Evaluation of the Lattice Boltzmann Method for wind modelling in complex terrain

Feasibility Study

Alain Schubiger, Sarah Barber, Henrik Nordborg

July 5, 2019

University of Applied Sciences Rapperswil (HSR) - Institute for Energy Technology

Table of contents

Background

New wind energy research program at the HSR

- Digitalisation
  - Numerical Modelling (CFD)
  - Internet of Things (IOT)
  - Machine Learning

New wind energy research program at the HSR

- Digitalisation
  - Numerical Modelling (CFD)
  - Internet of Things (IOT)
  - Machine Learning
- Human Factors
  - Acceptance
  - Skills
  - Teaching

New wind energy research program at the HSR

- Digitalisation
  - Numerical Modelling (CFD)
  - Internet of Things (IOT)
  - Machine Learning
- Human Factors
  - Acceptance
  - Skills
  - Teaching
- System Integration
  - Microgrids
  - Innovation
  - Recycling

New wind energy research program at the HSR

- Digitalisation
  - Numerical Modelling (CFD)
  - Internet of Things (IOT)
  - Machine Learning
- Human Factors
  - Acceptance
  - Skills
  - Teaching
- System Integration
  - Microgrids
  - Innovation
  - Recycling
- More infos by Sarah Barber

Background

How can we model the potential of a wind site?

Various tools are available to simulate and estimate wind resources.

Background

How can we model the potential of a wind site?

Various tools are available to simulate and estimate wind resources.

- Linear Models (WAsP, WindNinja, ...)

Background

How can we model the potential of a wind site?

Various tools are available to simulate and estimate wind resources.

- Linear Models (WAsP, WindNinja, ...)
- Navier-Stokes based CFD solvers (OpenFOAM, ANSYS Fluent, STAR-CCM+, ...)

Background

How can we model the potential of a wind site?

Various tools are available to simulate and estimate wind resources.

- Linear Models (WAsP, WindNinja, ...)
- Navier-Stokes based CFD solvers (OpenFOAM, ANSYS Fluent, STAR-CCM+, ...)
- Lattice-Boltzmann (LBM) based CFD solvers (PALABOS, OpenLB, PowerFlow, Xflow)

Background

How can we model the potential of a wind site?

Various tools available to simulate and estimate wind resources.

- Linear Models (WAsP, WindNinja, ...)
- Navier-Stokes based CFD solvers (OpenFOAM, ANSYS Fluent, STAR-CCM+, ...)
- Lattice-Boltzmann (LBM) based CFD solvers (PALABOS, OpenLB, PowerFlow, Xflow)

Problem: Linear models are fast but often not acurate enough and most Large Eddy Simulations are too computationally expensive to be applied outside the research environment

Method

What is the difference to traditional CFD?

Instead of solving the Navier-Stokes equation, we solve the Boltzmann transport equation, which is the analogue of the Navier-Stokes equation at a molecular level.

What is the difference to traditional CFD?

Instead of solving the Navier-Stokes equation, we solve the Boltzmann transport equation, which is the analogue of the Navier-Stokes equation at a molecular level.

How does it work?

Instead of macroscopic quantities like velocity or pressure, dynamics are described by the statistical quantity called probability distribution function and alternating collision and streaming steps

Pre-Study - Bolund Experiment

Figure 1: Bolund Experiment

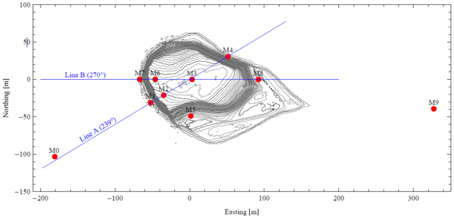


Figure 2: Location of Measurements

Measuring campaign performed in 2007 and 2008 by DTU Wind Energy. The Bolund hill has a geometrical shape that induces complex 3D flow. During the campaign, velocity and high frequency turbulence data were collected from 35 anemometers distributed on 10 masts. [?]

Simulation-Setup

PALABOS (Parallel Lattice Boltzmann Solver)
Open-source CFD solver developed by FlowKit

- Flow time 600 s
- No slip boundary conditions for lateral sides, top and water surface
- Time dependent logarithmic inlet profile corresponding to experimental guidelines
- Zero pressure gradient at outlet
- Smagorinsky LES, $C_s = 0.14$
- Simulations were performed on three different orthogonal grids $\Delta x = 0.25, 0.5, 1.0$ m (Immersed Solid approach)
- Neutral atmospheric conditions (thermal effects neglected)

Inflow Condition

Time dependent logarithmic inlet profile corresponding to experimental guidelines

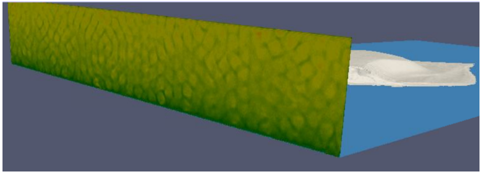


Figure 3: Turbulent inlet boundary condition

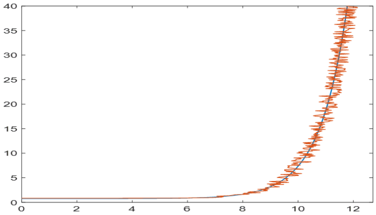


Figure 4: Inflow fluctuations given by turbulence intensity

Results

Results

Q-criterion shows expected vortex structures

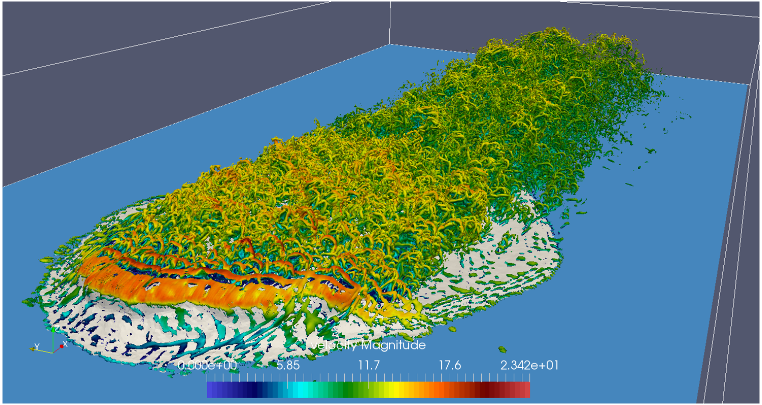
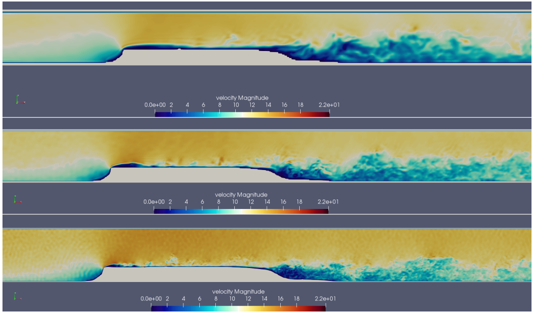


Figure 5: Q-criterion

Results

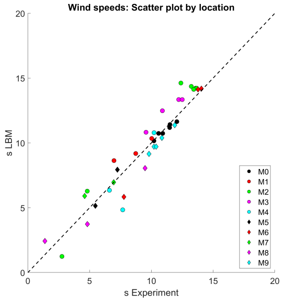
Instantaneous velocity field for the three different grids

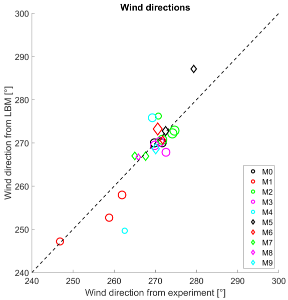


- Grid size affects boundary layer height and wake size

Comparison to experimental data, e.g. 0.5 m grid

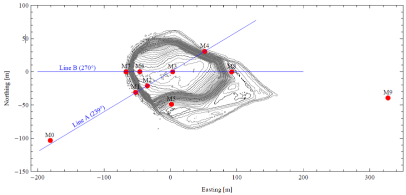
- Good agreement between field data and LBM results for wind speed and wind direction at the measurement points.
- Deviation of wind direction is small

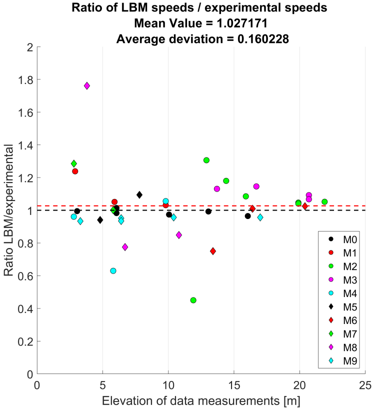




Comparison to experimental data, e.g. 0.5 m grid

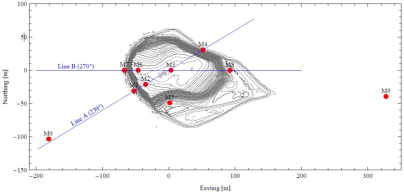
- Location of M4 and M8 in separated flow behind the hill lead to lower accuracy
- M2 deviations need further investigation

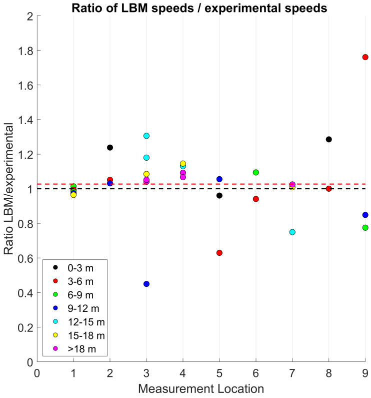




Comparison to experimental data, e.g. 0.5 m grid

- M2, M4, M8 are again the largest deviations
- Accuracy increases with height



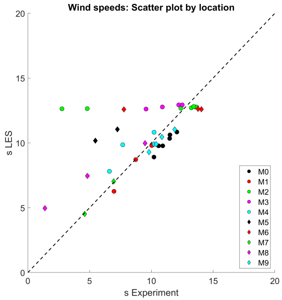


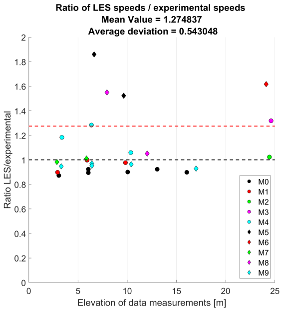
Reference simulation with ANSYS Fluent

- Same input profile
- Turbulent Kinetic Energy given by Bolund Hill Blind Test instead of artificial time dependent fluctuations
- Average mesh resolution of about 1 m (Geometry conforming Polyhedra Mesh)
- LES Turbulence

Comparison to experimental data, e.g. 0.5 m grid

- Generally poorer accuracy then LBM
- Under further investigation, but is taking time ...





Remark: One cause of deviation was an error at the inlet boundary condition.

Comparison of CPU Time

Table 1: CPU Time @ 120 cores

Solver	Δx [m]	#Nodes	CPU Time
LBM	1.0	5 Mio.	$\sim$ 25 min
LBM	0.5	40 Mio.	$\sim$ 11 h
LBM	0.25	330 Mio.	$\sim$ 13 d
Fluent	$\sim$ 1.0	9 Mio.	$\sim$ 6 d

Conclusion and future work

Conclusion and future work

Conclusion

- First LBM results are in good agreement with the experimental data, providing a good foundation for further developments
- Shorter computational time compared to other LES solver
- Application of PALABOS for modelling wind over complex terrain has been shown to be feasible, although much more work is required

Future work

- Moving to a bigger wind site
- Integration of Multi-Grid to better resolve the boundary layer and to reduce the overall number of nodes
- Integration of thermal effects
- Using GPU acceleration

Thank You