Analysis of wake effects for a floating two-turbine case

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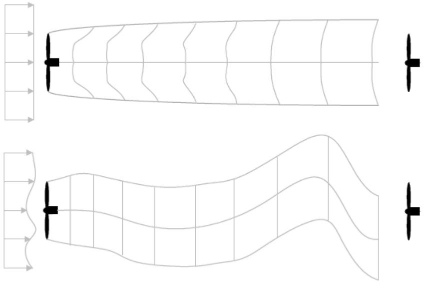
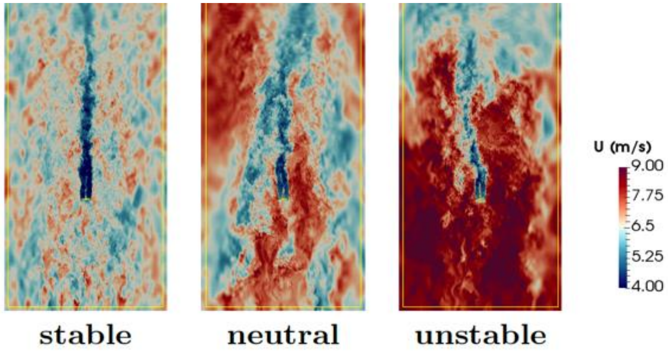
Motivation

- Wake effects have been observed for many years
- Recent developments in modeling wake meandering
- Little published work on floating wind turbine (FWT) wake interaction
  - How will slow meandering movement affect structures with long natural periods?

Horns Rev II Wind Farm



Uniforms vs. meandering wake deficit. Jonkman et al. (2017)



Wake meandering behavior in different atmospheric stability conditions. Churchfield et al. (2016)

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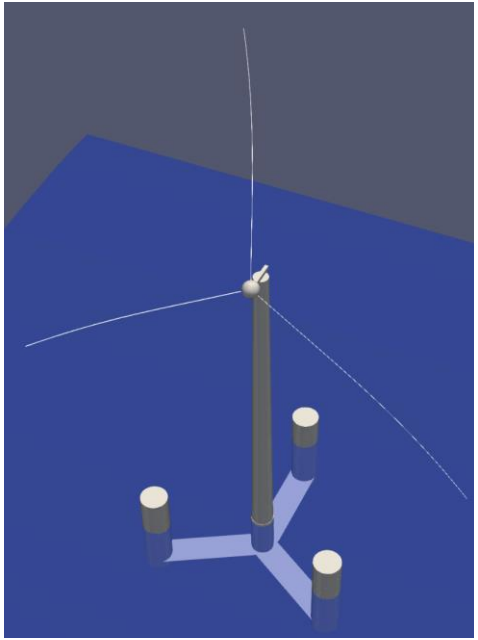
Approach

- Two 10 MW semi-submersible FWTs modeled in FAST.Farm
- Moderate environmental conditions with synthetically generated turbulent inflow from TurbSim and the Mann Model
- Compare platform motions and fatigue damage in the tower and mooring lines in the upstream and downstream FWTs

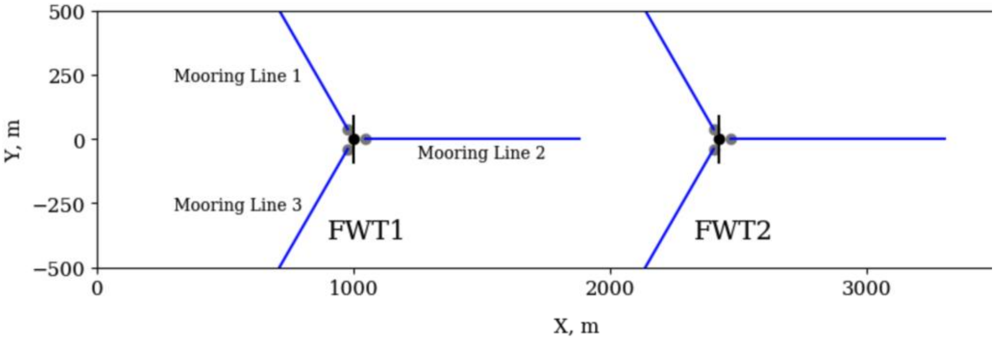
OpenFAST and FAST.Farm Model



Computational model of the CSC 10 MW visualized in OpenFAST

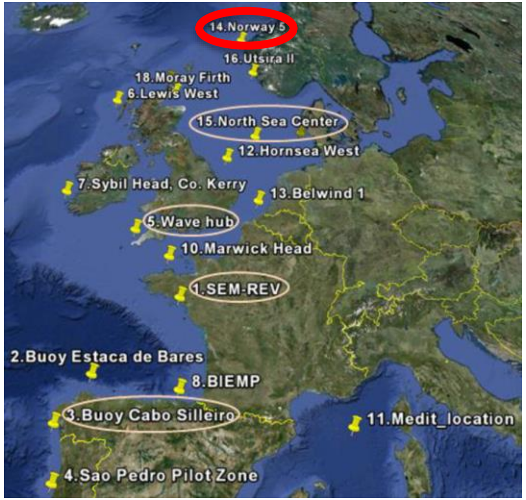
CSC 10 MW natural periods in SIMA and OpenFAST

Degree of Freedom	SIMA	OpenFAST
Surge (s)	88.3	85.1
Pitch (s)	26.3	24.8
Yaw (s)	60.4	58.5
Coupled pitch and tower bending (s)	2.4	2.5, 2.9



FAST.Farm computational domain (truncated in X)

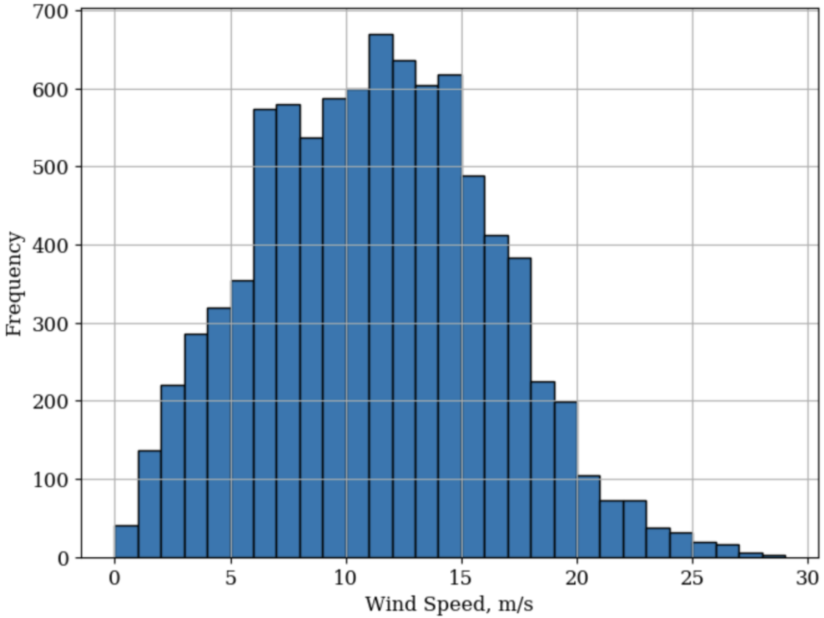
Environmental Conditions



Location of reference wind site - Site 14. Li et al. (2013)

Selected environmental conditions

H_s (m)	T_p (s)	U (m/s)	TI (%)	Shear Exponent (-)
2.5	9.5	10	15.72	0.055



Frequency of hub height wind speeds at Site 14

Ambient Wind Generation

- Method 1 (Kaimal – Coh u):
  - Turbsim, Kaimal turbulence model, spatial coherence only in u

- Method 2 (Kaimal – Coh u, v, w):
  - Turbsim, Kaimal turbulence model, spatial coherence specified in u, v, and w

- Method 3 (Mann):
  - HAWC2 precursor, Mann turbulence model, spatial coherence in all three dimension inherit to the model

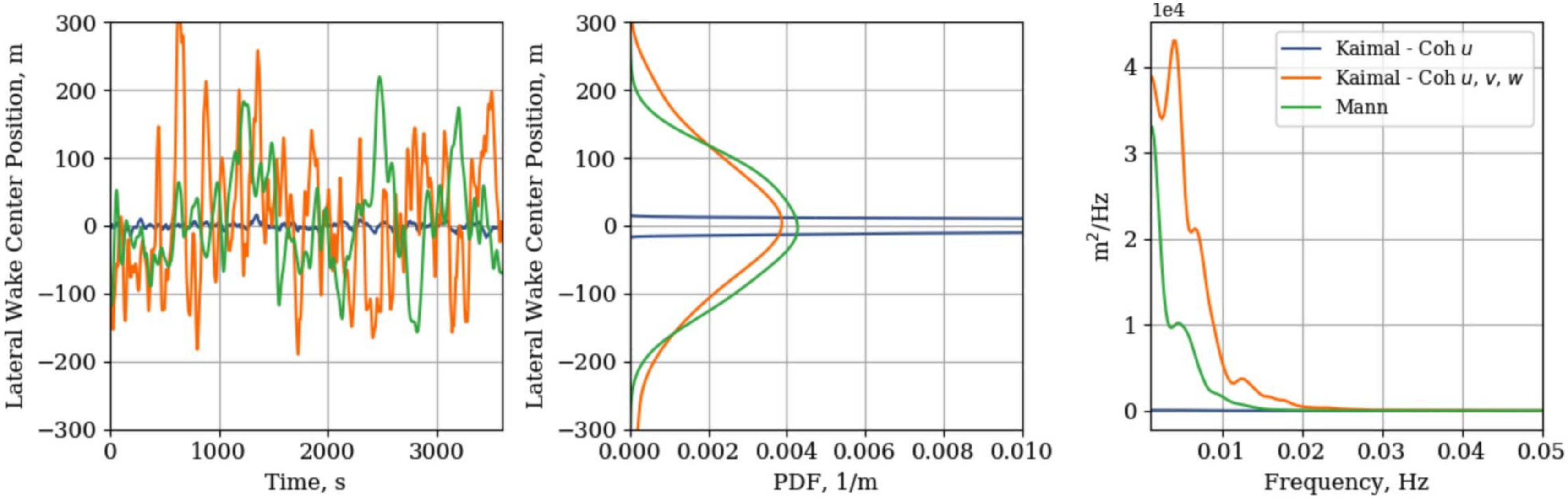
Exponential spatial coherence function in the Kaimal turbulence model:

$$Coh_{i,j_K} = \exp\left(-a_K\sqrt{\left(\frac{fr}{\bar{u}_{hub}}\right)^2 + (rb_K)^2}\right)$$

Spatial coherence parameters specified in TurbSim

Model name	a_u	b_u	a_v	b_v	a_w	b_w
Kaimal - Coh u	12.0	3.5273E-4	∞	0.0	∞	0.0
Kaimal - Coh u, v, w,	10.0	0.0	7.5	0.0	7.5	0.0

Wake Meandering

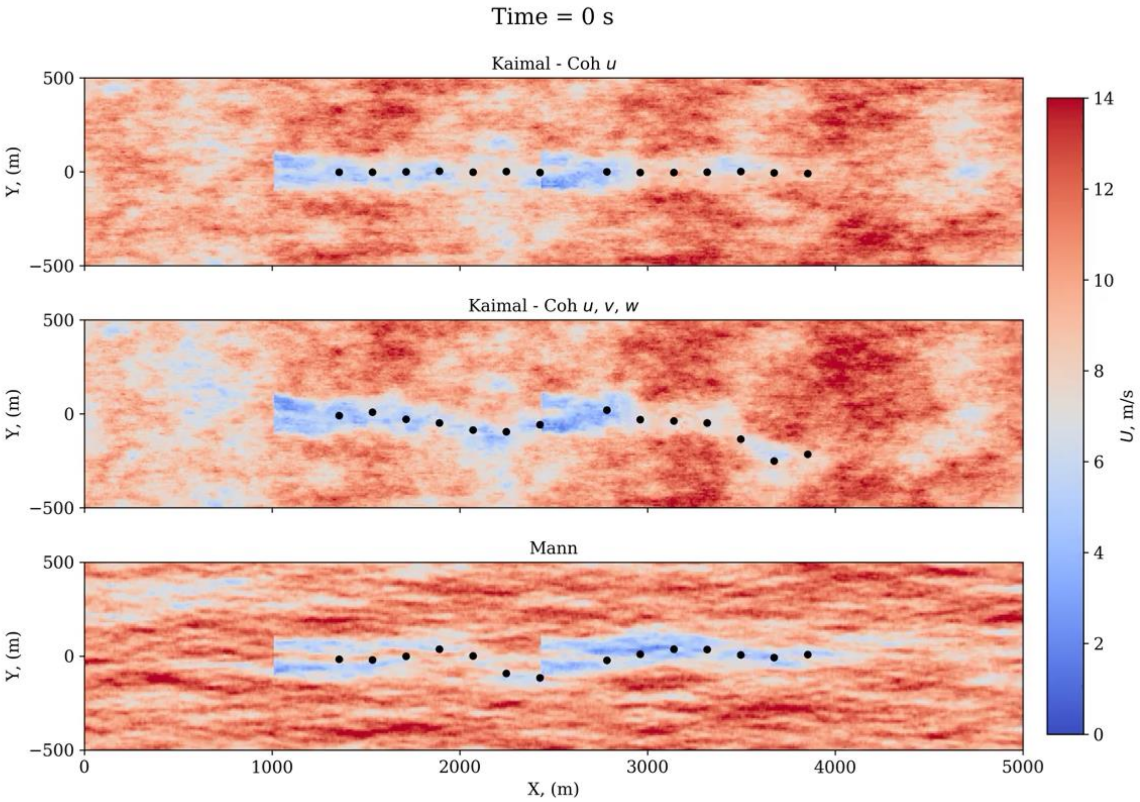


- Method 1 results in a uniform, axial wake deficit
- Methods 2 and 3 result in significant meandering with Method 2 having greater variance and somewhat higher frequency movement

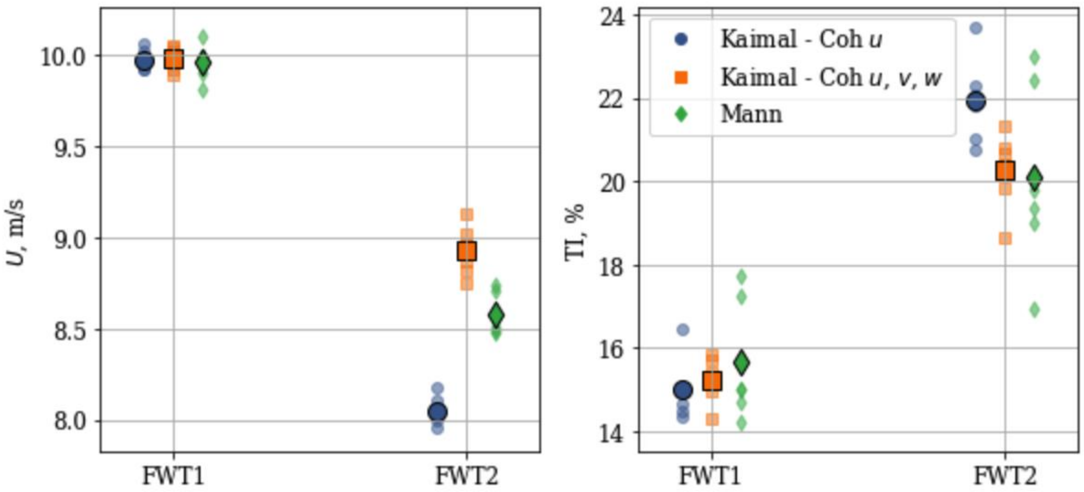
Wake Visualizations – XY Plane

- Lateral meandering is sensitive to spatial coherence in u and v

- Longer coherent shapes in the Mann Model



Velocity Deficit, Turbulence, and 3P



Mean 3P frequencies of each FWT

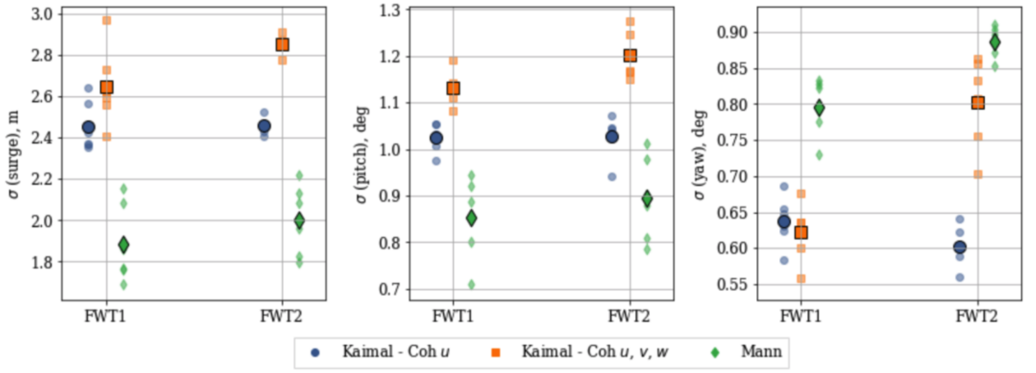
	FWT1	FWT2
Kaimal - Coh u	0.387 Hz	0.336 Hz
Kaimal - Coh u, v, w	0.387 Hz	0.345 Hz
Mann	0.386 Hz	0.358 Hz

- Velocity deficit is correlated with variance in upstream FWT’s lateral wake center
- Mean 3P frequencies are close to the coupled pitch and tower bending frequencies

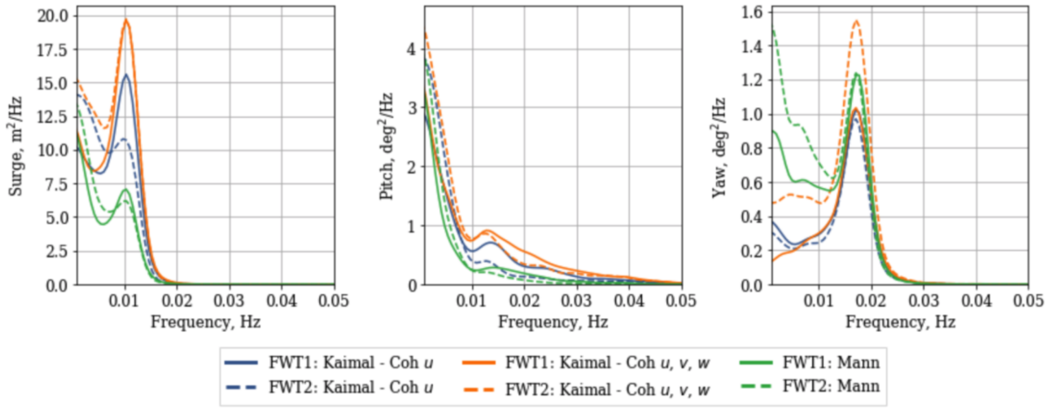
Platform Motions

- Increased surge, pitch, and yaw motions driven by low-frequency response

- Mann Model results in lower surge and pitch and greater yaw motions



Platform surge (left), pitch (middle), yaw (right) motion standard deviations

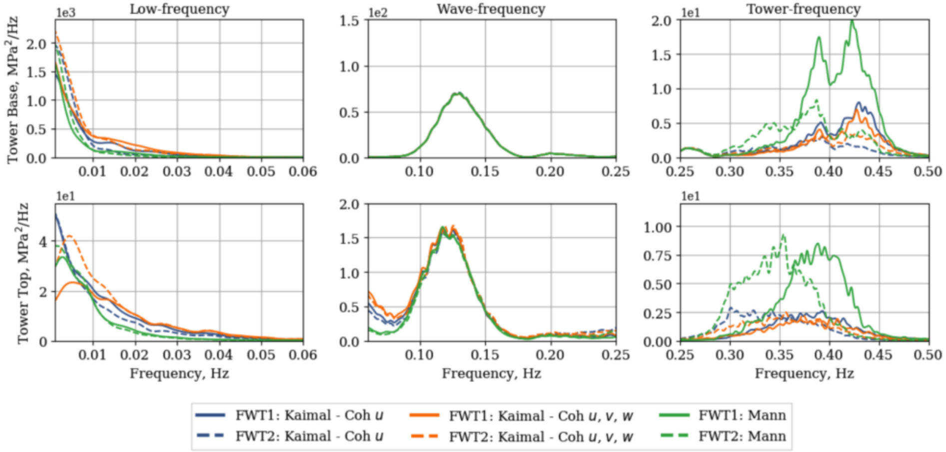


Platform surge (left), pitch (middle), yaw (right) motion spectra

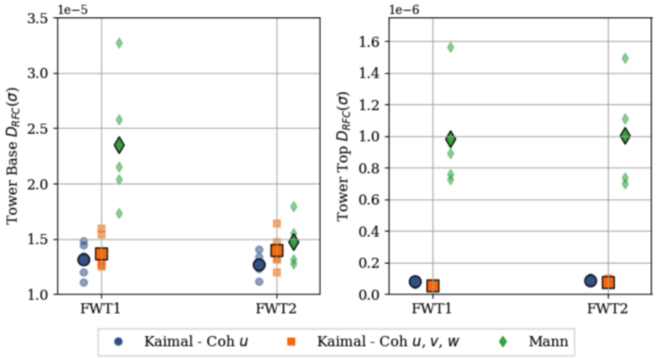
Fatigue - Tower

- Increased low-frequency structural loading does not necessarily translate to increased fatigue damage

- Responses in the 3P range contribute to the fatigue damage due to their large number of cycles



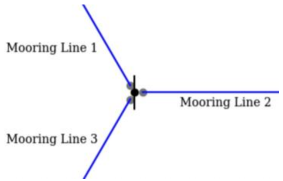
Tower base (top) and top (bottom) axial stress spectra



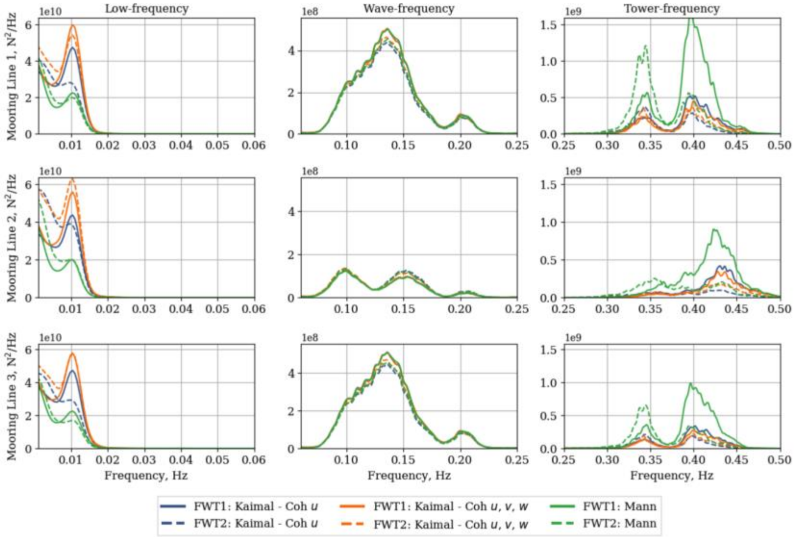
Tower base (left) and top (right) 1-h fatigue damage

Fatigue - Mooring

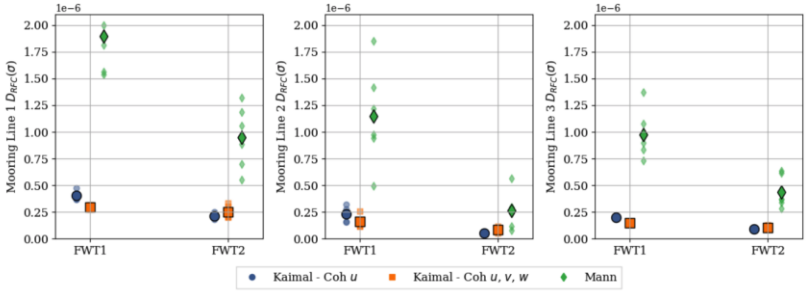
- Similarly affected by responses at 3P



- Mean roll offset increases the stiffness in mooring line 1 resulting in greater high-frequency excitation



Mooring line 1 (top), 2 (middle), and 3 (bottom) tension spectra



Mooring line 1 (left), 2 (middle), and 3 (right) 1-h fatigue damage

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Conclusions

- Spatial coherence of v- and w-velocity components affect wake meandering behavior

- Low-frequency meandering movement translates to increased low-frequency surge, pitch, and yaw motions

- Increased fatigue damage due to meandering was observed in the top of the tower, but other results were sensitive to 3P

Future Work

- Model an FWT with a more representative structural design of the tower, or with modifications made to the controller
- Comparison with other types of FWTs
- Additional load cases and with more rigorous generation of synthetic turbulent inflow

Lifes50+ OO-Star Wind Floater

Generic spar FWT

Thank you for your attention

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