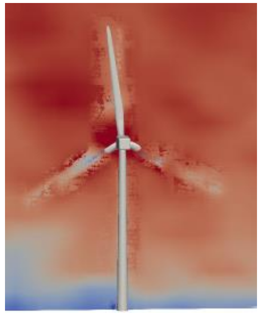
Hybrid RANS-LES of the Atmospheric Boundary Layer for Wind Farm Simulations at Exascale

Christiane Adcock[1], Jeremy Melvin[2], Shreyas Ananthan[2], Ganesh Vijayakumar[2], Gianluca Iaccarino[1], Marc Henry de Frahan[2]
[1]Stanford University. [2]The National Renewable Energy Laboratory. Contact: janiad@stanford.edu

Wind Farm Simulations at Exascale



ExaWind [1]: blade resolved simulation of 4-9 wind turbines in realistic atmospheric boundary layer (ABL) in 4x4 km area for one flowthrough time within four weeks of system time

Nalu-Wind [2]: unstructured-grid solver for incompressible Navier-Stokes eqns.

Capture effects of wake-ABL interaction and blade BL

Active Model Split [3]

Hybrid RANS-LES: unsteady RANS near walls, LES elsewhere

Key components:

1. Model split

$$\mathrm{D}_t\overline{u_i} = -\partial_i\overline{p} + \eta\partial_j\partial_j\overline{u_i} + \partial_j\left(\tau_{ij}^m + \tau_{ij}^e\right) + F_i$$

τ_{ij}^m: mean subgrid stress (≈RANS)

τ_{ij}^e: fluctuating subgrid stress (≈LES); responsible for energy transfer from resolved to unresolved

2. Active forcing

F_i: generate resolved fluctuations

3. Resolution adequacy indicator

Force where grid can resolve more fluctuations

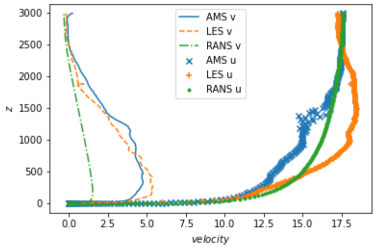
SST $k-\omega$ unsteady RANS model

$k-\omega$ near wall: overly sensitive to freestream velocity
$k-\epsilon$ away from wall: need damping function near wall; inaccurate for adverse pressure gradients

Bautista [4] boundary conditions:

$$u = 0;\ k = \frac{u_\tau^2}{\sqrt{\beta^*}};\ \omega = \frac{u_\tau}{\sqrt{\beta^*}\kappa y}$$

Results



All models capture Coriolis effect

AMS captures Coriolis effect better than RANS does

Noise from BC lingers in domain for AMS

SST $k-\omega$ length scale limiter

$\gamma^* = \gamma + (\beta - \gamma)\frac{l_t}{l_e}$ replaces γ (analogous to [5])

$l_t = k^{1/2}/(\beta^{*1/4})$: local mixing length

$l_e = .00027G/f_c$: maximum mixing length (neutral ABL)

As $l_t/l_e \to 0, \gamma^* \to \gamma$

As $l_t/l_e \to 1, \gamma^*\frac{\omega}{k} - \beta\rho\omega^2 \to \beta\left(\frac{\omega}{k}P - \rho\omega^2\right)$ (limits l_t)

Future Work

- Remove AMS active forcing near wall to reduce noise
- Continue developing length scale limiter
- Add non-neutral stability
- Modify M43 LES model to better capture effects of anisotropy (while using only mean quantities)
- Simulate blade resolved wind turbine with realistic ABL

Acknowledgements

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References

[1] Sprague, M.A., et al. “ExaWind: A Multifidelity modeling and simulation environment for wind energy”, J. Phys.: Conf. Ser. 1451 012071 (2020)
[2] Sprague, M. A., Ananthan, S., Vijayakumar, G., Robinson, M., "ExaWind: A multifidelity modeling and simulation environment for wind energy", NAWEA/WindTech (2019)
[3] [2] Hearing, S.W., Oliver, T.A. Moser, R.D., “Active model split hybrid RANS/LES”, arXiv (2020)
[4] Bautista, M.C., “Turbulence modelling of the atmospheric boundary layer over complex topography”, Ph.D. thesis, Ecole de Technologie Superieure Universite du Quebec (2015)
[5] Koblitz, T., “CFD modeling of non-neutral atmospheric boundary layer conditions”, Ph.D. thesis, DTU Wind Energy (2013)