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EFFECT OF WIND TURBINE YAW MISALIGNMENT ON WAKE MEANDERING

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Deepwind Conference, Trondheim, 18-20 January, 2023

Outline

- Motivation and Introduction
- Methods and tools
- Dynamic wake meandering model (DIWA)
- Results and discussion
- Conclusions

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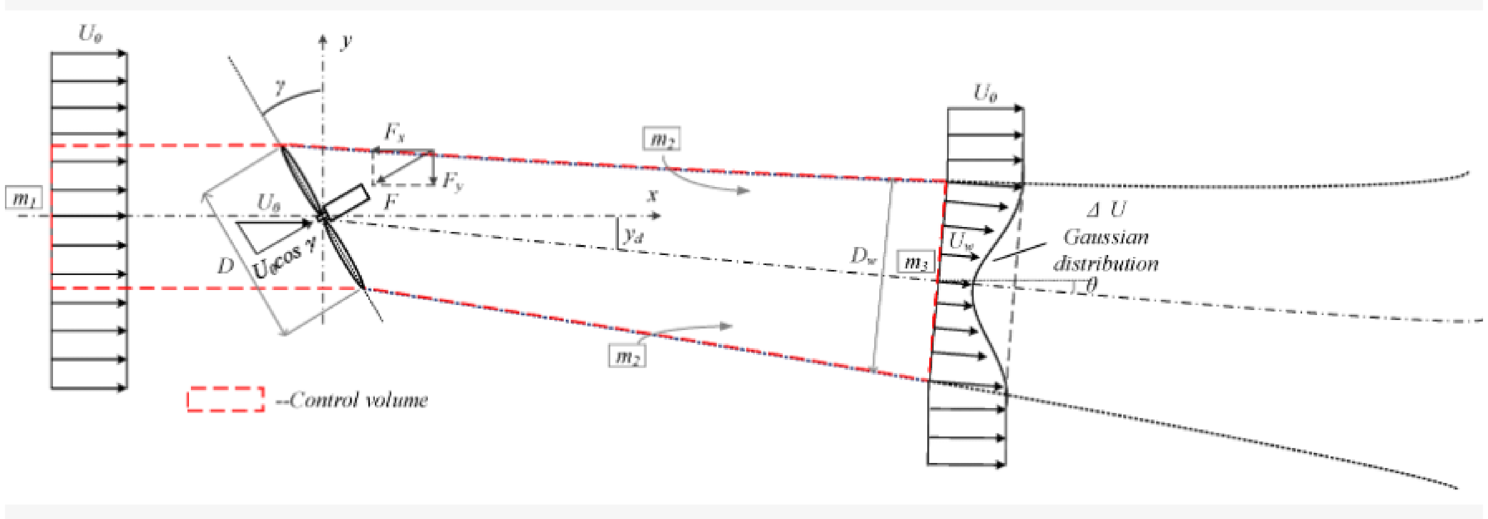
Introduction and Motivation

- Empirical models for steady state wake calculation
  - Jiménez et al. [1] presented a preliminary a wake deflection model based on LES results
  - Bastankhah and Porté-Angel [2] developed an analytical model to predict the wake deflection using wind tunnel.
  - Qian and Ishihara [3] developed an Analytical Wake Model for based on RANS simulations
- Validity of these models for large scale wind turbines
- Can we use these yaw deflectiom models with meandering in dynamic wake meandrering program (DIWA)



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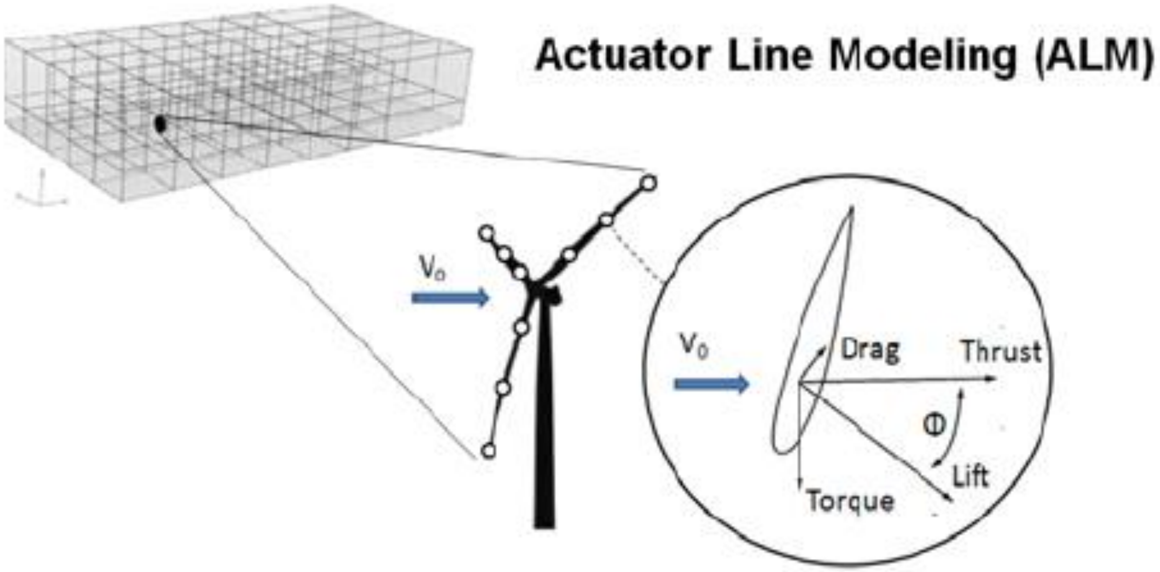
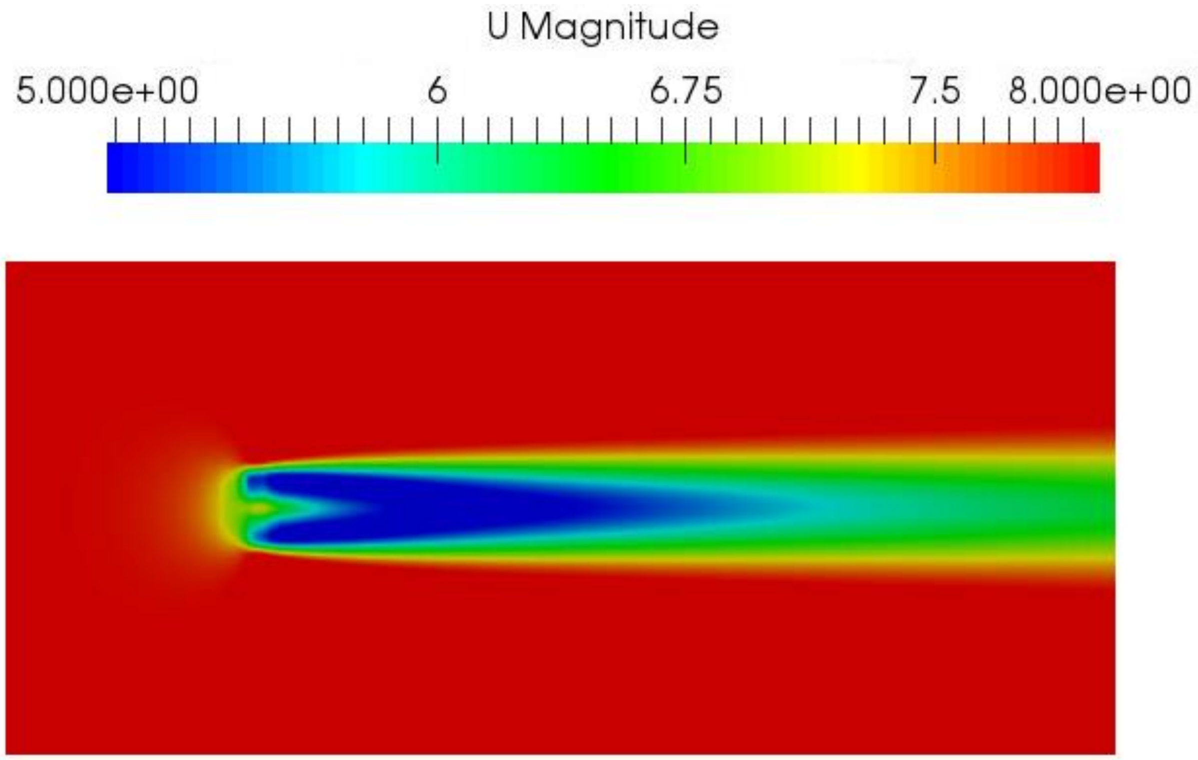
Methods and tool

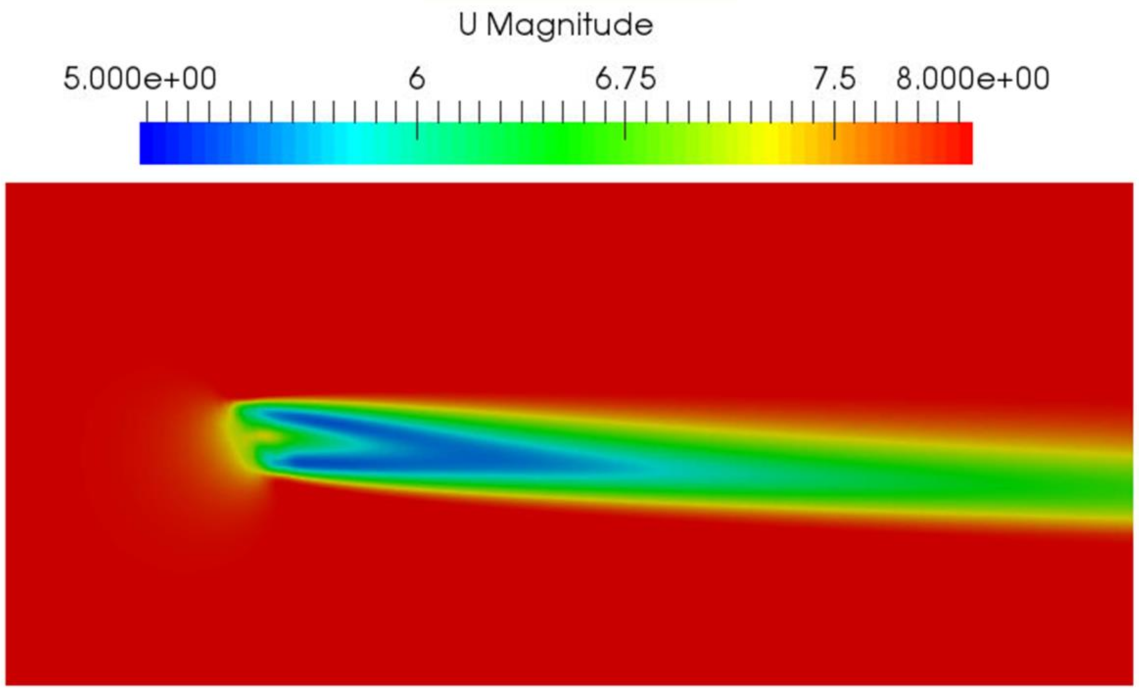
- RANS and LES for understanding the effect of yaw on wake deflection
- OpenFoam transient PisoFoam solver
- Actuator line model for the wind turbine
- RANS: K-epsilon turbulence model
- LES: Smagorinsky model
- Inflow conditions
  - Uambient = 8 m/s, TI = 10%
- Three yaw angles
  - 0, 10 and 20 degree



RANS CFD studies of NREL 5MW without and with yaw



Yaw = 0



Yaw = 20

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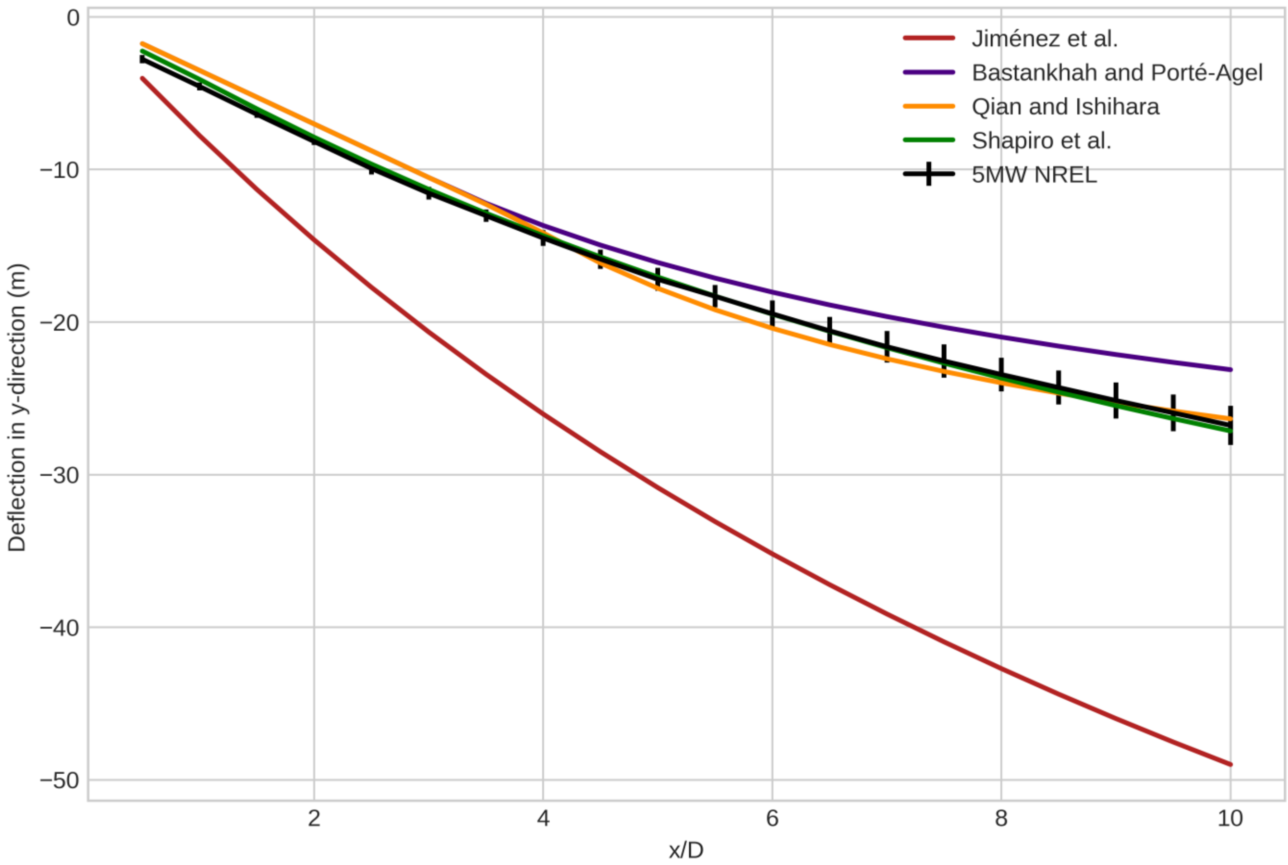
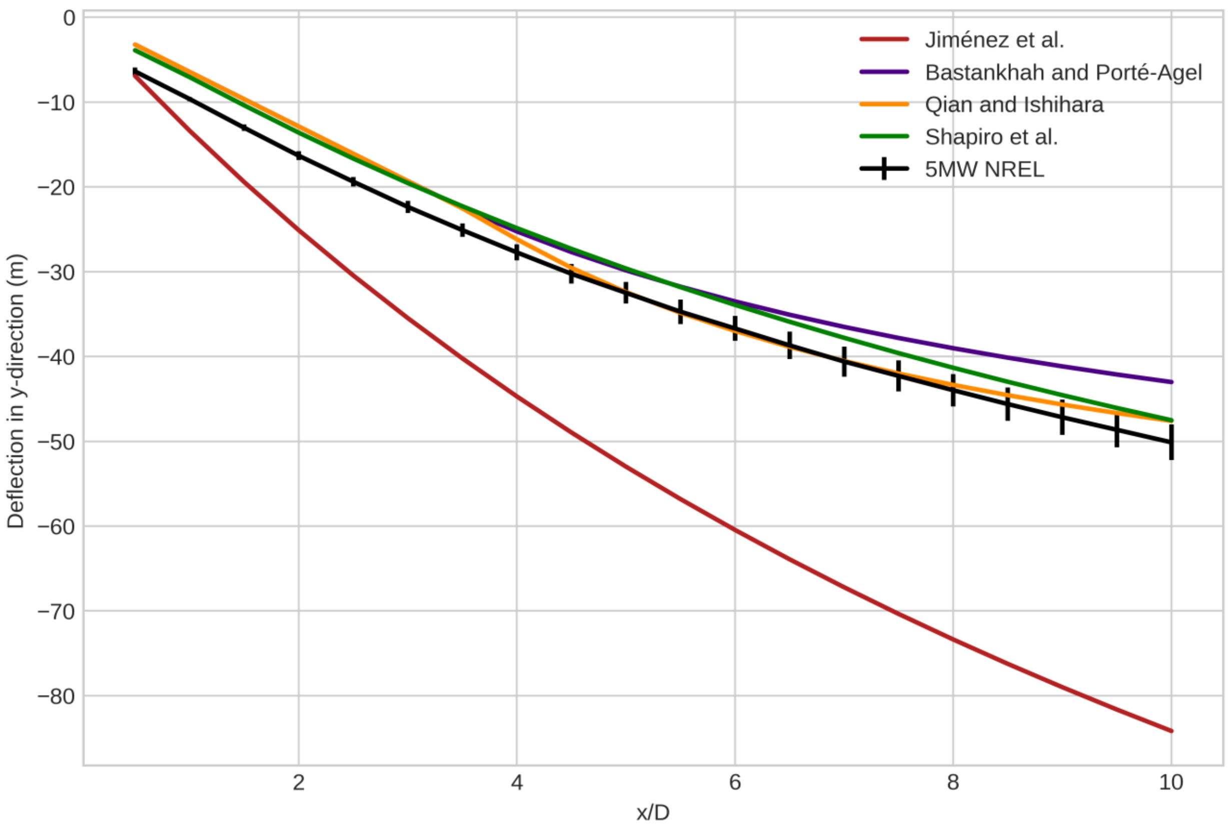
NRE5MW: Verification of Yaw with CFD models



Yaw = 10 degree



Yaw = 20 degree

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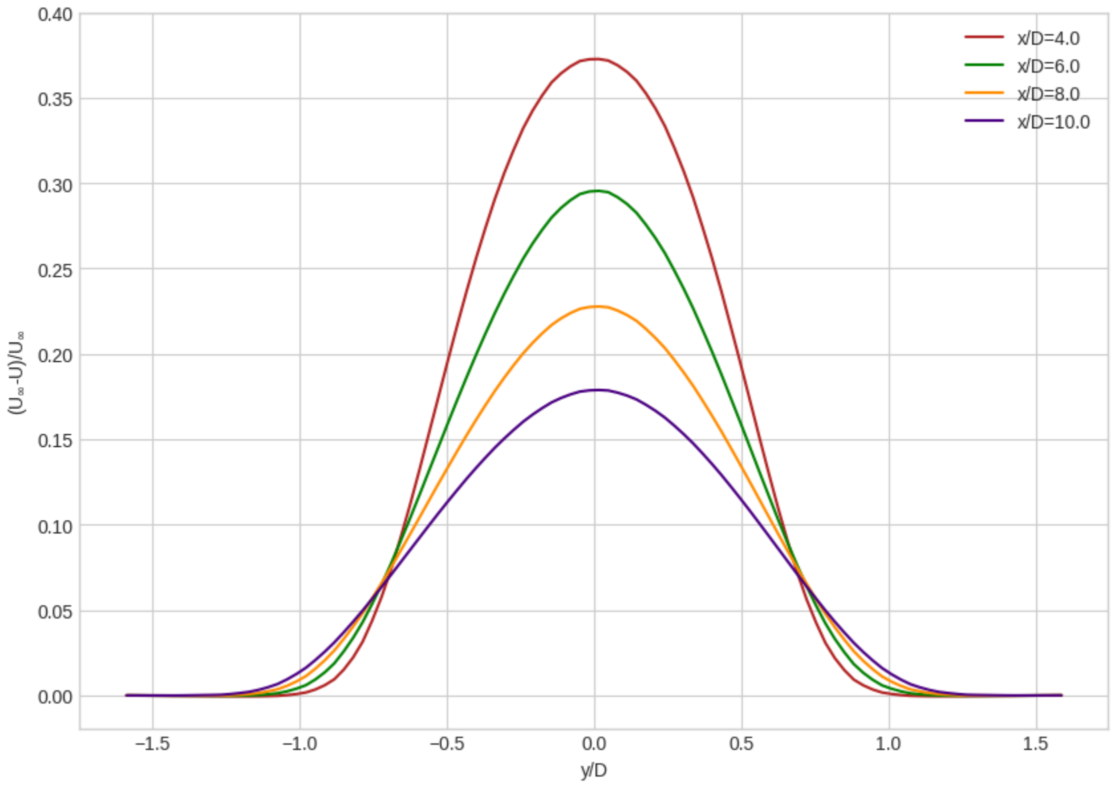
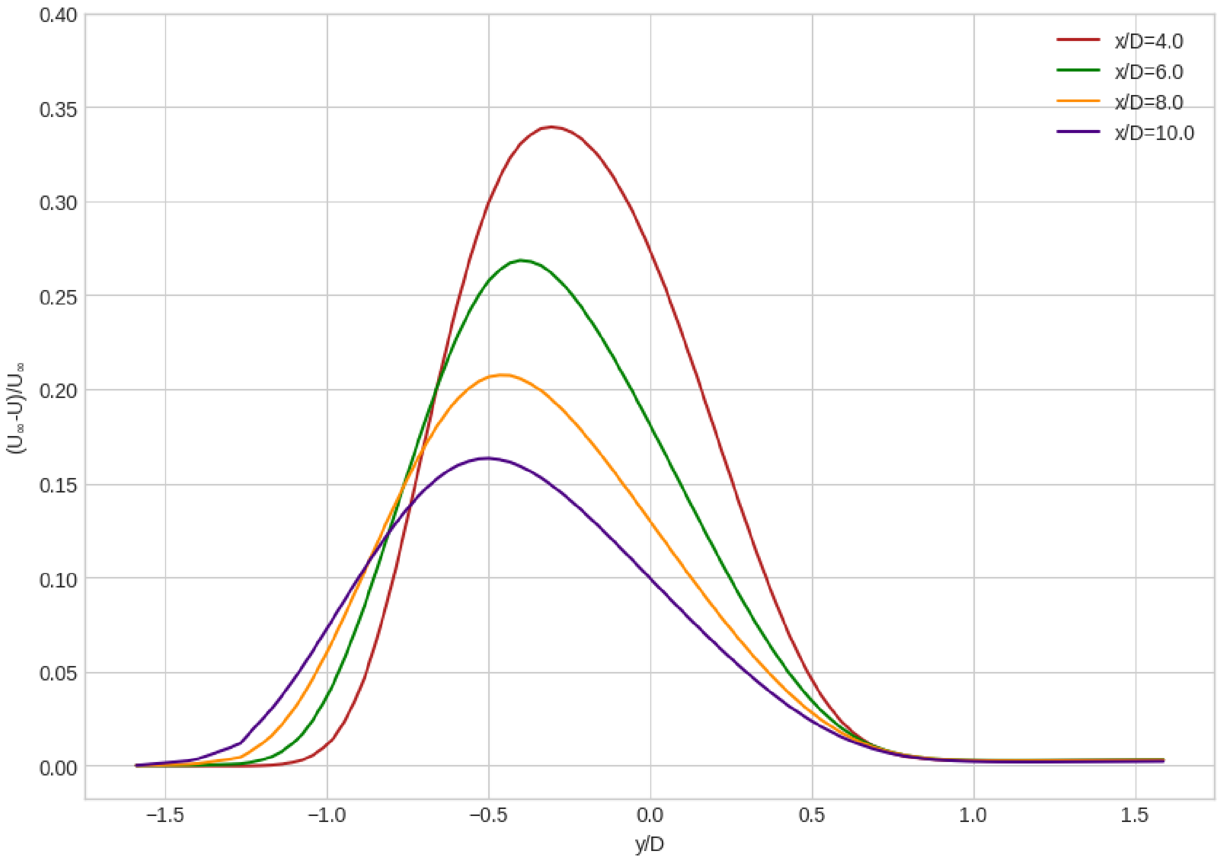
Velocity deficit



Without yaw



With yaw (10 degree)

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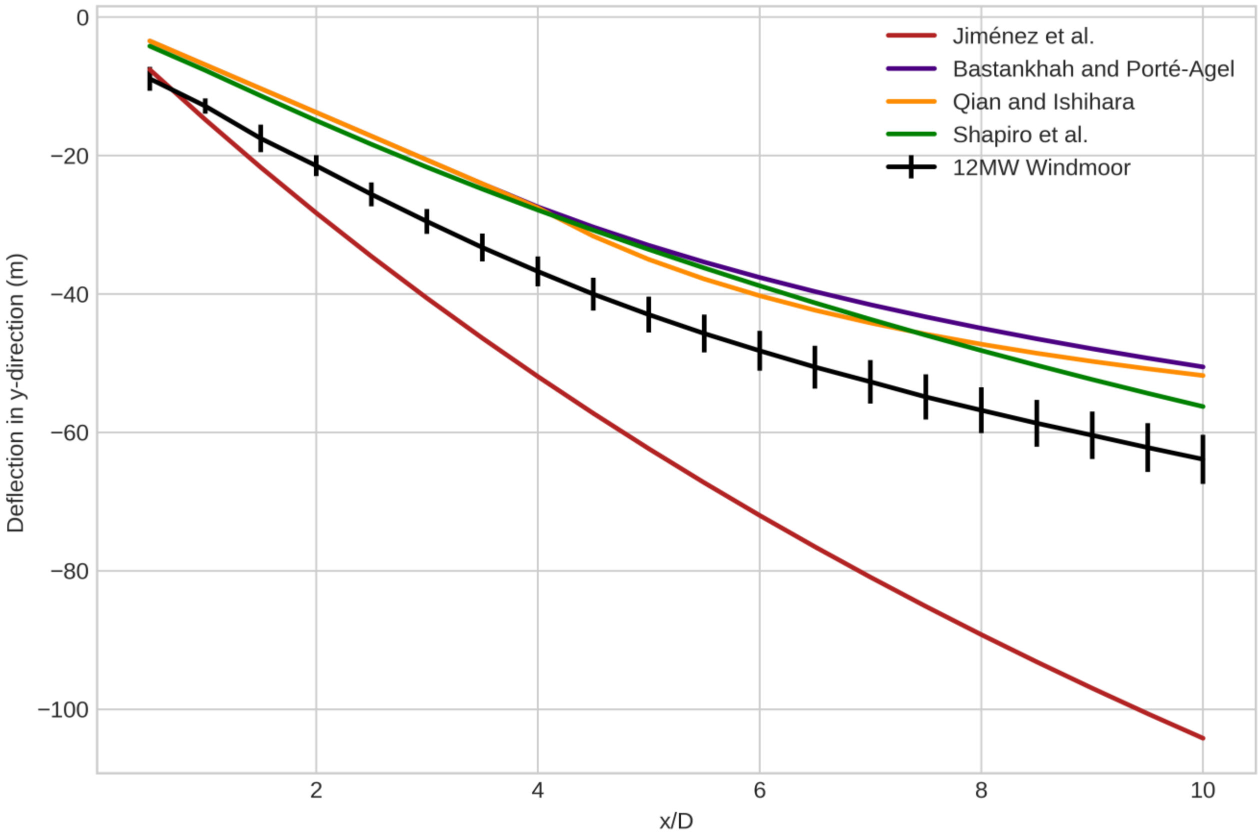
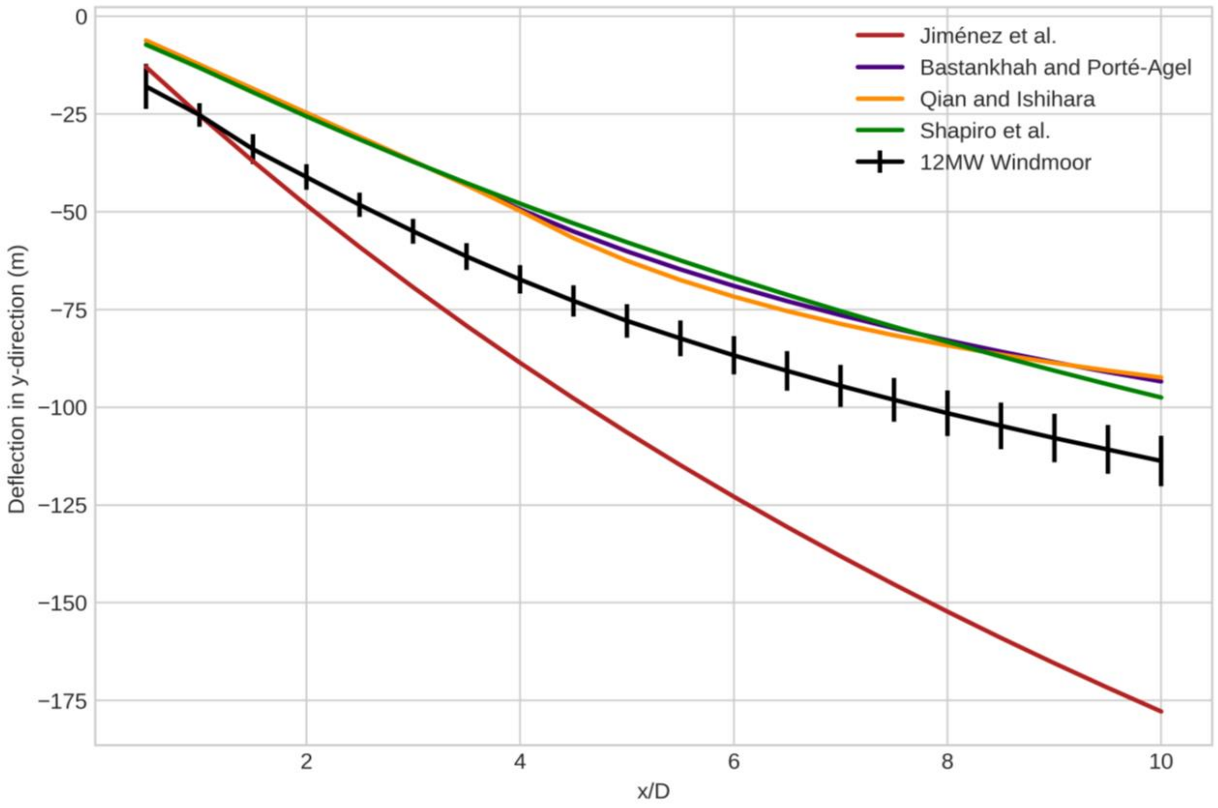
12 MW: Verification of Yaw with CFD models



Yaw = 10 degree



Yaw = 20 degree

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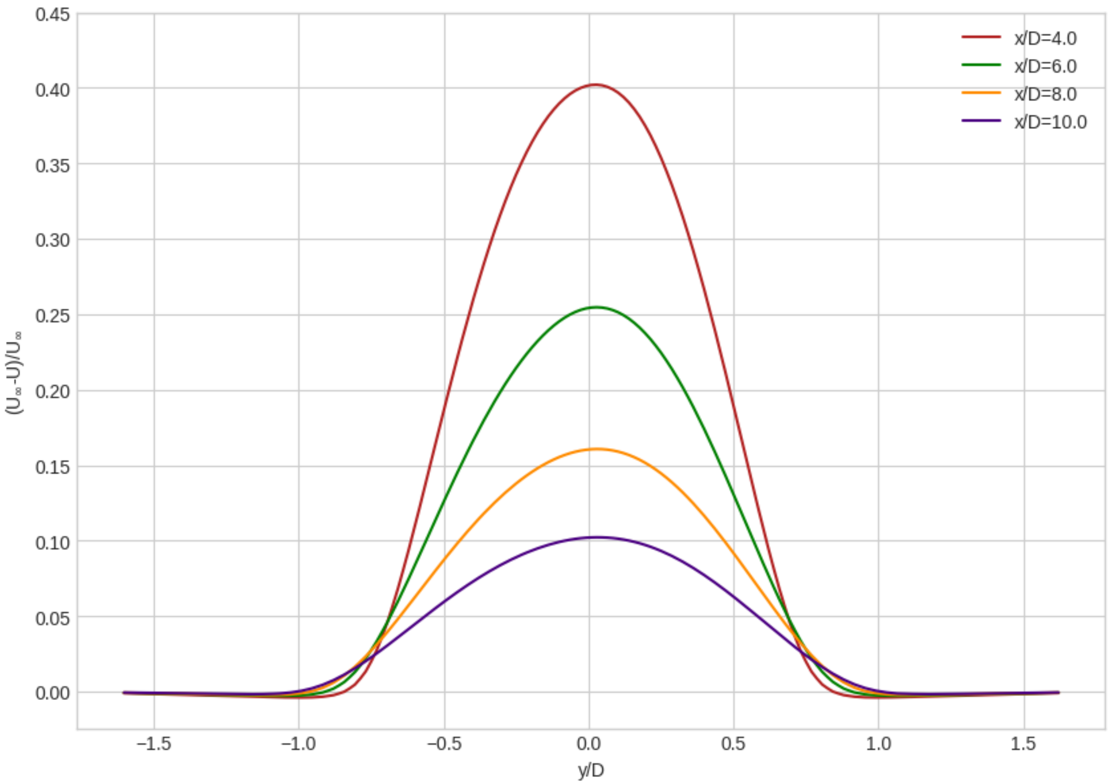
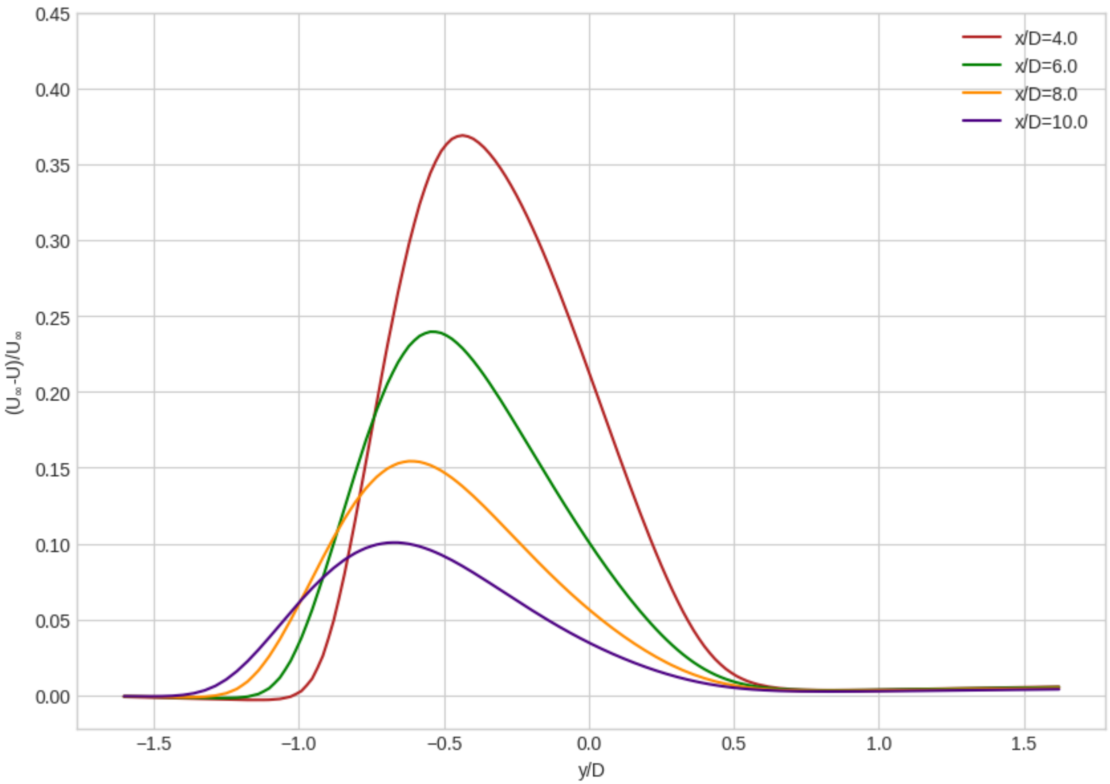
Velocity deficit (12 MW)



without yaw



with yaw

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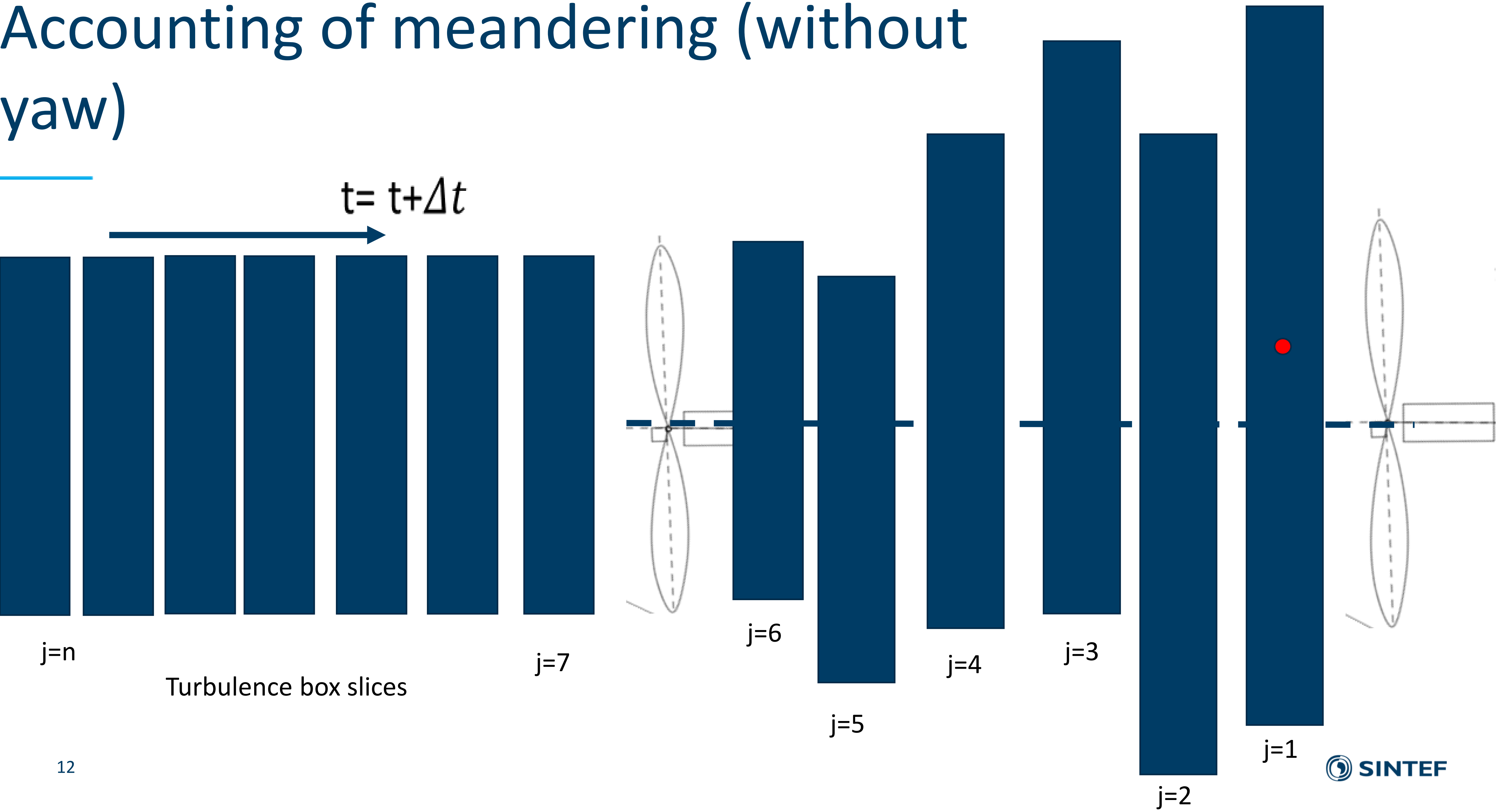
Transient inflow condition: Meandering study (Yaw effect)

Mann turbulence boxes slices → CFD domain
OpenFoam (Actuator line model for wind turbine)

Coupled results

Accounting of meandering (without yaw)



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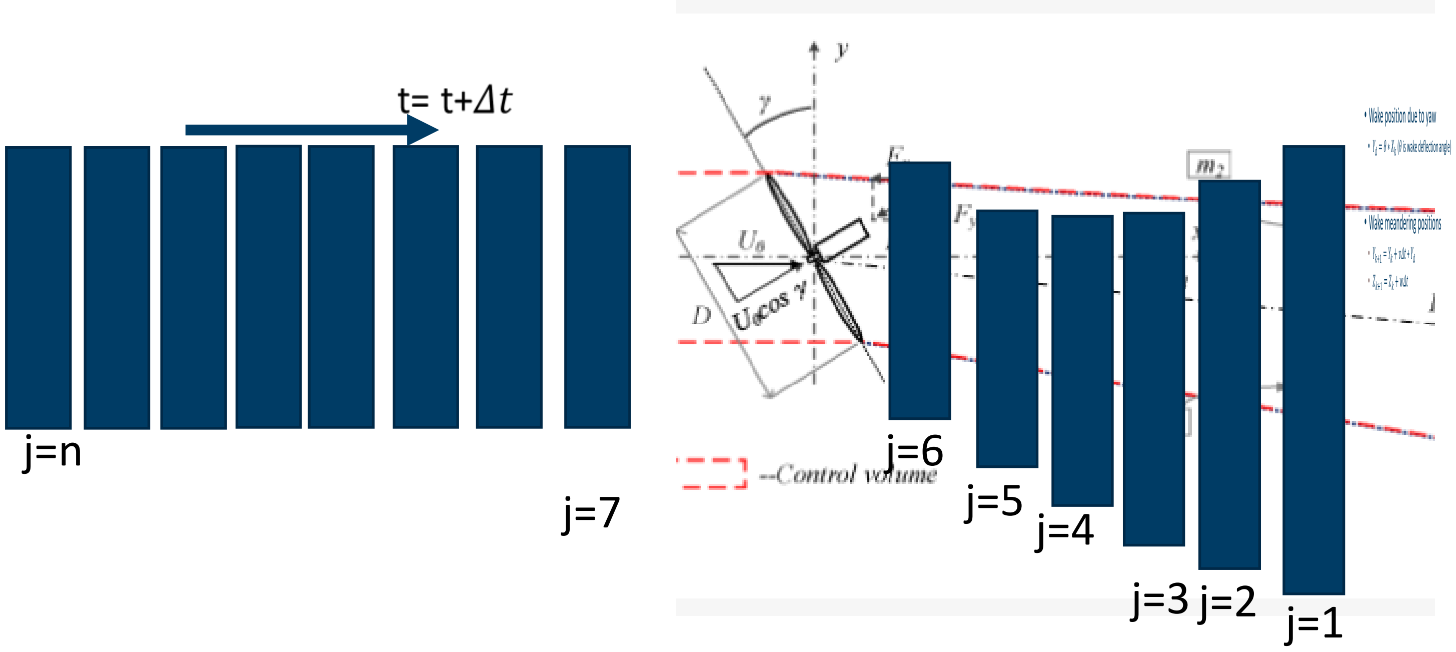
Implementation with meandering (Static yaw)

- Wake position due to yaw
  - $Y_d = \theta * X_k$ (θ is wake deflection angle)

- Wake meandering positions
  - $Y_{k+1} = Y_k + v\Delta t + Y_d$
  - $Z_{k+1} = Z_k + w\Delta t$

Accounting of wake deflection in meandering velocity calculation



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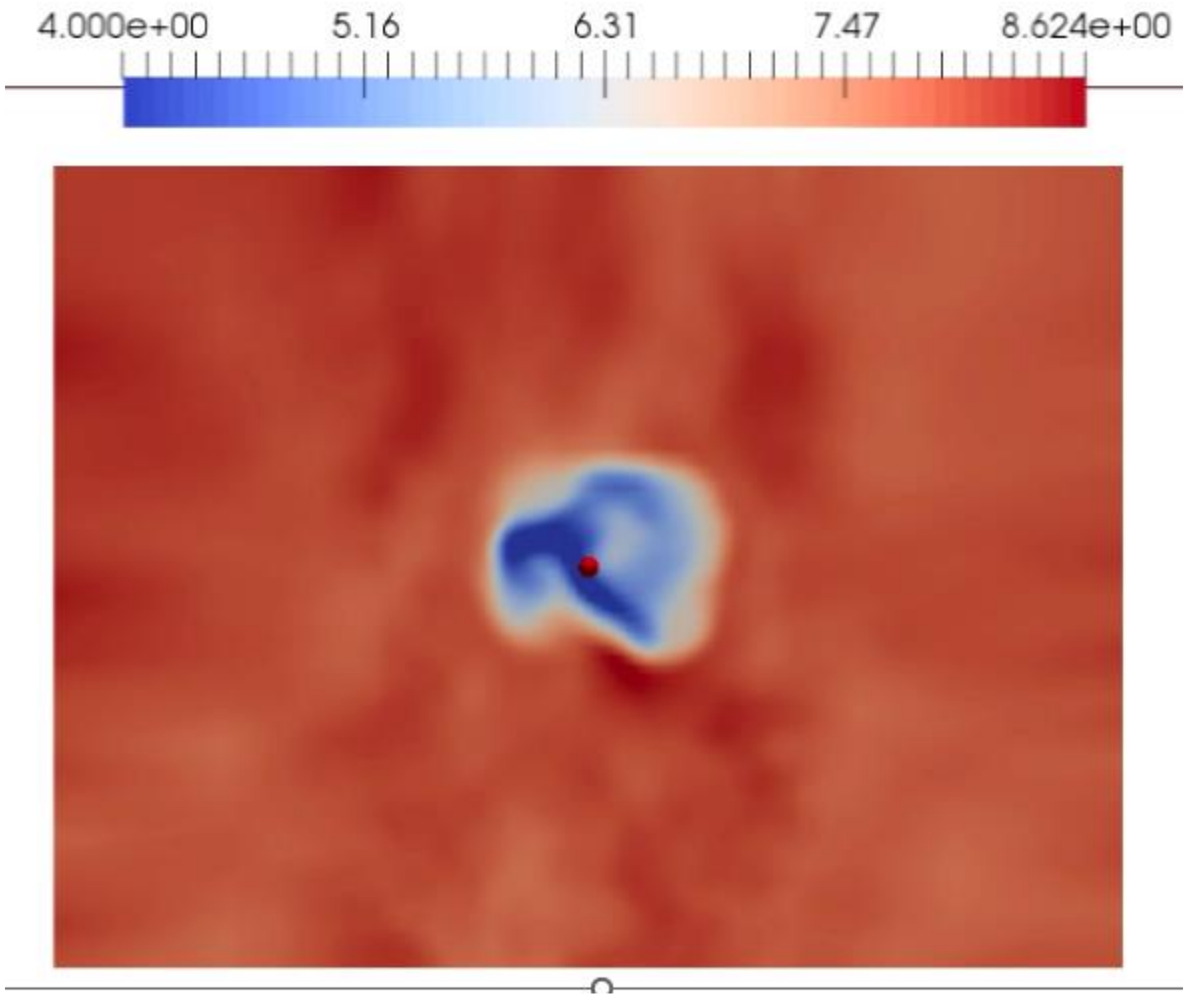
DIWA

- **Wake model:** Dynamic Wake Meandering modell
  - As recommended in the IEC standard (IEC 61400-1:2019)
- **Aerodynamics:** BEM with stiff blades.
- **Wind turbine control:** Cp-Ct curves as input, together with rotor speed and blade pitch angle and wind speed
- Turbulence boxes as input

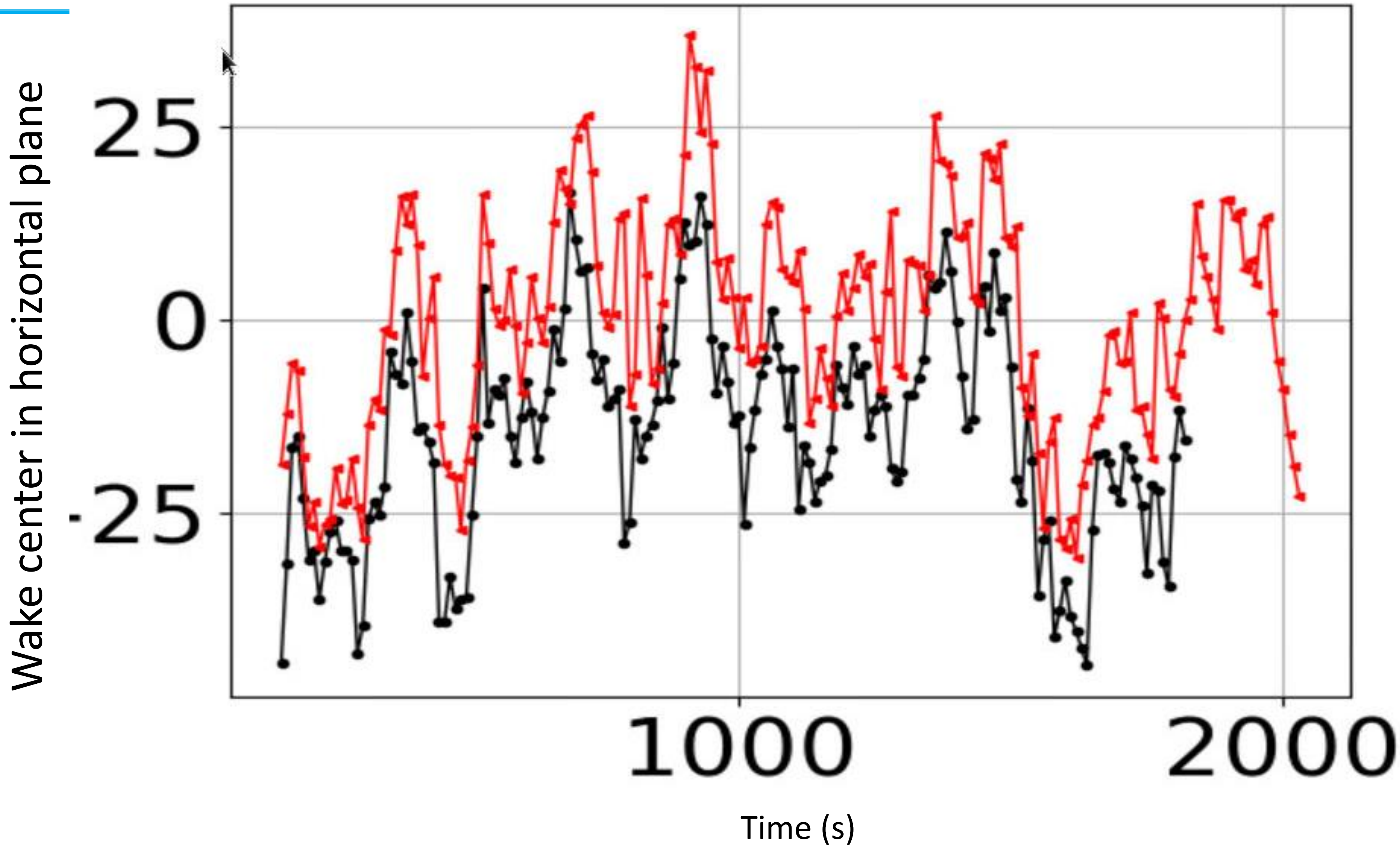
CFD results with and without yaw

Various methods of Wake center estimation [ref:4]

- Gaussian based approaches
  - 1-D Gaussian
  - 1-D Gaussian (Ideal Sigma)
  - 1-D Gaussian (Bastankhah)
  - 2-D Gaussian
- "constant momentum deficit" : The *momentum or energy flux* through the enclosed region
- "Constant area": A wake may be identified by contours that have a ***constant area***
- Maximum power
- Deficit weighted average method



Wake center position in Y direction (X/D = 8)



Red: Without yaw
Black: With yaw

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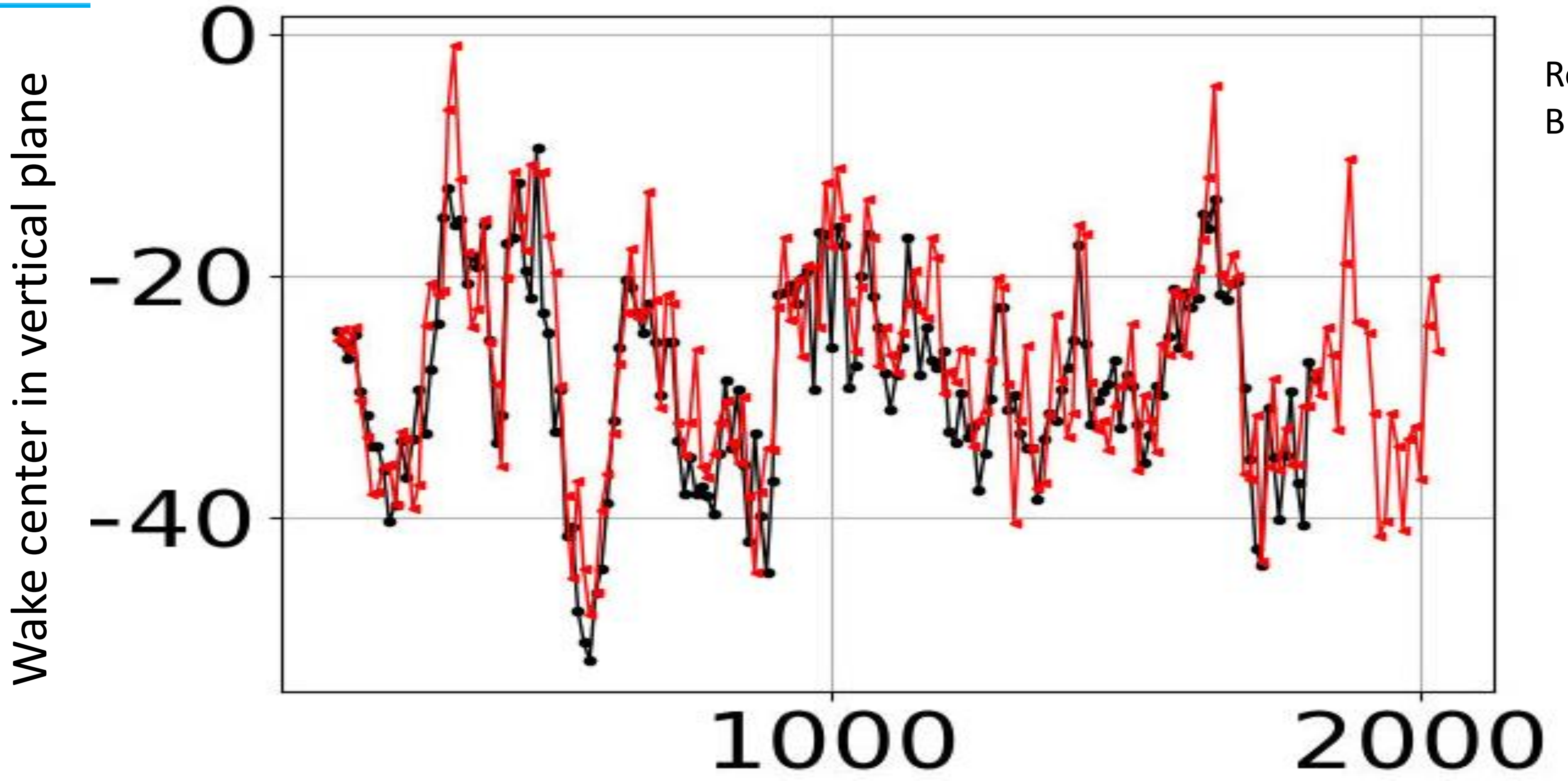
Wake center position in Z direction (X/D = 8)



Red: Without yaw
Black: With yaw

Time (s)

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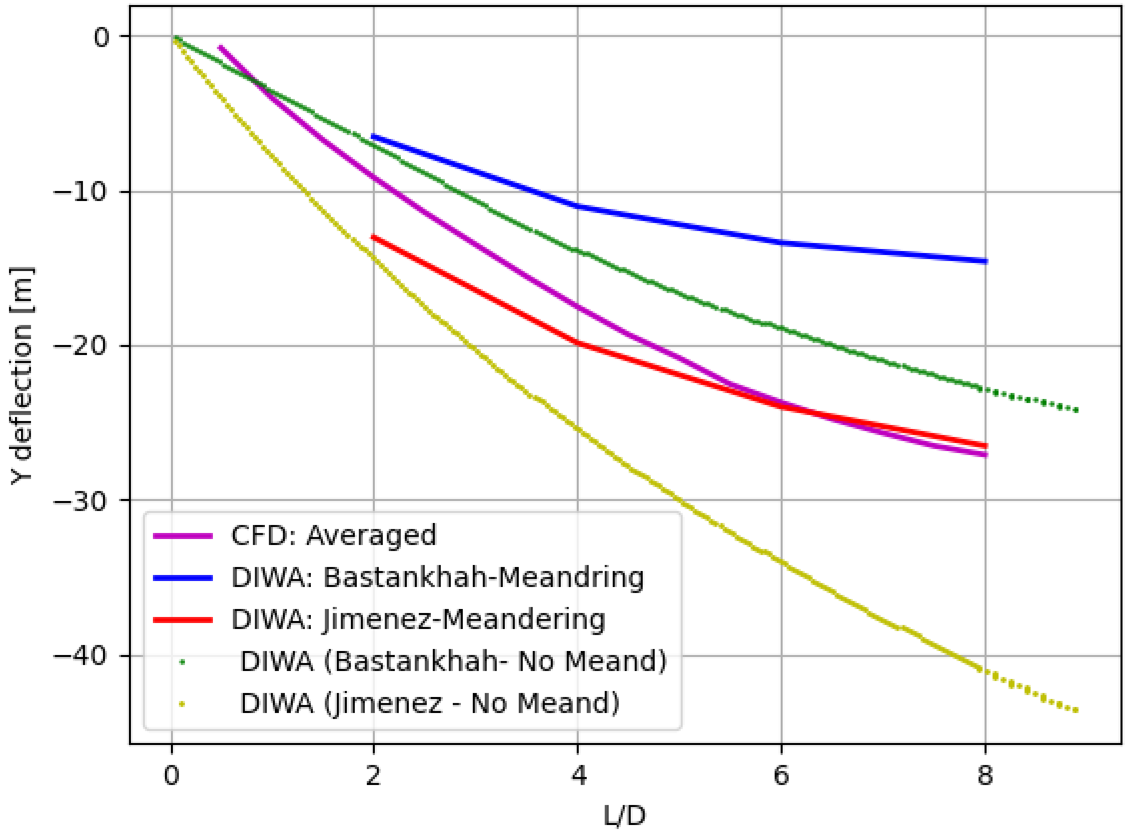
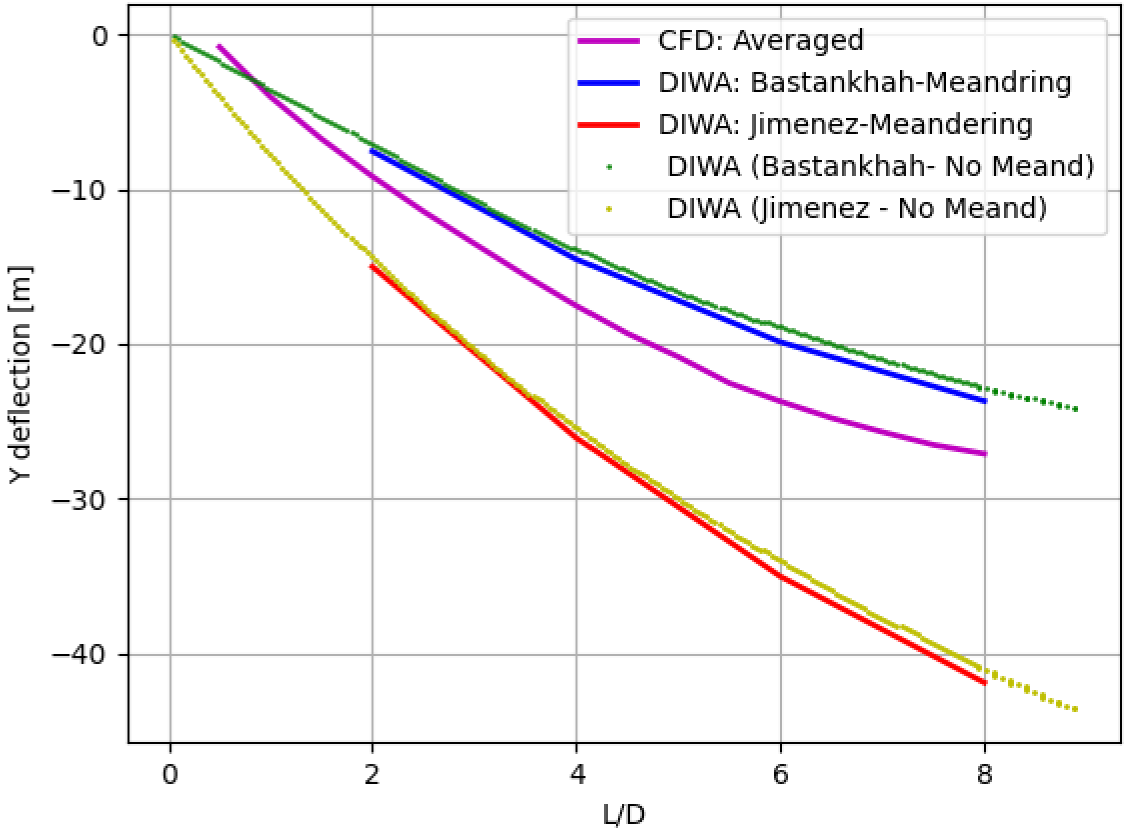
(NREL5MW: Yaw =10)



Accounting of wake deflection in meandering velocity calculation



Un-accounting of wake deflection in meandering velocity calculation

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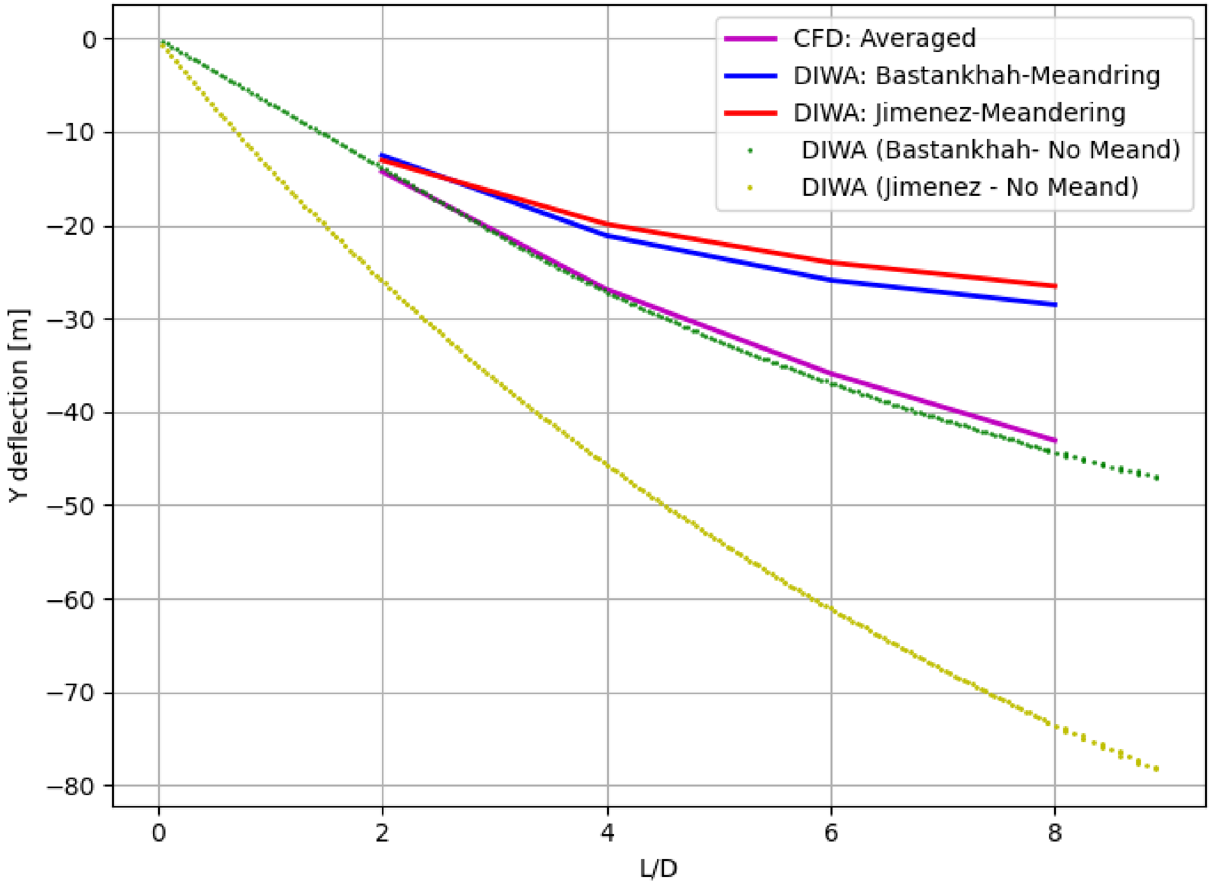
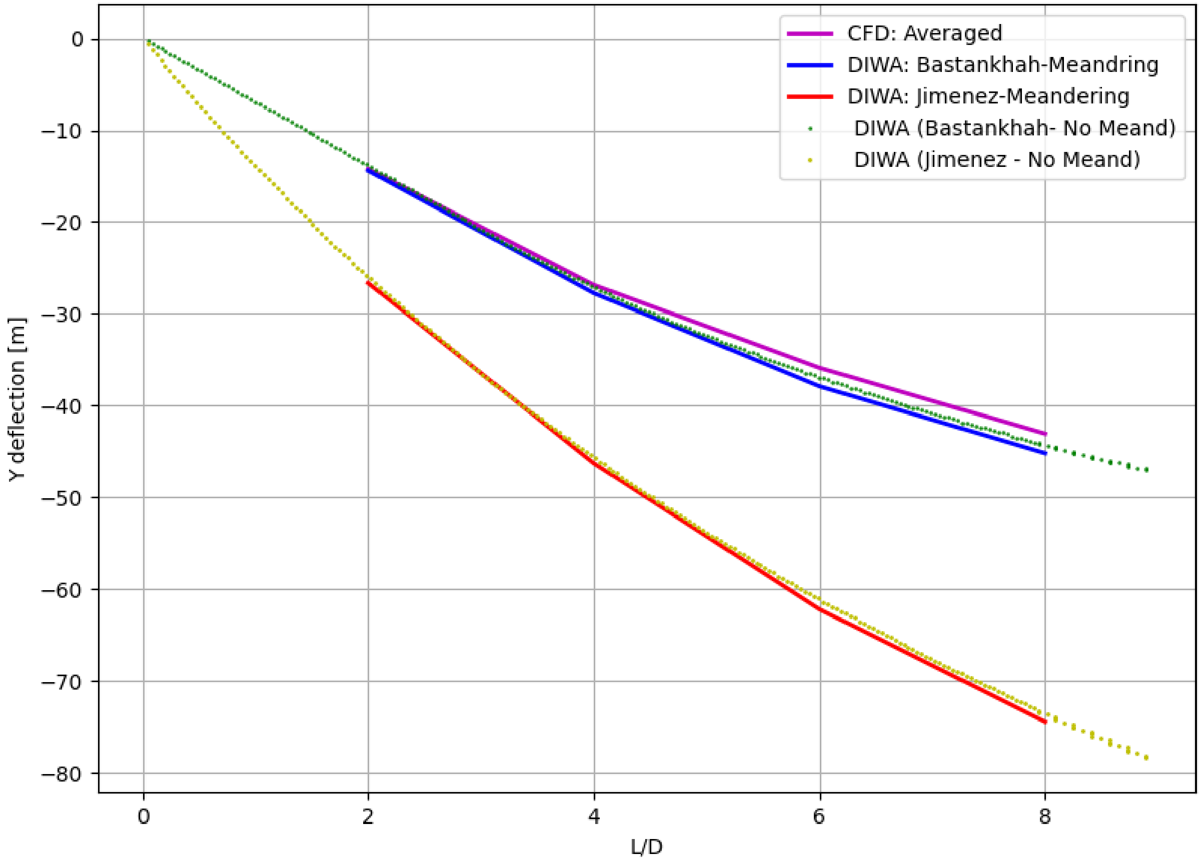
(NREL5MW: Yaw =20)



Accounting of wake deflection in meandering velocity calculation



Unaccounting of wake deflection in meandering velocity calculation

Conclusions

- Jimenez model overpredicts the wake deflection
- For large wind turbines (>5MW) Bastankhah, Shapiro, and Qian model underpredicts the initial wake deflection compared with current RANS simulations
- Need for better wake center tracking method
- The yawed turbine only affects meandering in horizontal plane
- Preliminary studies showed that effect of wake deflection can be directly added to the wake center positions in horizontal plane

Acknowledgement

The work performed here is a part of ongoing IPN project ImproveFlow and FME Northwind. Financial support received from these projects is greatly appreciated.

References

- [1] Jiménez et al, Application of a LES technique to characterize the wake deflection of a wind turbine in yaw, Journal of Wind energy, 2010
- [2] Bastankhah and Porte-Agel, A wind-tunnel investigation of wind-turbine wakes in yawed conditions, Wake Conference 2015
- [3] Qial and Ishihara, A New Analytical Wake Model for Yawed Wind Turbines, Energies, 2018
- [4] Elon Quon, https://ewquon.github.io/waketracking/

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