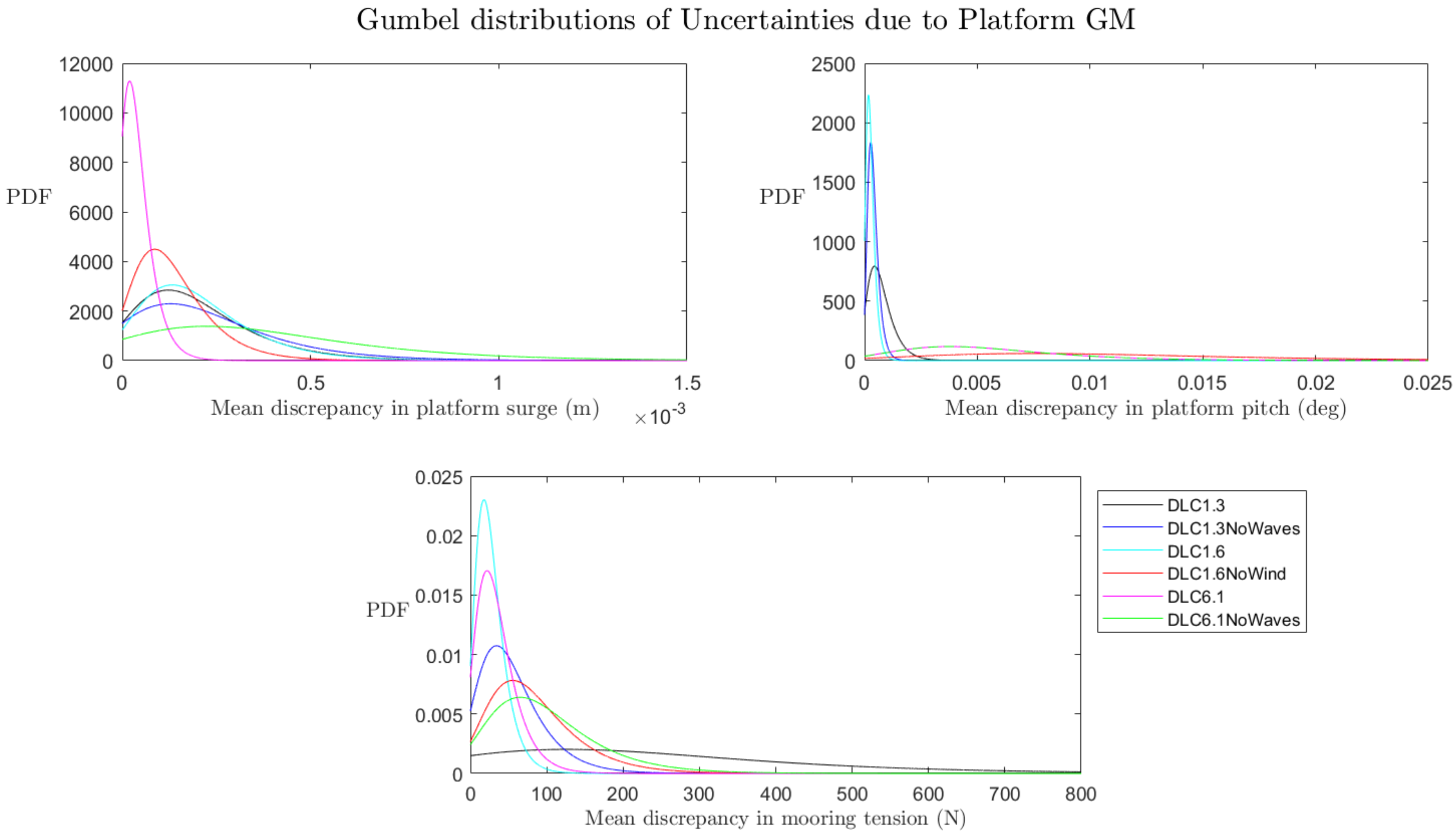
Inaccuracy in the length of the mooring lines are more relevant than in their mass per unit length.

Gumbel distributions of Uncertainties due to Mooring Length



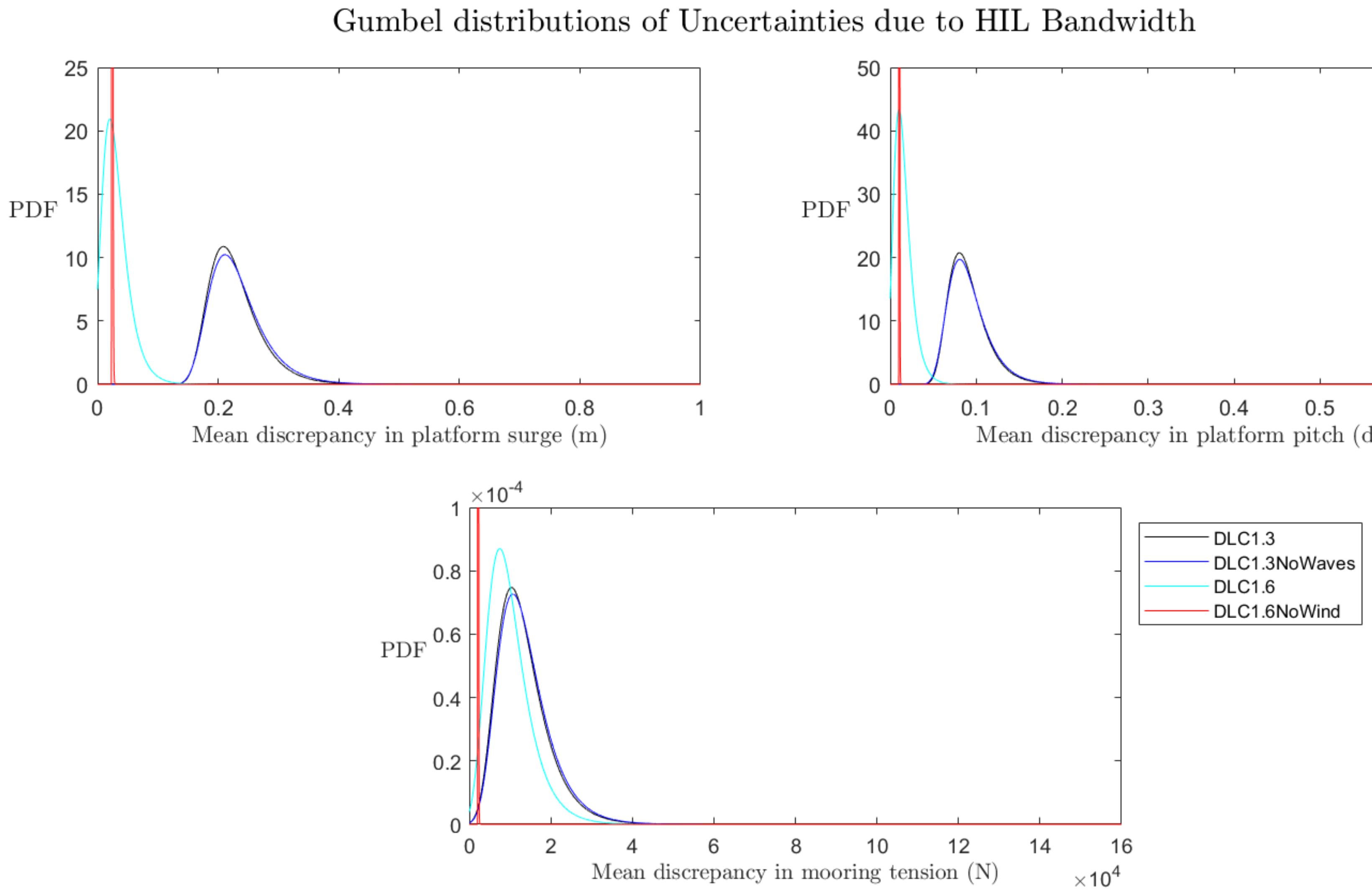
UNCERTAINTY PROPAGATION

Inaccuracy in the metacentric height are more relevant than in the Inertia for pitch tilt rotation.



UNCERTAINTY PROPAGATION

Amounts of introduced noise in the multi-fan latency are limited by the 10 ms time step.



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CONCLUSIONS

- Inaccuracy in the length of the mooring lines are more relevant than in their mass per unit length.

- The propagation of uncertainty in the platform GM presents significantly higher values than those ones due to discrepancies in the Iyy.

- The latency in the reaction forces of the coupling system has a larger effect than the limited coupling bandwidth. However, amounts of introduced noise in the multi-fan latency are limited by the 10 ms time step.

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Monte Carlo method:

- 10^3 simulations with error sources from:
  - Mooring length
  - Platform GM
  - HIL bandwidth

acting simultaneously to figure out the effect of combined discrepancies.

- Convergence analysis of the MPMean of combined discrepancies.

$$MPMean = \mu - 0.45 \cdot \sigma$$

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Thanks for your attention!

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