PossPOW

Estimation of Possible Power in Offshore Wind Farms during Downregulation

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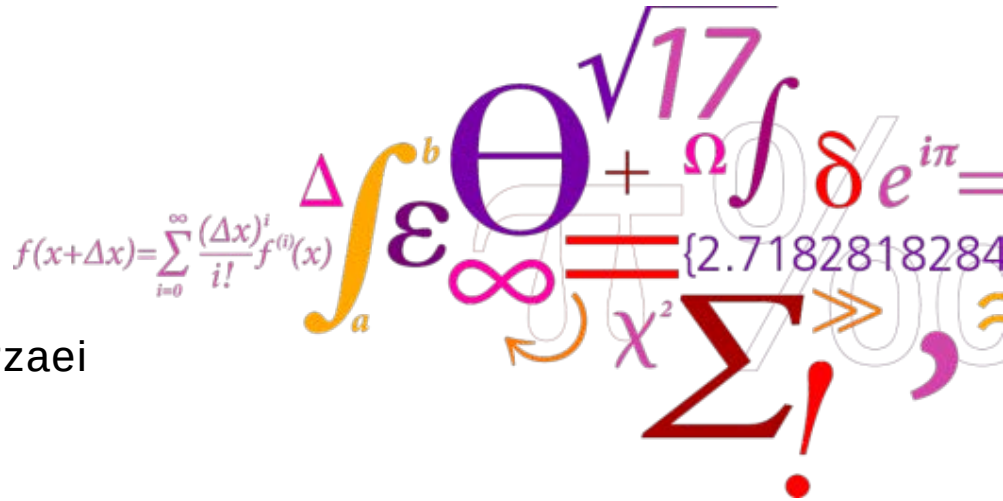

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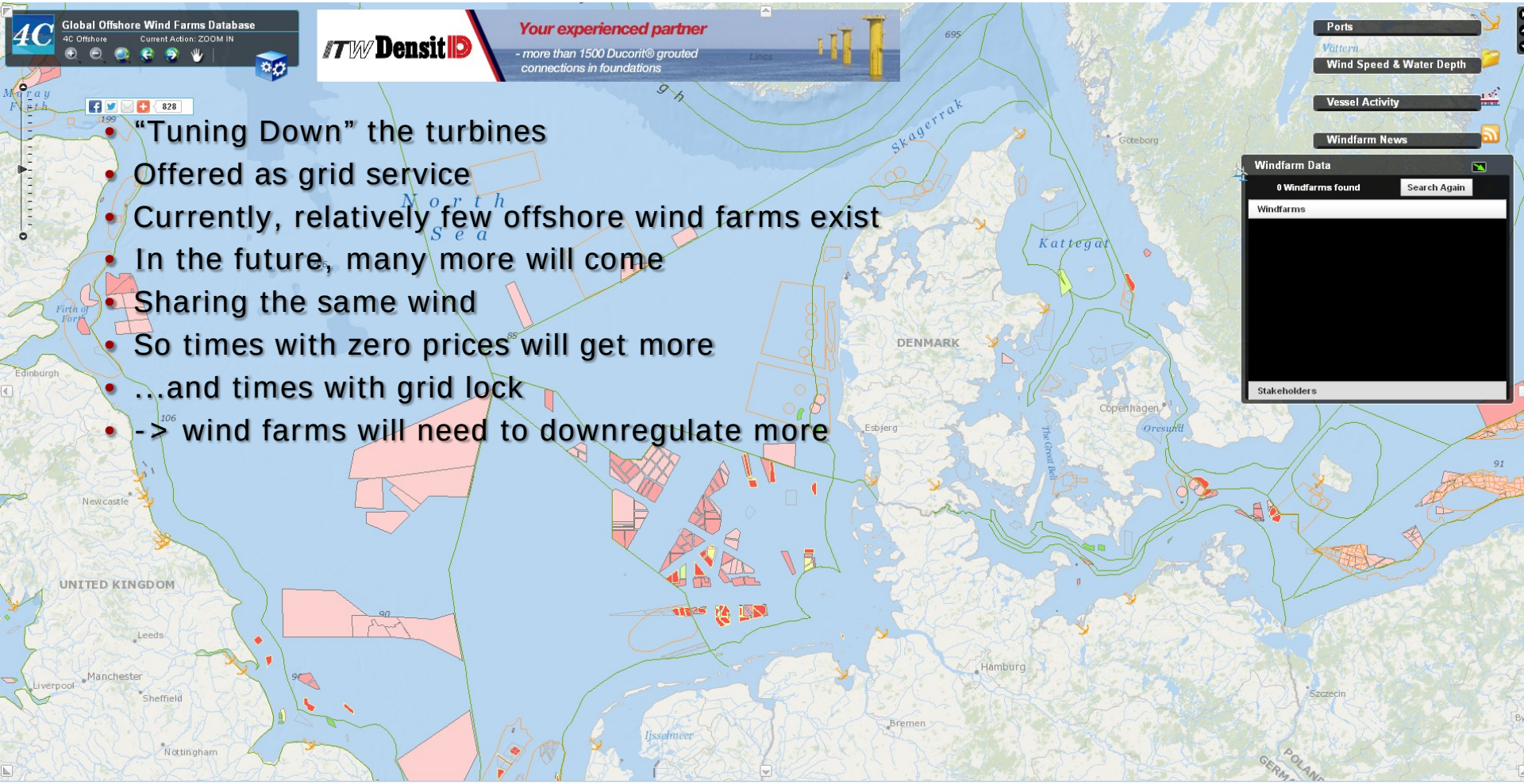
PossPOW – Background & Aim of the Project



- "Tuning Down" the turbines
- Offered as grid service
- Currently, relatively few offshore wind farms exist
- In the future, many more will come
- Sharing the same wind
- So times with zero prices will get more
- ...and times with grid lock
- -> wind farms will need to downregulate more

Image source: 4C Offshore.com

PossPOW – Background & Aim of the Project

- "Reserve Power" of offshore wind farms (i.e. how much the wind farm is down-regulated) can be traded on the grid services markets

- Estimation of possible (or Available) power of a downregulated single turbine is straight-forward & widely known

- ...but when it comes to the wind farm scale:
  - $\sum Possible\ Power_{single\ turbines} > Possible\ Power_{wind\ farm}$
  - Simply because a turbine in the wake of a downregulated turbine sees more wind than usual $\longrightarrow$ decreased wake effect

- Energinet.dk, UK National Grid and other Transmission System Operators (TSOs) have no real way to determine the available power of a whole down-regulated wind farm

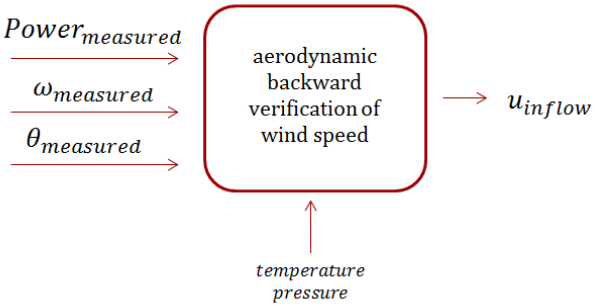
- *Therefore, PossPOW aims* $\longrightarrow$ verified & internationally accepted way to estimate the available power of downregulated offshore wind farms.

PossPOW – Wind Speed Estimation (Procedure)

- Nacelle Anemometer ⟶
  - not always available + high inaccuracy
- Power Curve method ⟶
  - no longer applicable due to downregulation
- Backward verification of wind speed

$$P = \frac{1}{2}\rho A_{rotor} c_P(\theta, \lambda) U_{eff}^3$$

- Power + rotor speed + pitch angle ⟶ incoming wind speed



- Estimation of $C_P\,(\lambda, \theta)$ ⟶ analytical model by Heier(1998)

$$C_P(\lambda, \theta) = c_1 \left(\frac{c_2}{\lambda_i} - c_3\theta - c_4\theta^{c_5} - c_6 \right) exp\left(\frac{-c_7}{\lambda_i} \right)$$

Where

$$\lambda_i = \left[\left(\frac{1}{\lambda + c_8\theta} \right) - \left(\frac{c_9}{\theta^3 + 1} \right) \right]^{-1}$$

Heier, S., 1998, *Grid Integration of Wind Energy Conversion Systems*, John Wiley & Sons Ltd, Chichester, UK, and Kassel University, Germany

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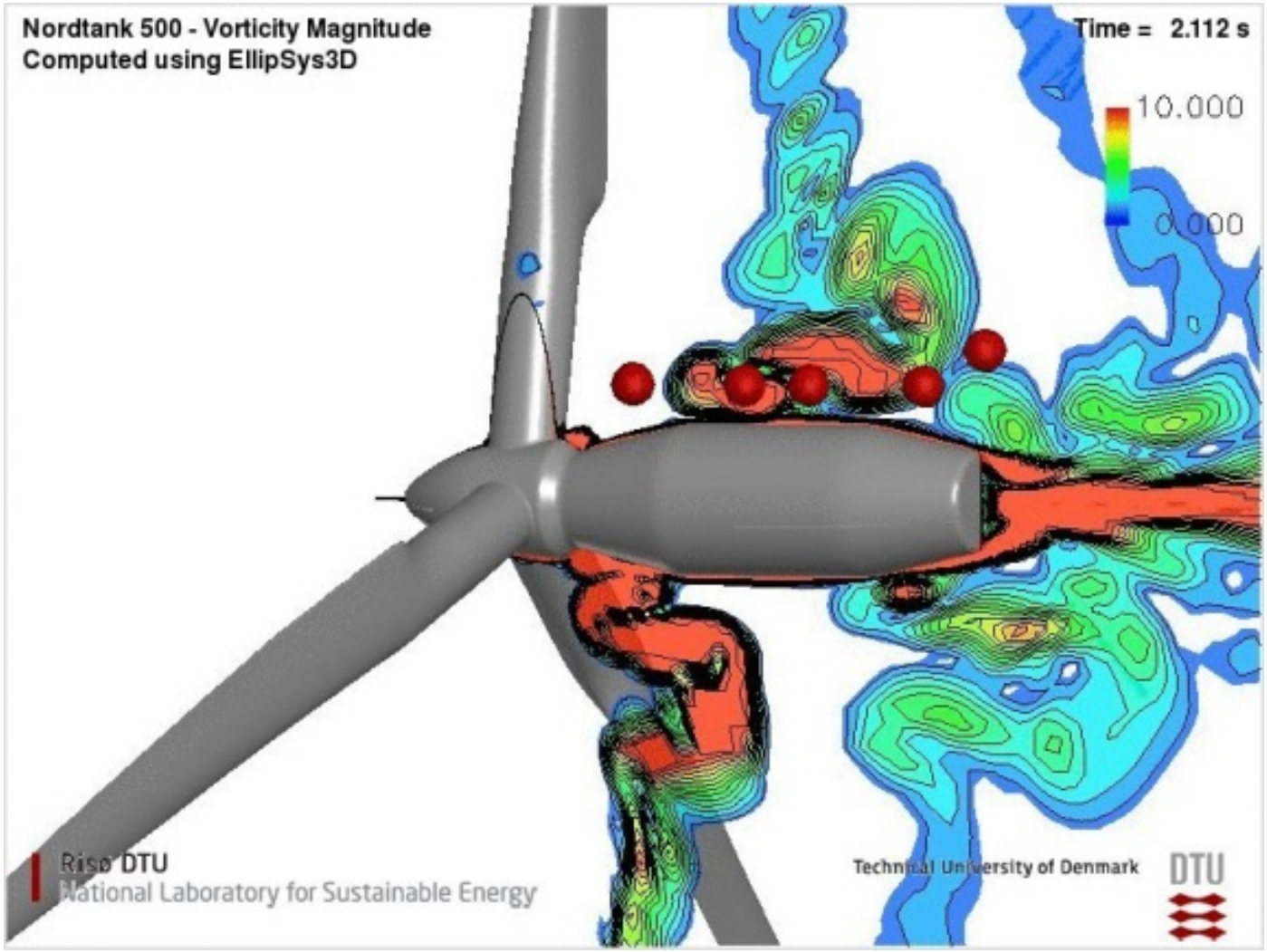

Zahle, F. and Sørensen, N. N. , 2011, Characterization of the unsteady flow in the nacelle region of a modern wind turbine. Wind Energy, 14: 271–283

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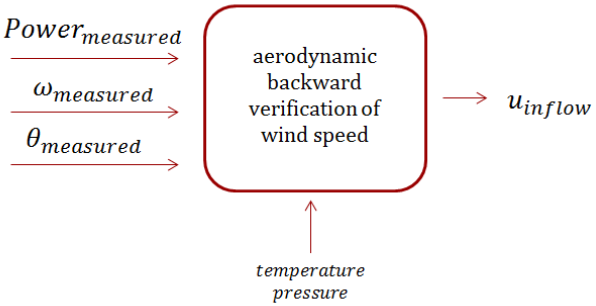

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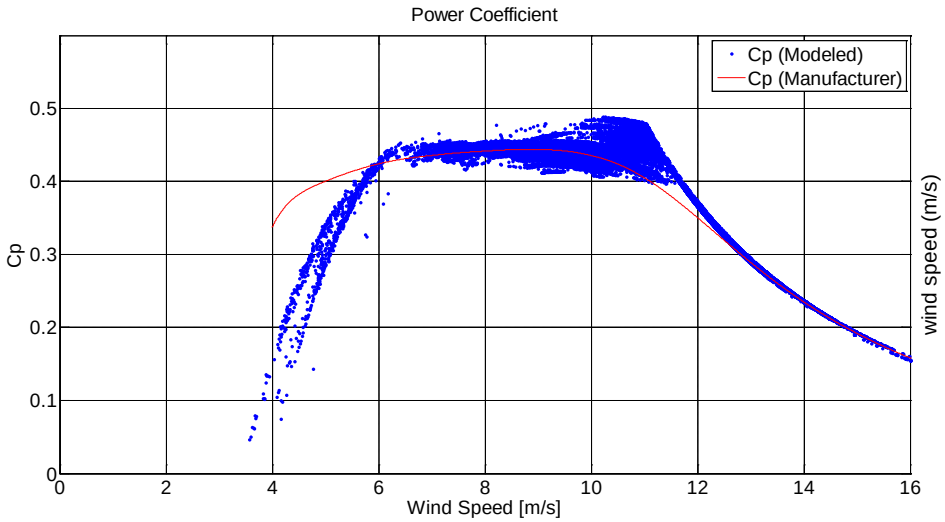
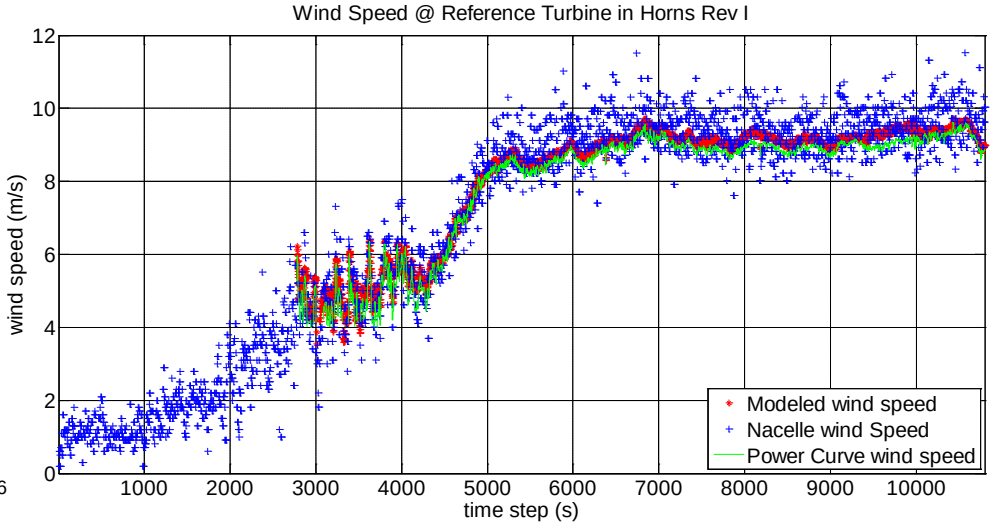
PossPOW – Wind Speed Estimation (Single Turbine)

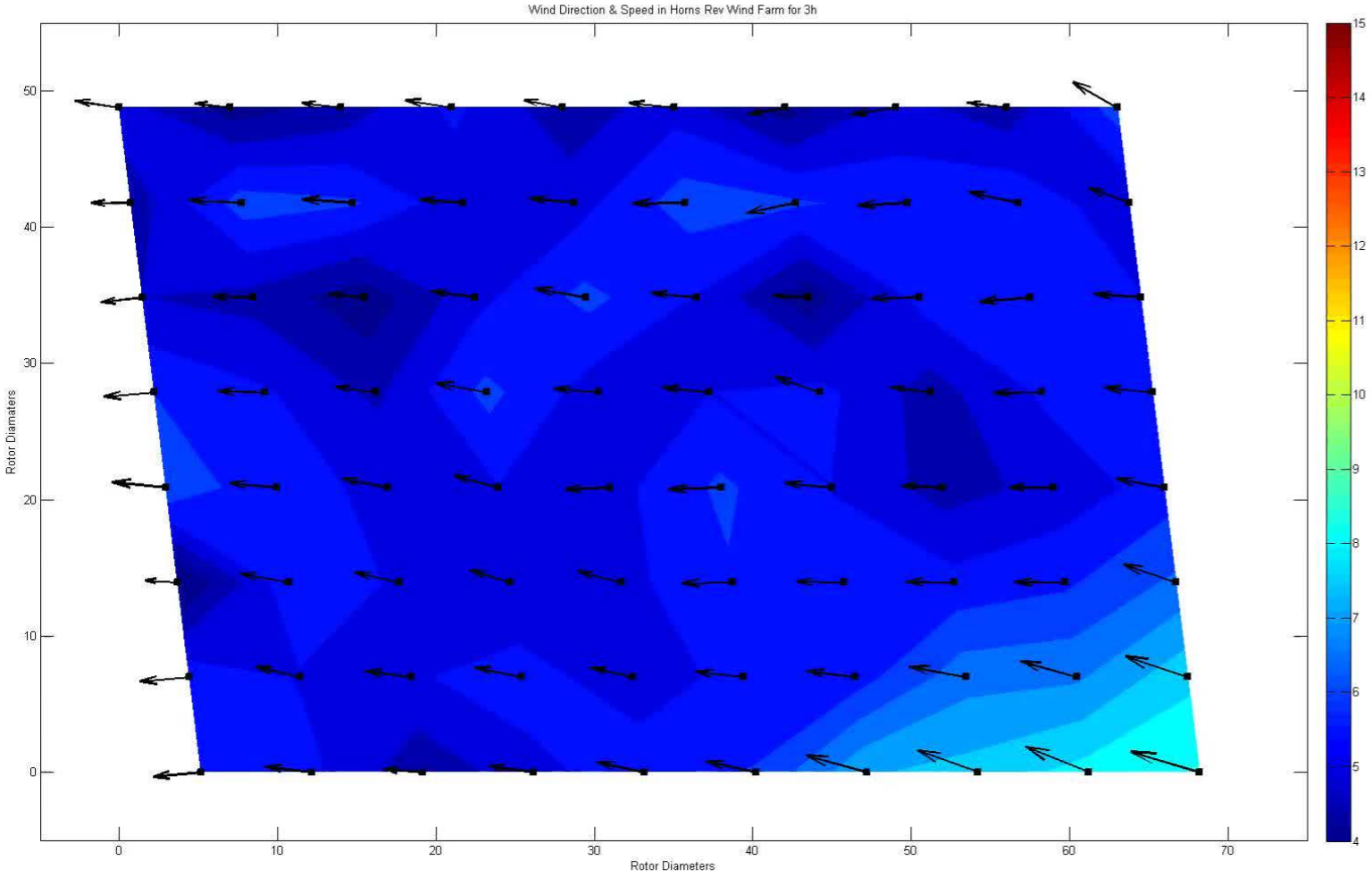
- Case Study : Horns Rev I ⟶ 80 Turbines & Vestas V80 2 MW-Offshore
  - Constants in C_P equation
  - 2 different second-wise datasets
    - Normal Operation : below cut-in to above rated wind speed





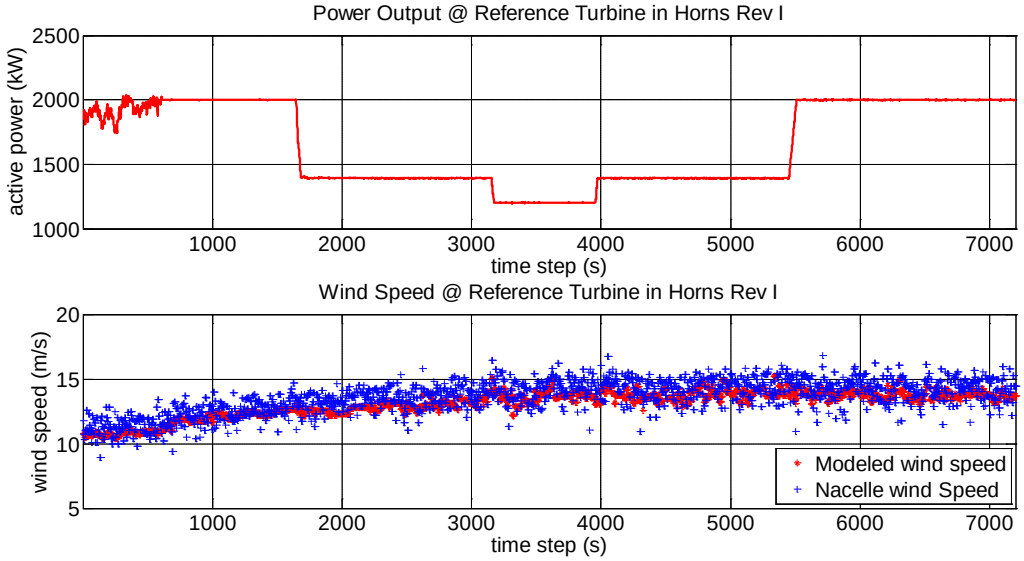
- Poor agreement in C_P for low wind speeds
- Over-estimation near transition region (control strategies)
- Nacelle anemometer seems to be measuring slightly higher

PossPOW – Wind Speed Estimation (Wind Farm)

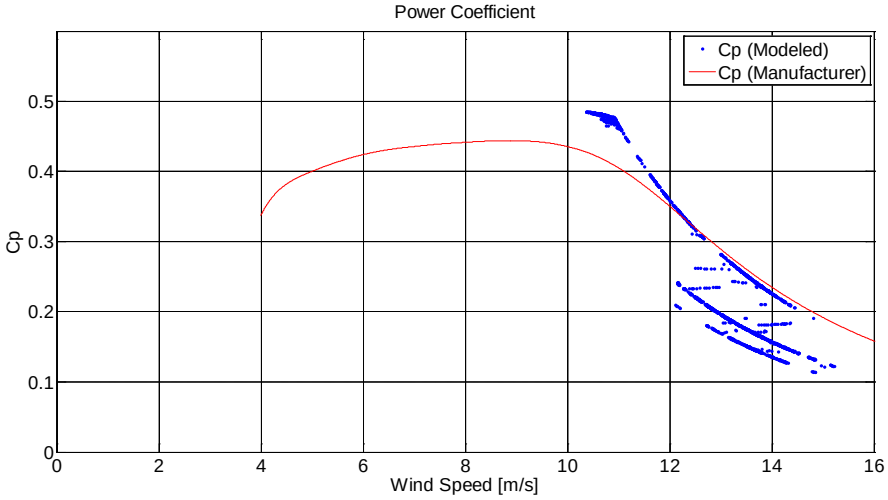


PossPOW – Wind Speed Estimation (DownRegulation)

- Downregulation: Horns Rev I Dataset

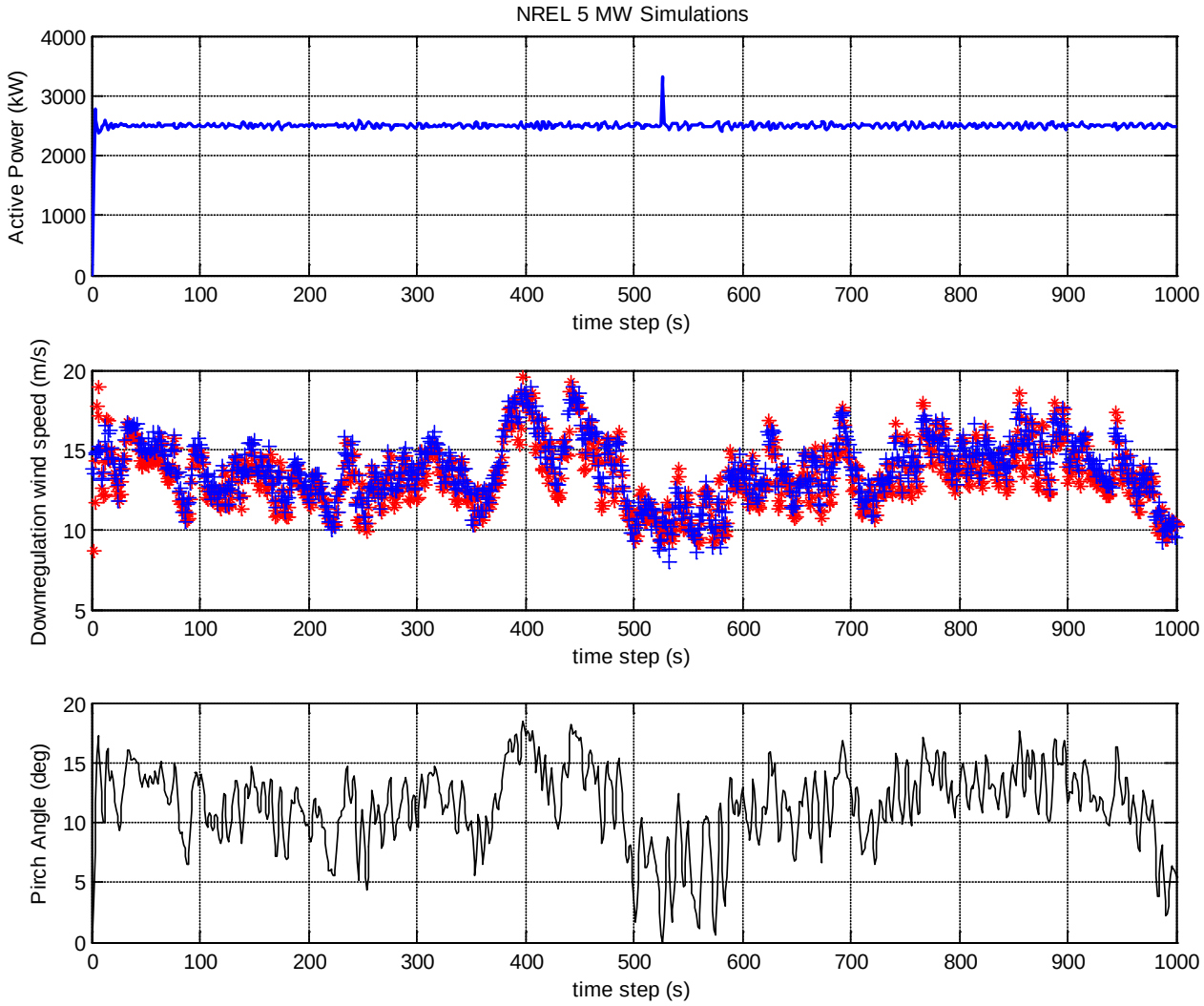


- App. 30% of downregulation
- Different control strategies applied
- Power Curve approach no longer applicable



PossPOW – Wind Speed Estimation (DownRegulation)

- Downregulation: NREL 5MW[1] Simulations



- 50% of downregulation
- Very good agreement with the simulations
- Active Pitch Control

1 Jonkman, J., Butterfield, S., Musial, S. and Scott G., Definition of a 5-MW Reference Wind Turbine for Offshore System Development. NREL/TP-500-38060 National Renewable Energy Laboratory, Golden, CO, 2007

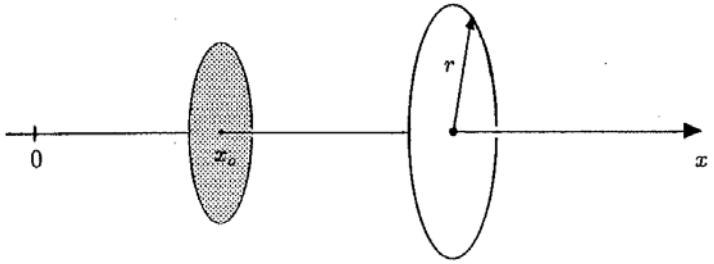
PossPOW - Wake modelling

- After the flow speed is estimated during down regulation;
  - Wake effects are to be considered as if the turbine is operating ideally to achieve the available power
  - No wake models are to be developed
  - However, the wake models are tuned to give good average wake losses, not instantaneous ones $\longrightarrow$ Real time implementation of the existing wake model(s)
    - Re-calibration of GCLarsen

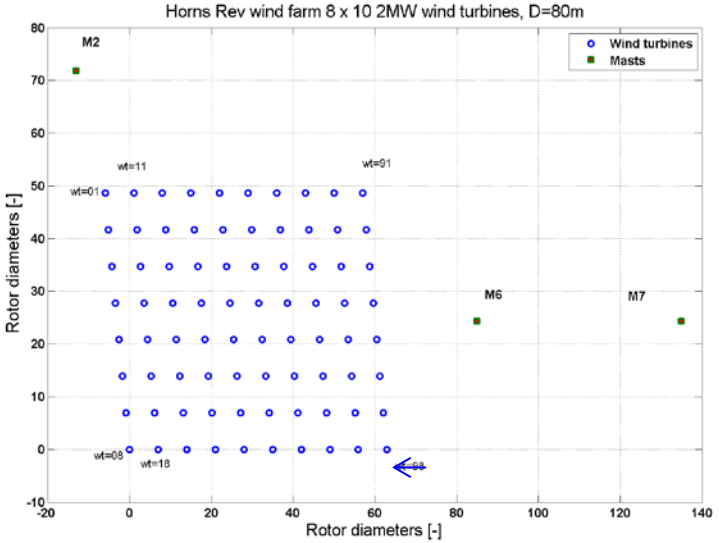
- The modeled wind speed for upstream turbines, i.e. without any "reduced" wake effect will be input to the integrated wake model to obtain *Available Power* during downregulation

PossPOW - Wake model re-calibration (for real time)

- GCLarsen wake model
  - Simple and robust
  - Implemented in WindPro
  - Performs relatively well also on offshore
- 2 parameters to adjust in single wake case



$$u_x(x,r) = -\frac{U_\infty}{9}\left(c_T A (x_0 + \Delta x)^{-2}\right)^{\frac{1}{3}}\left\{r^{\frac{3}{2}}\left(3c_1^2 c_T A(x_0+\Delta x)\right)^{-\frac{1}{2}} - \left(\frac{35}{2\pi}\right)^{\frac{3}{10}}\left(3c_1^2\right)^{-\frac{1}{5}}\right\}^2$$



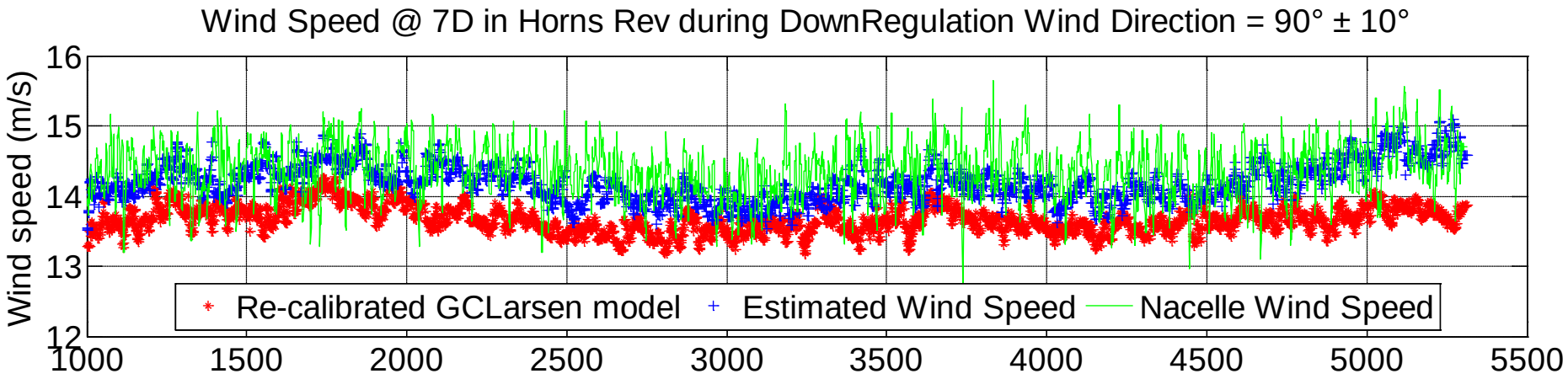
» All data filtered for wind direction 90±10°

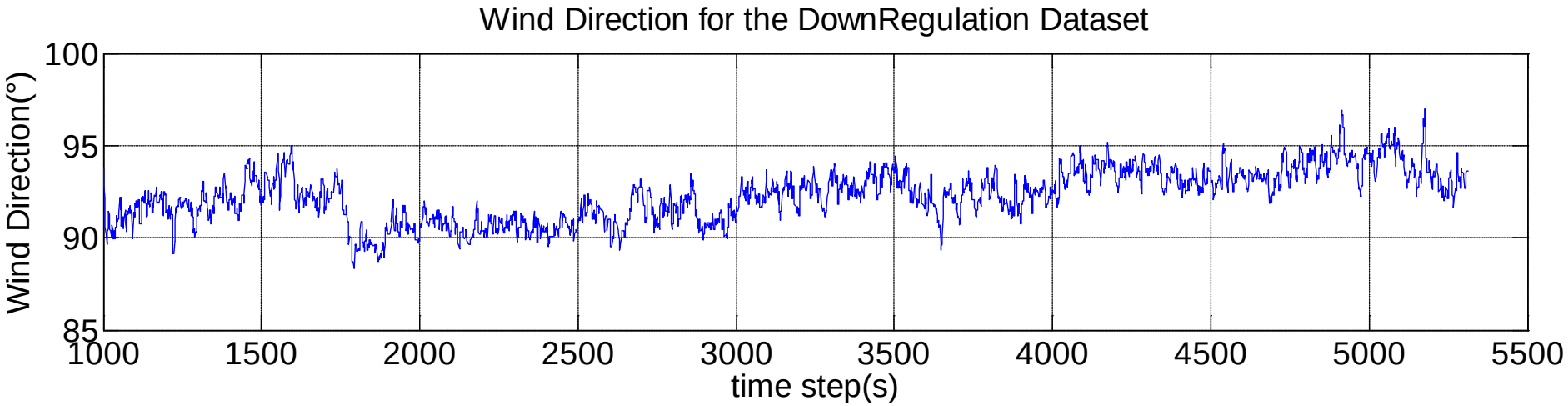
» Nonlinear Least Squaresfitting
  - $R^2 = 0.96$ & $RMSE = 0.41$

» Model was tested using the downregulated dataset
  - Modeled wind Speed < Downregulated dataset

Larsen G. C., 1998, *A Simple Wake Calculation Procedure,* Technical Report Risø-M-2760, Risø

PossPOW - Wake model re-calibration (for real time)





- Modeled wind Speed < Downregulated dataset as expected
- High quality data has been requested

PossPOW – Future Work

- Improve the recalibration of GCLarsen model for single wake case
  - Validation using normal operational dataset
- Re-parameterization for Wind Farm Scale
  - Dynamic factors
    - Wind direction variability $\longrightarrow$ upstream turbines
    - Meandering
    - 'Sweeping' $\longrightarrow$ row by row application of the model
- Consideration of other DTU Wake Models:
  - Dynamic Wake Meandering Model
  - Fuga
- The developed algorithm will be verified on some of the large offshore wind farms
  - Dedicated experiments are planned

PossPOW – Conclusion & Acknowledgements

- We are looking for a verified and accepted way to estimate the possible (or available) power of down-regulated offshore wind farms
  - Aerodynamic models for wind turbines
  - Wake modelling of large offshore wind farms
  - Stochastic model estimation & computer simulations
- First period of the project
  - ✓ *The estimation of wind speed using power, pitch & rotational speed*
- Second period
  - ✓ *Real-time implementation of the wake model(s) & finalized algorithm*
- Third period
  - ❑ *Measurements & verification of the algorithm*

- The partners of the PossPOW project are Vattenfall, Siemens, Vestas, and DONG

- PossPOW is a PSO project sponsored by Energinet, Contract ForskEL 10763

Thank you for your attention!