

TORQUE CONFERENCE
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**TOWARDS LES-RANS/LES COUPLING FOR SIMULATION OF A WIND
TURBINE ROTOR IN A NOCTURNAL ATMOSPHERIC CONDITION**

Manfred Imiela, Linus Wrba, Axel Probst, Galih Bangga, Antonia Englberger



Outline



1 Motivation & Structure

2 Methodology

3 Testcase Definition

4 Results from Validation Case (VC)

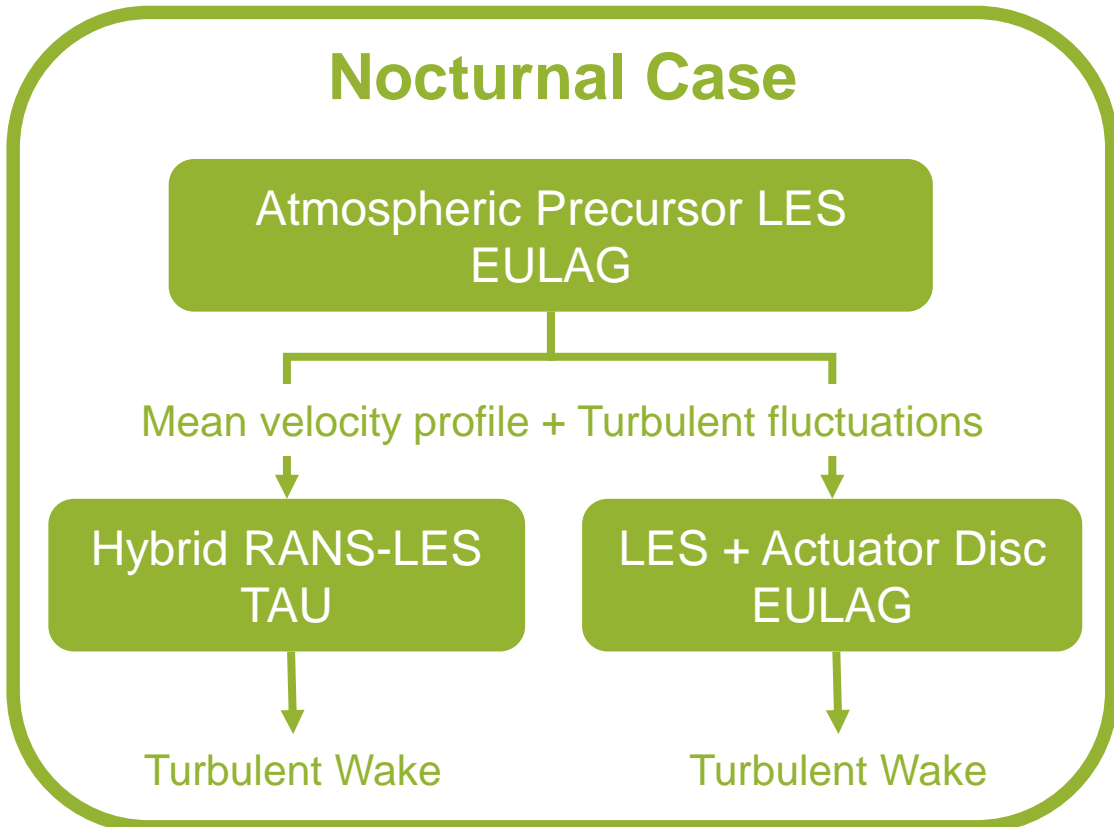
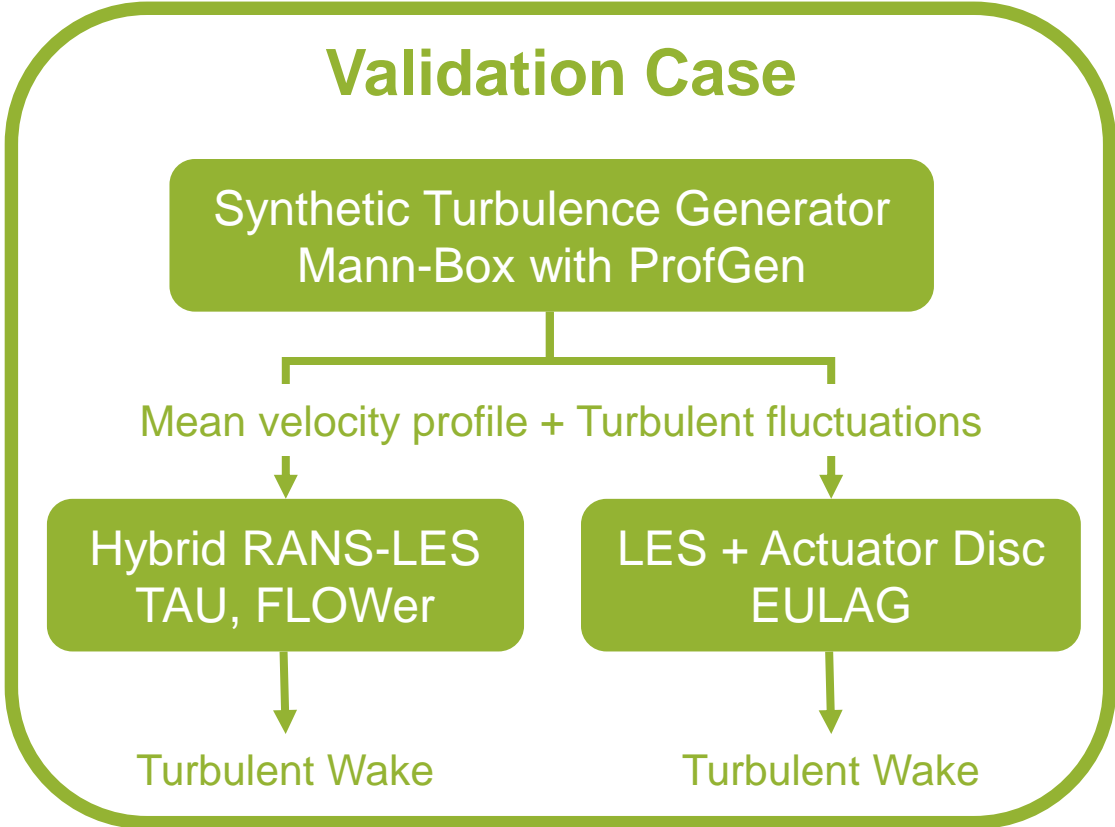
5 Results from Nocturnal Case (NC)

6 Summary & Outlook

Motivation & Structure

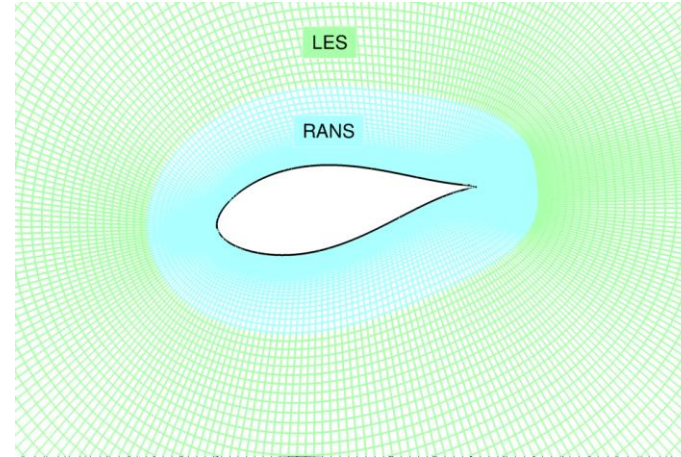
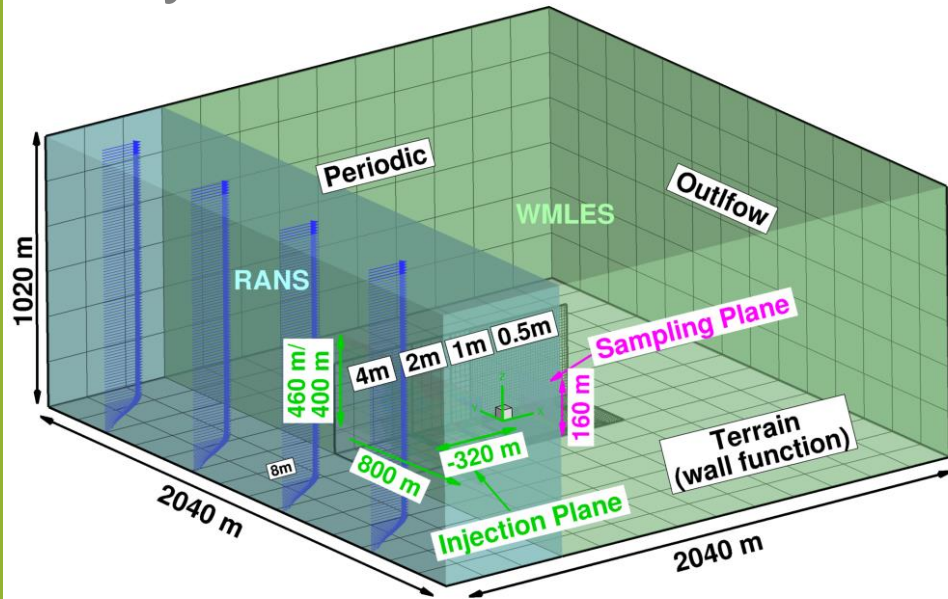


Rotor simulation under real atmospheric conditions

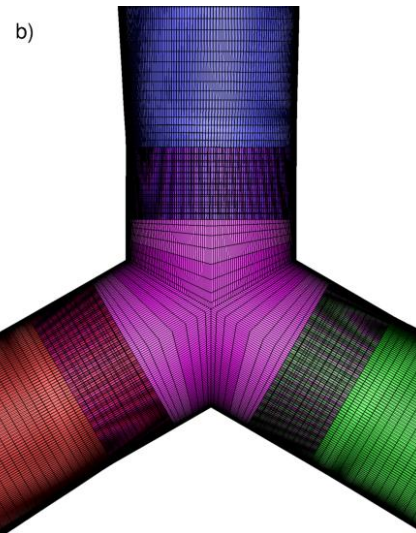
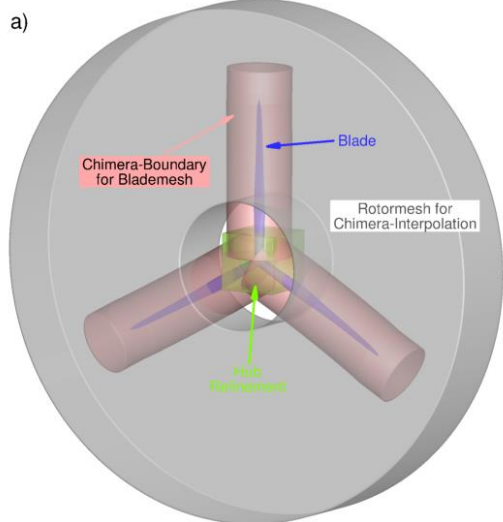


Methodology

Hybrid RANS-LES Simulation with TAU



Backgroundmesh	99.3e6
Rotor Refinement	2.4e6
Hub Refinement	0.9e6
Hubmesh	3*0.3e6
Blademesh	3*8.9e6
Total	130.2e6



Automatic Blending Function:

$$l_{hyp} = \tilde{f}_d(1 + f_e)l_{RANS} + (1 - \tilde{f}_d)l_{LES}$$

\tilde{f}_d depends on local grid and flow properties

f_e prevents log-layer mismatch

Body Force Formulation:

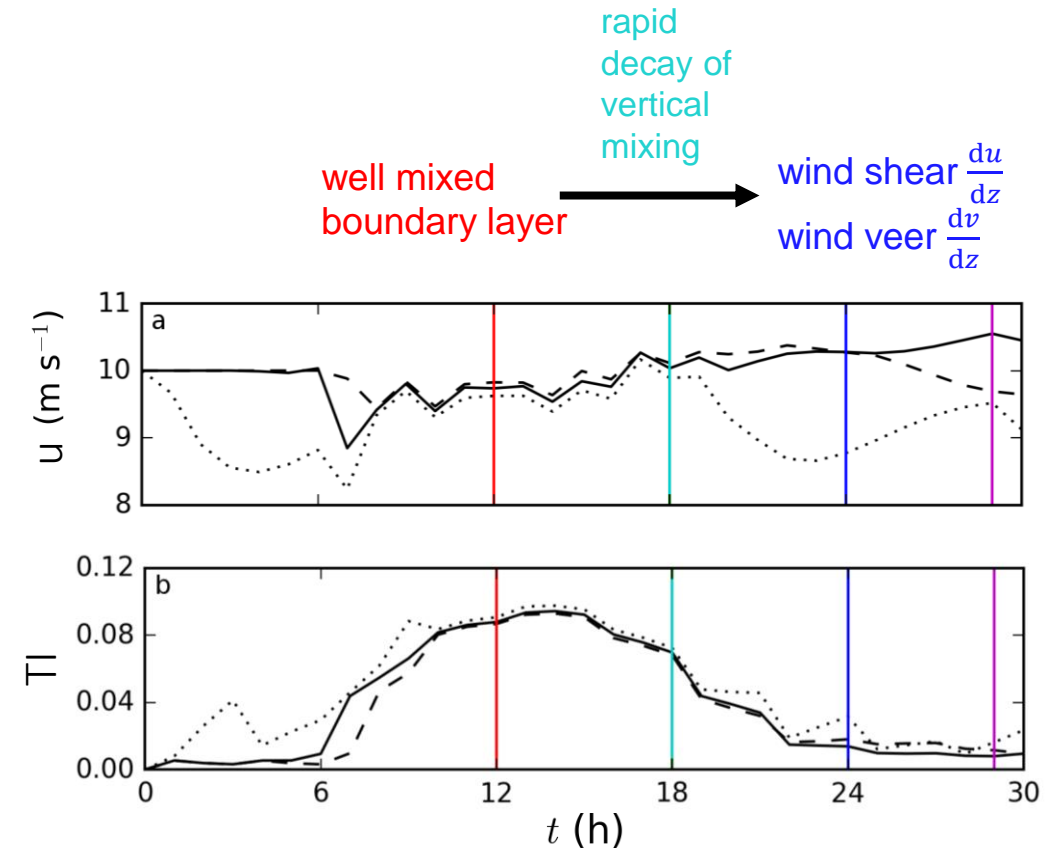
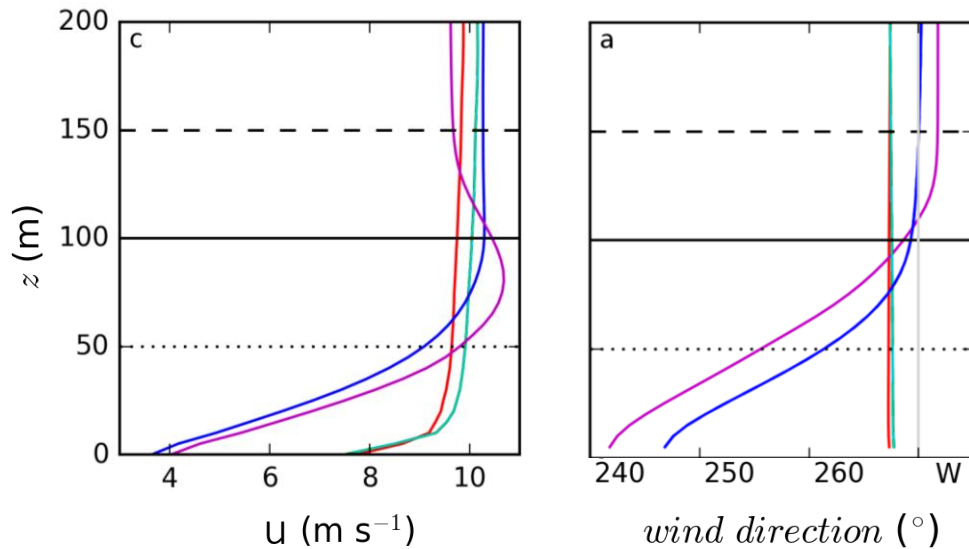
$$f_{bf} = \frac{\rho u'_i}{\Delta x_n} \left(u_n + \frac{1}{2} u'_n \right)$$

f_{bf} is introduced via momentum equation

Methodology

Precursor LES with EULAG

- EULAG solves boussinesq equations for incompressible atmospheric flow
- diurnal cycle simulation with temporal variation of surface heat flux
- periodic horizontal BC
- $\Delta = 5 \text{ m}$, $2.6 \times 2.6 \text{ km}^2$, $dt=0.1 \text{ s}$
- surface BC: partial slip & Neumann

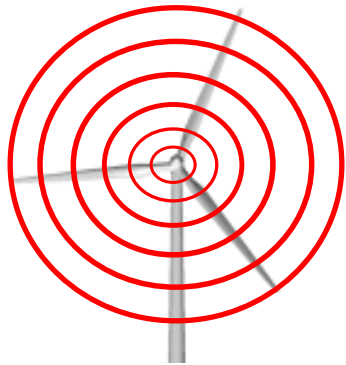


→ Extract nighttime stably-stratified situation as inflow condition.

Methodology

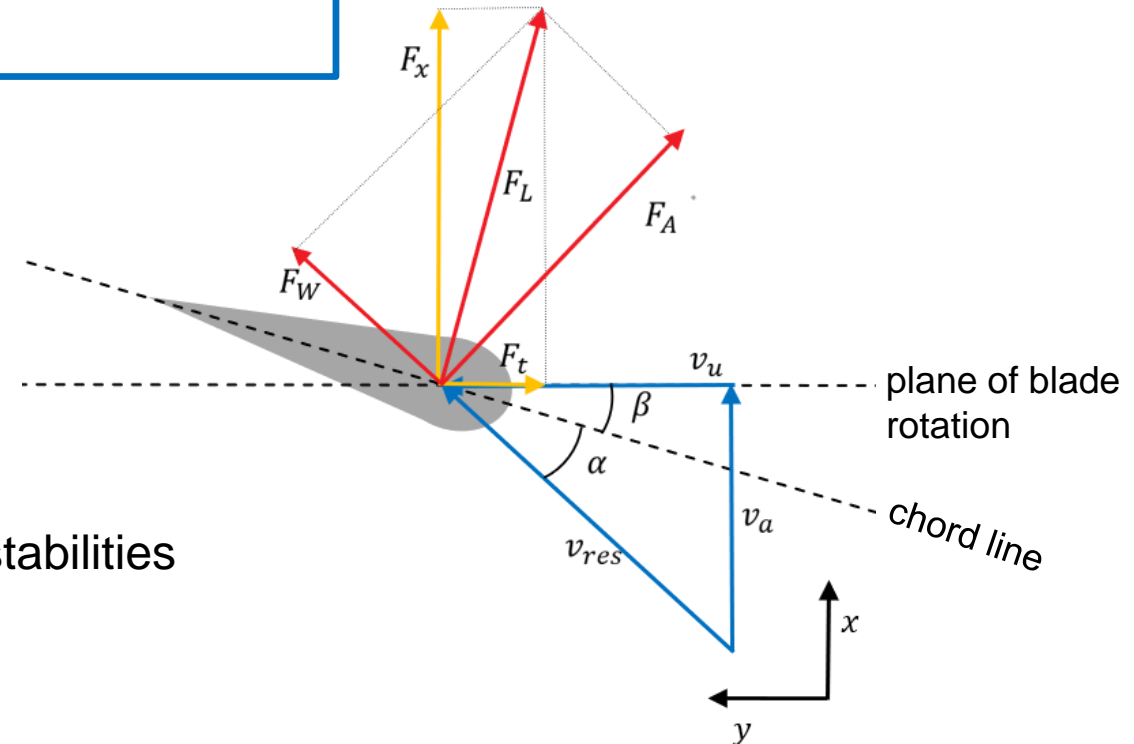
Actuator Disc Method – EULAG LES

- Rotor is parameterized as an rotating actuator disc
- Blade Element Momentum Theory (BEM)



- annular segments
- tabulated airfoil data (c_l, c_d, α)

- Calculation of the normal F_x and tangential F_t forces
- Turbine-induced force in momentum equation
 - Rotor is implemented as immersed boundary
- Gaussian smearing of the forces → avoid numerical instabilities

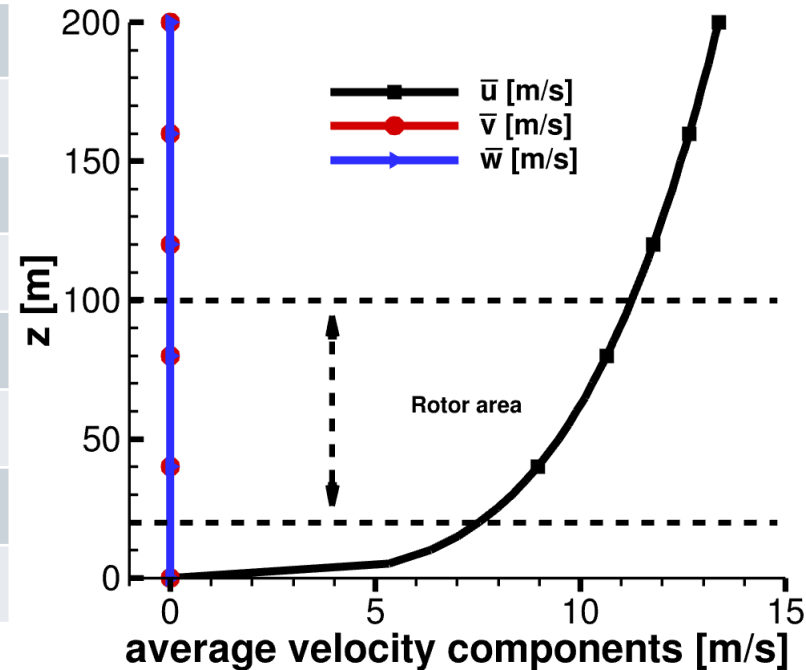


Testcase Definition

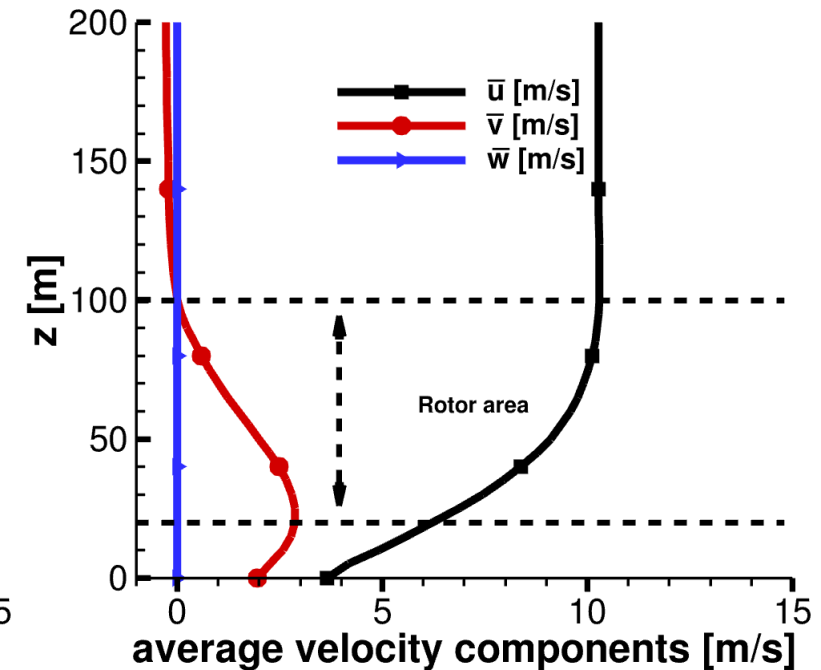


Parameter	Value
U_{hub} [m/s]	9.792
Z_{hub} [m]	57.19
α_s [-]	0.249
TI [%]	3.66
L [m]	32.026
n [RPM]	16.2
θ [°]	-4.75
γ [°]	-6.02 (VC)/-10.0 (NC)

Validation Case



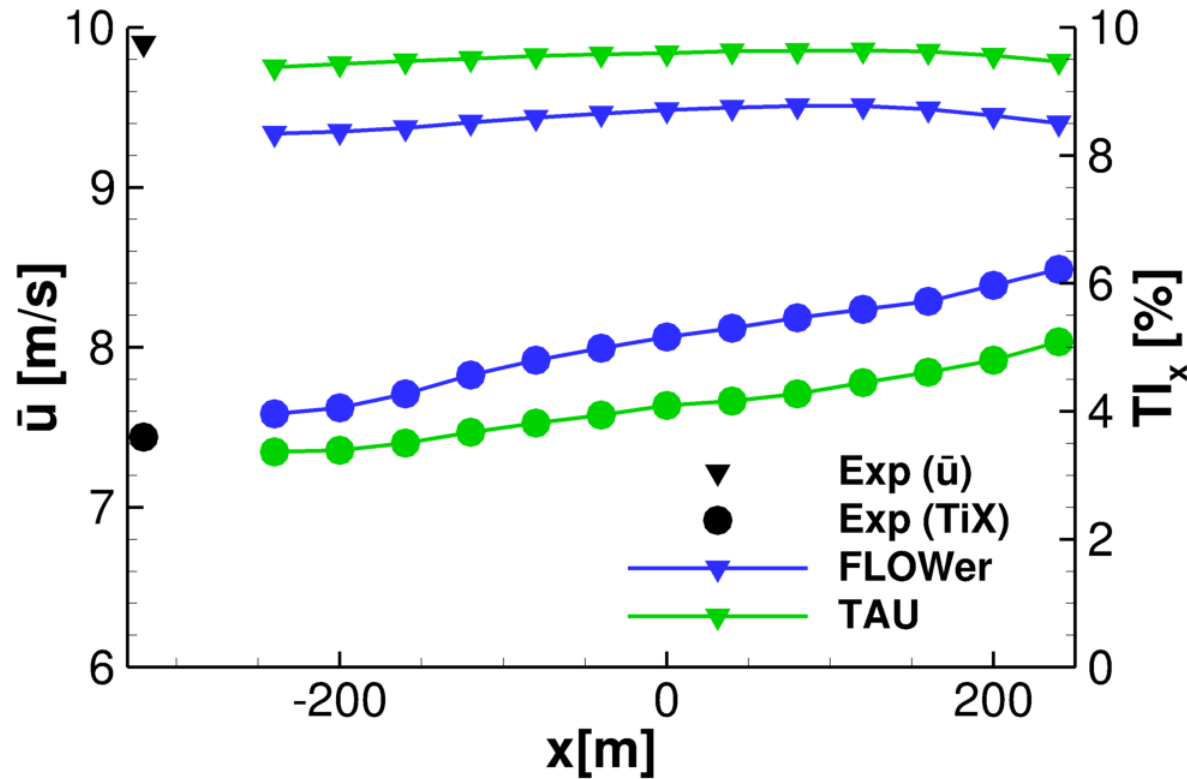
Nocturnal Case



- Streamwise velocity at hub height as comparable as possible
- Streamwise velocity component for VC has no limit vs. in NC it peaks at ~ 10 m/s @ upper rotor area
- No veer in VC vs. strong veer in rotor area in NC
- Mean vertical velocity component in both cases zero → no thermal activity

Results from Validation Case (VC)

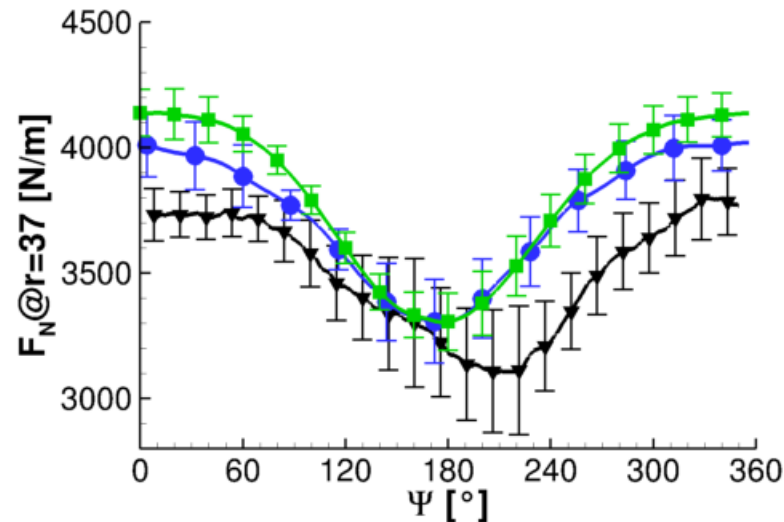
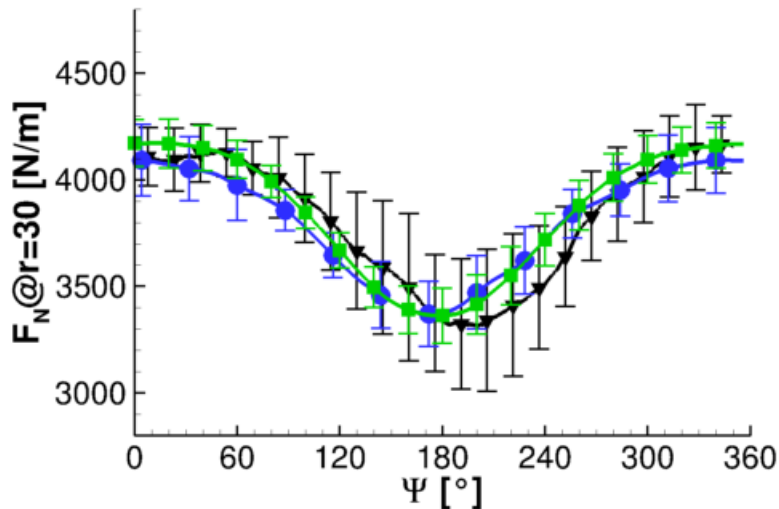
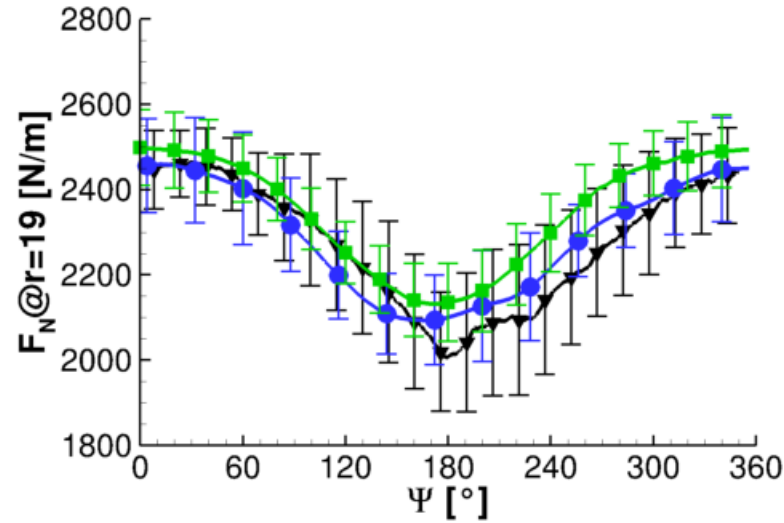
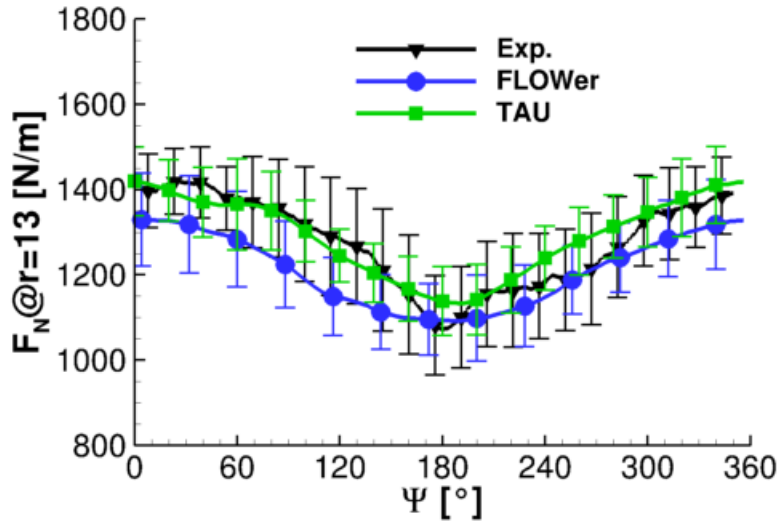
Empty Box: FLOWer vs. TAU vs. Experiment



- Compare streamwise development of mean velocity (\bar{u}) and turbulent intensity (Ti_x) @ hub height in middle cut ($y = 0$)
- In principal results between Codes match quite well (density normalization issue in FLOWer leads to small differences), but streamwise development of quantities very similar
- Comparison to experiment as close as possible (unfortunately only measurement data @ metmast 320m ahead of turbine)

Results from Validation Case (VC)

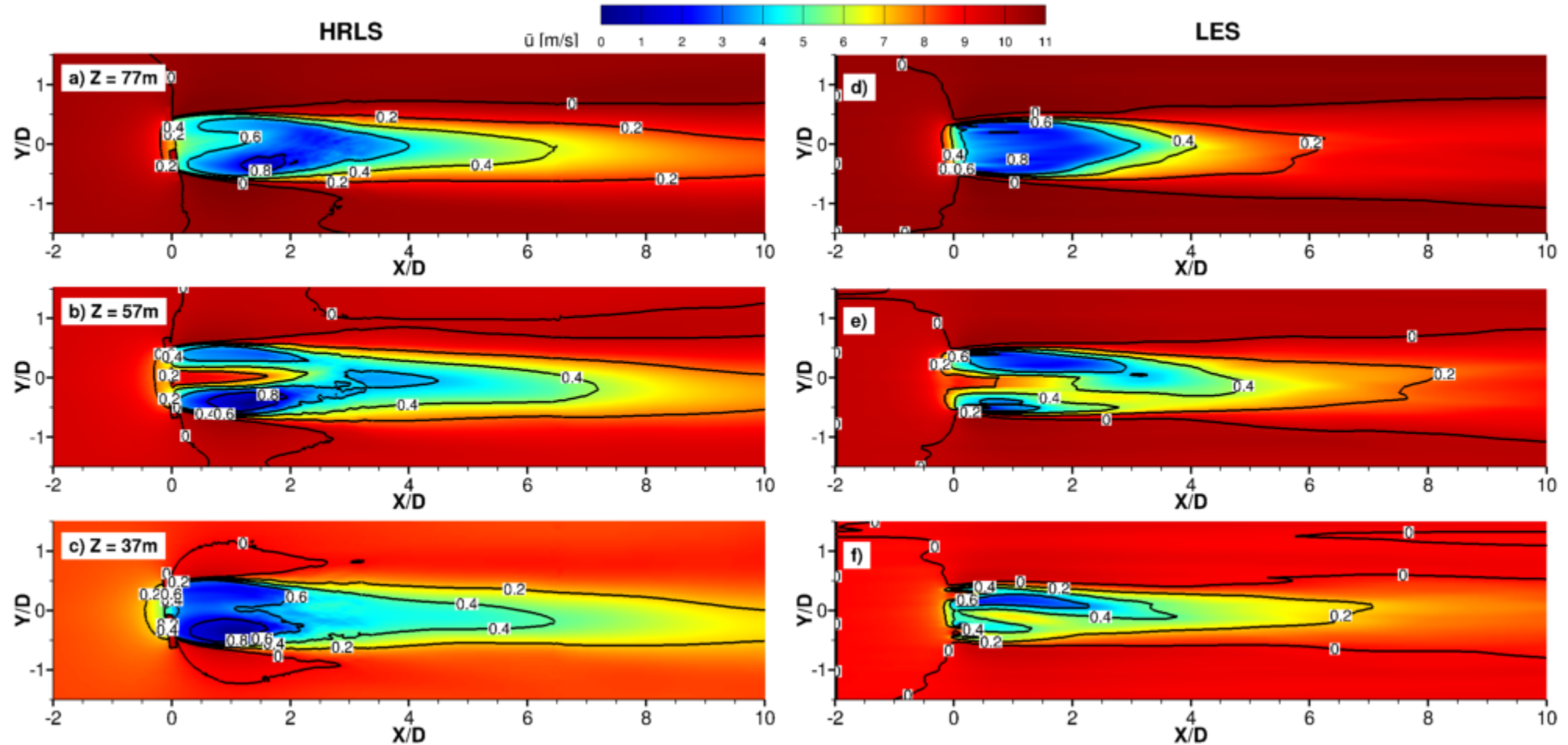
Rotor Simulation: FLOWer vs. TAU vs. Experiment



- Normal forces (in simulations) are averaged over 25 revolutions → mean value + standard deviation @ four radial stations
- Agreement among codes is excellent
- Agreement with experiment is very good; deviations only at outermost station

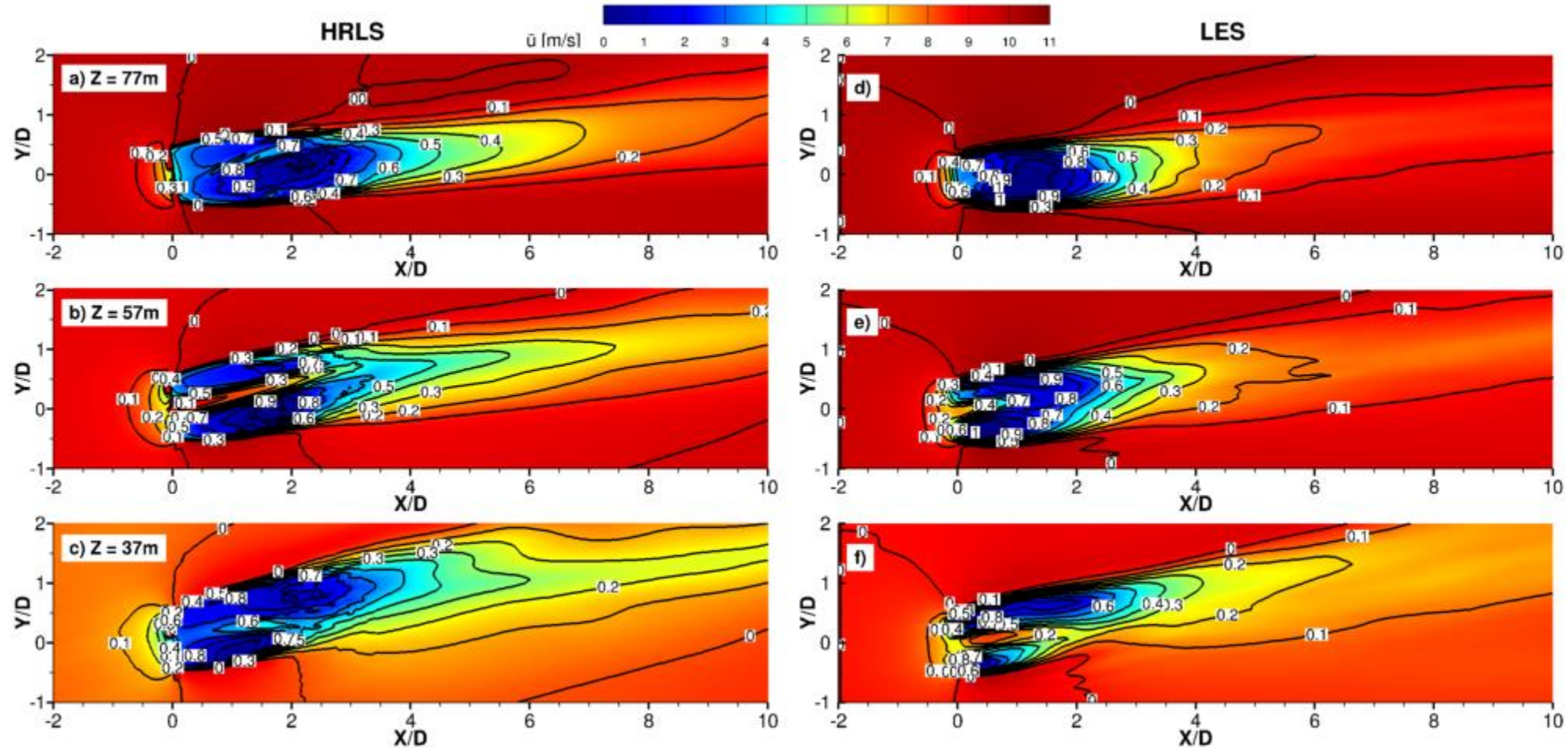
Results from Validation Case (VC)

Rotor Simulation: TAU vs. EULAG (+AD)



- Comparison of mean velocity (\bar{u}) and velocity deficit between TAU and EULAG (+AD) in 4 horizontal Cuts
- General agreement is good
- Wake in TAU persists longer
- Stronger differences are observed in the lower plane wrt lateral velocity deficit distribution

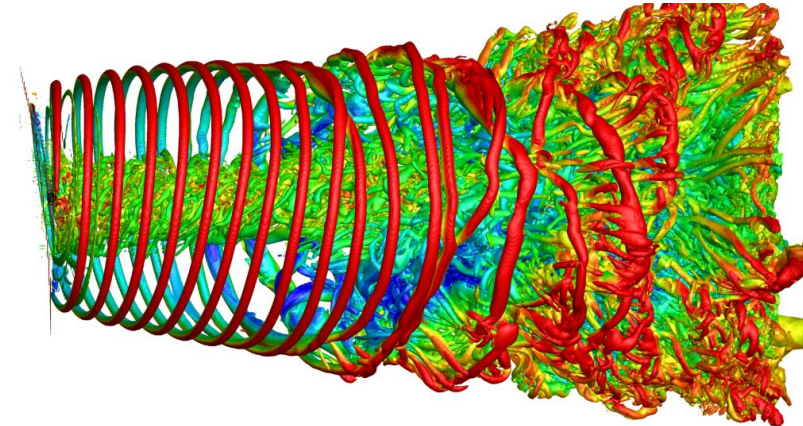
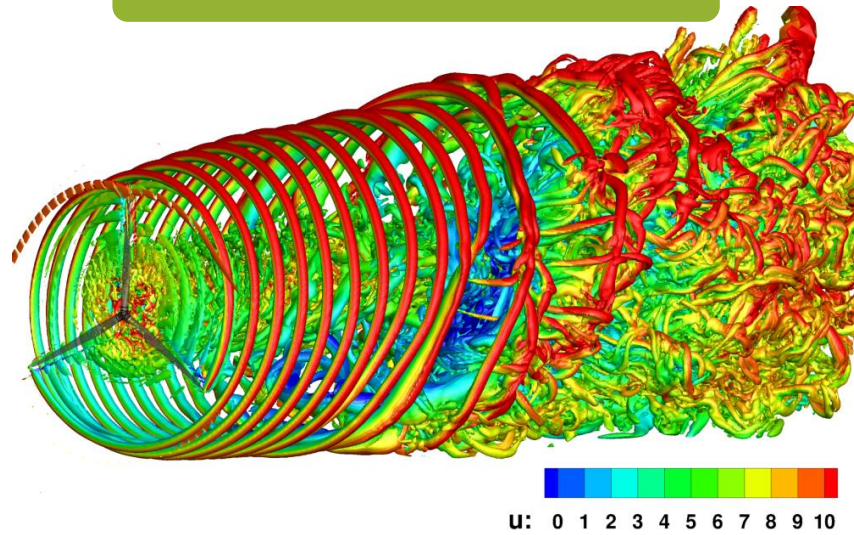
Results from Validation Case (NC) Rotor Simulation: TAU vs. EULAG (+AD)



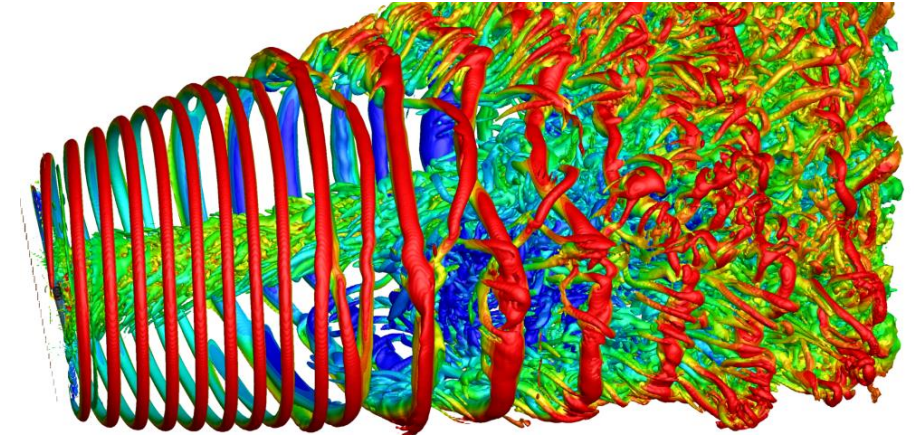
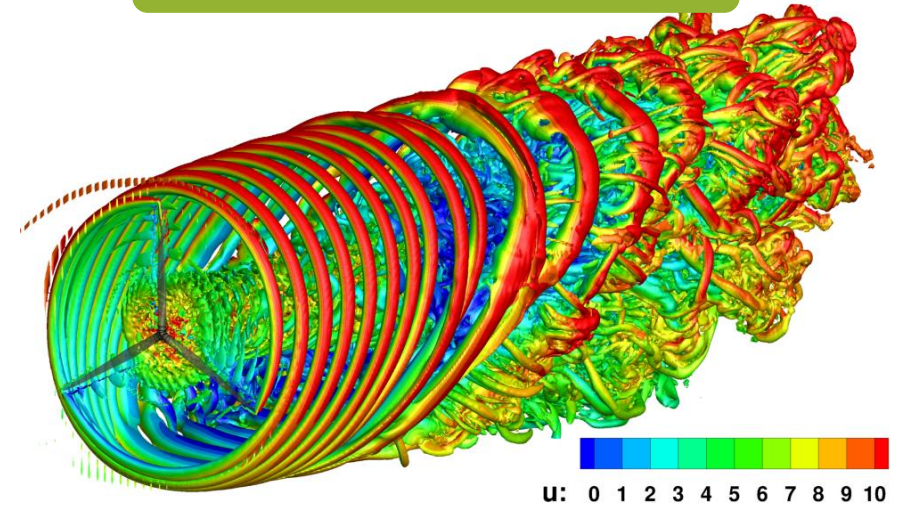
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- Stronger differences are observed in the lower plane wrt lateral velocity deficit distribution

Results from Wall modelled LES Validation Case vs. Nocturnal Case

Validation Case



Nocturnal Case



- Wake deflection in VC “opposite” to yaw direction as expected
- Wake deflection in NC is “counteracted” by veer

Summary



- Hybrid RANS-LES simulation of the DanAero rotor with moderate synthetic turbulent fluctuations was validated against experiment and another CFD code
- LES simulation of a nocturnal boundary layer of a similar location as the location of the DanAero rotor was performed resulting in a sheared and veered inflow profile with moderate fluctuations
- Global wake development can be captured with LES+AD simulations including veer, but local velocity deficits differ and dissipation of the wake is enhanced compared with the resolved approach (HRLS)
- Investigations with LES+AL and comparison with experiment are on the way