Stabilized finite element methods for the prediction of atmospheric flows over complex terrain

Matias Avila and Herbert Owen

Barcelona Supercomputing Center (BSC)
Jordi Girona 29 08034 Barcelona, Spain.
e-mail: matias.avila@bsc.es

ABSTRACT

We present a finite element formulation for the prediction of atmospheric flows over complex terrain. The Reynolds averaged Navier Stokes (RANS) equations are solved together with the energy equation and the k−ε turbulence model modified for Coriolis effects in the atmospheric boundary layer [1]. The implemented model is able to deal with thermally coupled flows [2] and wind inside forested canopies [3]. Close to the ground a law of the wall based on Monin-Obukhov equilibrium is imposed, using a two-velocity scale wall function including roughness effects.

We present a stabilized finite element formulation for the RANS equations based on the Variational Multiscale Method (VMM), which allows dealing with convection and Coriolis dominating terms and using equal order interpolations for velocity and pressure.

The resulting system of discrete equations forms a highly nonlinear-coupled system that needs to be properly linearized. The turbulence variables k and ε need to be limited from below to ensure that they remain positive throughout the domain during the course of the nonlinear iterations. This limitation introduces noise and oscillations in the solution fields. The use of the logarithmic form of turbulence variables (K=log k, E= log ε) [4] is also implemented, leading to positive k and ε values, free of clipping and limiters. In this work different linearization schemes are proposed.

Due to geometrical complexities introduced by the topography, anisotropic 3D grids and strong coupling between the equations, the nonlinear problem is very hard to converge. We will present our progress towards obtaining a robust code that can be easily used by the wind energy industry. It is interesting to note that CFD for wind assessment is currently dominated by finite volume codes. This is one of the few finite element approaches in the field.

Two complex terrain test cases are presented. The first one is in a hilly terrain close to Puebla, Mexico, where a wind farm has been placed. The second test case is a forested terrain in Ryningsnas, Sweden, where stable stratification is considered. The obtained results of both tests cases are compared against measurements.

The effect of the clipping and the stabilization method are discussed comparing the obtained solutions over two complex terrain cases. Oscillations of the turbulence unknowns are found close to detachment points with the non-logarithmic model. Smooth solutions, free of oscillations are obtained using the logarithmic form. However, the logarithmic scheme presents worse convergence behavior. The robustness of different linearization schemes is discussed. Finally, a mesh convergence study of the proposed method is presented.

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