Evaluation of the Wind Direction Uncertainty And Its Impact on Wake Modelling at the Horns Rev Offshore Wind Farm

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Aero-elastic Section, Wind Energy Department, DTU, Risø

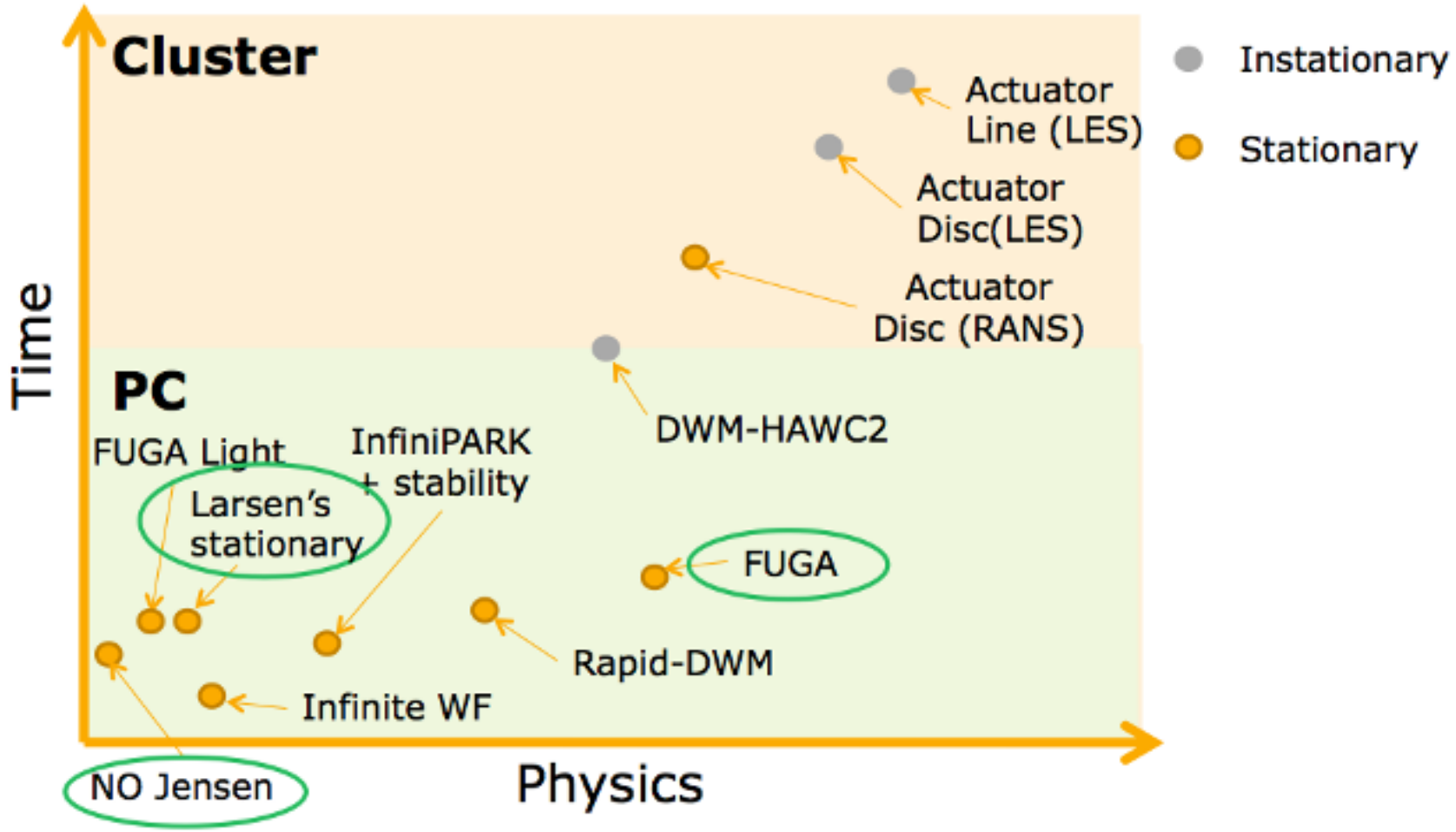
Windpower Monthly's Wind Farm Data Management and Analysis forum
23-25 September

DTU Wind Energy
Aero-Elastic Design Section - Risø

Outline

1. Why Uncertainty Matters?
   - Introduction
   - Method: Modelling the wind direction uncertainty
   - Results
2. Adding Value to Wind Farm Data
   - Machine Learning and Physical Modelling
   - The FUSED-Wind project
   - A Future Business Concept
3. Conclusion and Future Works

Overview of DTU's Wind Farm Flow Models



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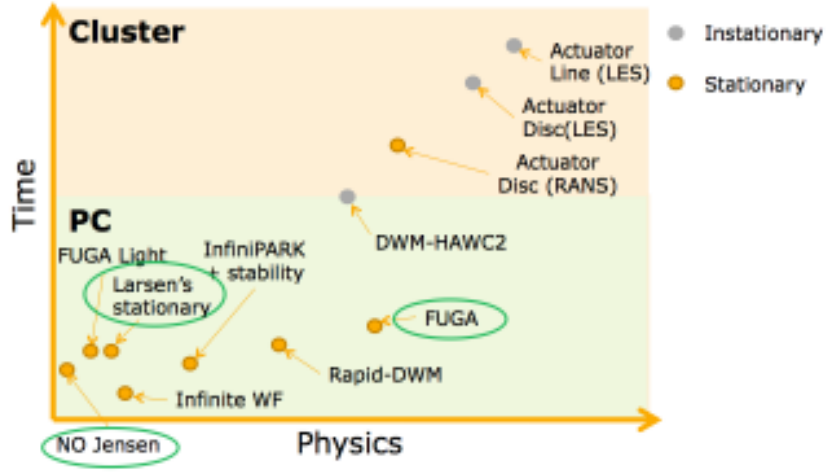
What Are Those Models used for?

- Estimating Annual Energy Production
- Wind Farm Optimization



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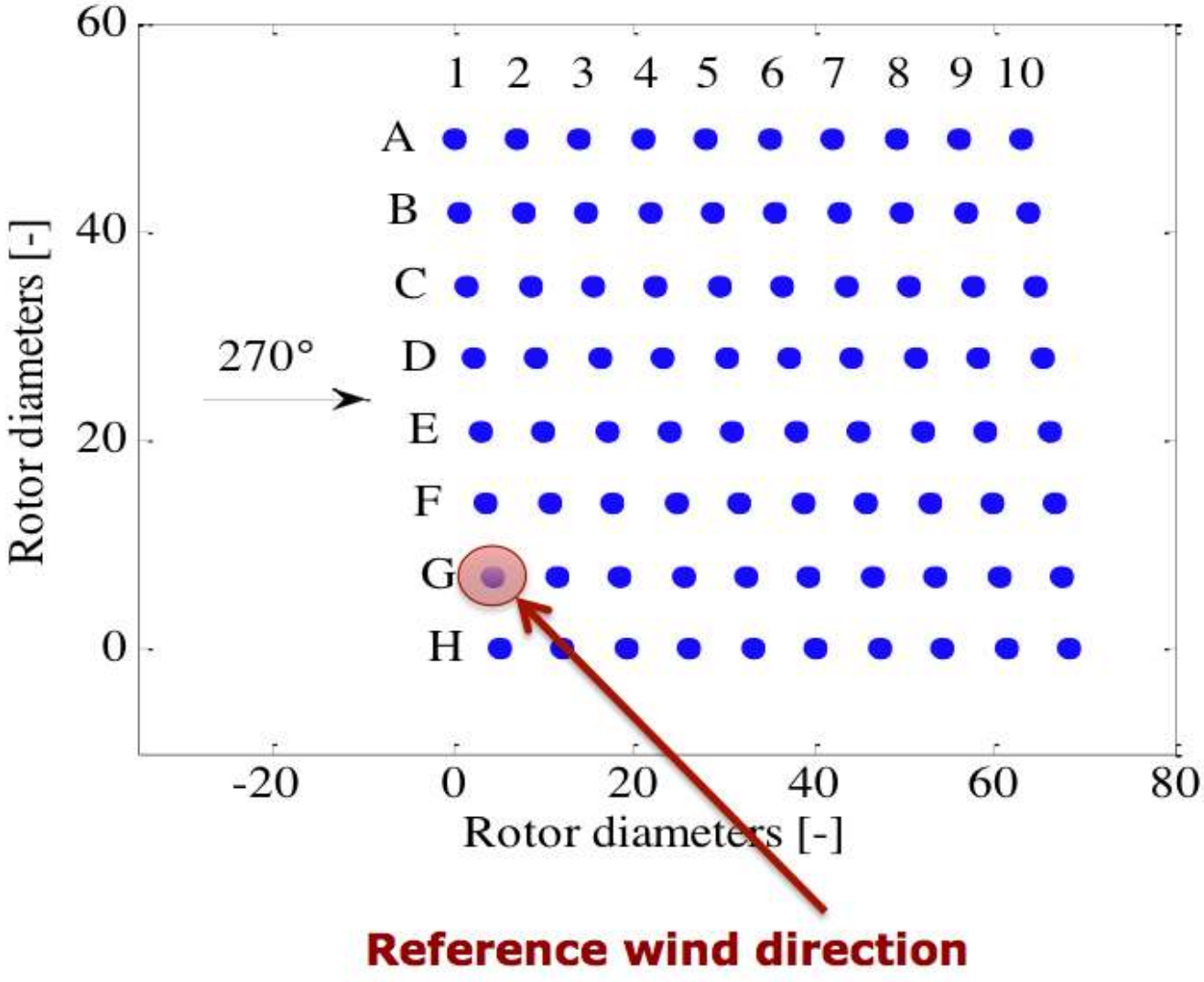
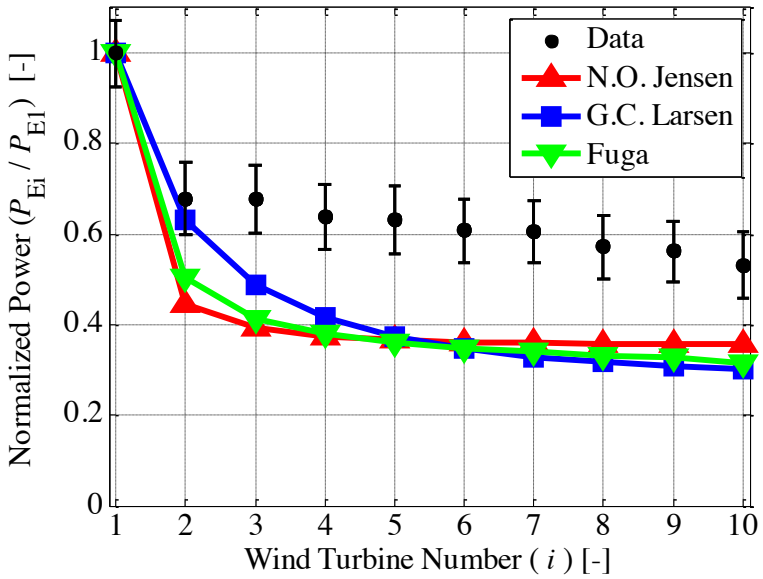
The Horns Rev test case - Western winds

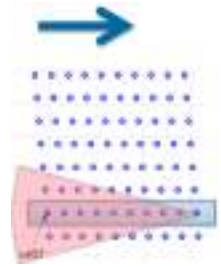


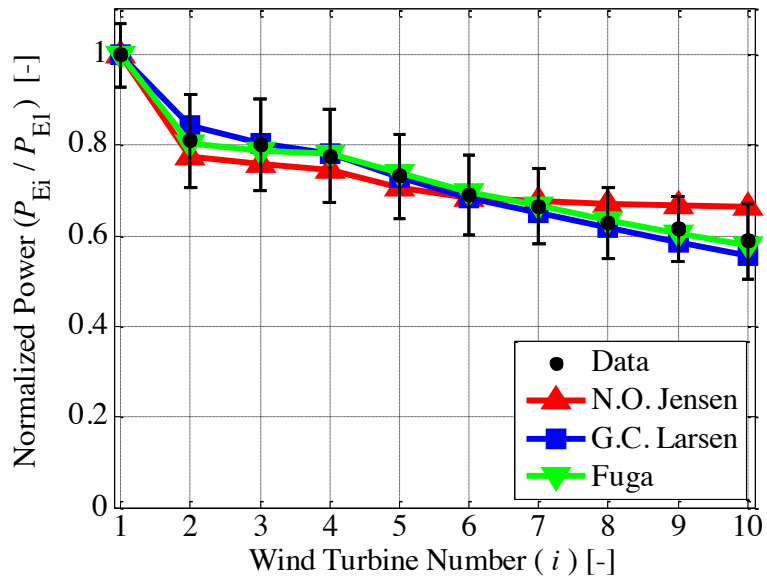
Results of the Wake Model Benchmarking: Confusion!

270° ± 2.5°

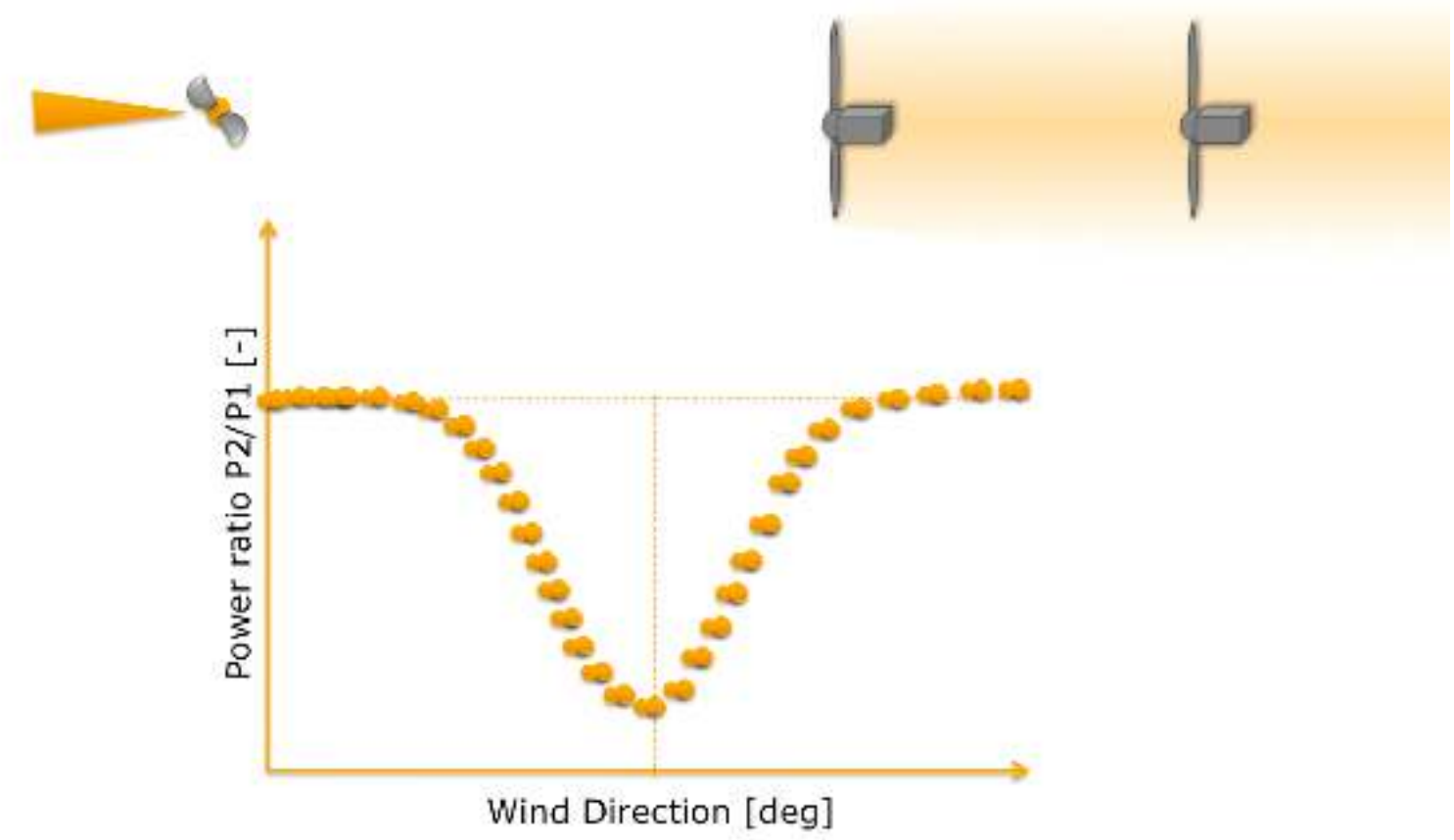


270° ± 15°





The effect of wind direction uncertainty on wind farm wake measurement



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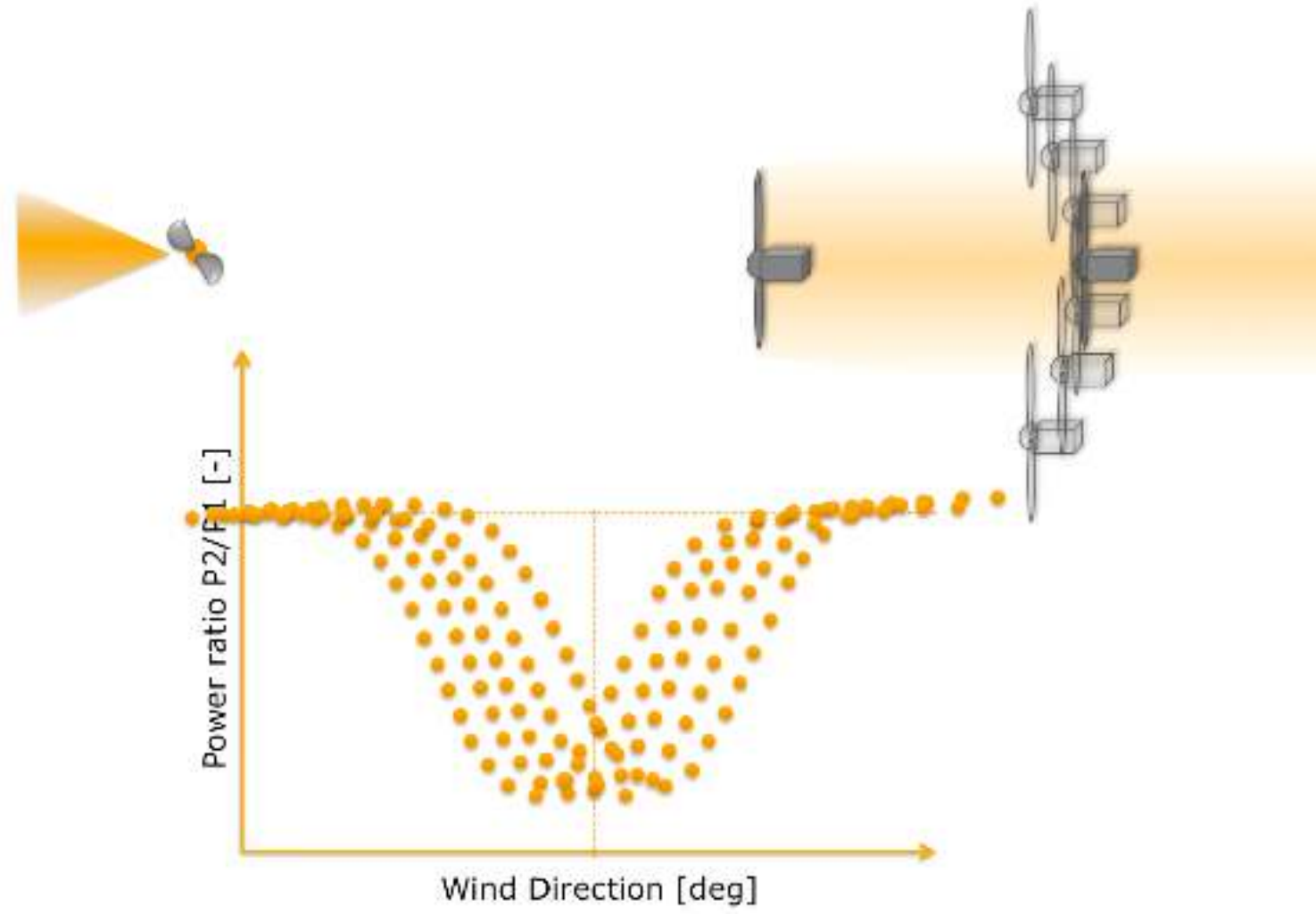

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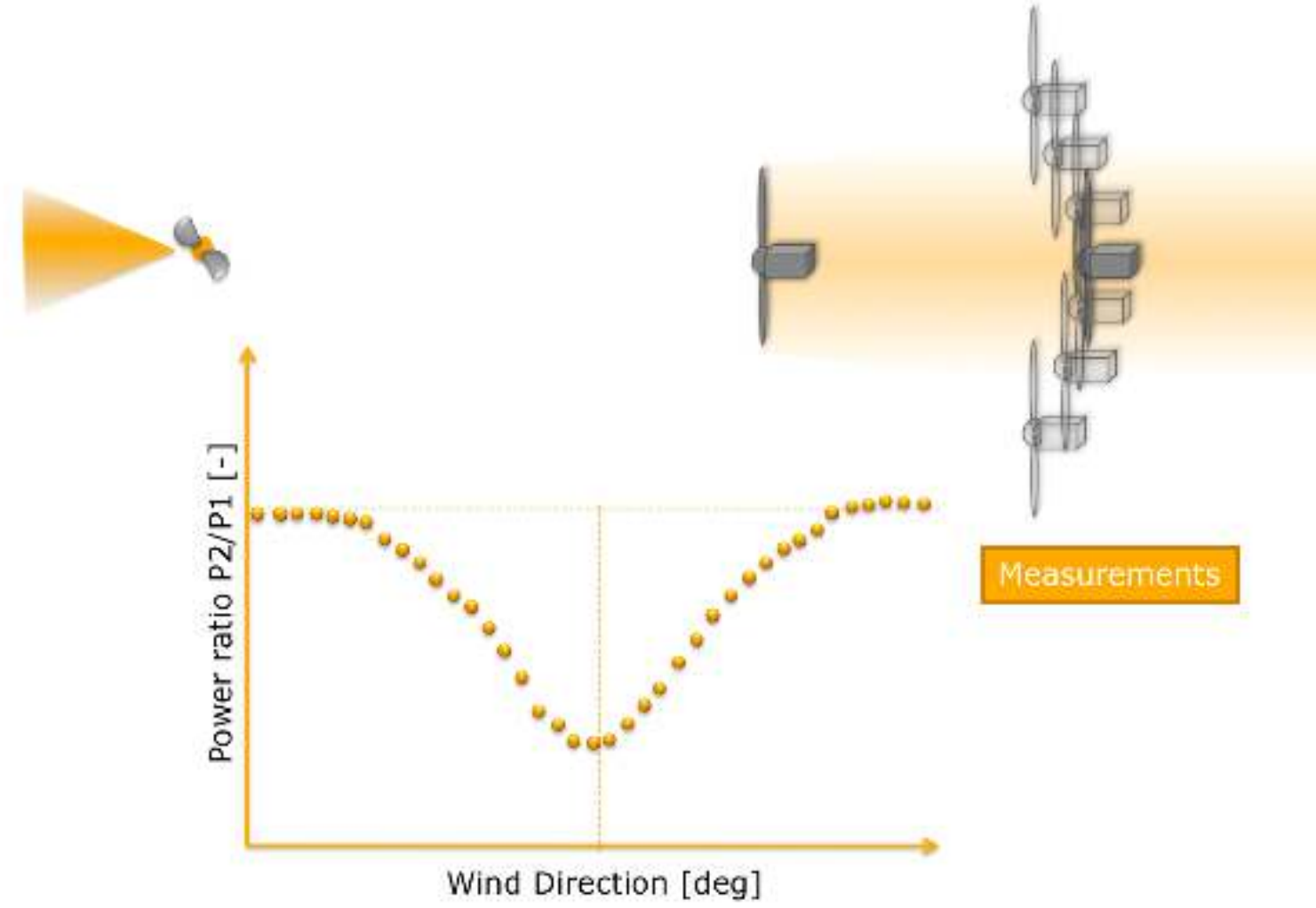

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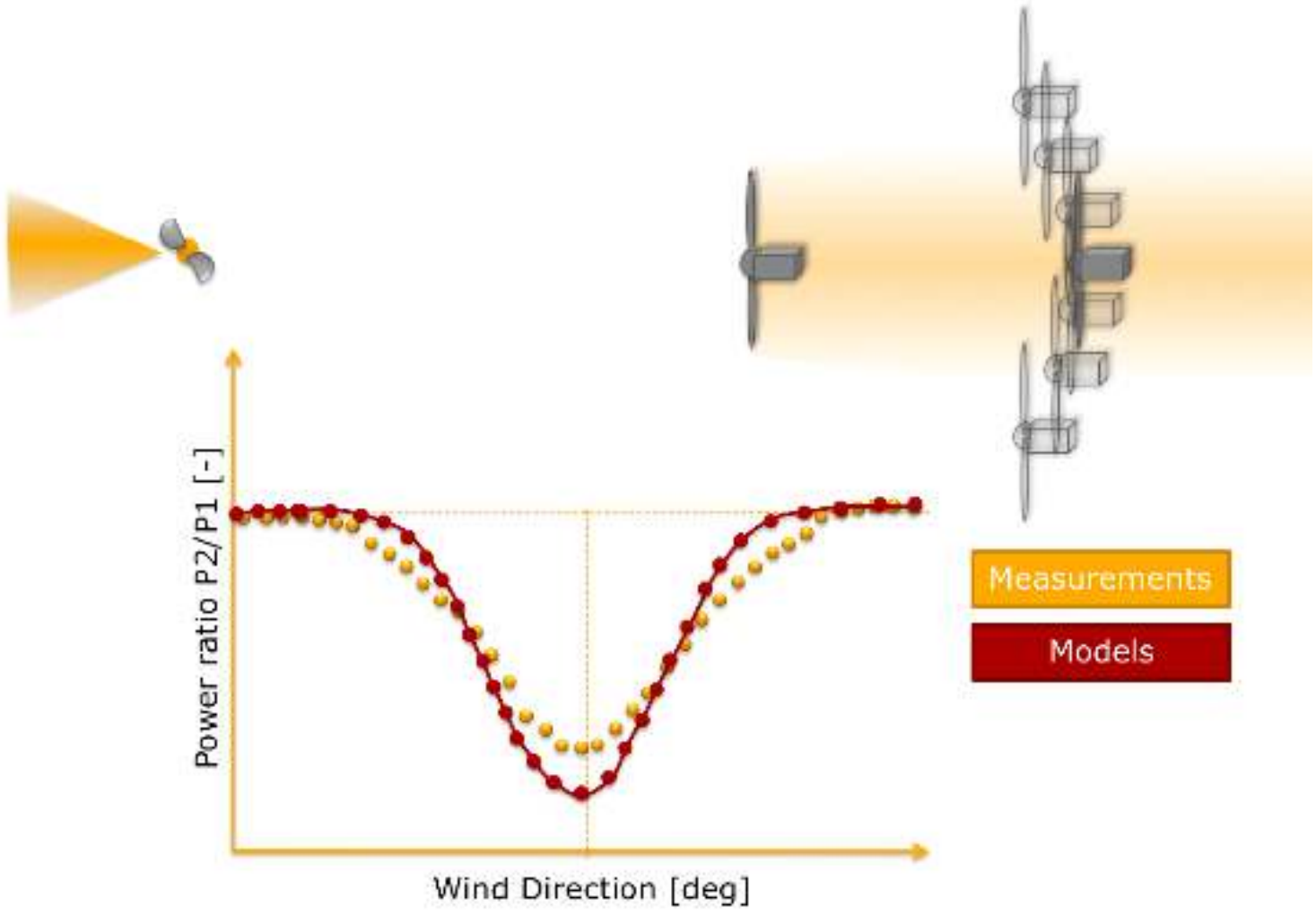

Sources of wind direction uncertainty

Random/temporal bias from the measurement device

- Yaw misalignment (when yaw sensor is used to measure direction)
- Time drift of the calibration
- Failures

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Atmospheric turbulence

- Small scale turbulence (sub 10-minute)
  -> This *should* be accounted by the models
- Large scale turbulence (i.e. wind directional trends, over 10-minute)

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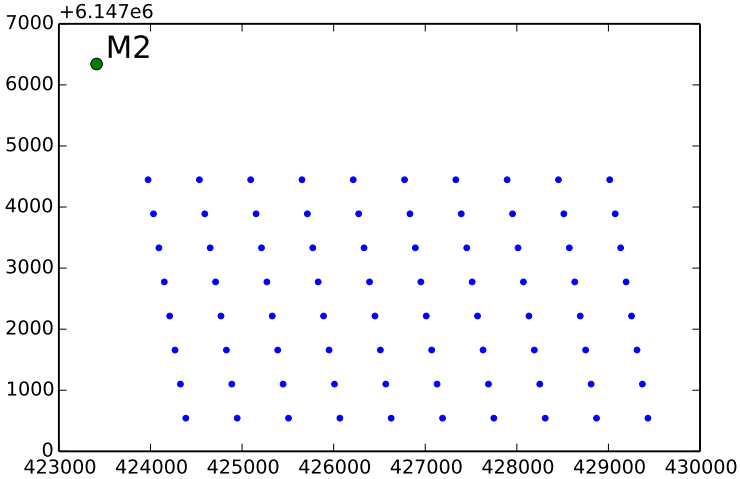
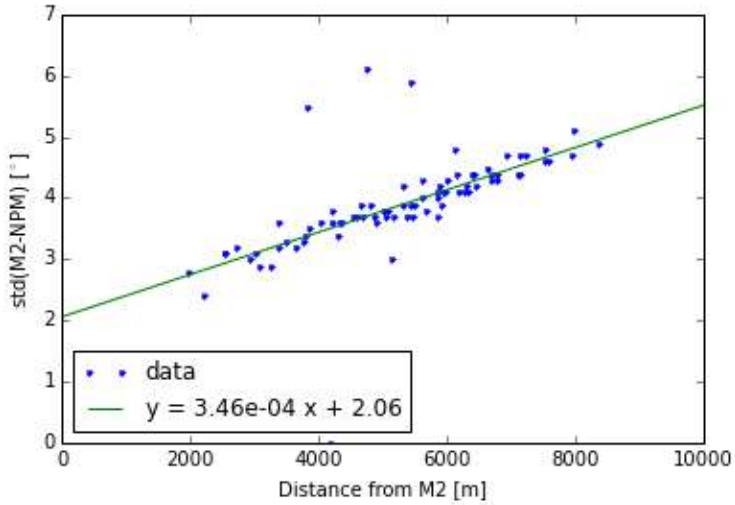
Wind direction coherence

- Spatial variability of the wind direction
- Different time-control volume averaging

Spatial decorrelation of wind direction

The wind direction correlation between M2 and the wind turbines decreases linearly with the distance





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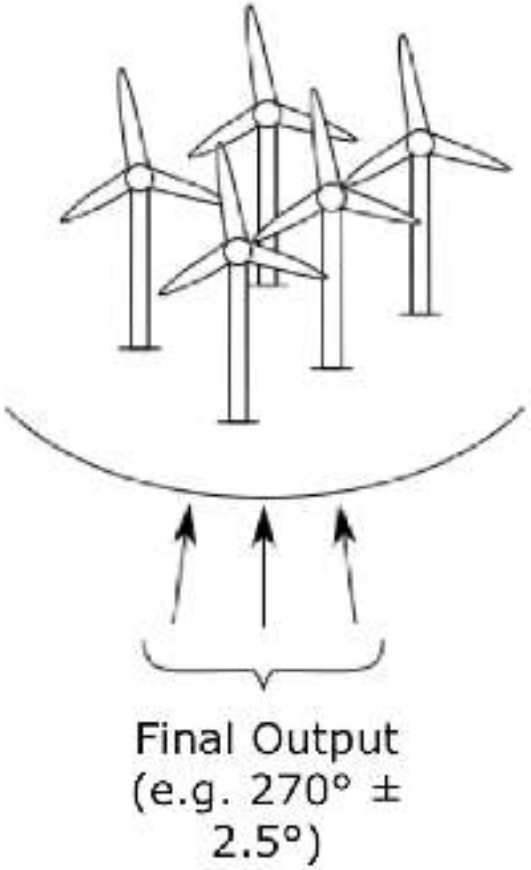
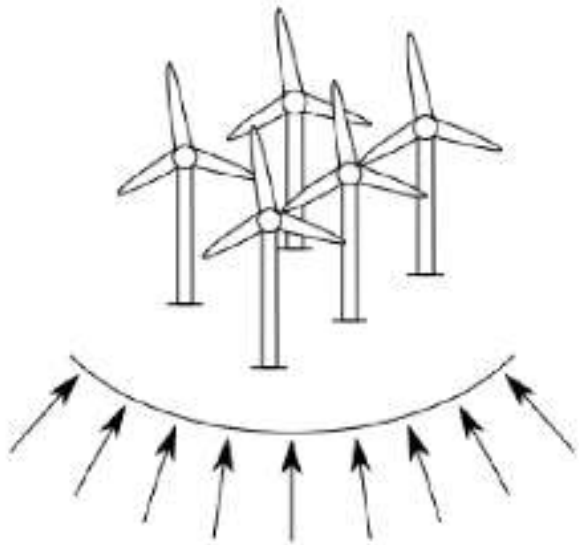
The "traditional" method

- Step 1: Run simulations with fixed and homogeneous wind direction covering the desired wind direction sector
- Step 2: Apply a linear average to reproduce the data post-processing



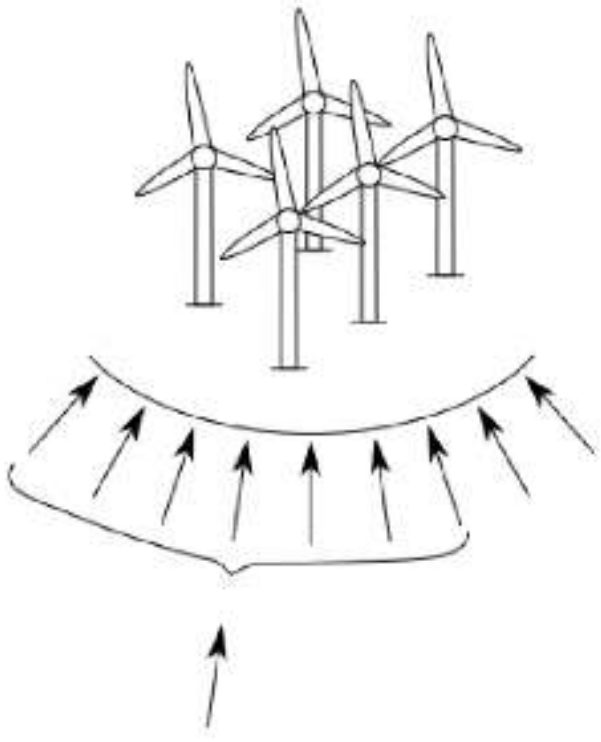
The proposed method

- Step 1: Run simulations with fixed and homogeneous wind direction



The proposed method

- Step 1: Run simulations with fixed and homogeneous wind direction
- Step 2: Apply a weighted average based on the probability function of a normal distribution on the interval $\pm 3\sigma$



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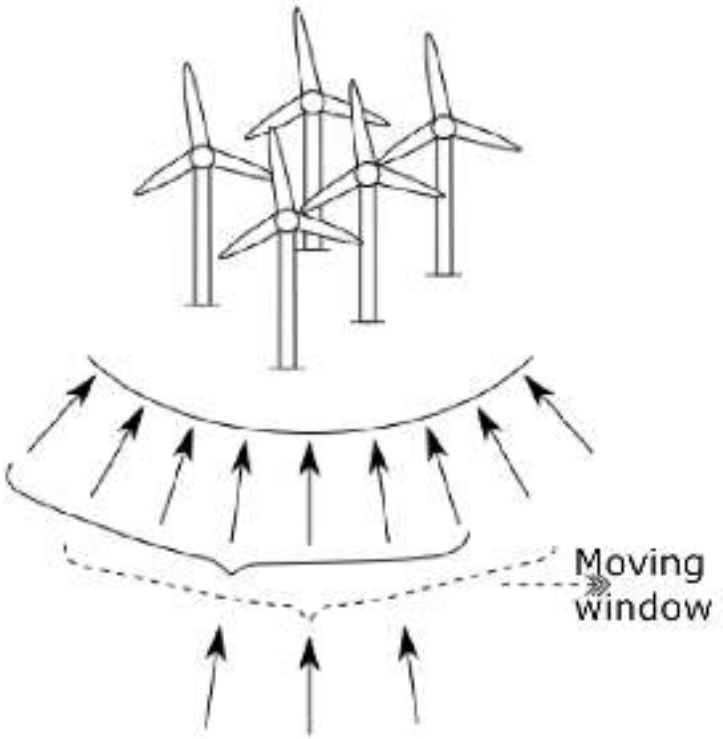

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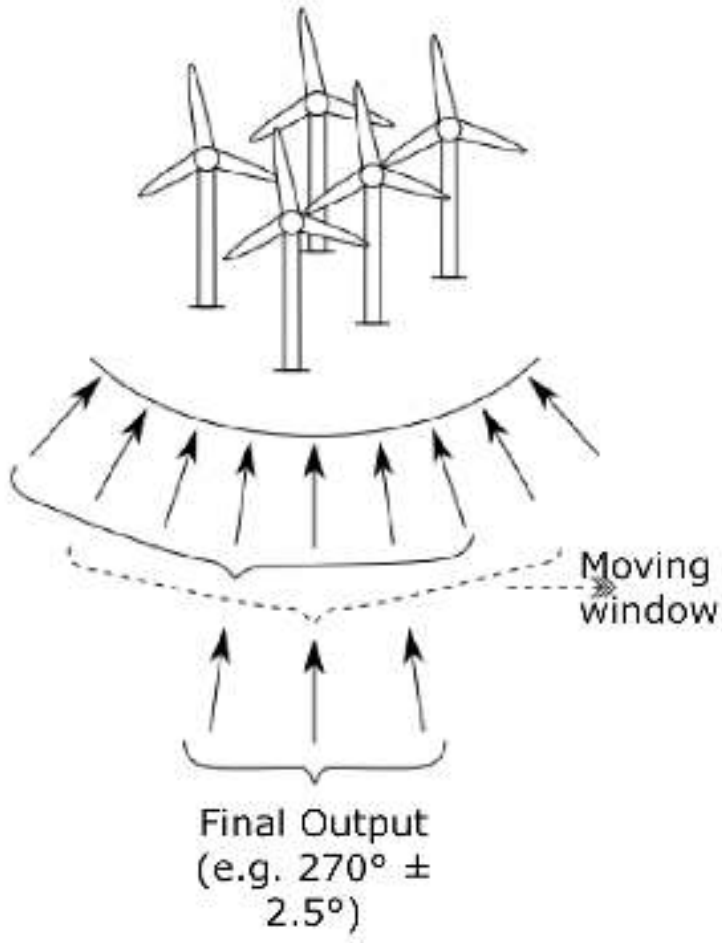
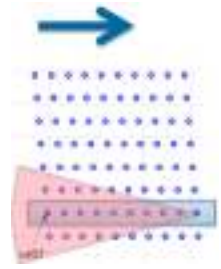
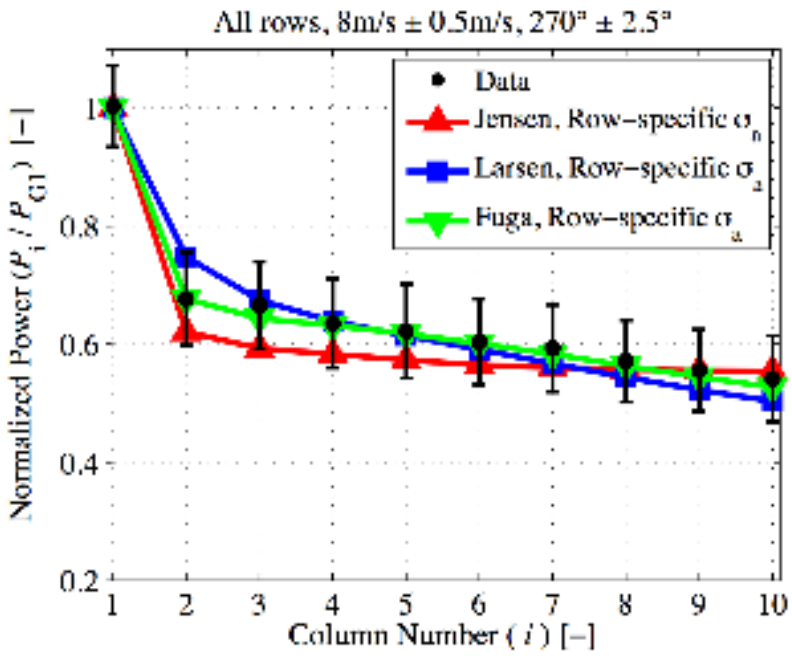


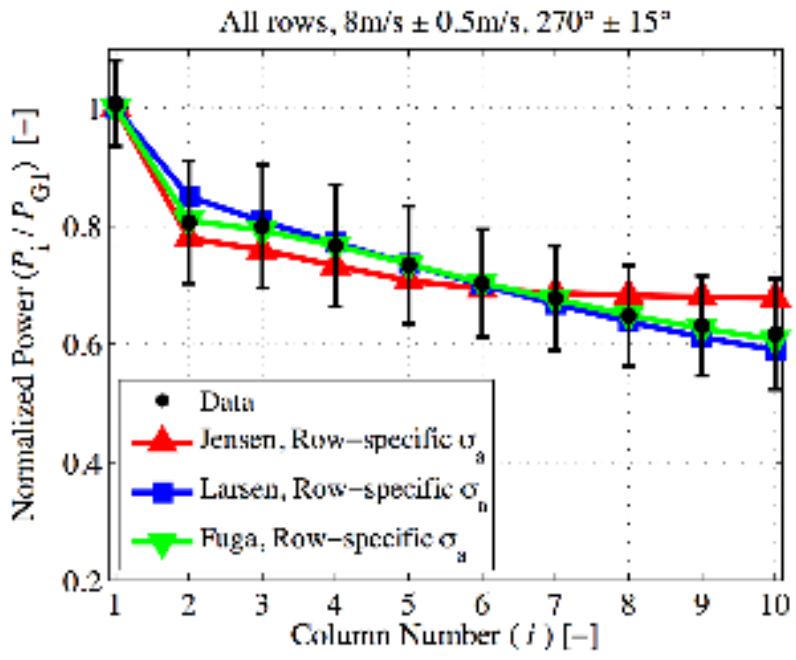
All the rows, using a row-specific wind direction uncertainty

270° ± 2.5°

270° ± 15°







Result for the whole wind farm in $\theta = 270°$

	270 ± 2.5°	270 ± 15°
Power Data	64.7%	73.9%
NOJ, Baseline	-20.9%	+0.4%
GCL, Baseline	-20.9%	-0.1%
Fuga, Baseline	-21.7%	-0.3%

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NOJ, σ=3.5°	-11.6%	+0.0%
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NOJ, row-specific	-3.1%	+0.1%
GCL, row-specific	-0.7%	-0.2%
Fuga, row-specific	-0.8%	-0.2%

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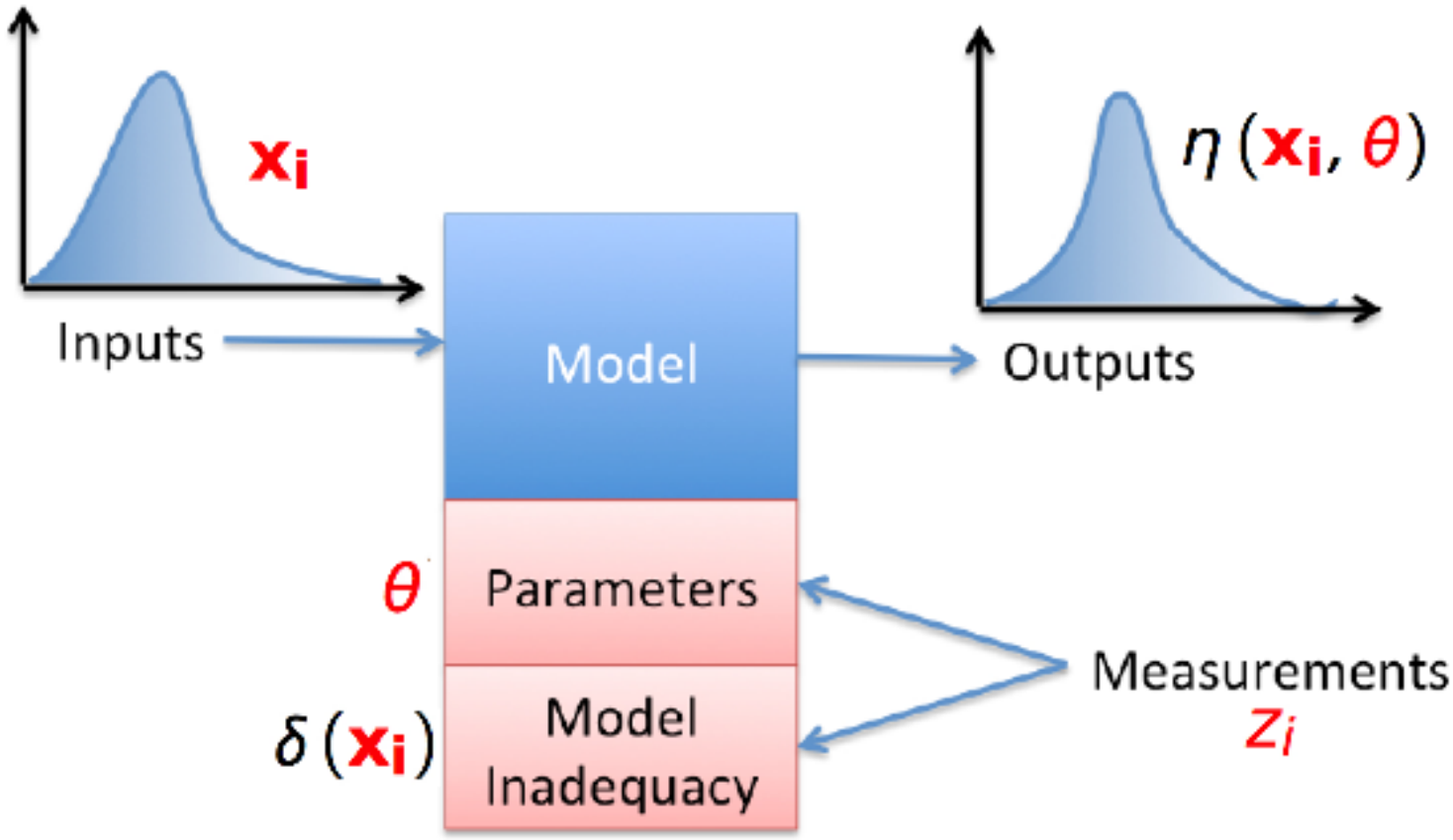
From Deterministic to Stochastic

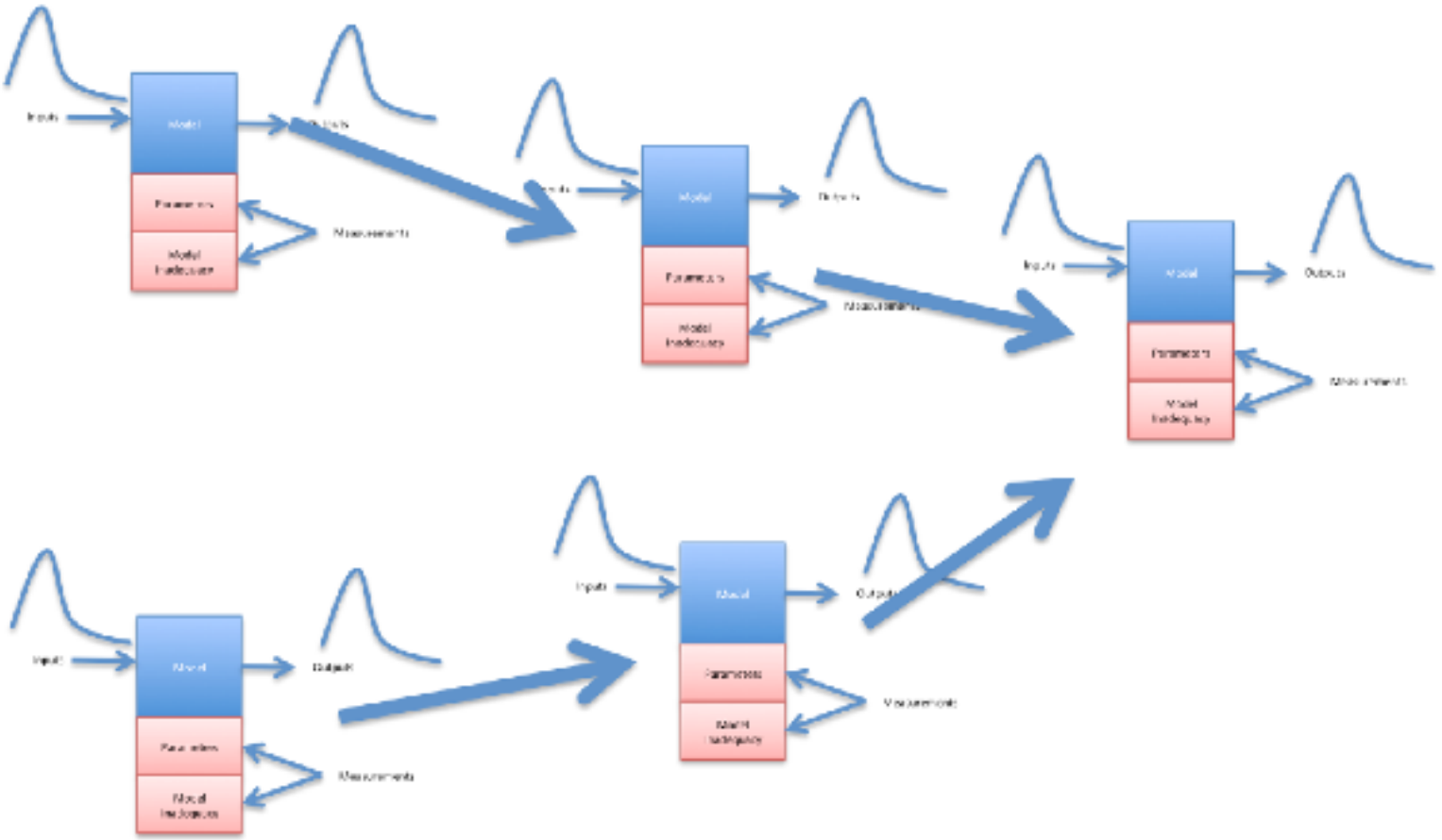
$$\zeta_i(\mathbf{x_i}) = \eta(\mathbf{x_i}) \tag{1}$$

From Deterministic to Stochastic

$$z_i = \zeta_i(\mathbf{x_i}) + \varepsilon_i = \eta(\mathbf{x_i}, \theta) + \delta(\mathbf{x_i}) + \varepsilon_i \quad (2)$$



System Engineering



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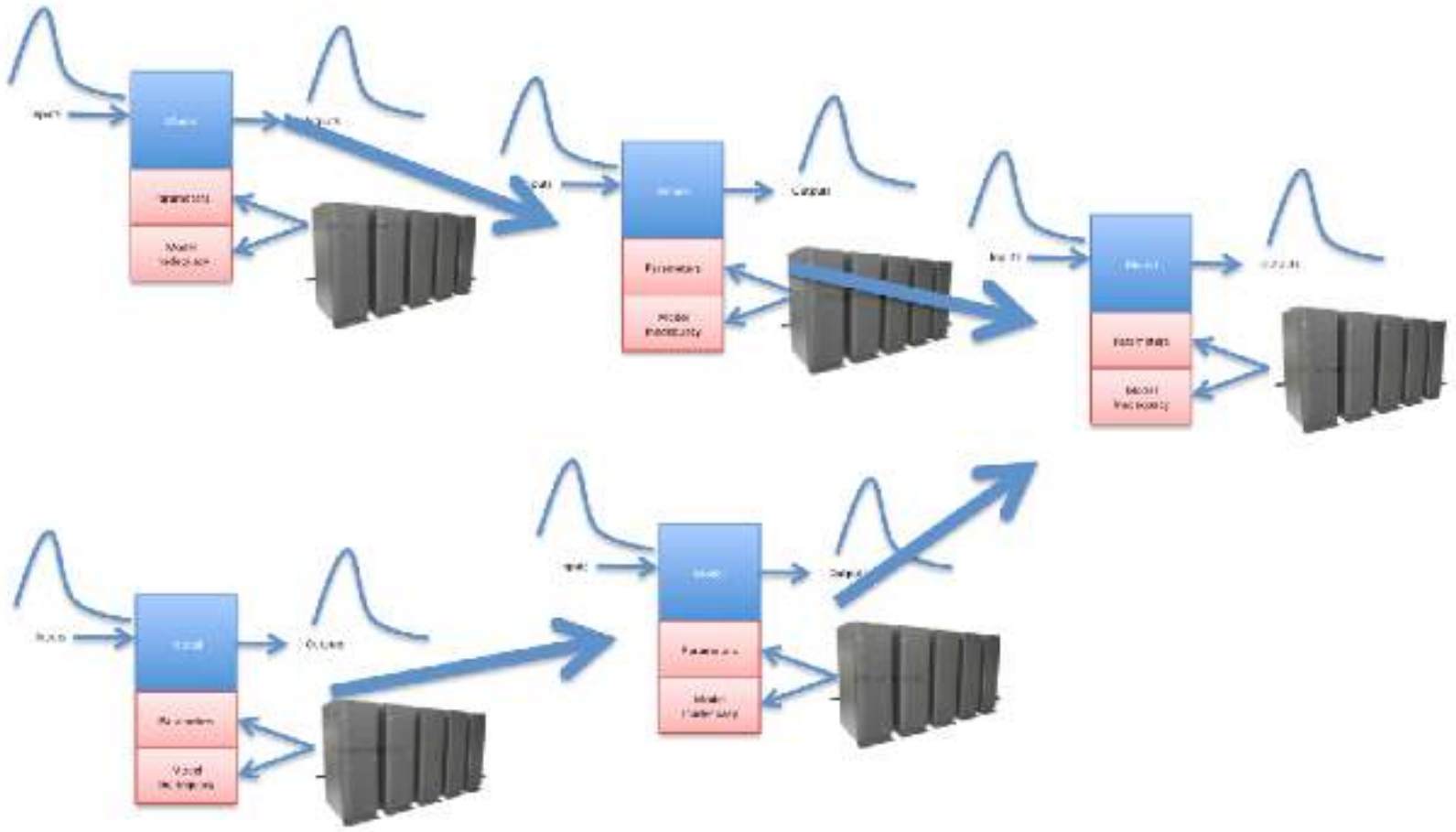
System Engineering - Big Data



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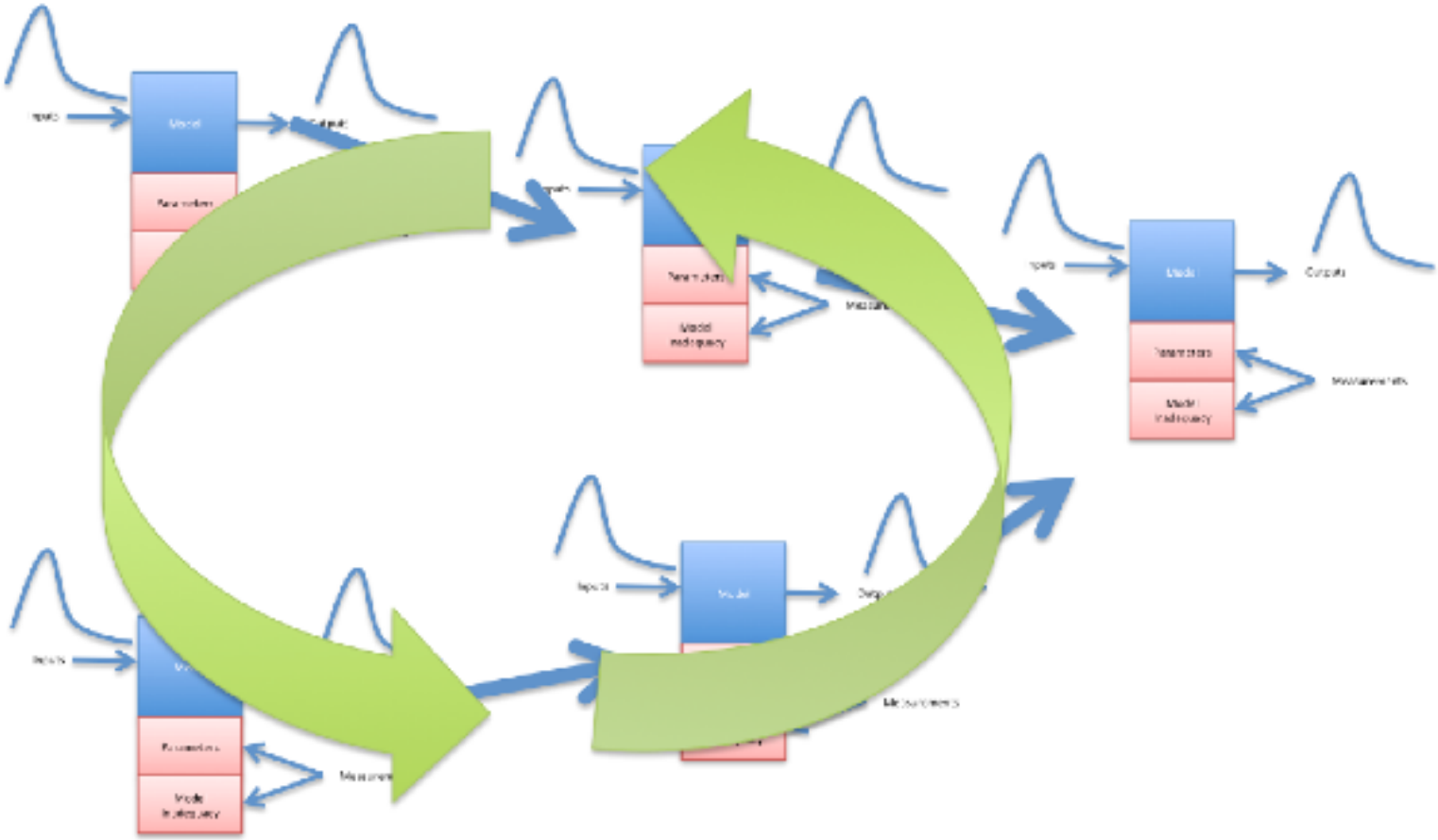
System Engineering - Augmented Intelligence



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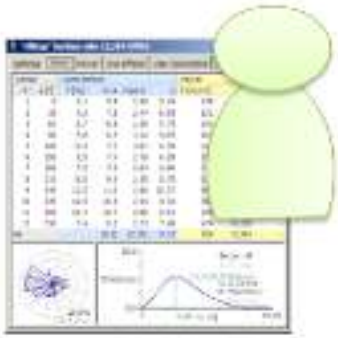
Connecting All Wind Energy Models in a Worflow

- Collaborative effort between DTU and NREL to create a **F**ramework for **U**nified **S**ystem **E**ngineering and **D**esigned of **Wind** energy plants.
- Based on OpenMDAO, a python based Open source framework for **M**ulti-**D**isciplinary **A**nalysis and **O**ptimization.
- FUSED-Wind will offer built in capabilities for Uncertainty Quantification, Machine Learning and Optimization

A Future Business Concept

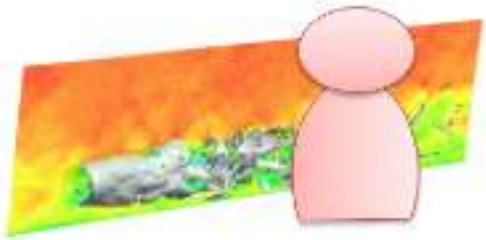
Concept



WAsP
SmartWake client

Cloud Cluster
SmartWake Server

Wind farm SCADA owners



Wake Modelers

A Future Business Concept

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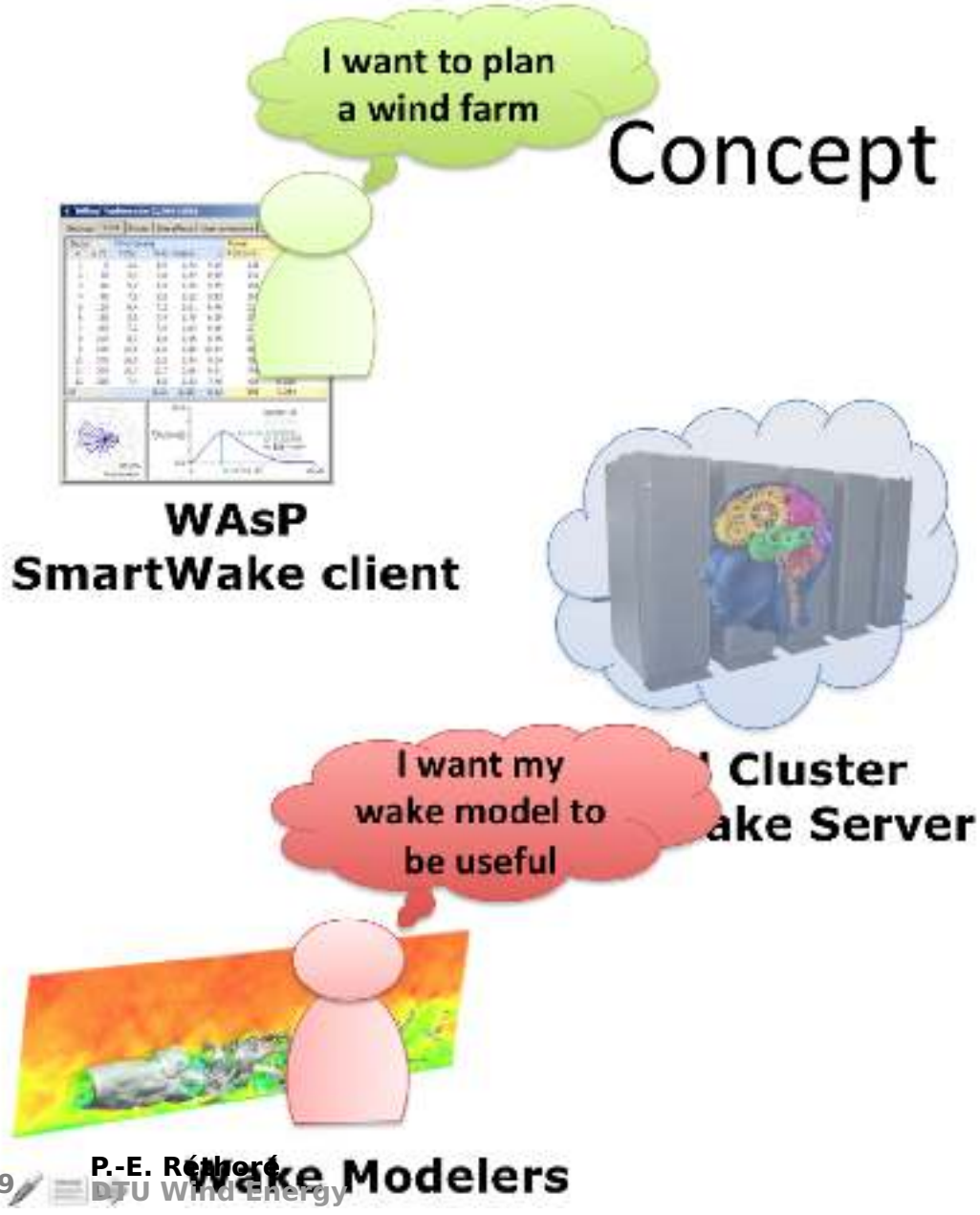

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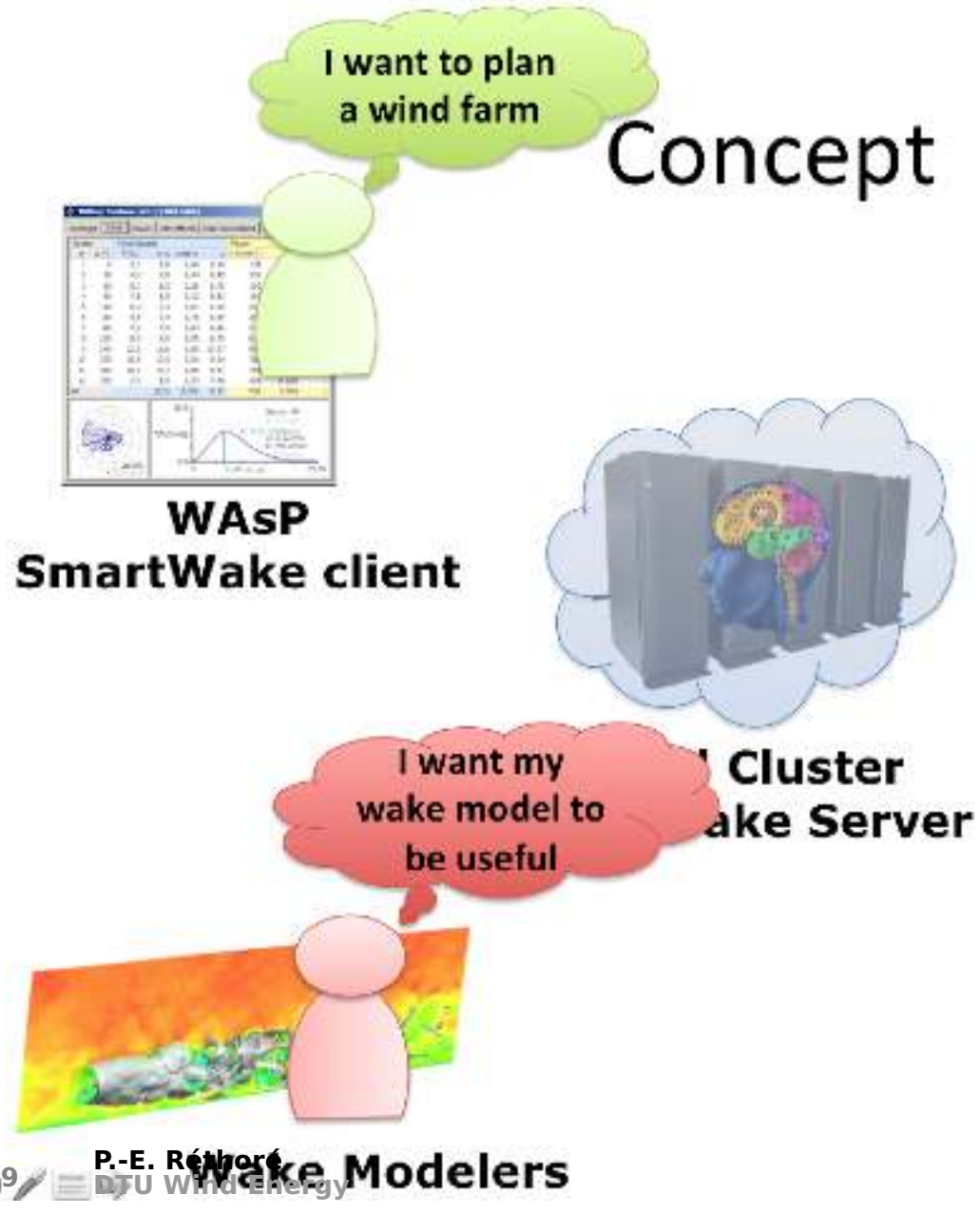

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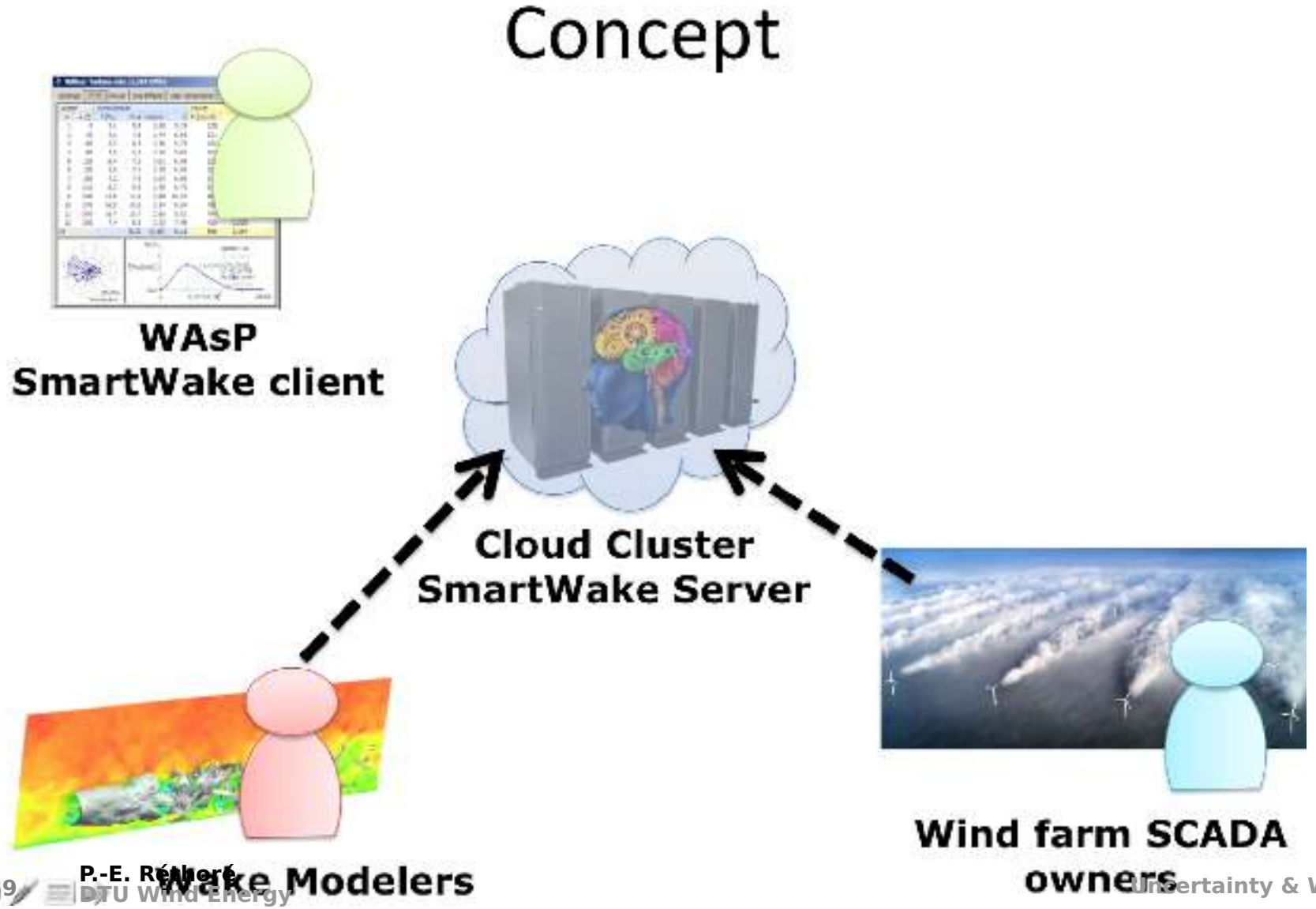

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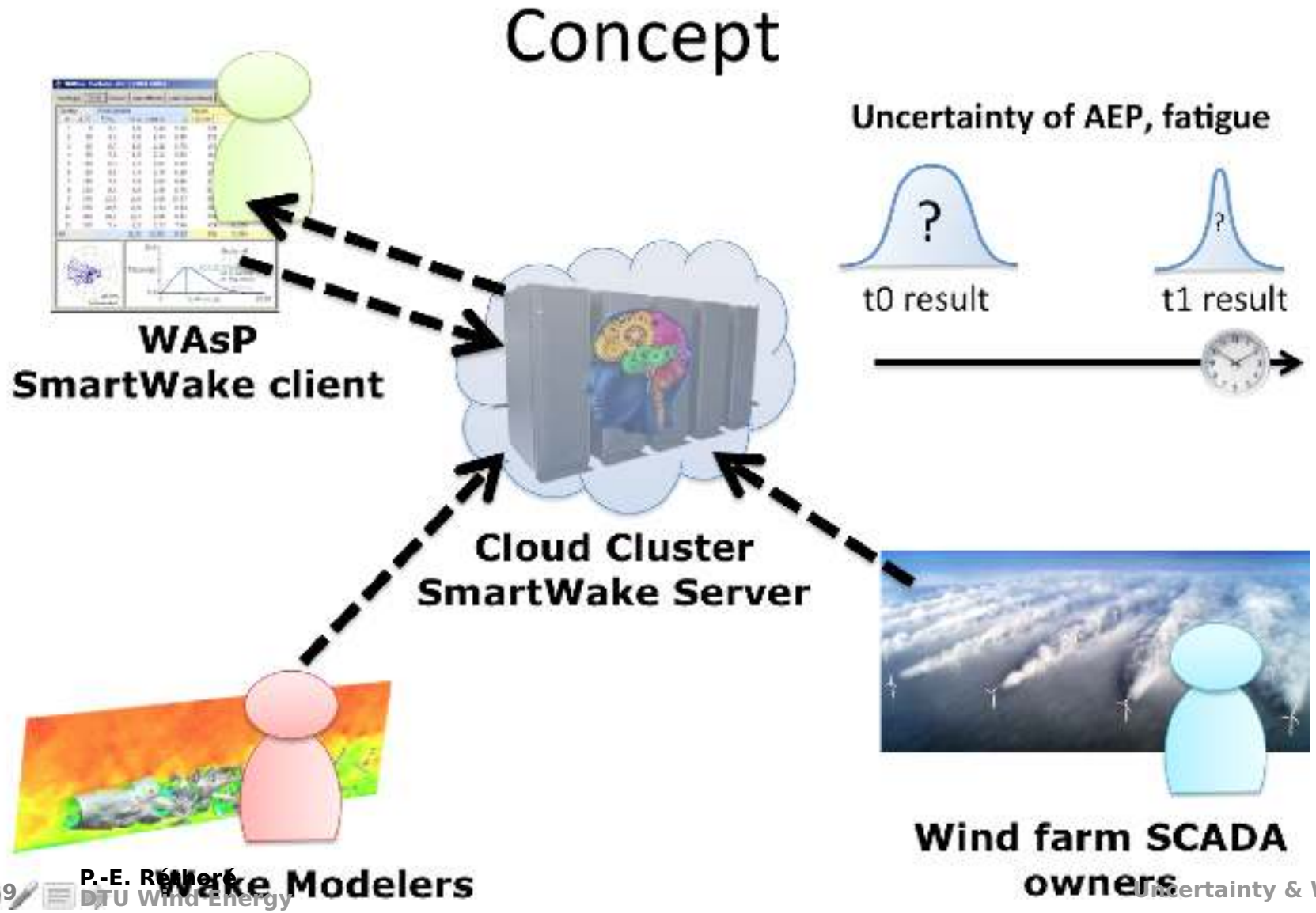

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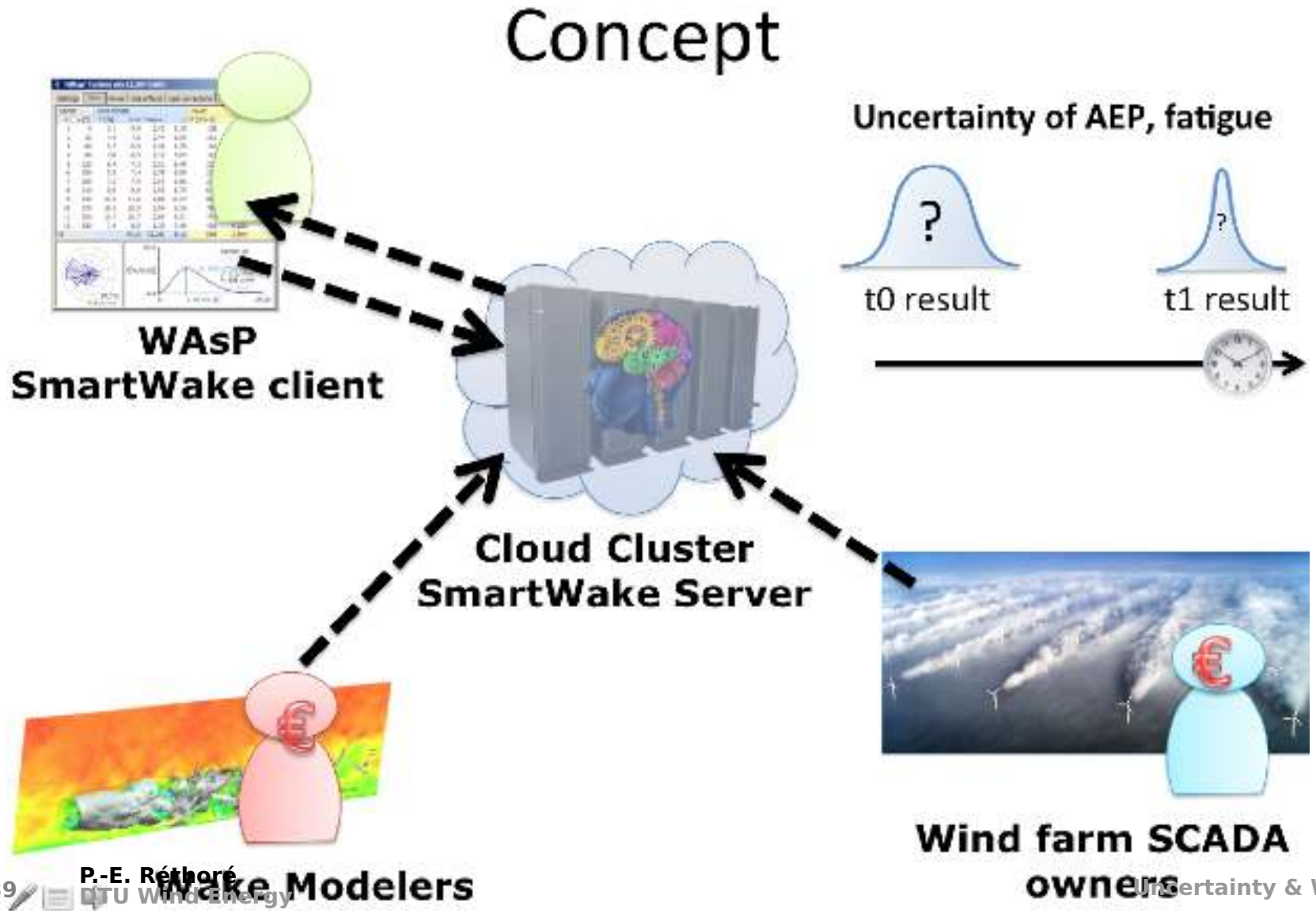

Conclusion

- The N.O. Jensen model, the G.C. Larsen model and Fuga are robust engineering models able to provide accurate predictions using wind direction sectors of 30°
- The discrepancies for narrow wind direction sectors are not caused by a fundamental inaccuracy of the current wake models, but rather by a large wind direction uncertainty included in the dataset
- We need some models and measurements for wind direction uncertainty to move forwards from this stage
- Do not "tune" your wake models to match the ±2.5° measurements!!!

Future work

Wind Farm Flow Model Uncertainty

- The method will be applied to other wake models and datasets
- Sample based uncertainty quantification to be investigated
- Work on estimating the wind direction uncertainty using the wind farm dataset

System Engineering

- Opening FUSED-Wind to the public
- Adding Uncertainty Quantification to FUSED-Wind

Thank you for your attention!

- Work funded by EUDP-WakeBench and EERA-DTOC
- Dataset graciously made available by DONG Energy and Vattenfall.
- Article submitted to wind energy and master thesis available on request