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Actuator grid method for turbulence generation applied to yawed wind turbines.

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Introduction and objectives

In the context of wind farms, new control strategies such as inducing a wind turbine yaw angle seem relevant to reduce wake interactions. [1]

- Need for **predictive tools**[2] to model yawed wind turbine wakes
- **Replicate** and **investigate** wind tunnel results [3,4] of turbine under yaw condition

Problematics

Replicate a wind tunnel configuration involves :

- **Turbulence grid** upstream the turbine (If turbulent inflow)
- Tower and nacelle → complex geometry effects
- Confinement of the **wind tunnel**, turbulence decay

Yawed wind turbine encounters particular aerodynamical effects :

- Dynamic stall, sweep along the blade span

Objectives

→ **Validation of high fidelity tools, in a complex configuration, for yawed wind turbine wake investigation**

- Investigate **9 experimental cases** [4]
- three yaw angles ($\gamma = +30^\circ; 0^\circ; -30^\circ$) and three different inflows :
 - (i) Laminar, flat profile
 - (ii) Turbulent (TI~10%), flat profile
 - (iii) Turbulent (TI~10%), sheared profile

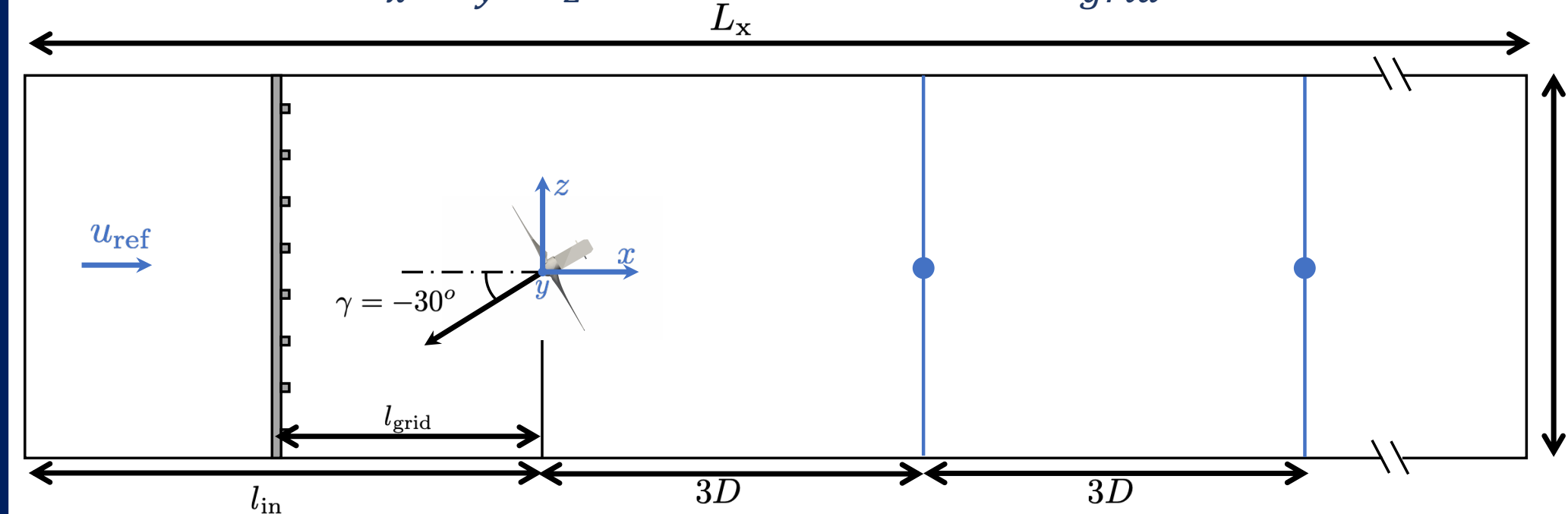
Configuration: wind tunnel and turbine

Wind turbine:

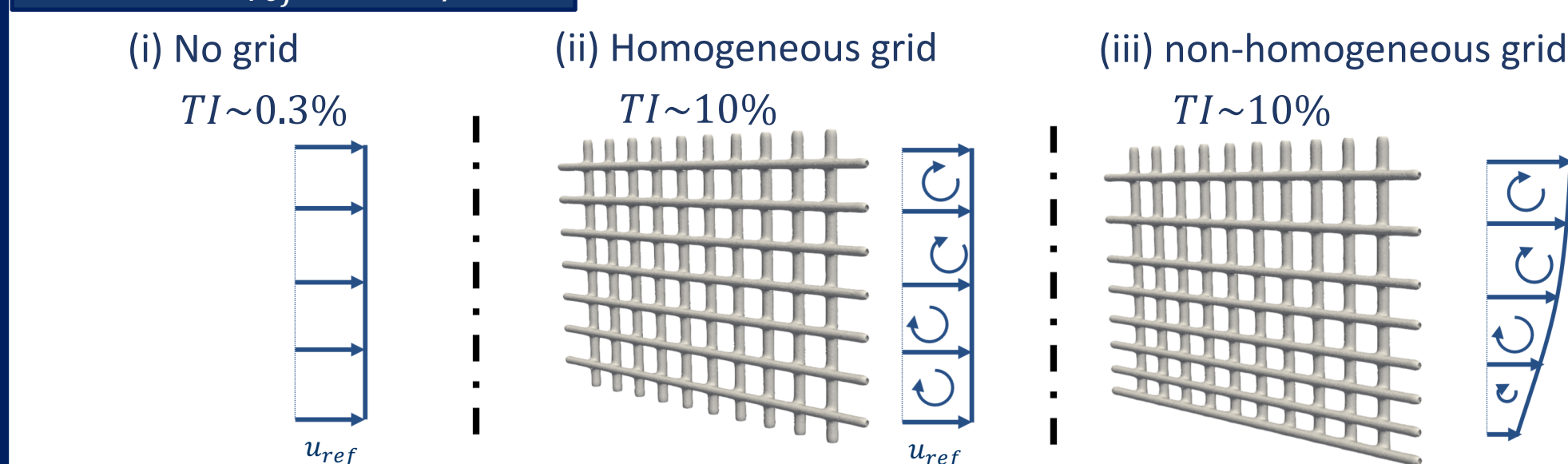
- Single wind turbine setup: LARS1, 3 blades with NREL S826 airfoils [3,4]
 - $D=0.894m$
 - $TSR=6$
 - $\gamma = +30^\circ; 0^\circ; -30^\circ$

Wind tunnel:

- Dimensions: $L_x \times L_y \times L_z = 14 \times 2.61 \times 1.8 m^3$, $l_{grid} = 2D$



Inflows: $u_{ref} = 10m/s$



Numerical setup

Flow solver:

YALES2 [5,6,7]

- **Low Mach number Navier Stokes equations solver**
- **4th order** central finite volume method and **4th order** time integration
- Turbulence model: **SIGMA** [8]
- **Unstructured meshes** are around **167 Million** cells each (9 cases)
- Wind tunnel walls are body fitted to the mesh
- Duprat et al. [9] wall model : $\langle y^+ \rangle_{walls} < 200$

Wind turbine:

- **Actuator Line Method** [10], 27 actuator elements per blade,
- $\langle \frac{c}{c} \rangle_{tip} = 0.57$
- No additional 3D unsteady effect correction [11,12,13]
- Tower and nacelle are body fitted to the mesh
- Duprat et al. [9] wall model : $\langle y^+ \rangle_{tower} < 100$

Turbulence grid:

- Emulated using **Dynamic Actuator Lines Method** [14] and the actual **turbulence grid** geometry

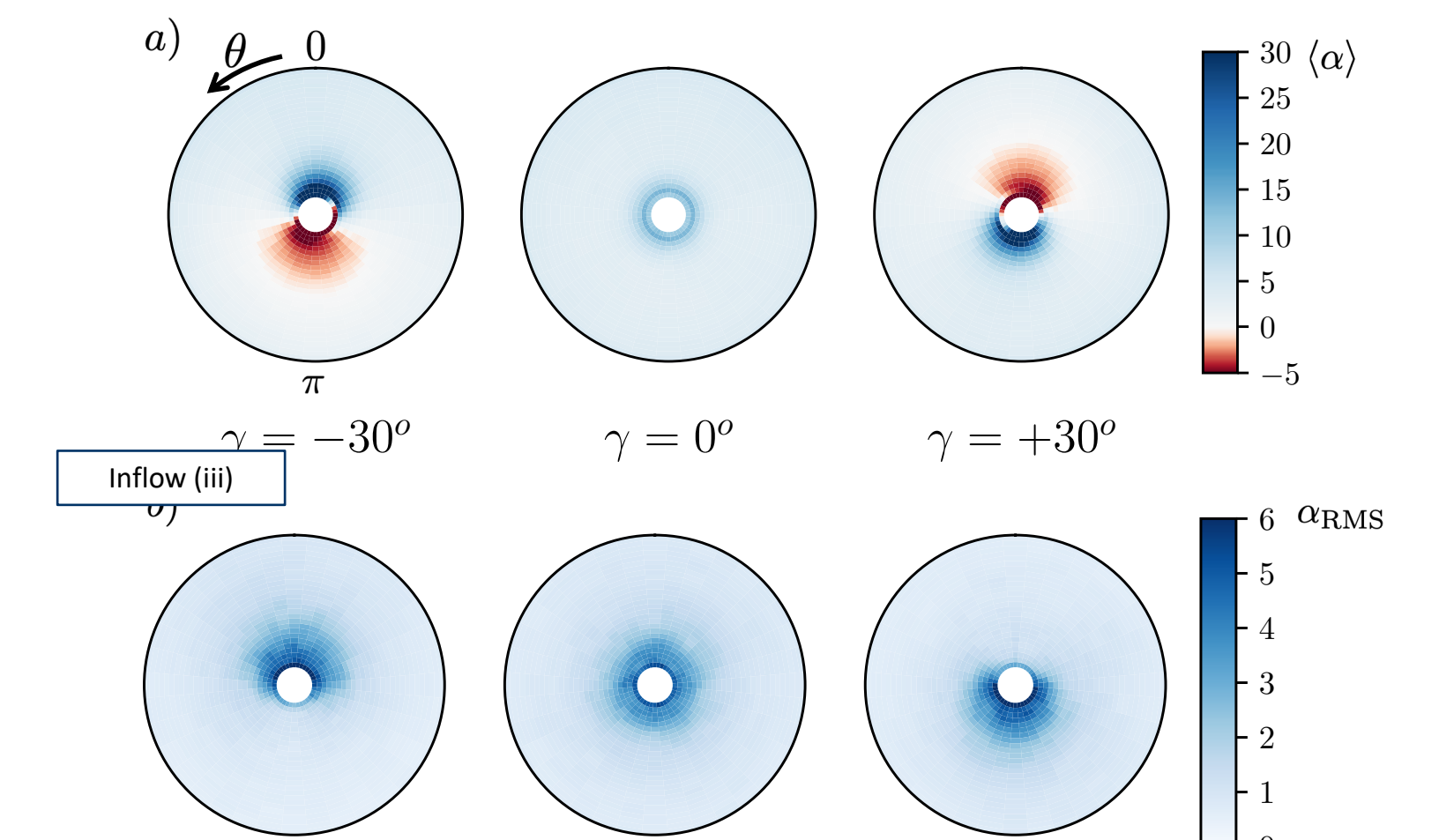
Computation cost:

- Each computation on **1092 cores** for 10s (15 flow through) ~**40kCPU**

Performances and azimuthal loads

Azimuthal angle of attack (AoA)

- **Near hub variation of AoA** due to azimuth for yawed cases (-5° up to 30°) potential **dynamic stall**
- **Negative AoA** → local negative contribution to turbine Torque



Turbine performances (power and thrust coefficient) differs significantly from the experimental results:

- C_p up to **+20%** and C_T up to **9%** → due to the absence of corrections

Conclusion

- High fidelity simulations show the ability to represent complex operating conditions (turbulence injection, wind tunnel confinement, complex geometries)
- Flow diagnostics present the main features from experimental data
- Dynamic stall near hub is highlighted
- Turbine performances discrepancies → to be improved by adding corrections to the ALM

→ **High fidelity tool able to predict wind turbine wakes in yaw and turbulence complex configurations**

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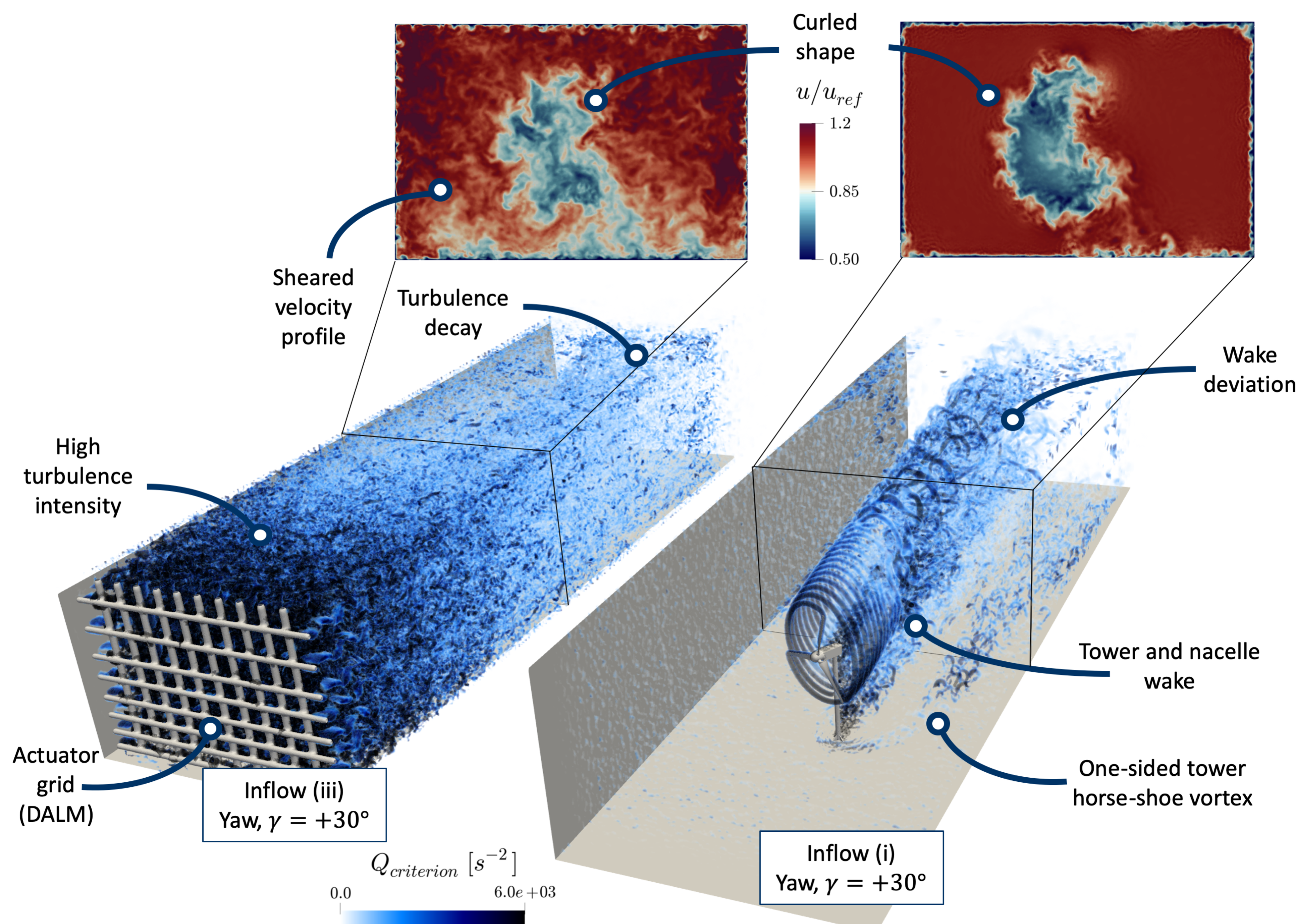
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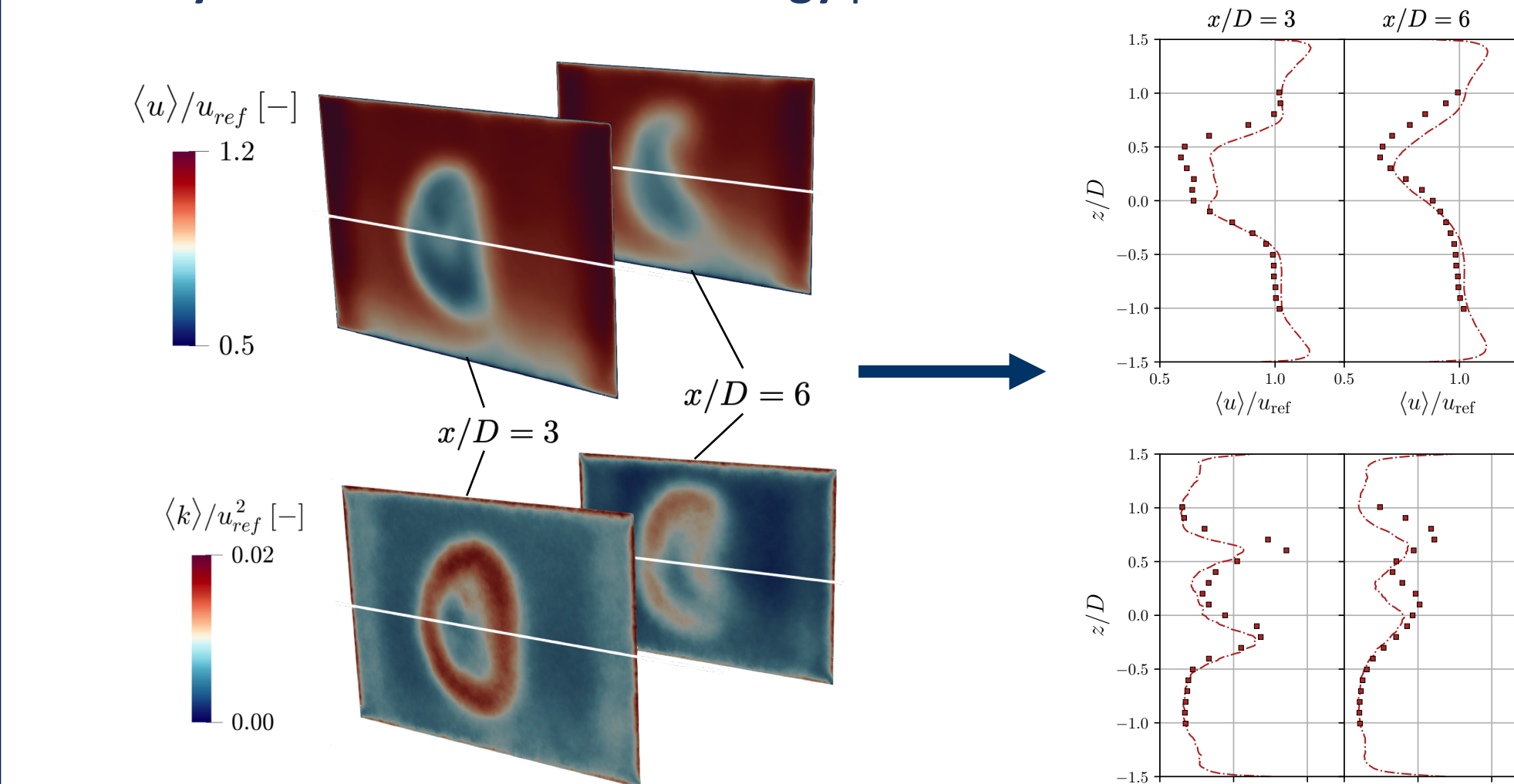


Wake topology



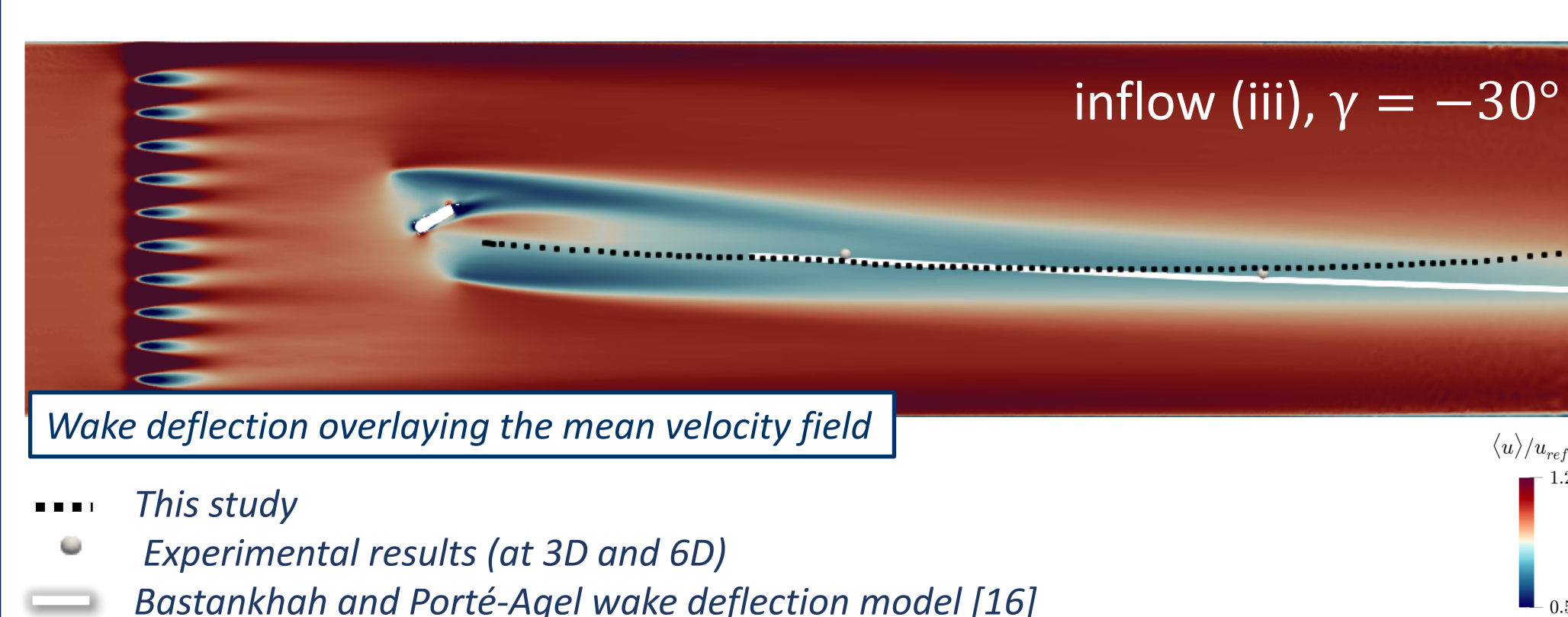
Inflow and yaw impact on wake

Velocity and Turbulent Kinetic Energy profiles:



- Velocity deficit slightly underestimated for yawed cases in respect to experimental data [3]
- TKE profiles show slightly overestimated turbulence decay in the turbine wake
- Similar results to experiment for the non yawed cases

Wake deflection quantification using an available power approach [15]



- Slightly higher estimation of the deflection (at 3D and 6D)
- Good agreement with Bastankhah and Porté-Agel [16] model up to 6D → **confinement redirect** the wake towards its center after 6D