



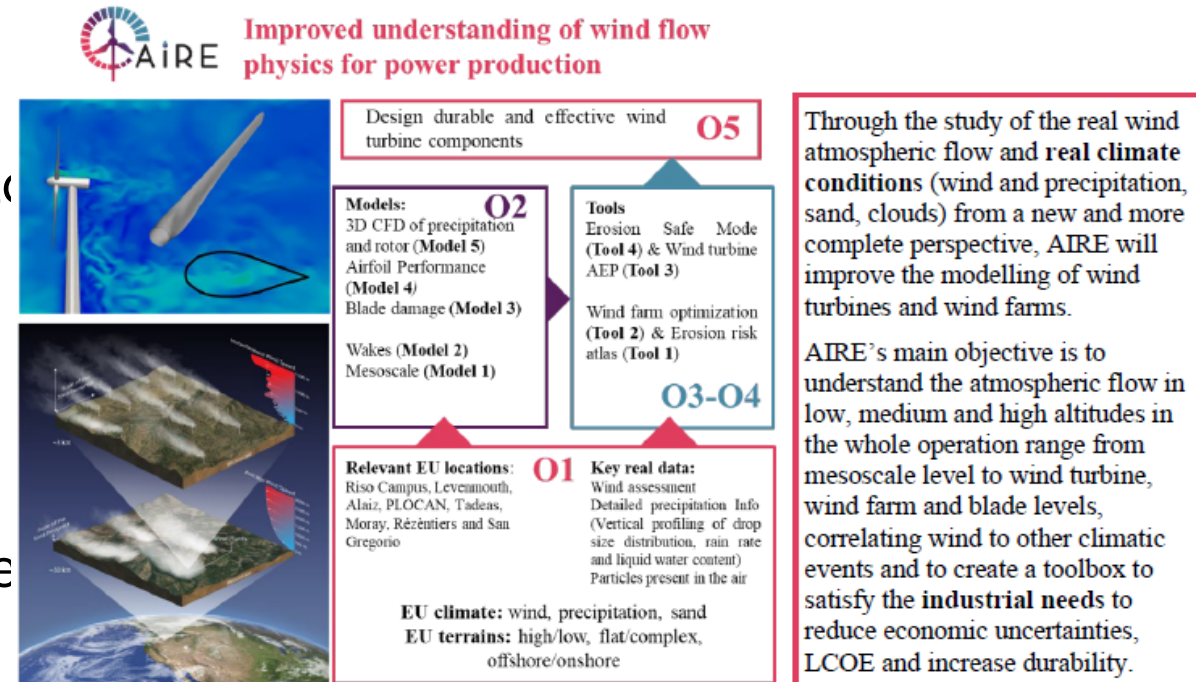
# DTU WPP<sub>ctrl</sub>

Application of an integrated wind farm control toolbox for optimized operation including blade erosion

Thanasis Barlas, Jens Visbech, Maria Aparicio-Sanchez, Irene Eguinoa, Jonas Schulte

# Project/task objectives

- EU AIRE focuses on real climate conditions impact (altitude, complex terrain, precipitation, sand)
- T4.3 focuses on including effects of blade erosion and erosion safe operation in wind farm (control) tools
- Linked to T4.5 where an optimal erosion-safe curtailment strategy is developed



# Motivation

On a wind farm level:

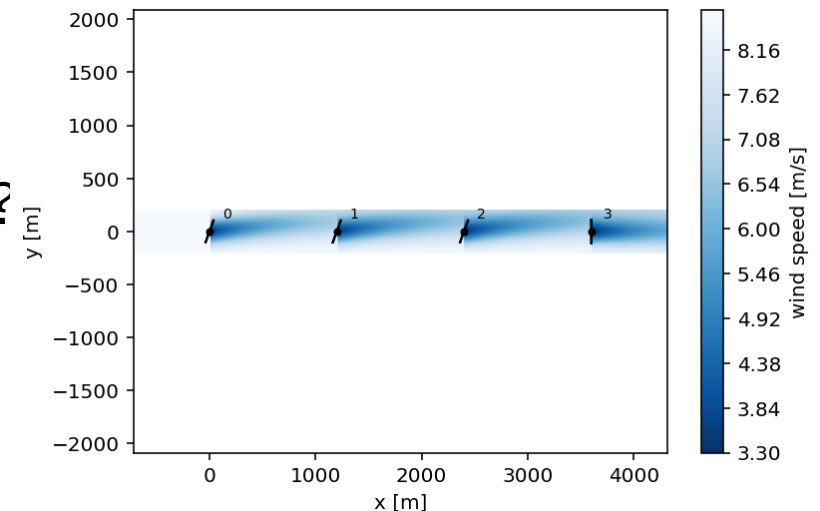
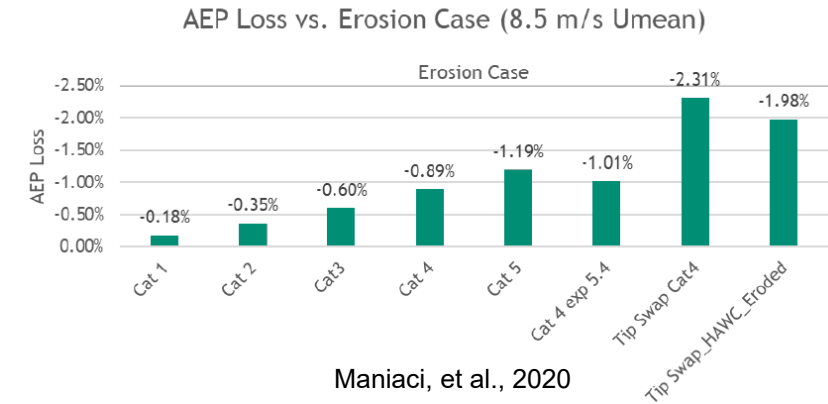
- Impact of erosion
- Impact of erosion safe mode
- Impact of yaw misalignment control

Include:

- dynamic effects of farm flow
- realistic WT\_ctrl, WPP\_ctrl, WFF\_ctrl, servos

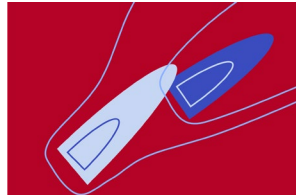
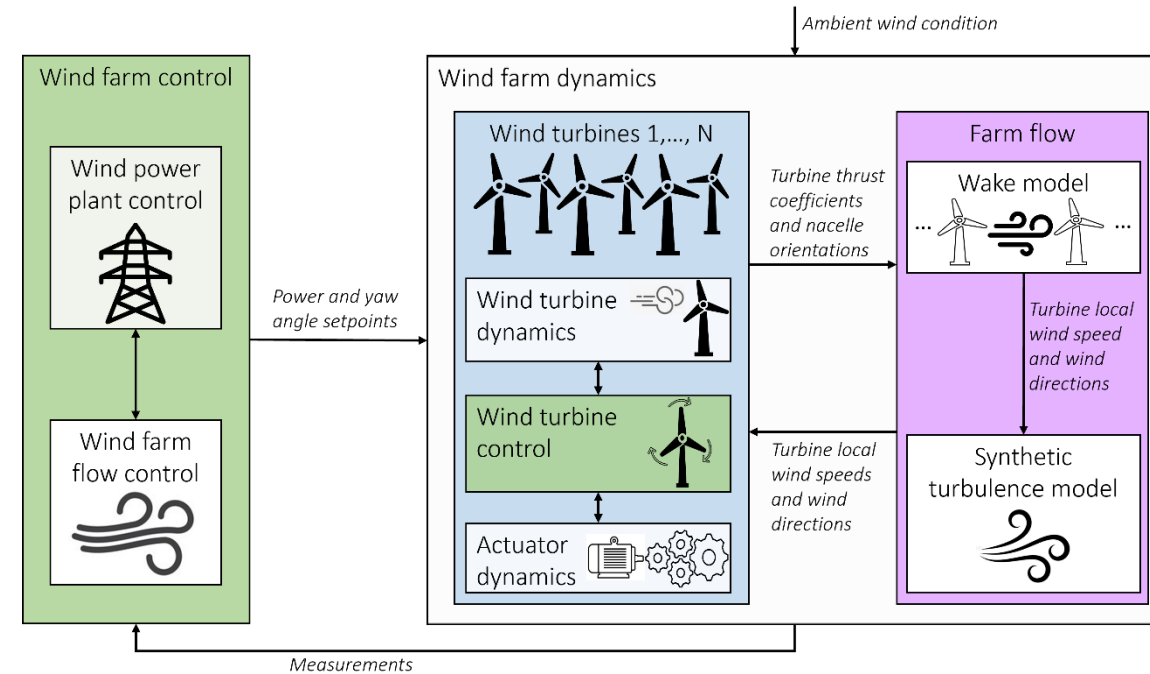
'Why not just use a tool like FLORIDyn or Dynamiks?'

- Focus on integrated WPP ctrl with realistic WT ctrl
- Need for flexibility in  $C_p/C_t = f(\text{TSR}, \text{pitch}, \text{yaw}, \text{erosion})$
- Need for flexibility in different wake model implementations



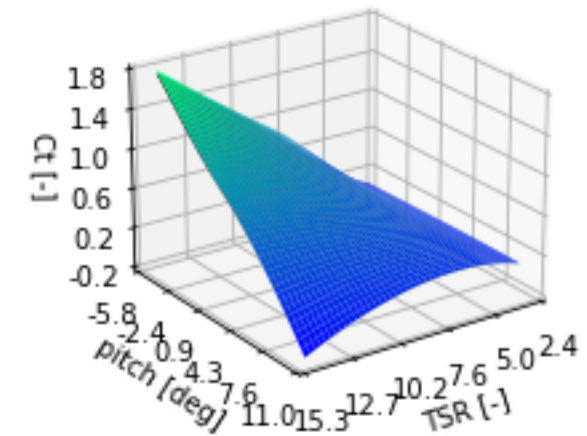
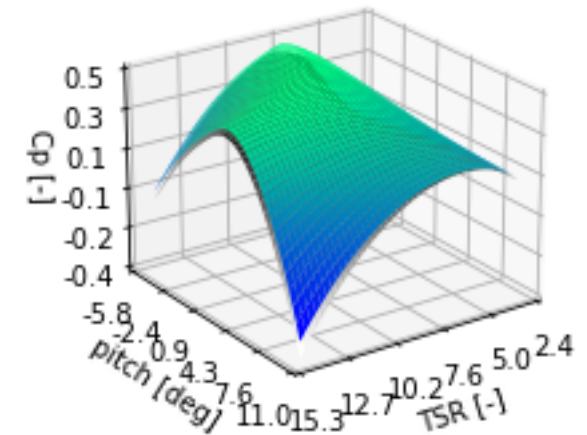
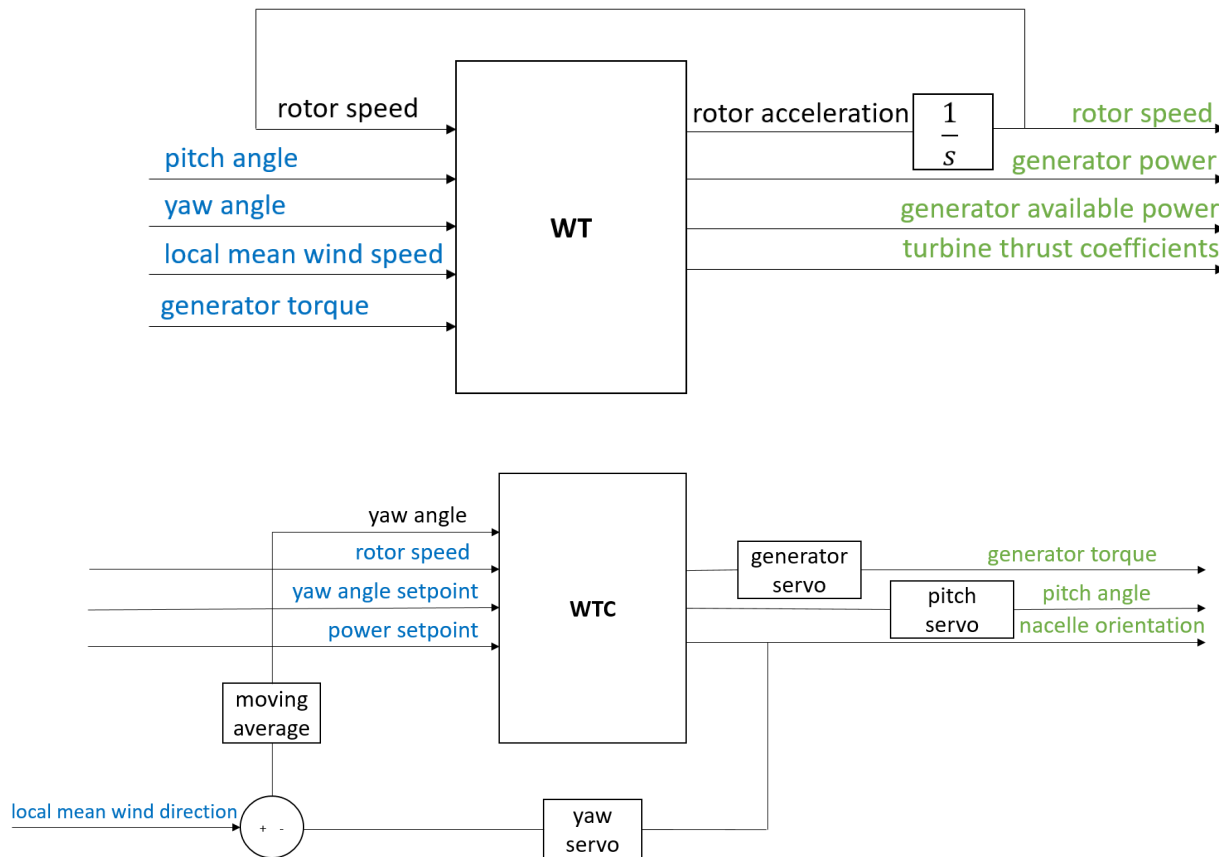
# Overview

- Control framework for WPPC and WFFC
- Time domain
- Realistic WTC (DTU-WEC)
- Realistic WPPC (MPPT, balance, delta)
- Flexibility for realistic WFFC
- Earlier Simulink model in EU-FarmConnors (with FLORIS)
- New Python implementation (with PyWake, FLORIS, FOXES)



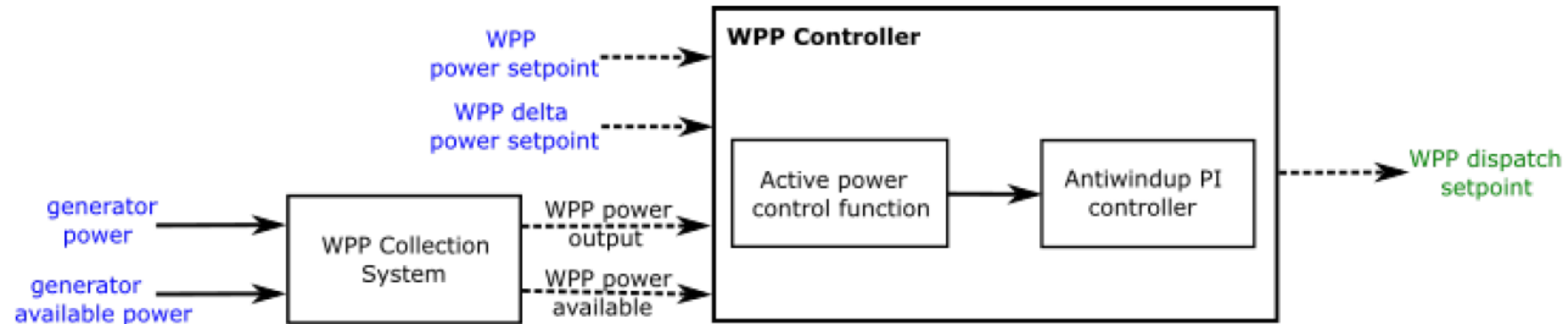
# DTU WPP<sub>ctrl</sub> modules

- WT and WTC
- $C_p/C_t = f(\text{TSR}, \text{pitch}, \text{yaw}, \text{erosion})$

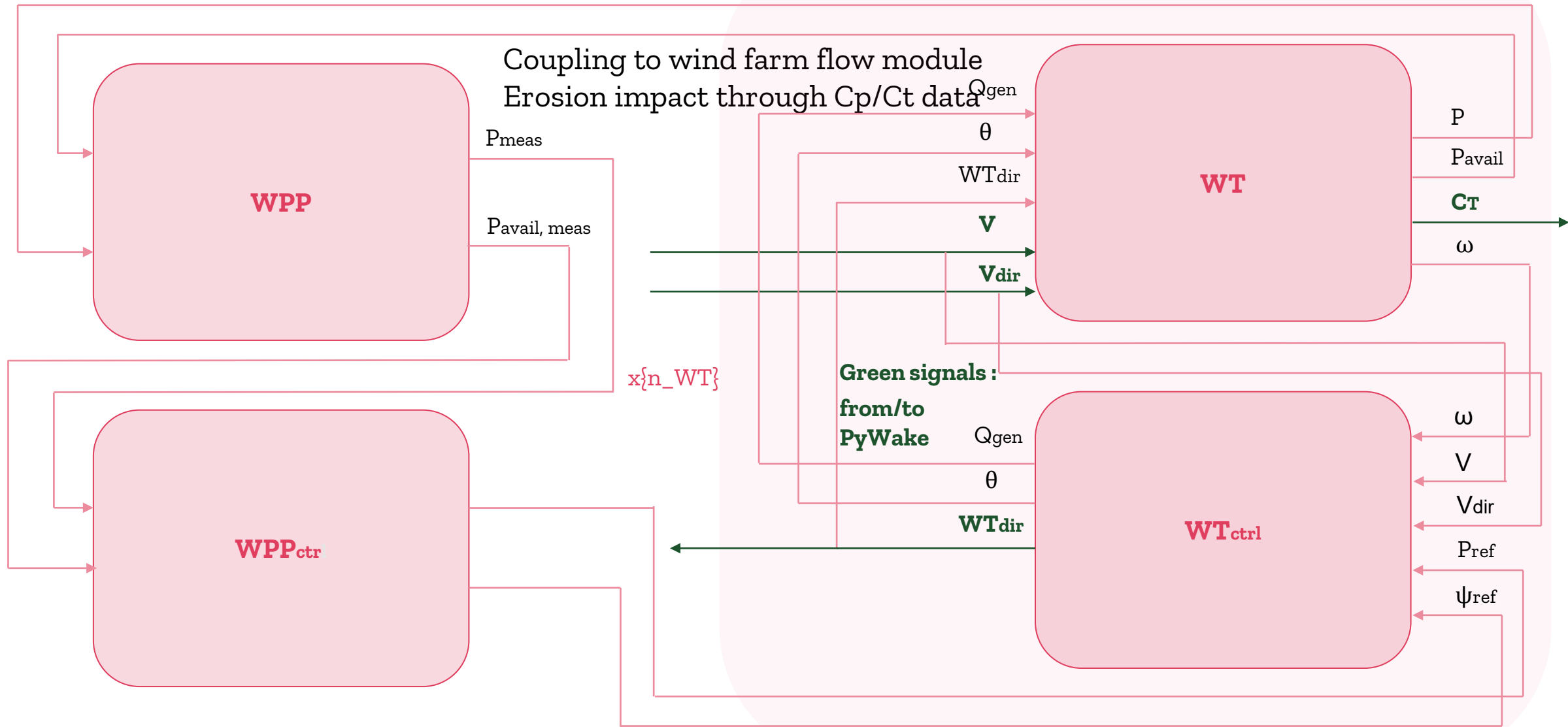


# DTU WPP<sub>ctrl</sub> modules

- WPP and WPPC/WFFC
- Dispatch of power setpoints (WPPC) and yaw setpoints (WFFC)



# DTU WPP<sub>ctrl</sub> modules integration



# DTU WPP<sub>ctrl</sub> updates/status

Coupling with PyWake/FLORIS/FOXES for quasi-steady wake effects with synthetic turbulence and wake advection

The code repository is shared here:

[gitlab.windenergy.dtu.dk/aire/dtu-wpp-ctrl](https://gitlab.windenergy.dtu.dk/aire/dtu-wpp-ctrl)

Includes basic documentation and examples

DTU WPP CTRL

- DTU wind power plant controller
- Wind turbine 1-DOF dynamic model using tabular  $C_p/C_t=f(\text{tsr}, \text{pitch}, \text{yaw}, \text{erosion})$
- DTU WEC wind turbine controller including yaw actuation and servos
- Wind power plant collection system
- Wind power plant controller with MPPT, balance and delta modes
- Coupling with PyWake for quasi-steady wake effects with synthetic turbulence and wake advection

The code repository is located here.

Alternative coupling with FLORIS from CENER is located here.

Alternative coupling with FOXES from IWES is located here.

Wind farm control

Wind farm dynamics

Wind turbines 1, ..., N

Wind turbine dynamics

Wind turbine control

Actuator dynamics

Farm flow

Wake model

Synthetic turbulence model

Ambient wind condition

Turbine thrust coefficients and nacelle orientations

Turbine local wind speeds and wind directions

Power and yaw angle setpoints

Measurements

### Content

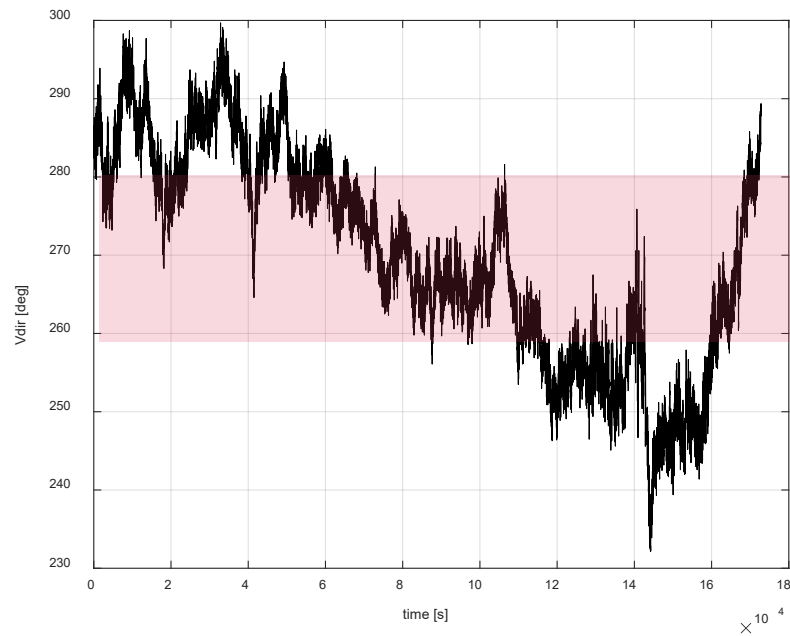
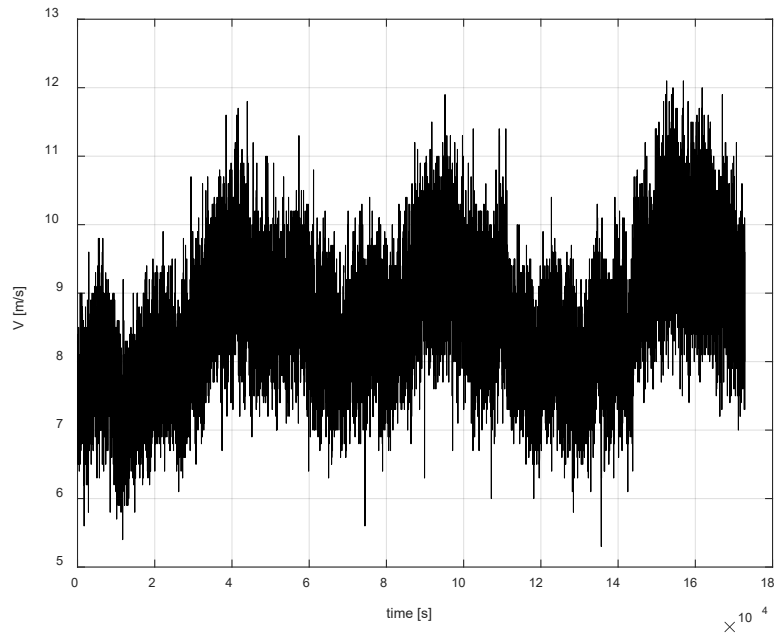
- Installation
- Getting started
- Examples
  - Wind steps from cut-in to cut-out at full wake direction on an array of 4xIEA-15MW-RWT at 5D
  - Wind direction ramp from full wake, to +30deg, and back at full wake direction on an array of 4xIEA-15MW-RWT at 5D
  - Impact of erosion level on an array of 4xIEA-15MW-RWT at 5D with 48h inflow data from Horns Rev
  - Impact of erosion safe mode (20% derating) on an array of 4xIEA-15MW-RWT at 5D with 48h inflow data from Horns Rev
  - Impact of erosion safe mode (20% derating) combined with sector-based yaw misalignment on an array of 4xIEA-15MW-RWT at 5D with 48h inflow data from Horns Rev
- Parameters
  - Input
  - Output
  - Parameters
  - Variables

Next

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Built with Sphinx using a theme provided by Read the Docs.

# Test case

- Array of 4 IEA-15MW-RWT at 5D
- 48h 1Hz inflow data from Horns Rev
- Around partial/rated power and full wake



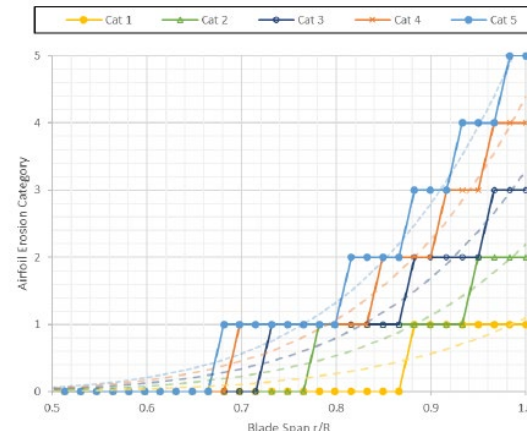
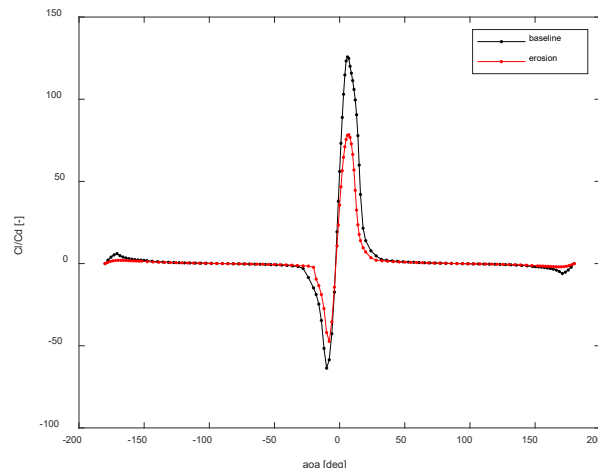
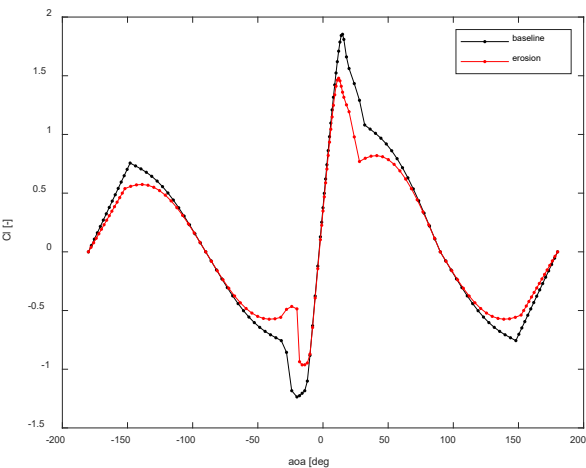
# Test case

- Erosion Cp/Ct input from IEA T.46/LEARCat (Cat 3)

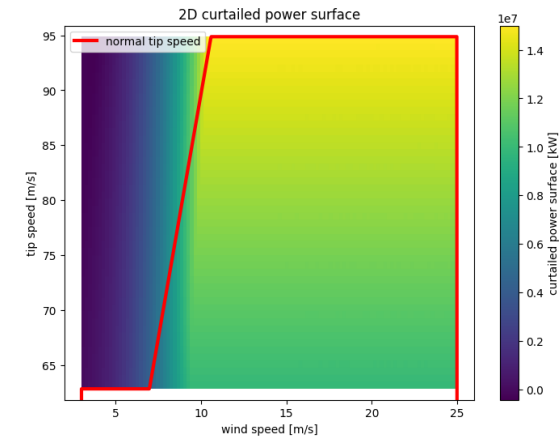
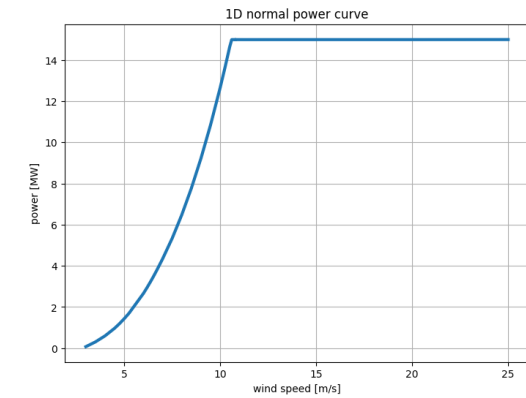
Cases:

- Baseline
- Erosion
- Erosion safe mode (ESM)
- ESM and yaw misalignment control (Yaw\_ctrl)

FFA-W3-211 (at 77%-100% span)

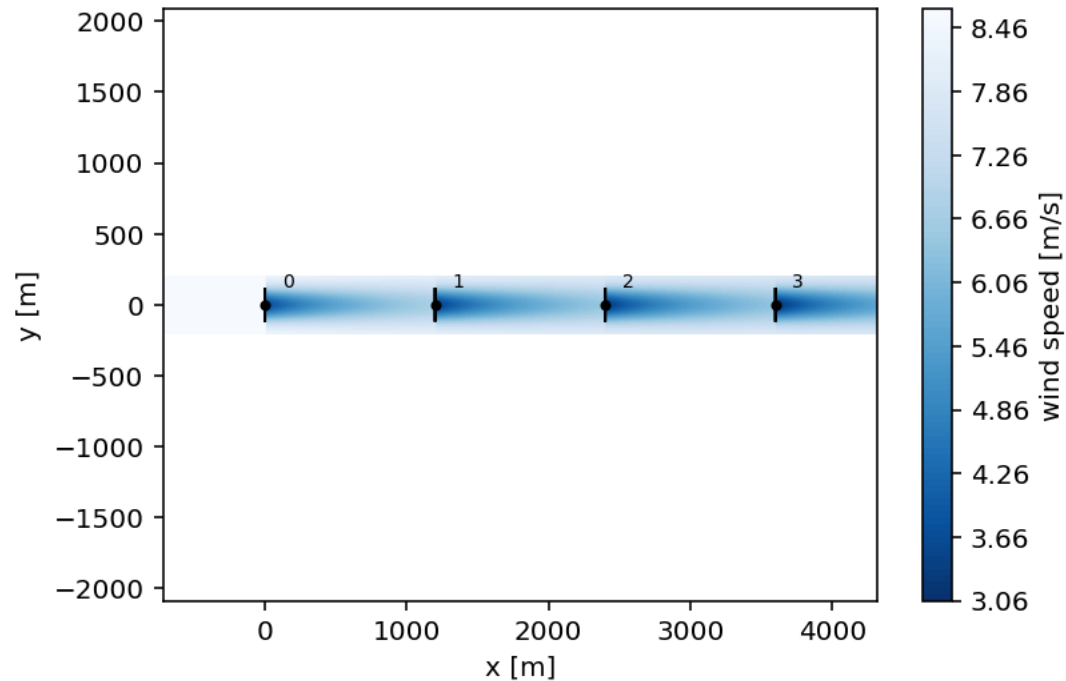


Maniaci, et al., 2020

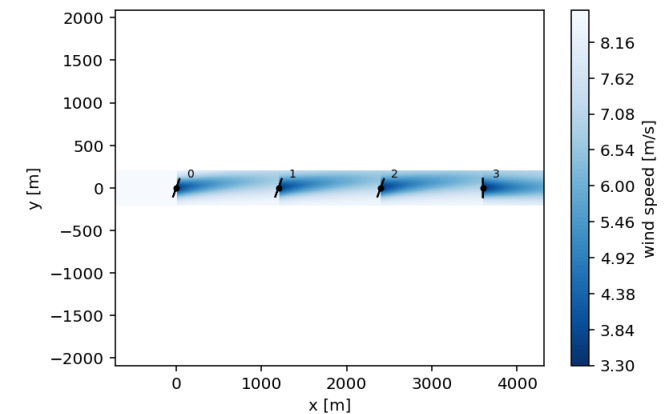
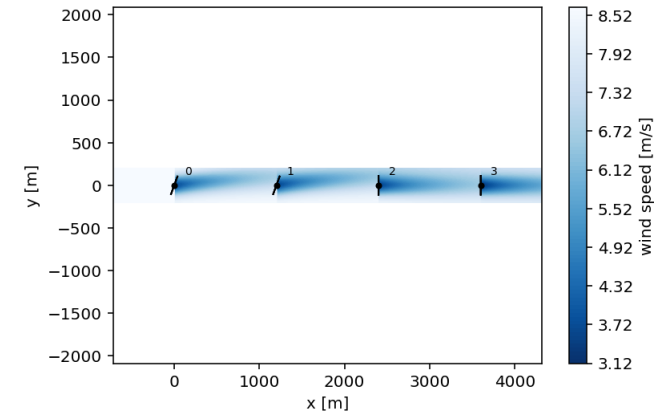
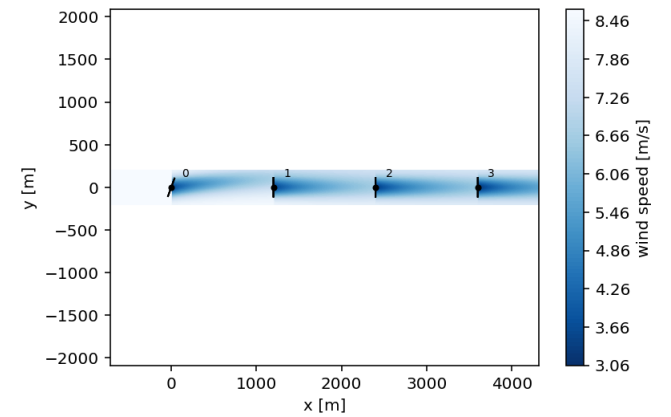


# Results

- Flow maps with yaw misalignment
- $V_{dir}$  sector  $270^\circ \pm 11.3^\circ$
- Example yaw  $20^\circ$

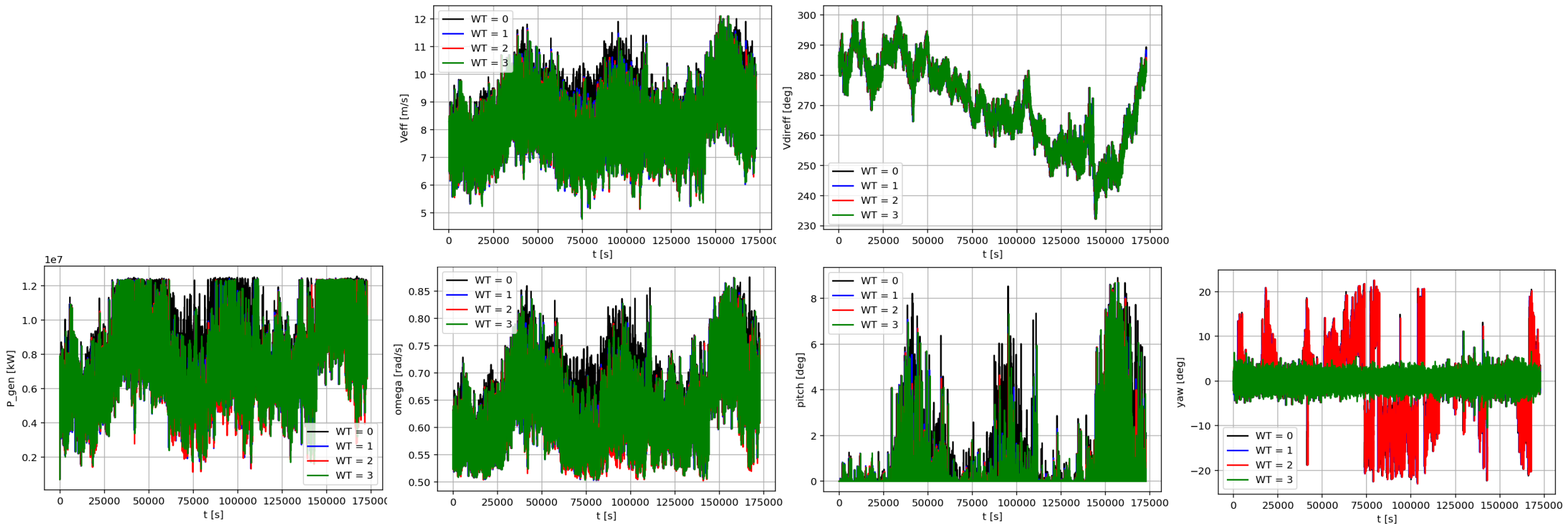


**PyWake models:**  
wake\_deficitModel=IEA37SimpleBastankhahGaussianDeficit()  
superpositionModel=SquaredSum()  
deflectionModel=JimenezWakeDeflection()  
turbulenceModel=CrespoHernandez()  
rotorAvgModel=EqGridRotorAvg(3)



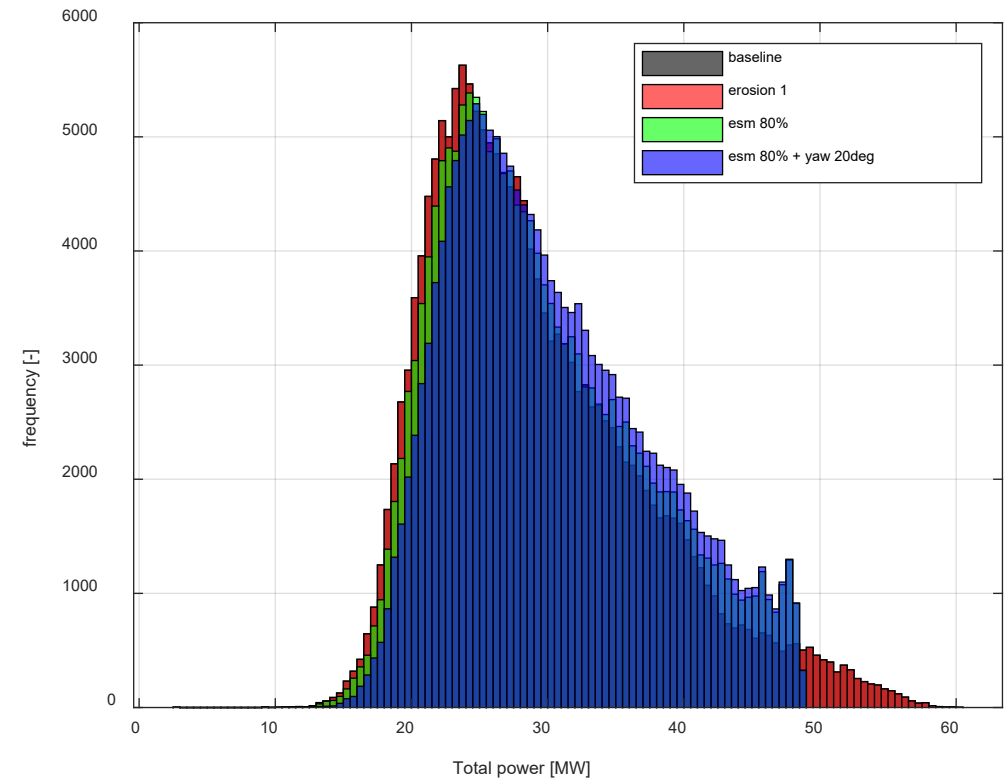
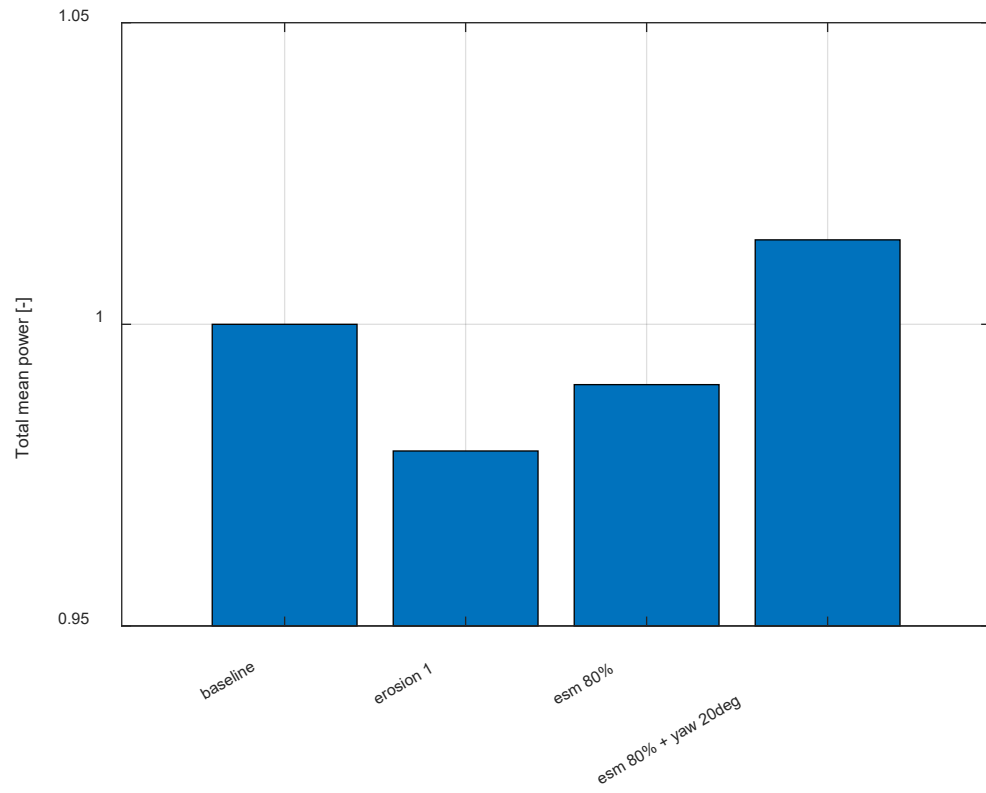
# Results

- Operational for ESM+Yaw\_ctrl
- ESM: 80% derating
- Yaw\_ctrl:  $\pm 20$ deg in sector



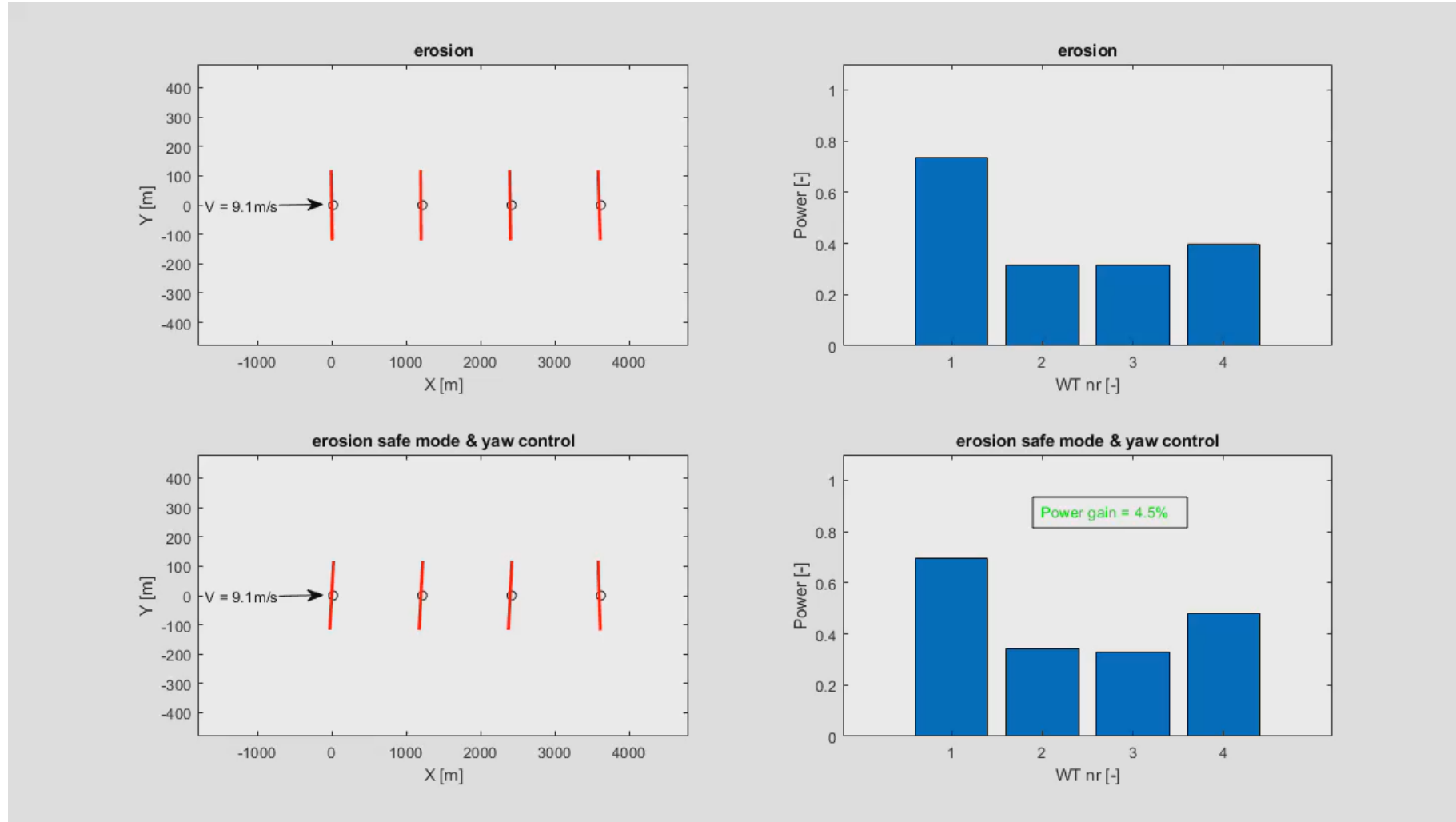
# Results

- Power impact of erosion (-2.1%), ESM (-1.0%)
- Potential power recovery with ESM+Yaw\_ctrl (+1.4%)
- Steady-state prediction with ESM+Yaw\_ctrl: +3.2%



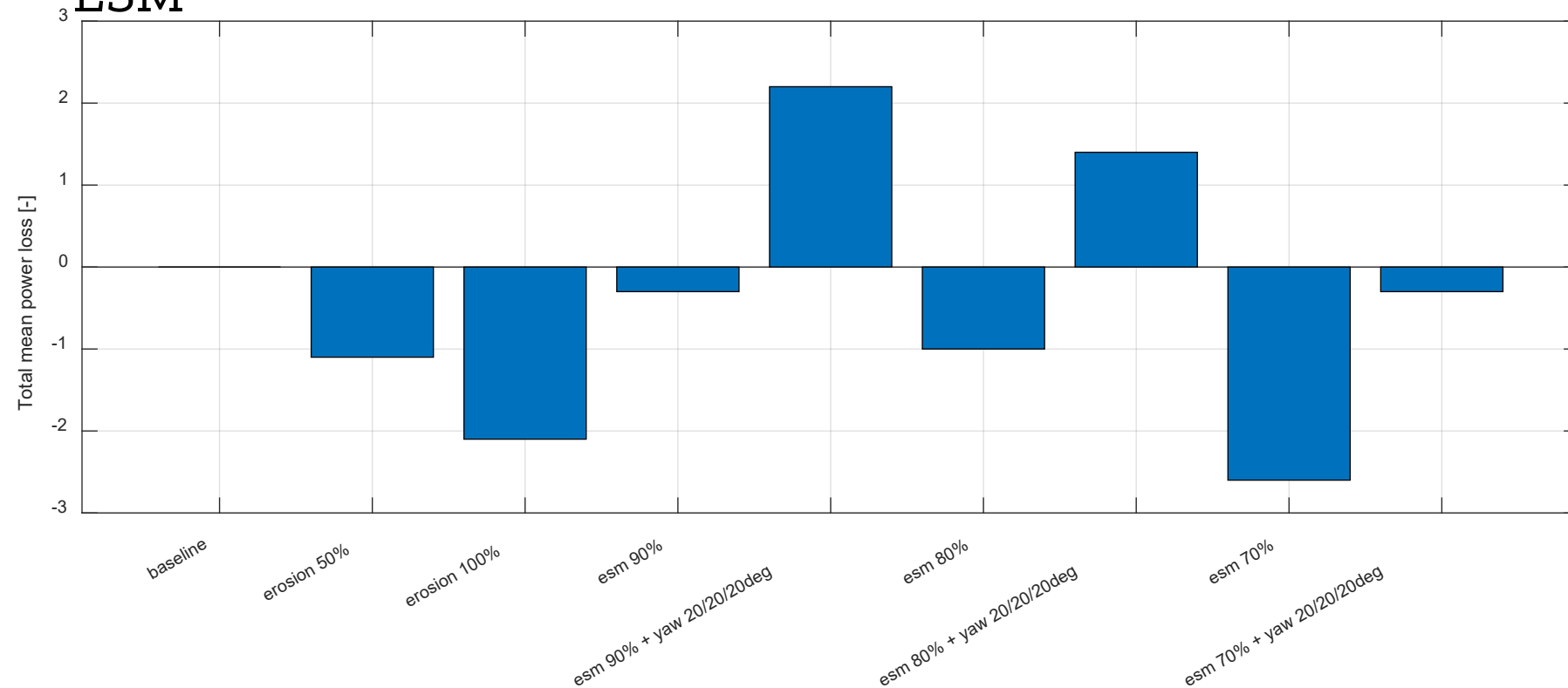
# Results

Animation of simulation case with erosion vs ESM+Yaw\_Ctrl



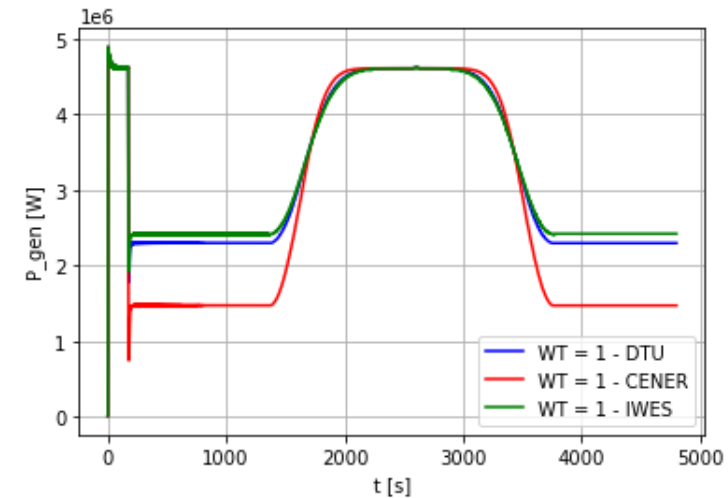
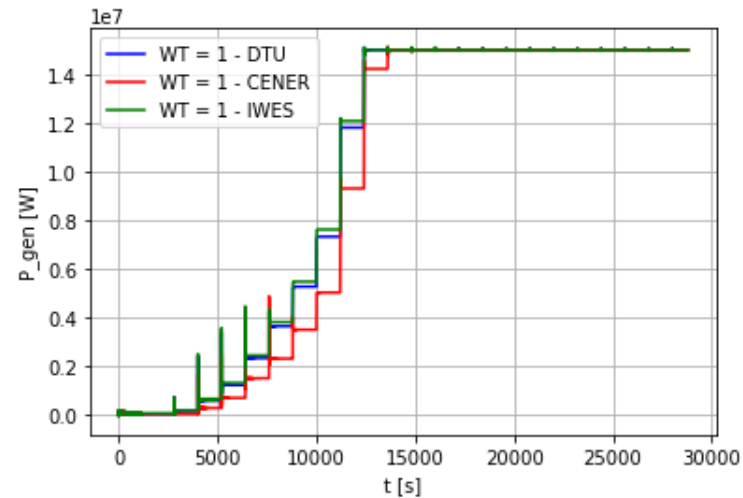
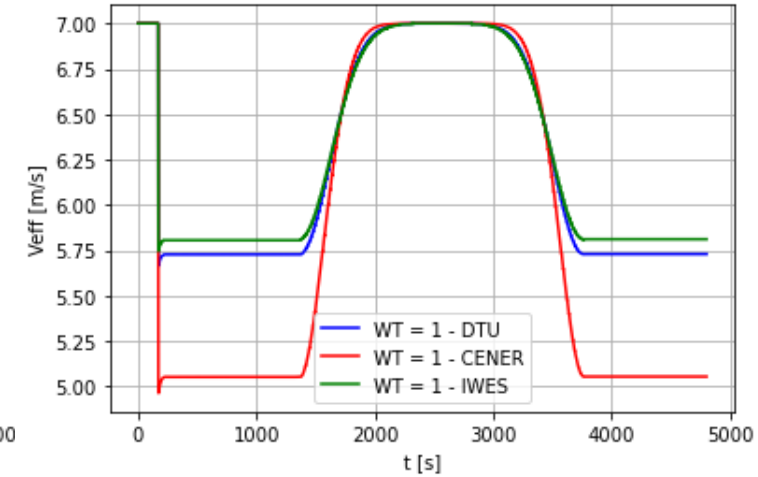
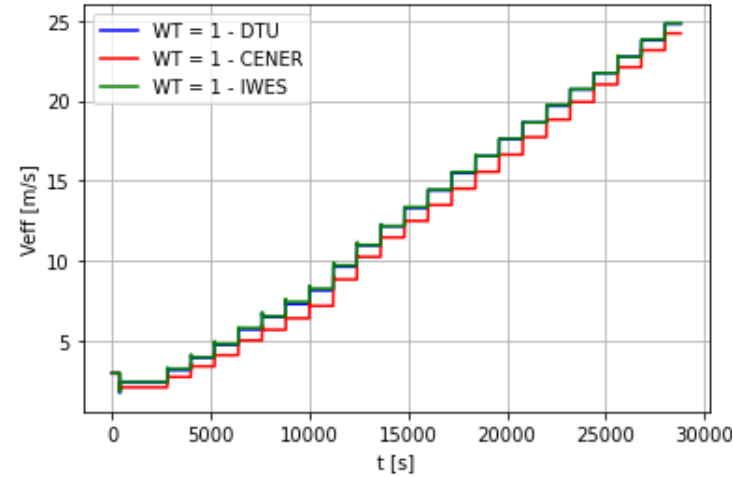
# Results

- Sensitivity to erosion, ESM, Yaw\_ctrl
- Feasible power recovery/gain with Yaw\_ctrl down to ~70% derating in ESM



# Results

- Comparison PyWake, FLORIS, FOXES
- Wind step test
- Wind dir ramp test

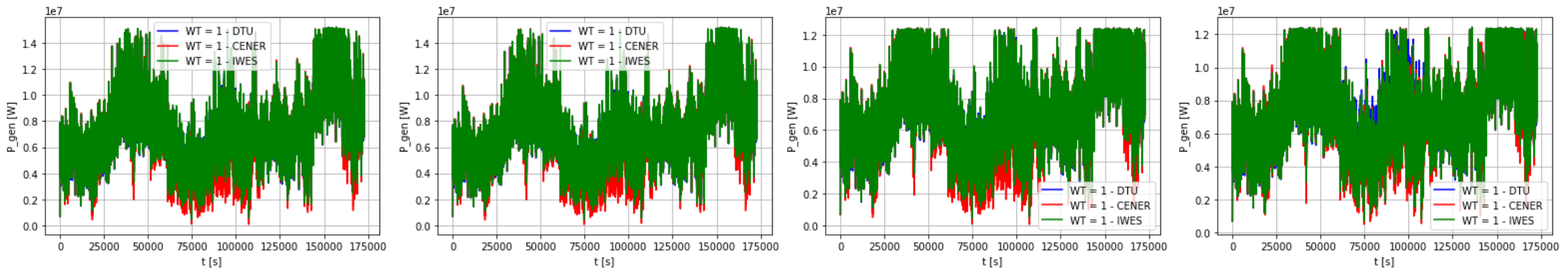


# Results

- Comparison PyWake, FLORIS, FOXES
- Inflow case (48h 1Hz inflow data from Horns Rev)

Cases:

- Baseline
- Erosion
- Erosion safe mode (ESM)
- ESM and yaw misalignment control (Yaw\_ctrl)

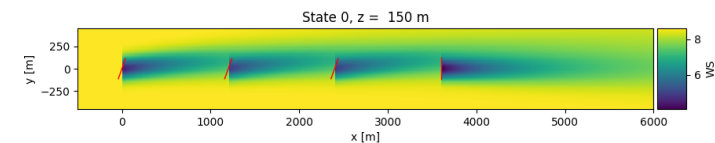
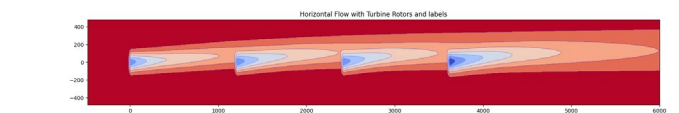
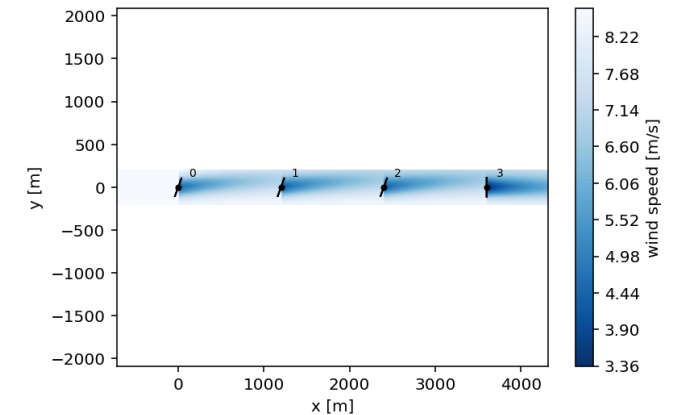


# Results

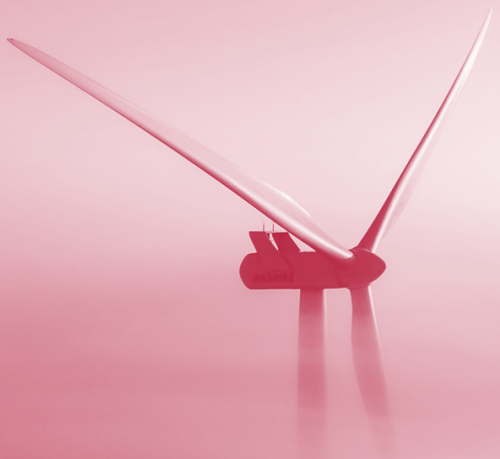
- Comparison PyWake, FLORIS, FOXES
- Prediction of mean power impact of ESM/Yaw\_ctrl
- Dynamic vs static cases
- Impact of static wake

% compared to baseline (no erosion)

case	DTU	DTU	CENER	CENER	IWES	IWES
	dyn	st	dyn	st	dyn	st
Erosion	-2.1	-1.4	-2.1	-1.1	-2.2	-1.5
ESM	-1.0	0.0	-1.0	0.0	-1.0	0.0
ESM & Yaw	1.4	3.2	2.5	18.8	0.0	-10.7



# Conclusion



- Control framework for WPPC and WFC
- Erosion impact through Cp/Ct data
- ESM and Yaw\_ctrl capabilities
- Python implementation (with PyWake/FLORIS/FOXES)
- Impact of erosion, ESM, Yaw\_ctrl
- Impact of wake model choice
- Dynamic vs static

Next steps:

- Study effect of different erosion levels
- Apply to field test cases



# Thank you.

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[gitlab.windenergy.dtu.dk/aire/dtu-wpp-ctrl](https://gitlab.windenergy.dtu.dk/aire/dtu-wpp-ctrl)