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

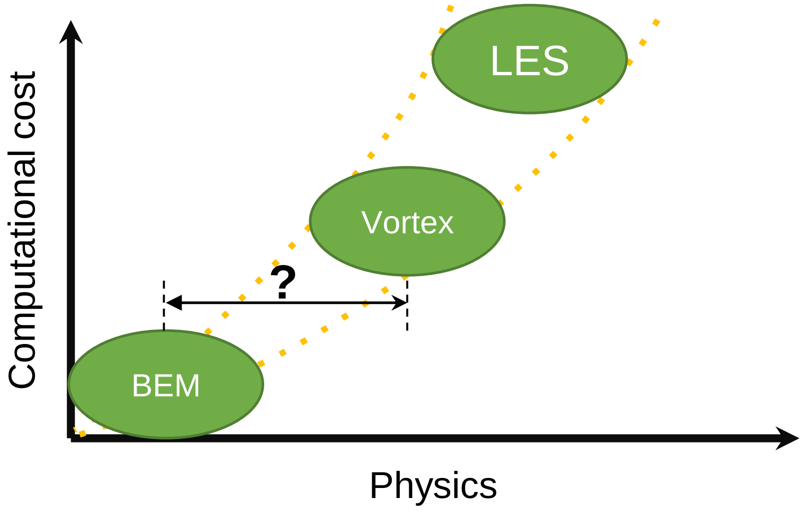
Introduction

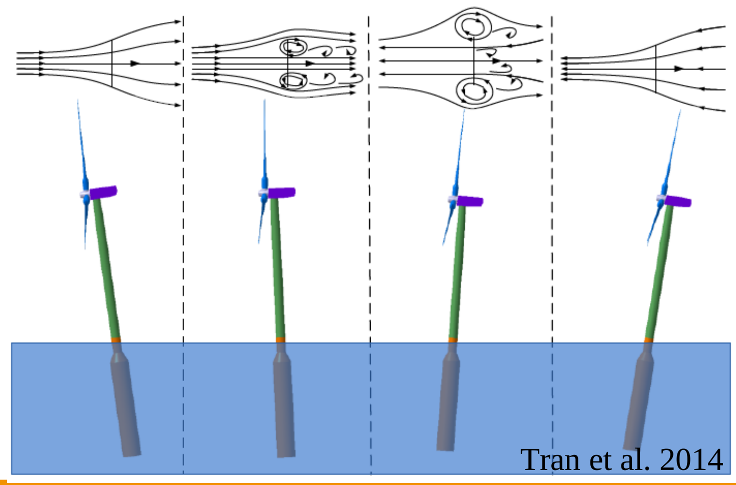
Aerodynamic approaches

- 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

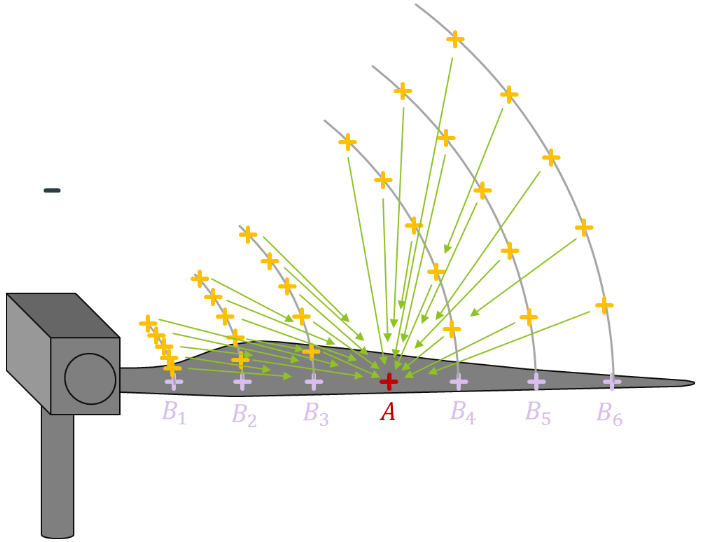
  - **Vortex method**:
    - State of the art
    - Free vortex wake model based on lifting line theory
    - Unsteady, less empirical corrections
    - Higher computational cost





Aerodynamic approaches

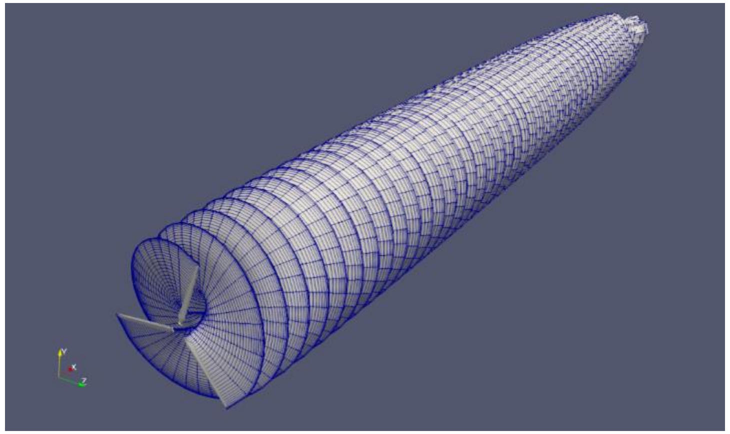
- Calculation cost:
  - Larger than BEM
  - N-body problem
  - Ideal time step: equivalent to $\Delta\theta \in [5°; 10°]$
  - Wake length: $\theta \geq 2\pi N_{rot}$ with $N_{rot} \in [15; 25]$



- Aero-elastic simulations constraints:
  - Time step often driven by the controller : $\Delta\theta \approx 0.1°$
  - Low time step → very high number of vortex elements

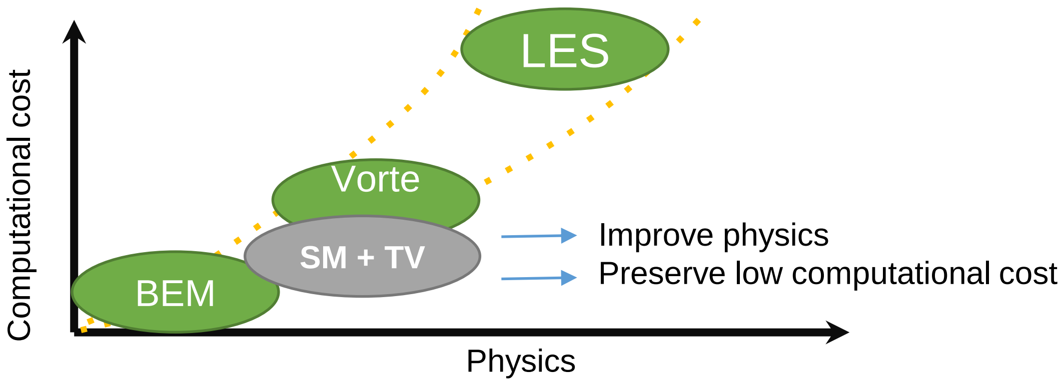
→ Time-consuming routines ported to GPU (CUDA)

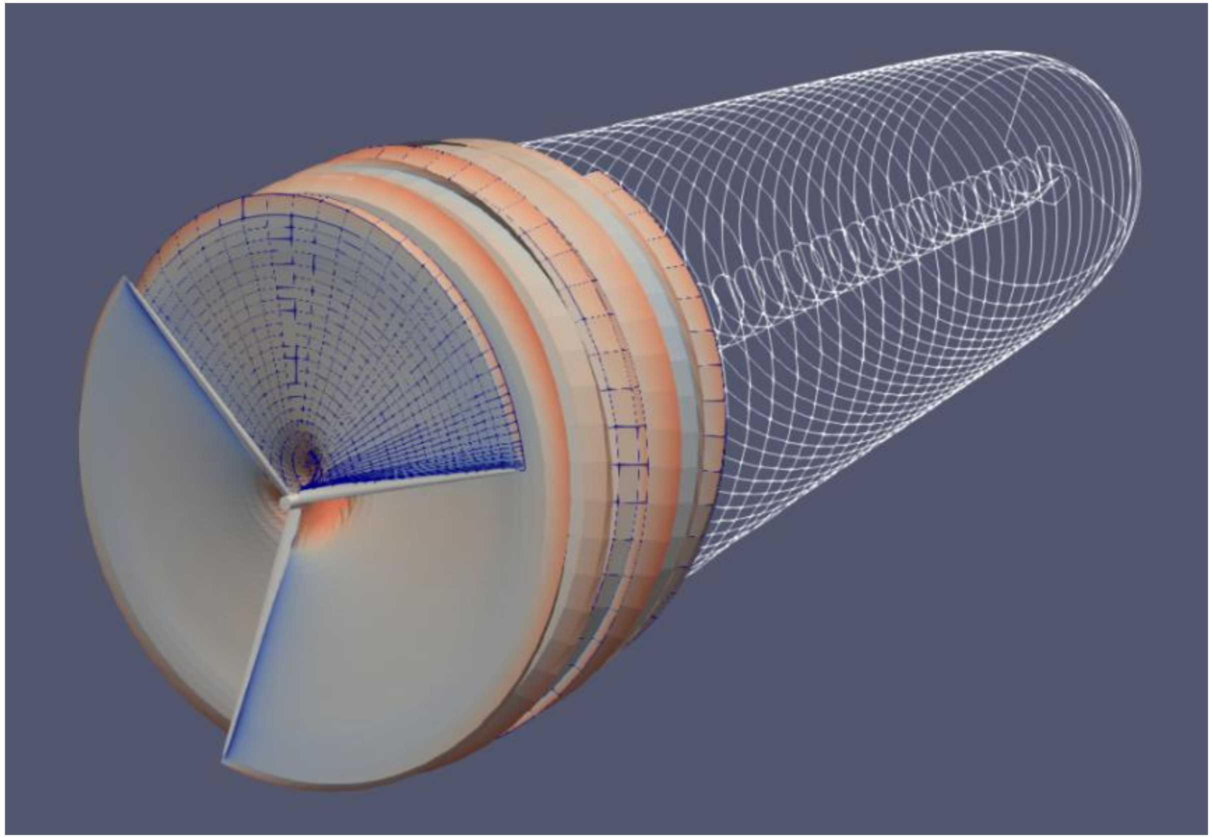
→ Still not enough : the number of filaments must be reduced



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

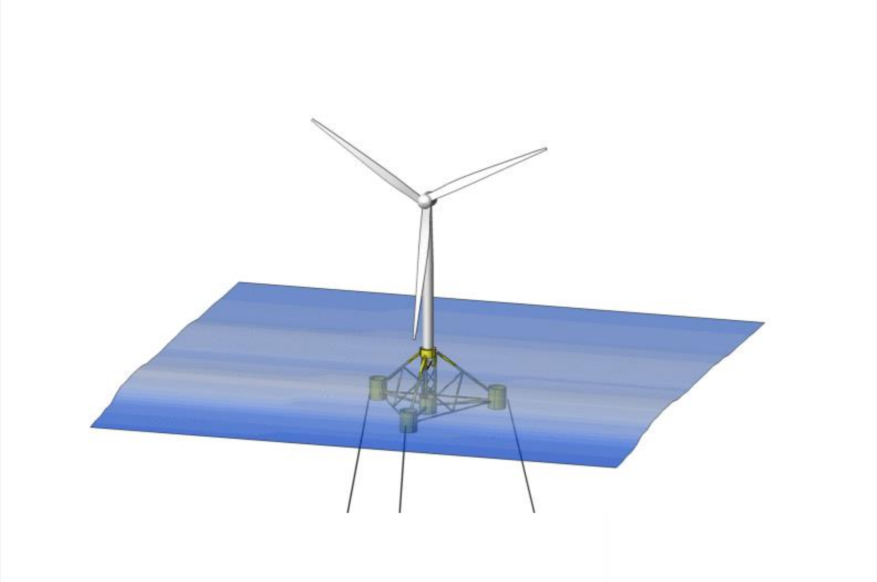


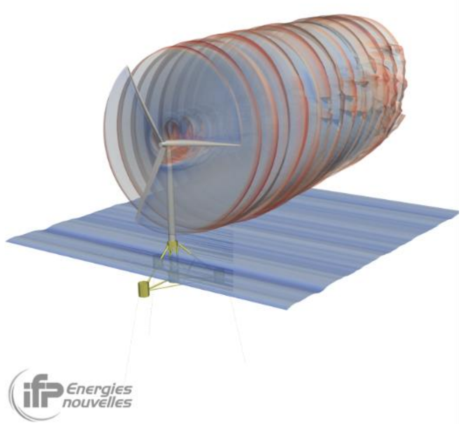


Methodology

Aerodynamic approaches

- BEM (DTU, EDF, IFPEN):
  - HAWC2 / DIEGO / DeepLines Wind^{TM} (DLW)
  - Coupled with servo-hydro-elastic models
- Vortex Method (IFPEN)
  - CASTOR + DLW
  - Coupled with servo-hydro-elastic models

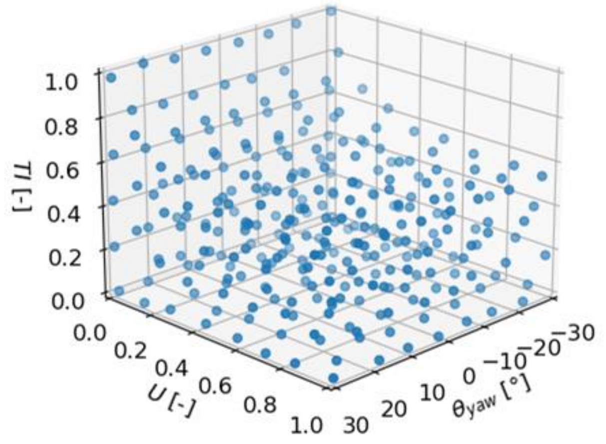




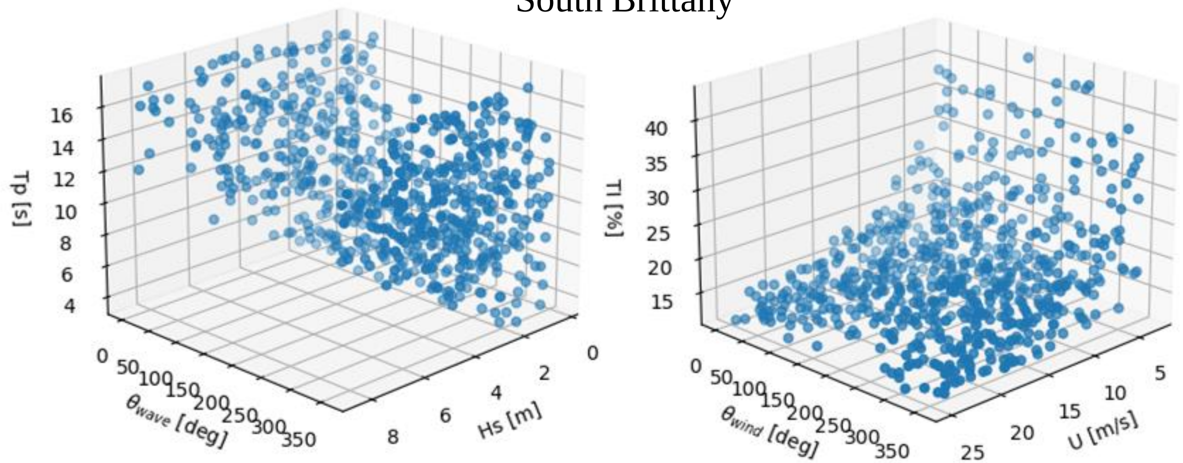
Study cases

- 2 wind turbines:
  - **Teesside**
    - Monopile 2.3MW
    - DoE: $\boldsymbol{U, TI, \theta_{yaw}}$
    - **300** BEM, **30** Vortex (iterative GP)
  - **South Brittany**
    - Floating (UMaine) 15MW
    - DoE: $\boldsymbol{U, TI, \theta_{\text{wind}}, H_s, T_p, \theta_{wave}}$
    - **700** BEM, **60** Vortex (iterative GP)

Teesside



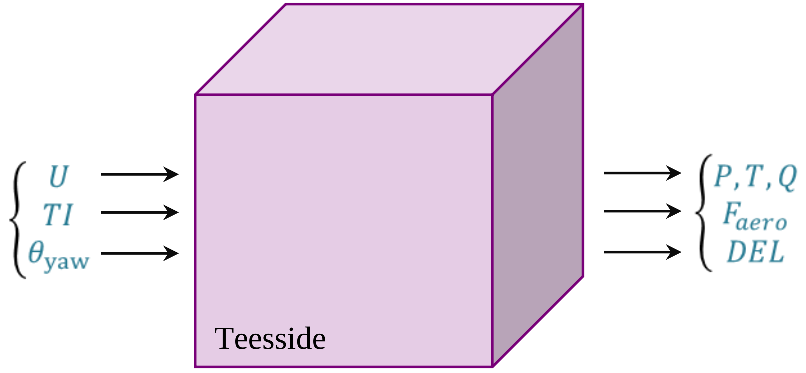
South Brittany

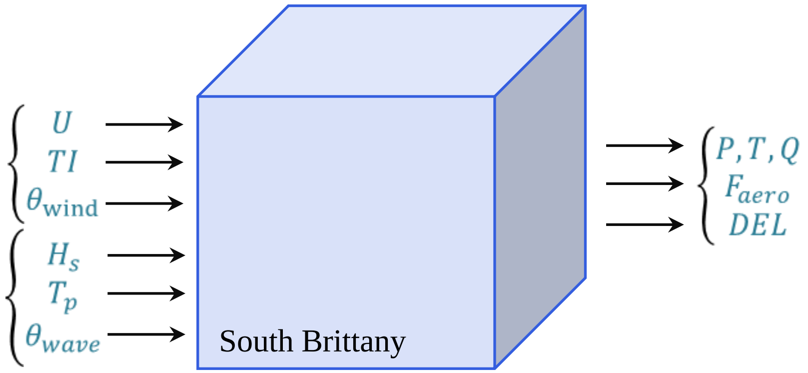


Results

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

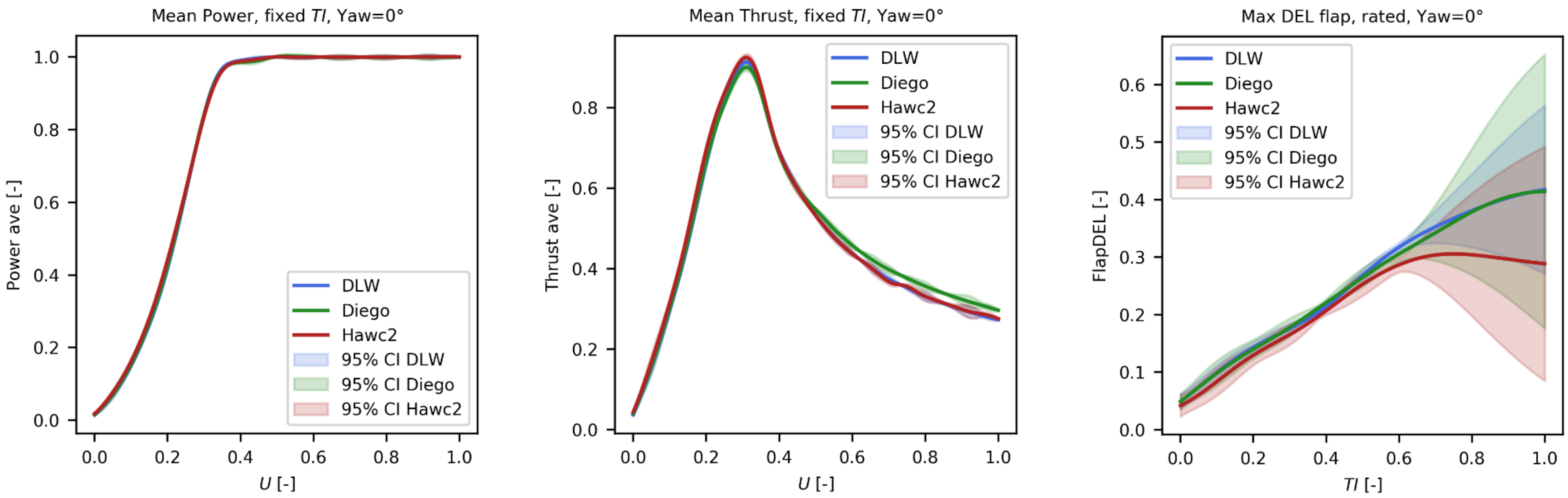




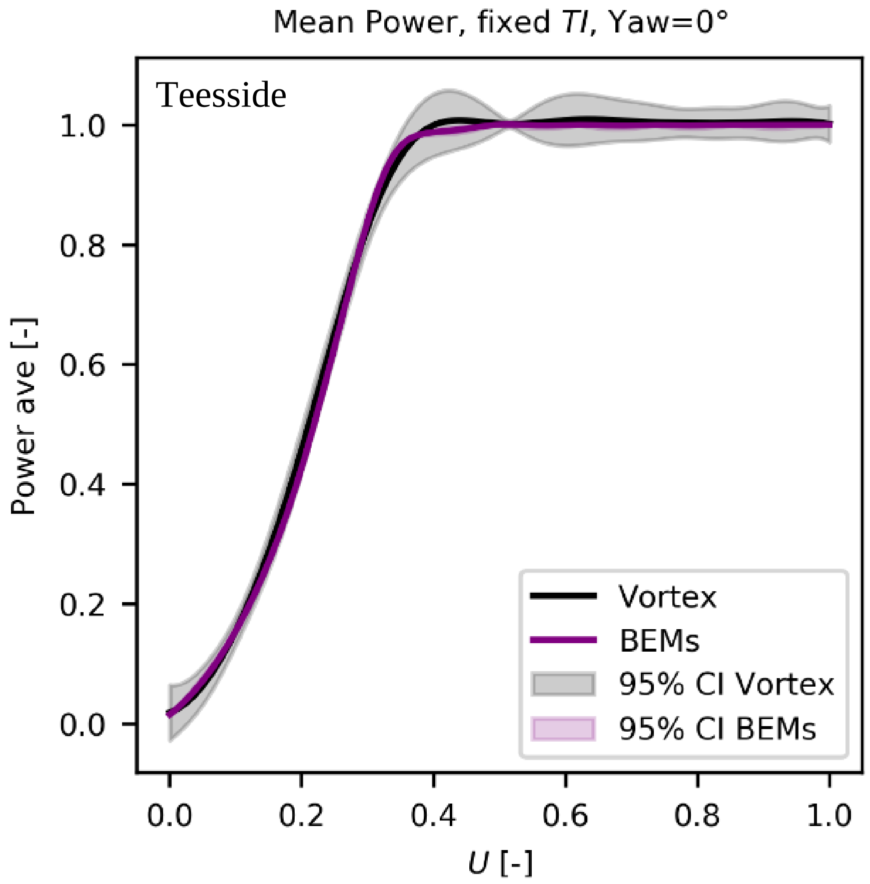
Results

- 3 software:
  - HAWC2, DIEGO, DLW

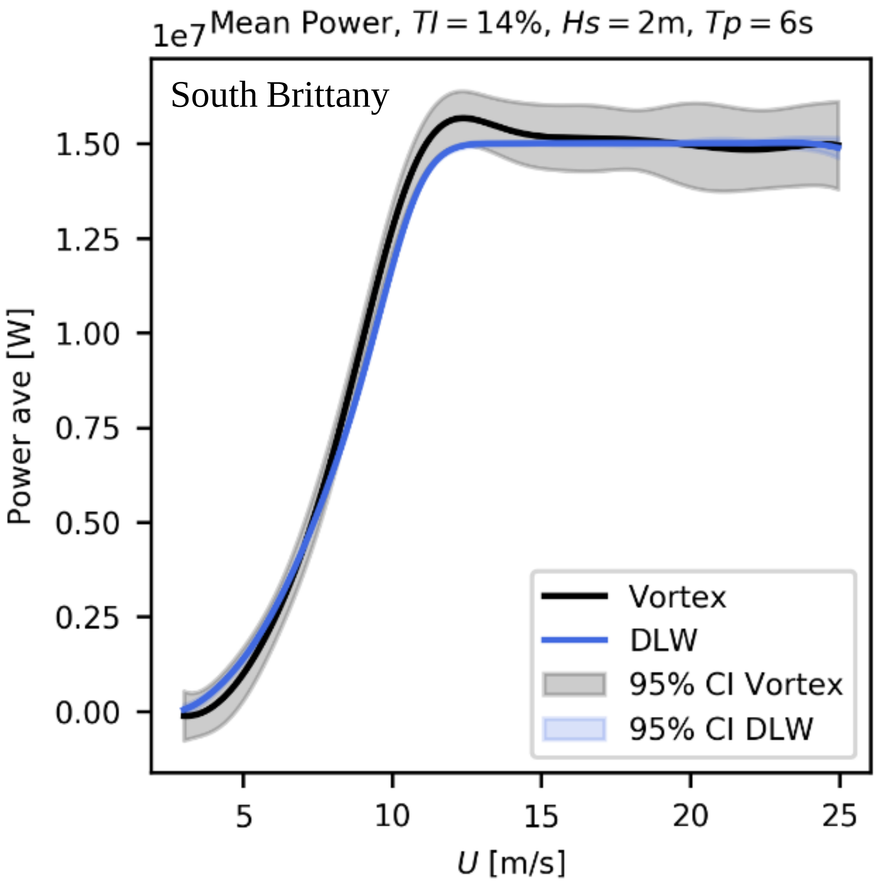
Teesside



Results

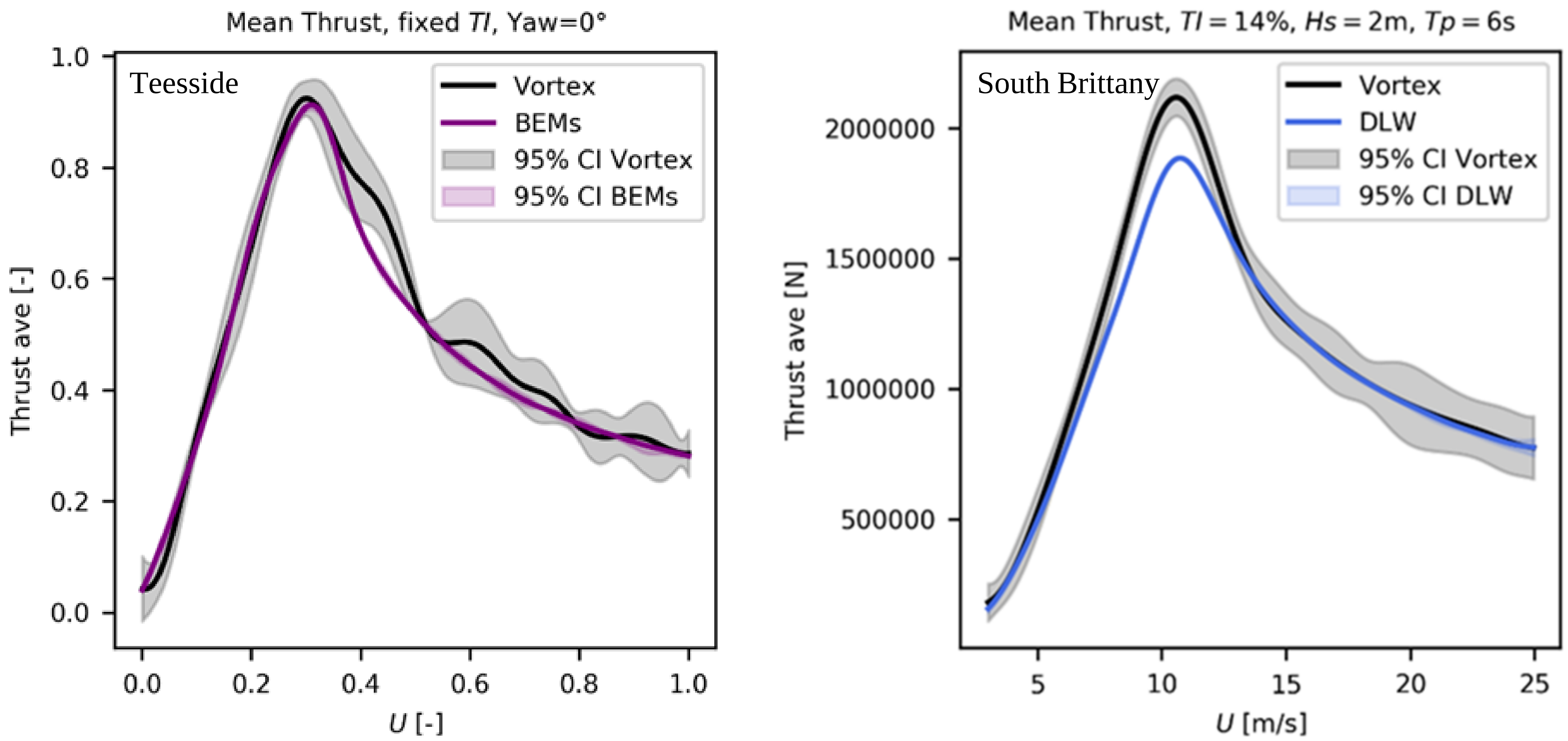


Mean Power, fixed TI, Yaw=0°
Teesside
Power ave [-]
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
U [-]
Vortex
BEMs
95% CI Vortex
95% CI BEMs



1e7
Mean Power, TI = 14%, Hs = 2m, Tp = 6s
South Brittany
Power ave [W]
1.50
1.25
1.00
0.75
0.50
0.25
0.00
5
10
15
20
25
U [m/s]
Vortex
DLW
95% CI Vortex
95% CI DLW

Results



Mean Thrust, fixed TI, Yaw=0°
Teesside
Vortex
BEMs
95% CI Vortex
95% CI BEMs
Thrust ave [-]
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
U [-]
Mean Thrust, TI = 14%, Hs = 2m, Tp = 6s
South Brittany
Vortex
DLW
95% CI Vortex
95% CI DLW
Thrust ave [N]
2000000
1500000
1000000
500000
5
10
15
20
25
U [m/s]

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

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 101006689