The dynamic response of offshore wind turbines and their sensitivity to wind field models

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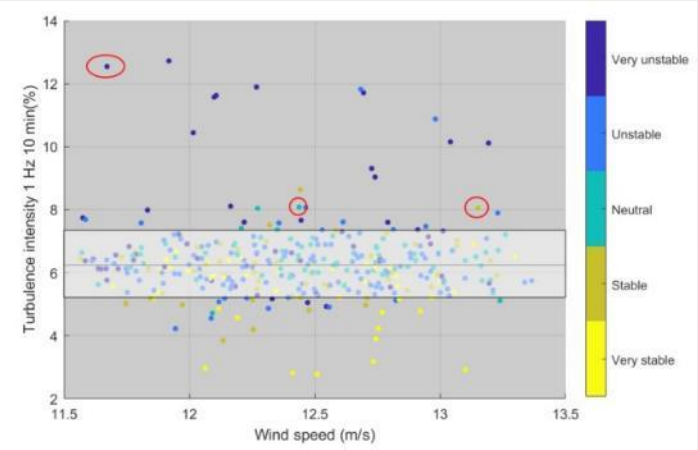
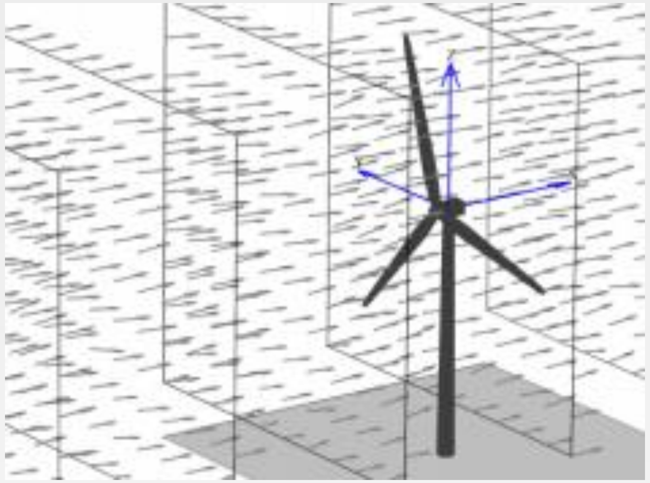
Outline

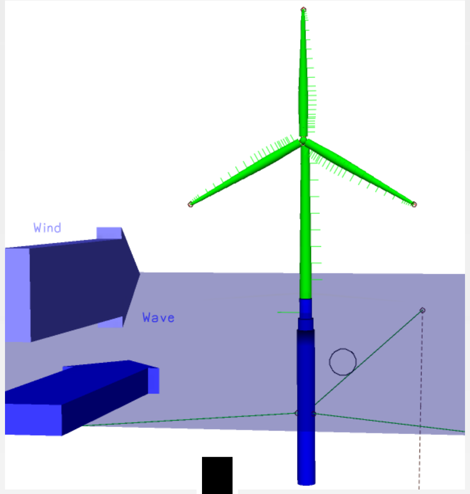
- DATA ANALYSIS



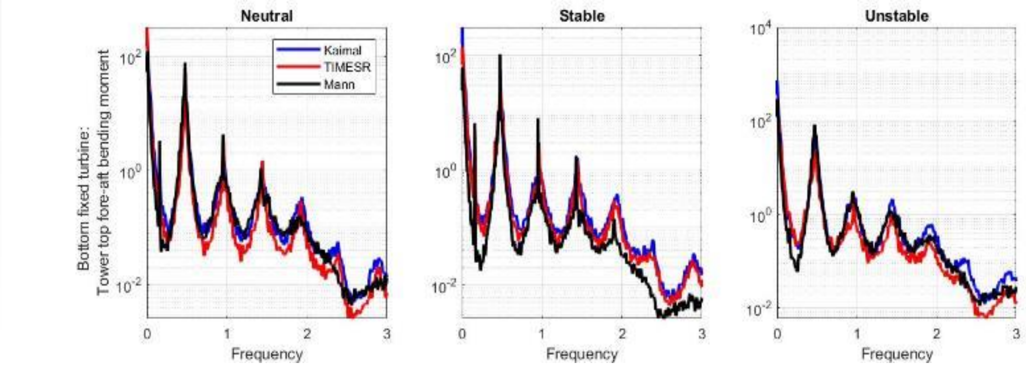
- WIND FIELDS



- WIND TURBINE SIMULATION



- TURBINE LOAD RESPONSE ANALYSIS



RESULTS AND CONCLUSIONS

Motivation

Generate turbulence wind fields based on: IEC standard and measurements

Find the impact on turbine response due to coherence and atmospheric stability

Investigate global and local responses of offshore wind turbines

Bottom fixed and spar floater simulations

Simulation program: SIMA
Input: pre-generated wind fields

Global response:

- Tower bottom fore-aft bending moment (TBBM)
- Tower top fore-aft bending moment (TTBM)
- Tower top yaw moments (TTYM)

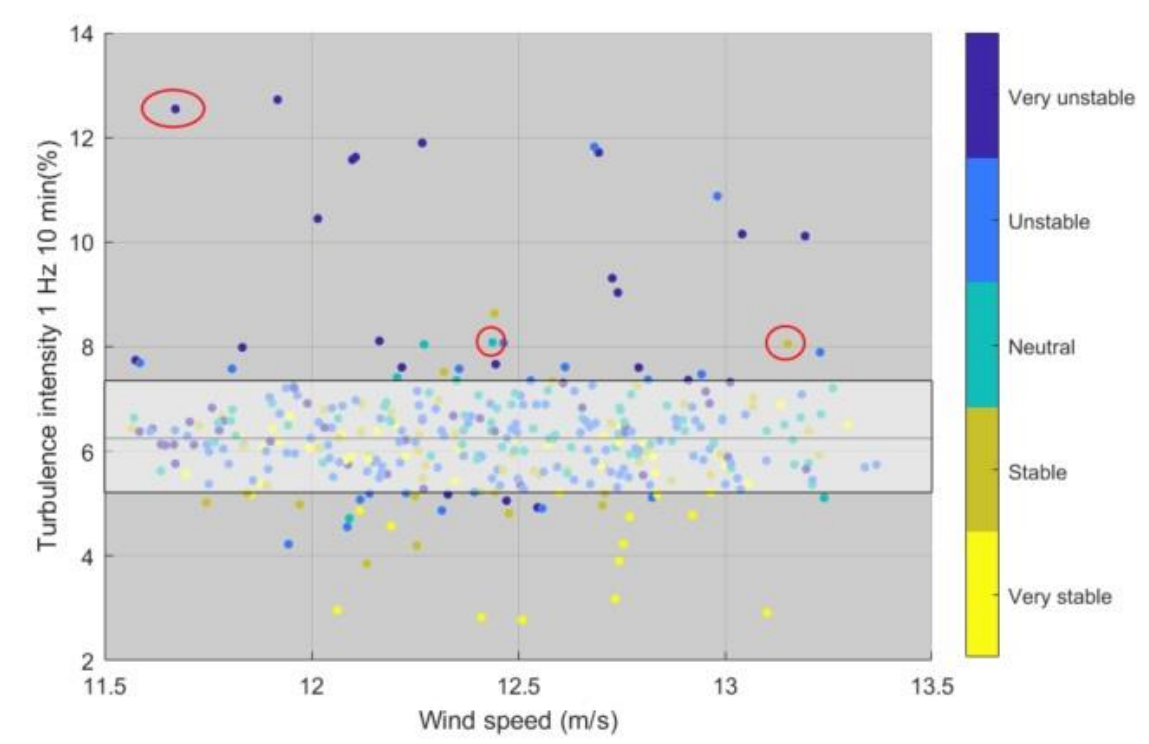
Local response:

- Flapwise bending moment in the blade root (one blade) (FBM)

Measurements and time series selection

Below rated (+/- 7.5 m/s)	**Atmospheric conditions:** **Neutral, stable and unstable**
Close to rated (+/- 12.5 m/s)	
Above rated (+/- 17.5 m/s)	

= Totally 9 selected time series



Stability classification, Obukhov length:

$$L = \frac{-\bar{\theta}_v {u_*}^3}{kg(\overline{w'\theta_v})_s}$$

The wind fields

Kaimal spectral model: *TurbSim turbulence simulator*

- Reproduce turbulence time series using Kaimal spectrum and IEC exponential coherence function

Mann uniform shear model: *DTU Mann generator*

- Three-dimensional wind boxes with turbulence from spectral tensor. Coherence implicit.

TIMESR: *A TurbSim option*

- Spectral amplitudes and phase angles measured time series. (40, 60 and 80 m height). Davenport coherence function.

Mean wind speed	Atmospheric stability:
+/-7.5 m/s	Neutral
	Stable
	Unstable
+/-12.5 m/s	Neutral
	Stable
	Unstable
+/-17.5 m/s	Neutral
	Stable
	Unstable

Each wind speed case and atmospheric condition:

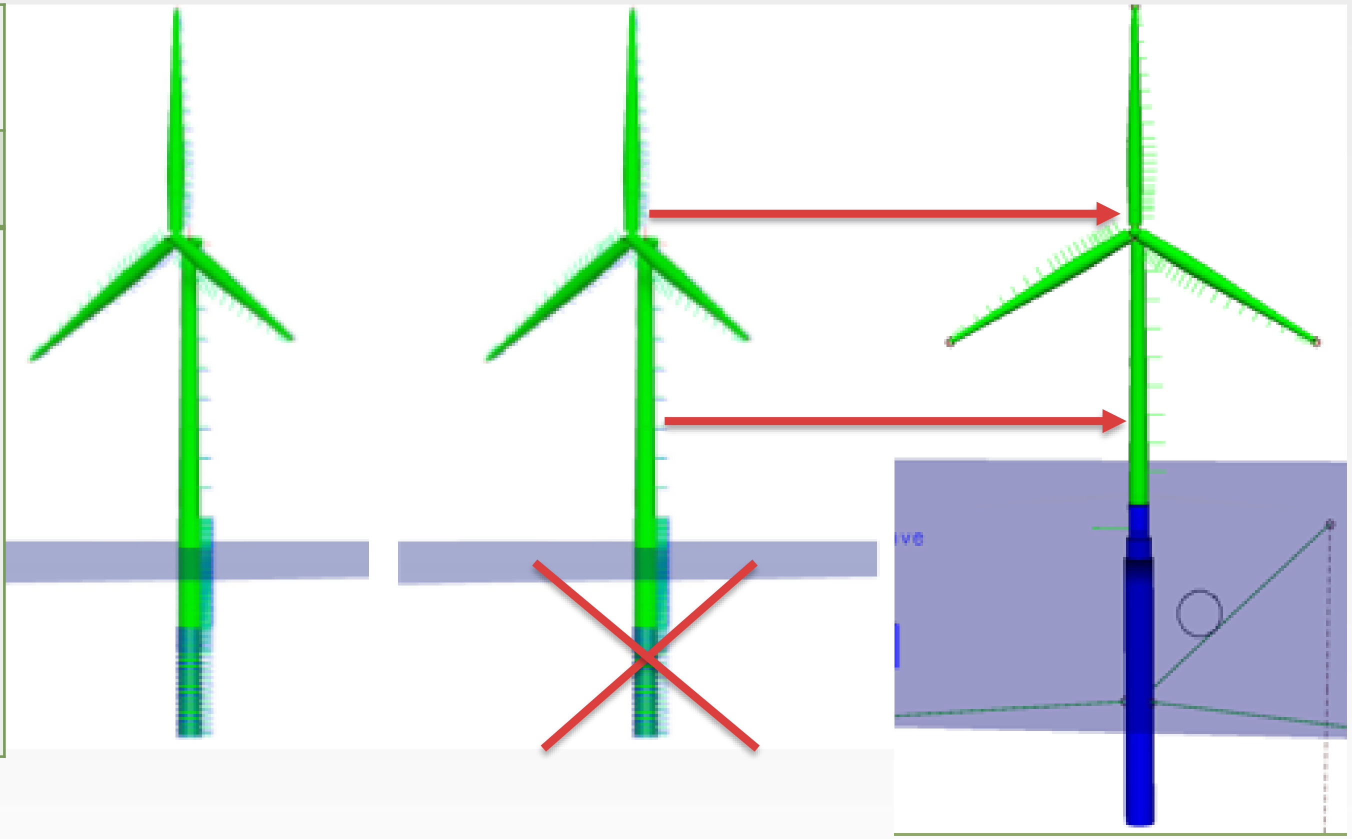
Same ***turbulence intensity***

Same ***wind shear profile***

DTU 10 MW offshore wind turbines

The main properties of the DTU 10 MW reference turbine (RWT)

Parameter	DTU 10 MW
Rated power	10 MW
Rated wind speed	11.4 m/s
Number of blades	3
Rotor diameter	178.3 m
Hub height above sea level	119 m
Minimum rotor speed	6.0 rpm
Maximum rotor speed	9.6 rpm
Control	Variable speed, collective pitch

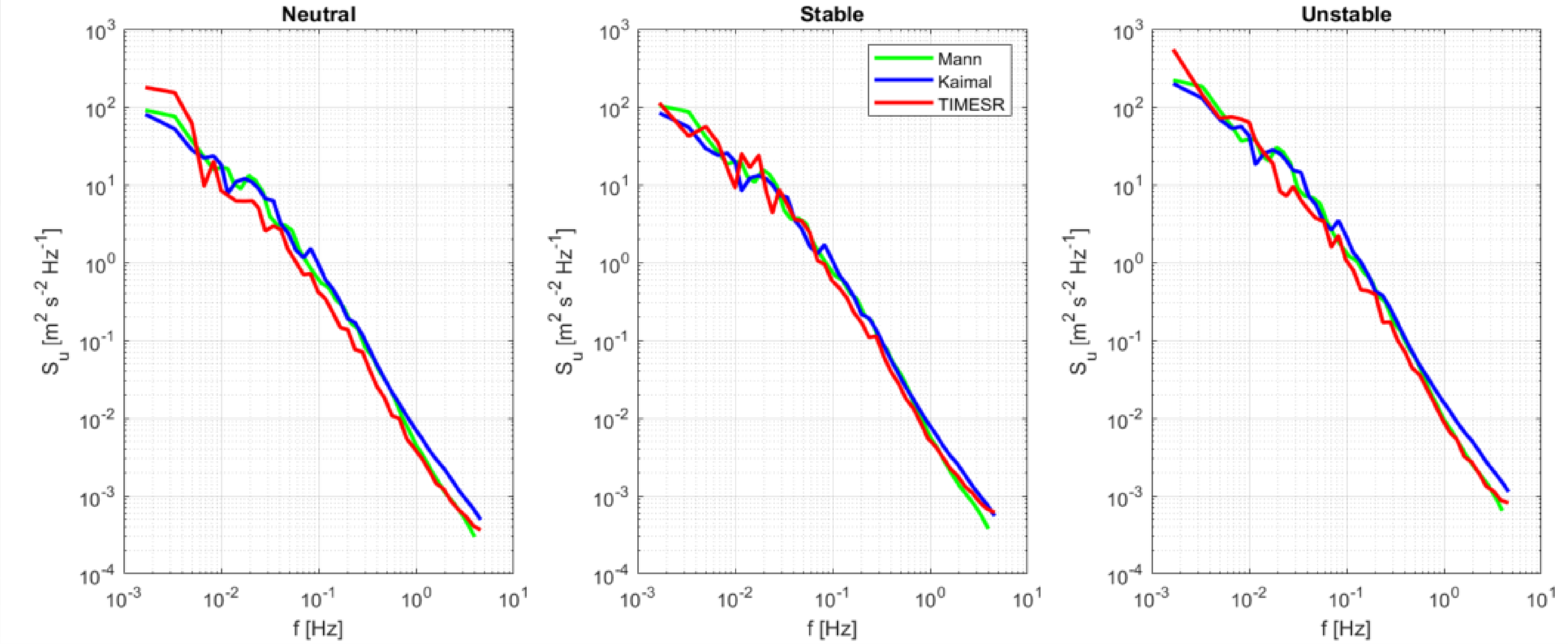


Bottom fixed turbine with monopile foundation

Floating turbine with spar substructure

Results: the generated wind turbulence

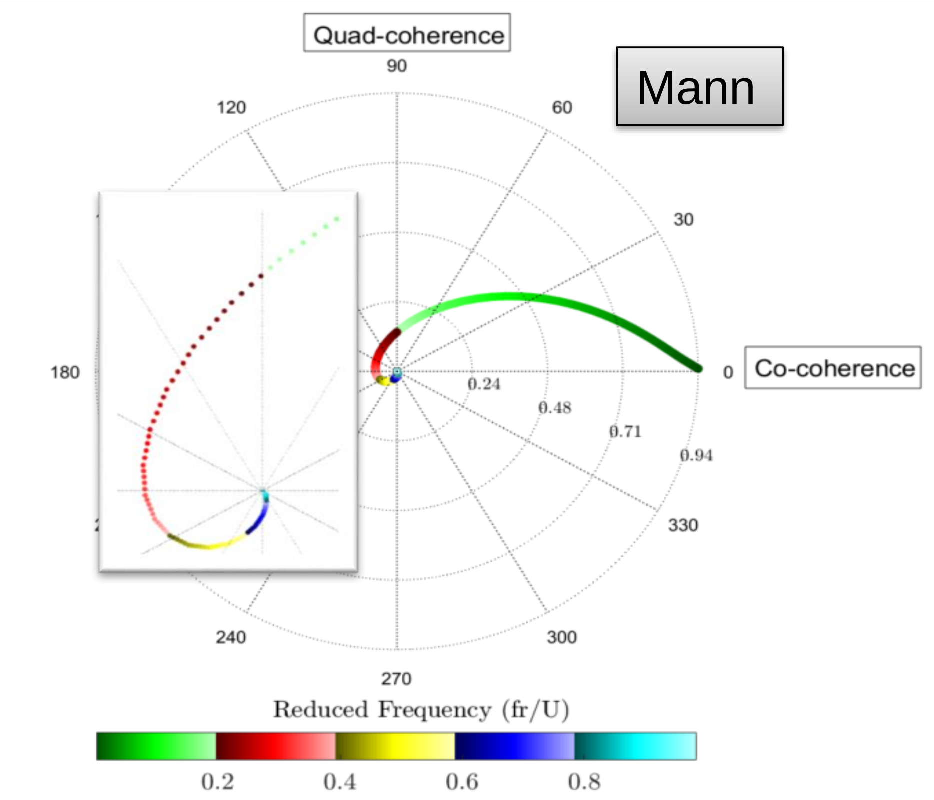
Power spectral density at the hub centre for 12.5 m/s mean wind speed. Simulated fields.

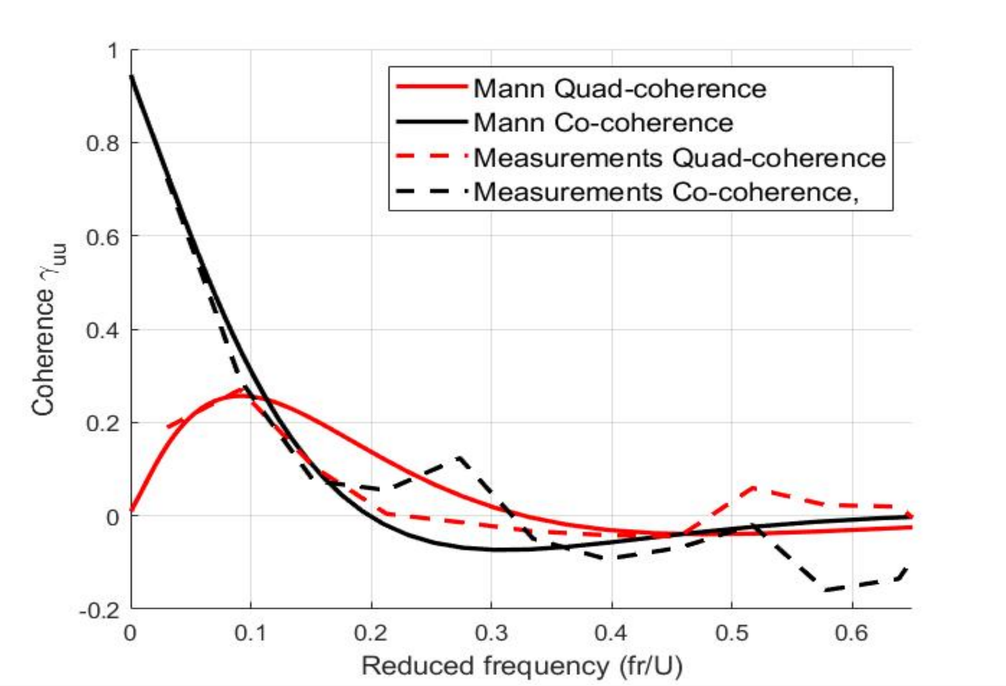


Results: the generated wind turbulence

The relation between co- and quad coherence of the u-component for 12.5 m/s mean wind speed.
40 m vertical separation distance

$$\gamma_{xy}(f) = \frac{S_{xy}(f)}{\sqrt{S_x(f) \cdot S_y(f)}} = Co_{xy}(f) + iQu_{xy}(f)$$

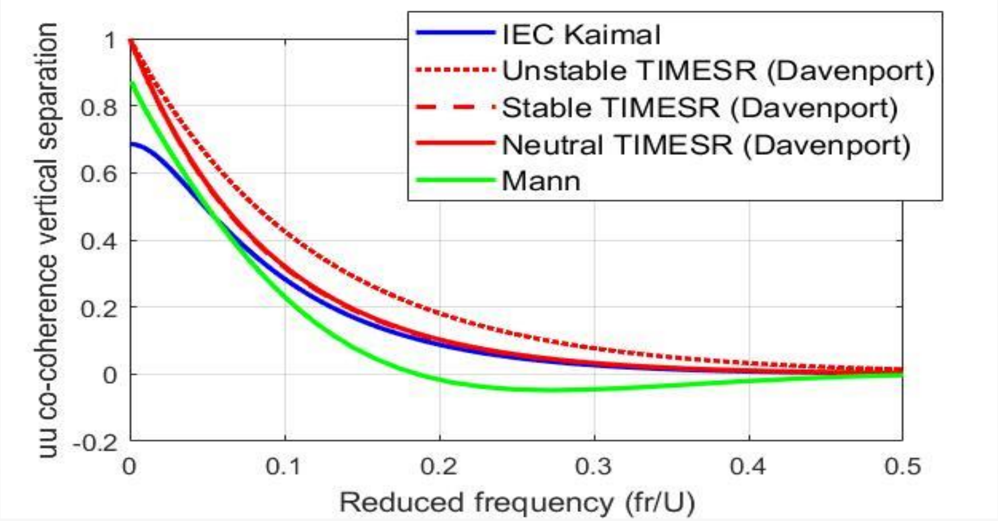




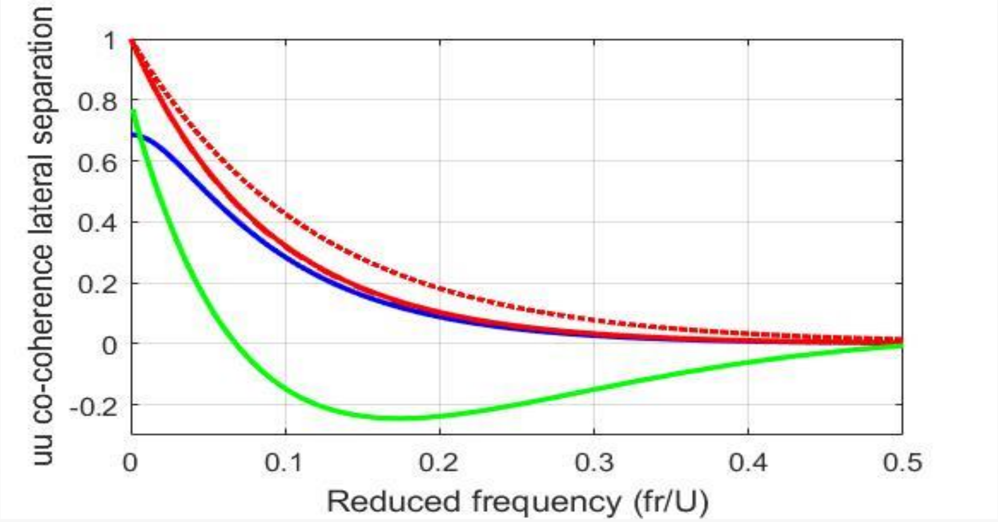
Results: the generated wind turbulence

The co-coherence of the u-component for 12.5 m/s mean wind speed. Separation D/2 (89.15m)

Vertical separation

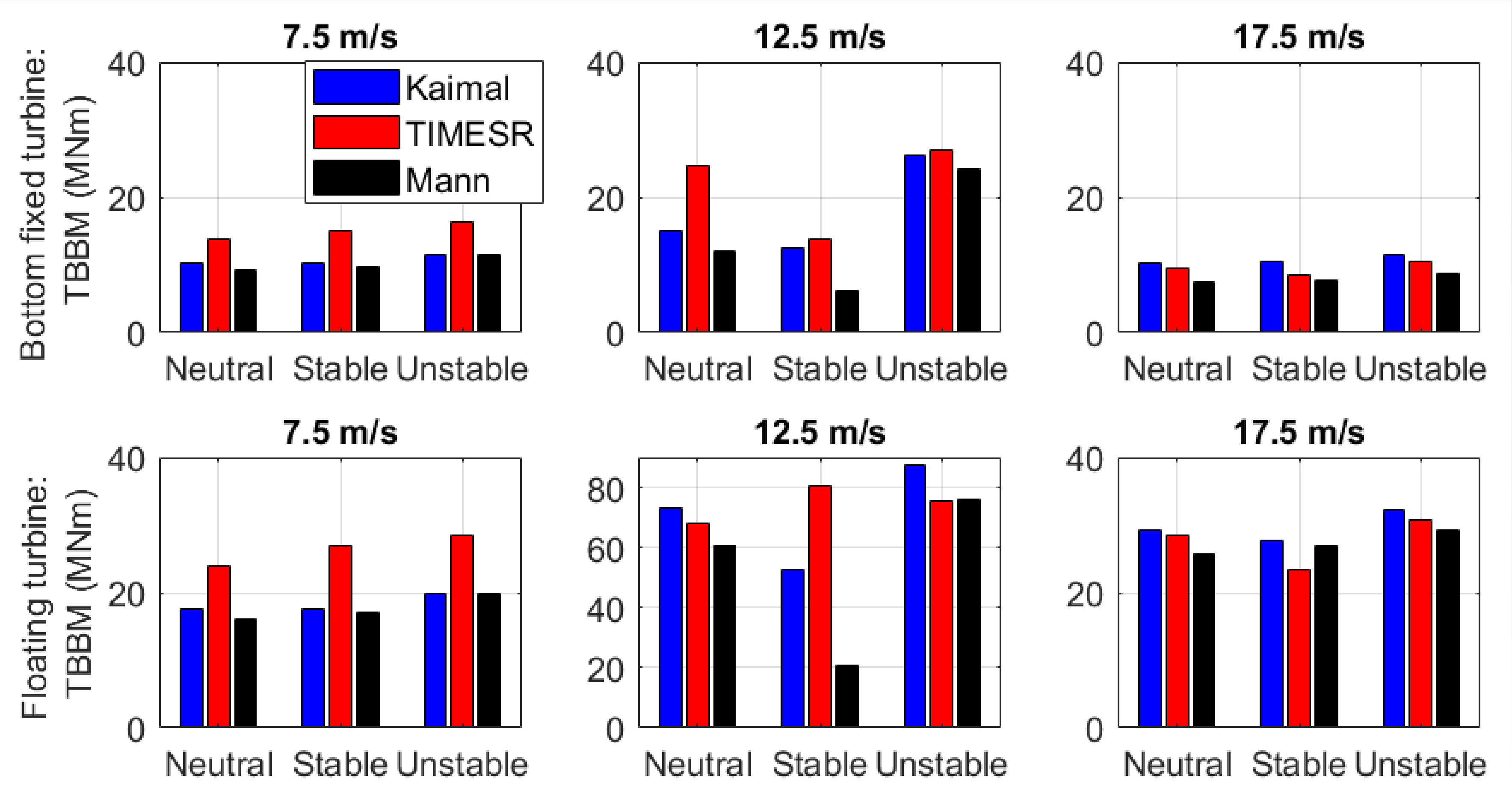


Horizontal separation



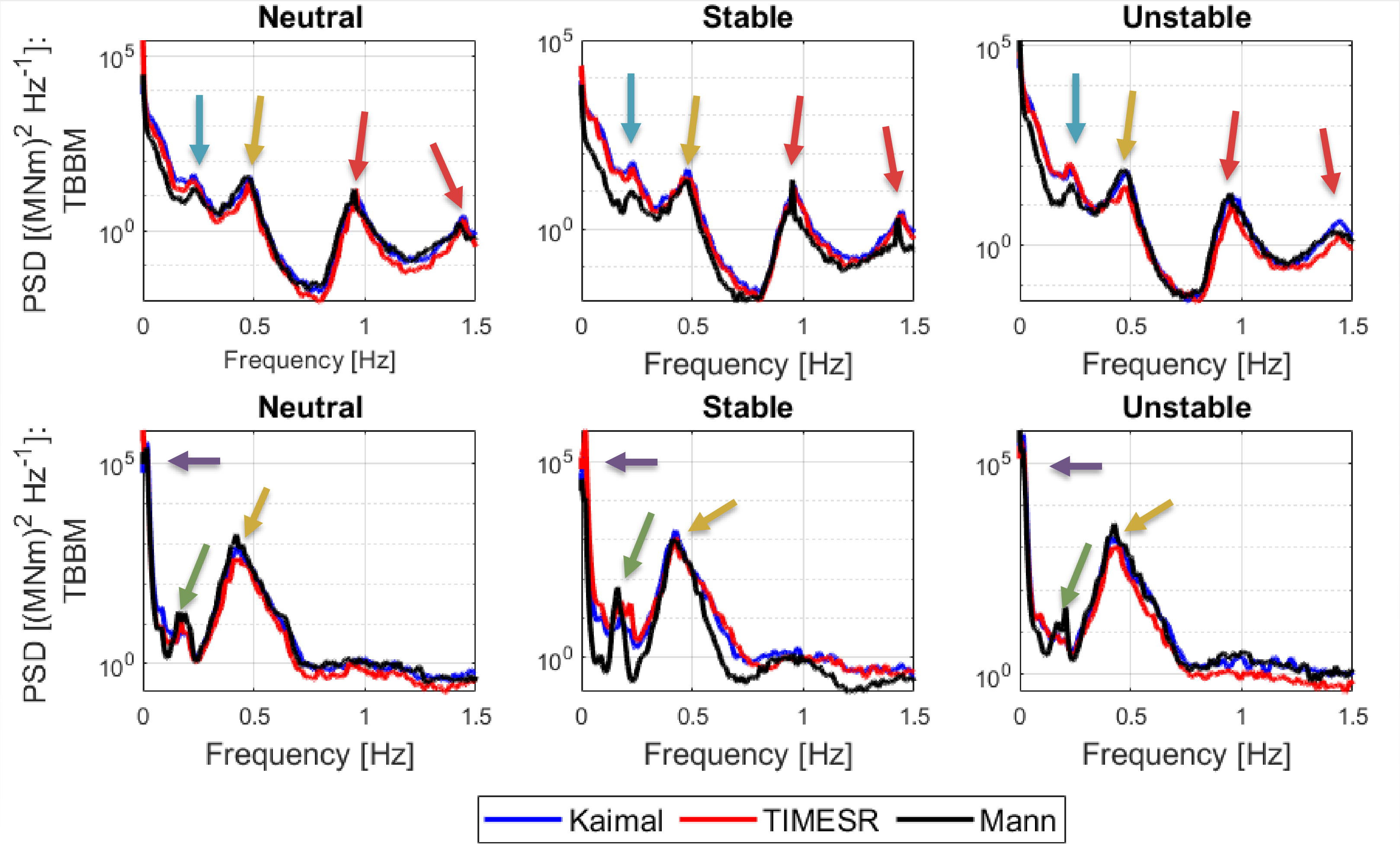
Results: Tower bottom fore-aft bending moment:

Standard deviation of TBBM in MNm.



Load spectra of TBBM.

top: bottom fixed, bottom: floating

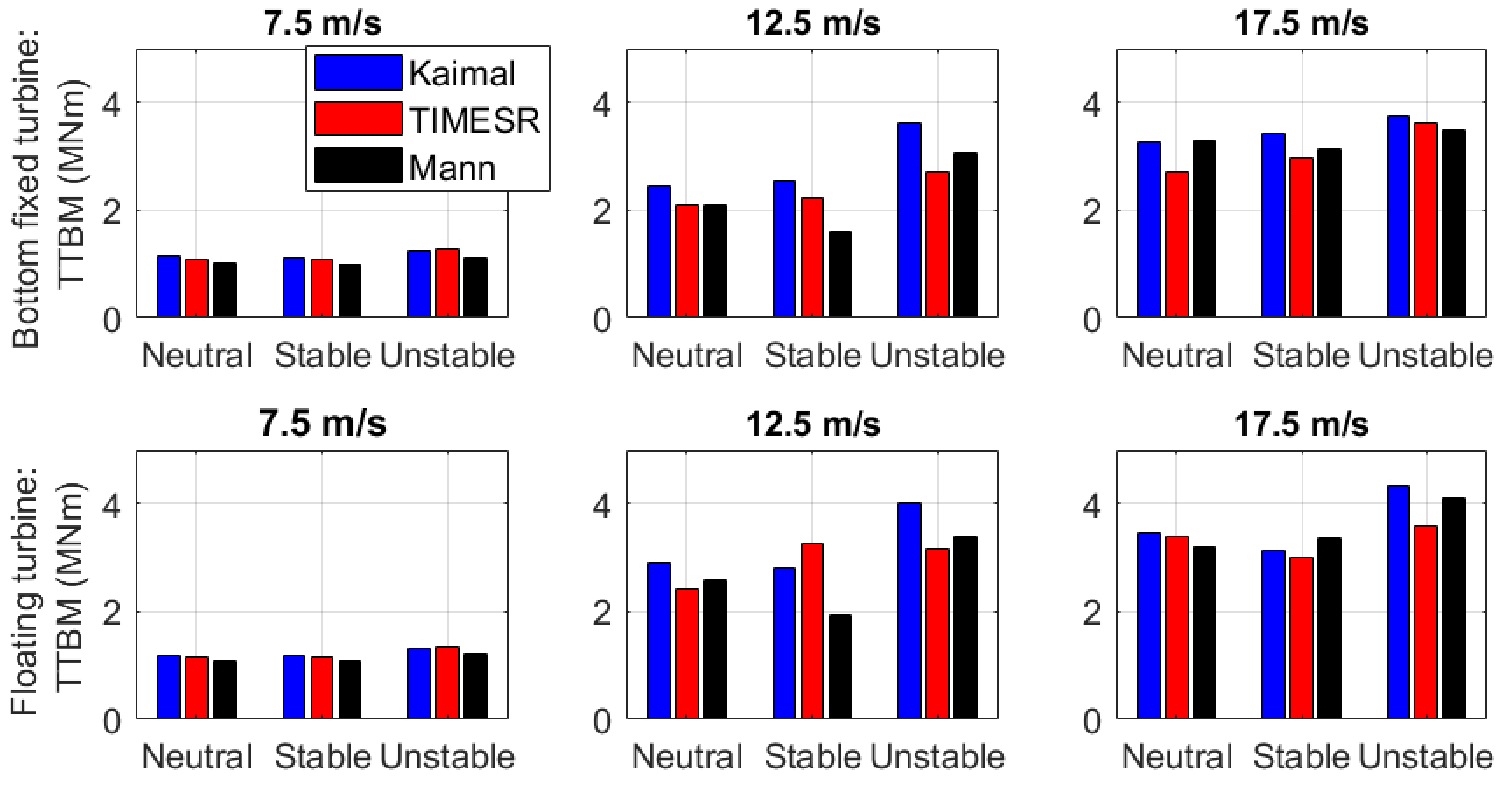


- 1st tower fore-aft bending mode
- 1P frequency
- 3P frequency
- Blade modes
- Platform pitch mode

Close to rated wind speed (±12.5 m/s)

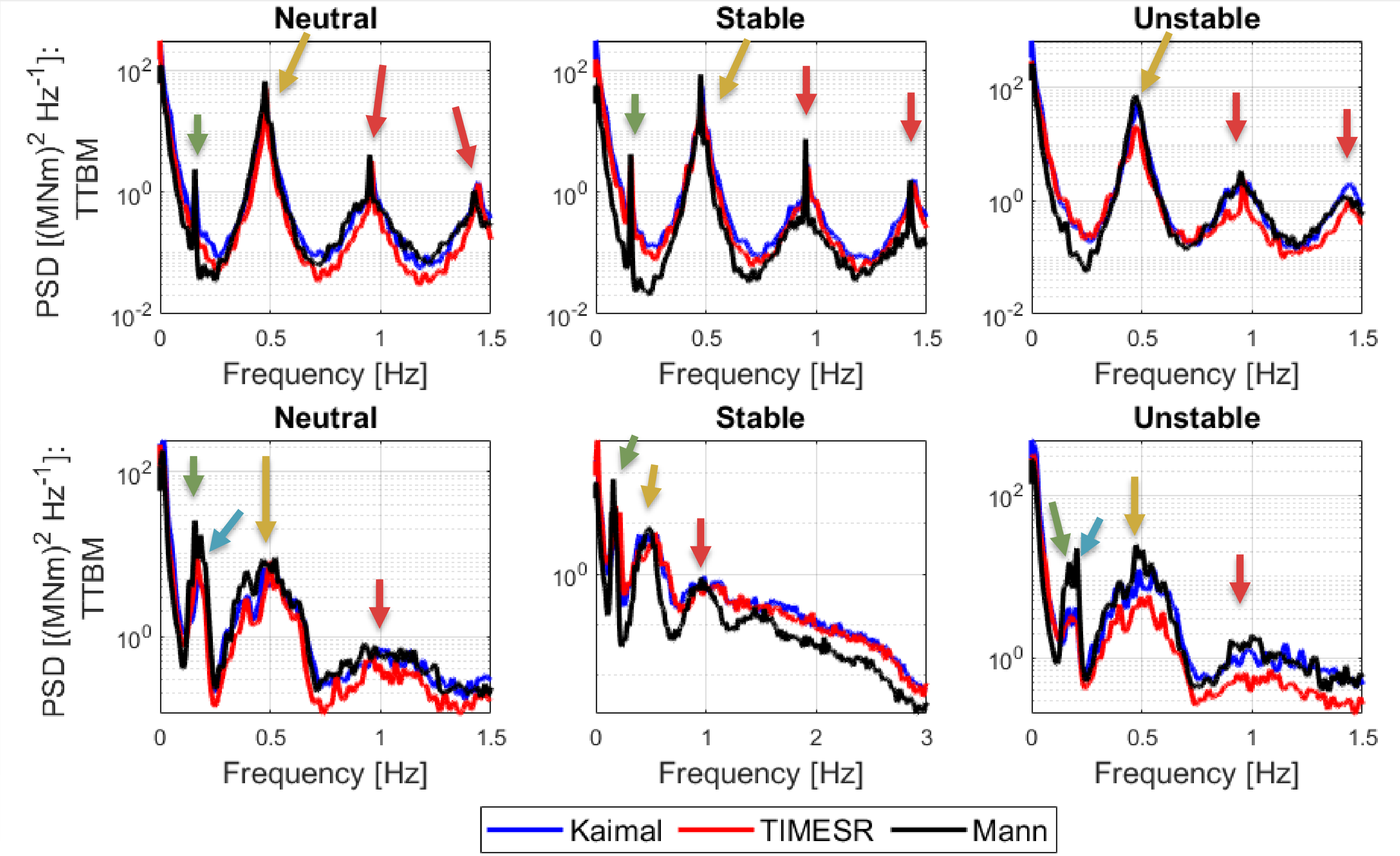
Results: Tower top fore-aft bending moment:

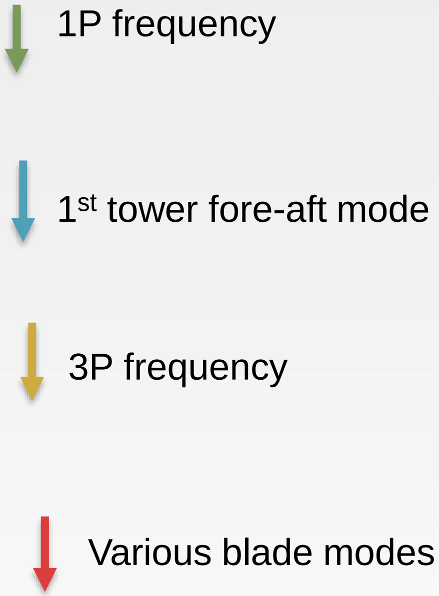
Standard deviation of TTBM in MNm.



Load spectra of TTBM.

top: bottom fixed, bottom: floating

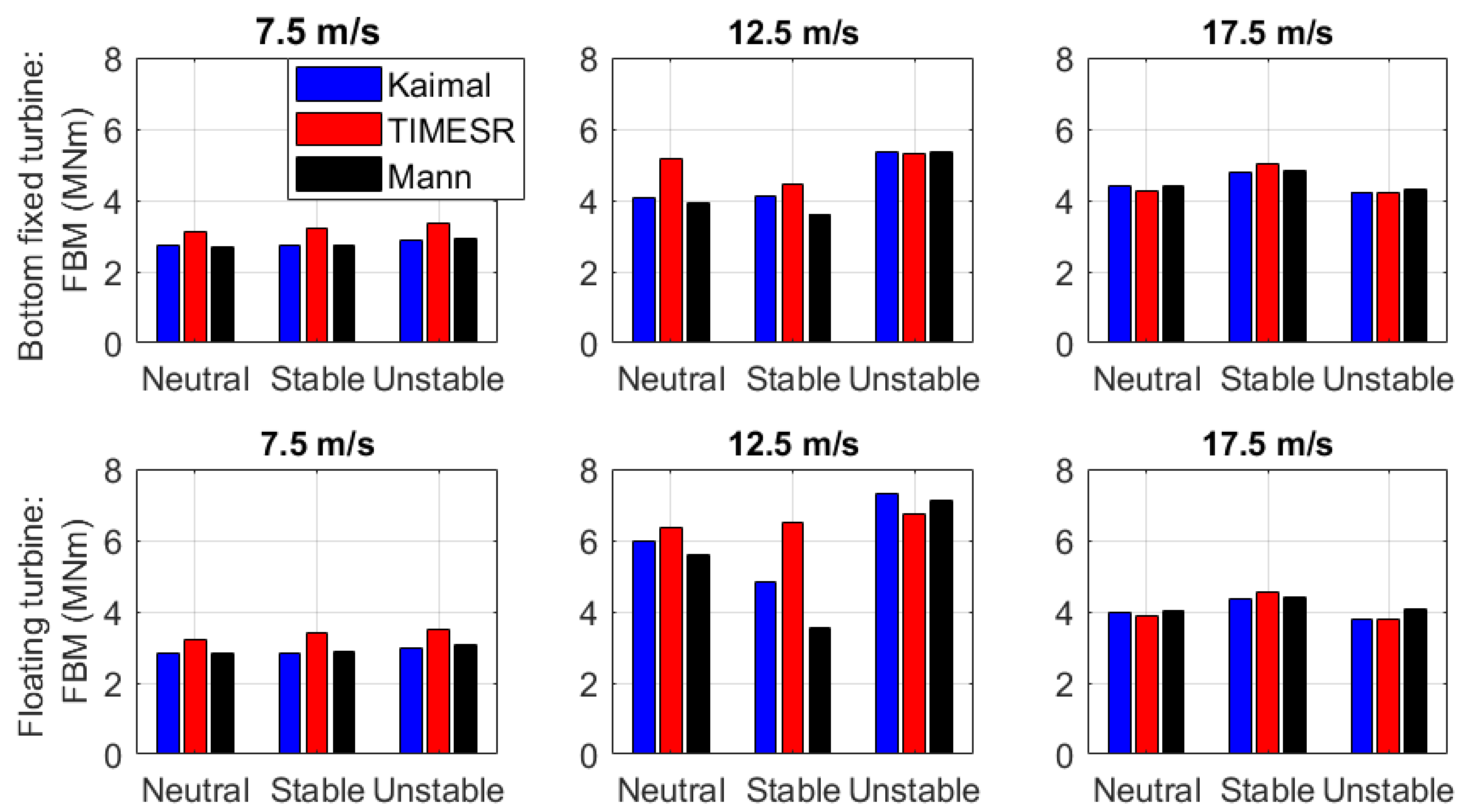




Close to rated wind speed (±12.5 m/s)

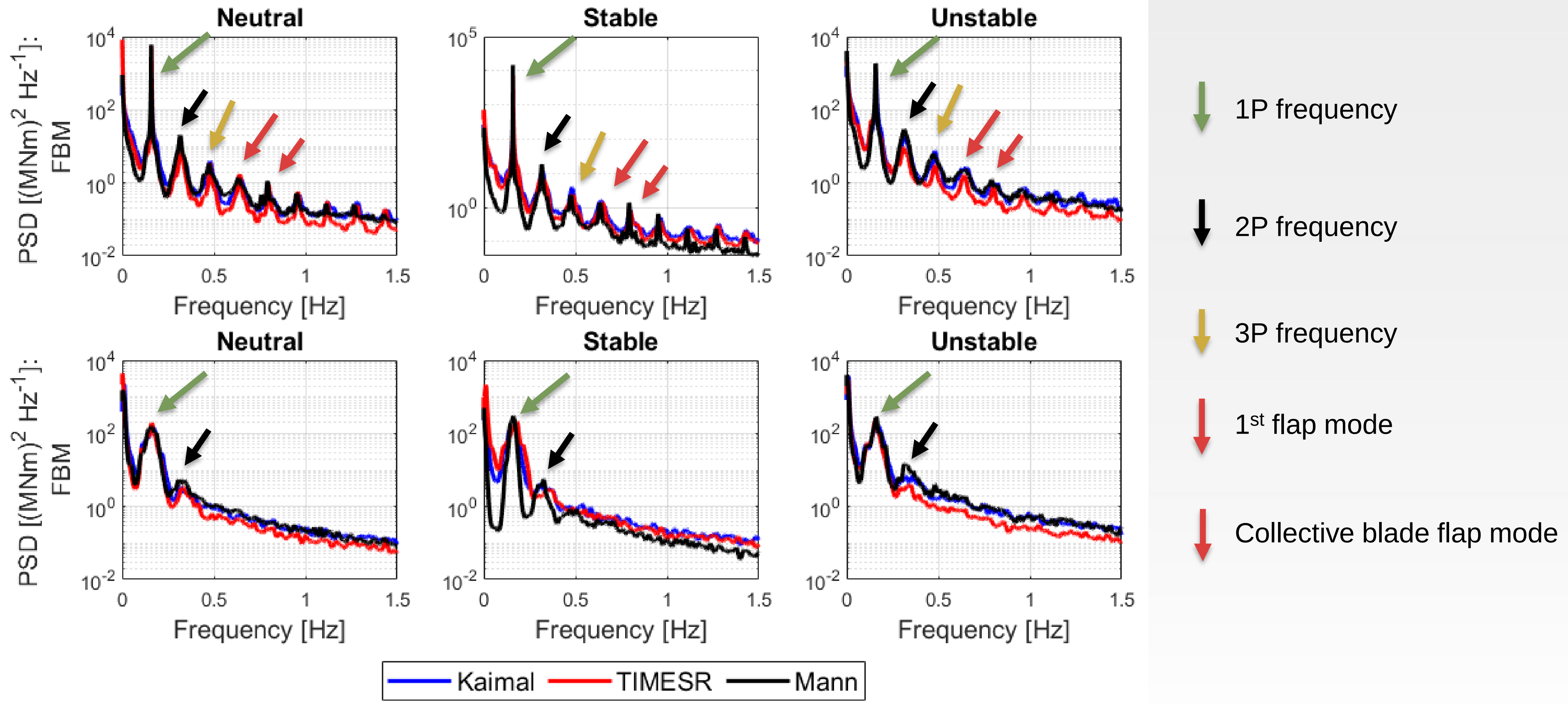
Results: Flap-wise bending moment

Standard deviation of FBM in MNm.



Load spectra of FBM.

top: bottom fixed, bottom: floating



Close to rated wind speed (±12.5 m/s)

Conclusions

- Various techniques for generating turbulent wind field gives large differences in coherence.
- Co-coherence may be negative and quad-coherence significant.
- Global and local loads on a fixed and a floating wind turbine has been investigated.
  - Loads are sensitive to choice of wind model.
  - Loads are sensitive to atmospheric stability.
- It is not obvious which model gives the most realistic results

Thank you for the attention!

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