

Advances to Faster-than-Realtime LES of Wind Farm Flows

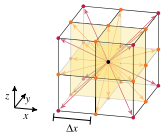
Stefan Ivanell
Professor, Head of Wind Energy Division, Dept. of Earth Sciences, Uppsala University
Guest Professor KTH
Director Swedish Wind Centre

Outline

Background of SWC



HPC developments for wind farm and turbine simulations



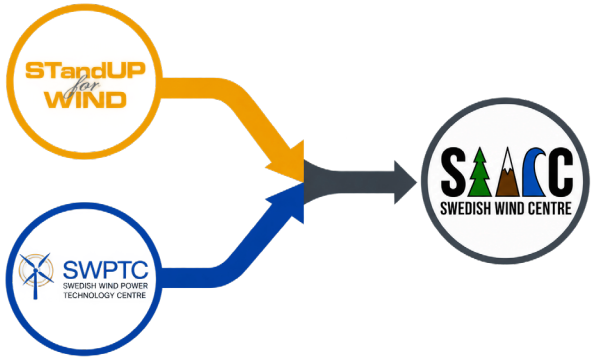
Short about LBM – why now applicable to Wind Energy flows



Examples of latest HPC simulations

Conclusions and outlook

Swedish Wind Centre Background



2015 — 2023 — 2027

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Region Gotland · VÄSTRA GÖTALANDSREGIONEN · SVENSKA KRAFTNÄT

HPC and high fidelity wind farm modelling

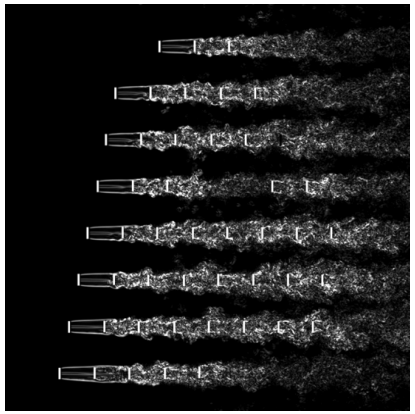
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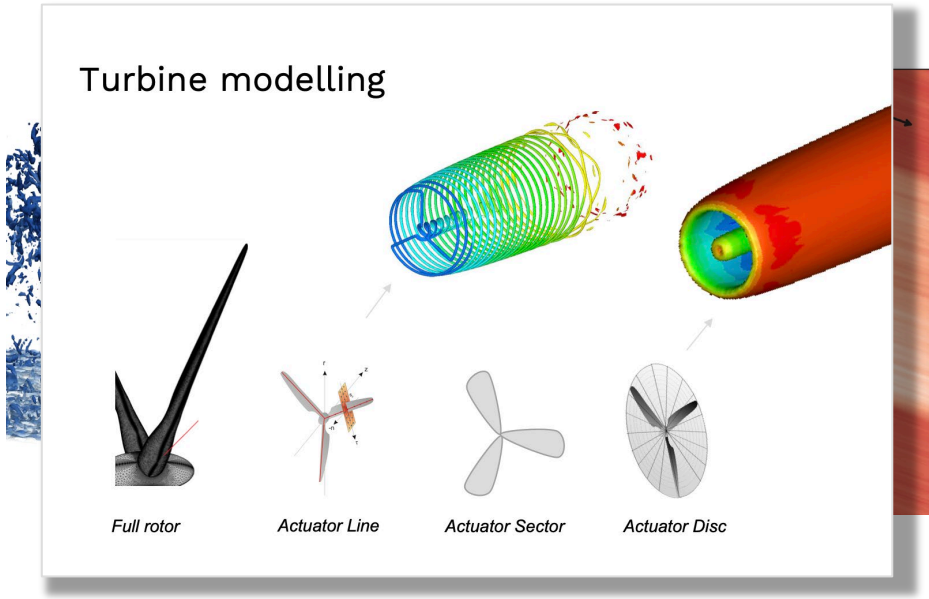
First wind farm simulation LES/ACD

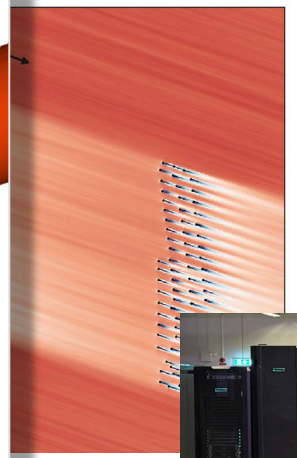
First Isothermal ABL LES using LBM/ACL

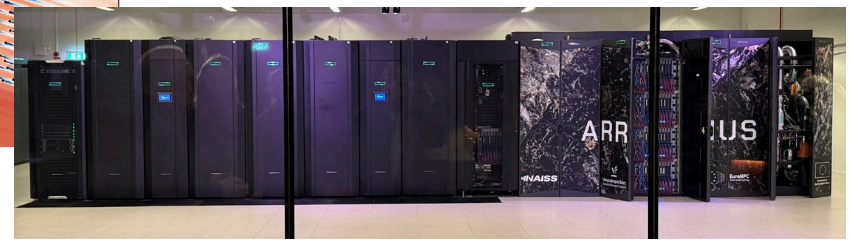
Isothermal ABL LES Farm to Farm ACD Real time

CNBL Farm ACL Real time 10B nodes, 36 GPUs









2014 2021 2026 Today

[1] Large-eddy simulations of the Lillgrund wind farm, Nilsson et al., Wind Energy 18 (3), 449-467, 2014
[2] Wall-modeled lattice Boltzmann large-eddy simulation of neutral atmospheric boundary layers Asmuth et al., Physics of fluids 33 (10), 2021
[3] Invited presentaion, Euromech, Ivanell, London, 2026
[4] Large-eddy simulation of thermally stratified atmospheric boundary layers with a lattice Boltzmann method, Korb et al., Wind Energy Science 11 (7), 2567-2583, 2026

HPC and high fidelity turbine modelling

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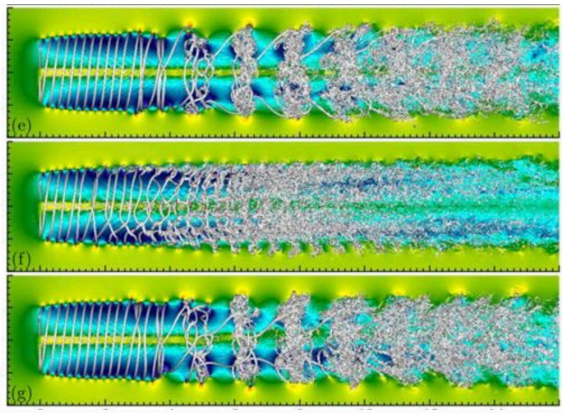
Tip spiral instabilities and helix control LES ACL

Vertical Axis flow

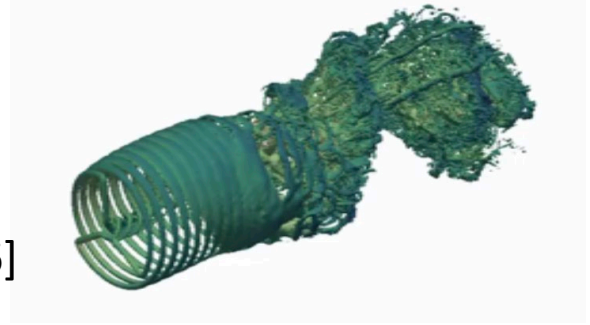
Towers and nacelle

Floating

[5]



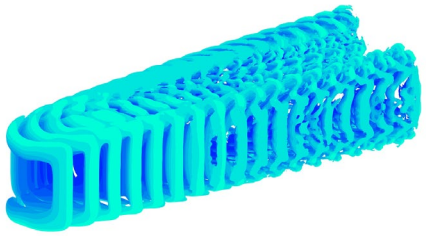
[6]



[7]

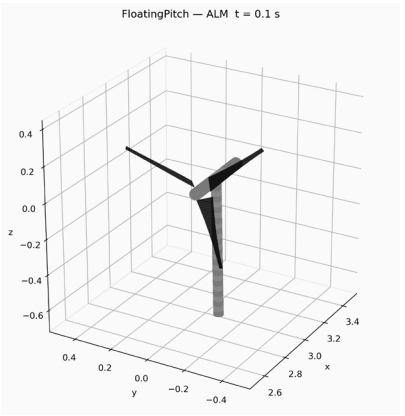


[8]



[9]

[10]



[5] The stability of wakes of floating wind turbines, VG Kleine, L Franceschini, BS Carmo, A Hanifi, DS Henningson, Physics of Fluids 34 (7)

[6] The characteristics of helically deflected wind turbine wakes, H Korb, H Asmuth, S Ivanell, Journal of Fluid Mechanics 965, A2

[7] Numerical simulation of dynamic stall on vertical-axis wind turbine, Yu-Cheng Lu, Ardeshir Hanifi and Dan S. Henningson, J. Phys.: Conf. Ser. 3016 012029, 2025

[8] Assessment of GPU-Accelerated Large Eddy Simulations for VAWTs using the Cumulant Lattice Boltzmann Method, N Horneff, AM Forsting, N Troldborg, S Ivanell, MOL Hansen, 2026

[9] Influence of Tower and Hub on the Wake of a Model Scale Wind Turbine using the Lattice Boltzmann Method, D Sukhman, J Bartl, TH Hansen, S Ivanell, Journal of Physics: 3224 (3), 032006

[10] Sukhman et al. zenodo.org/records/19003501

The Lattice Boltzmann Method

- Discretize domain with cubic grid of nodes with spacing Δx
- 27 populations $f_{\iota\kappa\lambda}$ with $\vec{c}_{\iota\kappa\lambda} = \frac{\Delta x}{\Delta t}[\iota, \kappa, \lambda]^T$
- Populations advect along $\vec{c}_{ijk}$:

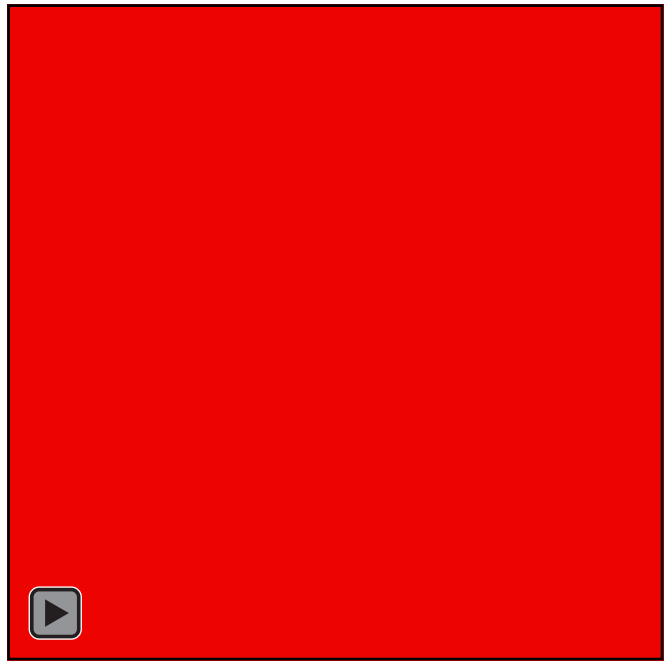
$$f^*_{\iota\kappa\lambda}(x + \vec{c}_{\iota\kappa\lambda}\Delta t, t + \Delta t) = f_{\iota\kappa\lambda}(x, t)$$

- And then collide:

$$f_{\iota\kappa\lambda} = f^*_{\iota\kappa\lambda} + \Omega(f)$$

- Density $\rho = \sum f_{\iota\kappa\lambda}$, velocity $\vec{u} = \sum \vec{c}_{\iota\kappa\lambda} f_{\iota\kappa\lambda}$

➢ Solves the Navier-Stokes equations



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Research group working on LBM



Professor



PostDoc



Researcher/
Nordex



Vattenfall









PhD
students



HVL



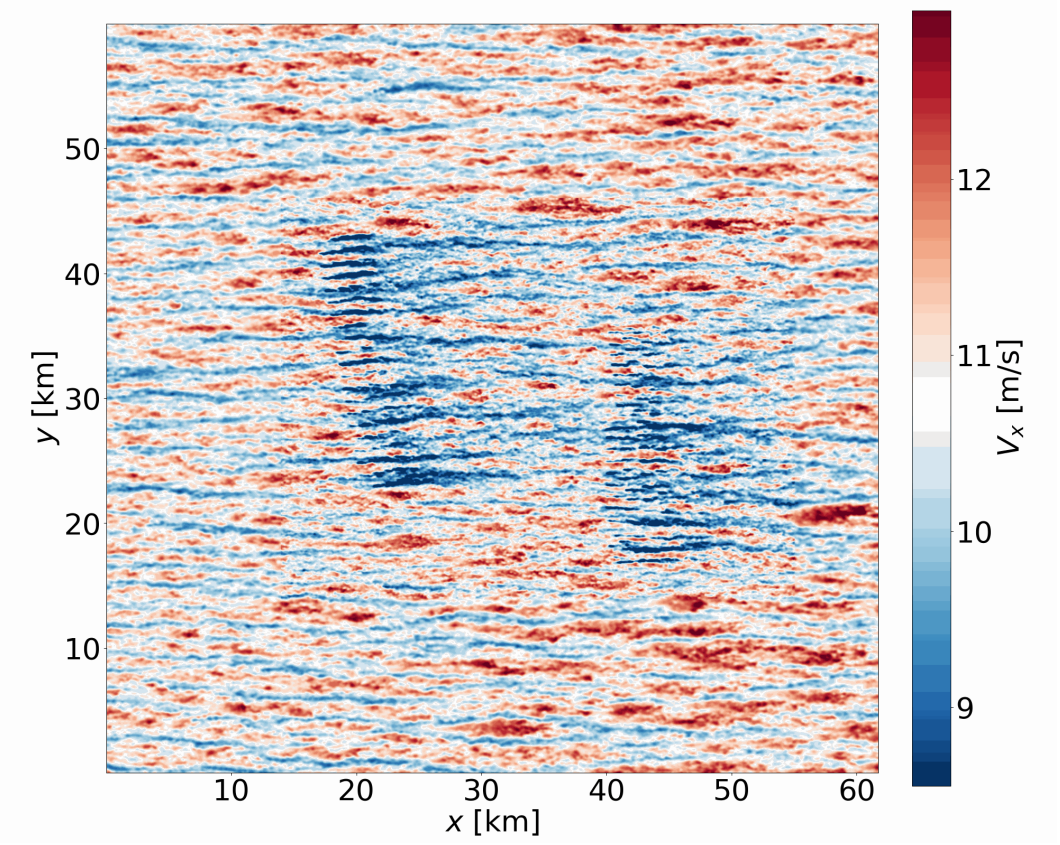
DTU

PhD projects
in
collabouration

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Farm to farm

- ADM looser resolution requirements
  → allows simulation of very large domains
- AD model: Numerical actuator disk (Navarro-Diaz et al. 2021)
- Example: Real offshore wind farms, North Sea:
  - 72 ADM of 4MW turbines
  - 80 ADM of 3.6MW turbines
- Domain: 63km x 60 km x 1.1km
  - Finest resolution: 10m
  - Over 1.8B nodes
- Successor on 4 GPUs (total 480GB)
- Real time factors:
  - Precursor ≈ 1.82
  - Successor ≈ 1.64



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Combining all our recent developments:

- Wind farm in CNBL
- 100 ALM of 15 MW turbines
- Combines precursor / successor, stratification, Coriolis, wall model
- Domain: 28.8km x 36 km x 4km
  - Resolution: 7.5m
  - Over 10B Nodes
- Successor on 36GPUs (total 3.24TB)
  - Parallelized with MPI+Cuda
- Real time factors:
  - Precursor ≈ 0.59
  - Successor ≈ 0.49



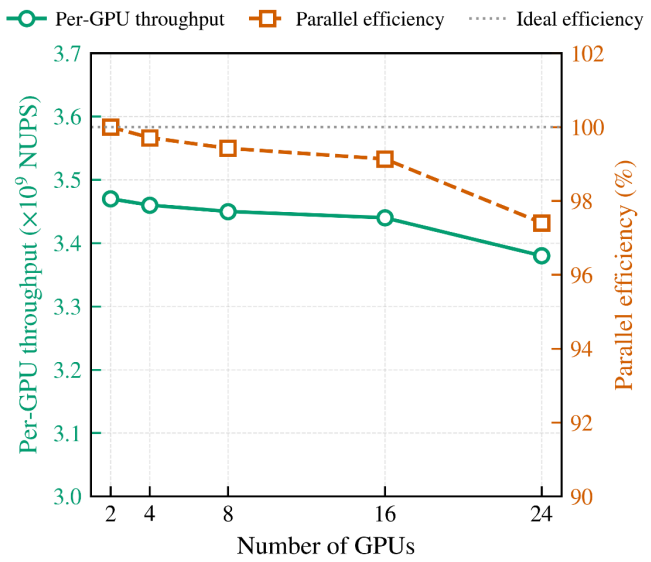
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Conclusions and outlook

- HPC wind turbine and wind farm simulation has made large progress through the StandUp environment
- UU's LBM framework is as accurate as traditional LES with same capabilities as other wind energy LES solvers
- But 1-2 orders of magnitude more efficient and faster
  - In many cases around real-time performance
- Farm and Farm-to-farm simulations using ADM/ALM in CNBL
- Real time control with LES
- Large parameter studies

Outlook:

- Meso-microscale coupling with WRF
- Validated aeroelastic coupled simulations
- Improved multiple (36+) GPU parallelization efficiency
- Complex terrain
- Floating systems



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Thanks for your attention!

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Campus Gotland,
Guest Professor KTH
&
Director SWC

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WIND ENERGY

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References

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