Benchmarking results from multiple wake models on operational data from offshore wind farms

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Background

Yield methodology gap identified

Wakes and blockage identified as sources of the gap

Developing new wake model and benchmarking framework

Continuous analysis of asset performance

Deploying new wake model

Benchmarking new and other wake models

External wake model benchmarking

Benchmarking multiple wake models from external providers

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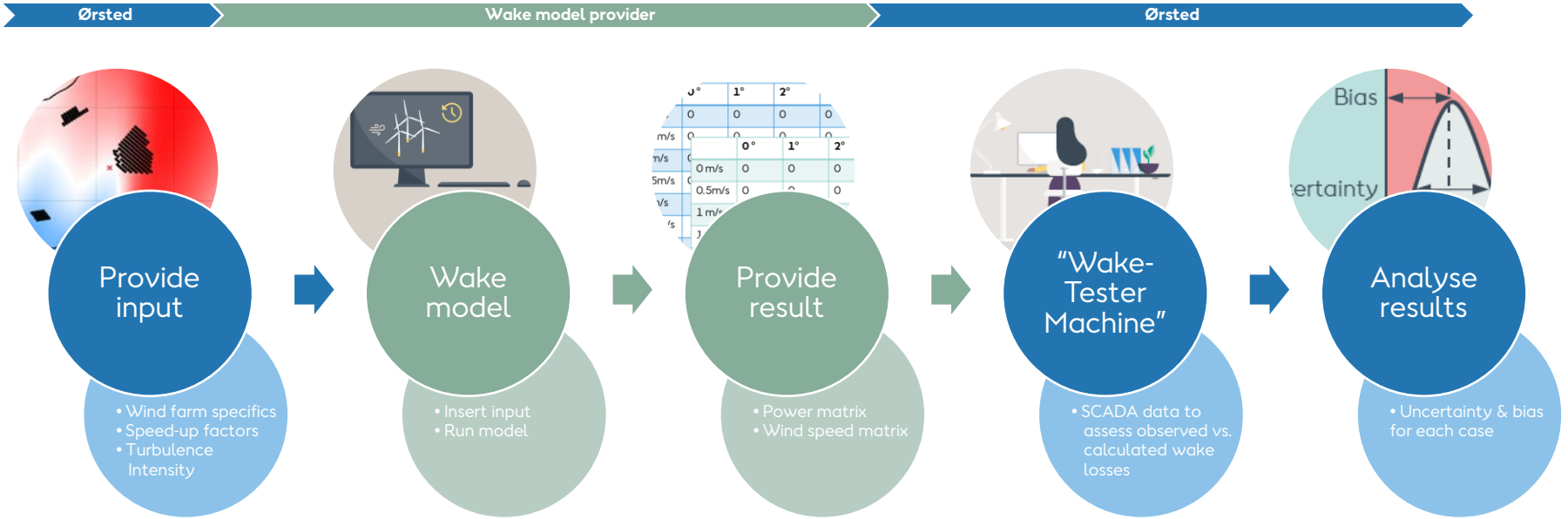
Wake model benchmarking framework



N G Nygaard et al: Large-scale benchmarking of wake models for offshore wind farms, J. Phys.: Conf. Ser. 2265 022008.
https://iopscience.iop.org/article/10.1088/1742-6596/2265/2/022008, 2022

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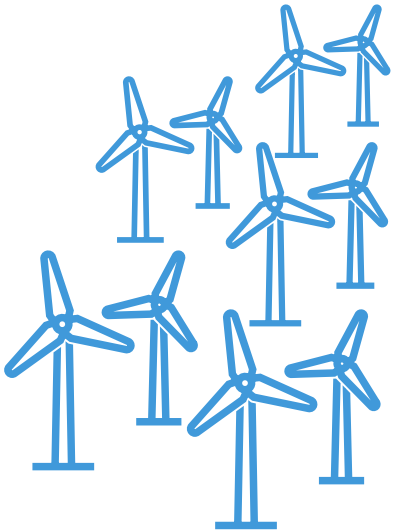
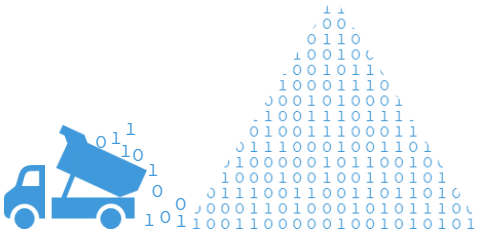
Wake model benchmarking scope

19 offshore wind farms



1415 turbines analysed



122 data years

6,400,000 time stamps

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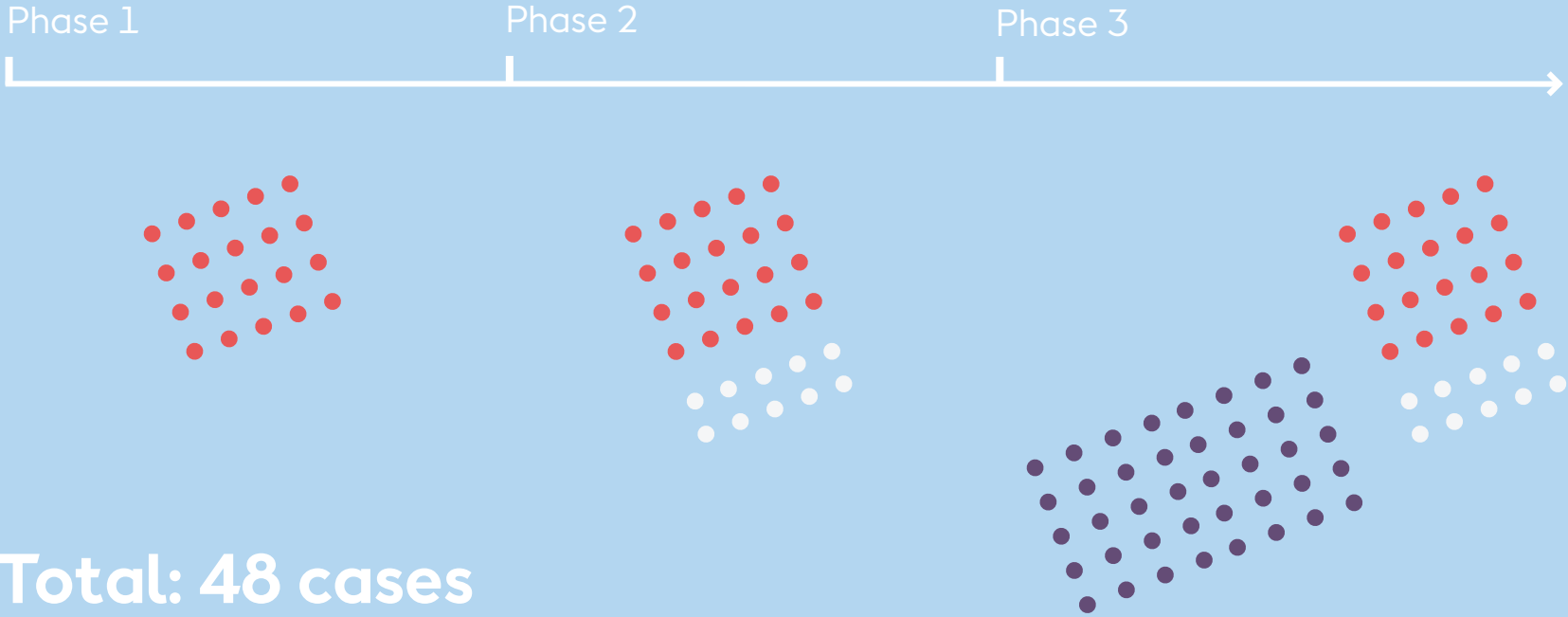
Multiple cases

Resolving different wind farm phases



Total: 48 cases

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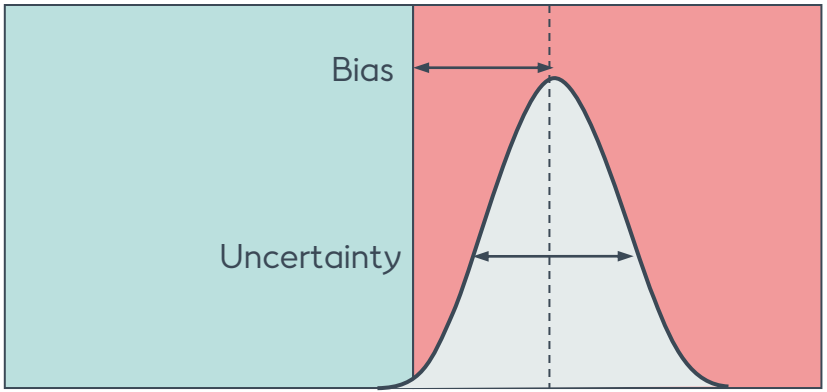
Wake model benchmarking result format

$$\epsilon = 100\% \frac{\mathrm{Loss}_{\mathrm{obs}} - \mathrm{Loss}_{\mathrm{model}}}{\mathrm{Loss}_{\mathrm{obs}}}$$

The relative error is in percent of the wake loss

For a **true** wake loss of 10% a relative error of +20% means a **modelled** wake loss of 8%

In that case the AEP would be 2% lower than predicted



Wake loss too low AEP overestimated

Wake loss too high AEP underestimated

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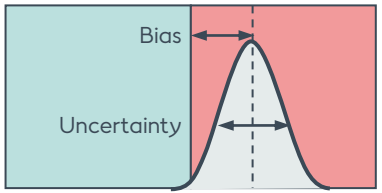
Results collected for all 48 cases

Wake loss too low AEP overestimated

Wake loss too high AEP underestimated



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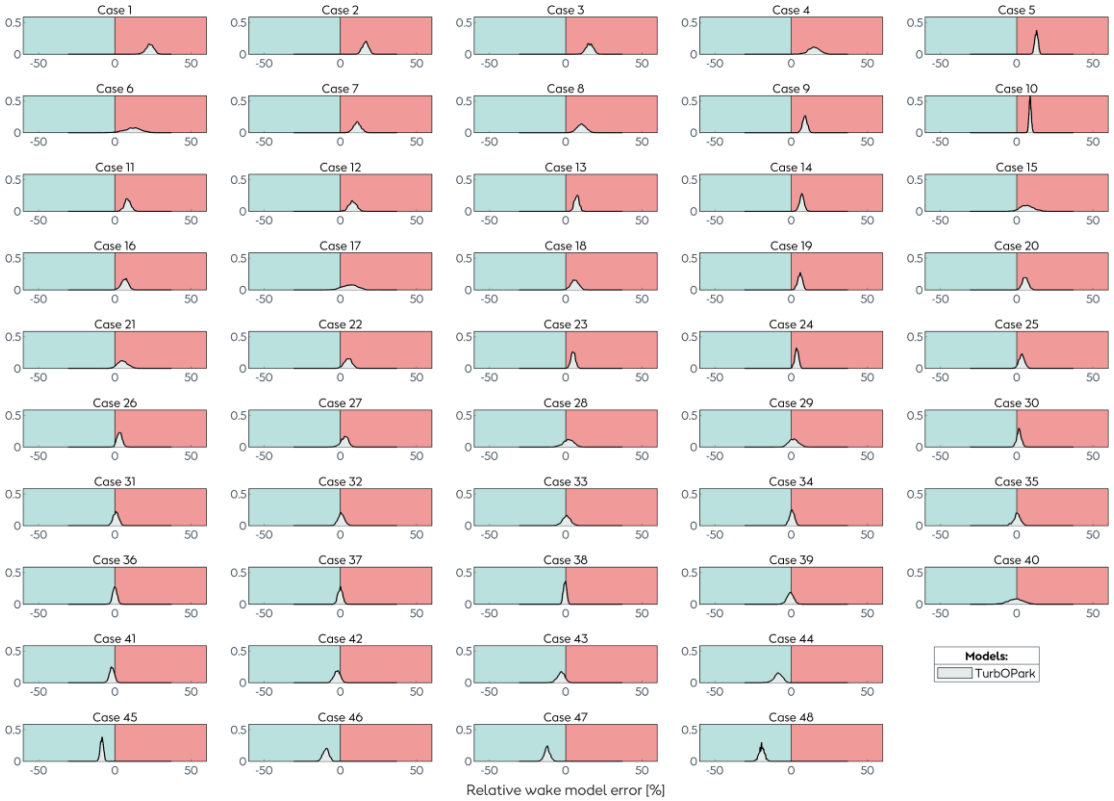

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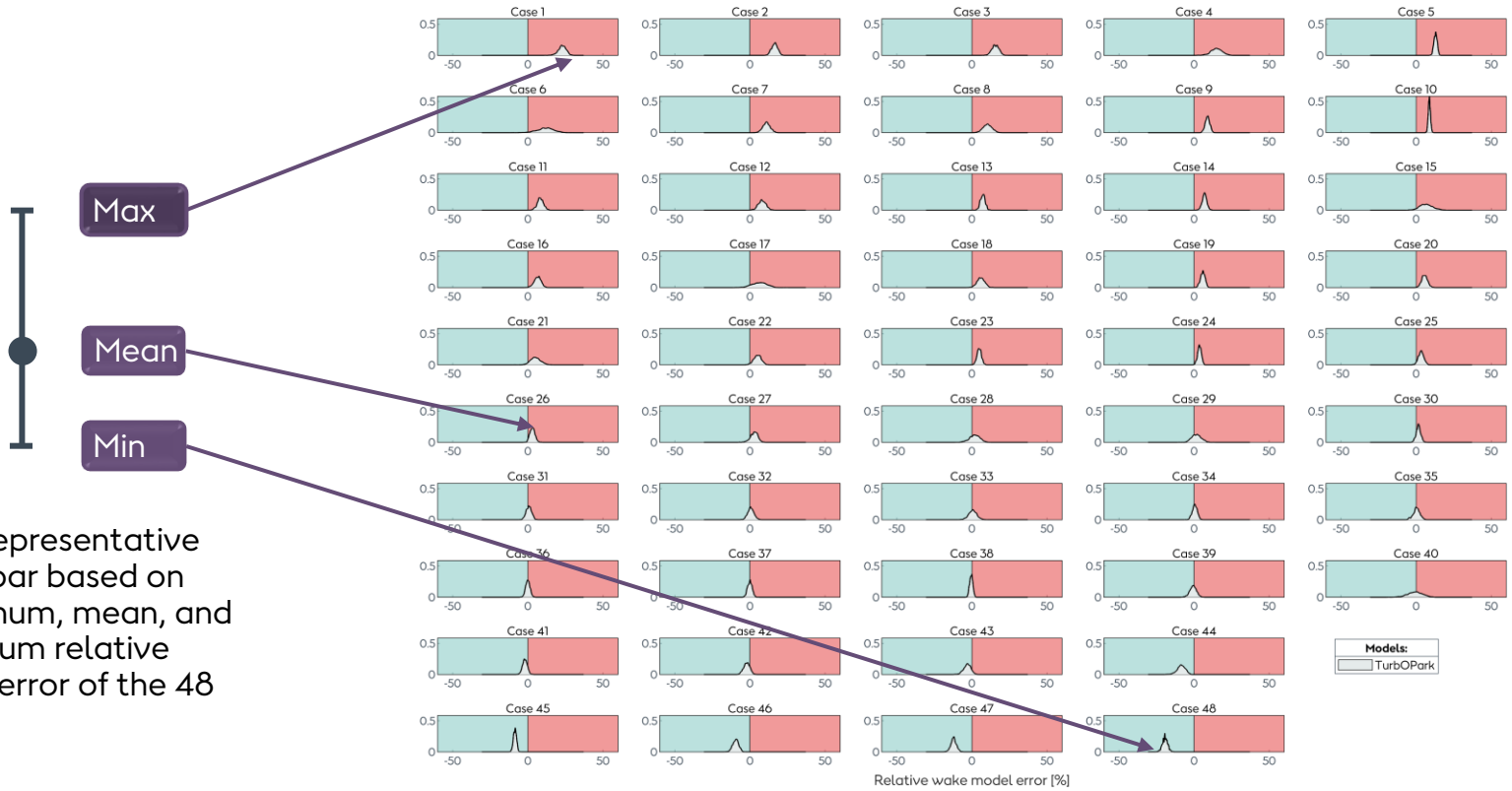
Aggregating all 48 cases



One representative error bar based on maximum, mean, and minimum relative wake error of the 48 cases.

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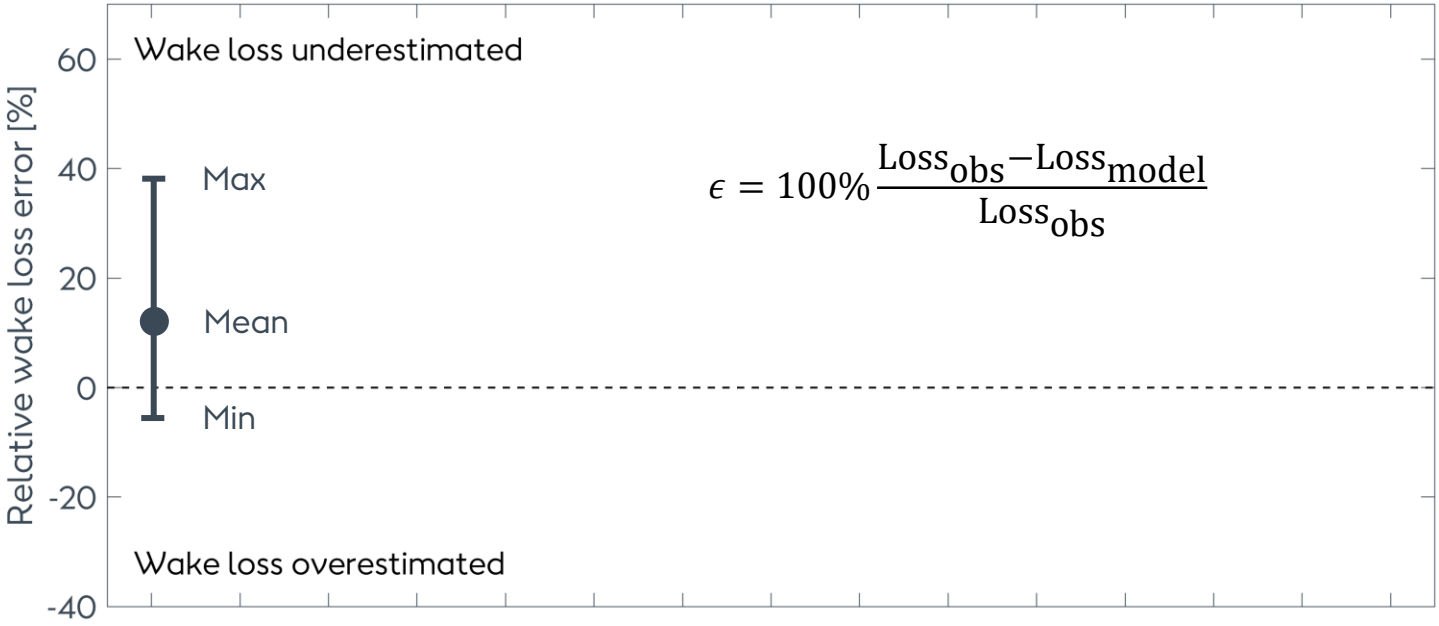
Result format for multiple wake models

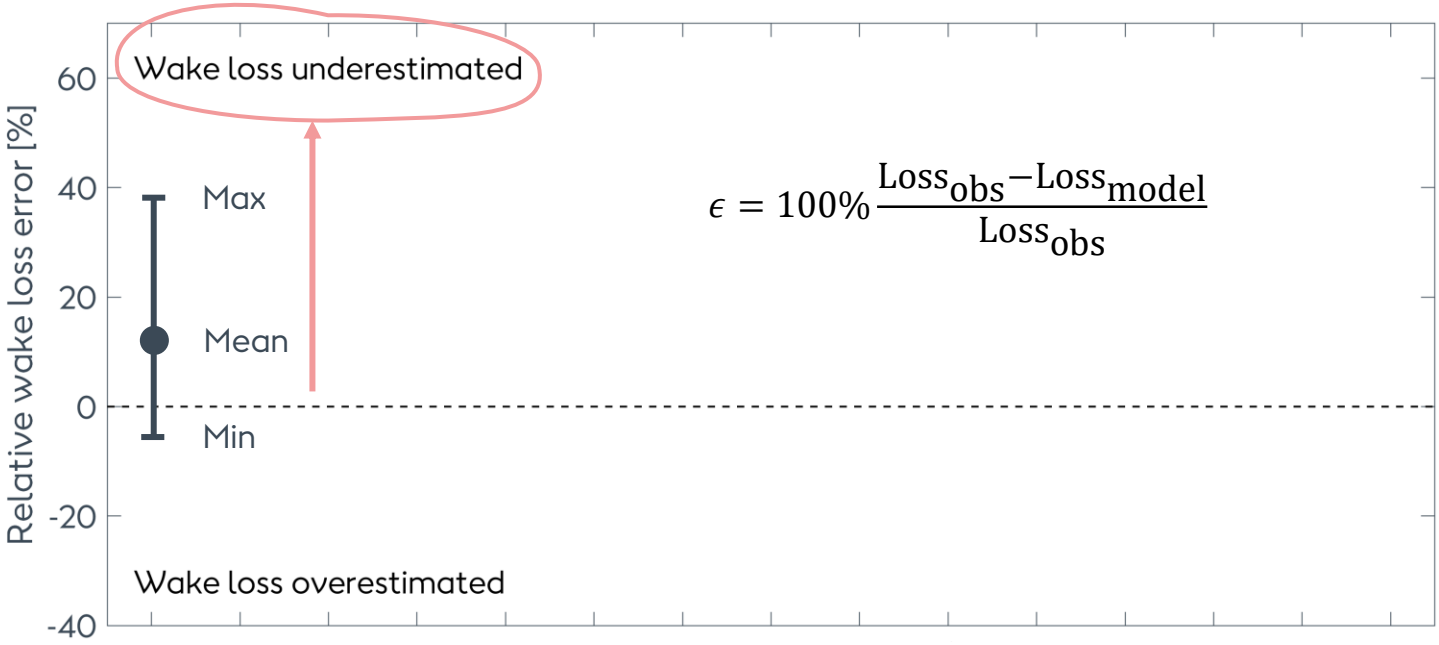
Aggregating all 48 cases



Errors are relative to the observed wake loss

Result format for multiple wake models

Aggregating all 48 cases



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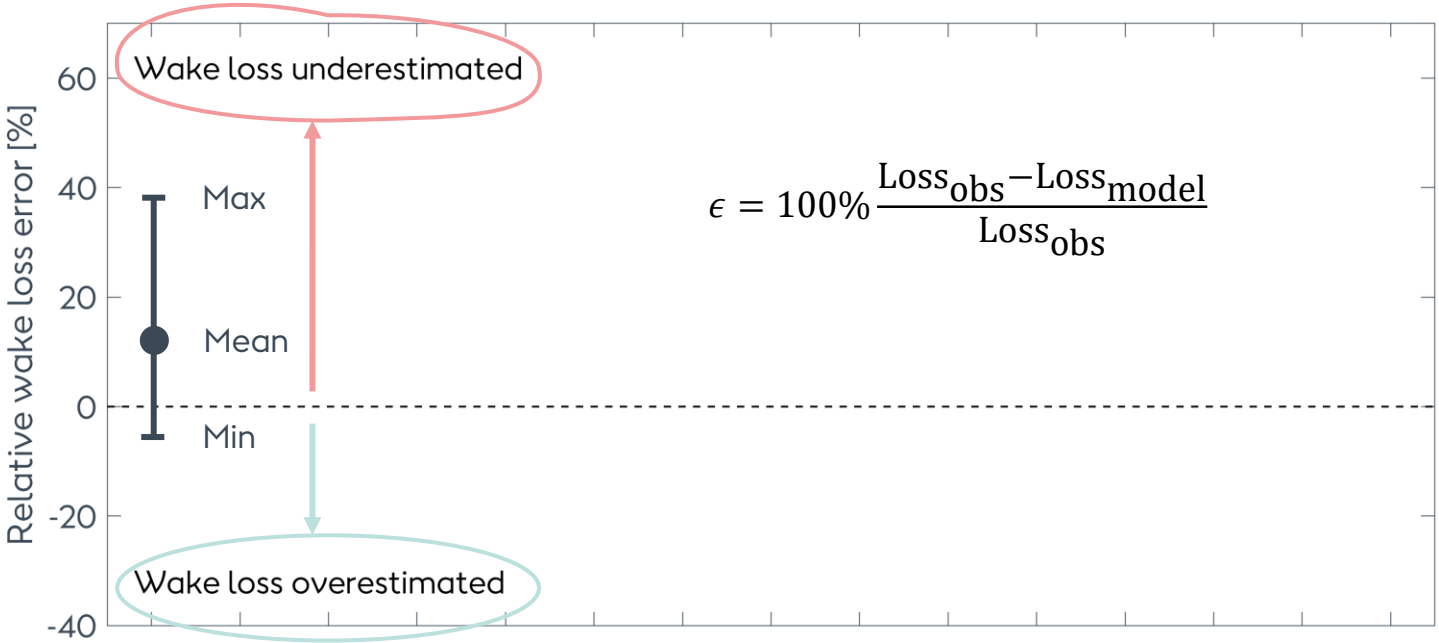
Result format for multiple wake models

Aggregating all 48 cases



Errors are relative to the observed wake loss

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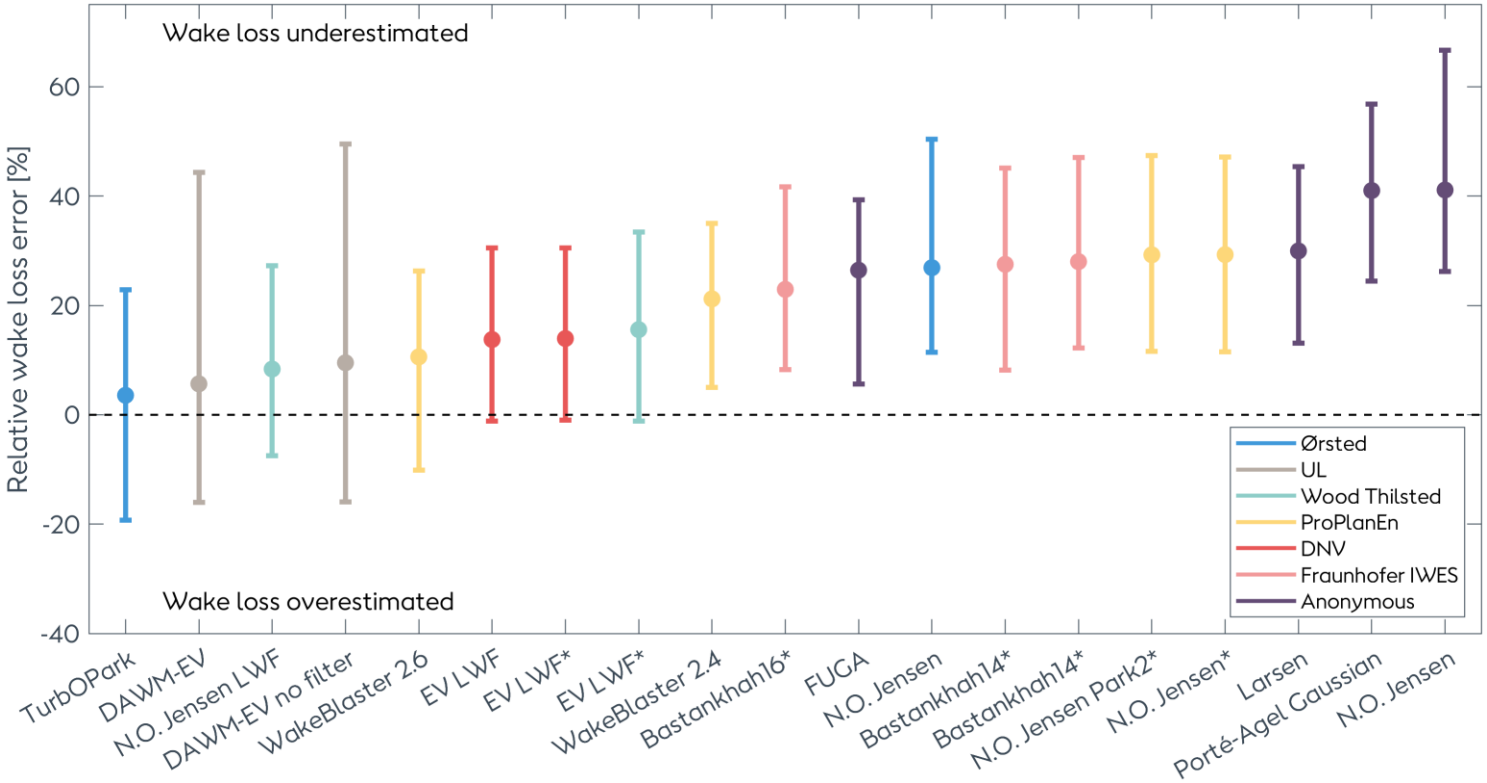
Results for multiple wake models

Provider	Software	Model name
Ørsted	internal tool	TurbOPark
Ørsted	internal tool	N.O. Jensen
Wood Thilsted	WindFarmer Analyst	N.O. Jensen LWF
Wood Thilsted	WindFarmer Analyst	EV LWF*
UL	Openwind	DAWM-EV
UL	Openwind	DAWM-EV no filter
ProPlanEn	WakeBlaster 2.6	WakeBlaster 2.6
ProPlanEn	WakeBlaster 2.4	WakeBlaster 2.4
ProPlanEn	WindPRO 3.5	N.O. Jensen Park2*
ProPlanEn	WindPRO 3.5	N.O. Jensen*
Fraunhofer IWES	flappy	Bastankhah16*
Fraunhofer IWES	flappy	Bastankhah14*
Fraunhofer IWES	flappy	Bastankhah14*
DNV	WindFarmer Analyst	EV LWF
DNV	WindFarmer Analyst	EV LWF*
Anonymous	FUGA	FUGA
Anonymous	PyWake	Larsen
Anonymous	PyWake	Porté-Agel Gaussian
Anonymous	PyWake	N.O. Jensen

Results for multiple wake models

Aggregating all 48 cases



** No blockage model/correction has been included.*

Errors are relative to the observed wake loss.

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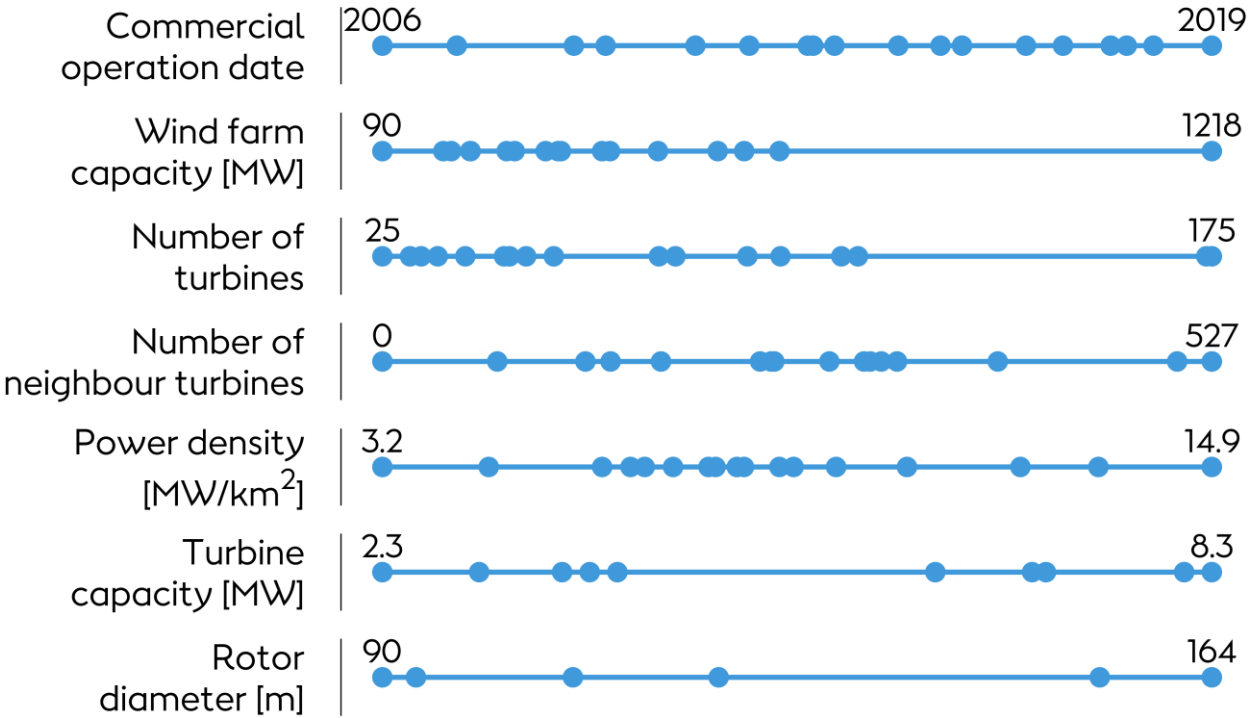
Can we learn something more from all this data?

Overview of all 48 cases



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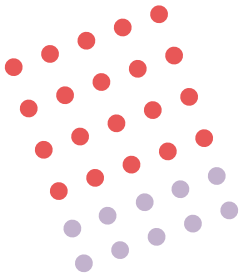
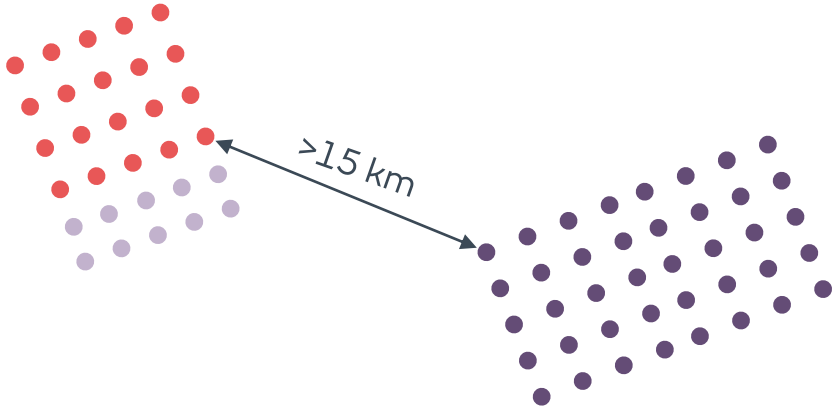
A small deep-dive

Wake model performance in cases with no neighbour & distant neighbour





Definition of no neighbour cases

- Target wind farm doesn't have neighbours or only have immediate neighbours (i.e. cluster)

Definition of distant neighbour cases

- Fulfil no neighbour case definition and also have neighbours more than 15 km from target wind farm

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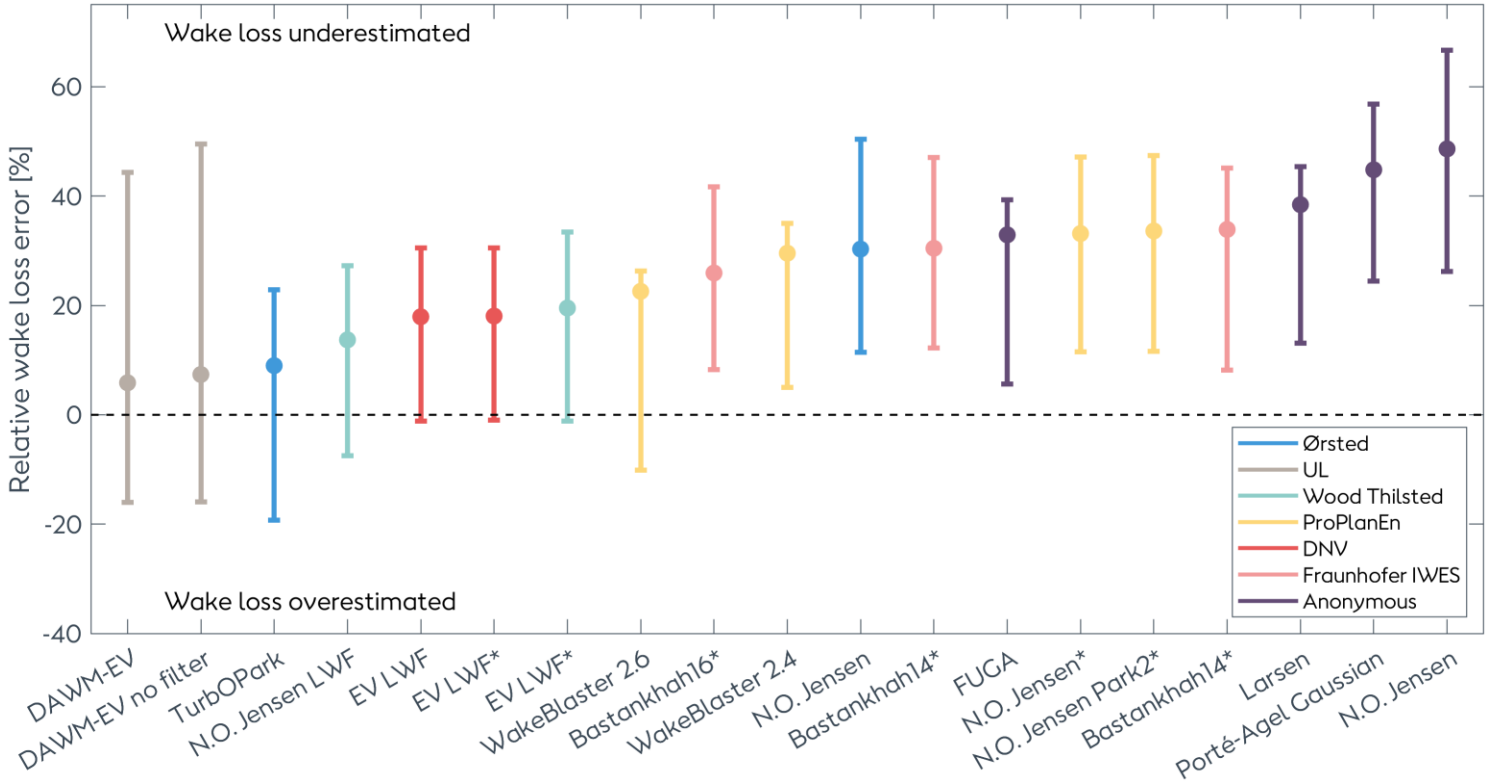
A small deep-dive

Wake model performance with no neighbours, 6 cases



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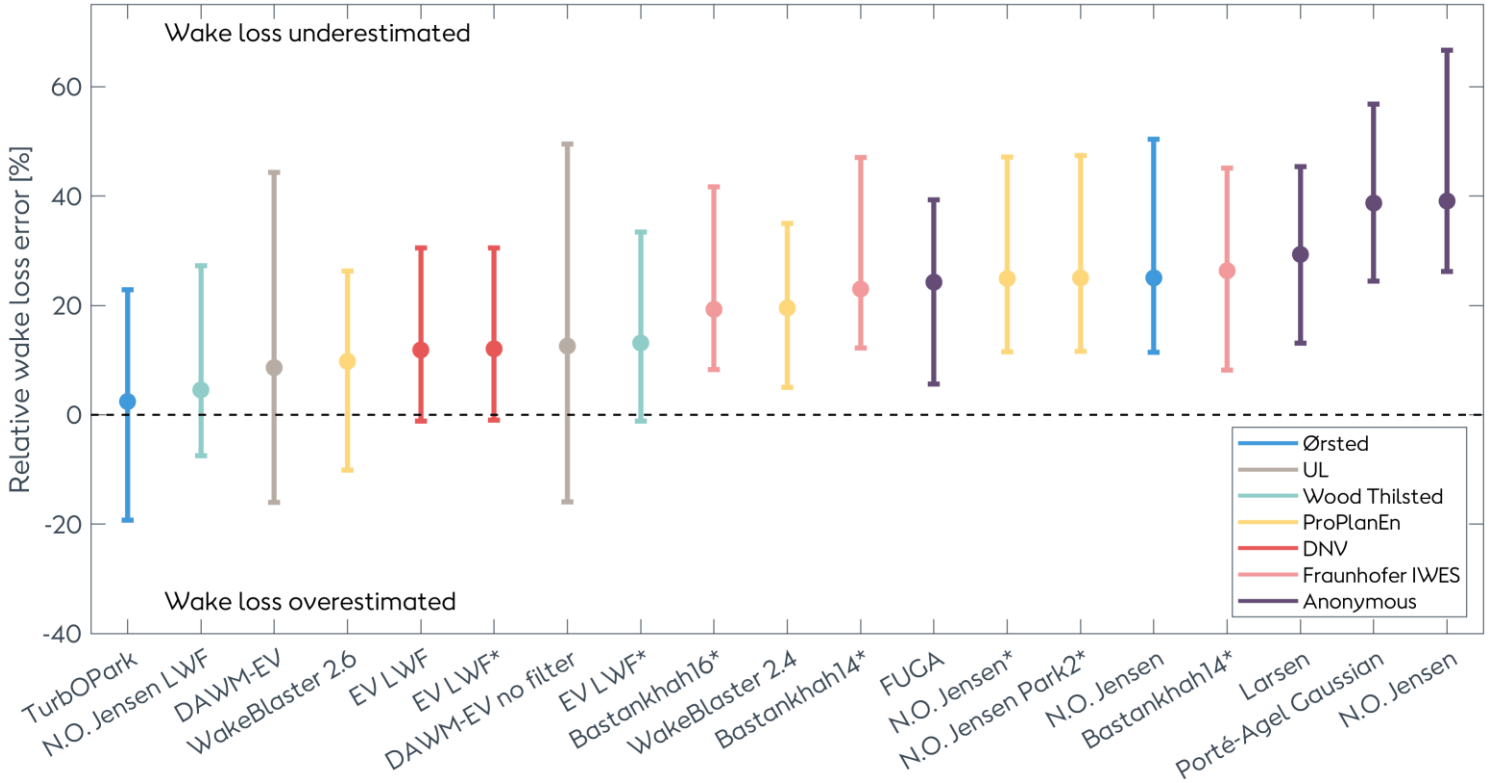
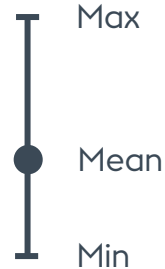
A small deep-dive

Wake model performance with distant neighbours, 7 cases





** No blockage model/correction has been included.*

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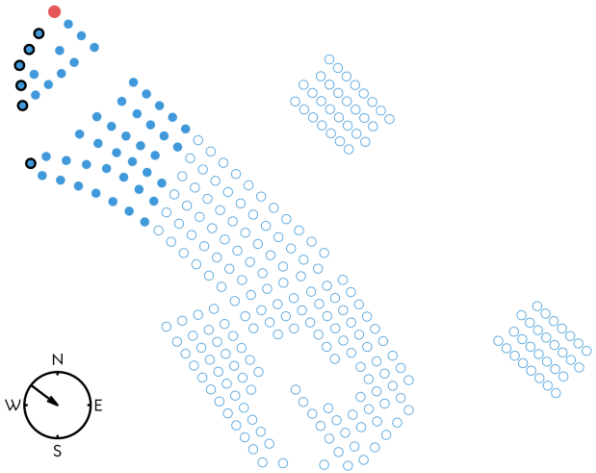
Thank you for listening!

Backup slides

Reference turbine freestream method



1. Identify turbines (●) unwaked by other **target** wind farm turbines
   Ignore neighbour wind farms!
2. Choose reference turbine (●)
   Unwaked turbine with highest power
3. Observed *reference gross* power = N P_{ref}
4. Observed net power is sum of power over all target turbines
5. Run wake model for multiple inflow wind speeds
6. Choose model run where wind speed at the reference turbine **best matches** the measured wind speed at the reference
7. Modelled *reference gross* and net power from chosen model run

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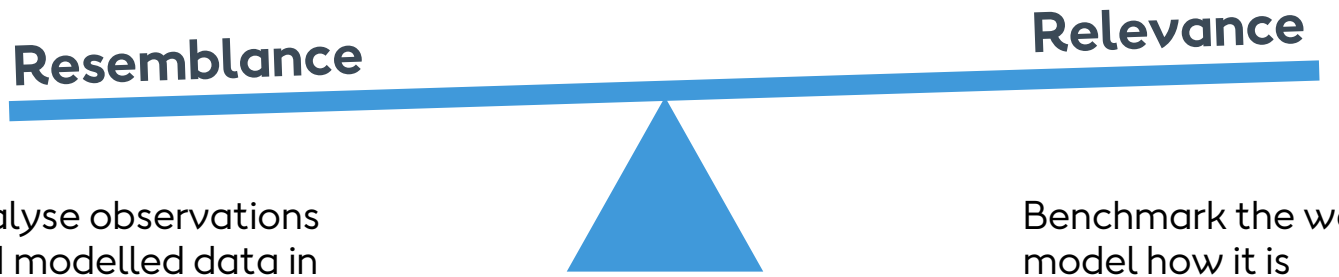
Guiding principles of wake model benchmarking



Analyse observations and modelled data in the same way

Benchmark the wake model how it is intended to be used

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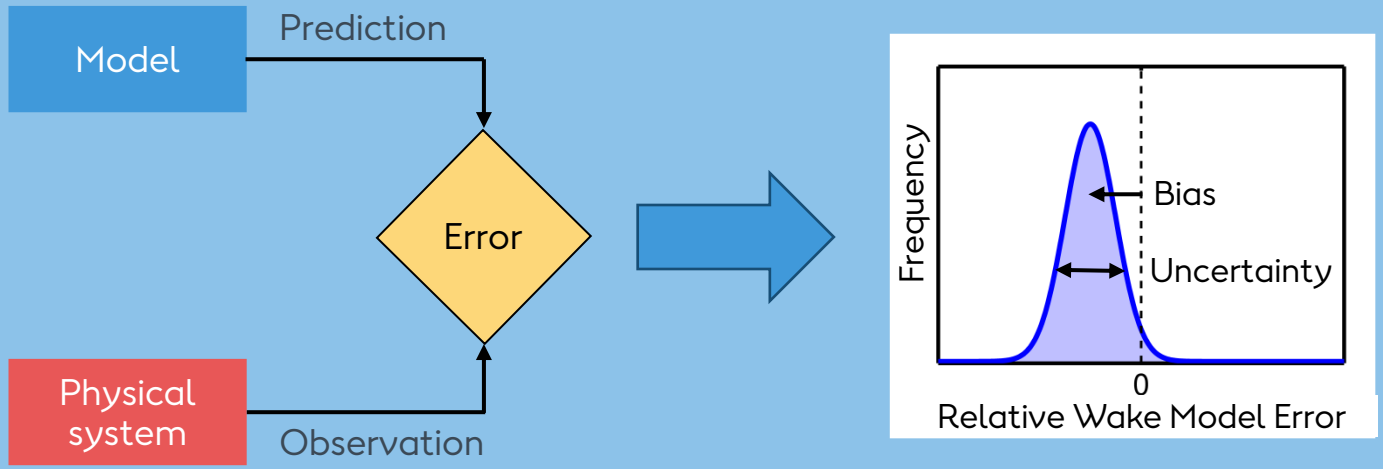
Validation of wake models incl. assessing uncertainty and bias

Time series of observations used to calculate wake model error for full Ørsted asset portfolio

Benchmarking of models

- ❑ We want the distribution of errors for each wind farm for each, incl. bias and uncertainty
- ❑ Wake Model Uncertainty = width of error distribution
- ❑ Wake Model Bias = median wake model error



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Bootstrapping time series

Original time series:

Bootstrap samples:

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Uncertainty – from distribution of model error