Influence of wake meandering paths on floating wind turbine response

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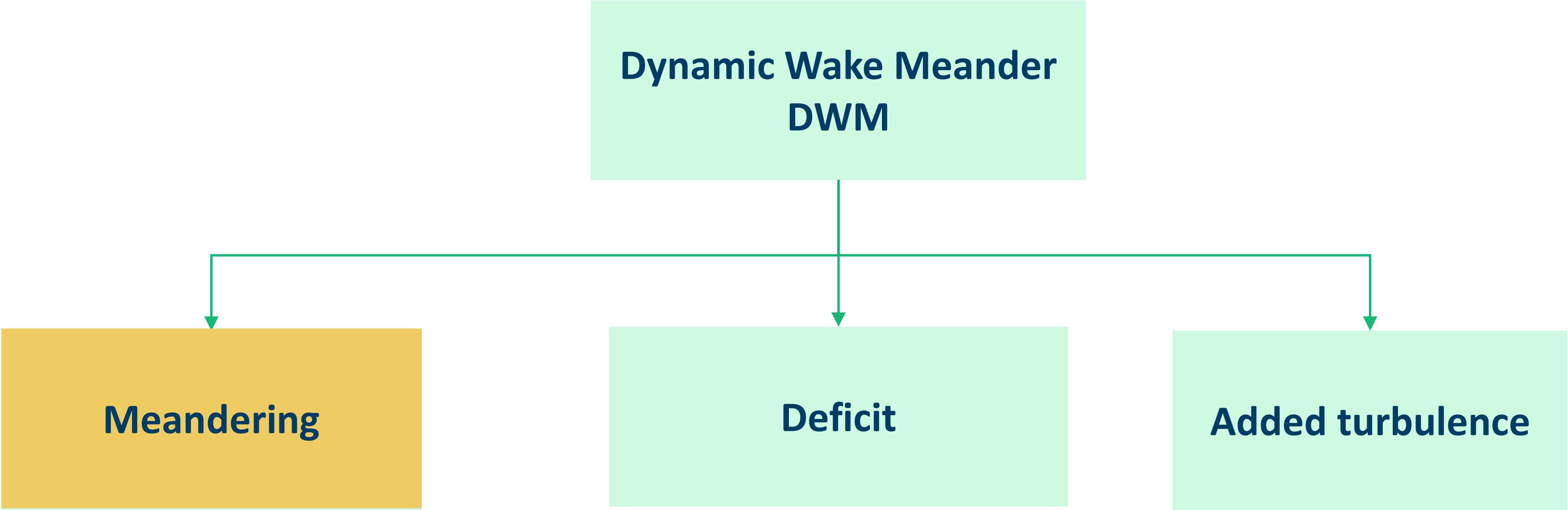
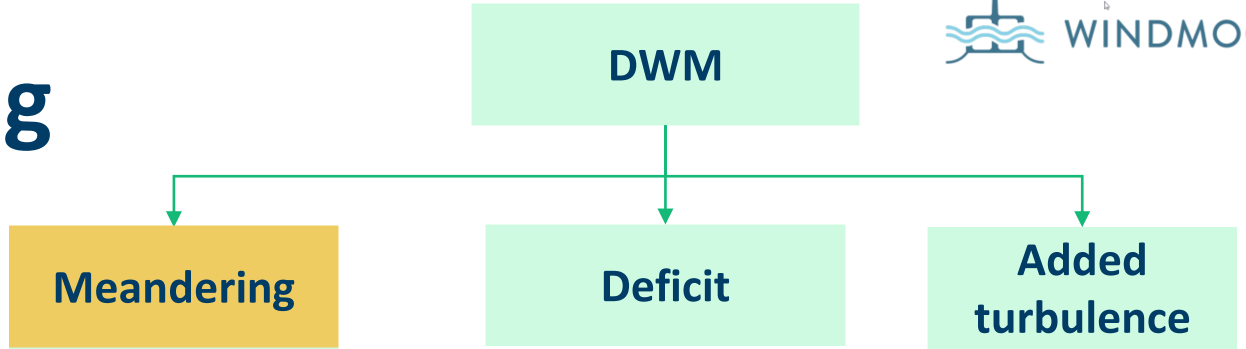
Wind modelling in Park

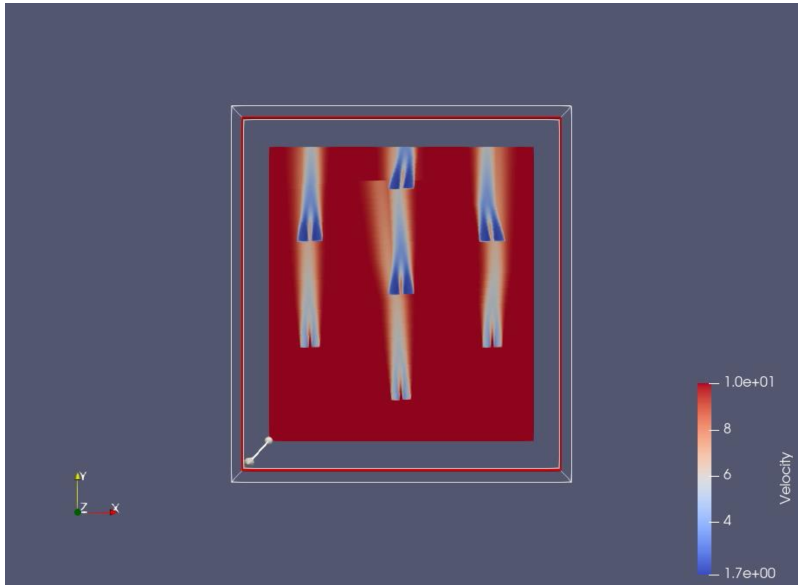
- Using the Dynamic Wake Meandering (DWM) model

Photograph of Horns Rev 1 offshore wind farm. (Vattenfall, Photographer: Christian Steiness)



Wake meandering

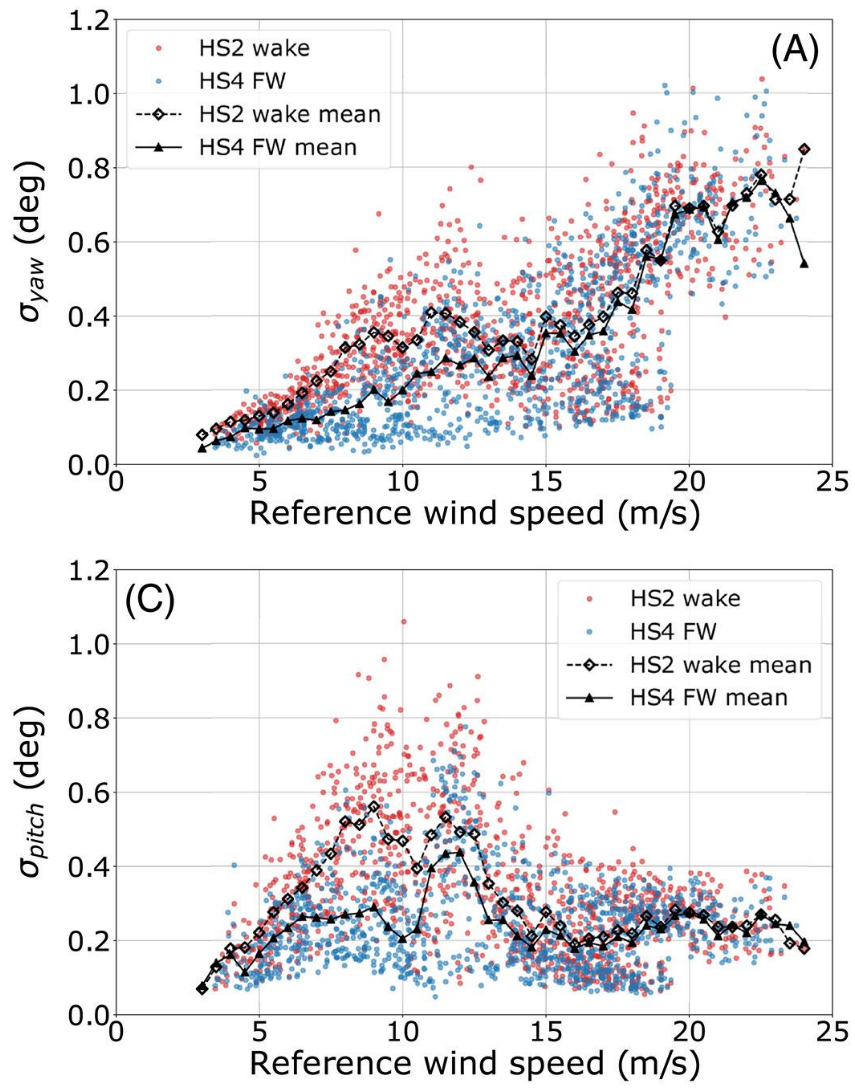




- The meandering is due to the large scale turbulence in the flow
- It is often assumed that the advection velocity for the meandering can be taken as the ambient mean wind speed

Floating wind and wakes

- The high eigen periods of floaters can be in the same range as the meandering path of the wake
- Increased yaw, pitch and roll response for the floater in wake for Hywind Scotland is reported by Jacobsen and Godvik [1]
- The increase in response is highest for the lowest wind speed, and lower for increasing wind speed



[1]Jacobsen, Arnhild, and Marte Godvik. "Influence of wakes and atmospheric stability on the floater responses of the Hywind Scotland wind turbines." *Wind Energy* 24.2 (2021): 149-161.

DWM simulation

SOFTWARE	Developed by	Advection speed	Grid size - meandering
HAWC2	DTU	Mean wind speed	1D[2]
FAST.Farm	NREL	Wake velocity	0.08 D-0.24 D[3]
DIWA (H2)	SINTEF	Mean wind speed	1D
DIWA (FF)			0.08 D-0.24 D

The 12 MW Windmoor is used[4]. This rotor has a diameter of 216.9 m. The DWM simulations were performed with fixed turbines, where the rotor has no tilt and the blades are not coned. (No deflection of the meandering path)

[2] Larsen, T. J., and A. M. Hansen. "How 2 HAWC2, the user's manual, Risø-R-1597 (ver. 12.9)(EN)." *Risø National Laboratory, Technical University of Denmark* (2021).
[3] Shaler, K., J. Jonkman, and N. Hamilton. "Effects of inflow spatiotemporal discretization on wake meandering and turbine structural response using FAST. Farm." *Journal of Physics: Conference Series*. Vol. 1256. No. 1. IOP Publishing, 2019.
[4] Silva de Souza, Carlos Eduardo, et al. "Definition of the INO WINDMOOR 12 MW base case floating wind turbine." (2021).

Methodology

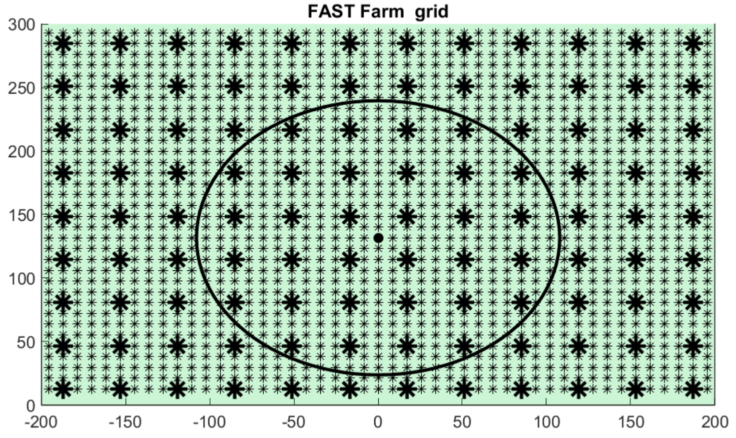
- Three wind speeds, and three sea states are simulated. The response analysis are run for 3600 s, and the first 600 s are removed.
- SIMA is used for the response analysis for all meandering paths. The meandering path from the different DWM tools are imported to DIWA (SINTEF DWM code) and the wake wind boxes are generated.

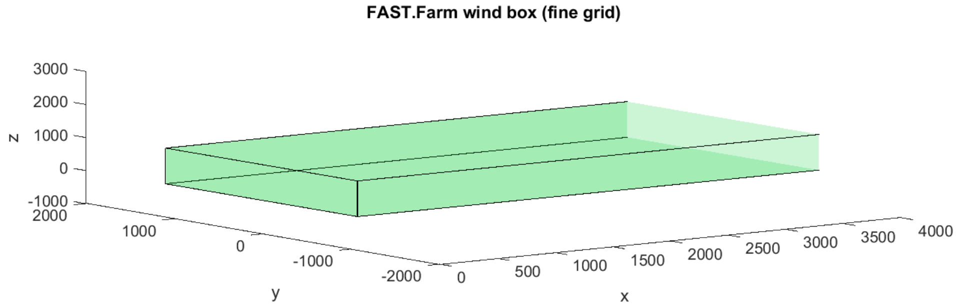
Wind speed	TI (aim) [5]	$\alpha\varepsilon$ [5]	Γ [5]	L [5]	Hs [6]	Tp [6]
7.5 m/s	4.39	0.014	3.72	37.7	2.3	8.3
12 m/s	4.25	0.021	3.21	37.5	2.9	8.4
16 m/s	4.61	0.031	2.96	39.4	3.5	8.6

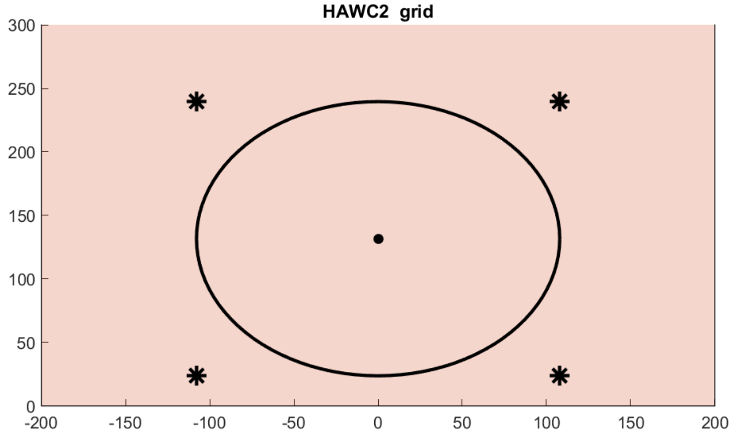
[5] Mann parameters fitted to LES data, neutral condition - Rivera-Arreba, Irene, et al. "Effects of atmospheric stability on the structural response of a 12 MW semisubmersible floating wind turbine." *Wind Energy* 25.11 (2022): 1917-1937.
[6] Site 14 in Li, Lin, Zhen Gao, and Torgeir Moan. "Joint distribution of environmental condition at five european offshore sites for design of combined wind and wave energy devices." *Journal of Offshore Mechanics and Arctic Engineering* 137.3 (2015).

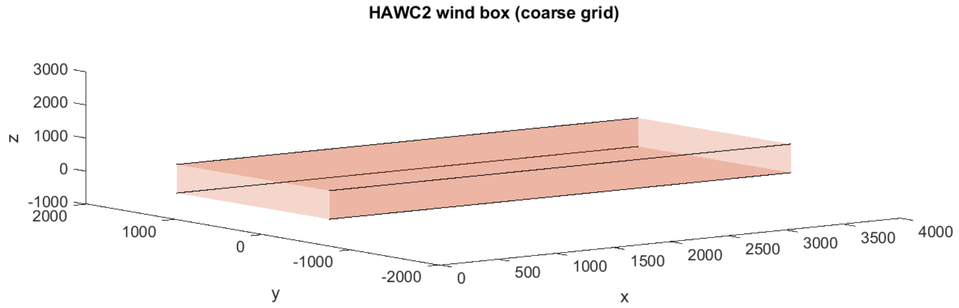
Wind boxes

- Two separate wind boxes are generated for each wind speed and seed



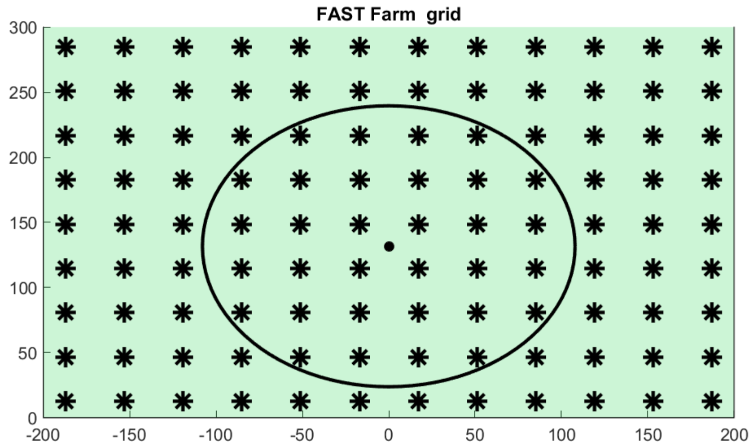


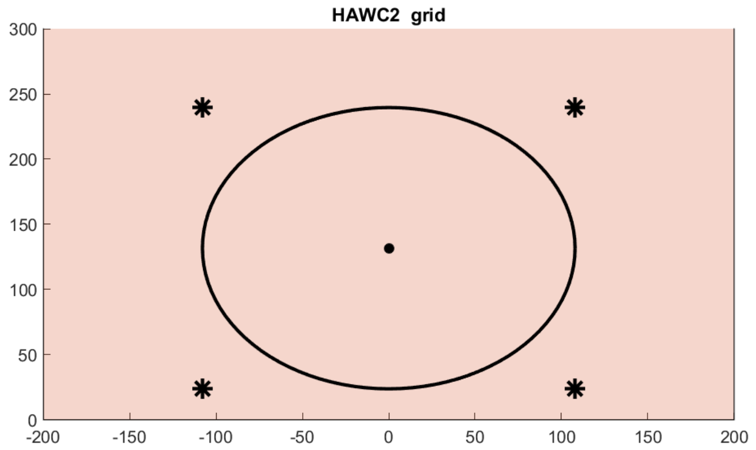


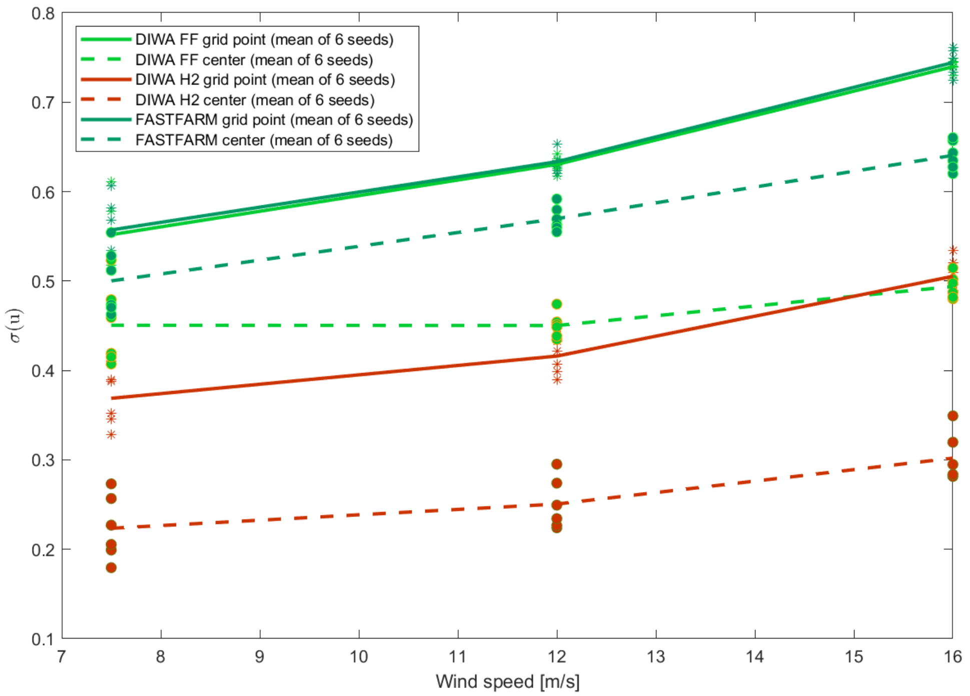


Wind boxes

- Two separate wind boxes are generated for each wind speed and seed
- Grid points from the "fine gridded box" are used to construct a meandering box with coarser grid



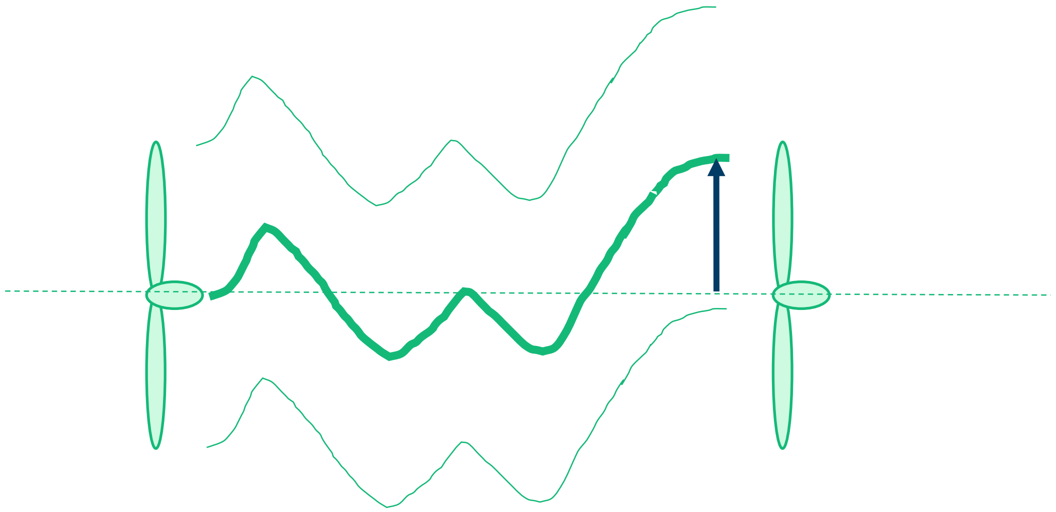


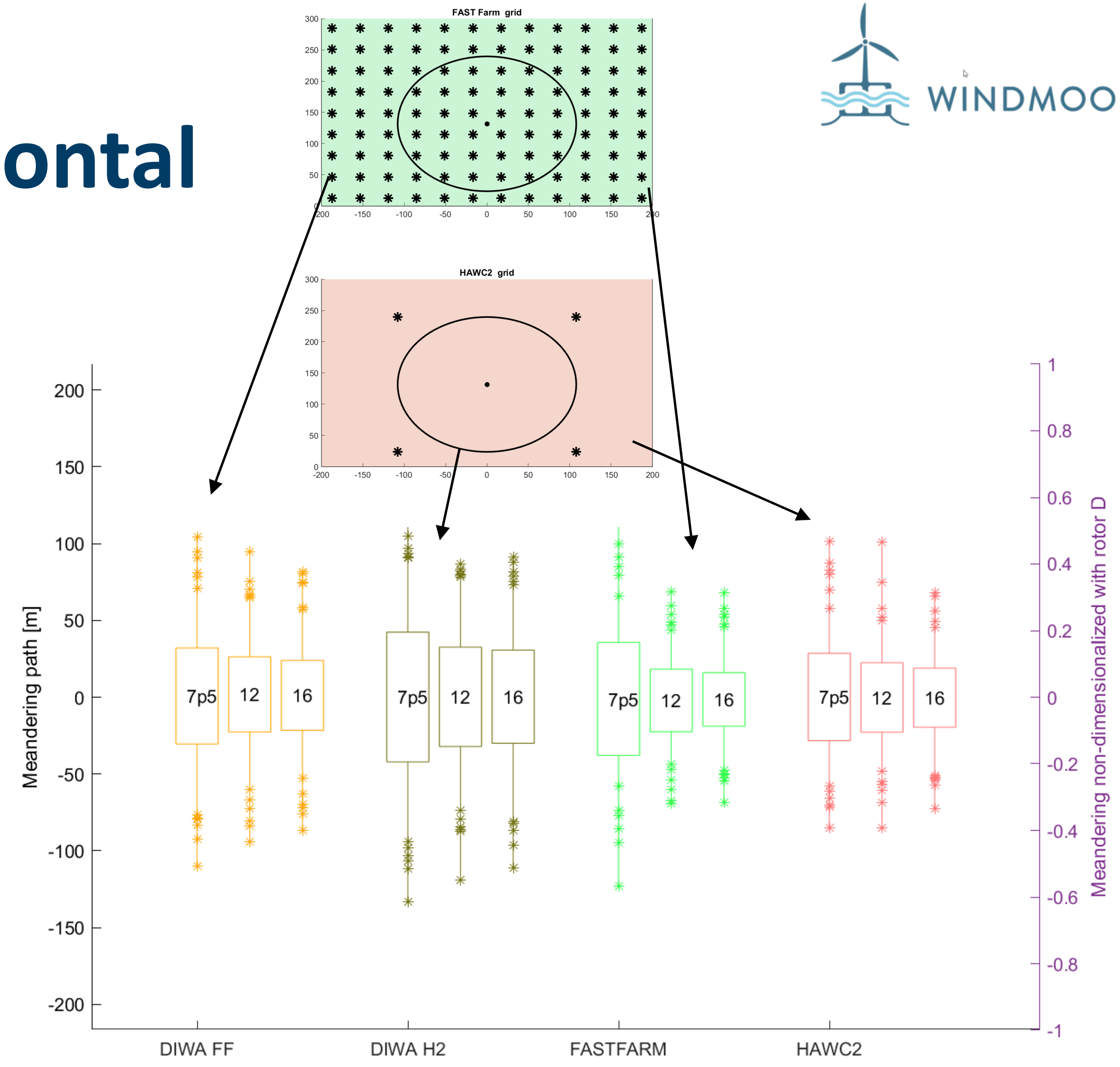


Meandering horizontal

The difference between DIWA FF and DIWA H2 are the wind box used as input for meandering. DIWA H2 has a coarse box with low turbulence while DIWA FF has a finer grid and higher turbulence

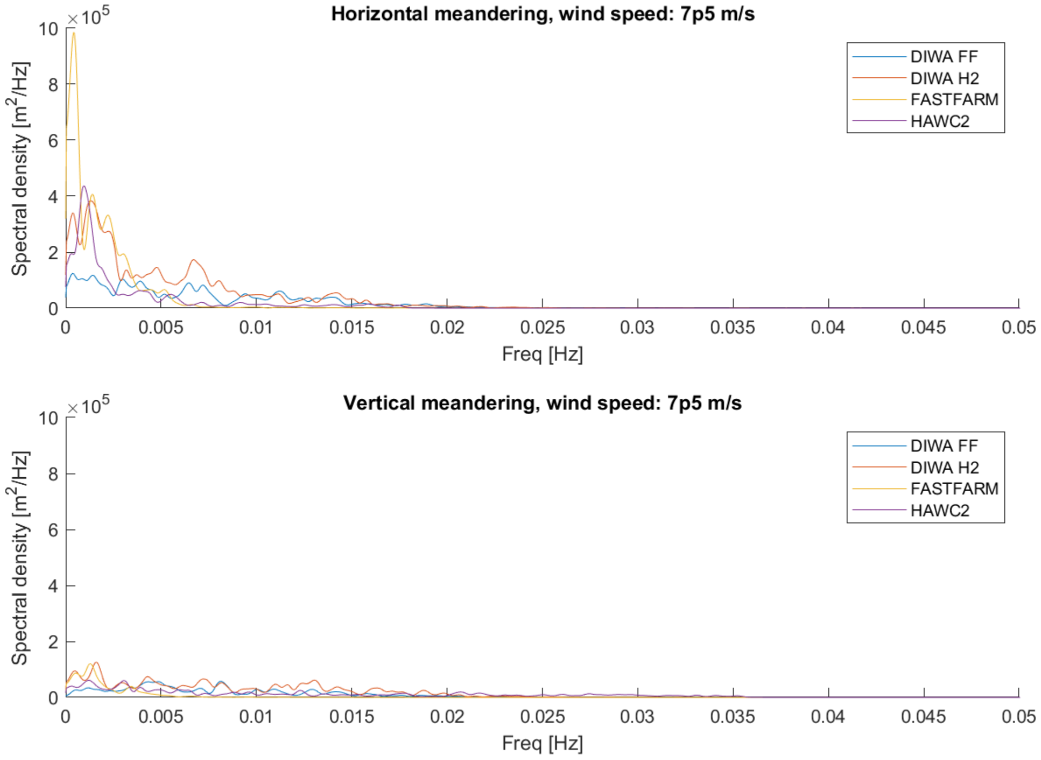
All show a decreasing trend in standard deviation due to wind speed





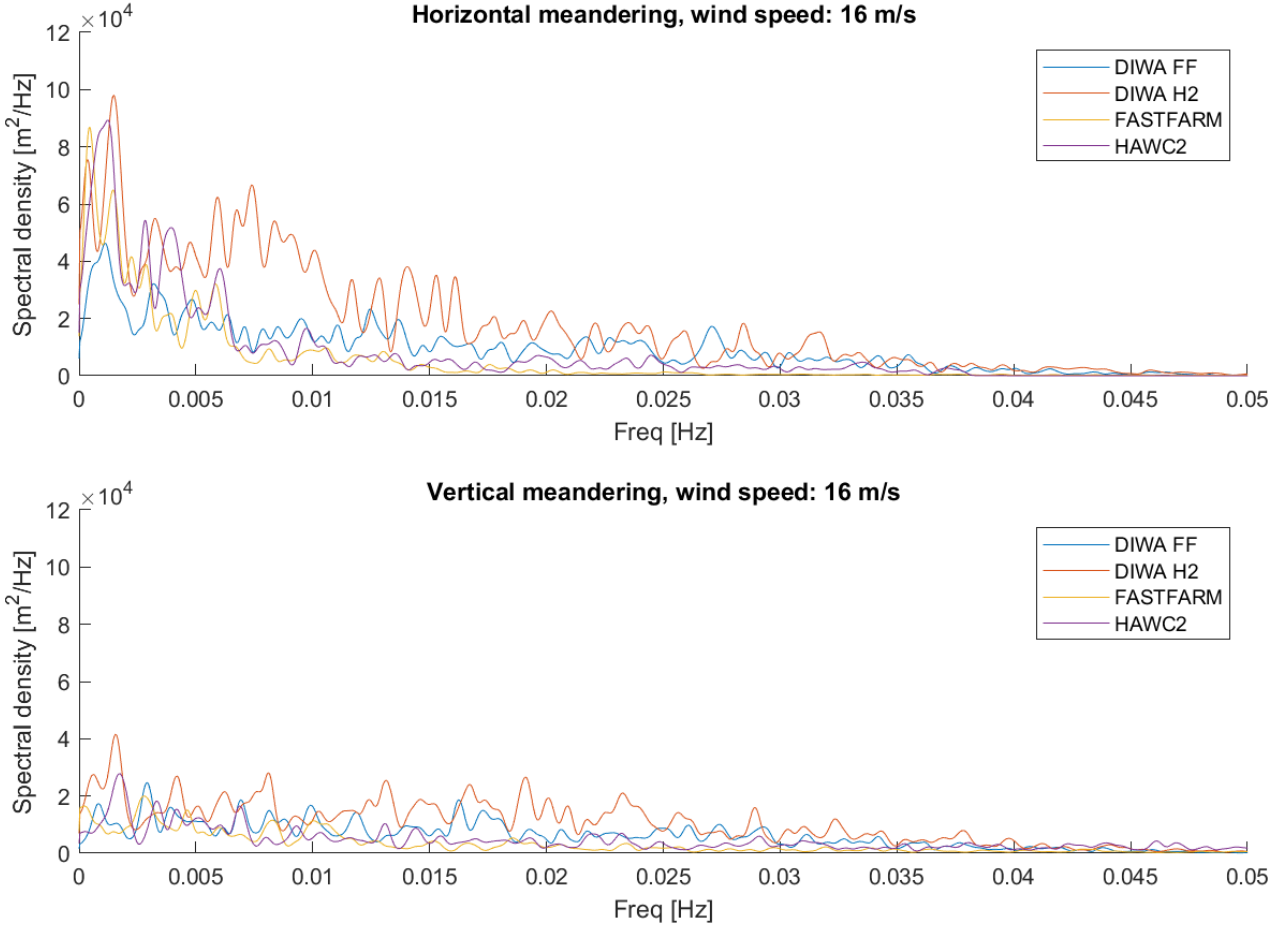
Frequency distribution of the meandering

- The lowest wind speed (7.5 m/s) has the highest energy
- For the lowest wind speed FAST.Farm has most energy at the low frequency (quasi-static response)
- Eigenfrequencies for the INO WINDMOOR:
  - Surge/sway: 0.01 Hz
  - Yaw: 0.011 Hz
  - Pitch: 0.033 Hz



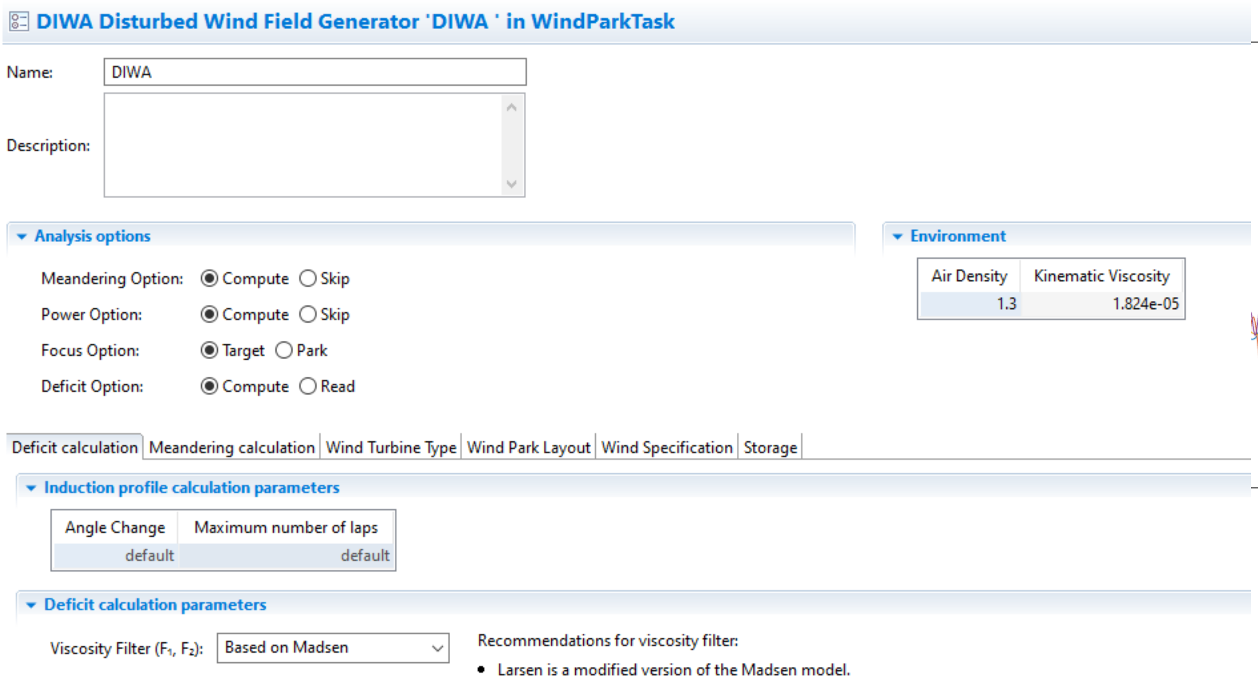
Frequency distribution of the meandering

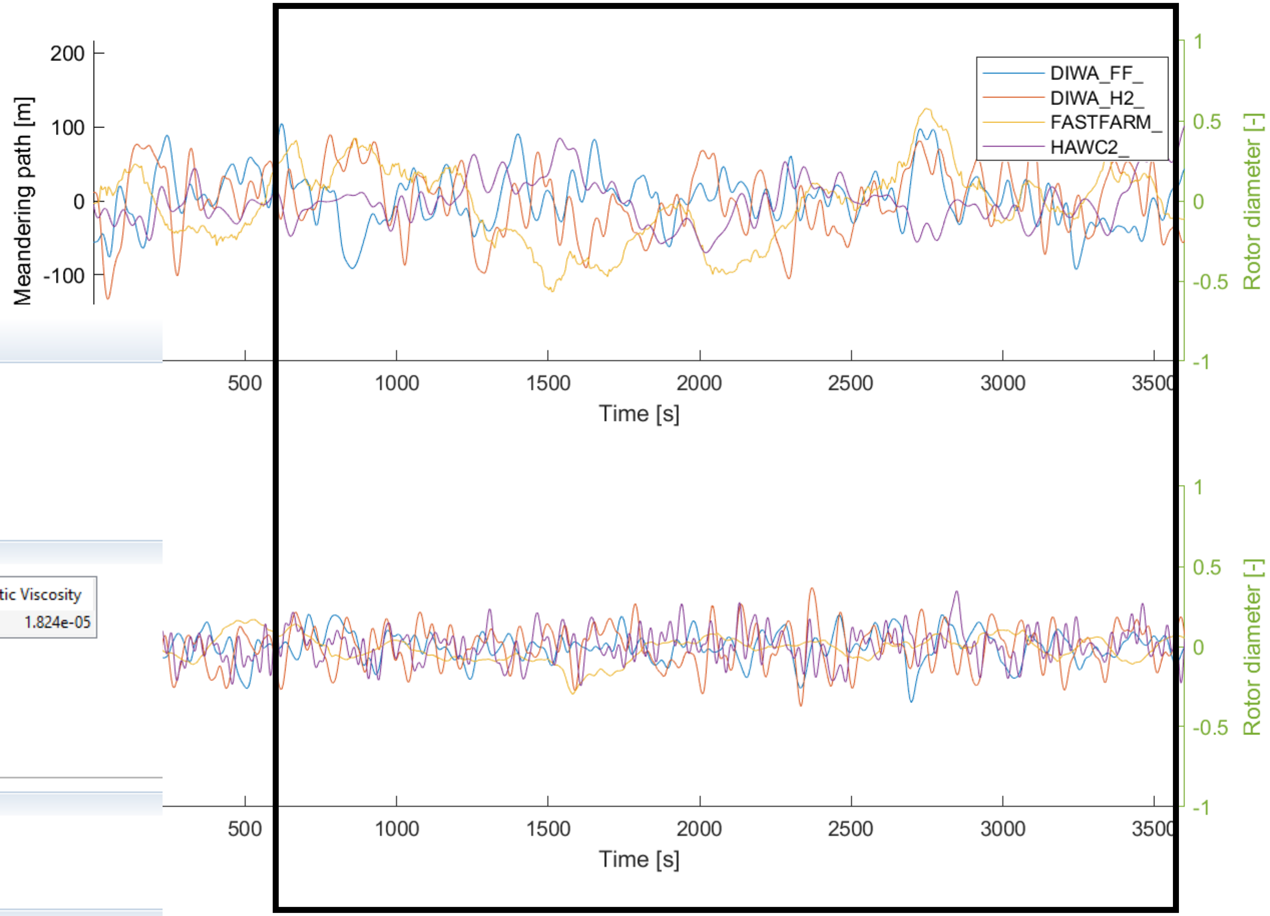
- The lowest wind speed (7.5 m/s) has the highest energy
- At higher wind speeds DIWA with a coarse grid has higher energy around 100-200 s (typical floater response).
- Eigenfrequencies for the INO WINDMOOR:
  - Surge/sway: 0.01 Hz
  - Yaw: 0.011 Hz
  - Pitch: 0.033 Hz



Meandering imported in DIWA

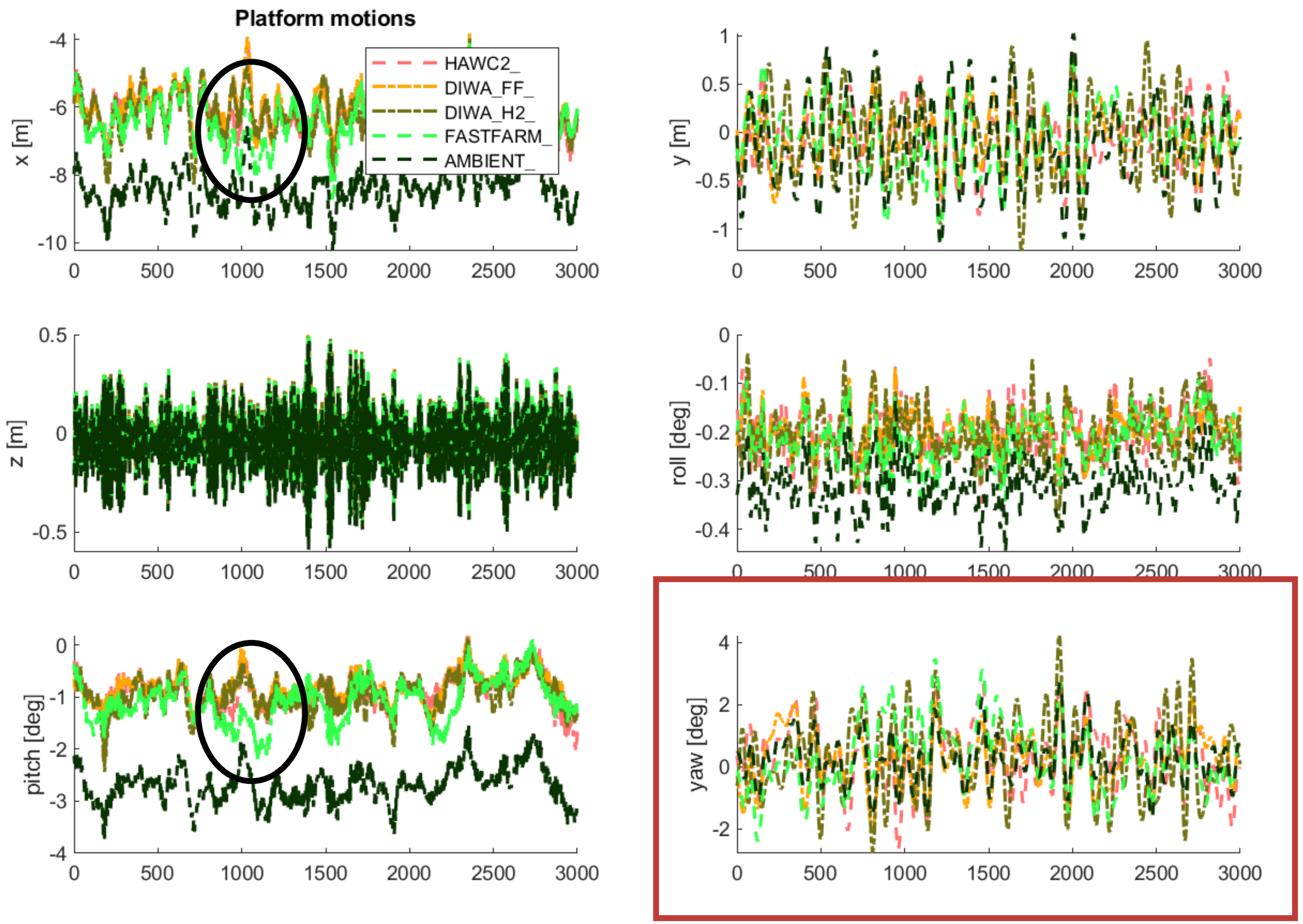
The meandering path is imported to DIWA, and new wake fields are produced. The first 600 s of the simulation is removed due to transients



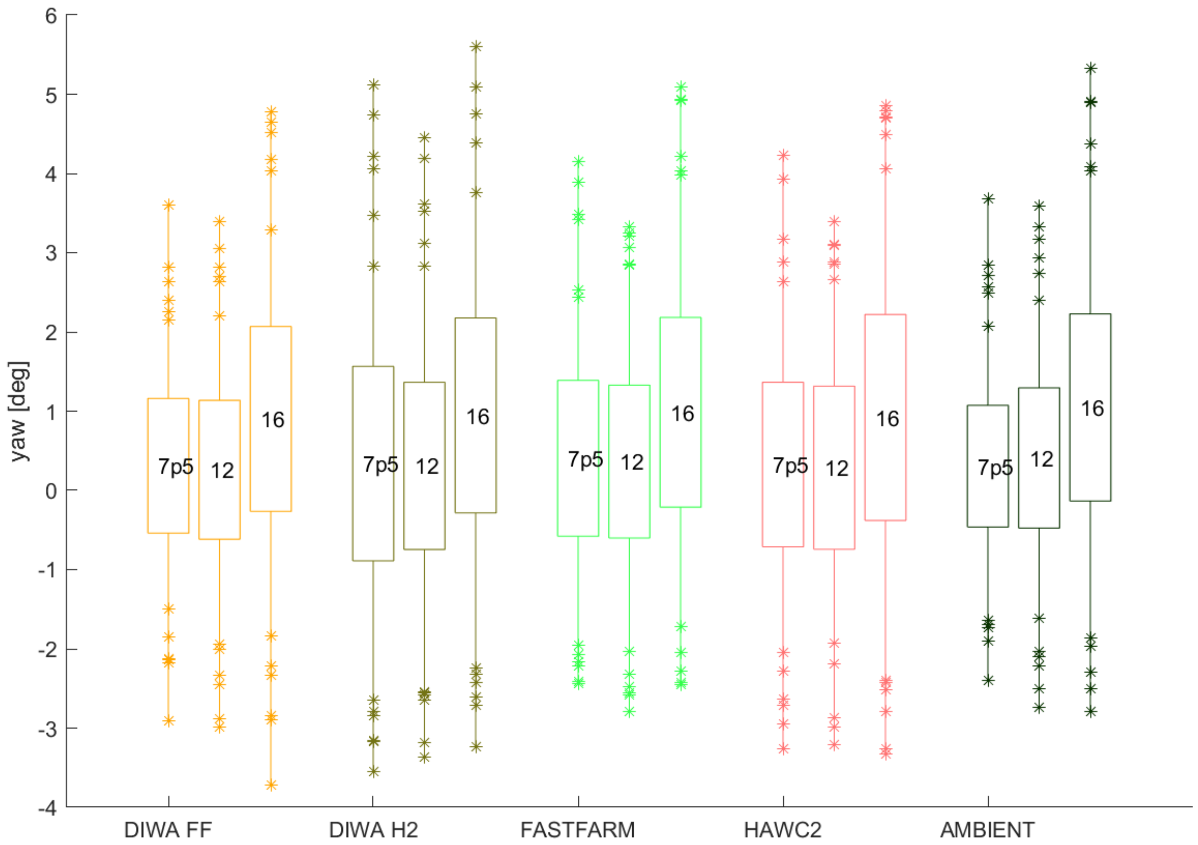


Response – time history – 7.5 m/s

- Time domain simulations are performed using SIMA developed at SINTEF Ocean
- Time history of the different floater motions.



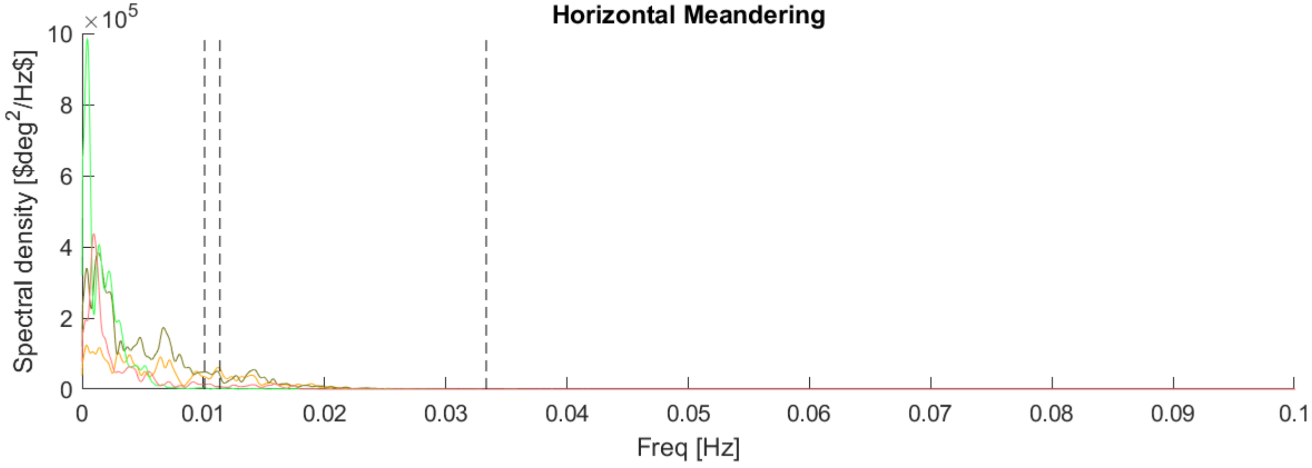
Yaw response

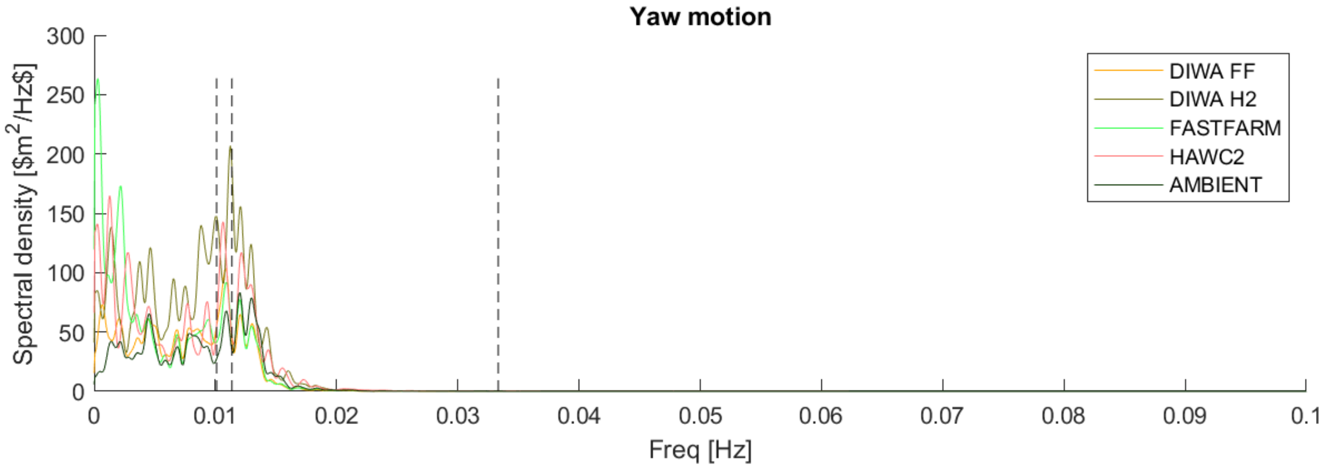


Yaw at 7.5 m/s	Std dev	% diff to ambient
DIWA FF	0.85	10 %
DIWA H2	1.23	60 %
FAST.Farm	0.98	28 %
HAWC2	1.04	35 %
AMBIENT	0.77	0 %

Yaw response 7.5 m/s

- Dashed lines are eigenfrequencies for the INO WINDMOOR:
  - Surge/sway: 0.01 Hz
  - Yaw: 0.011 Hz
  - Pitch: 0.033 Hz





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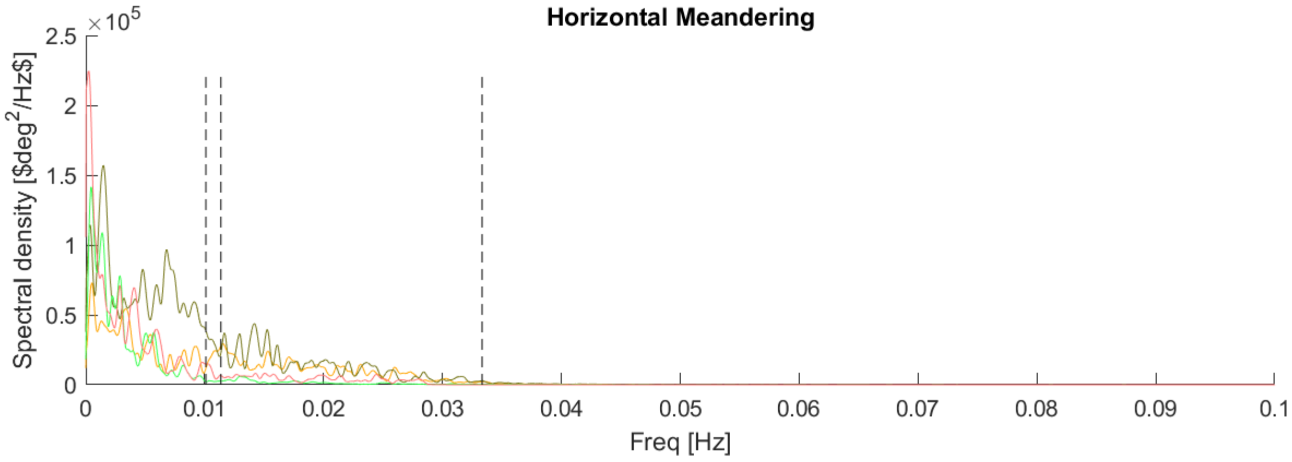
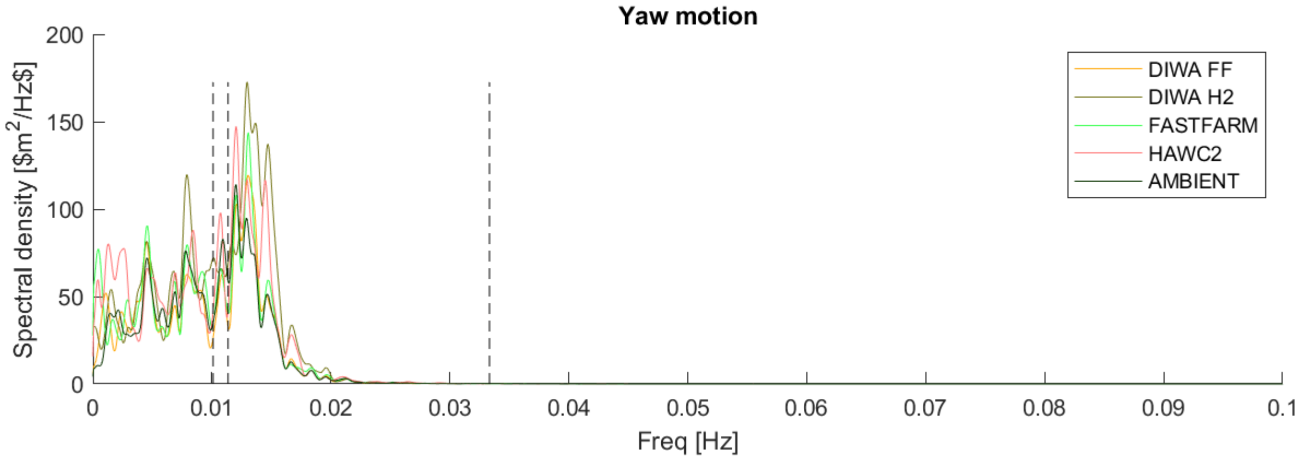
FAST.Farm	0.98	28 %
HAWC2	1.04	35 %
AMBIENT	0.77	0 %

Yaw response 12 m/s

- Dashed lines are eigenfrequencies for the INO WINDMOOR:
  - Surge/sway: 0.01 Hz
  - Yaw: 0.011 Hz
  - Pitch: 0.033 Hz

Yaw at 12 m/s	Std dev	% diff to ambient
DIWA FF	0.88	-1 %
DIWA H2	1.08	19 %
FAST.Farm	0.96	9 %
HAWC2	1.03	16 %
AMBIENT	0.89	0 %

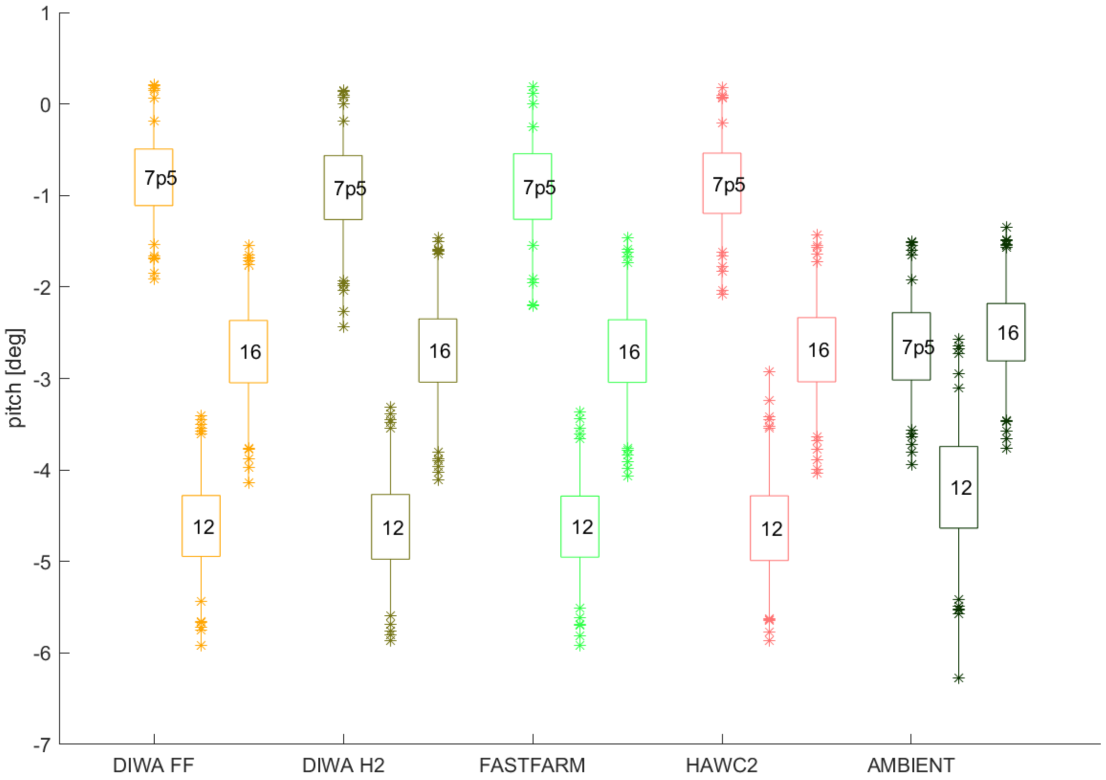




Pitch response – std dev +- max

The front turbine has a higher pitch due to higher thrust force for 7.5 m/s

Pitch response is very similar between the meandering paths.



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Discussion

WINDMOOR

- The difference in response for the INO Windmoor for the different DWM tools is relatively small. The largest difference is for the yaw motion
- Floaters, that have a softer system, may be more sensitive to the choice of DWM software than seen in this study
- Similar to the measured response from Hywind Scotland, the largest difference in the study is found for yaw at below rated conditions

SOFTWARE	Developed by	Advection speed	Grid size - meandering
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FAST.Farm	NREL	Wake velocity	0.08 D-0.24 D
DIWA (H2)	SINTEF	Mean wind speed	1D
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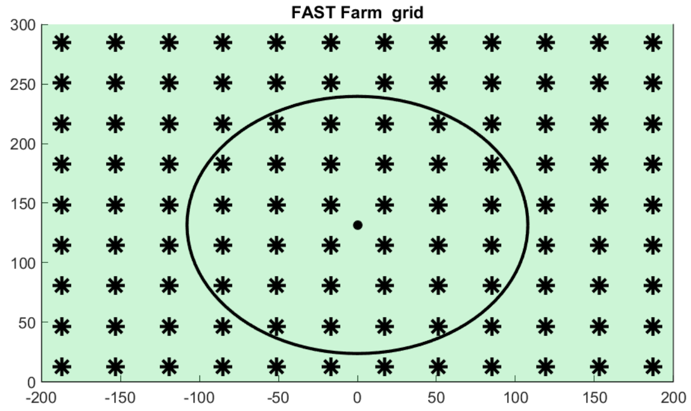
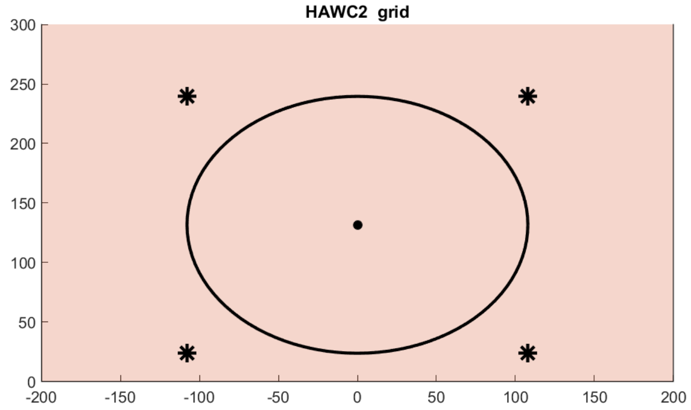
Conclusion

- The input wind file is very important, and this study illustrate the importance of grid size of the wind box.
- In this study, the response is more sensitive to grid size than the software chosen
- At low wind speed, the meandering of FAST.farm has a high low-frequency meandering component.
- DIWA with a very coarse grid has a the highest response for the yaw motion.





Acknowledgement

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