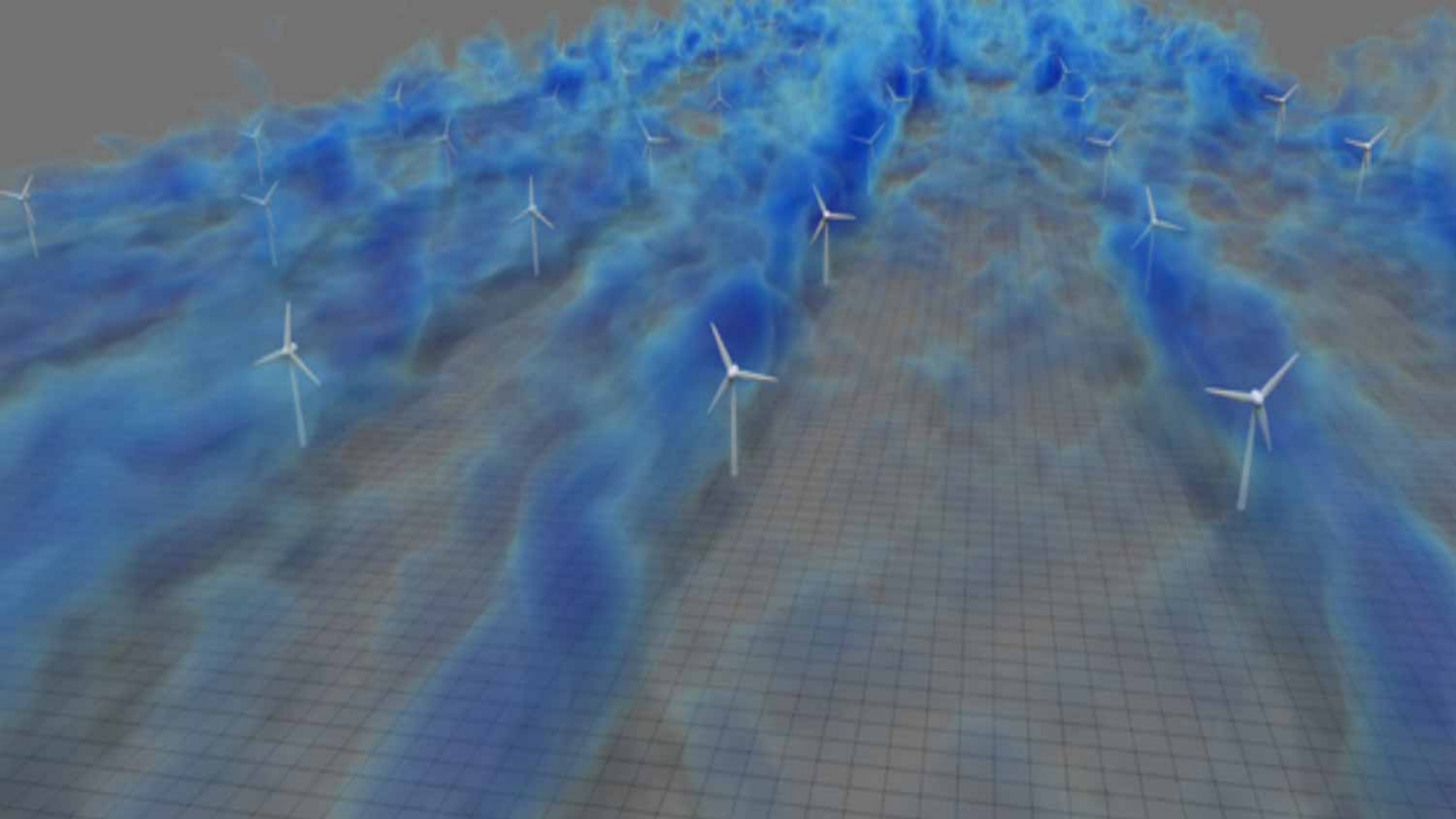
A survey on wind farm control and the OPWIND way forward

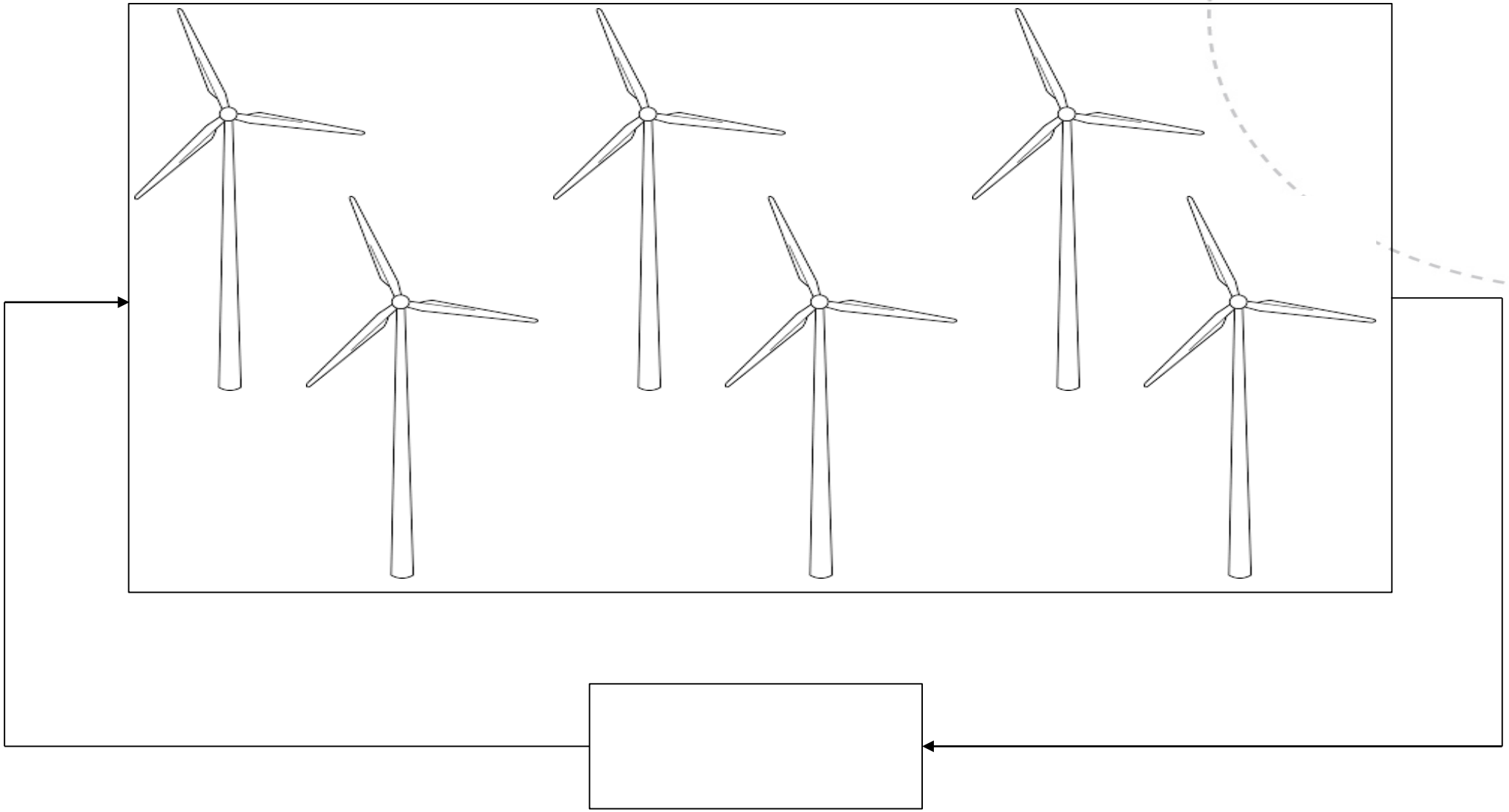
DeepWind 2019 – Leif Erik Andersson

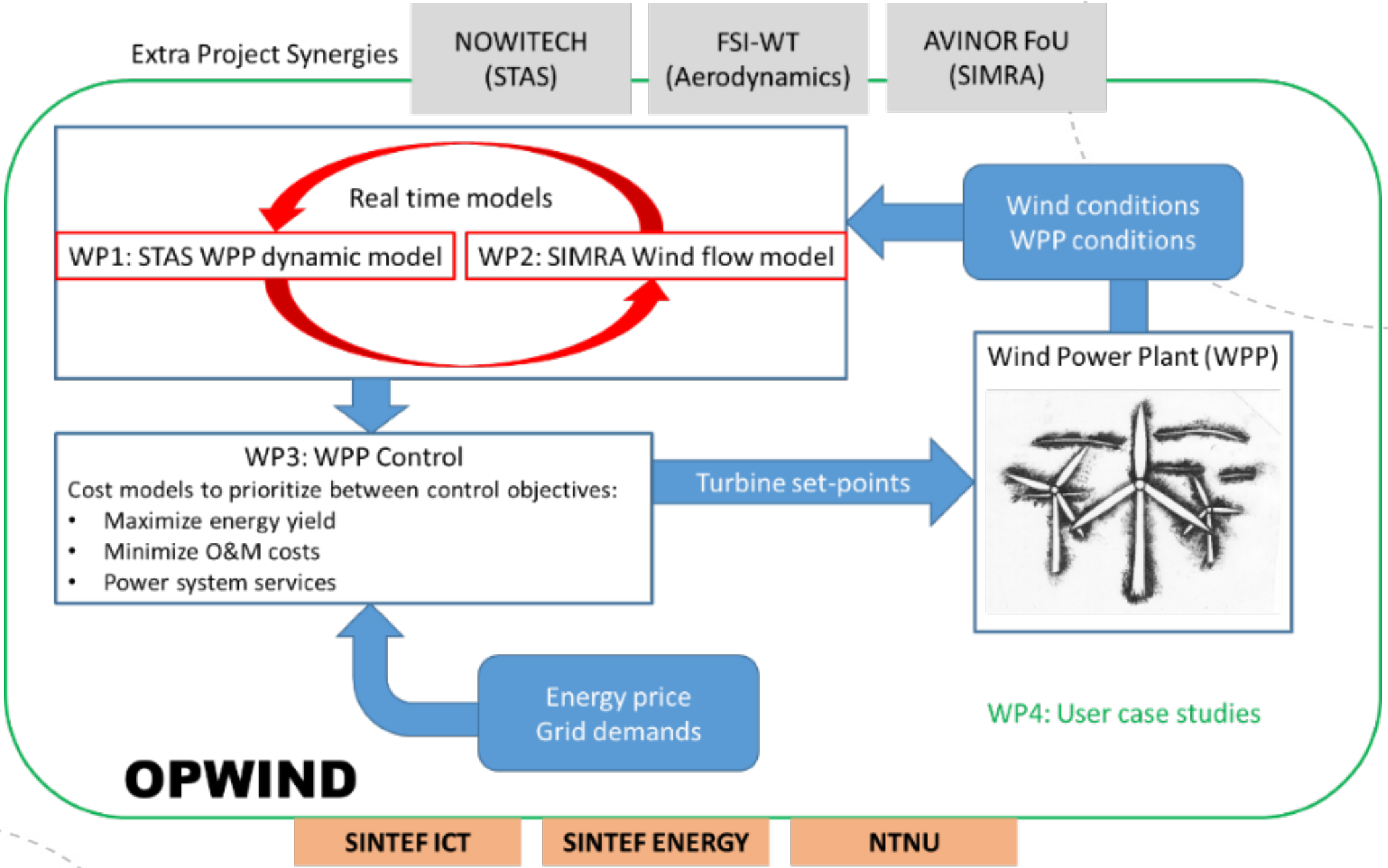
18.01.2019

OPWIND

NTNU AMOS
Centre for Autonomous Marine Operations and Systems

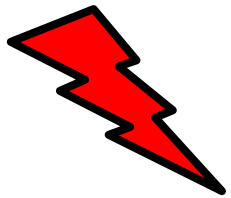





Extra Project Synergies
NOWITECH (STAS)
FSI-WT (Aerodynamics)
AVINOR FoU (SIMRA)
Real time models
WP1: STAS WPP dynamic model
WP2: SIMRA Wind flow model
Wind conditions
WPP conditions
Wind Power Plant (WPP)
WP3: WPP Control
Cost models to prioritize between control objectives:
• Maximize energy yield
• Minimize O&M costs
• Power system services
Turbine set-points
Energy price
Grid demands
WP4: User case studies
OPWIND
SINTEF ICT
SINTEF ENERGY
NTNU

High fidelity models

- Task:
  - Solve numerically the 3D unsteady Navier-Stokes equations
- Direct Numerical Simulation (DNS)

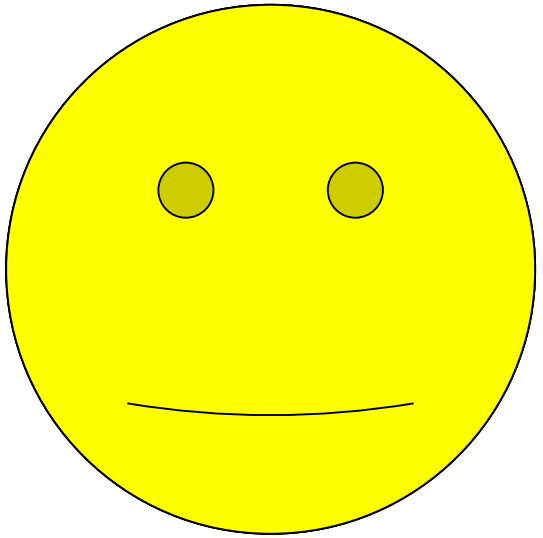


- Large Eddy Simulations (LES)

  - e.g.:
    - *Ellipsys3D (1995)*
    - *PALM (2001)*
    - *SP-Wind (2010)*
    - *SOWFA (2012)*

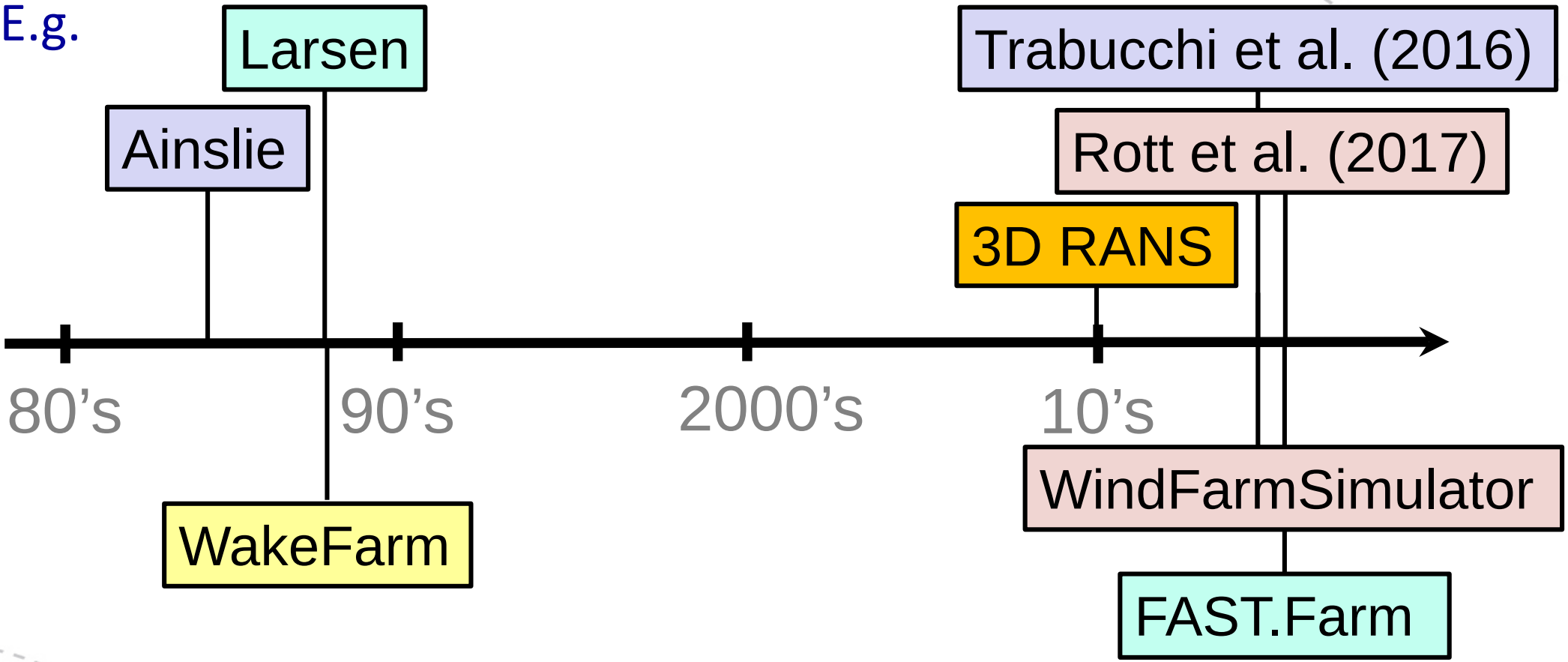
Medium fidelity models

- Compromise between accuracy and computational costs
- E.g.



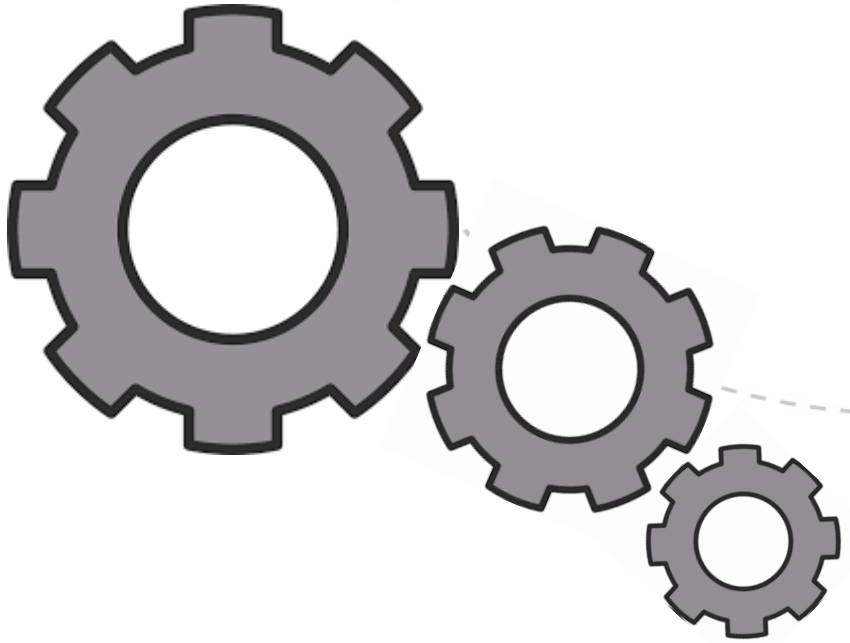
Medium fidelity models

- Compromise between accuracy and computational costs
- E.g.

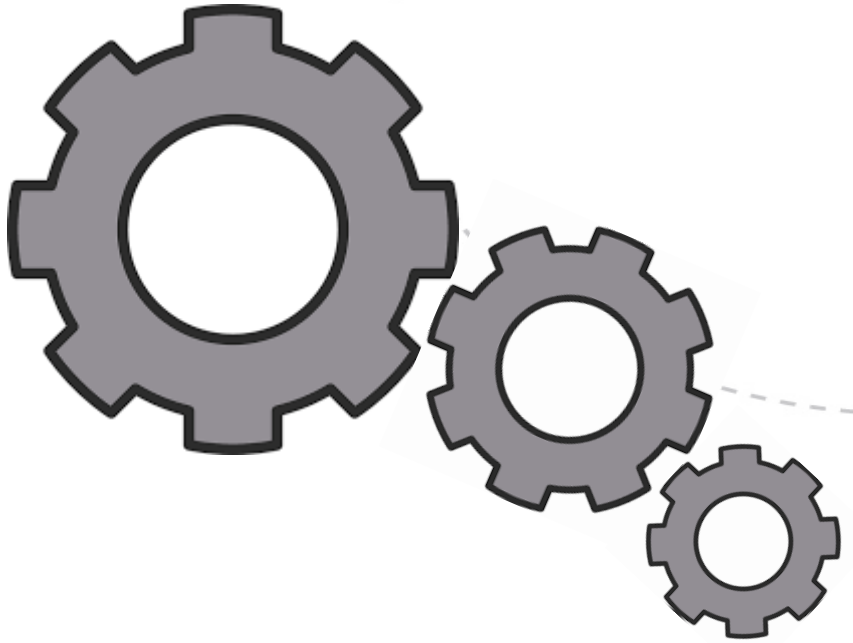


Engineering models

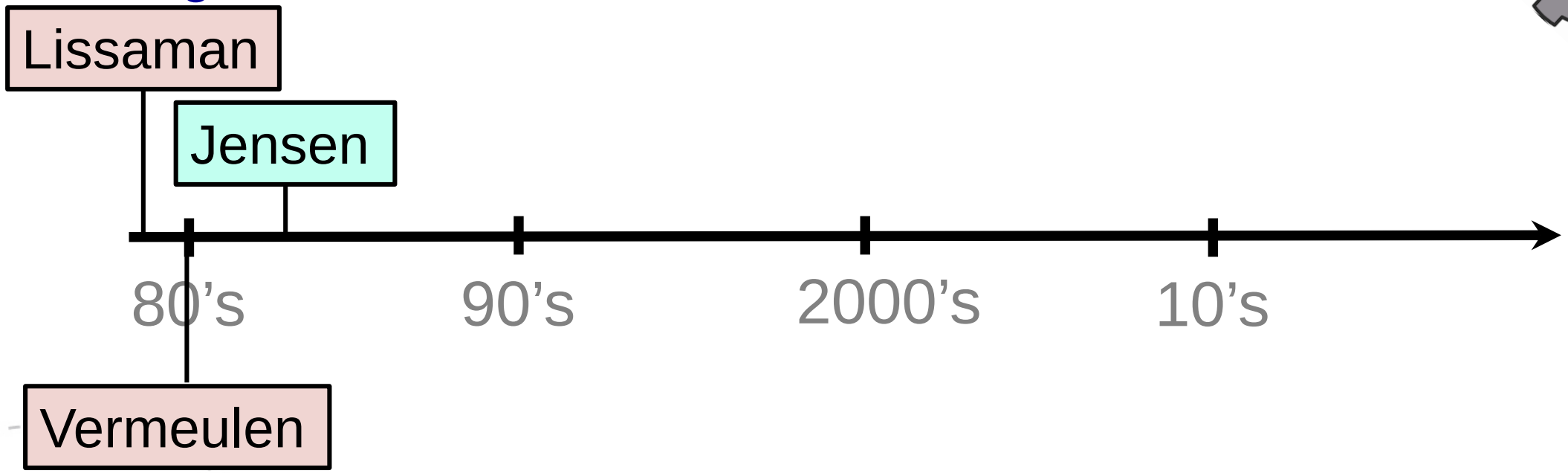
- Focus on simplicity
- Small number of parameters
- Steady-state vs dynamic



Engineering models

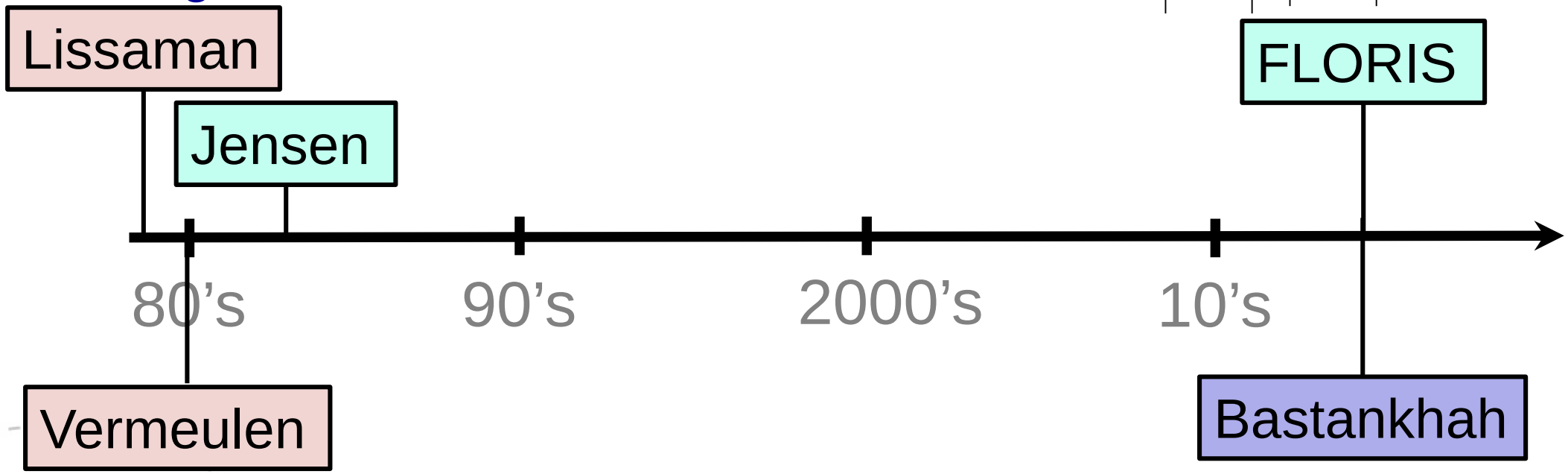


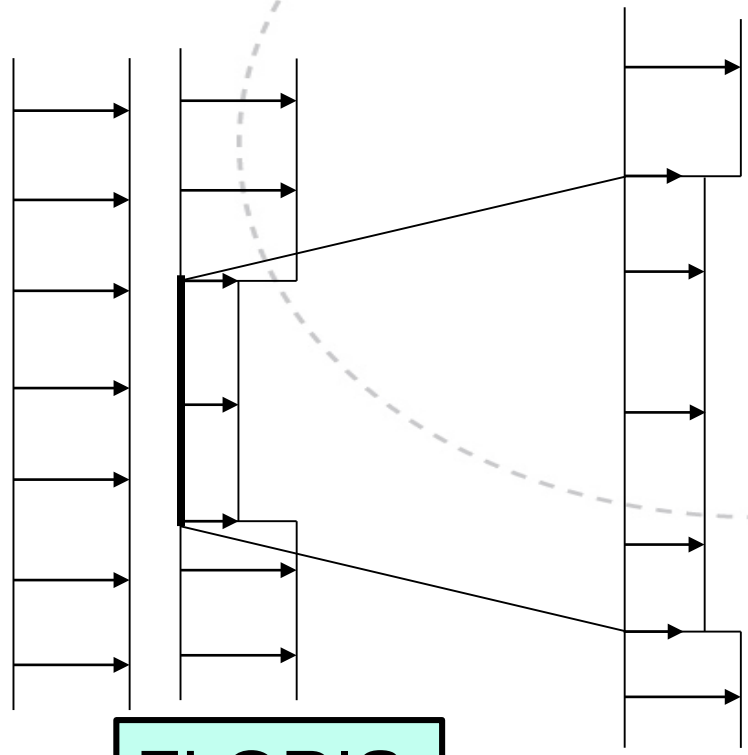
- Focus on simplicity
- Small number of parameters
- Steady-state vs dynamic
- E.g.



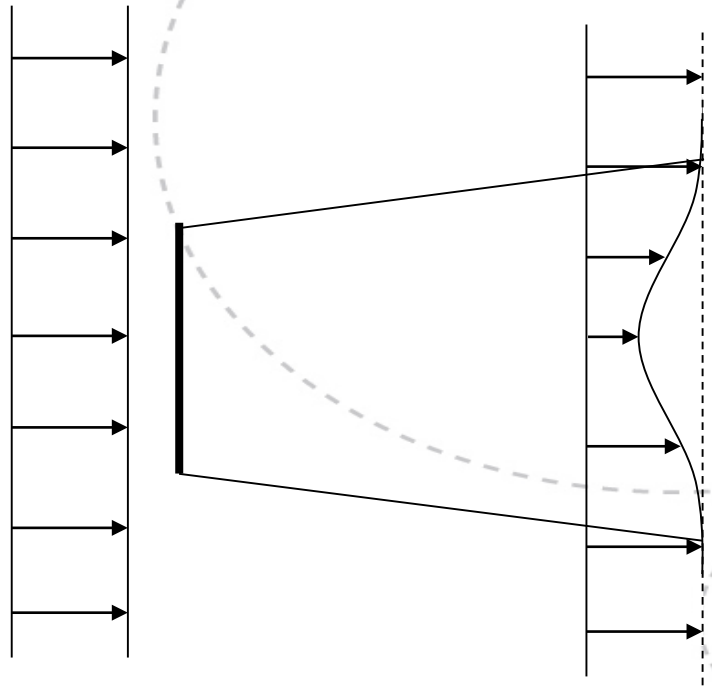
Engineering models

- Focus on simplicity
- Small number of parameters
- Steady-state vs dynamic
- E.g.

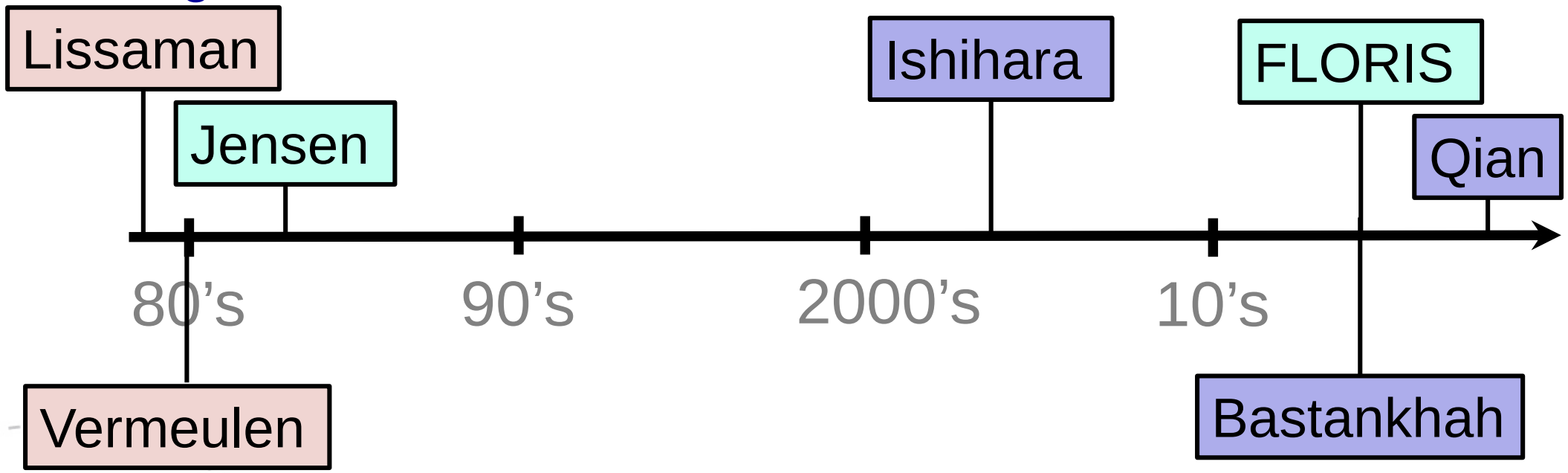




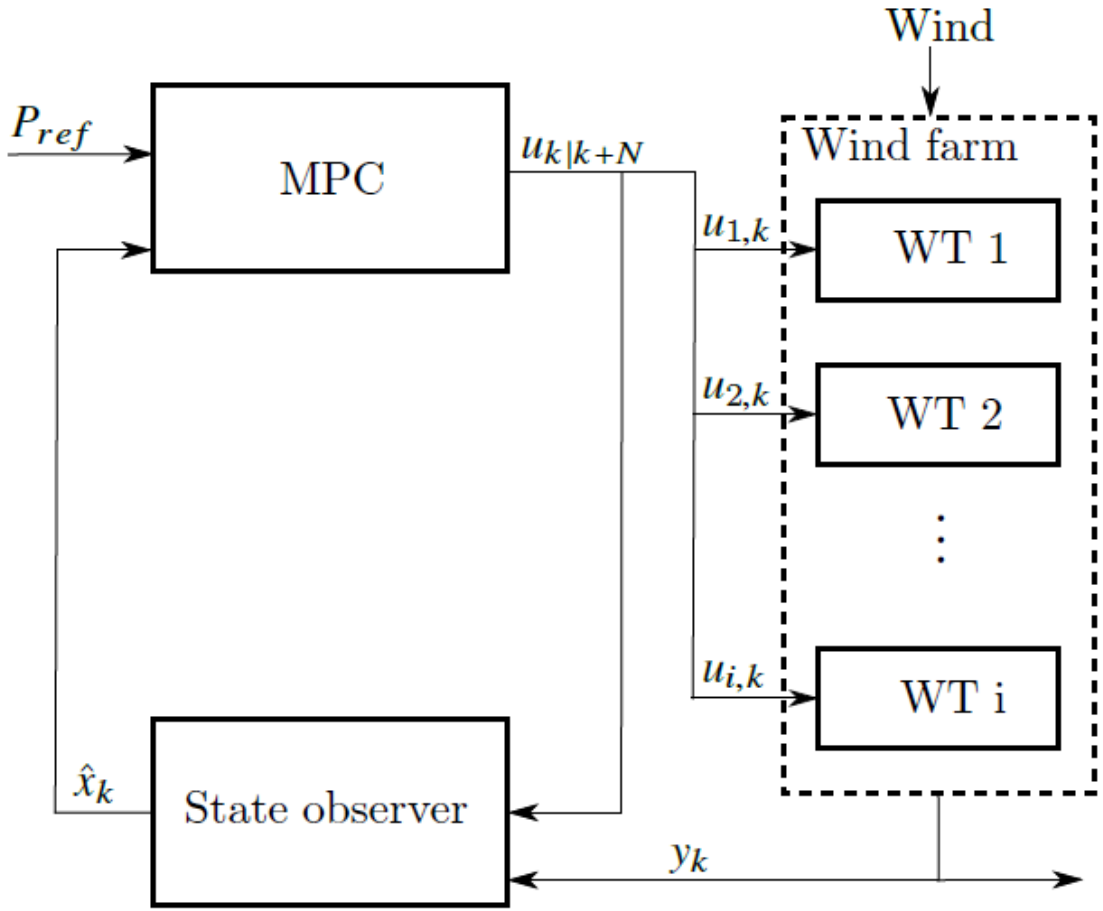
Engineering models



- Focus on simplicity
- Small number of parameters
- Steady-state vs dynamic
- E.g.



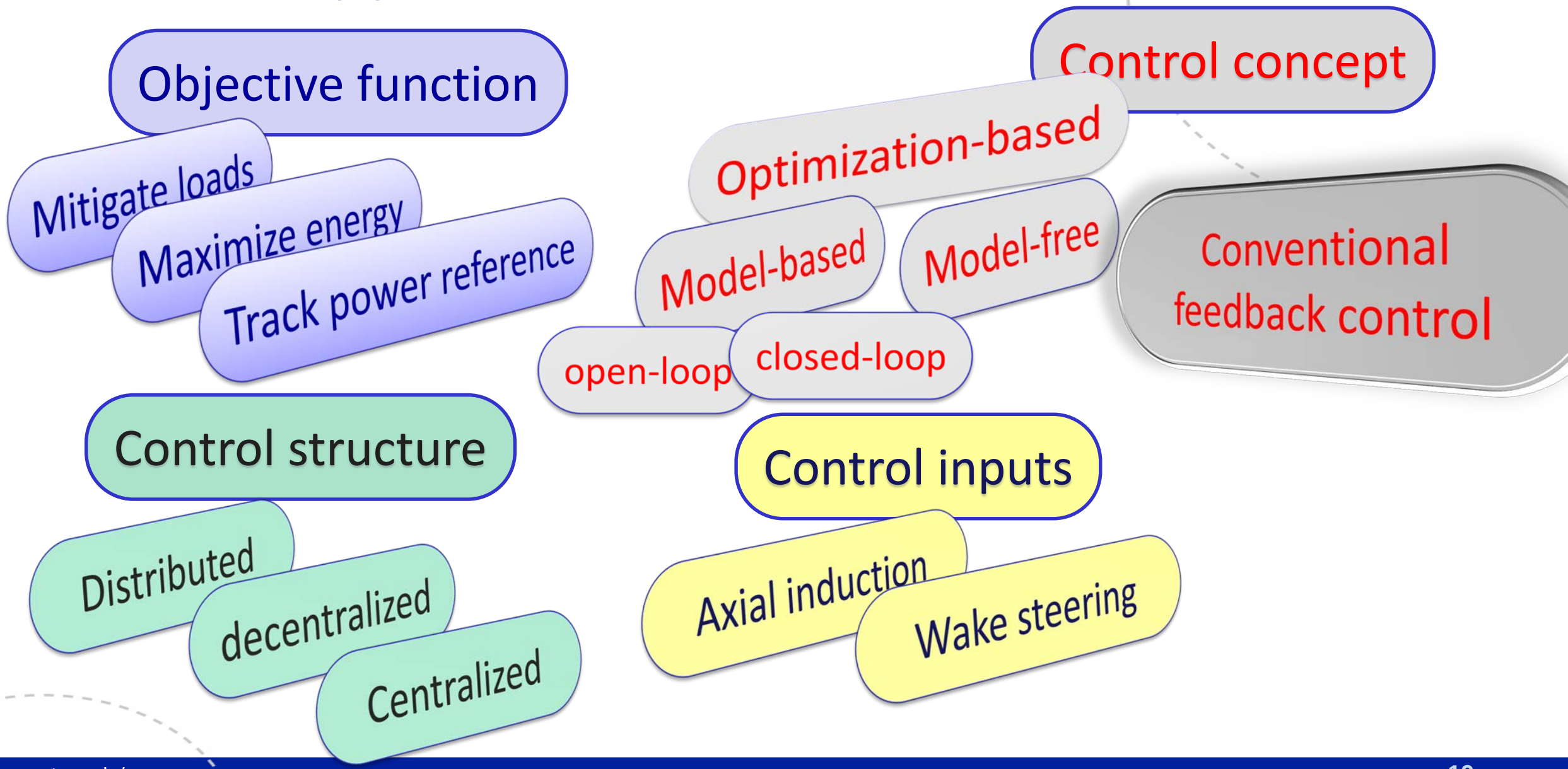
Example – centralized model-predicitive control (MPC)



OPWIND

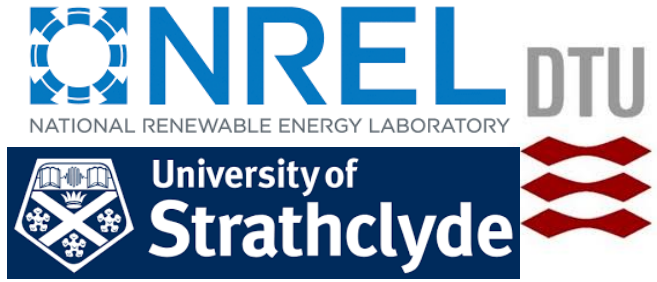
NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Control approaches

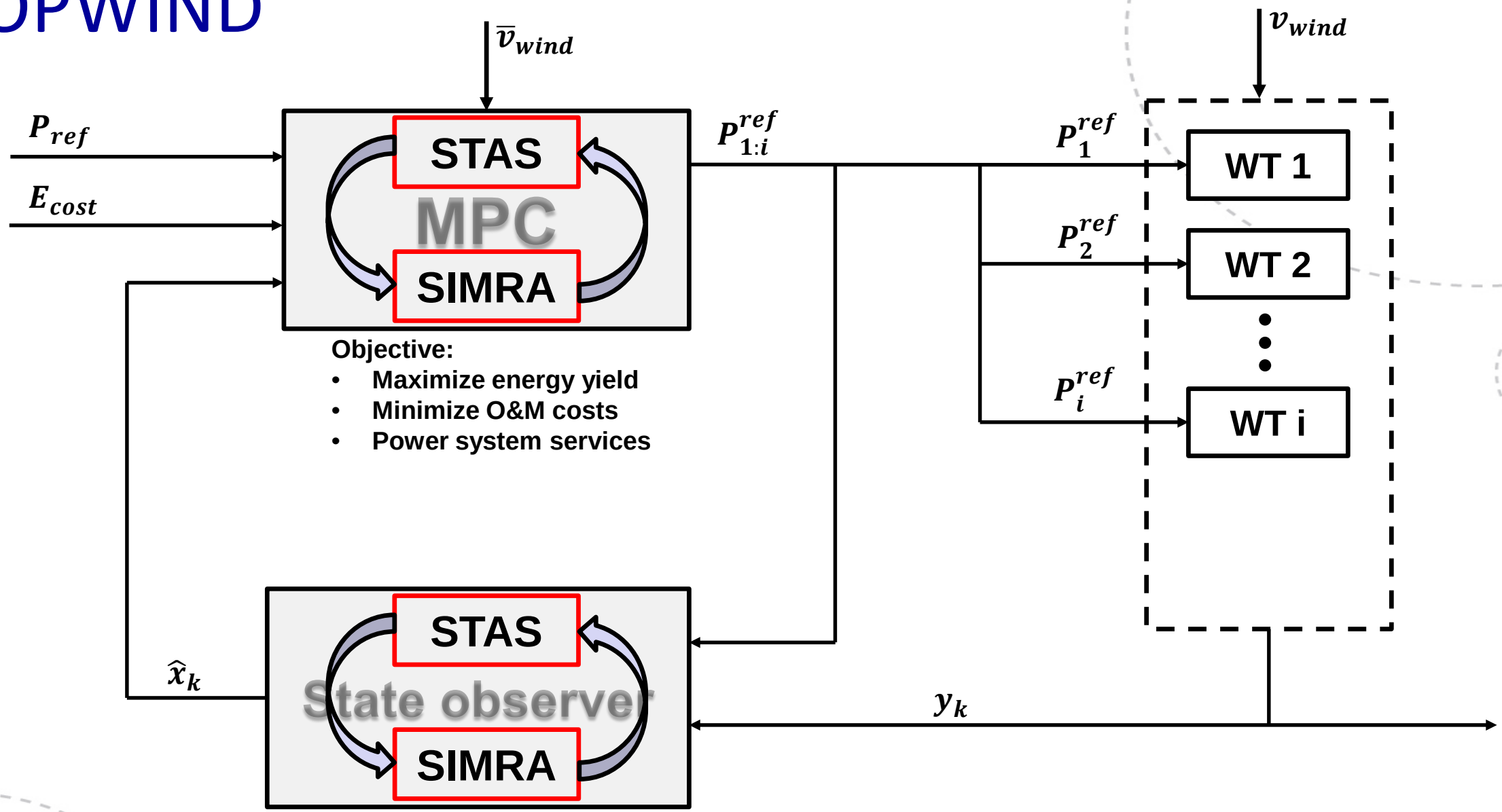


OPWIND

- OPerational control for WIND power plants



OPWIND


$\bar{v}_{wind}$
v_{wind}
P_{ref}
E_{cost}
STAS
MPC
SIMRA
$P_{1:i}^{ref}$
P_1^{ref}
P_2^{ref}
P_i^{ref}
WT 1
WT 2
WT i
Objective:
• Maximize energy yield
• Minimize O&M costs
• Power system services
$\hat{x}_k$
STAS
State observer
SIMRA
y_k

Thank you!

Questions?

OPWIND

NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Modifier Adaptation with Gaussian process regression

- Optimize model does not necessarily optimize plant
- Idea: Correct the model with plant measurements

$$\mathbf{u}_{k+1}^{*} = arg\min_{\mathbf{u}} \phi(\mathbf{u}) + (\mathcal{GP})_k^{\mathbf{\Phi}_p - \mathbf{\Phi}}(\mathbf{u}, \mathbf{U}_k)$$

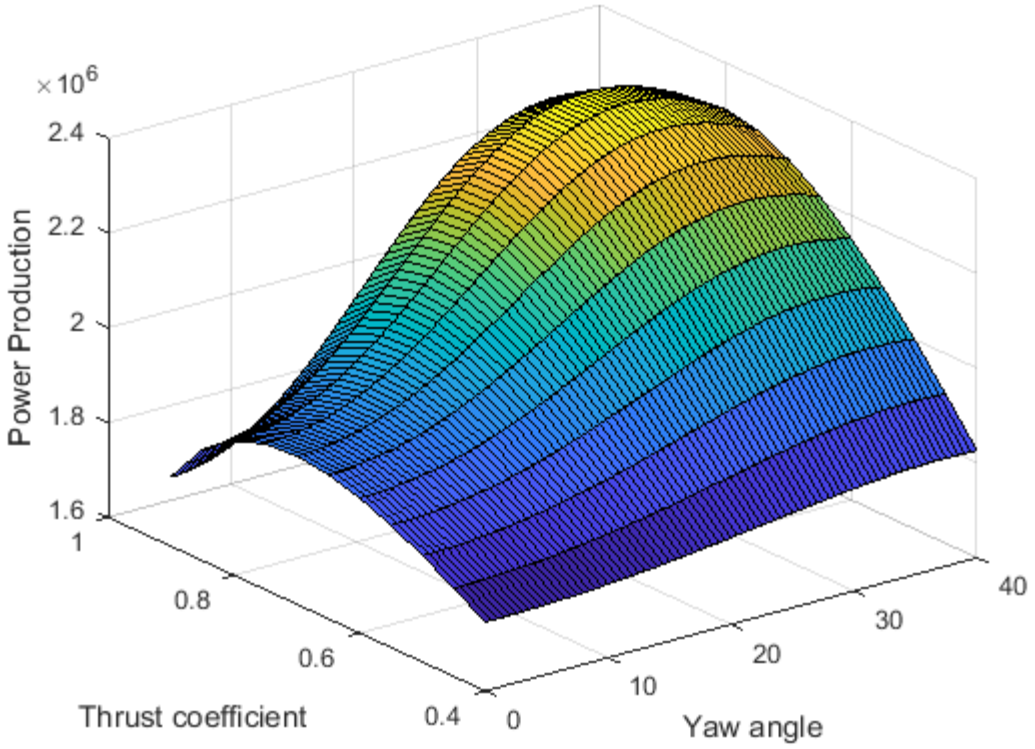
$$s.t. \quad G_i(\mathbf{u}) + (\mathcal{GP})_k^{(G_{p,i} - G_i)}(\mathbf{u}, \mathbf{U}_k) \leq 0, \quad i = 1, \ldots, n_g,$$

$$\mathbf{u} \in \mathcal{U},$$

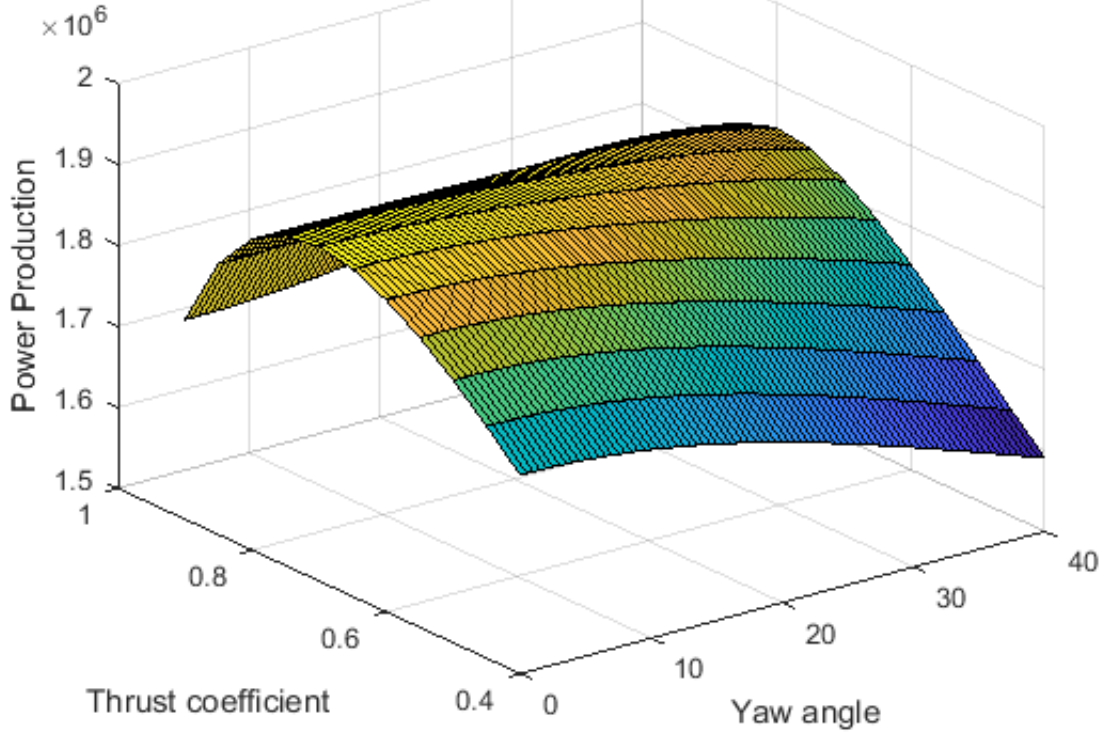
NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Example – 2 turbines & 2 control inputs

Plant objective function



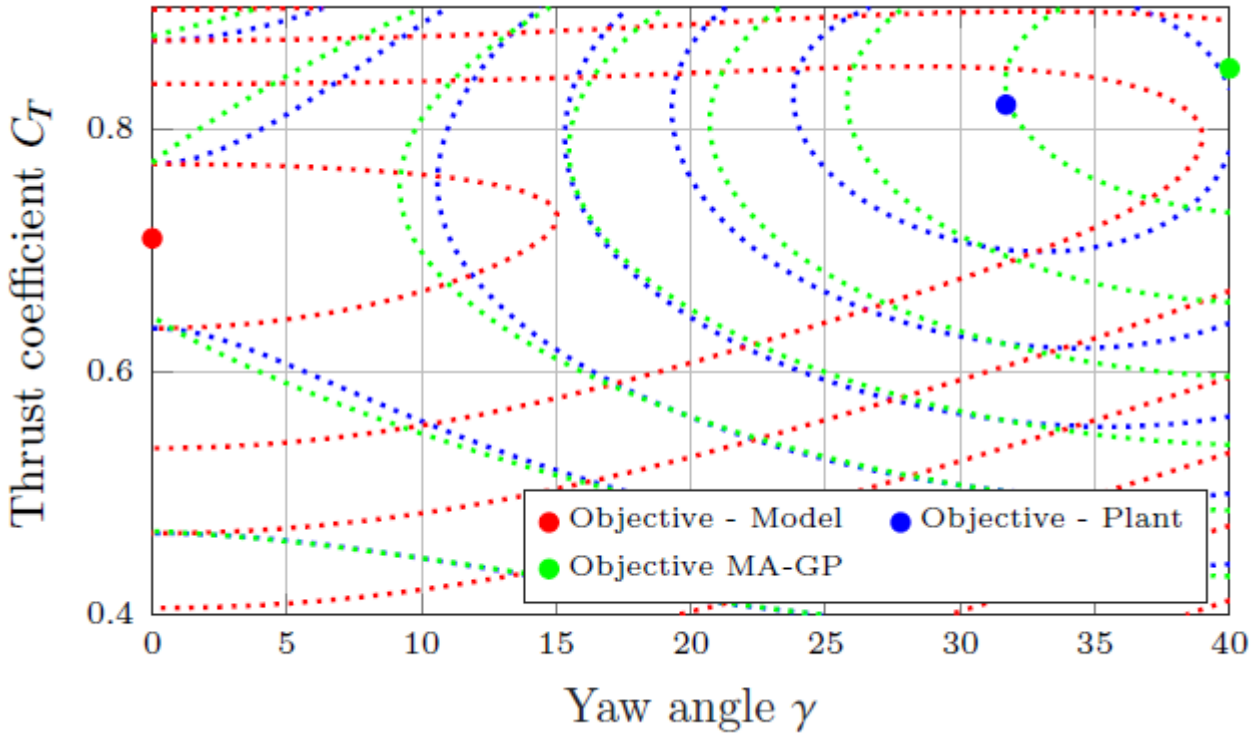
Model objective function

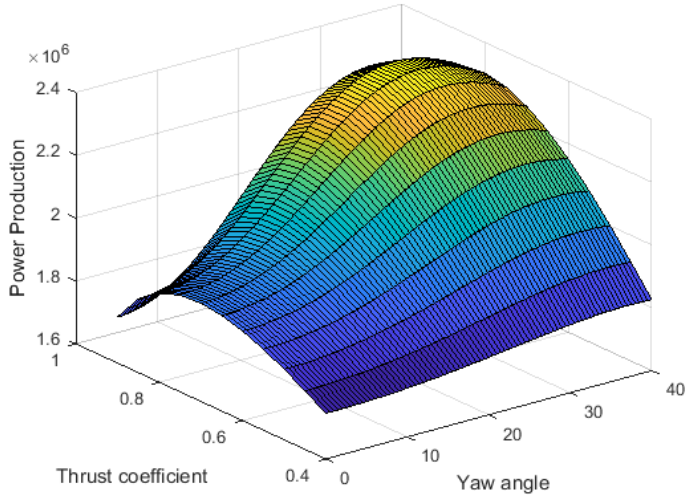


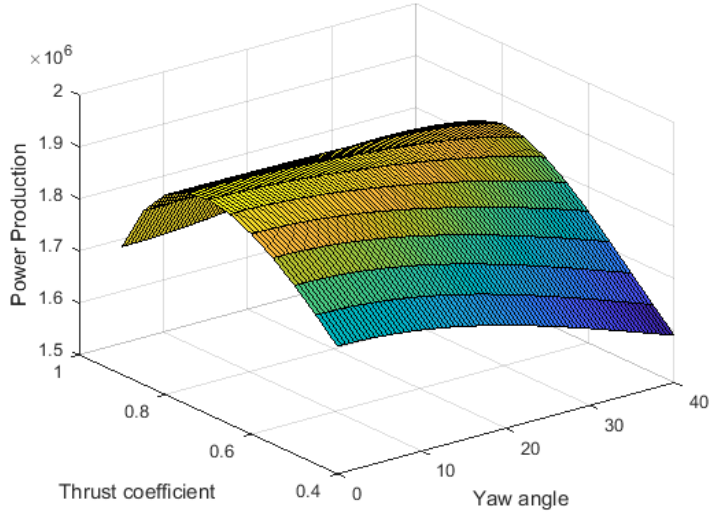
NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Example – 2 turbines & 2 control inputs

Corrected objective function – after training



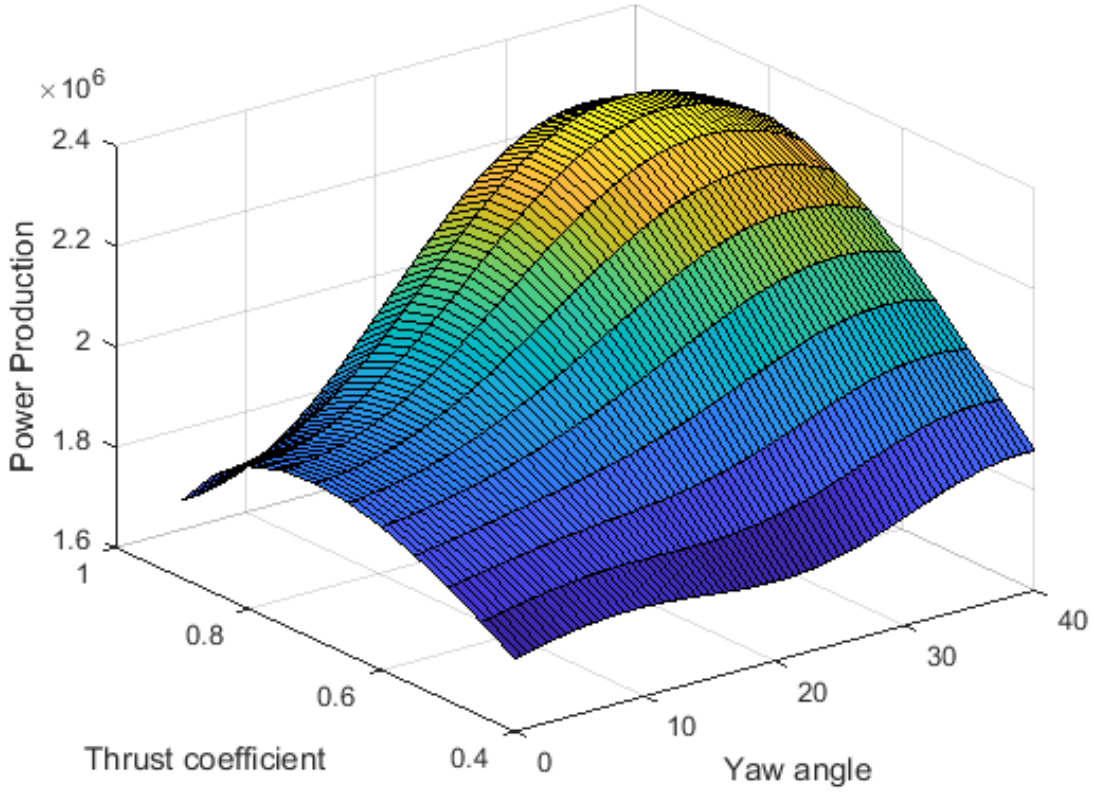


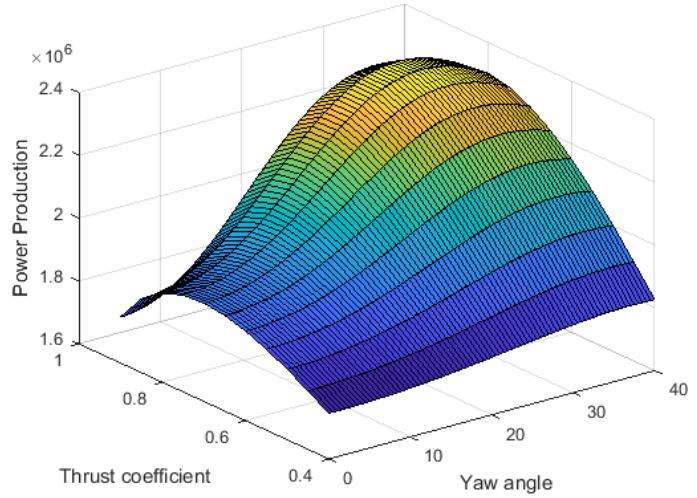


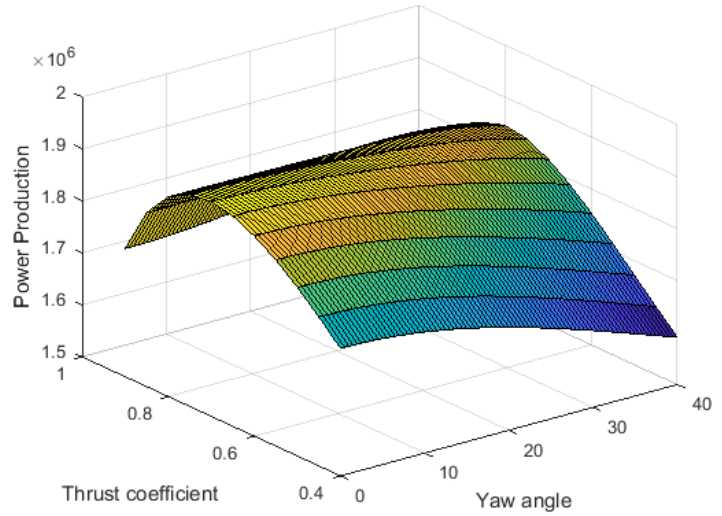
NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Example – 2 turbines & 2 control inputs

Corrected objective function – 10 iteration







NTNU AMOS
Centre for Autonomous Marine Operations and Systems