Validation of RANS solvers in OpenFOAM for the atmospheric boundary layer in complex terrain

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H. Nugusse, C. Peralta, S.P.Kokilavani (FH-Kiel) and J. Schmidt

habtom.nugusse@uni-oldenburg.de

Fraunhofer Institute for Wind Energy and Energy System Technology IWES, Oldenburg

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Overview

- Site assessment for wind farms in complex terrain.
- Need to validate tools for this purpose.
- Two case studies: Askervein and Bolund hills.
- CFD-simulations with OpenFOAM®
  - OpenFOAM’s simpleFoam RANS solver
  - k-epsilon, RNG k-epsilon, k-Omega SST
  - New structured mesher.
Case studies (Askervein & Bolund)

Askervein Hill (126 m height). 1983 measuring campaign.

Bolund hill (12 m height). 2008 measuring campaign.

Z₀ = 0.03 m

Z₀ = 0.0003 m
Terrain Meshing

- **snappyHexMesh**: OpenFOAM's native (unstructured) mesher: needs blockMesh background mesh.
- Cumbersome to use, especially in complex terrain.
- terrainBlockMesher (Jonas Schmidt)
  
  [https://github.com/jonasIWES/terrainBlockMesher](https://github.com/jonasIWES/terrainBlockMesher)
  
  - Generates a generalized blockMeshDict for blockMesh
    - Uses splines and lines to adapt to the terrain.
    - Produces a fully structured mesh.
    - Allows the use of mesh grading in the horizontal and vertical directions.
    - Easy to setup, but more expensive in terms of cell number.
terrainBlockMesher mesh

The ground patch of computational domain of the terrain using terrainBlockMesher and the blockGrading splitting into three regions with different resolution, with finer resolution around the hill.
ABL modelling in OpenFOAM

- Boundary conditions
  - Inlet: atmBoundaryLayerInletVelocity & atmBoundaryLayerInletEpsilon (Richards and Hoxey 93).
  - Outlet: Fully developed flow, Neumann zero gradient condition for all variables, fixed pressure.
  - Top: Slip.
  - Ground: No slip for velocity, std OF wall functions (kqRWallFunction, epsilonWallFunction, nutRoughWallFunction).
  - Sides: Slip.
- Turbulence modeling: k-epsilon, RNG k-epsilon, k-omega SST
- Solver: SIMPLE algorithm. All simulations converged to $10^{-5}$. 
Mesh sensitivity
Mesh sensitivity analysis using terrainBlockMesher for Askervein

Speedup & normalized TKE results at 10 meters height above the hill surface along the line A for grid sensitivity dependencies.

(H. Nugusse)
Mesh sensitivity analysis using terrainBlockMesher for Bolund

Speedup & normalized TKE results at 2 meters height above the hill surface along the line B for grid sensitivity dependencies. 

S.P. Kokilavani
Mesher comparison
Comparison of terrainBlockMesher & snappyHexMesh for Askervein

Speedup & normalized TKE results at 10 meters height above the hill surface along the line A using terrainBlockMesher and snappyHexMesh.  

H. Nugusse
Comparison of terrainBlockMesher & snappyHexMesh for Bolund

Speedup & normalized TKE results at 2 meters height above the hill surface along the line B using terrainBlockMesher and snappyHeMesh

S.P. Kokilavani
Turbulence model comparison
Comparisons among turbulence models for Askervein

Speedup & normalized TKE results at 10 meters height above the hill surface along the line A for comparisons of three turbulence models.

H. Nugusse
Comparisons among turbulence models for Bolund

Speedup & normalized TKE results at 2 meters height above the hill surface along the line B for comparisons of three turbulence models.

S.P. Kokilavani
Conclusions

• OpenFOAM’s RANS solver is able to reproduce some of the experimental data.

• For Askervein hill, the RNG k-epsilon model produces better predictions.

• For Bolund hill, the standard k-epsilon model seems to perform better.

• Results based on the terrainBlockMesher mesh gave better results than those based on a snappyHexMesh mesh.

• Results from Askervein hill are encouraging.

• Results from Bolund hill remain challenging.

• Study additional wind directions: lines AA, B for Askervein and line A for Bolund (239, 255, 90 degrees).
Thank you!

Questions?