Presentación en Wind Energy Science Conference, 2019

Computation of the available power of a down-regulated wind farm through a Markov Chain Monte Carlo approach

Autores: Patricia Cobelli, Bruno López, Andrés Guggeri, Rodrigo Alonso, Álvaro Díaz, Martín Draper, Gabriel Usera

Mayo 2019

Proyecto: Aporte de reserva rotante a través de parques eólicos.

Agencia Nacional de Investigación e Innovación

Fondo Sectorial de Energía, 2017

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Wind Energy Science Conference 2019

Computation of the available power of a down-regulated wind farm through a Markov Chain Monte Carlo approach

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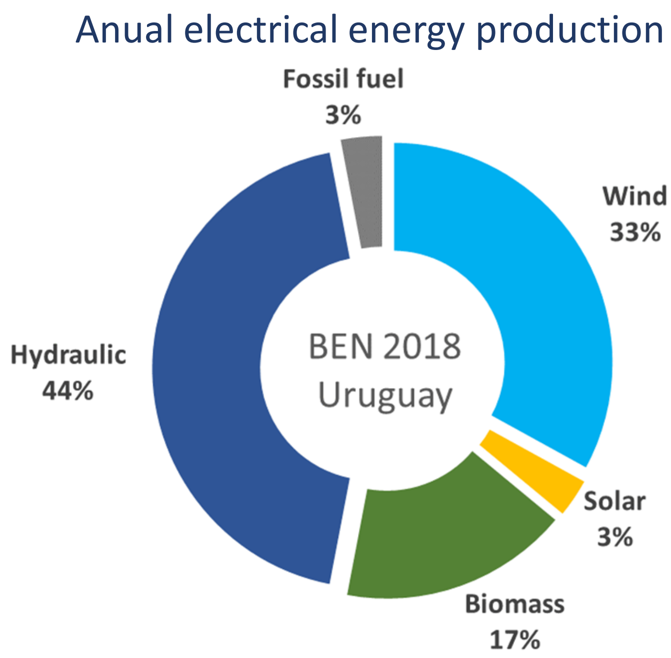
imfia

MFC

Motivation

- Wind energy production rapidly increasing participation in electrical market share.

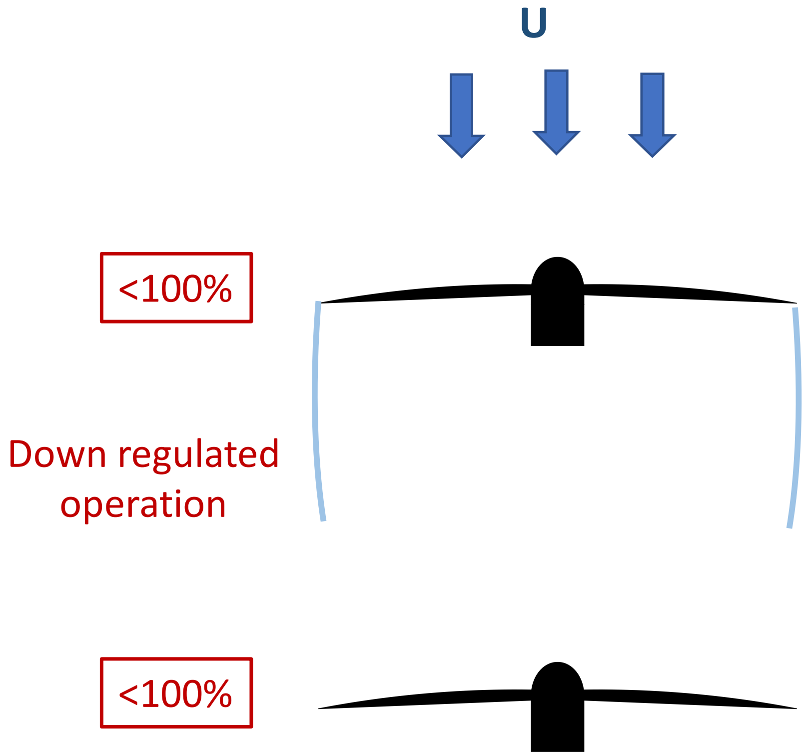
- Challenges to Transmission System Operator
  - Increase electrical power fluctuations
  - Ancillary services to power grid
    - Down-regulated operation (APC)
    - Power reserve



Outline

- Methodology
- Validation
- Results
- Conclusions and future work

Methodology I scheme



"Possible power of down-regulated offshore wind power plants: The PossPOW algorithm". Göçmen, T. et al. (2018)

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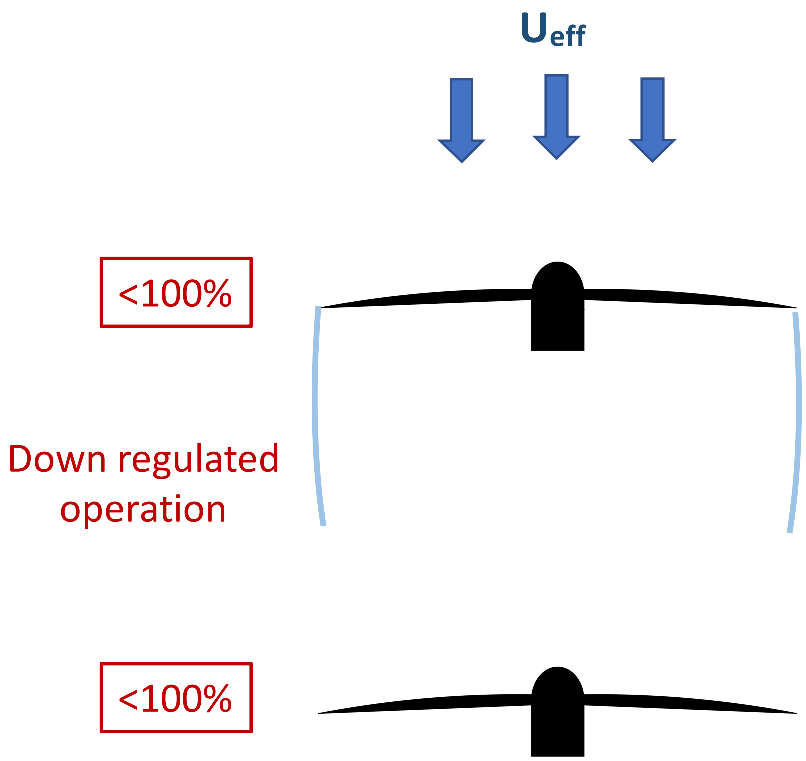

U_{eff} computation

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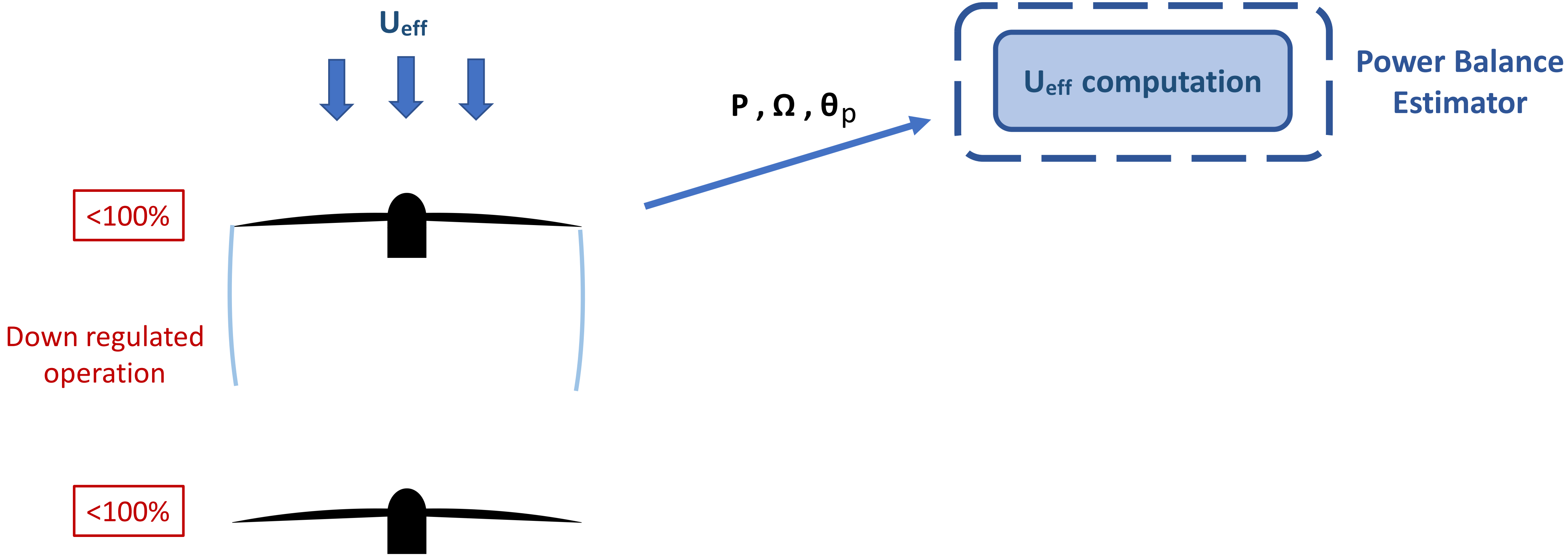

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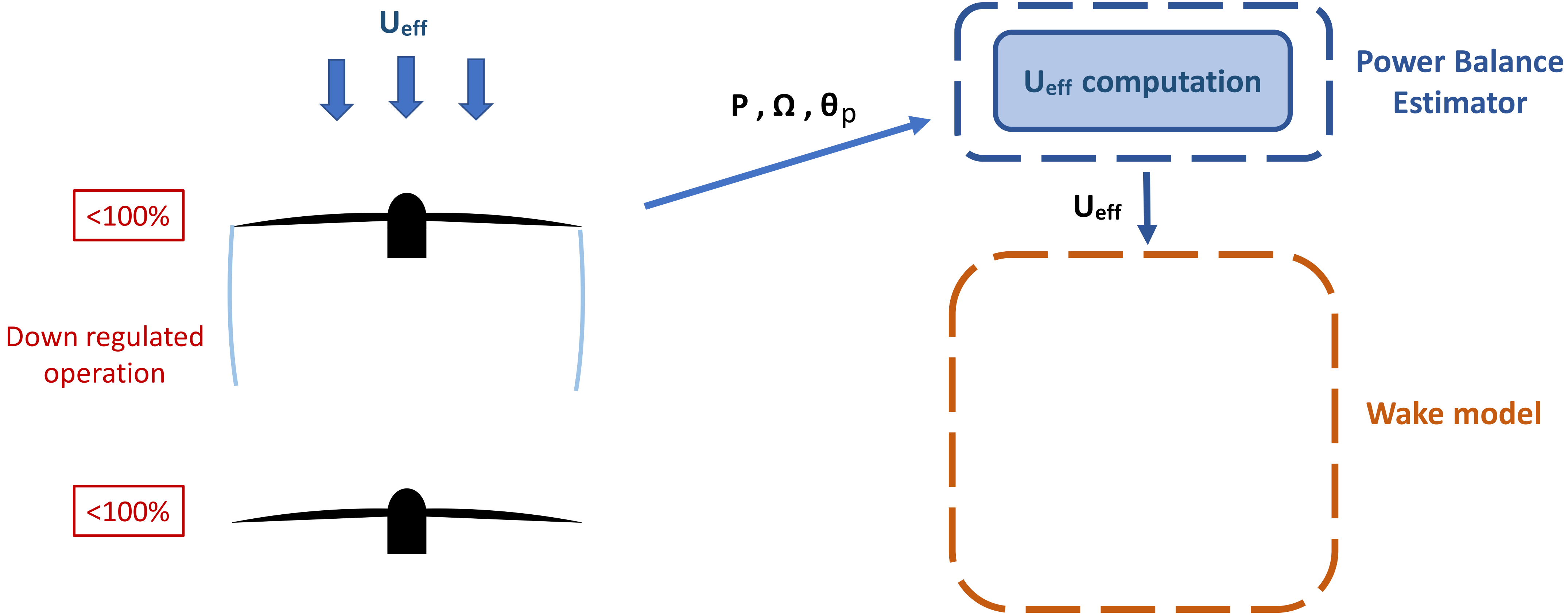

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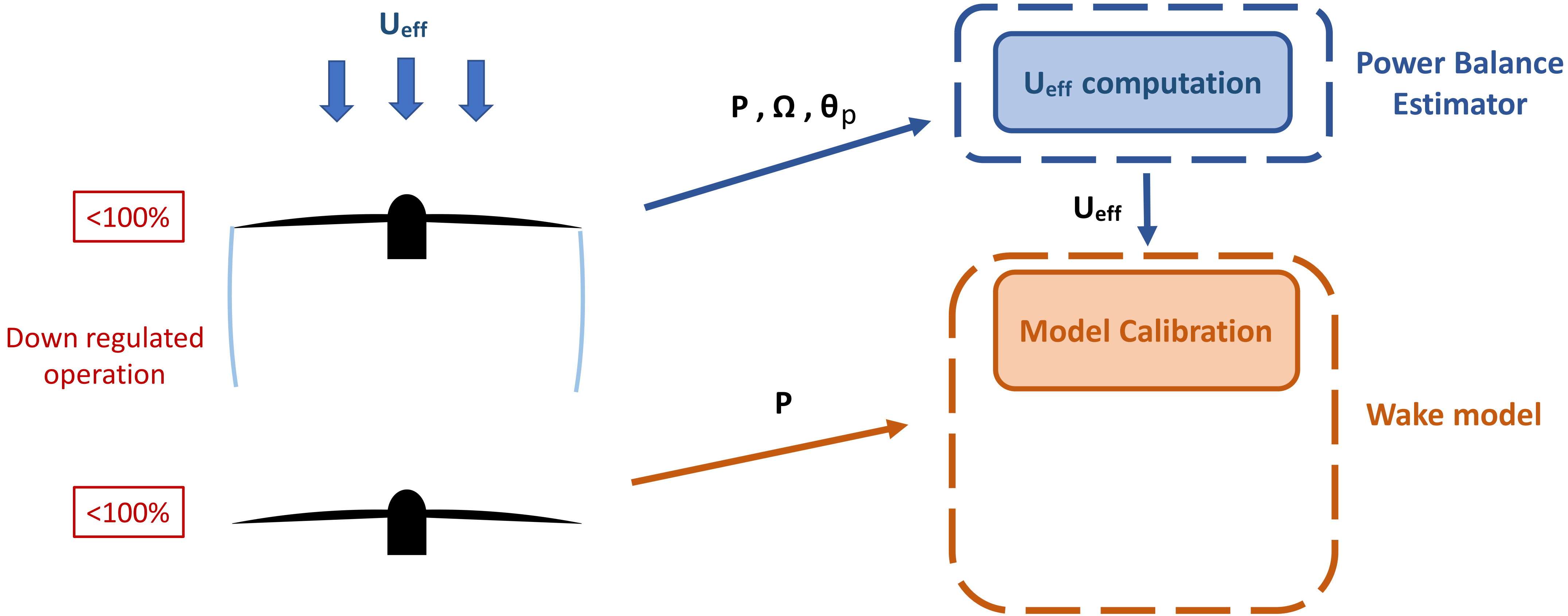

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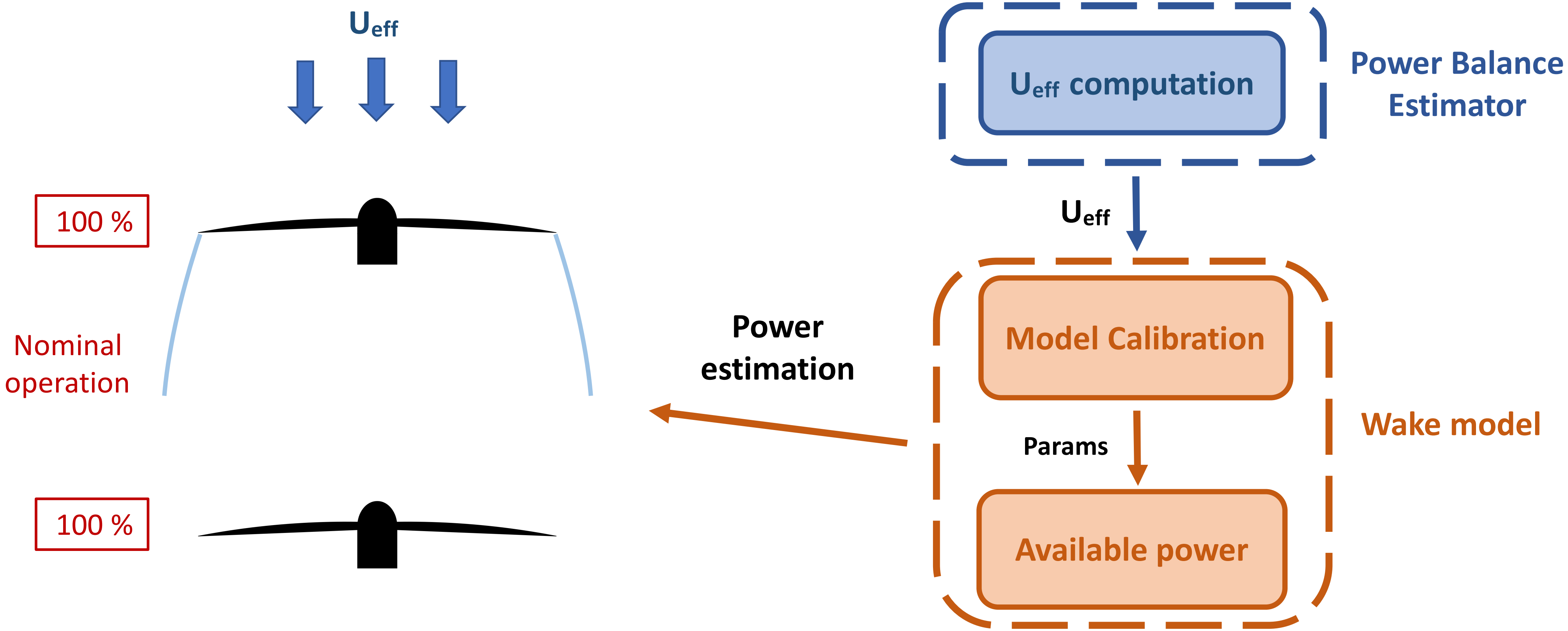

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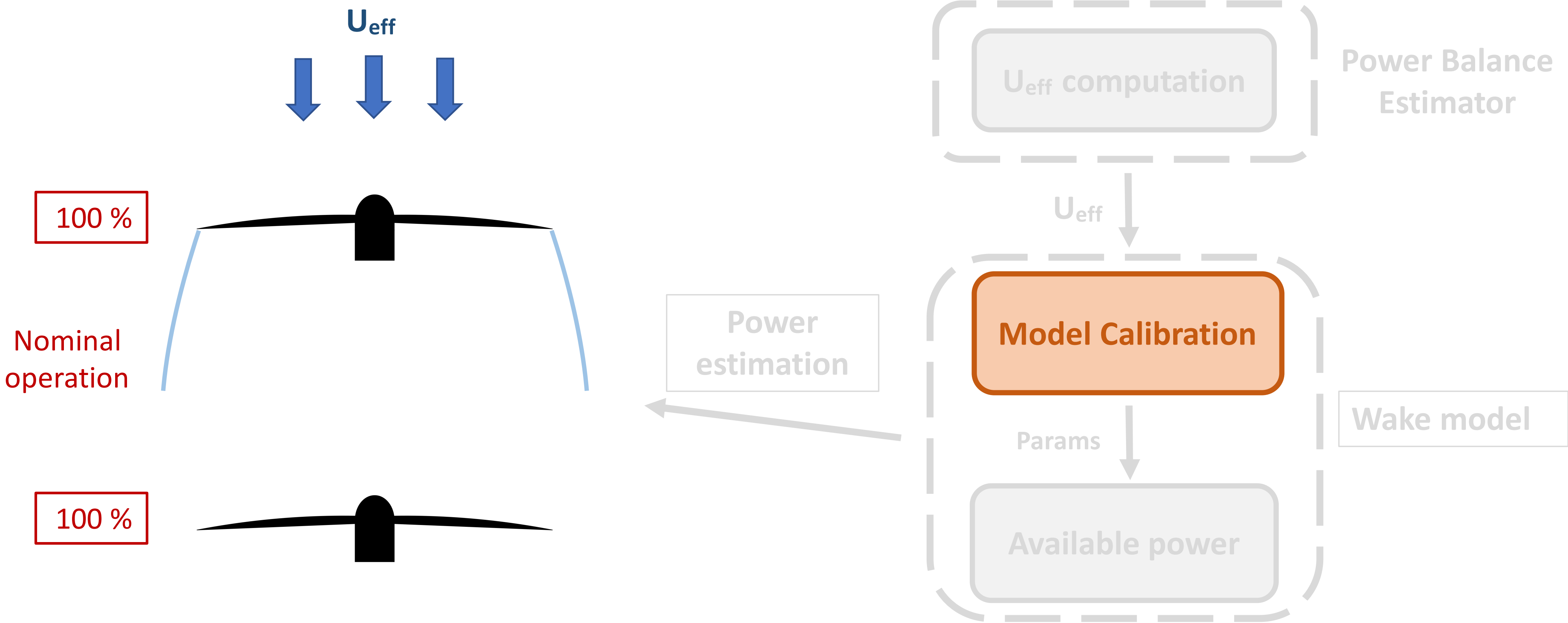


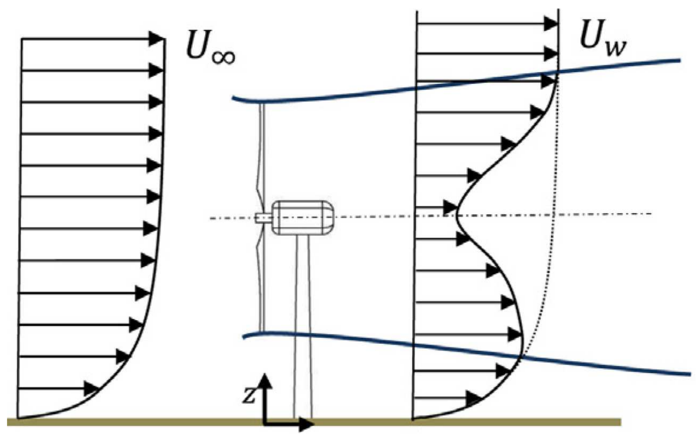
"Possible power of down-regulated offshore wind power plants: The PossPOW algorithm". Göçmen, T. et al. (2018)

Methodology I wake model

“A new analytical model for wind-turbine wakes”. Bastankhah M., Porté-Agel F. (2014)

$$\frac{\Delta U}{U_\infty} = \left(1 - \sqrt{1 - \frac{C_T}{8(\sigma/d_0)^2}}\right) . e^{\left(-\frac{(r/d_0)^2}{2(\sigma/d_0)^2}\right)}$$

$$\frac{\sigma}{d_0} = k^* \frac{x}{d_0} + 0.2\sqrt{\beta}$$



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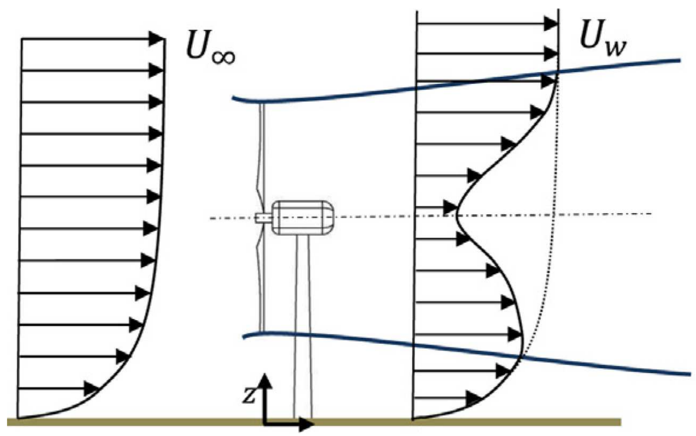
Needs calibration!!



Methodology I bayesian analysis

Physical system

$$\tilde{P} = g(k^*) + \varepsilon$$

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Physical system

$$\tilde{P} = g(k^*) + \varepsilon$$

Bayesian inference

$$p\left(k^* \middle| \tilde{P}\right) = \frac{p(k^*)\,.\,p\left(\tilde{P} \middle| k^*\right)}{p\left(\tilde{P}\right)}$$

Methodology I bayesian analysis

Physical system

$$\tilde{P} = g(k^*) + \varepsilon$$

Bayesian inference

$$p(k^*|\tilde{P}) = \frac{p(k^*) \, . \, p(\tilde{P}|k^*)}{p(\tilde{P})}$$

$$p(k^*|\tilde{P}) \propto p(k^*) \, . \, L(k^*|\tilde{P})$$

Posterior distribution ∝ Prior distribution . Likelihood function

Methodology I likelihood function

Conditional probabilty distribution of measurements

$$\tilde{P} = g(k^*) + \varepsilon \quad \longrightarrow \quad \varepsilon \sim N(0, \hat{\sigma}^2)$$

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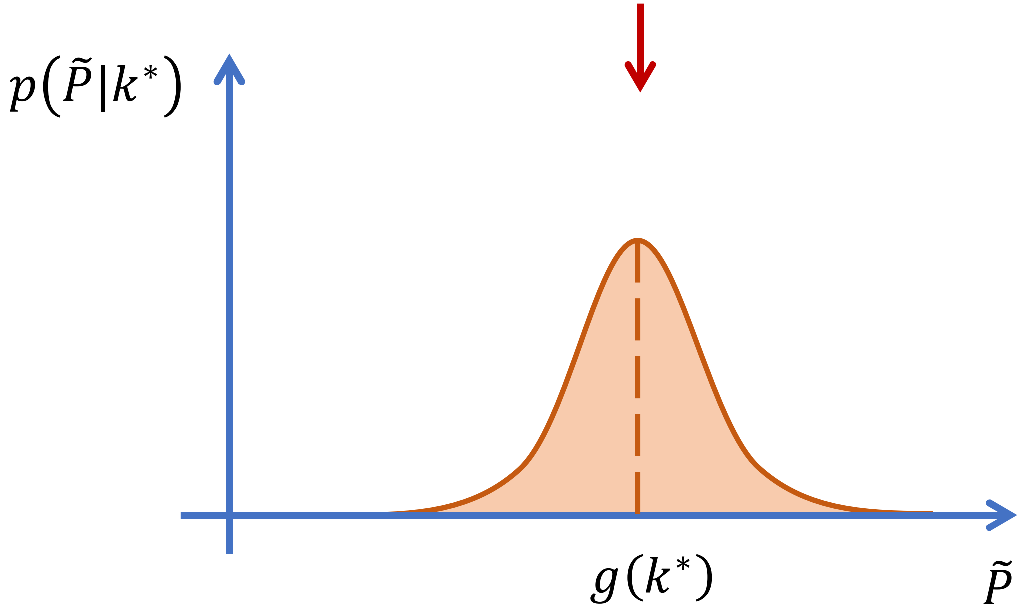

Methodology I likelihood function

Conditional probabilty distribution of measurements

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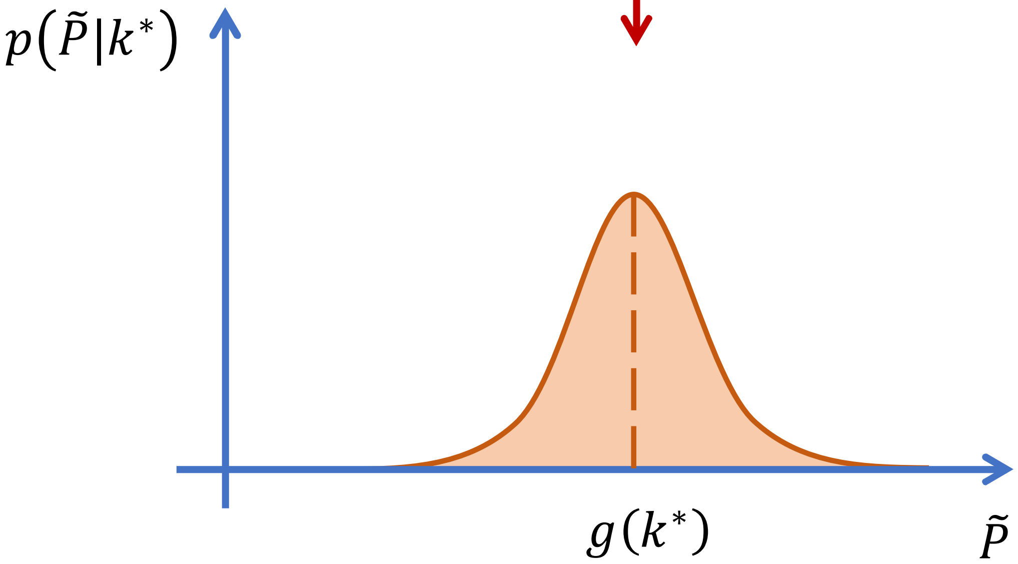


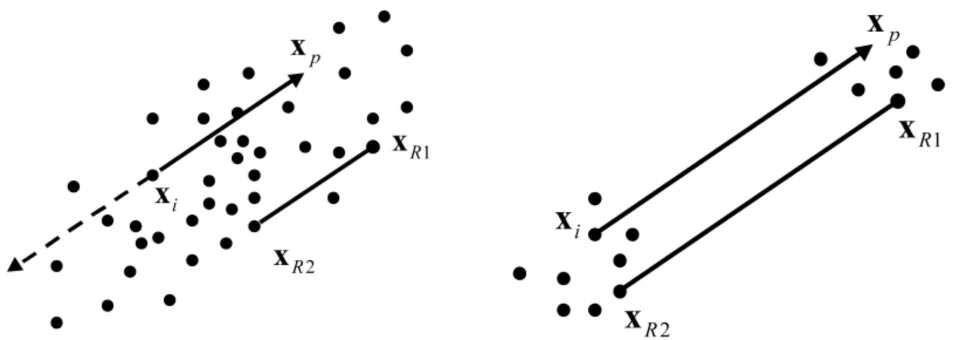
$$e_t(k^*) = \tilde{p}_t - g_t(k^*)$$

$$L(k^*|\tilde{P}, \hat{\sigma}_t^2) = \prod_{t=1}^{n} \frac{1}{\sqrt{2\pi\hat{\sigma}^2}} . e^{-\frac{1}{2}\left(\frac{e_t(k^*)}{\hat{\sigma}}\right)^2}$$

$$s^2 = \frac{1}{n-1} \sum_{t=1}^{n} \left(e_t(k^*)\right)^2$$

Methodology I DREAM

- Markov chain Monte Carlo (MCMC) method for parameters sampling using the posterior distribution.
- Based on the Differential Evolution Markov Chain method.
- Multi chain method: parallel sampling trajectories.

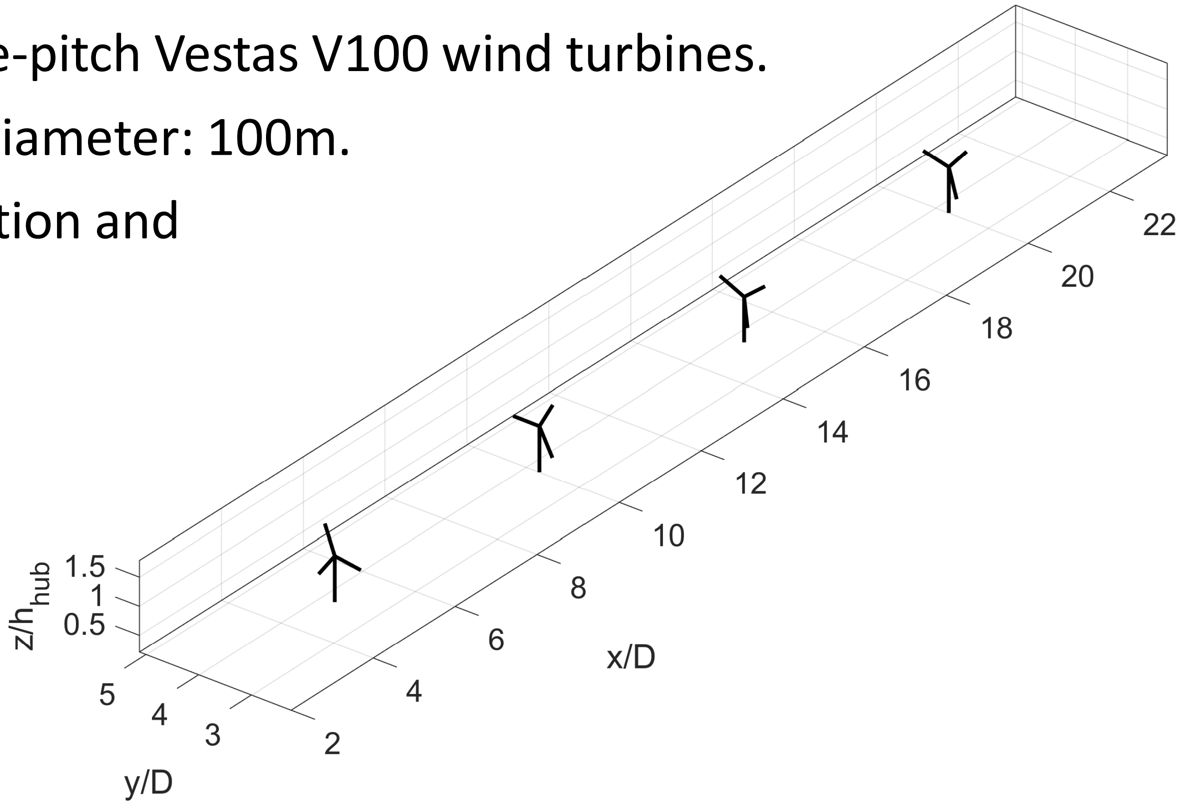


$$p_{acc} = min\left(1, \frac{p(X_p)}{p(X_i)}\right)$$

“Markov chain Monte Carlo simulation using the DREAM software package: Theory, concepts and MATLAB implementation”. Vrugt, J. (2016)

Validation I setup

- 7.6 MW wind farm in flat terrain.
- 4 variable-speed, variable-pitch Vestas V100 wind turbines.
- Hub height: 95m. Rotor diameter: 100m.
- Aligned in the wind direction and
  spaced 5*D each other.

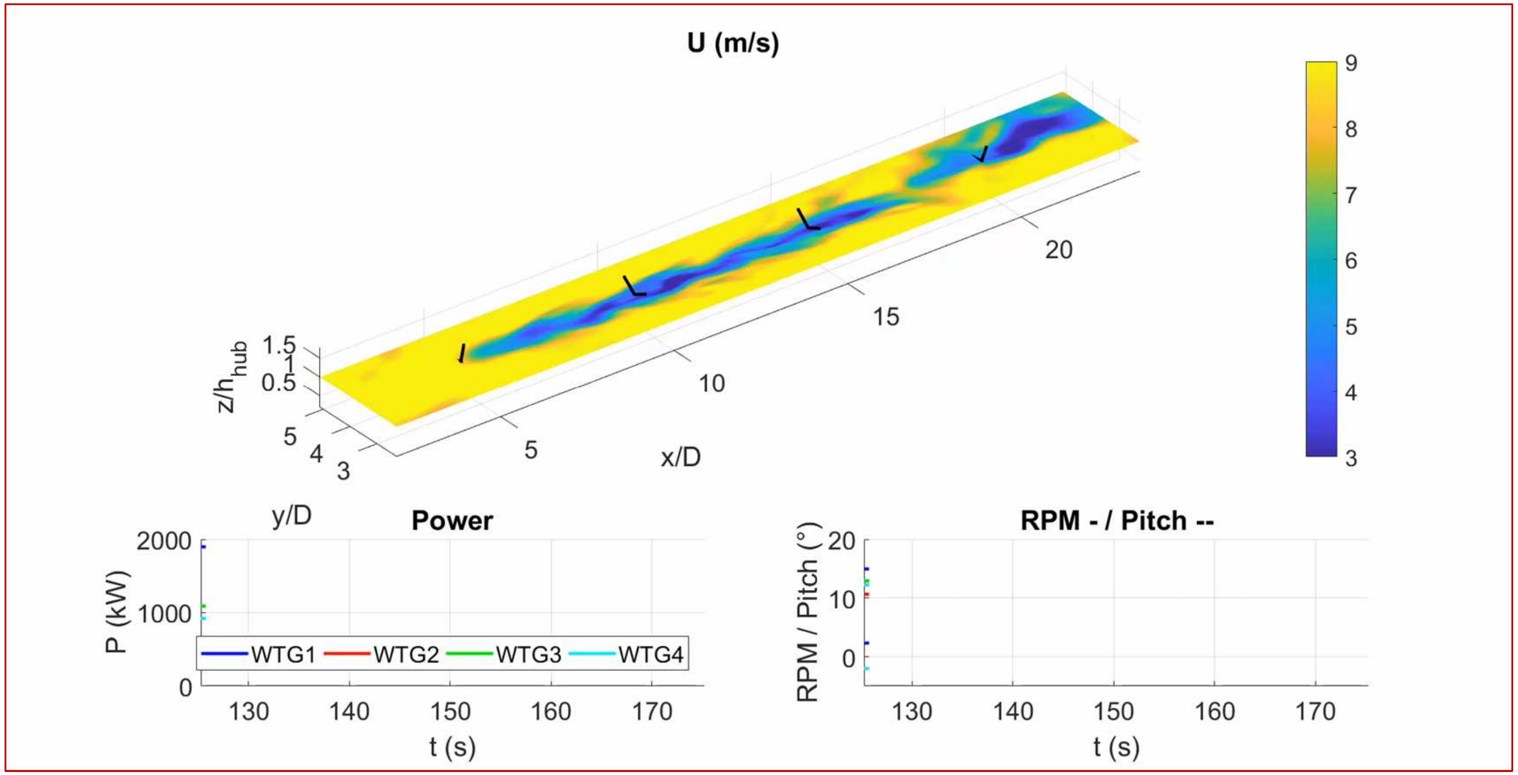


Validation I CFD solver

Caffa3d

- Finite volumen method
- 2nd order accuracy
- Structured grid blocks
- Parallelization by MPI

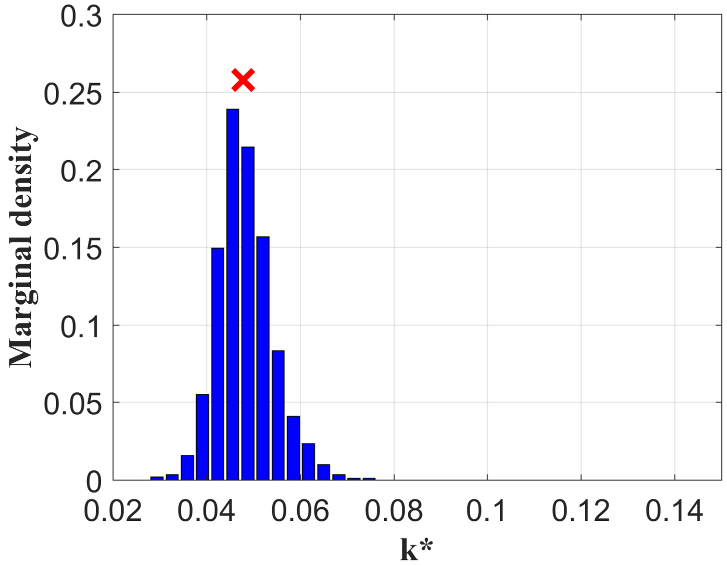
- Large Eddy Simulations
- Actuator Line Model
- Pitch and torque control



"Simulation of a 7.7 MW onshore wind farm with the Actuator Line Model". Guggeri, A. et al. (2017)

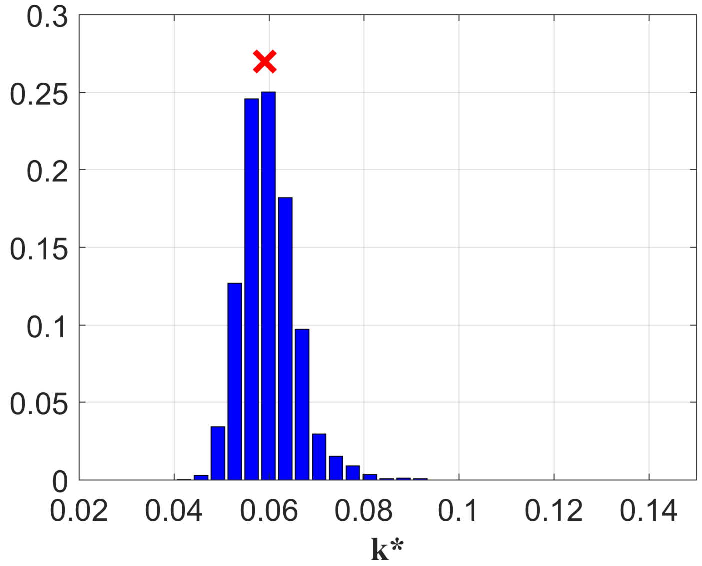
Results | calibration

1st WT



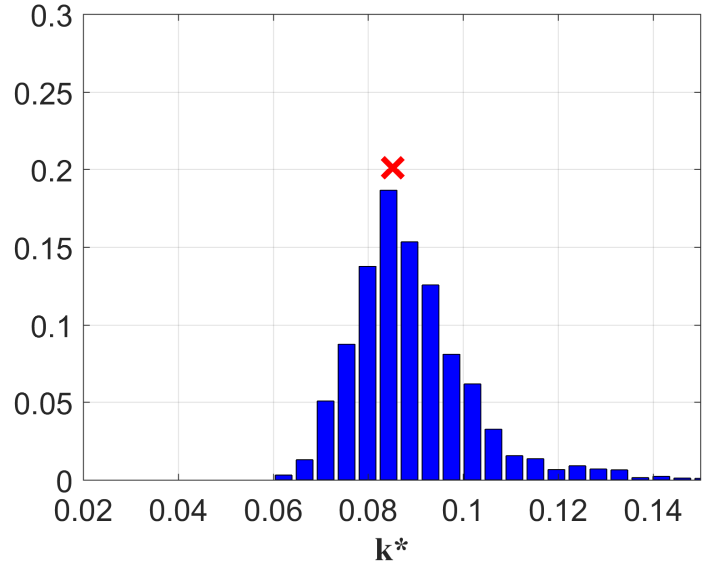
$k^* = 0{,}045$

2nd WT



$k^* = 0{,}059$

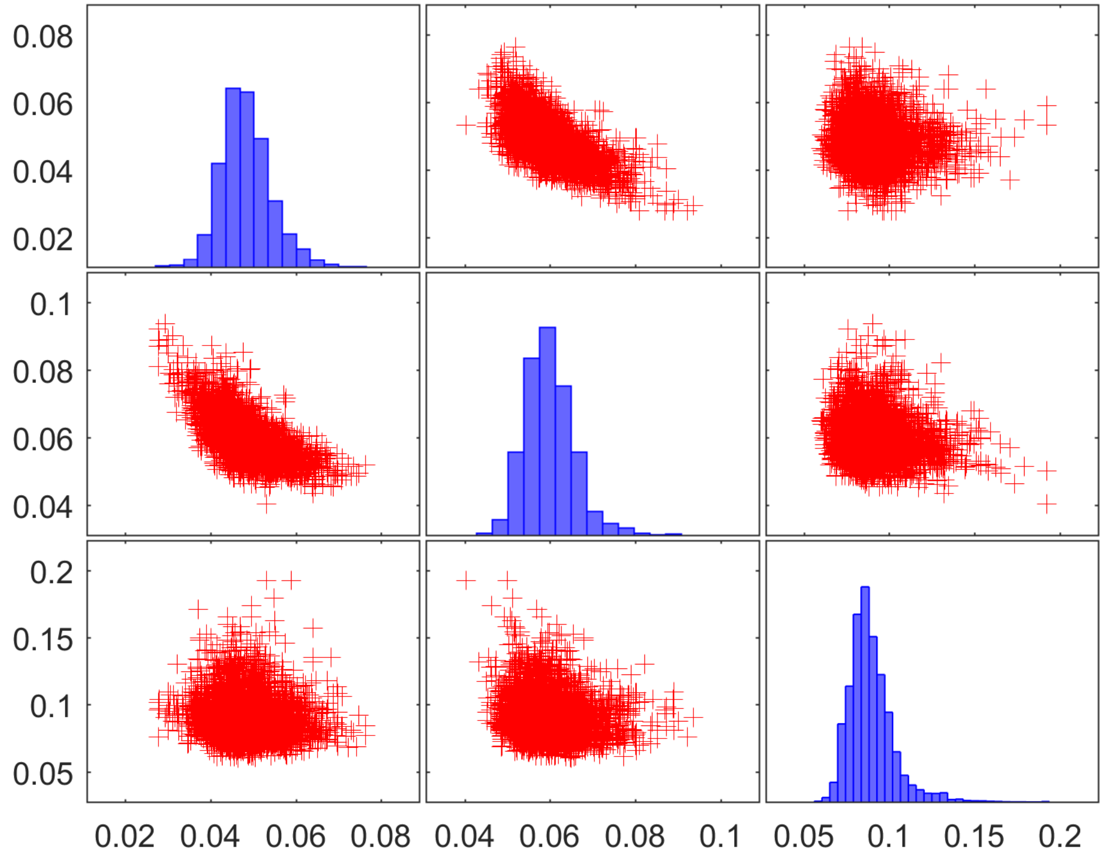
3rd WT



$k^* = 0{,}085$

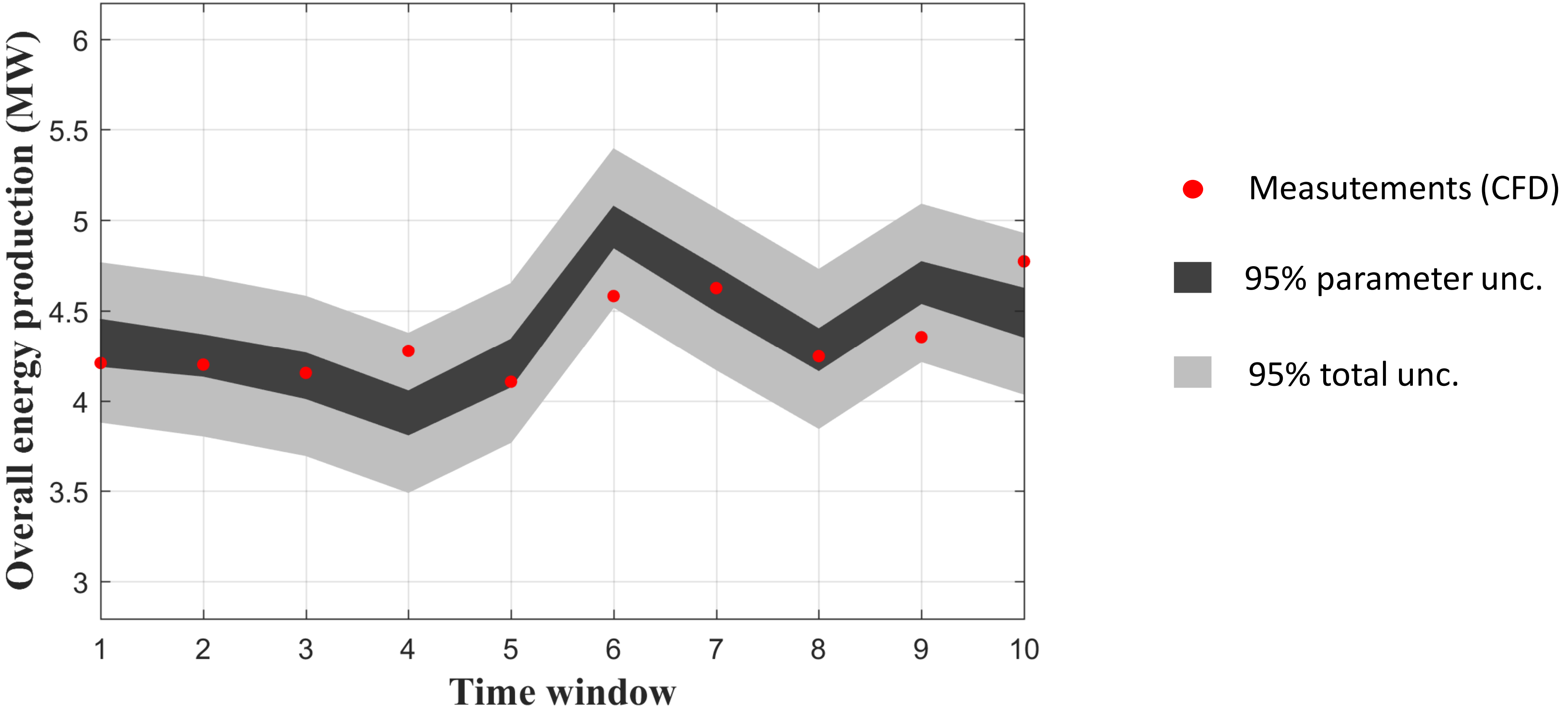
Results I calibration

Two-dimensional correlation plots of posterior parameter samples



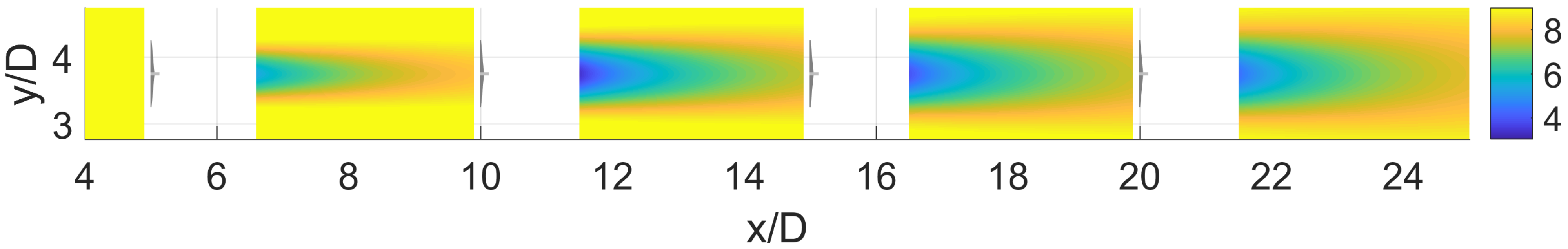
Results I calibration

Down-regulated wind farm at 70%

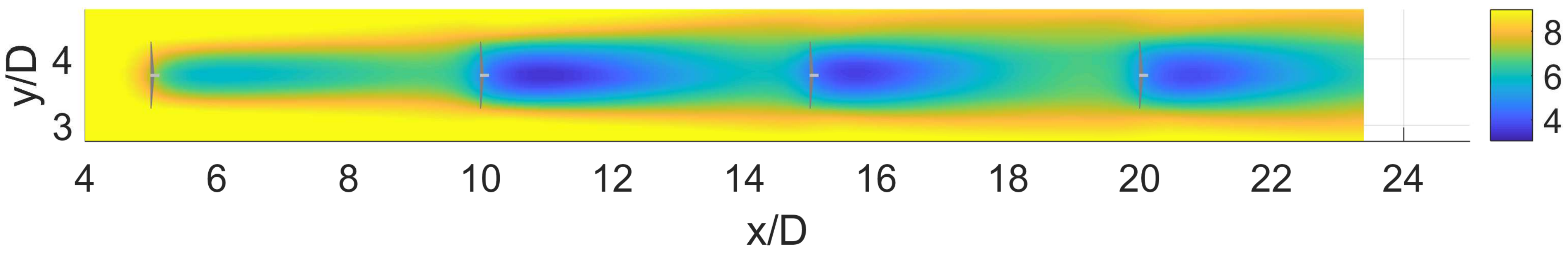


Results I validation

Wind field – Wake model

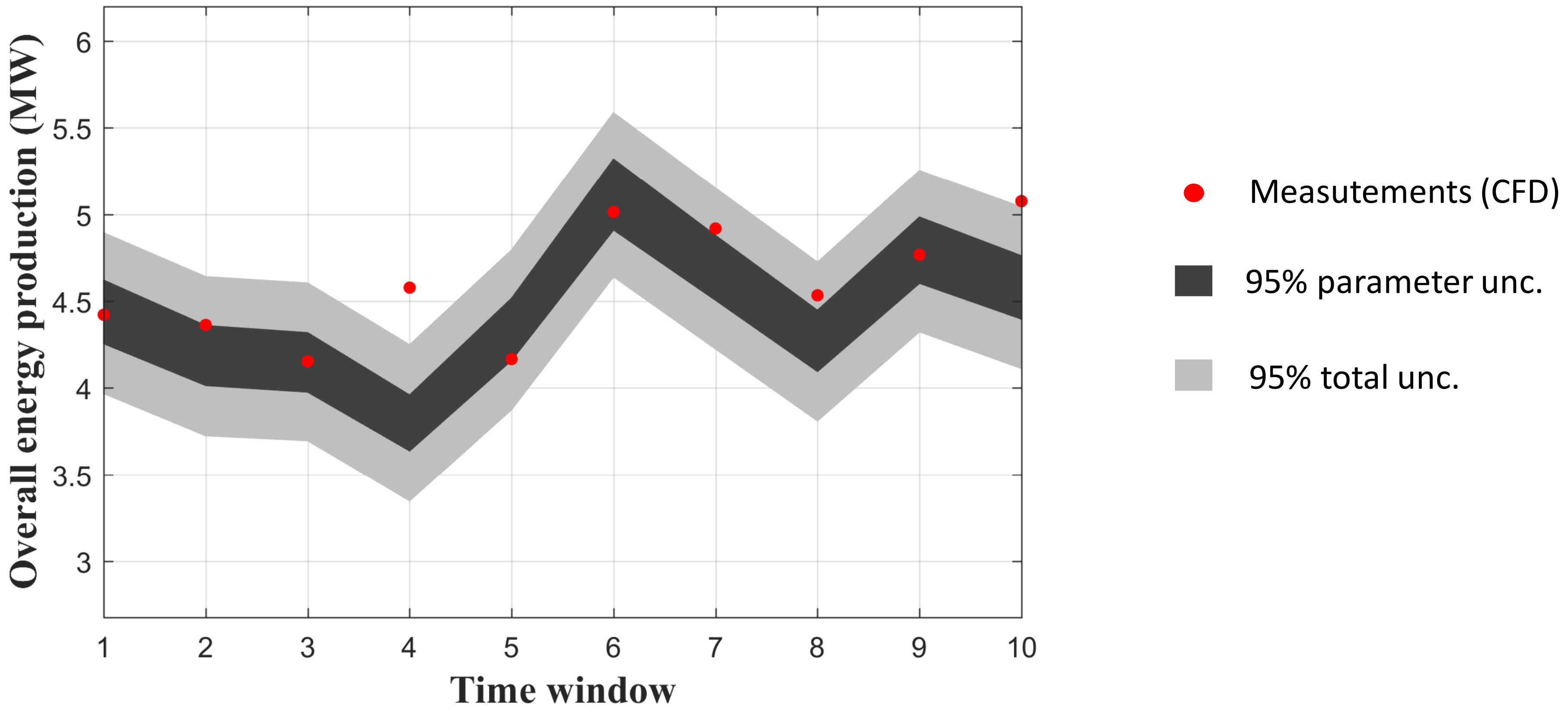


Wind field – CFD simulations



Results I validation

Avaliable power estimation vs. Wind farm at 100%



Conclusions

- The methodolgy presents overall good results.
- Satisfactory implementation of bayesian analysis techniques for parameter calibration.
- Precise estimation of model uncertainties.

Future work

- Explore DREAM paralellization features
- Evaluate other wake models or mid-Fidelity models
- Explicit dependence on turbulence intensity
- GPU programming

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Thank you for your attention!