Smart, Aware, Integrated Wind Farm Control Interacting with Digital Twins (ICONIC)

Professor Xiaowei Zhao
Intelligent Control and Smart Energy Research Group
University of Warwick
Xiaowei.zhao@warwick.ac.uk

10 September 2024

Funded by the European Union

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the granting authority. Neither the European Union nor the granting authority can be held responsible for them

UKRI Innovate UK

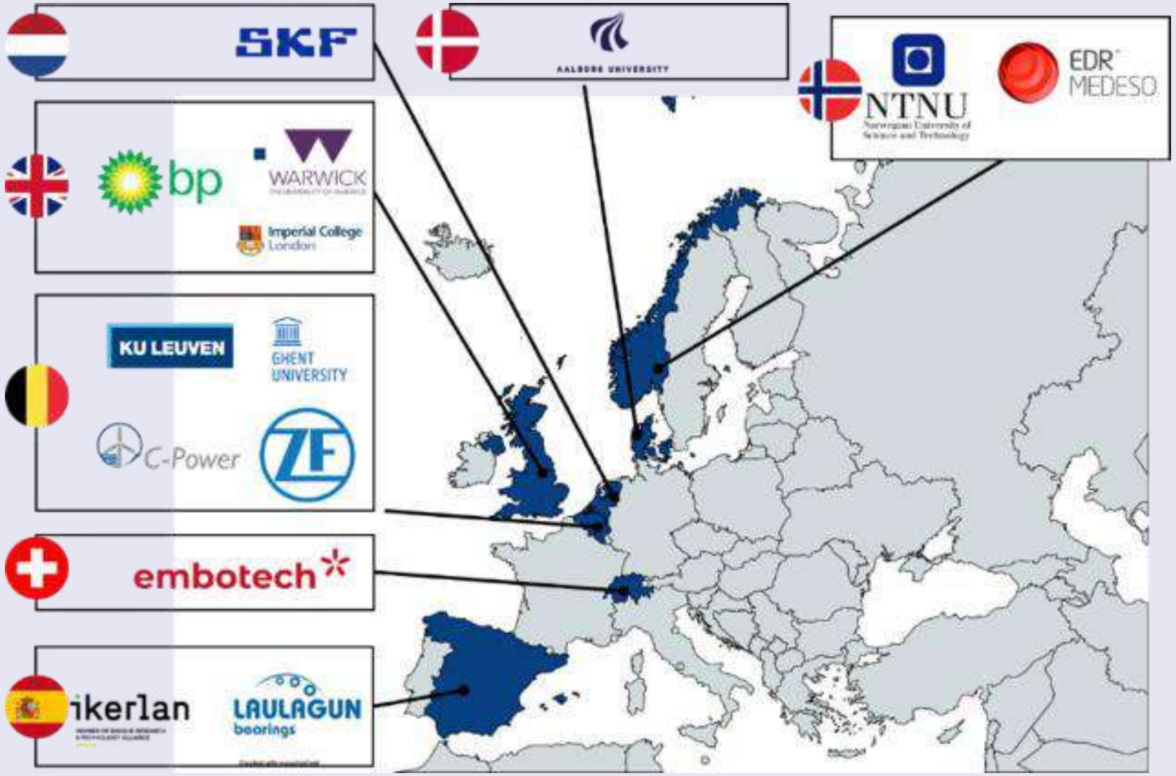
Innovation project supported by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Innosuisse – Swiss Innovation Agency

ICONIC Project partners



48 months
01/12/2023
30/11/2027

14 partners

6 work packages

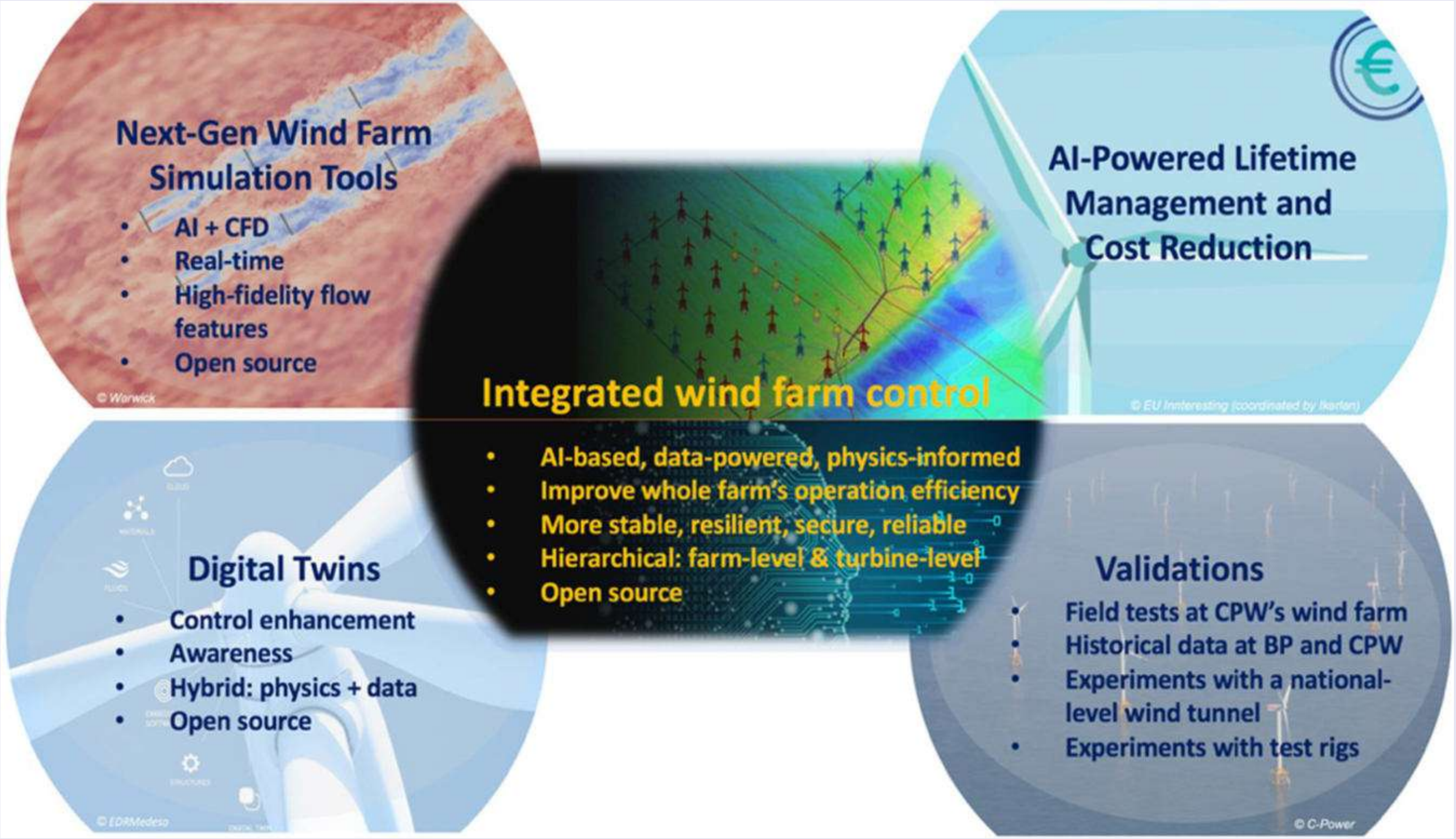
31 deliverables

6 milestones

3 reporting periods

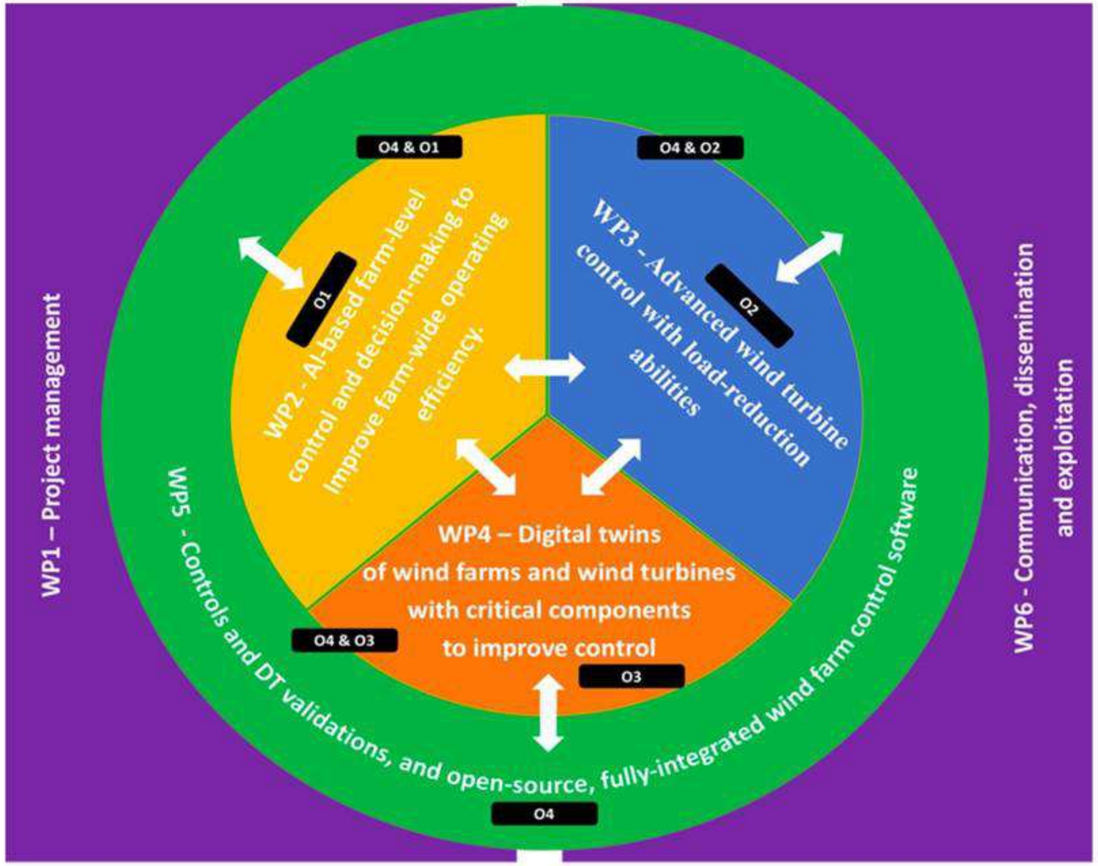
Budget: € 5,894,950.5 (= € 3,897,447.50 + £1,677,517)

Key Ambition of ICONIC



Main Objectives of ICONIC

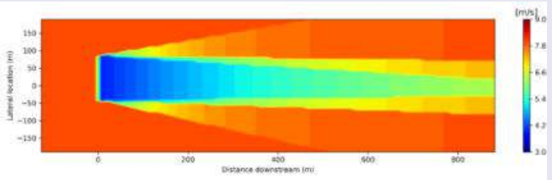
- O1: Develop new wind farm control tools to improve wind farm operations leveraging AI innovations.
- O2: Investigate turbine control solutions with load-reduction abilities to deliver farm-wide objectives.
- O3: Develop digital twins and physical tools for awareness and control enhancement considering RUL assessment of wind turbine key components.
- O4: Validate and exploit the integrated control system and DTs via wind tunnel tests, historical operational data, dedicated test rigs, and field tests, and bring ICONIC’s key innovations to TRL5



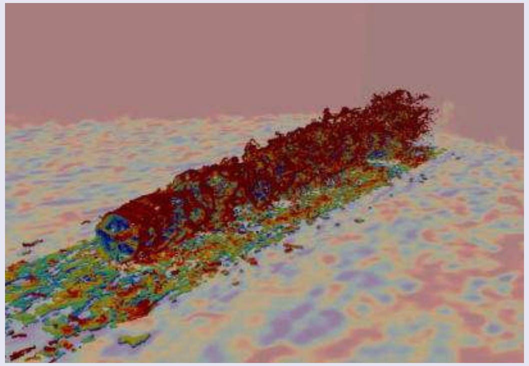
Research Highlights #1

Control-Oriented Wind Farm Modelling via CFD and Machine learning

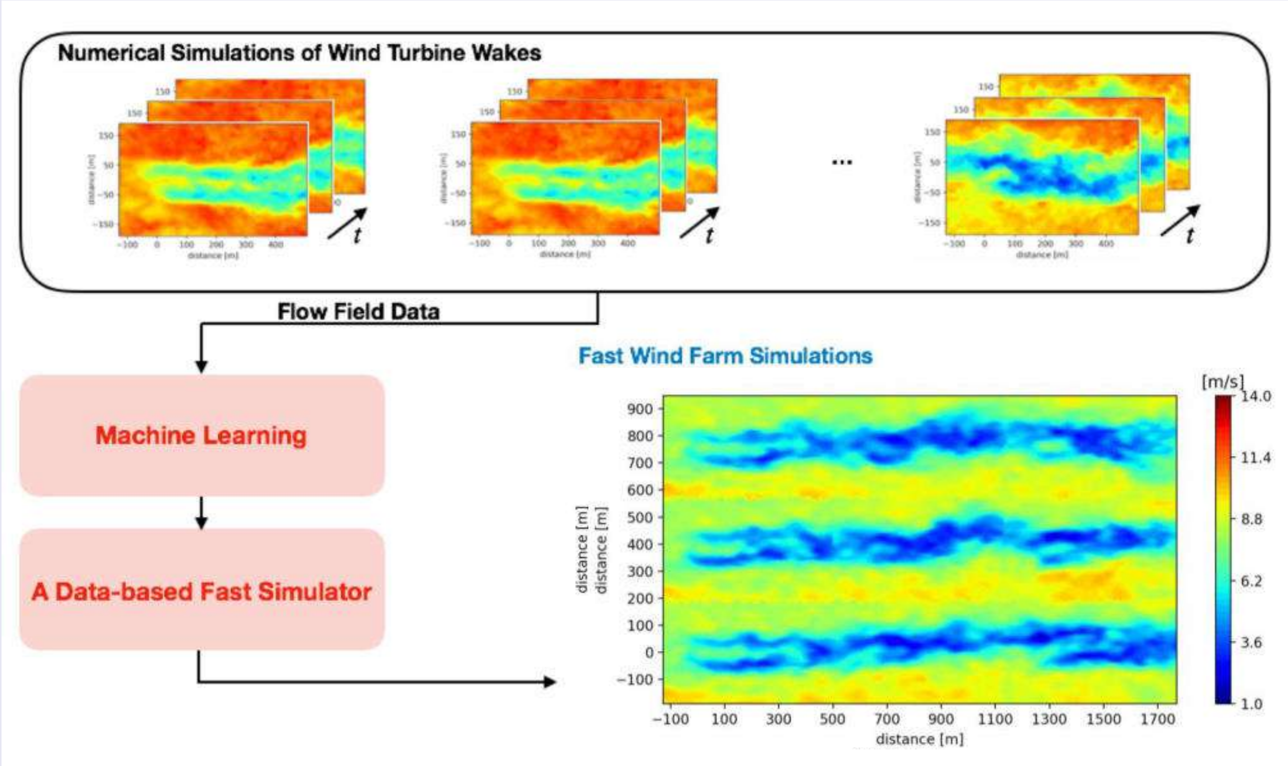
- CFD models - accurate but slow
- Analytical wake models - fast but inaccurate



Low fidelity model FLORIS

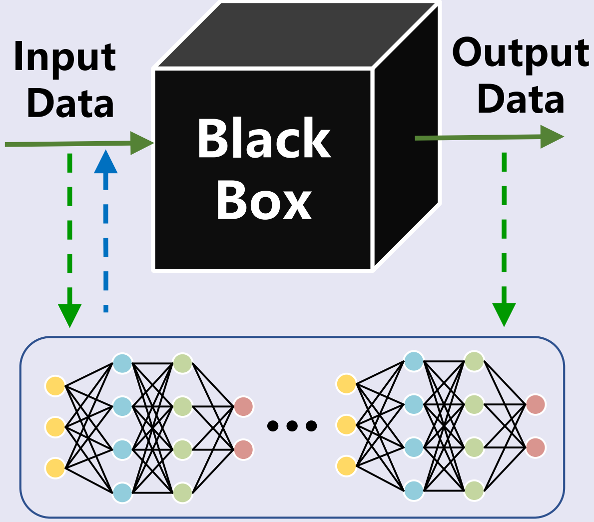


High fidelity LES by SOWFA

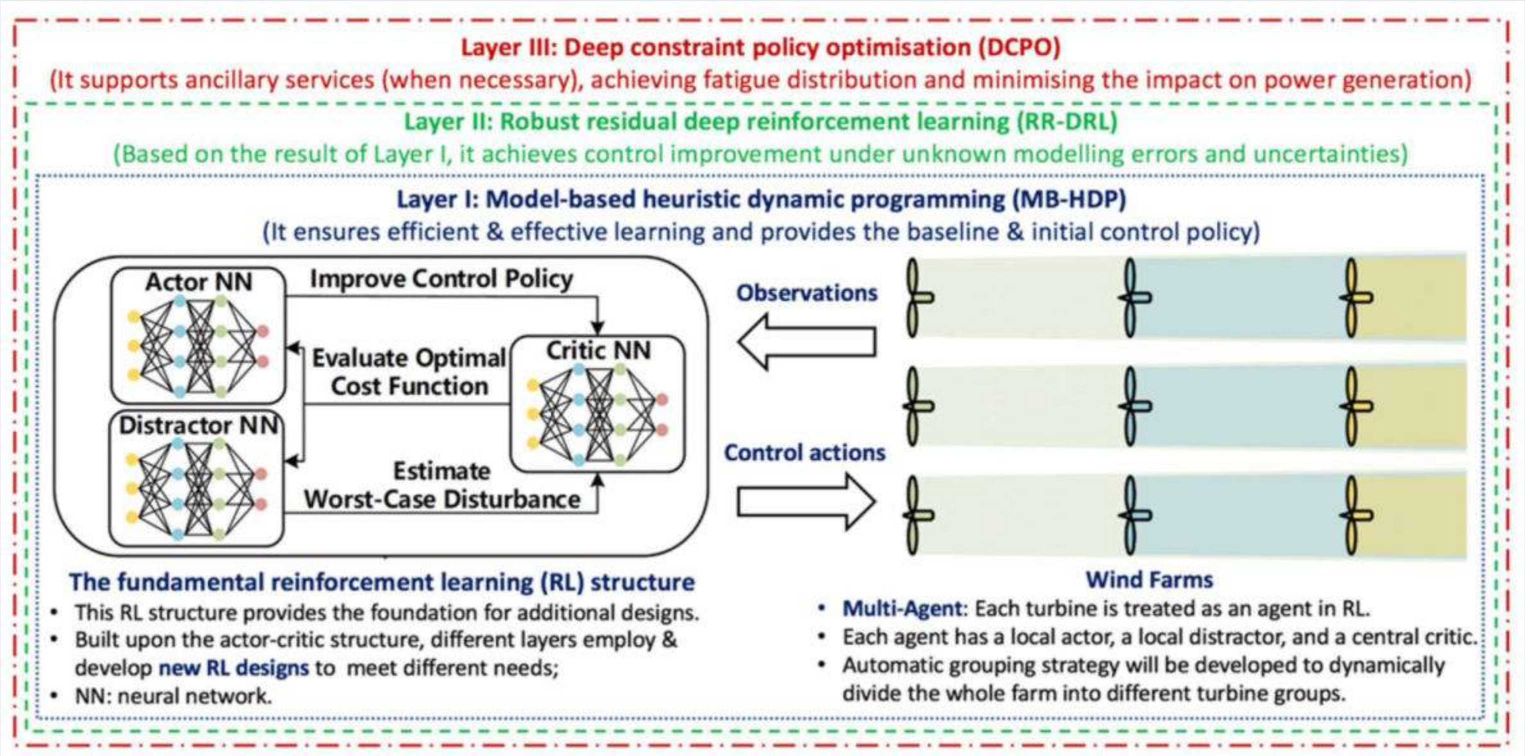


Research Highlights #2

AI-Based Farm-Level Control and Decision-Making to Improve Operating Efficiency of Wind Farms



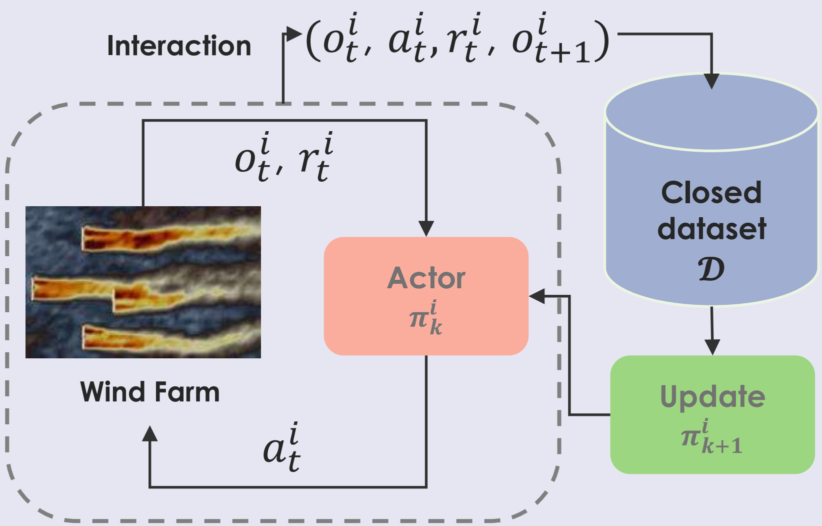
Deep reinforcement learning-based intelligent control



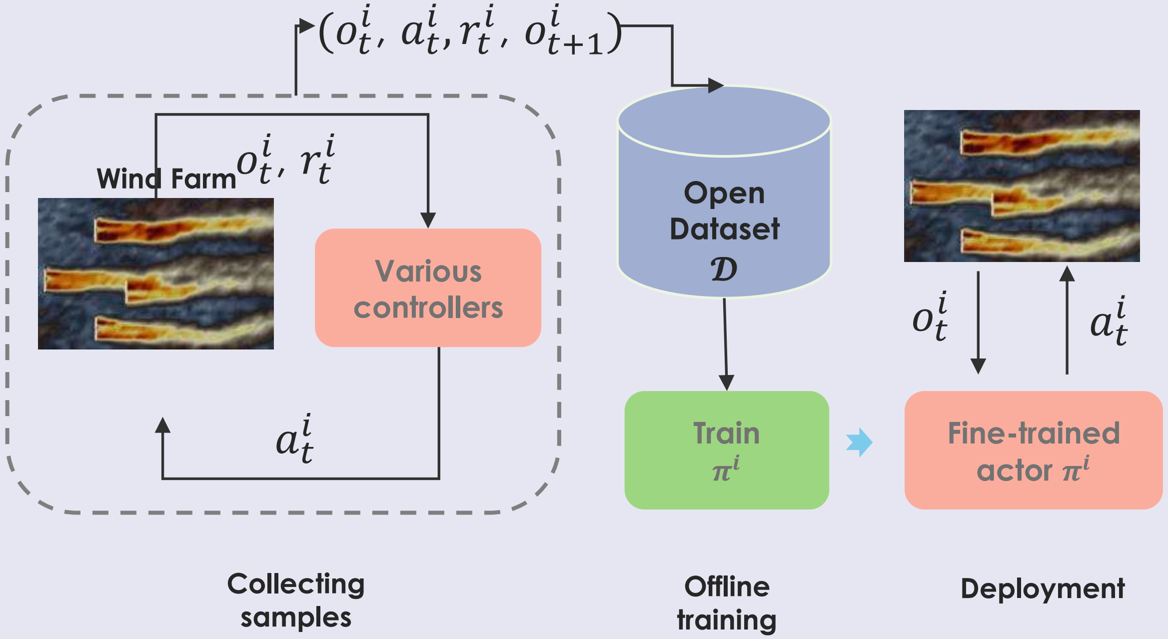
Research Highlights #2

Offline RL-based wind farm control

Online RL-based wind farm control



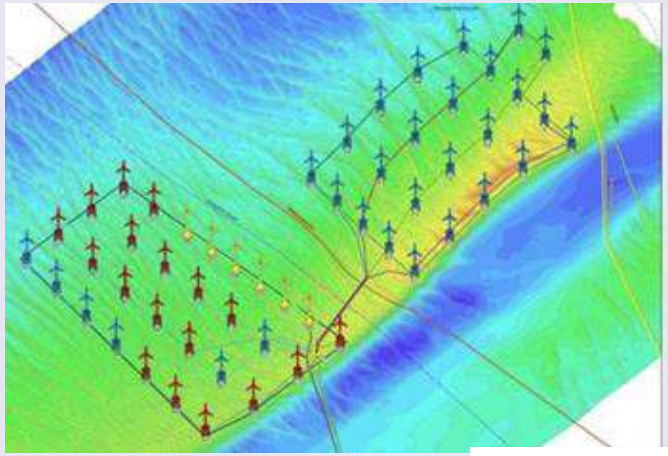
Offline RL-based wind farm control



Y. Huang and X. Zhao, Wind Farm Control via Offline Reinforcement Learning with Adversarial Training, *IEEE Transactions on Automation Science and Engineering*, under revision, 2024.

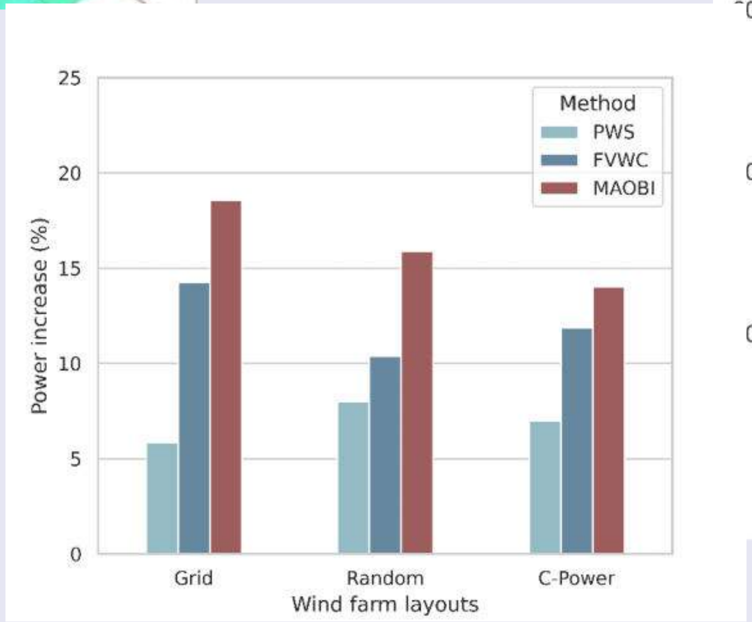
Research Highlights #2

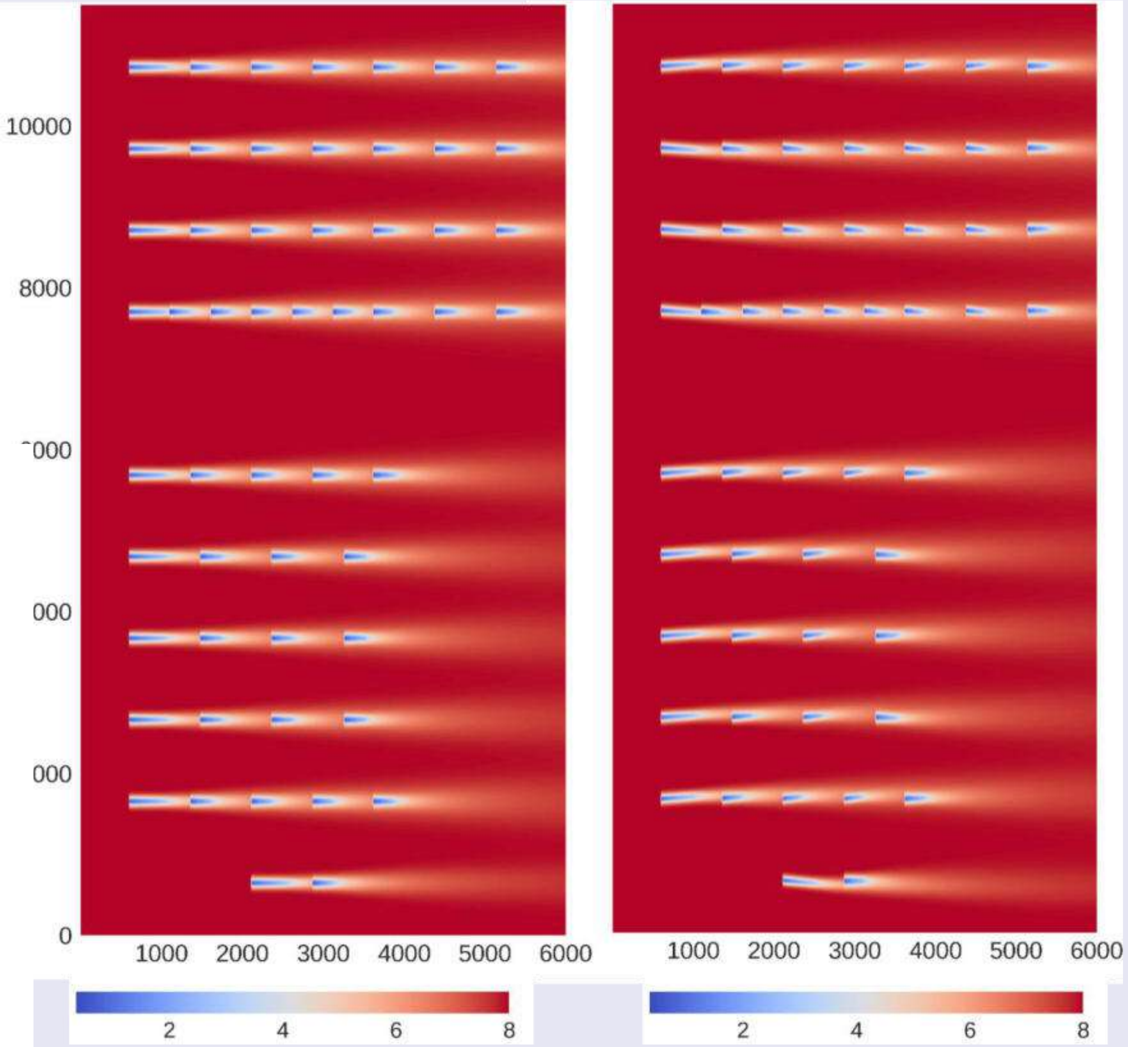
Offline RL-based wind farm control



C-Power wind farm layout

Performance comparison between three methods under three layouts





Research Highlights #3

Advanced Turbine-Level Control with Load-Reduction Abilities

- A novel stochastic MPC for pitch and torque control to reduce conservativeness and enhance performance.
- A novel tube MPC method for yaw control to ensure strict safety requirements
- Time-critical justification for MPC methods to achieve complexity reduction and computational time boundedness
- Control performance enhancement with LIDAR measurements

Research Highlights #4

Wind Farm Digital Twin via Physics-Informed Deep Learning

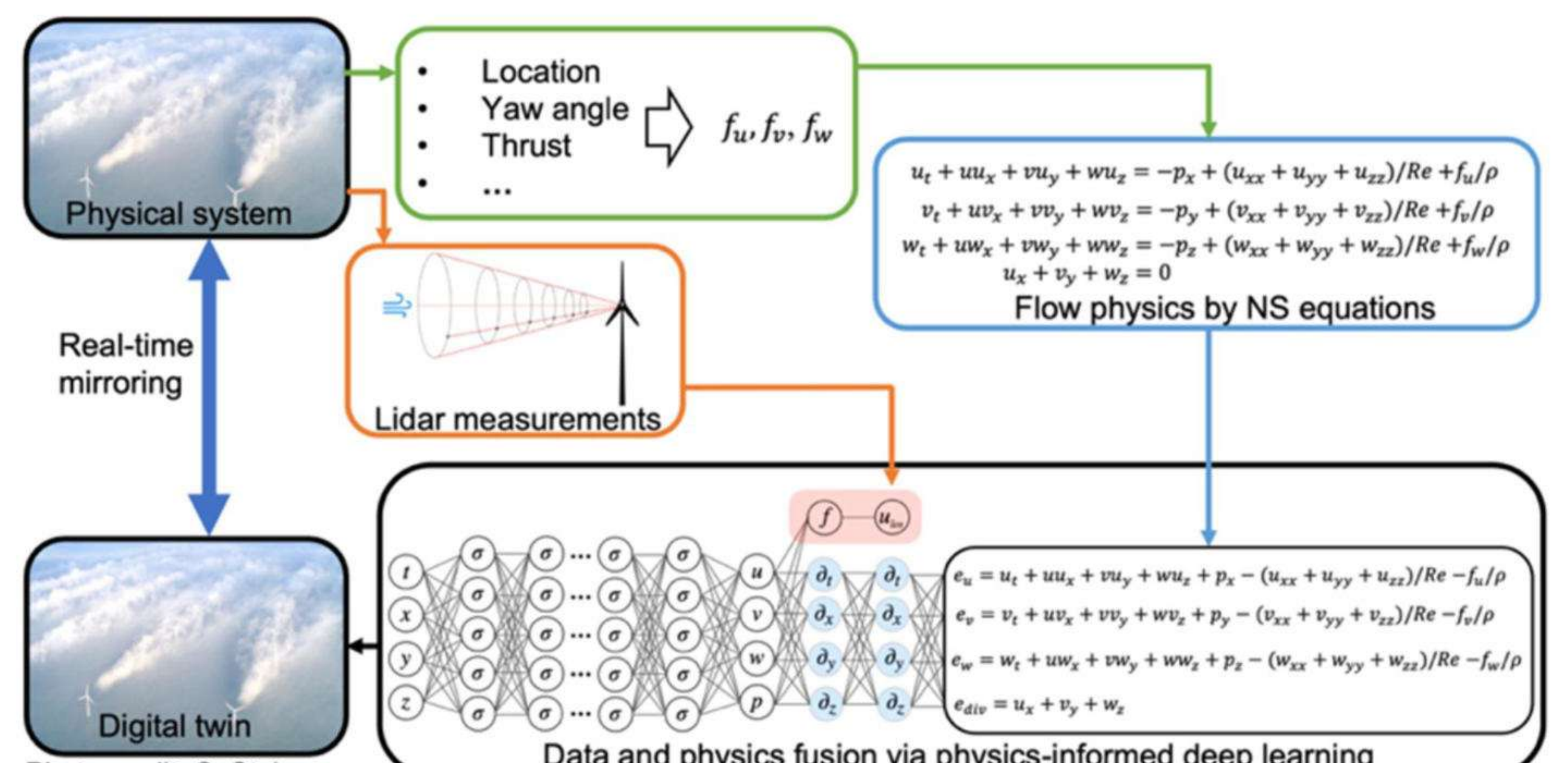
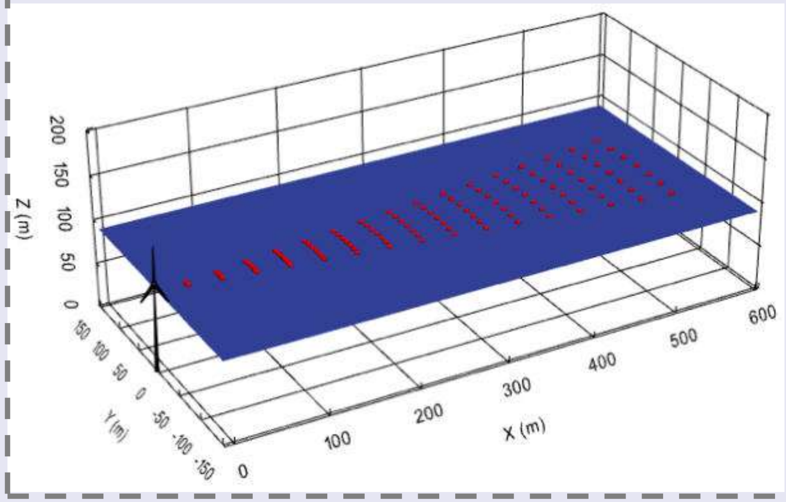


Photo credit: C. Steiness

Research Highlights #4

- Data (Lidar) + Physics (NS equations) + ML
- Reconstruct in situ spatiotemporal wind turbine wake flow fields

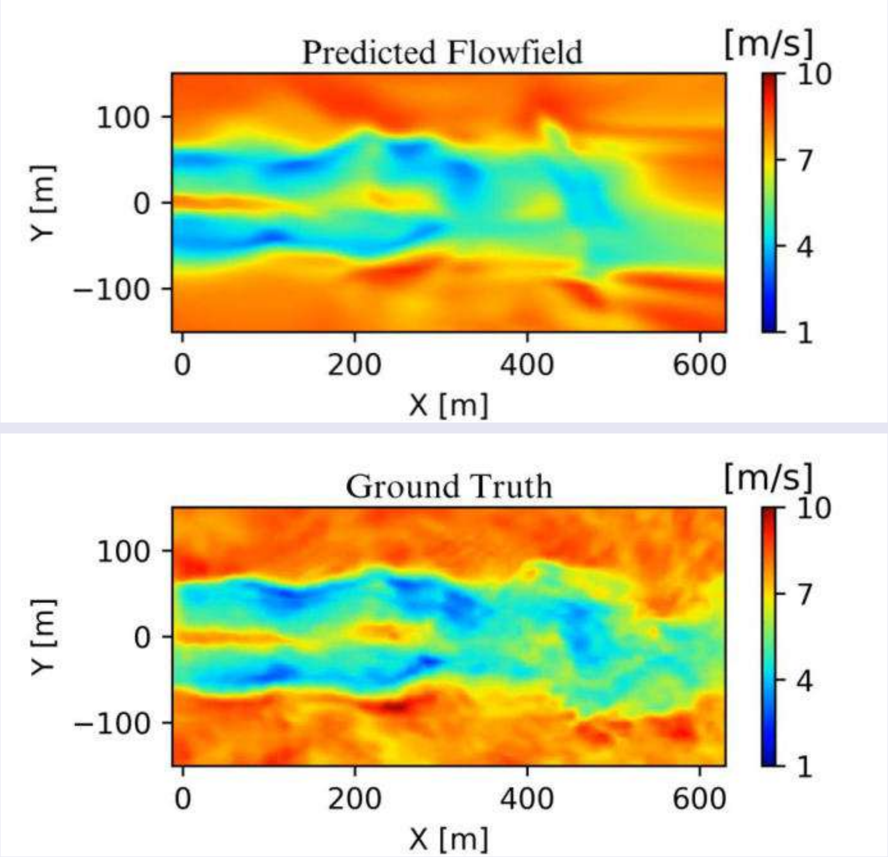
Lidar measurements: line-of-sight, sparse



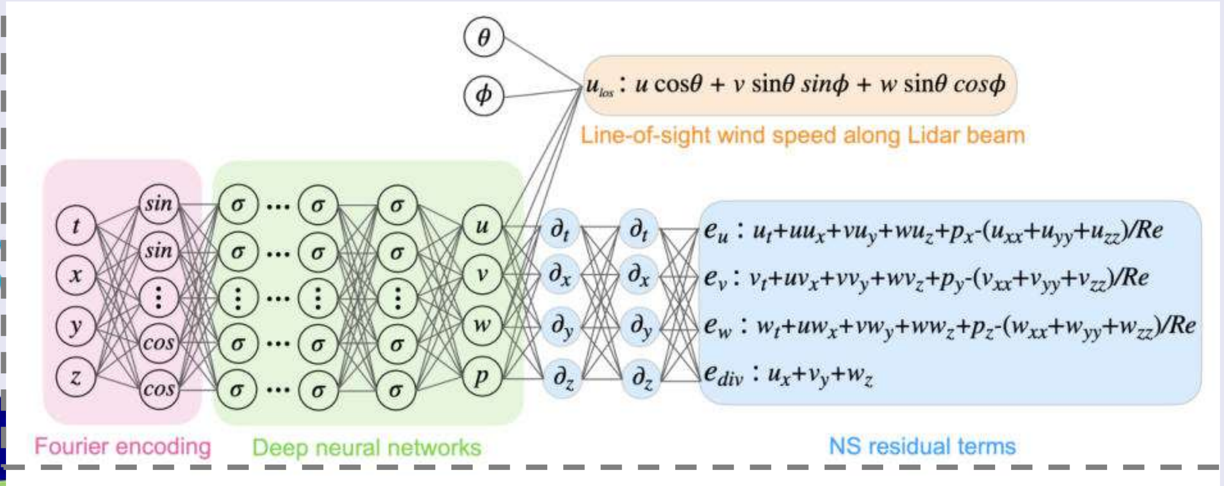
Input

Output

Dynamic flow fields



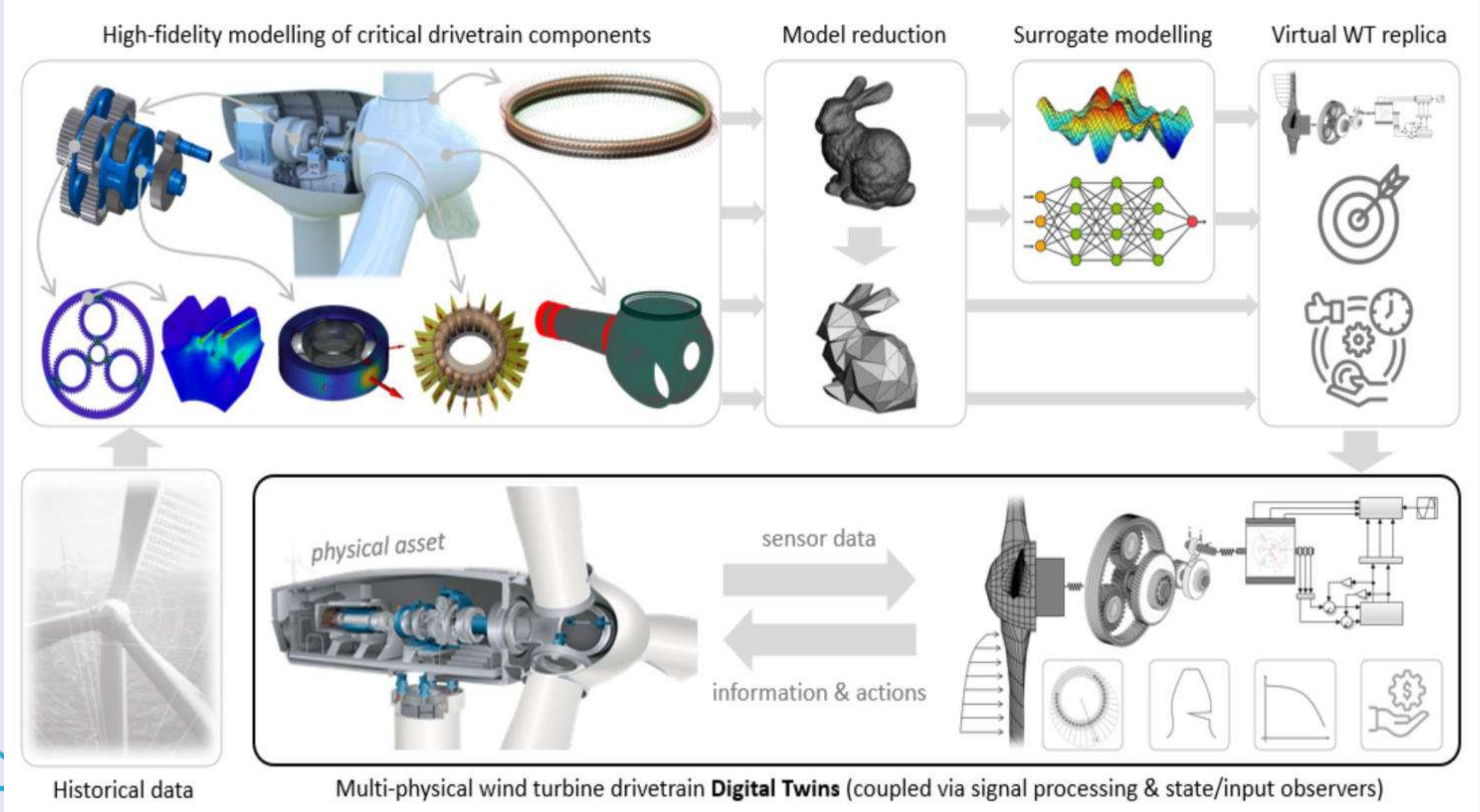
Physics-informed neural networks: fusing Lidar data and NS equations



J. Zhang and X. Zhao, Reconstruction of dynamic wind turbine wake flow fields from virtual Lidar measurements via physics-informed neural networks, *Journal of Physics: Conference Series* **2767**, 2024.

Research Highlights #5

Digital Twins and Lifetime/RUL Estimations of Critical Components

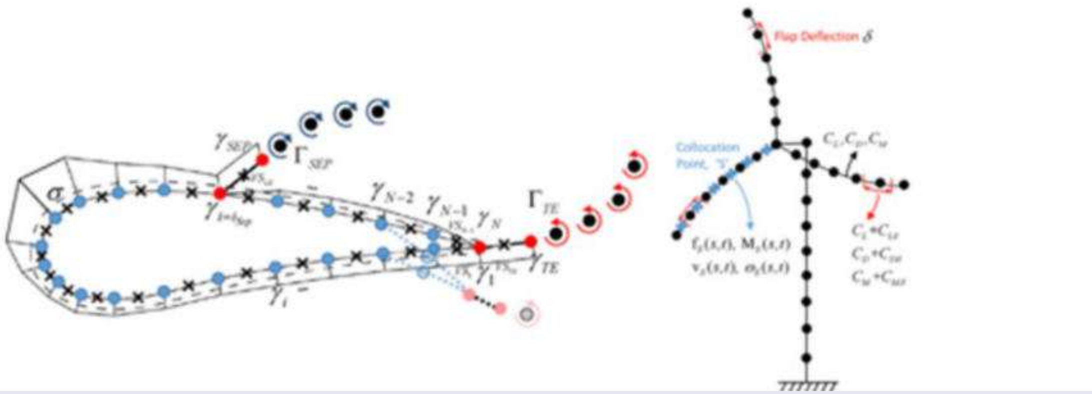


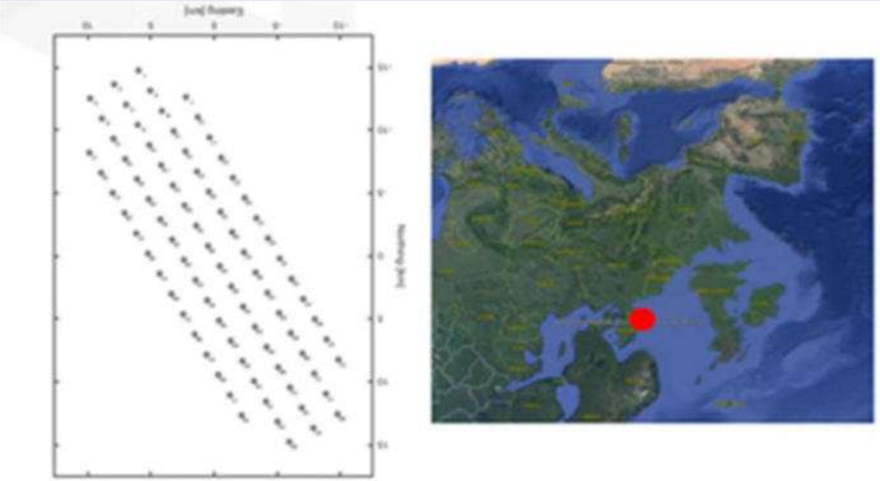
Research Highlights #6

Current Status, Outlook, Impact & Ways for future 20MW Wind Turbines

		OFFSHORE WIND TURBINES					
		2020 - BAU		2030		2050	
	Unit	Avg *	Max**	Avg *	Max**	Avg *	Max**
Worldwide: installed capacity	GW	29.1[a]		228[b] 175-210[e]		1000[b]	
Europe: Installed capacity	GW	22[c]		78[b] 77-127[d]		215[b]	
Wind turbine unitary nominal power	MW	7,2[k]	12[f]	10-12	15-20[n]	20[o]	>20
Capacity factor	%	38[k]	63[f]	36-58[b]		43-60[b]	
Wind farm size	GW	621[e]	1,21[j]	1-1.5	3	---	---
Number of turbines per wind farm	[]	87[e]	174[j]	83-125	125	---	---
Hub height	m	100	150[f]	Optimised values respect to the 12 MW in 2020	160.2[g]	Optimized values respect to the 20 MW in 2020	---
Rotor diameter	m	154	220[f]		276[g]		---
Blade length	m	75	107[f]		135[g]		---
Blade weight	Tn	---	---		259[g]		---
Blade root diameter	m	4[s]	6[s]		5.5-7[g]		8-10[q]
Power train nominal torque (LSS)	kNm	---	---		26.711[g]		---
Power train nominal speed	rpm	---	---		7,15[g]		---

Wind turbine size forecast (inc. 20MW) from Innteresting.





Layout and virtual location of CS3 wind farm.

Research Highlights #7

Comprehensive Validations of Controls and Digital Twins

- Wind tunnel tests
- Numerical Simulations – various fidelities
- Field tests

- Case study #1: C-power (offshore)
- Case study #2: BP (onshore)
- Case study #3: Virtual farm design (20MW)

Thanks for your attention

Professor Xiaowei Zhao
Intelligent Control and Smart Energy Research Group
University of Warwick
Xiaowei.zhao@warwick.ac.uk
10 September 2024