Adding Complex Terrain and Stable Atmospheric Condition Capability to the OpenFOAM-based Flow Solver of the Simulator for On/Offshore Wind Farm Applications (SOWFA)

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In this work, we will present improvements to the OpenFOAM-based Simulator for On/Offshore Wind Farm Applications (SOWFA), which has been developed at the U.S. National Renewable Energy Laboratory (NREL). SOWFA is composed of an incompressible atmospheric/wind farm large-eddy simulation (LES) solver, ABLPisoSolver/windPlantPisoSolver, based on the OpenFOAM-standard buoyantBoussinesqPisoFoam, coupled with NREL's FAST wind turbine structural and system dynamics model. An example of a flow computed with SOWFA is given in Fig. 1, which shows a vertical contour of instantaneous resolved wind speed within the 48-turbine Lillgrund wind farm in the water off Sweden and Denmark [1].

SOWFA is currently limited to computing wind farm flow over flat terrain under neutral or unstable atmospheric conditions. The flat terrain limitation exists because we have employed planetary surface shear stress models commonly used in the atmospheric LES community that rely on Monin-Obukhov similarity theory. The surface stress models assume flat homogeneous terrain over which a planar average wind profile can be calculated, which is then used to determine the average planetary surface stress. The limitation that only neutral and unstable atmospheric conditions can be simulated arises from the fact that the flow solver relies on a cell face-based subgrid-scale (SGS) stress formulation, which deviates from the OpenFOAM-standard cell-centered turbulence variable approach meaning that the OpenFOAM-standard SGS models are not compatible with our custom LES solver. The reason for our choice of this approach will be discussed further in the presentation and accompanying paper. Because of its simplicity, we have only implemented the standard Smagorinsky model into this nonstandard face-based SGS formulation, but Brown et al. [2] showed that the standard Smagorinsky model does not perform as well as models with backscatter in simulating stable atmospheric flow. Furthermore, Beare et al. [3] have shown that at typical grid resolution, more sophisticated SGS models than the standard Smagorinsky model are able to capture more stable atmospheric boundary layer details. Also, the Lagrangian-averaged scale-dependent dynamic Smagorinksy model of Stoll and Porté-Agel [4] has been shown to perform well in stably stratified atmospheric flows [5].

To circumvent these limitations, we are implementing a local planetary surface stress model that does not require horizontal averages in a plane of homogeneity, following the work of Wan et al. [6] This will allow the solver to compute flow over irregular terrain. To create a terrain-conforming mesh, we employ OpenFOAM's moveDynamicMesh solver. We have also found a way to use the standard OpenFOAM cell-centered SGS stress approach with results very similar to our previous face-centered SGS stress approach, meaning that the entire suite of standard OpenFOAM SGS models can now be used with our atmospheric/wind farm flow solver. We will modify the Lagrangian-averaged scale-independent dynamic Smagorinsky model of Meneveau et al. [7], which is a standard model included with the current version of OpenFOAM, to become the scale-dependent version of Stoll and Porté-Agel [4].

With these enhancements to the SOWFA flow solver, we will compute a terrain flow case, such as the Askervein hill [8] or the hill geometries computed by Sullivan [9]. We will also compute the well-documented stably stratified atmospheric boundary layer computed in the Global Energy and Water Cycle Experiment (GEWEX) Atmospheric Boundary Layer Study (GABLS) model intercomparison [3]. Finally, we will combine the two enhancements to compute wind farm flow in complex terrain and stable atmospheric conditions and compare the results with the same flow under neutral, and possibly unstable conditions.

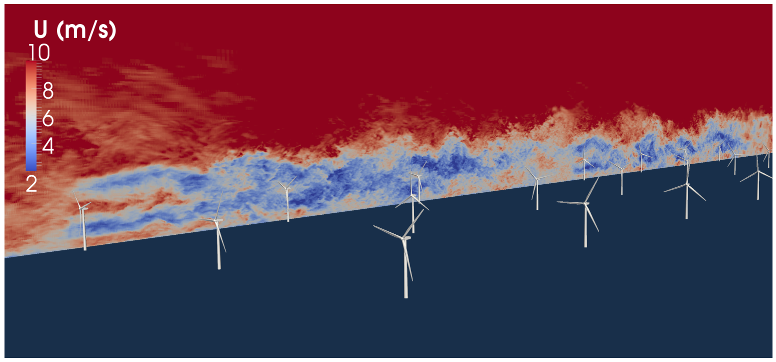

Figure 1: A vertical slice of instantaneous resolved wind speed in the Lillgrund offshore wind farm computed by Churchfield et al. [1]

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