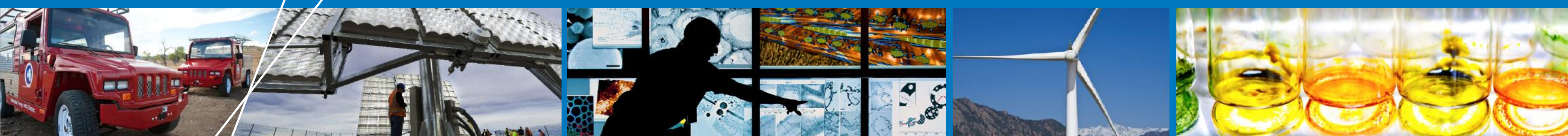
OC5 Project Phase II: Validation of Global Loads of the DeepCwind Floating Semisubmersible Wind Turbine



DeepWind Conference – Trondheim, Norway

Amy Robertson

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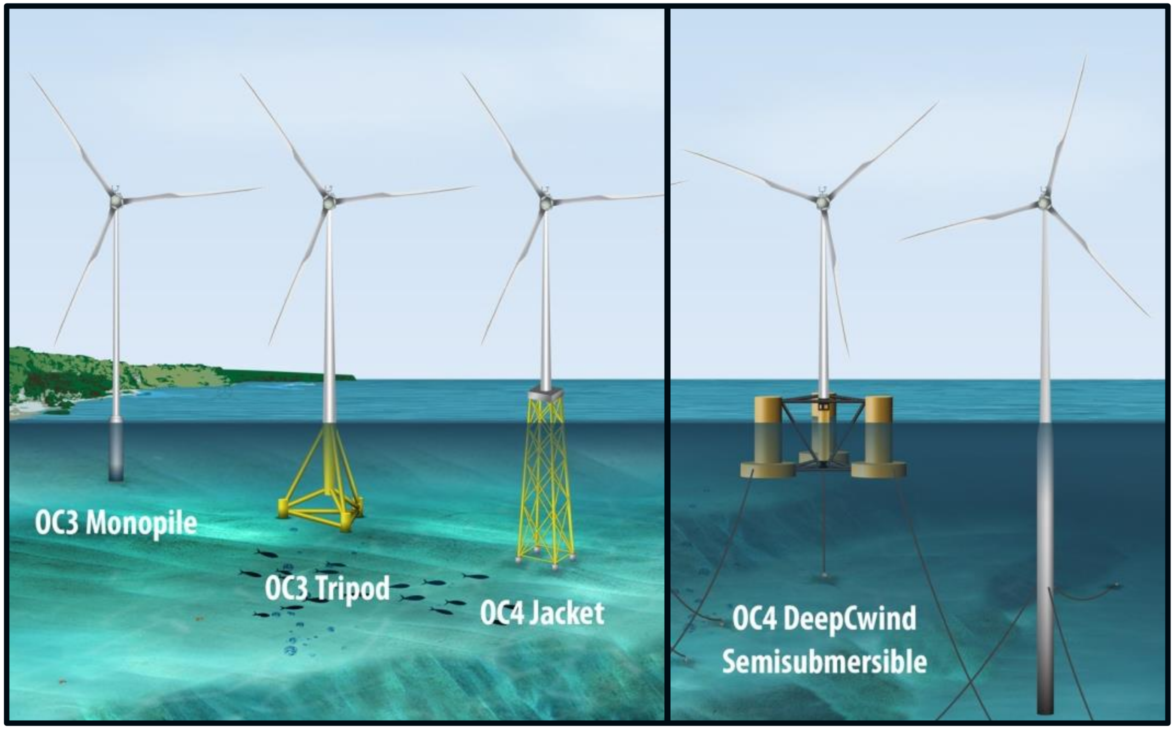
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Co-Authors

- ***Fabian F. Wendt -*** National Renewable Energy Laboratory, Colorado, USA
- ***Jason M. Jonkman -*** National Renewable Energy Laboratory, Colorado, USA
- ***Wojciech Popko -*** Fraunhofer IWES, Germany
- **Habib Dagher** - University of Maine, USA
- ***Sebastien Gueydon***, MARIN, Netherlands
- ***Jacob Qvist -*** 4Subsea, Norway
- ***Felipe Vittori,*** CENER, Spain
- **José Azcona***,* CENER, Spain
- ***Emre Uzunoglu,*** CENTEC, Portugal
- ***Carlos Guedes Soares****, CE*NTEC, Portugal
- ***Rob Harries -*** DNV GL, England
- ***Anders Yde -*** DTU, Denmark
- ***Christos Galinos***, DTU, Denmark
- ***Koen Hermans***, ECN, Netherlands
- ***Jacobus Bernardus de Vaal***, IFE, Norway
- ***Pauline Bozonnet -*** IFP Energies nouvelles, France
- ***Ludovic Bouy -*** PRINCIPIA, France
- ***Ilmas Bayati*** - Politecnico di Milano, Italy
- ***Roger Bergua*** **-** Alstom Wind, Spain
- ***Josean Galvan,*** Tecnalia, Spain
- ***Iñigo Mendikoa,*** **Tecnalia, Spain**
- ***Carlos Barrera Sanchez -*** Universidad de Cantabria – IH Cantabria, Spain
- ***Hyunkyoung Shin -*** University of Ulsan, Korea
- ***Sho Oh,*** University of Tokyo, Japan
- ***Climent Molins,*** Universitat Politècnica de Catalunya, Spain
- **Yannick Debruyne,** WavEC Offshore Renewables, Portugal

IEA Wind Tasks 23 and 30 (OC3/OC4/OC5)

- Verification and validation of coupled offshore wind modeling tools are need to ensure their accuracy, and give confidence in their usefulness to users.
- Three research projects were initiated under IEA Wind to address this need:



OC3 = Offshore Code Comparison Collaboration (2005-2009)

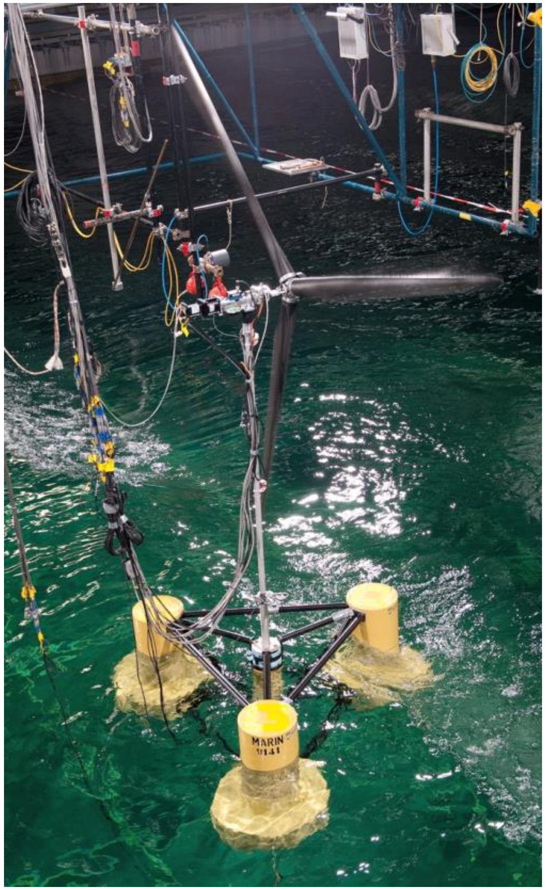
OC4 = Offshore Code Comparison Collaboration, Continuation (2010-2013)

OC5 = Offshore Code Comparison Collaboration, Continuation, with Correlation (2014-2017)

OC5 Project Phases

- OC3 and OC4 focused on ***verifying*** tools (tool-to-tool comparisons)
- OC5 focuses on ***validating*** tools (code-to-data comparisons)

Phase I:
Monopile - Tank Testing

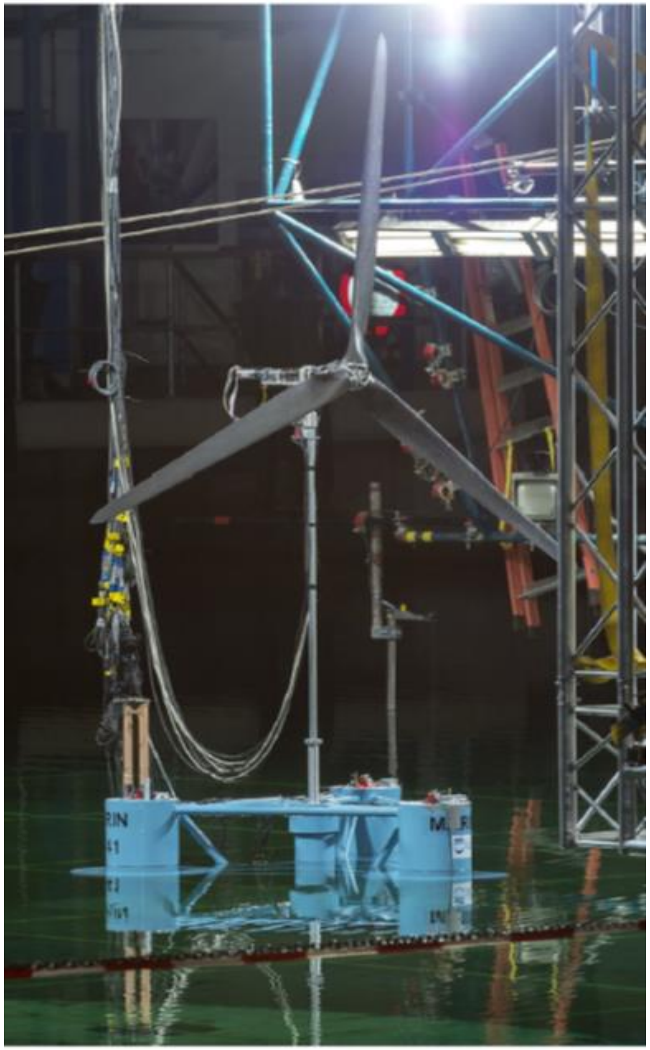


Phase II:
Semi - Tank Testing

Phase III:
Jacket/Tripod – Open Ocean

OC5 Phase II

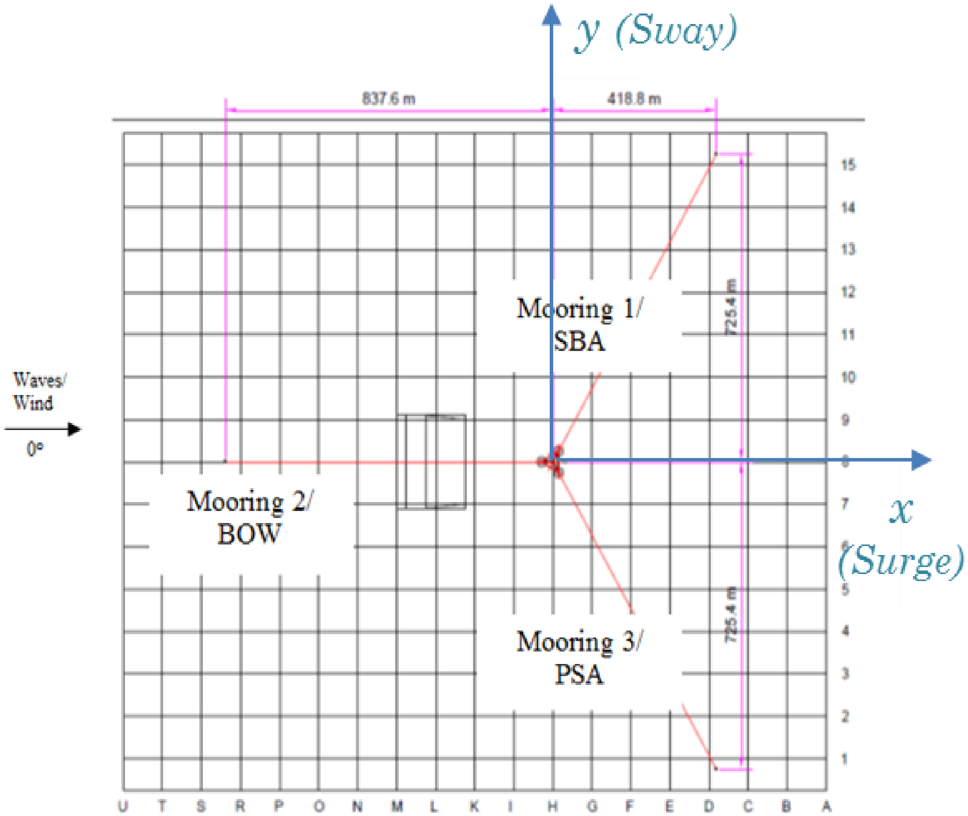
- **Objective**: validate ultimate and fatigue loads in tower/moorings
- Test Data from **DeepCwind** project:
  - Carried out by the DeepCwind consortium, led by the University of Maine
  - MARIN wave basin - 2013
  - 1/50th-scale floating semisubmersible
  - MARIN Stock Wind Turbine
  - Same platform as OC4, but different turbine
  - **Thank you to:** Andrew Goupee and Habib Dagher for allowing us to use the data in the OC5 project



Instrumented OC5-DeepCwind model in the MARIN offshore basin

Test Summary

- **Tests:**
  - Free-decay
  - Wind-only
  - Wave-only
  - Wind/wave
- **Recorded data:**
  - Rotor torque and position
  - Tower-top and -base forces an moments
  - Mooring line tensions
  - 6DOF platform motions
  - Accelerations on the nacelle, tower, and platform



Layout of the floating wind system in the tank

Summary of Tools and Modeling Approach

Participant	Code	Aero-dynamics		Hydrodynamics							Moorings		
		Dyn. Wake	Unst. Airfoil	2^{nd}+ WK	1^{st} PF	2^{nd} PF	ME	Meas. Wave	Stretch	Inst. Pos.	Dyn.	Hydro Exc.	Seabed Fric.
4Subsea	OrcaFlex-FAST v8												
CENER	FAST v6 + OPASS												
CENTEC	FAST v8												
DNV GL	Bladed 4.8												
DTU ME	HAWC2												
DTU PF	HAWC2												
ECN-MARIN	aNySIM-PHATAS v10												
IFE	3DFloat												
IFP_PRI	DeepLinesWind V5R2												
NREL PF	FAST v8												
NREL ME	FAST v8												
POLIMI	FAST v8.15			Diff									
Siemens PLM	Samcef Wind Turbine												
Tecnalia F7O	FAST v7 + OrcaFlex 9.7												
Tecnalia F8	FAST v8.16												
UC-IHC	Sesam												
UOU	UOU + FAST v8												
UPC	UPC + FAST												
UTokyo	NK-UTWind												
WavEC FAST	FAST v8												
WavEC FF2W	FF2W												

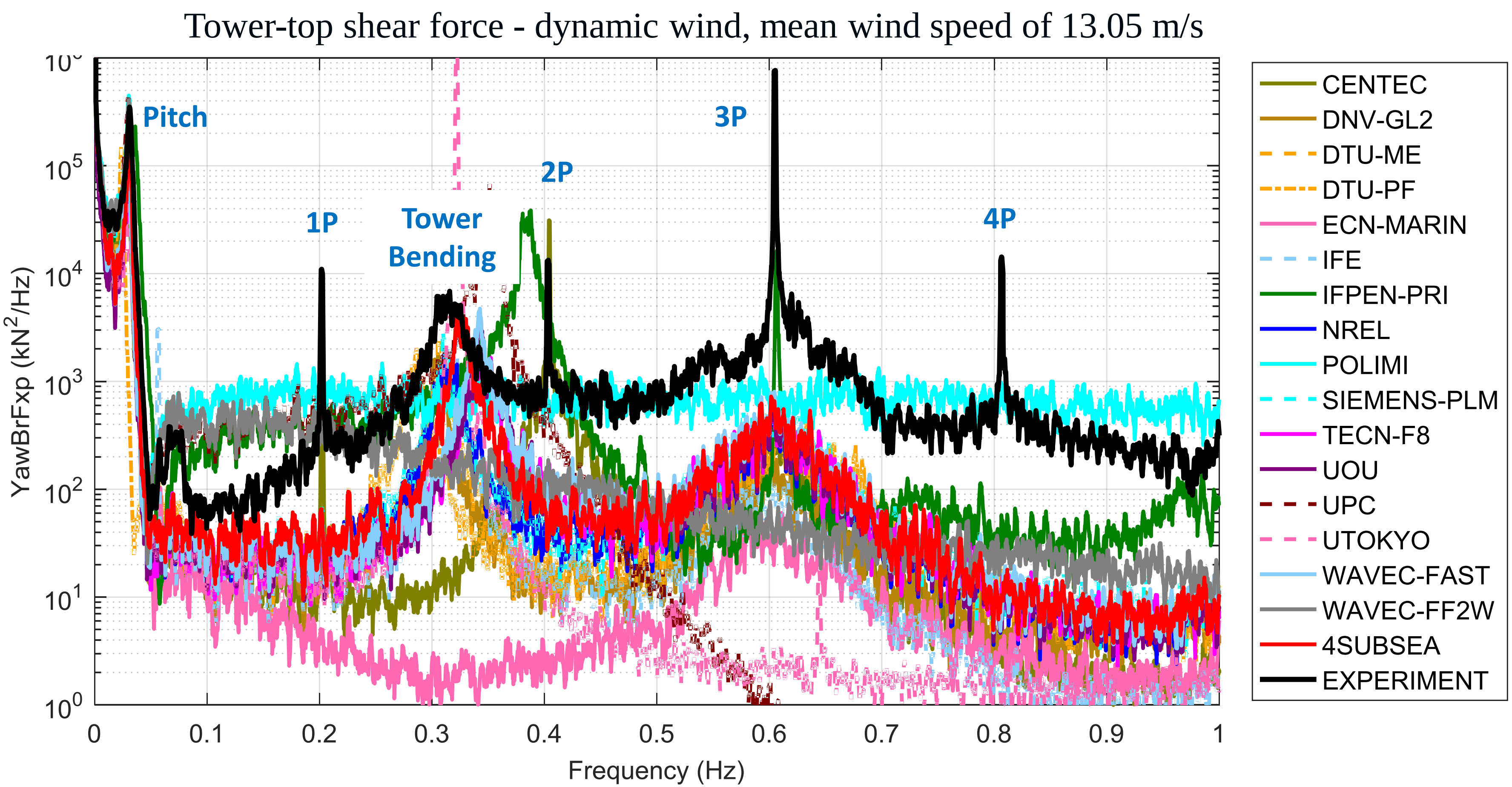
Calibration

- **Static Equilibrium -** position and loads (tower/moorings)
  - Tuning of nacelle CM to achieve near 0 pitch
  - System properties needed adjustment for 0 heave equilibrium
- **Mooring Offsets** – load/displacement curve for moorings
  - Adjustment to mooring line length/stiffness properties
- **Free Decay –** eigen-frequencies and damping
  - Adjustment of C_D and $C_{A,}$ or calculation of damping matrix
  - Additional linear damping matrix
  - Additional stiffness in surge/pitch to match natural frequencies (cable bundle influence?)

DOF	Frequency (Hz)	Period (s)	Damping Coeff. (linear, p) (quadratic, q)
Surge	0.00937	107	0.1095 0.1242
Sway	0.00890	112	0.0795 0.1265
Heave	0.0571	17.5	0.0094 0.2733
Roll	0.0305	32.8	0.0648 0.0625
Pitch	0.0308	32.5	0.0579 0.0686
Yaw	0.0124	80.8	0.1446 0.0165
Tower Bending Fore/Aft (F/A)	0.315	3.18	
Tower Bending Side/Side (S/S)	0.325	3.08	

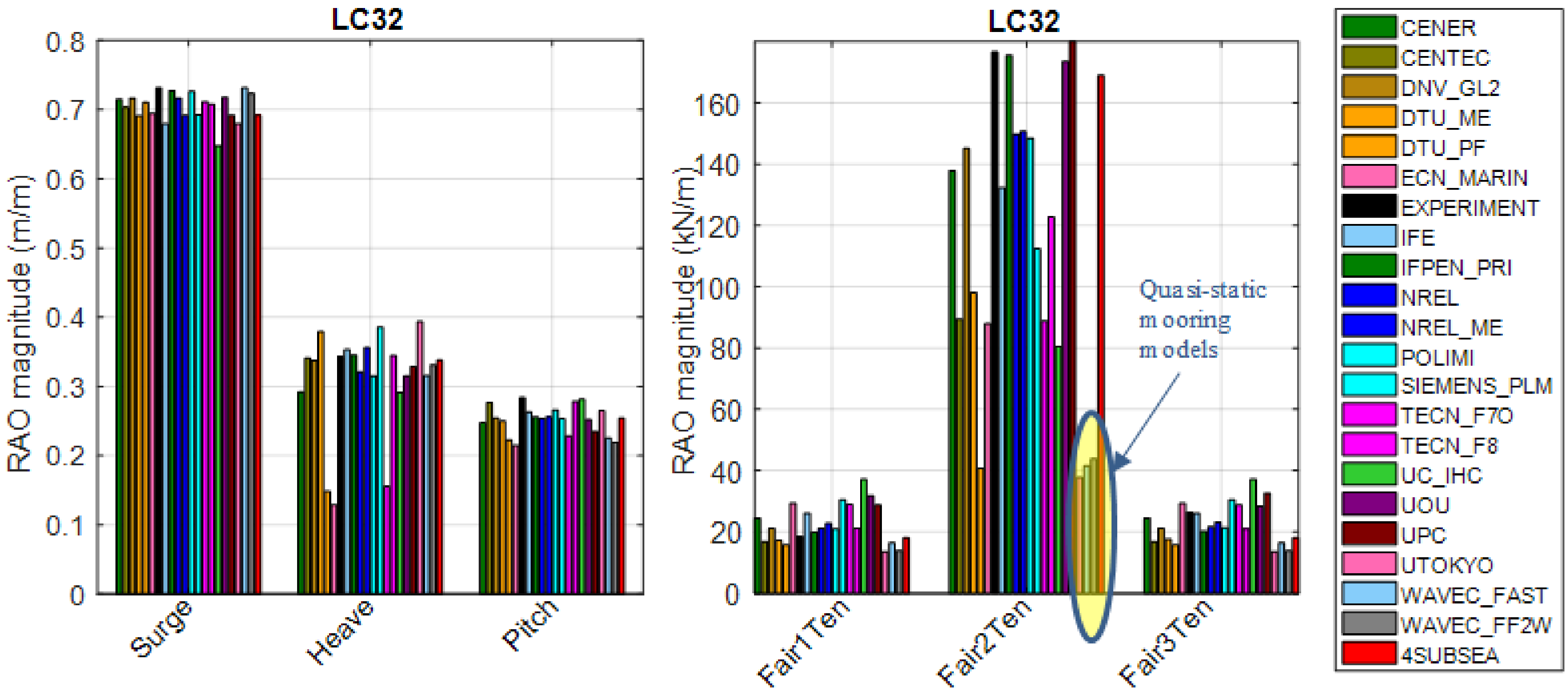
Calibration – Wind-Only Tests

- **Check aerodynamic properties**
  - Tuning done by UMaine, and used by all participants
  - Modification of wind model to better match tests (shear, coherence, turbulence)
  - Variations in individual blade mass and pitch to create 1P, 2P, and 4P excitation



Calibration – Wave-Only Tests

- **Regular wave tests used to:**
  - Tune mooring properties
  - Assess heave excitation
- **Some models are missing critical elements of heave excitation**
  - Dynamic pressure on base columns for Morison solutions
  - Relative fluid velocity for viscous drag calculation
- **Also showed issues related to using a quasi-static mooring model**

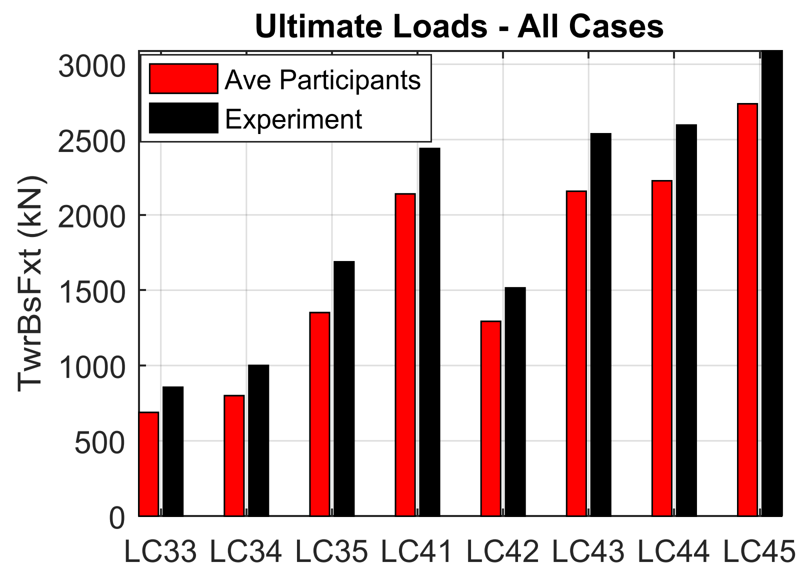


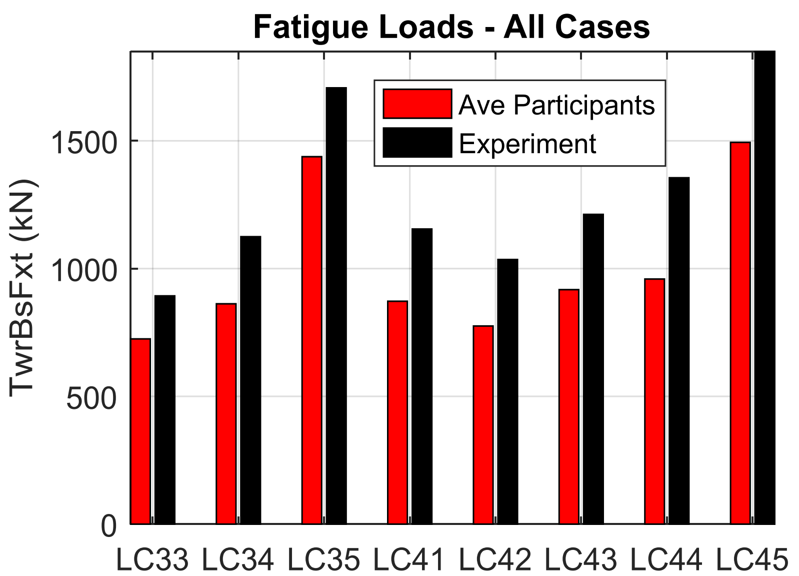
Validation Tests

Load Case	Description	RPM	Blade Pitch (deg)	Wave Condition	Wind Condition	Sim. Length (min)
3.3	Operational Wave	0	90	Irregular: H_s = 7.1 m, T_p = 12.1 s, γ=2.2, JONSWAP	N/A	176
3.4	Design Wave	0	90	Irregular: H_s = 10.5 m, T_p = 14.3 s, γ=3.0, JONSWAP	N/A	180
3.5	White Noise Wave	0	90	White noise: H_s = 10.5 m, T_{range} =6-26 s	N/A	180
4.1	Oper. Wave Steady Wind 1	12.1	1.2	Irregular: H_s = 7.1 m, T_p = 12.1 s, γ=2.2, JONSWAP	$V_{hub,x}$= 12.91 , $V_{hub,z}$= -0.343 σ_x = 0.5456, σ_z = 0.2376	180
4.2	Oper.Wave Steady Wind 2	12.1	15.0	Irregular: H_s = 7.1 m, T_p = 12.1 s, γ=2.2, JONSWAP	$V_{hub,x}$ = 21.19, $V_{hub,z}$ = -0.600 σ_x = 0.9630, σ_z = 0.4327	180
4.3	Oper. Wave Dynamic Wind	12.1	1.2	Irregular: H_s = 7.1 m, T_p = 12.1 s, γ=2.2, JONSWAP	NPD spectrum, µ = 13.05	180
4.4	Design Wave Steady Wind 1	12.1	1.2	Irregular: H_s = 10.5 m, T_p = 14.3 s, γ=3.0, JONSWAP	$V_{hub,x}$= 12.91 , $V_{hub,z}$= -0.343 σ_x = 0.5456, σ_z = 0.2376	180
4.5	White N. Wave Steady Wind 1	12.1	1.2	White noise: H_s = 10.5 m, T_{range} = 6-26 s	$V_{hub,x}$= 12.91 , $V_{hub,z}$= -0.343 σ_x = 0.5456, σ_z = 0.2376	180

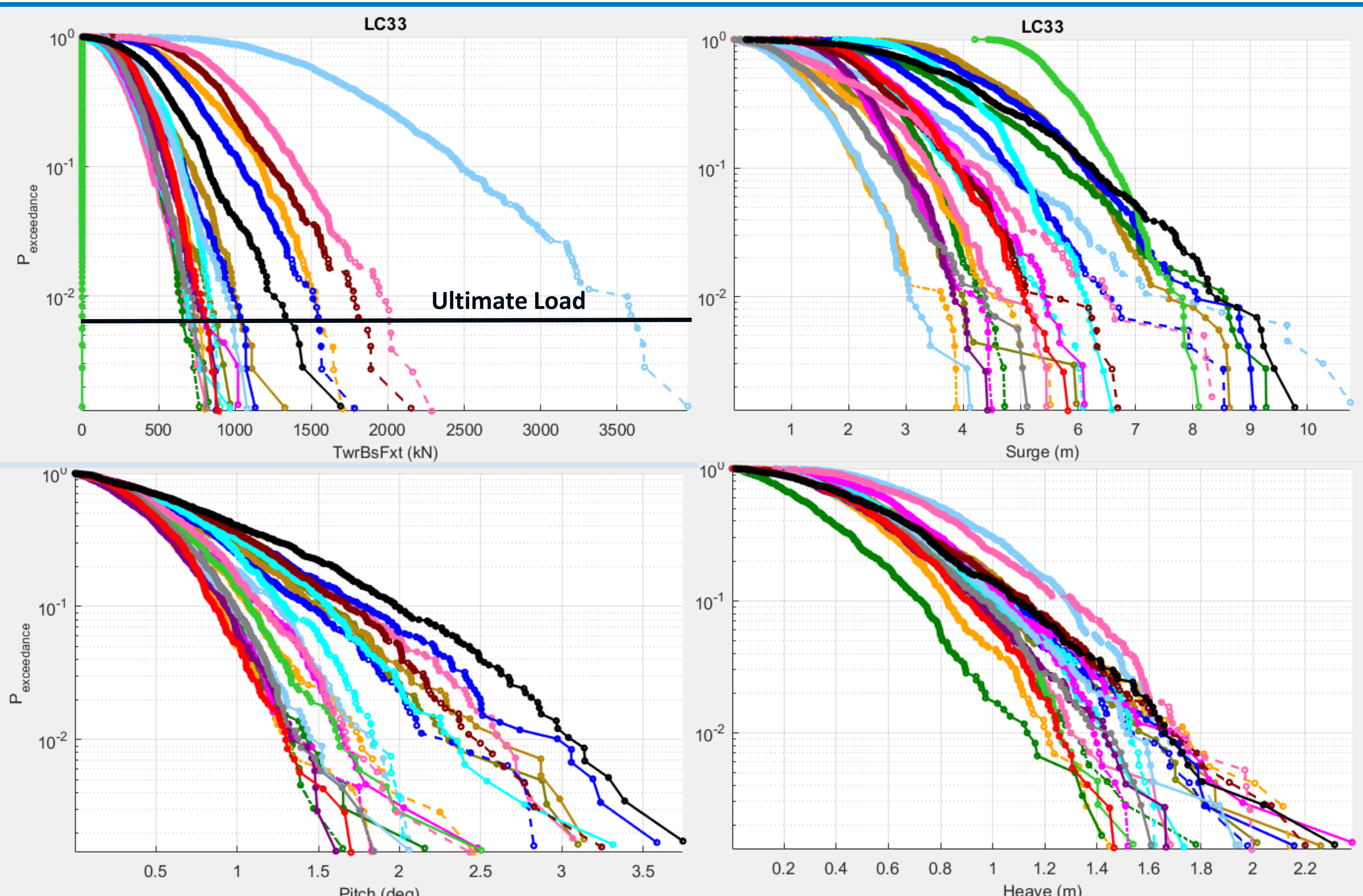
Validation – Ultimate and Fatigue Loads

- **Validation assessed by comparing ultimate and fatigue loads for the:**
  - Tower-top shear force
  - Tower-base shear force
  - Upwind mooring line
- **Simulations generally underestimated these loads**
  - Error greater for fatigue
  - When wind is included, tower loads are higher, fatigue error greater, ultimate error smaller
  - Error generally larger at tower bottom compared to tower top (only bottom shown here)
  - Not a significant change for different wind/wave conditions



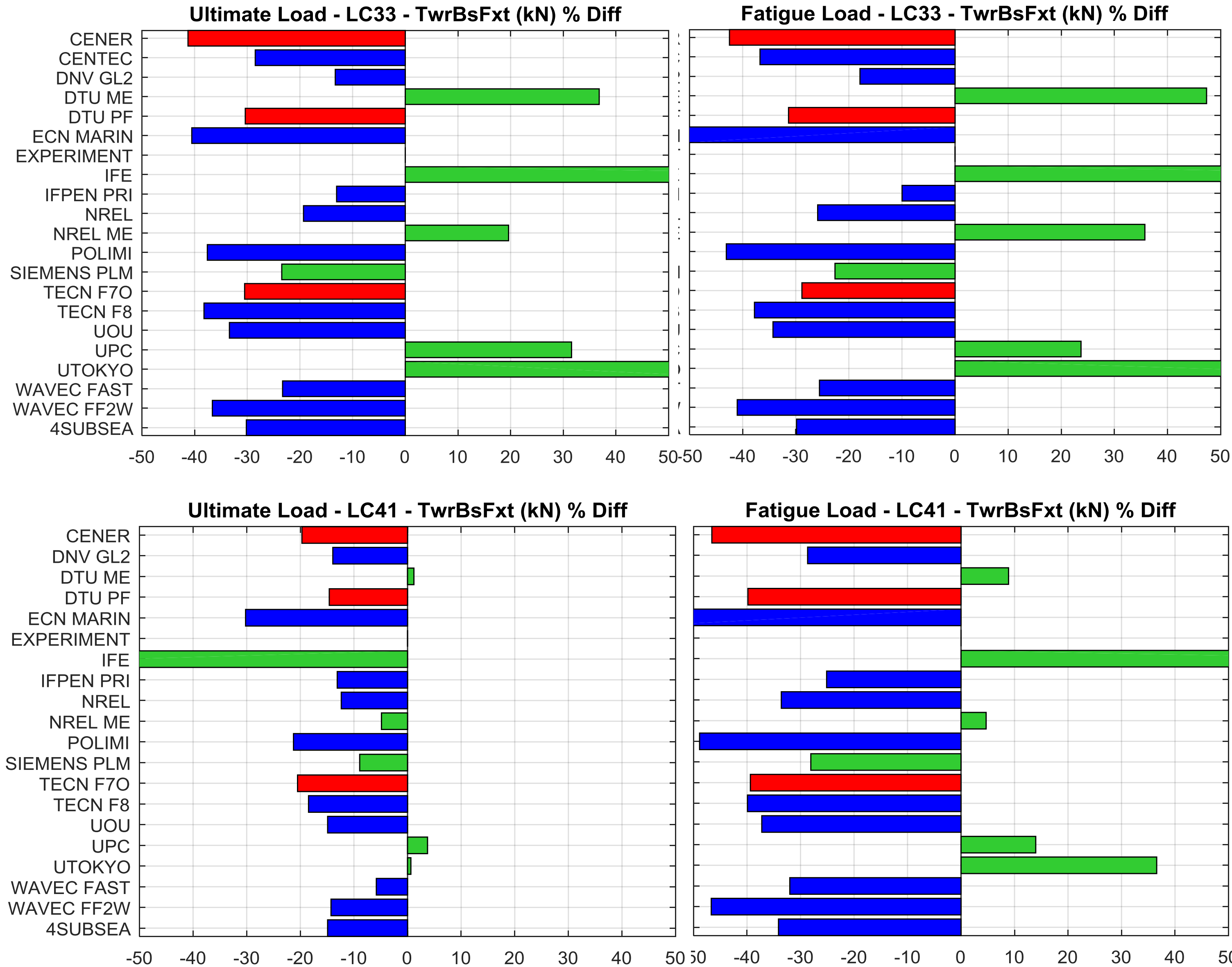


Exceedance Probability Plots



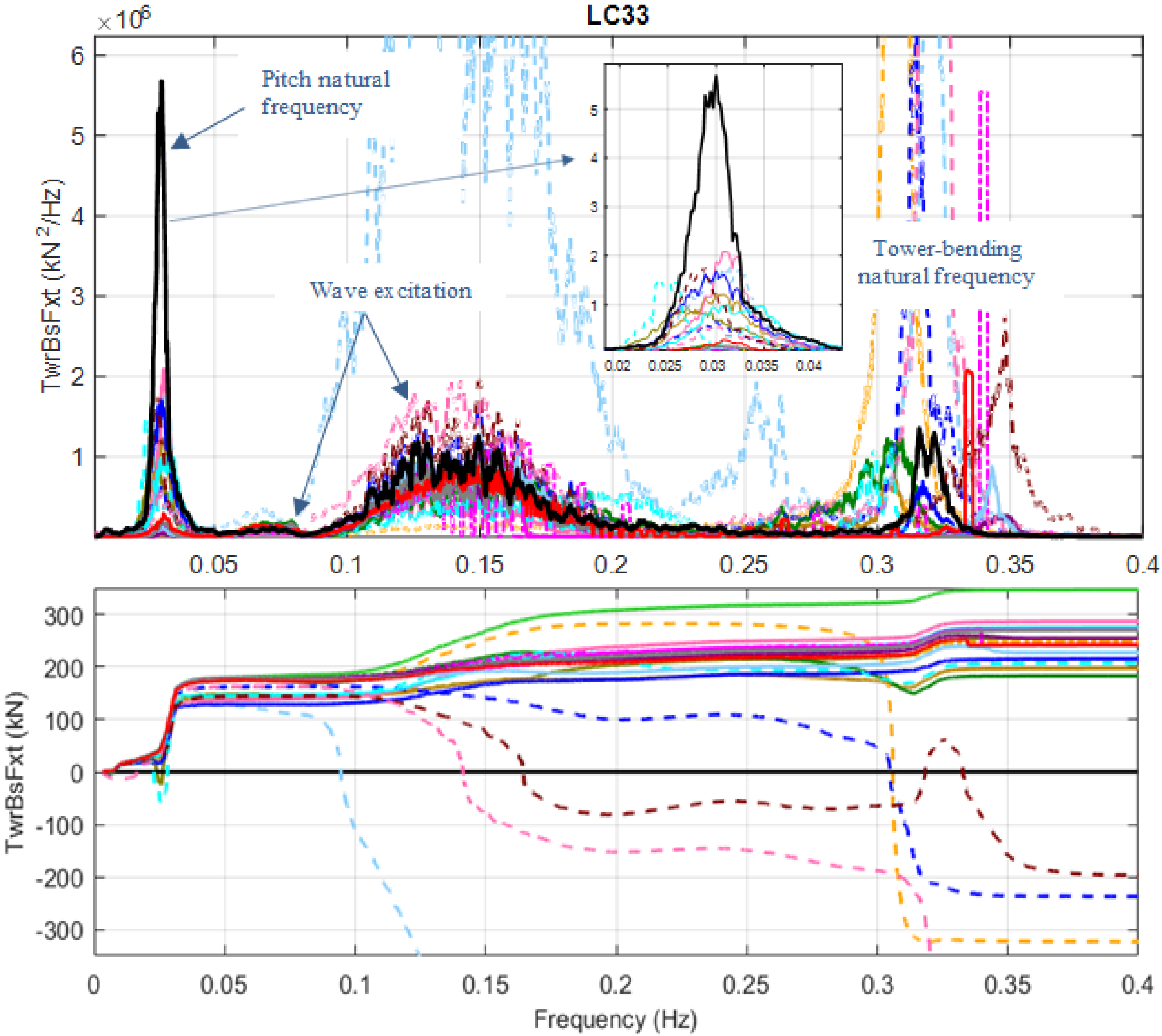
Ultimate/Fatigue Loads – LC 3.3 and 4.1

- **Colors:**
  - Red = PF-only
  - Green = ME-only
  - Blue = PF+ME
- Most PF models under-predicting loads
- Without wind, most ME-only models over-predicting loads



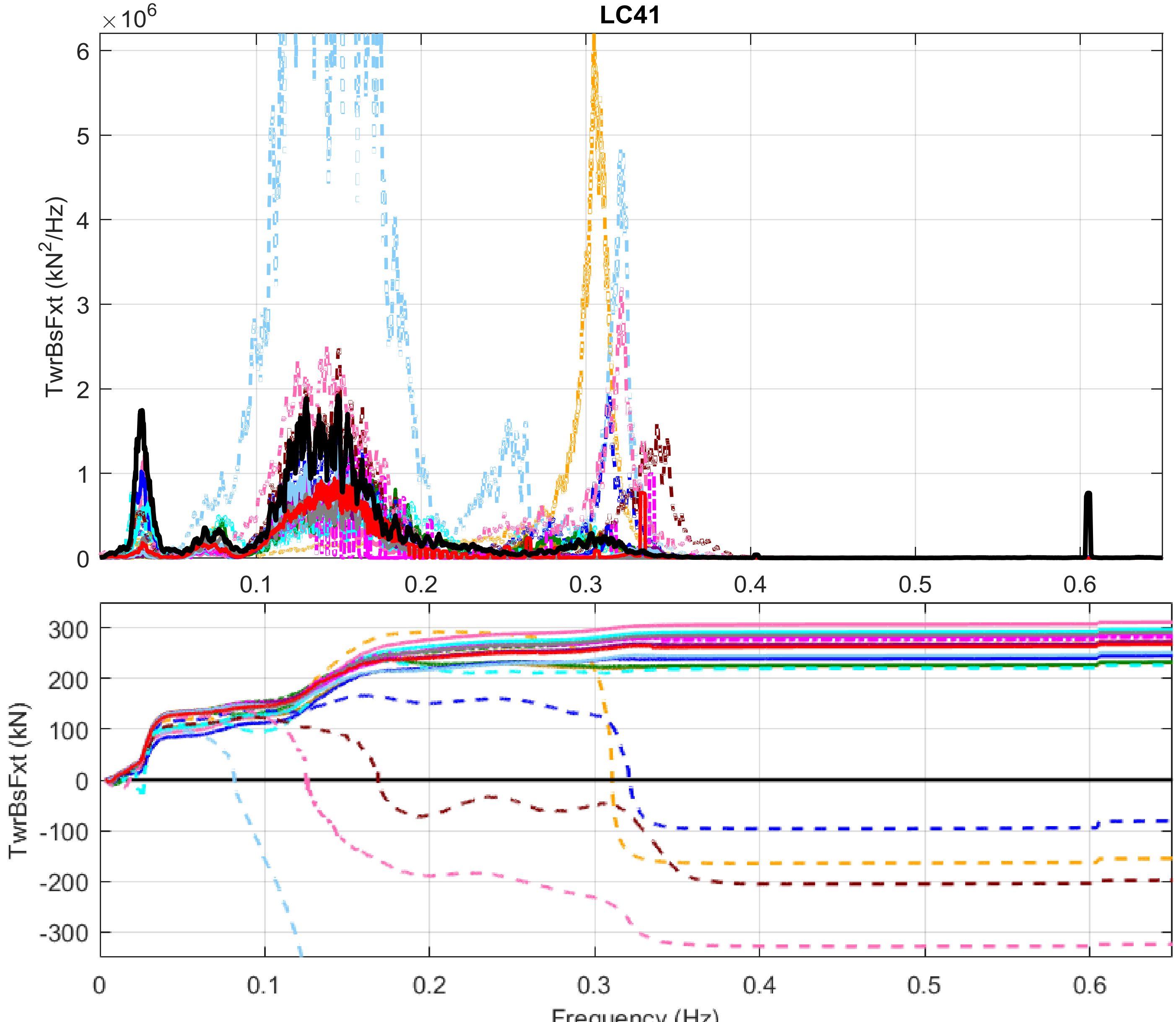
Tower Base PSD – LC 3.3 – Waves Only

- **Line Style:**
  - Solid = PF+ME
  - Dash = ME-only
  - Dash-Dot = PF-only
- **Distinct peaks:** pitch, waves, tower bending
- **Cumulative PSD Difference**
  - Sum integrated PSD difference from low to high frequencies
  - Shows where largest model error occurs



Tower Base PSD – LC 4.1 – Waves + Wind

- **With wind added:**
  - Pitch/Tower peaks decrease for all
  - Experiment response to waves increases ??
- **For PF-models,** error about the same for pitch as linear wave region
- **For ME-only models**, most still have largest error at tower bending frequency
- 3P excitation apparent, but does not significantly affect ultimate/fatigue loads



Conclusions

- **Fairly consistent under-prediction of ultimate/fatigue loads**
  - Seeing an average of about 20% under-prediction
  - Not bad, but would like to better understand reasons
  - See this level of error for wave-only, so not just due to wind
- **Saw some issues with the test data:**
  - Wind: large broad-band frequency excitation and 1P/2P/3P/4P excitation
  - Instruments and cabling could be adding influence
  - Hysteresis of mooring lines
- **Modeling approach influences:**
  - Nonlinear wave forces (2nd-order PF, 2nd-order wave kin., wave stretching, etc.)
  - Axial excitation on heave plates
  - Dynamic mooring models
  - Not much focus on aerodynamics
  - Most ME-only models – large tower bending excitation
- **Uncertainty**
  - Difficult to determine if differences caused by modeling error or test uncertainties
  - Uncertainty not assessed here, but examined in ISOPE paper by Robertson, 2017
- **Future Recommendations:**
  - Address uncertainty in model tests
  - Use CFD to assess modeling errors

Robertson, A. et al. “Uncertainty Analysis of OC5-DeepCwind Floating Semisubmersible Offshore Wind Test Campaign”. To be presented at The International Society of Offshore and Polar Engineers Conference, June 2017.

Thank You!

Amy Robertson
+1 (303) 384 – 7157
Amy.Robertson@nrel.gov

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