A NEW WAKE DETECTION METHODOLOGY TO CAPTURE WIND TURBINE WAKES USING ADAPTIVE MESH REFINEMENT AND LARGE EDDY SIMULATION

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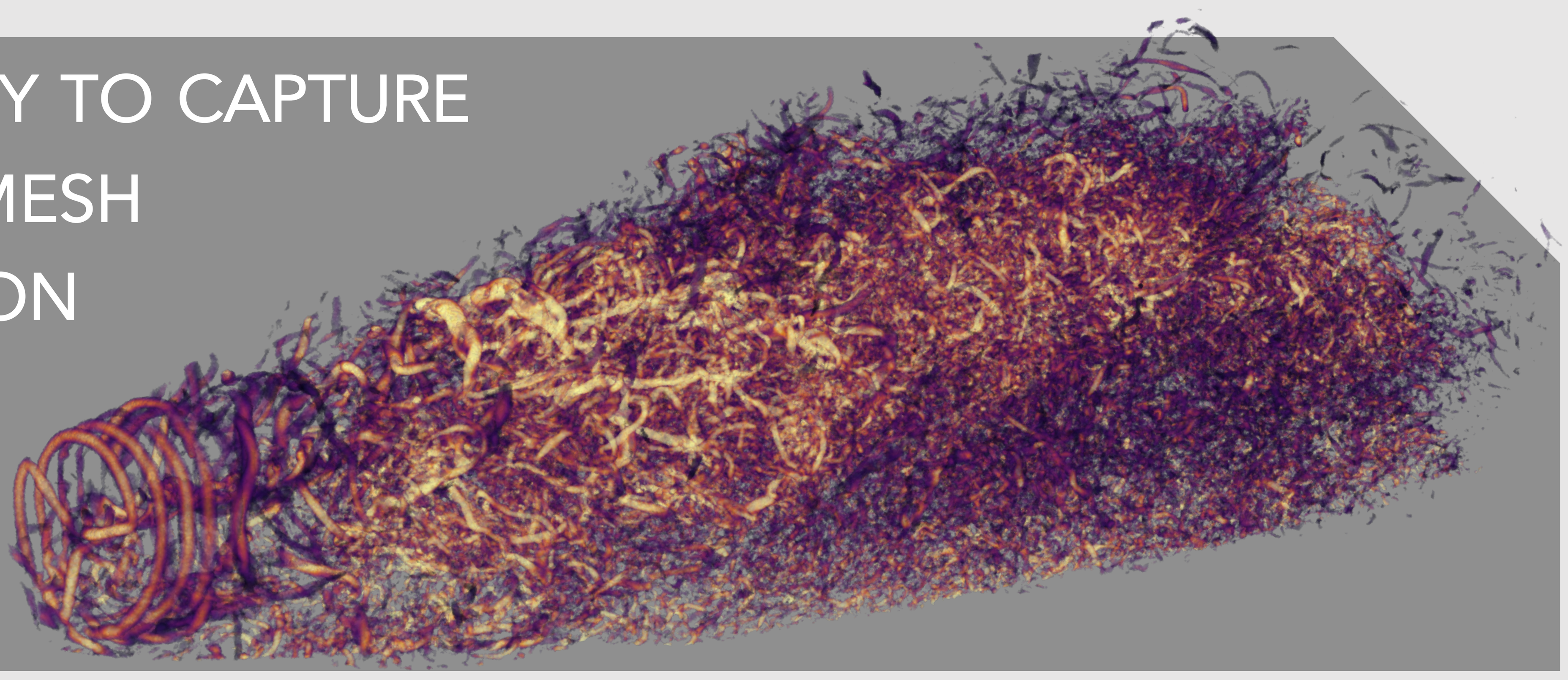


1 ▸ CONTEXT

In the context of wind farms, numerical prediction of turbulent vortical wakes released downstream of wind turbines constitutes a challenging problem.

- Need for **predictive tools** to model wind turbine wakes

Problematics

Properly capturing complex, three-dimensional, unsteady wakes involves:

- A **Large Eddy Simulations** approach [1]
- A adequate mesh [2]
- A compromise between computational cost and wake accuracy

→ **Adaptive Mesh Refinement** is applied in the wake region

Objectives

Development of a new wake detection method
Application of AMR strategy within the wake envelope

2 ▸ METHODOLOGY

Detection

Strategy: **progress variable** ϕ transported on the Eulerian grid with a source term $\dot{\omega}_\phi$ in the rotor region:

$$\frac{\partial \rho \phi}{\partial t} + \nabla \cdot (\rho \boldsymbol{u} \phi) = \nabla \cdot (\rho D_\phi \nabla_\phi) + \dot{\omega}_\phi$$

Average wake position is given by overlaying the progress variable over fluid iterations

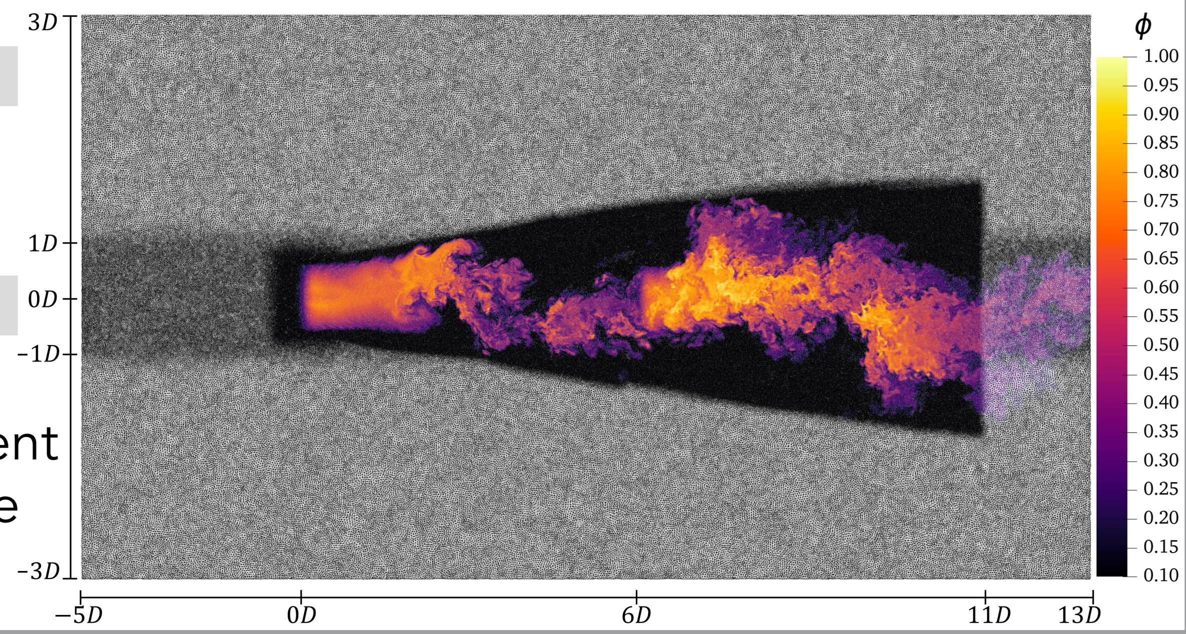
$$\hat{\phi}\,(\boldsymbol{x}, t+dt) = \max\left(\hat{\phi}\,(\boldsymbol{x}, t), \phi^*(x)\right) \text{ with } \phi^*(\boldsymbol{x}) = \begin{cases} 1, \text{if } \phi(\boldsymbol{x}) > 0.1 \\ 0, \text{if } \phi(\boldsymbol{x}) \leq 0.1 \end{cases}$$

Mesh size

User-dependent target value [2]

Frequency

Occuring iteratively.
Triggered when current mesh too far from the objective mesh.



3 ▸ SETUP

YALES2 [3,4,5]

Flow solver

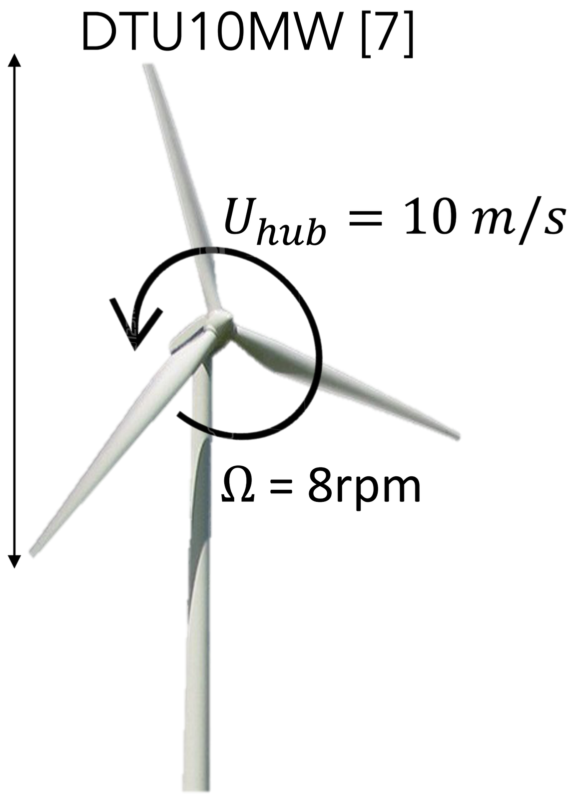
- **Low Mach number Navier Stokes equations solver**
- 4^{th} **order** central finite volume method ; 4^{th} **order** time integration
- Turbulence model: **SIGMA** [6]

Wind turbine

- **DTU10MW**, $\lambda_{opt} = 7.5$
- **ALM**: 50 points per blade

Turbulence

- **Precursor** Database Method [8,9]
- $u(z) = \frac{u_\tau}{\kappa} \log\left(\frac{z+z_0}{z_0}\right)$ $\quad z_0 = 0.02\ m$



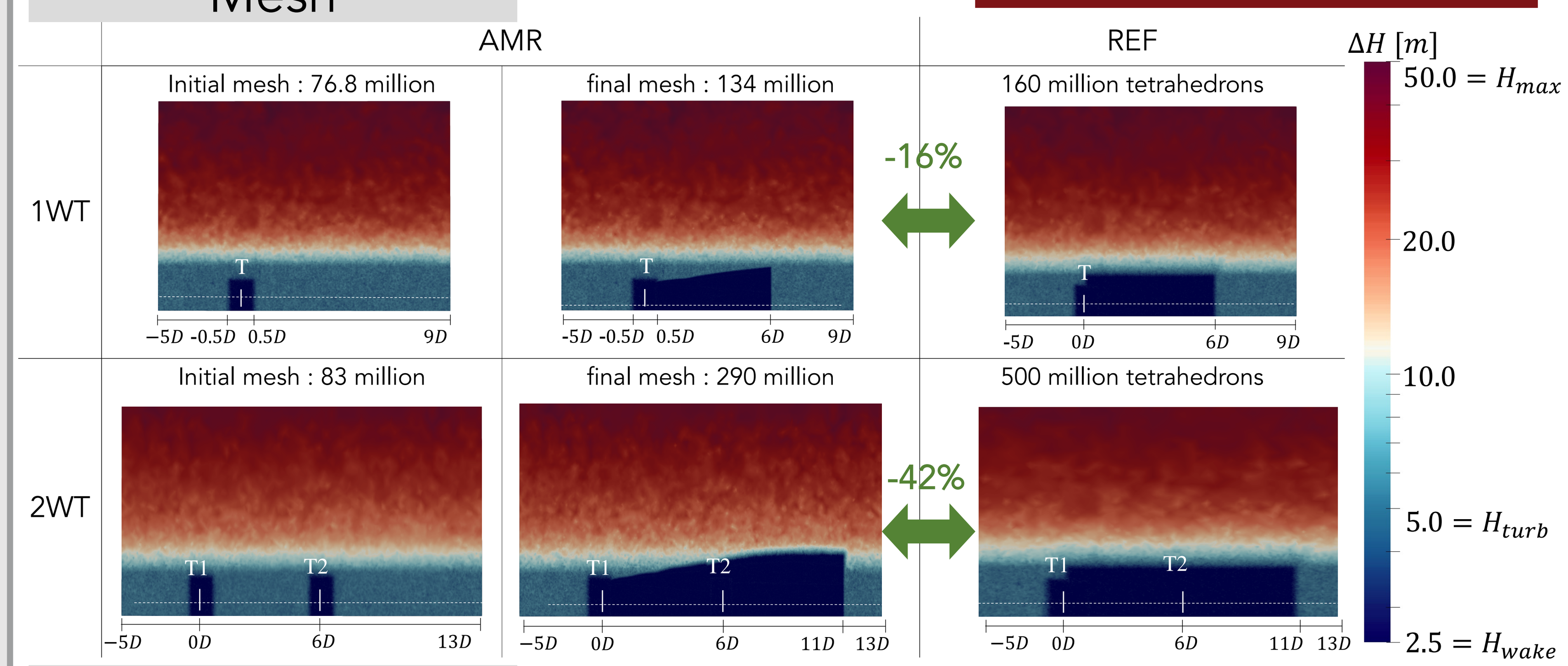
Configuration

- 1 Wind turbine → Reference / AMR (Comparison)
- 2 Wind turbines → Reference / AMR (Comparison)
- Time-varying yaw misalignment: $\gamma = 15 \sin\left(\frac{\pi}{60} + t\right)$

4 ▸ RESULTS

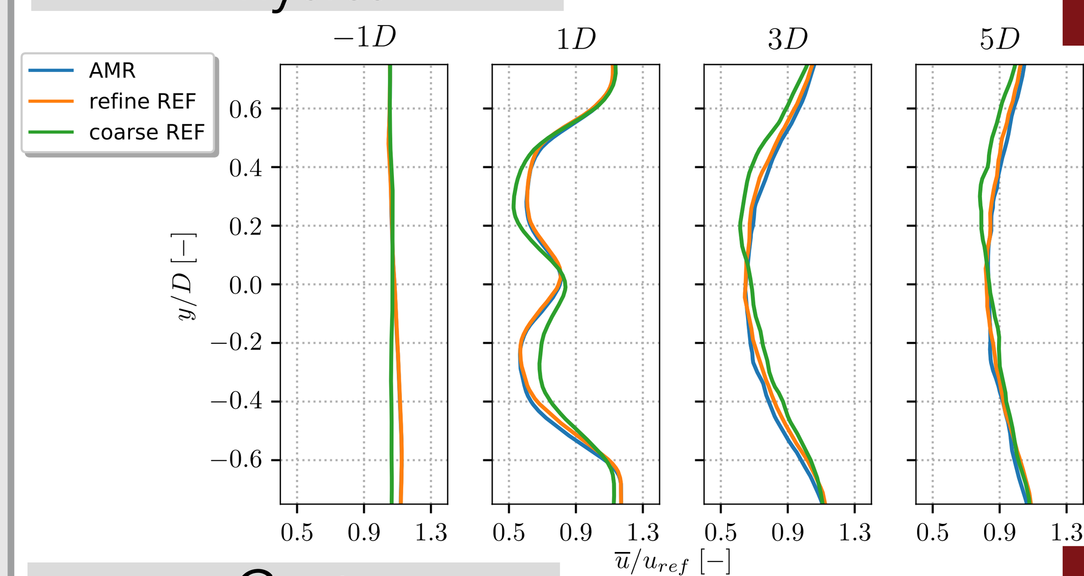
Mesh

Mesh size reduction



Physics

Same physical precision



Relative L2 norm error	1WT	2WT
$\bar{u}_y$ [%]	1	2.4
TKE [%]	5.5	11.3
ΔC_P [%]	0.8	0.8
ΔC_T [%]	0.18	0.23

Cost

Cost reduction

setup	cases	#elem [x10⁶]	physical time [s]	adapt time [%]	khCPU
1WT	REF	160	1440	/	24.2
	AMR	77-135	1440	3.5	16.3
2WT	REF	500	2880	/	174
	AMR	83-290	2880	2.1	83

5 ▸ CONCLUSION & PERSPECTIVES

Methodology:

- Allows to **properly capture wind turbine wakes**
- Define an accurate wake envelope
- Negligible cost

AMR:

- Exhibits similar physical precision
- 30% to 50% computational **cost reduction**

Cost reduction for the same physical precision

Perspectives:

→ A more dynamic mesh refinement approach
→ A non user-dependent target cell size [2]

6 ▸ REFERENCES & AKNOWLEDGMENTS

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