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Uncertainty evaluation of BEM approaches for offshore wind turbine design



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Highly advanced Probabilistic design and Enhanced Reliability methods for high-value, cost-efficient offshore WIND

Main objective: reduce the Levelized Cost Of Energy (LCOE) by reducing the uncertainty in the complete chain of modeling OWTs in a wind farm

Uncertainty evaluation of BEM approaches for offshore wind turbine design



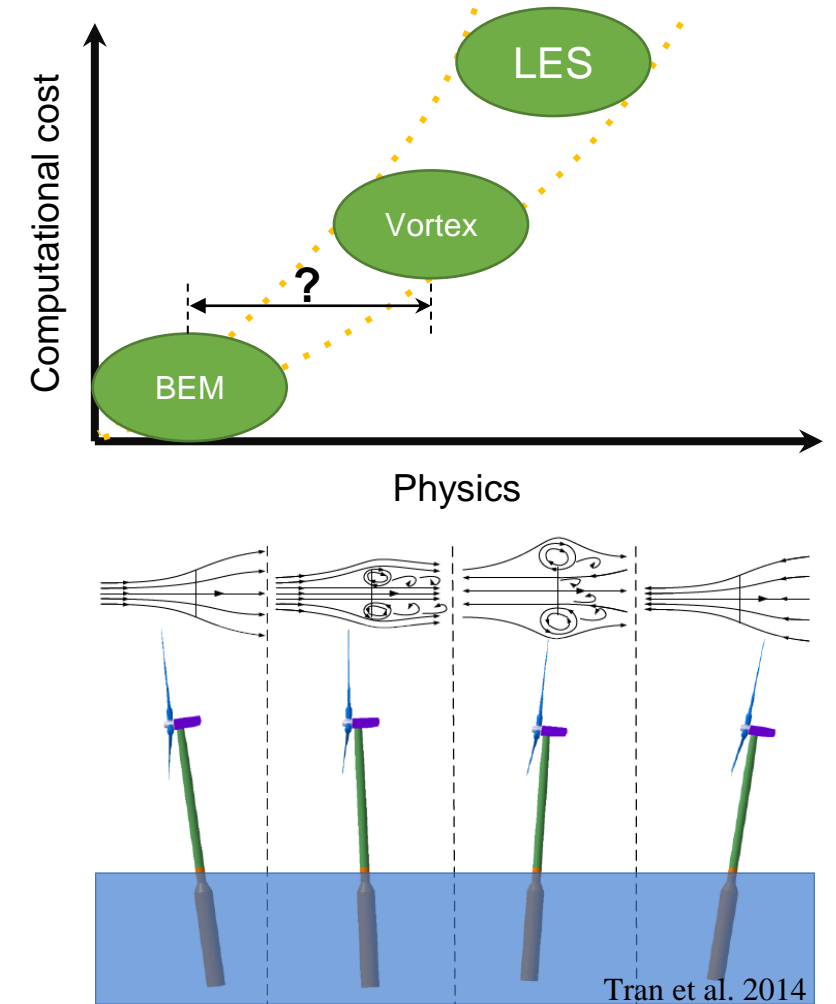
Main goal: to evaluate the uncertainty of Blade Element momentum approaches, by comparing them with a high fidelity model

Introduction



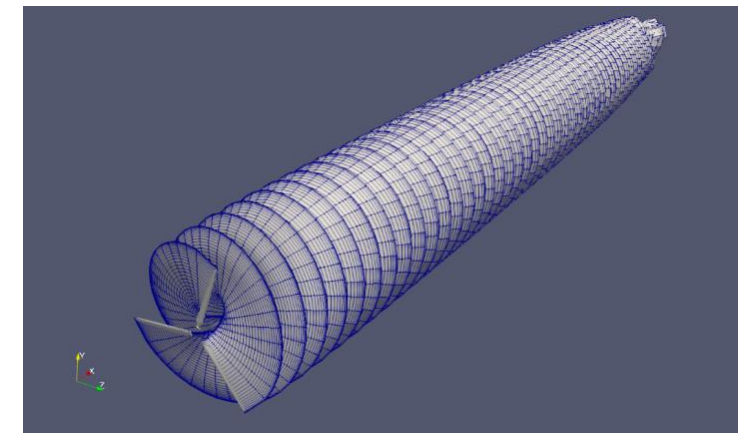
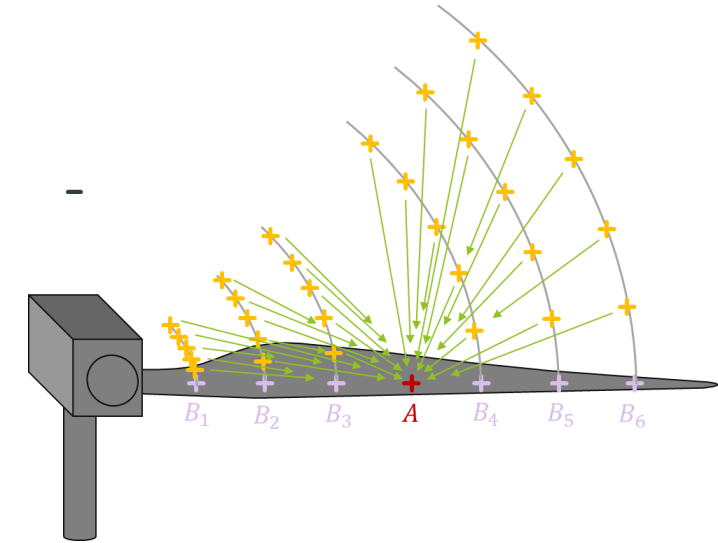
Aerodynamic approaches

- Aerodynamic methods
 - Different levels of complexity
- **Blade Element Momentum (BEM):**
 - Widely used for design
 - Steady conditions, empirical corrections
 - Low computational cost
 - Limitations for large/floating wind turbines
- **Vortex method:**
 - State of the art
 - Free vortex wake model based on lifting line theory
 - Unsteady, less empirical corrections
 - Higher computational cost



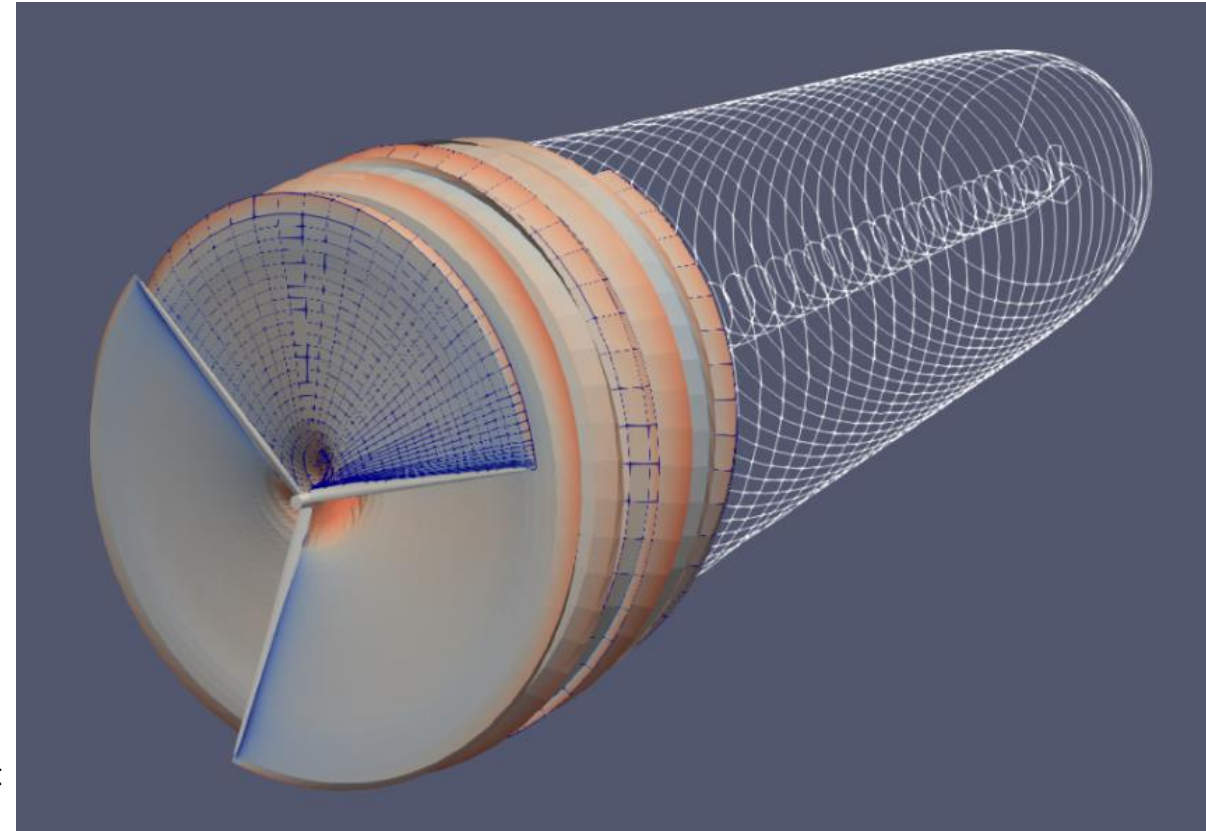
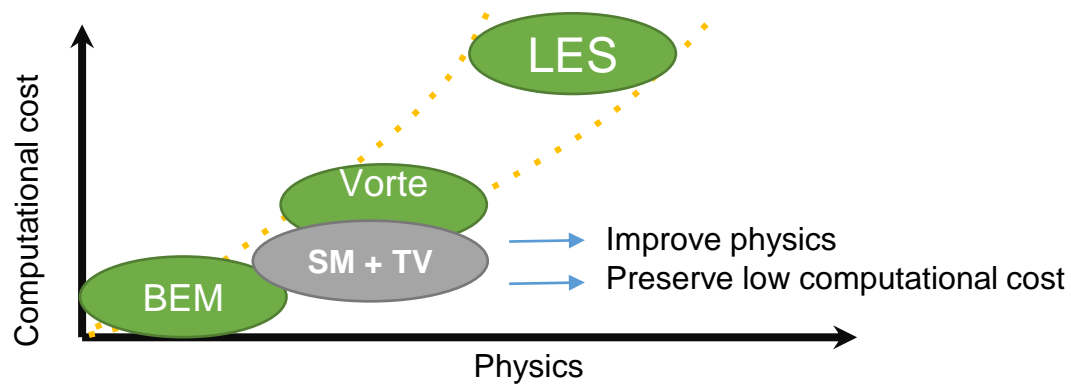
Aerodynamic approaches

- Calculation cost:
 - Larger than BEM
 - N-body problem
 - Ideal time step: equivalent to $\Delta\theta \in [5^\circ; 10^\circ]$
 - Wake length: $\theta \geq 2\pi N_{rot}$ with $N_{rot} \in [15; 25]$
- Aero-elastic simulations constraints:
 - Time step often driven by the controller : $\Delta\theta \approx 0.1^\circ$
 - Low time step \rightarrow very high number of vortex elements
 - \rightarrow Time-consuming routines ported to GPU (CUDA)
 - \rightarrow Still not enough : the number of filaments must be reduced



Aerodynamic approaches

- Reducing vortex sheet:
 - Shed Merging:
 - Shed filaments are progressively merged
 - Tip Vortex:
 - Filaments are conserved in the near wake. Then, a transition to “Tip Vortex” is applied



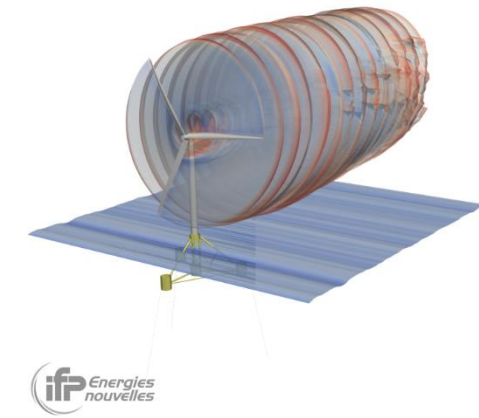
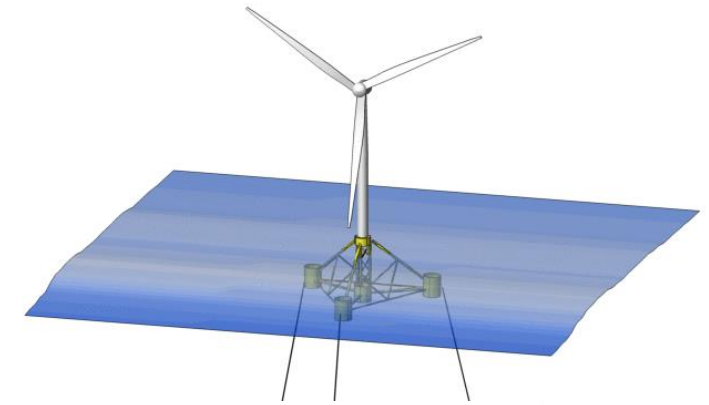
Methodology



Aerodynamic approaches

- BEM (DTU, EDF, IFPEN):
 - HAWC2 / DIEGO / DeepLines Wind™ (DLW)
 - Coupled with servo-hydro-elastic models

- Vortex Method (IFPEN)
 - CASTOR + DLW
 - Coupled with servo-hydro-elastic models

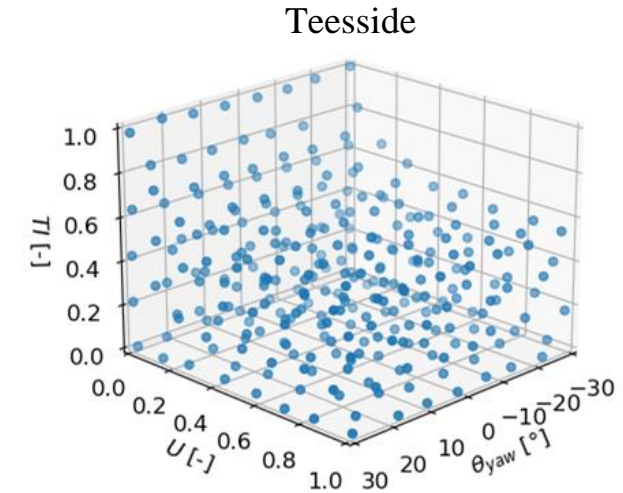


Study cases

- 2 wind turbines:

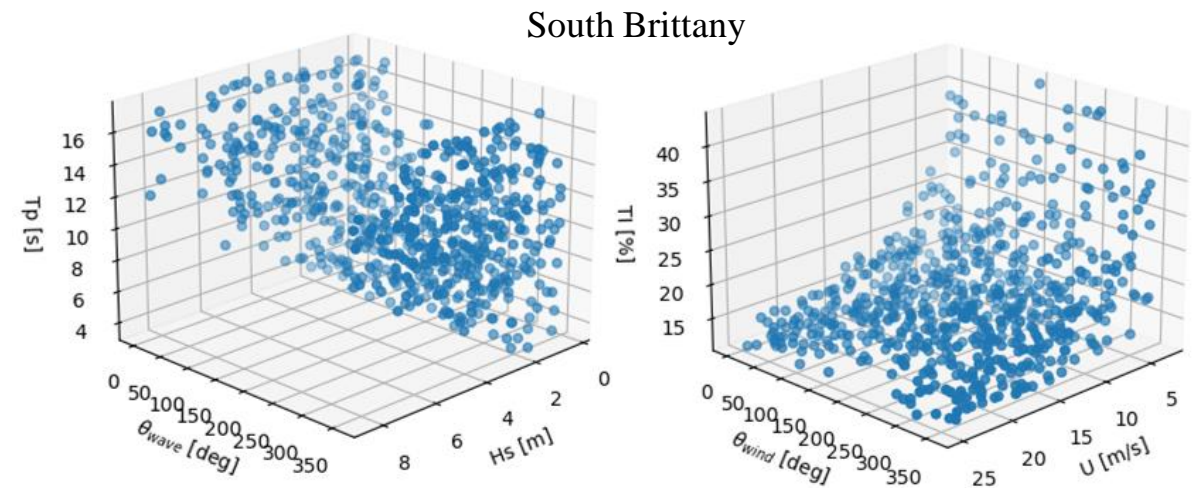
- **Teesside**

- Monopile 2.3MW
- DoE: U, TI, θ_{yaw}
- 300 BEM, 30 Vortex (iterative GP)



- **South Brittany**

- Floating (UMaine) 15MW
- DoE: $U, TI, \theta_{wind}, H_s, T_p, \theta_{wave}$
- 700 BEM, 60 Vortex (iterative GP)

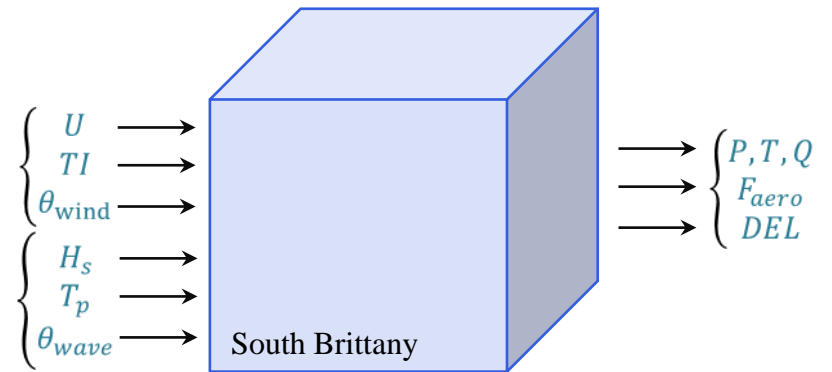
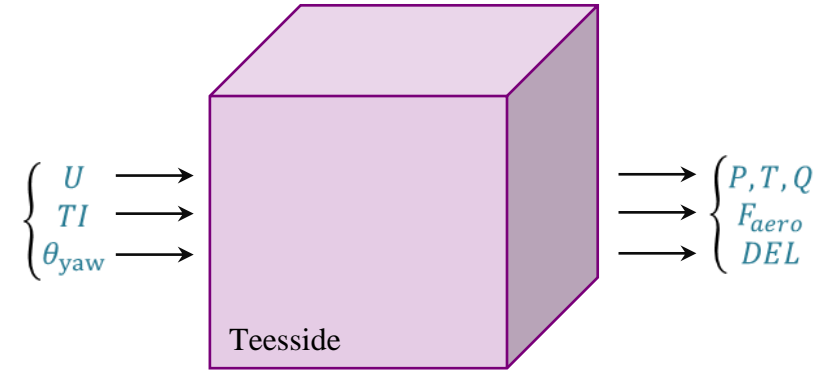


Results



Results

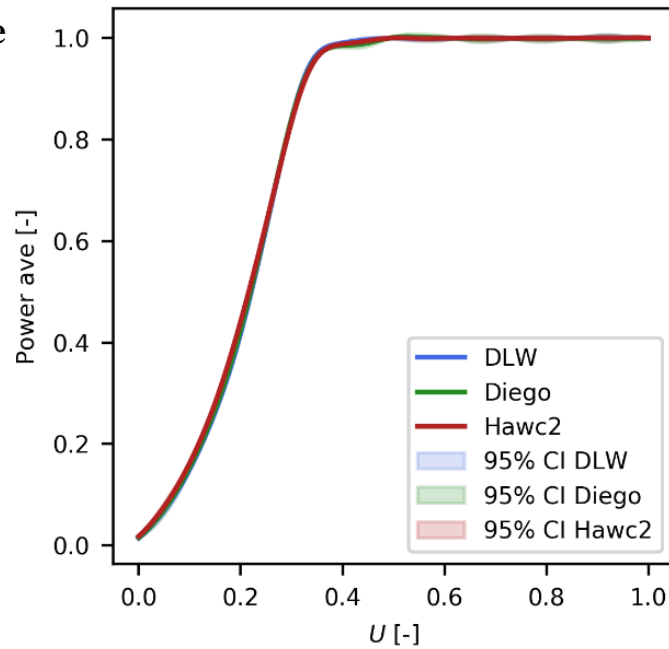
- Several GP models have been trained based on different relevant responses in the simulation results from both the BEM and Vortex simulations.
- Output: **metamodels** for BEM and Vortex
 - For several variables and inputs parameters
 - Integrated forces on the rotor (Thrust, Power, Torque)
 - Aerodynamic forces along the blades (over 5 points)
 - Damage at the blade root



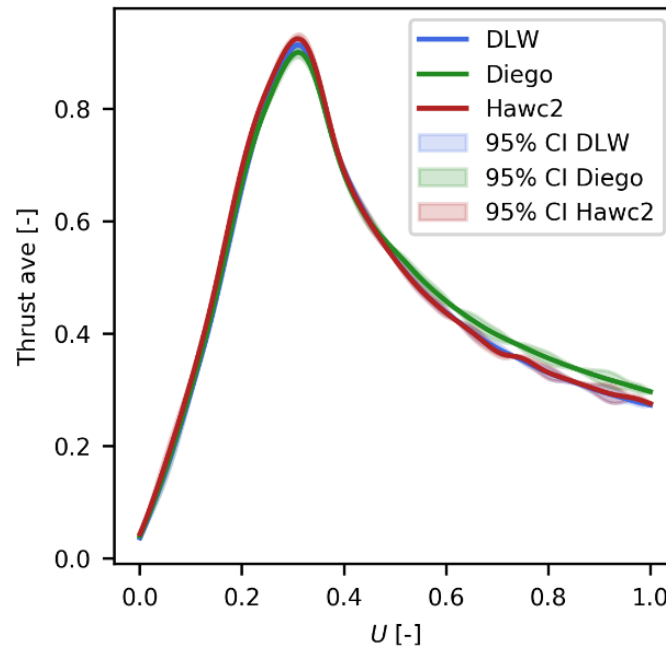
Results

- 3 software:
 - HAWC2, DIEGO, DLW

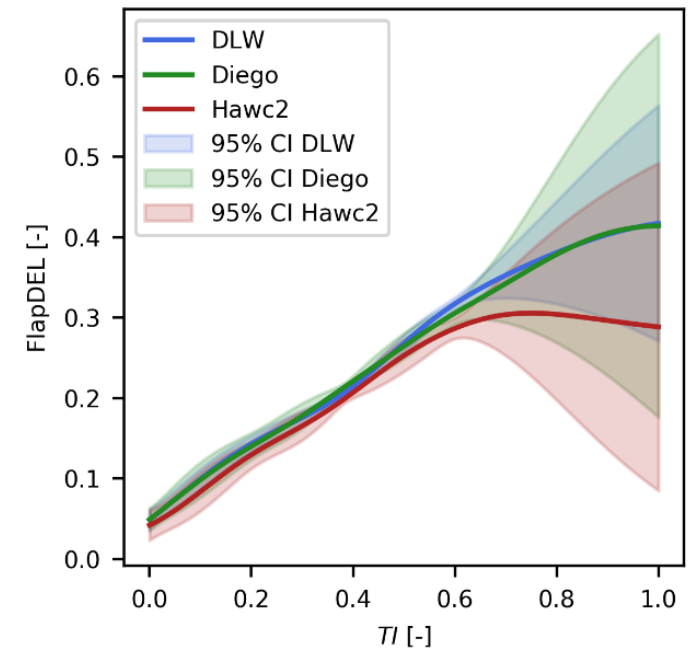
Mean Power, fixed Tl , Yaw=0°



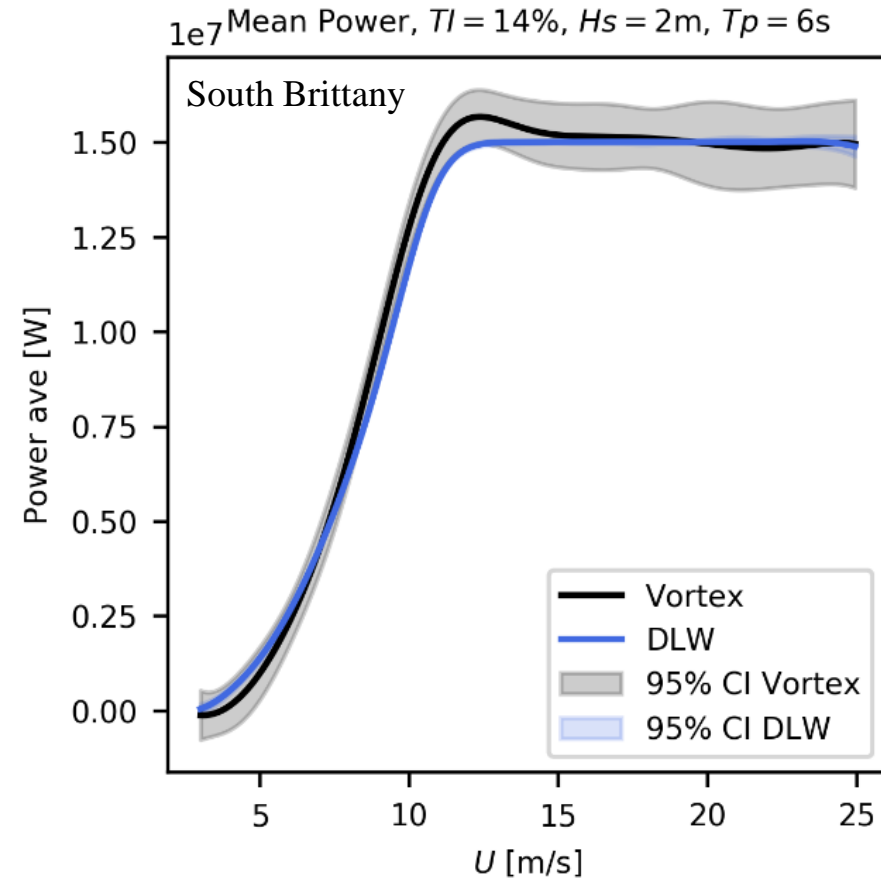
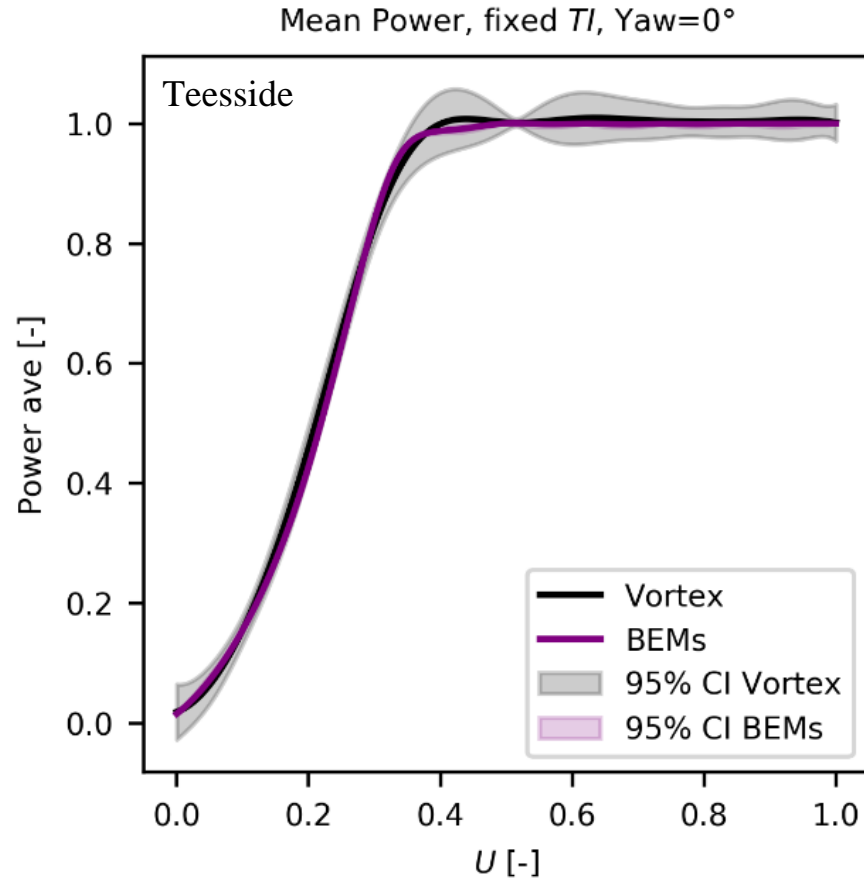
Mean Thrust, fixed Tl , Yaw=0°



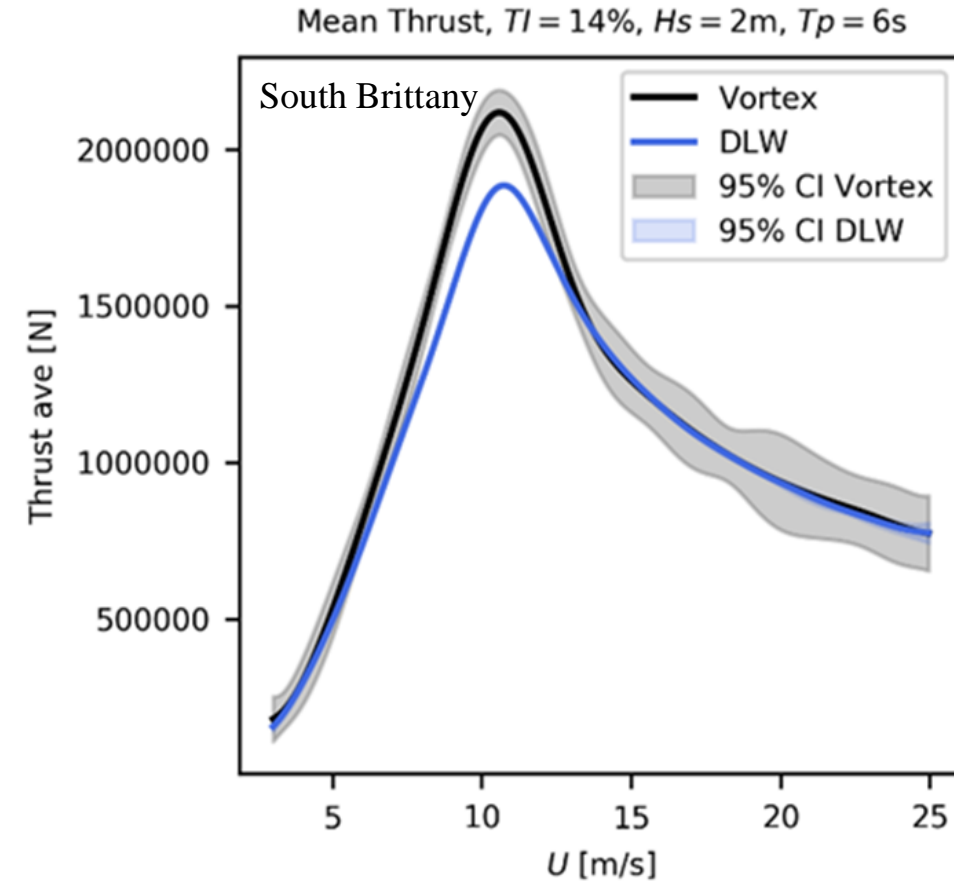
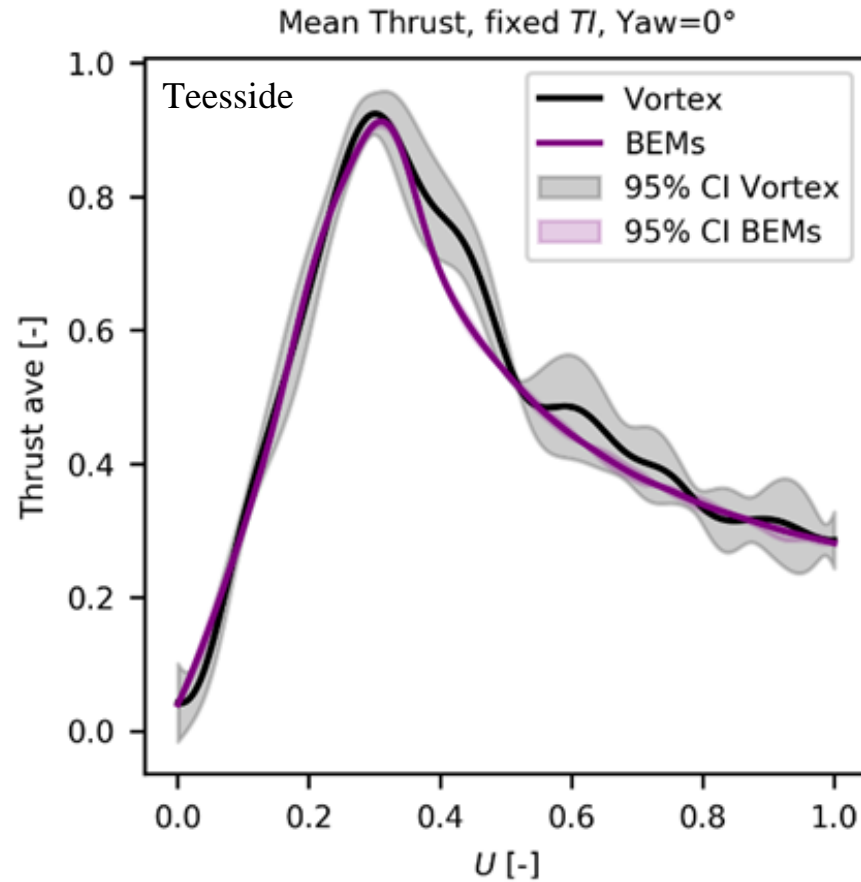
Max DEL flap, rated, Yaw=0°



Results



Results



Uncertainties

➤ relative discrepancy between the BEM and Vortex GPs

- Teesside:

	delFlap	delEdge	Power	Thrust
Min	-9.8%	-15.2%	-8.3%	-12.6%
Max	13.4%	9.7%	14.6%	13.9%
Mean	0.2%	0.2%	2.0%	2.3%
Std	3.0%	2.4%	3.3%	4.2%

- South Brittany:

	delFlap	delEdge	Power	Thrust
Min	-34.0%	-33.5%	-3.3%	-18.6%
Max	9.3%	9.2%	7.2%	27.7%
Mean	-1.8%	-5.2%	1.3%	4.4%
Std	4.2%	4.6%	2.4%	5.9%

Conclusions



Summary, Conclusions and future work

- Comparison between BEM and Vortex models for two different offshore technologies:
 - BEM models, using different ASHE tools (Diego, Hawc2, and DLW)
 - Vortex model, Castor + DLW
- Several GP models have been trained based on results from both the BEM and Vortex simulations.
- Benchmark, overall good agreement between BEM codes.
- BEM vs Vortex differences are higher for the floating wind turbine.
- GPs or metamodels can be used in two different ways:
 - either to select a conservative response with a specified confidence level for all relevant input scenarios
 - or to fully quantify the uncertainties between both approaches.

Future work

- Estimate the **model uncertainty** by comparing **engineering models** with high fidelity **LES simulations**.

Acknowledgements



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