Wind in Complex Terrain using CFD

A. Bechmann[1,*], N. N. Sørensen[1,2], J. Johansen[1]
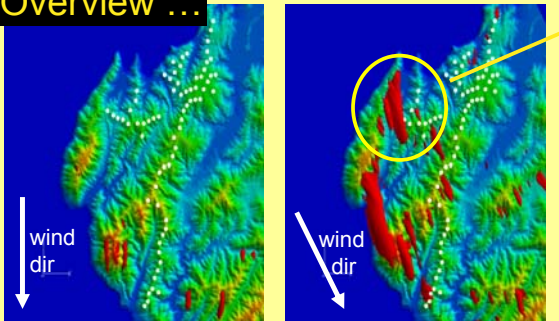[1]Wind Energy Dep., Risø National Laboratory / DTU, DK-4000 Roskilde, Denmark
[2]Department of Civil Engineering, Aalborg University, DK-9000 Aalborg, Denmark
[*]E-mail: andreas.bechmann@risoe.dk
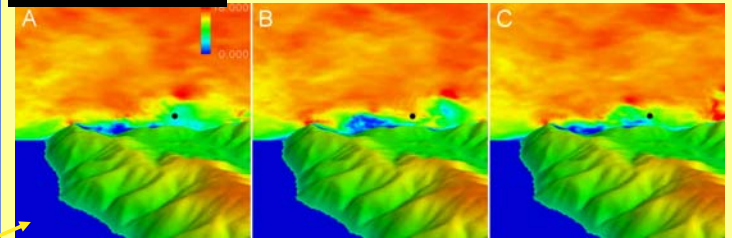
Introduction

An increasing number of wind farms are erected at sites with complex terrain with the hope of a large energy production. By placing wind turbines in hilly terrain, along ridges and even in mountainous areas, wind phenomena like flow separation and recirculation can, however, greatly increase the structural loads on the wind turbines. Computational fluid dynamics (CFD) provide a unique tool to predict these critical winds and is becoming an indispensable method for industry for siting of wind turbines in complex terrain.

Overview …

CFD results from a complex site showing regions of high turbulent kinetic energy for two wind directions.
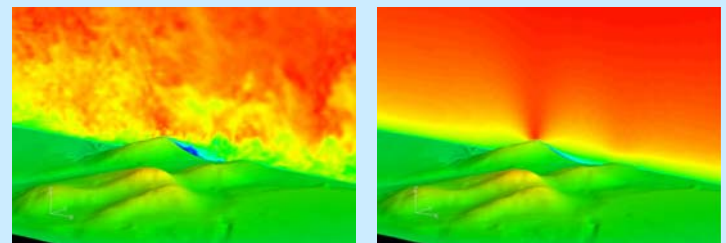
… and detail

Vertical plane showing contours of wind speed at three incidences (A→B →C) - wind is from left. The color code from high to low speed: Red, yellow, green, blue. The black dot symbolizes a wind turbine.

Example: New Zealand site

CFD is an important tool for siting of wind turbines since it provides both an overview of the wind at the entire site and locally experienced by the individual wind turbines. The figure on the left gives an overview of a planned wind farm near Wellington in New Zealand with white dots symbolizing wind turbines. CFD simulations of the wind over this complex terrain show that some wind turbines are covered in high turbulence for specific wind directions. Based on CFD results wind farm developers can chose not to erect certain wind turbines, place wind turbines capable of withstanding the high loads or use wind sector management. The figure above gives a detailed description of the wind at a critical location: A. a recirculation bubble behind the ridge is formed. B. the low speed bubble is advected past the wind turbine. C. the process is repeated.
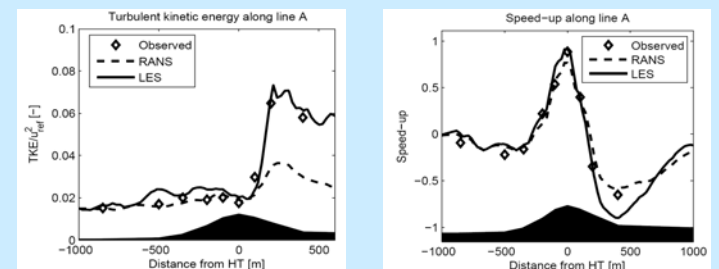
CFD Methods: RANS and LES

The CFD code EllipSys3D has been developed through a collaborative effort between DTU and Risø for more than 15 years. For terrain simulations the Reynolds Averaged Navier-Stokes (RANS) approach is mostly used. Solving the RANS equations with EllipSys provides information on the mean wind and mean level of turbulent kinetic energy at a site of interest - valuable information for wind farm developers (see figure to the right). A newly developed method is hybrid Large-Eddy Simulation (LES). With LES the large unsteady structures of the flow are resolved – providing detailed information on the turbulent wind. A downside with LES is the increased computational cost. Ultimately, both RANS and LES are needed in the future and development on both is continued.

Instantaneous velocity contours of the wind over the Askervein hill using LES (left) and RANS (Right). LES gives detailed information of the turbulent wind; However, the computational cost is high.

Experimental background

Experimental data is always important for validating numerical models. However, contrary to many industrial flows, where experimental data are plentiful, only limited experimental data is available for flow over terrain. One of the best known and best documented field campaigns is that performed in 1982 and 1983 over the Askervein hill. Even though the geometry of the hill is relatively simple it is a valuable test case for validating the performance of CFD models. On the figure to the right simulation results from LES and RANS are compared to measurements. As seen both methods capture the flow upstream of the hill well. In the lee side, however, differences are observed.

LES and RANS results. Turbulence intensity (left) and Speedup (right).

Outlook

The present CFD simulations are only valid for neutrally stratified atmospheric conditions. For other temperature conditions, e.g. night time conditions, the CFD code needs further development – this is planned for the future. Future work also consists of an experimental campaign on the small hill Bolund located near Risø. The Bolund hill has complex geometrical characteristics found in many complex wind turbine sites. It is important to validate the CFD models ability to capture the wind over such terrain.