Simulation of a conventionally neutral boundary layer with two-equation URANS

M. Baungaard[1,2], M. P. van der Laan[1], M. Kelly[1] and E. Hodgson[1]

[1]Technical University of Denmark, DTU Wind and Energy Systems, 4000 Roskilde, Denmark
[2]University of Oxford, Department of Engineering Science, Oxford OX1 3PJ, UK

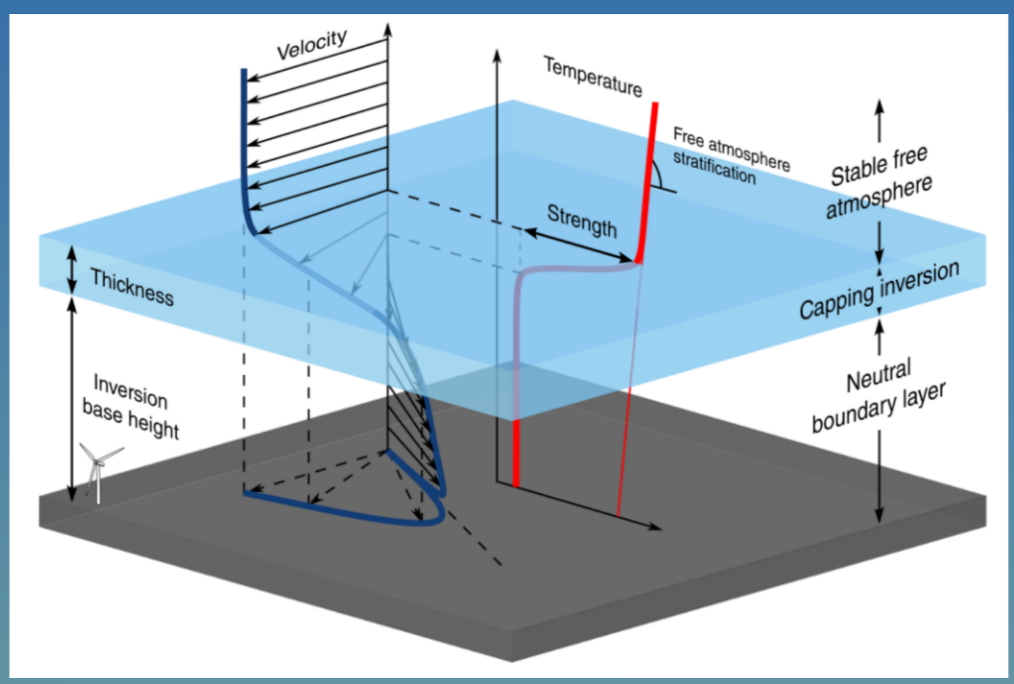
DTU

UNIVERSITY OF OXFORD

CARLSBERG FOUNDATION

1 The conventionally neutral boundary layer (CNBL)

For numerical simulations of wind farm flows one needs a model for the atmospheric inflow aka. a "precursor". The CNBL has become a popular inflow choice for large-eddy simulations (LESs) in the recent years, because it includes physical phenomena such as wind veer and an inversion-layer.



[1]

On the other hand, the usage of CNBLs in URANS simulations has not been explored much in the litterature so far, which is therefore the motivation for this work.

2 Unsteady Reynolds-Averaged Navier-Stokes (URANS) for horizontally homogeneous flows

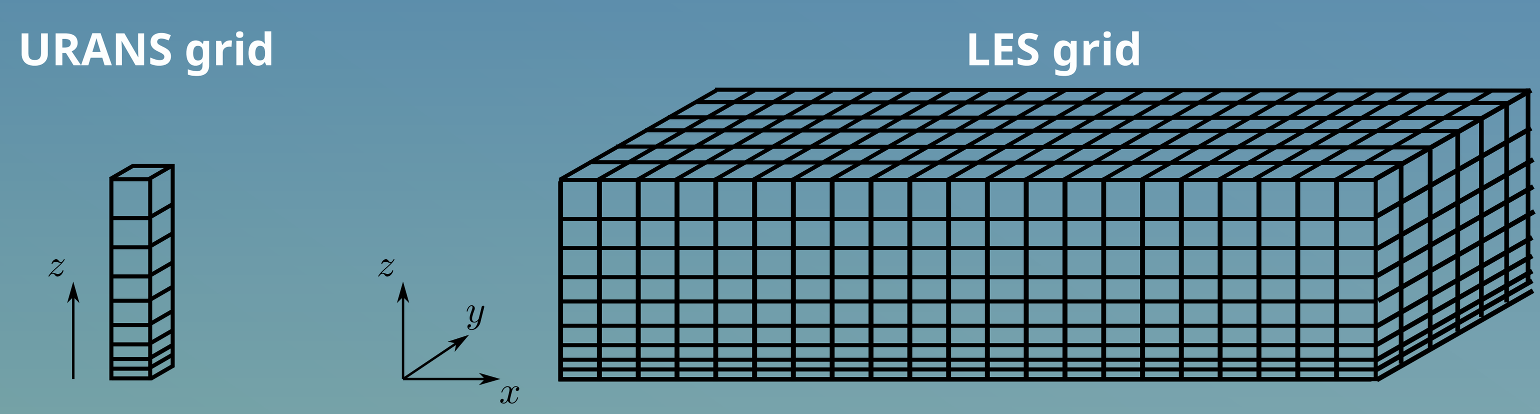
Over flat and uniform terrain (for example, ocean or farmland), the URANS equations are

$$\frac{\partial U}{\partial t} = f_c(V - V_g) - \frac{\partial \overline{u'w'}}{\partial z}, \quad \frac{\partial V}{\partial t} = f_c(U_g - U) - \frac{\partial \overline{v'w'}}{\partial z}$$

$$\frac{\partial \Theta}{\partial t} = -\frac{\partial \overline{\theta' w'}}{\partial z}.$$

The k-ε model of Koblitz et al. [2] is used to model the *turbulent fluxes* and a specific trait of this model variant is that the Mellor-Yamada lengthscale (l_{MY}) is used to set the maximum turbulence length scale ($l_{\max}$). Alternatively, this limiter can be turned off by setting $l_{\max} \to \infty$.

A major advantage of URANS for horizontally homogeneous flows is that a 1D grid can be used for the solver, which makes it very fast to solve compared to LES.



3 Numerical setup and results

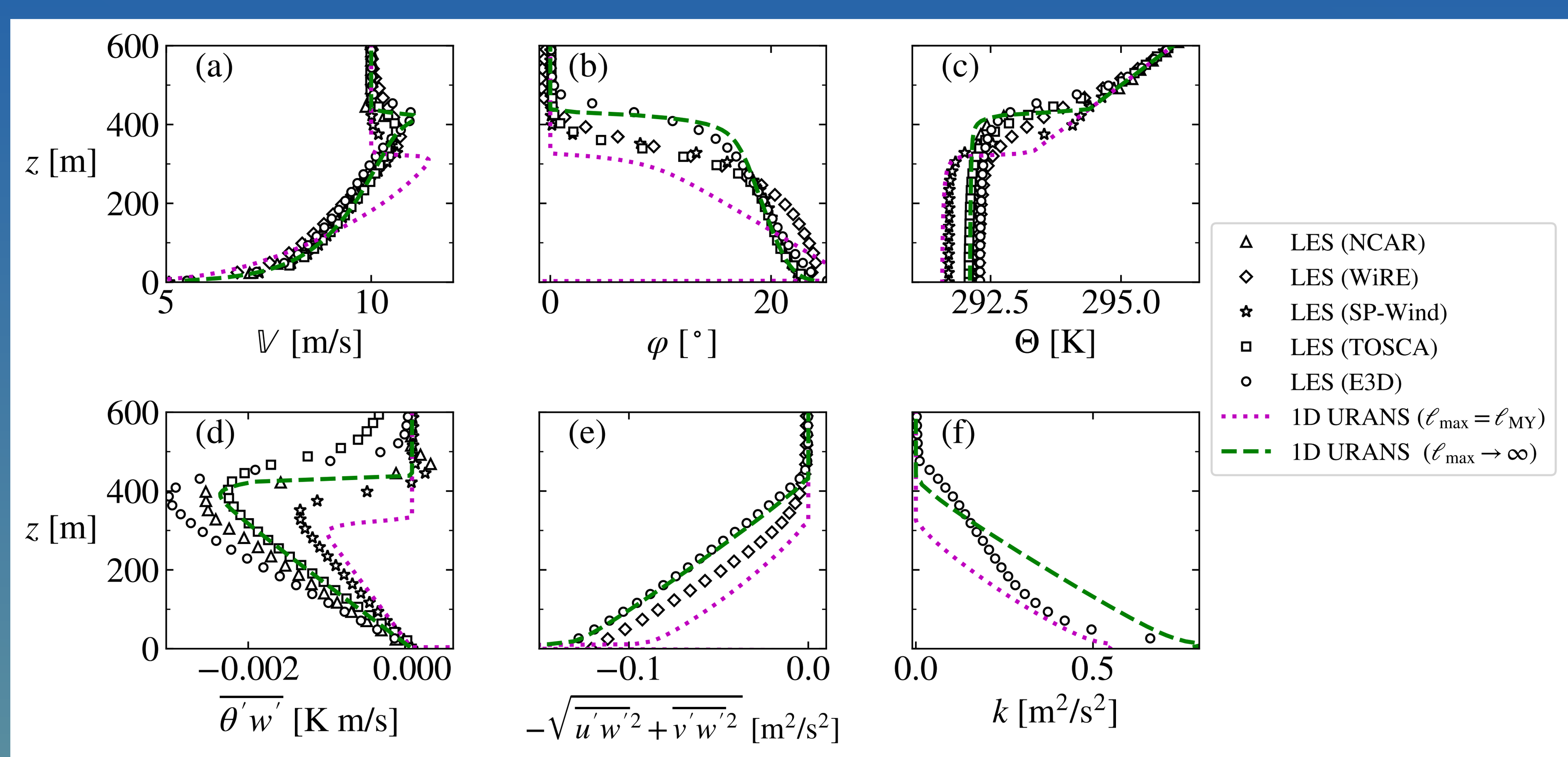
The "n04" case from Pedersen et al. (2014) [3] has been studied in this work, which is a popular CNBL reference case that has been simulated with several LES codes.

We simulate it with URANS using the EllipSys1D code and also run our own LES with the EllipSys3D code. The LES setup is similar to that used by Hodgson et al. (2023) [4].

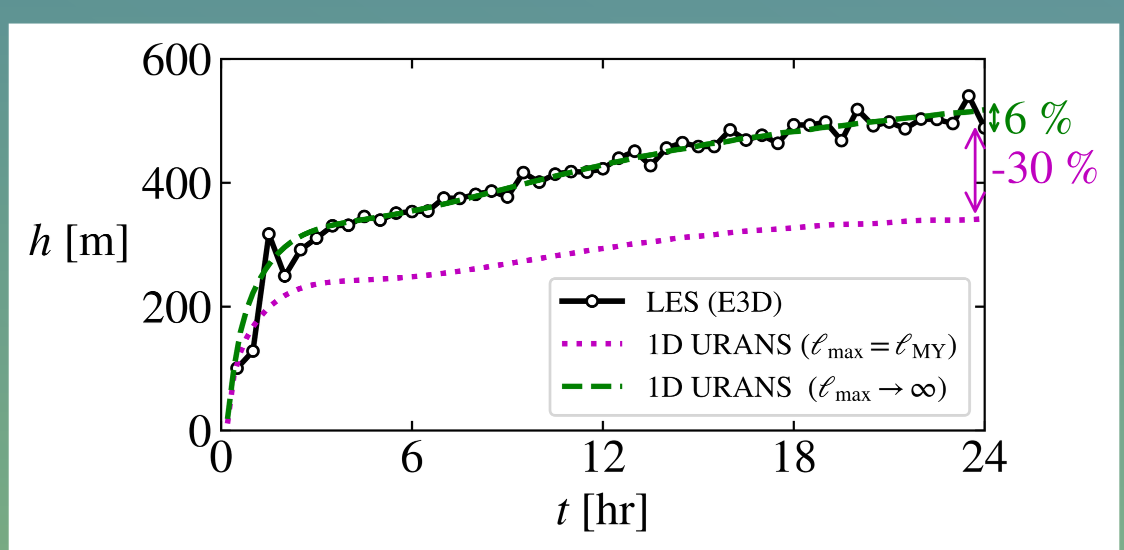
	URANS	LES (E3D)
Domain size	none×none×1.0 km	2.56 km×2.56 km×1.0 km
Resolution	none×none×128	256 × 256 × 128
Sim. time	24 hr	24 hr
Timestep	1 s	1 s
Turb./SGS model	Koblitz k-ε	Deardorff 1-eq
Comp. cost	25 core-seconds	4500 core-hours

LES is $\mathcal{O}(10^6)$ more costly than URANS!!

ABL profiles (time-averaged over $t \in [23.0, 24.0]$ hr)



ABL height evolution



4 Conclusions

1. URANS is much faster than LES for CNBL simulations.
2. URANS with Koblitz et al. k-ε model gives reliable results, if we use $l_{\max} \to \infty$.
3. Future work:
   - Use URANS CNBL precursor for wind farm simulations.
   - Fix sharp upper inversion.
   - Incorporate ABL anisotropy.

References:
[1] Allaerts & Meyers (2015), Physics of Fluids
[2] Koblitz et al. (2015), Wind Energy
[3] Pedersen et al. (2014), Boundary-layer Metereology
[4] Hodgson et al. (2023), Wake conference

Contact:
plaa@dtu.dk

Paper ID: 292

eawe european academy of wind energy

TORQUE 2024