A systematic validation of CFD flow modelling on commercial wind farms sites

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Abstract

We present here what we believe to be the most comprehensive validation of the commercial application of CFD on wind farms seen to date, with 115 very diverse sites and 2500 mast pairs. Previously published validations have generally rested on very small sample sizes and narrow categories of site types. The validation we present here is of a different character: all multi-mast sites on which we performed CFD in 2012 and 2013 were systematically included, without any manual selection or filtering criteria.

Purpose

CFD can reduce flow modelling errors, leading to better wind farm designs, better project returns, and ultimately lowering the cost of wind energy. However, CFD also places higher demands on the expertise of the user, both in terms of setting up and running simulations, but also of interpreting the vast quantities of information produced.

DNV GL aims to help the financial community make informed judgments regarding the bankability of the latest modelling techniques. To this end we have consistently published growing validations as our CFD service has matured and ventured into new types of geographies and challenging flows.

The present validation focuses on the setup and execution of simulations, in an approach that mimics a blind test. When CFD is deployed in a formal energy analysis, engineering judgment can extract additional value by making manual adjustments and producing an intelligent initiation strategy based on the model’s performance on different parts of a site. However, in order to ensure absolute objectivity in this study, only the raw model outputs were considered.

Methods

Simulations

• In-house software powered by STAR-CCM+, a state-of-the-art CFD solver
• Reynolds-Averaged Navier-Stokes (RANS) equations with k-ε closure
• Stability modelled on a subset of the sites: transport equation for potential temperature, shallow Boussinesq approximation, source term in the turbulent kinetic energy equation.
• Forestry: source terms for turbulence production and aerodynamic drag.
• For purpose of comparison, linear model calculations were also performed.

Choice of sites

• All sites on which we ran CFD and a linear model in 2012 and 2013, and which were equipped with at least two meteorological masts.
• Exclusion criteria: only one site mast; linear model results not available.
• No exceptions, no filtering, no cherry-picking, no tuning.
• Total of 115 sites with 2500 mast pairs, located across a range of continents, representing a broad variety of terrain types and atmospheric conditions.

Error metric

• Relative error on long-term, hub-height mean wind speed (MWS) resulting from cross-predictions between masts, averaged for all mast pairs on a given site.
• Advantage: MWS is readily available from our existing commercial processes, making possible its systematic collection in a busy commercial environment.
• Drawbacks: directional information is discarded; includes noise resulting from long-term correlation and vertical extrapolation errors, and from the inclusion of many mast pairs where no microscale model can be expected to perform well.

This was deemed an acceptable trade-off given the vast amount of data produced.

Results

Averaged across all sites, the error on MWS was one fifth lower with CFD than with the linear model (4% vs. 5%).

On the 70% of sites where CFD was more accurate than the linear model, it reduced error on MWS by 2% on average. In the context where CFD is executed in addition to the linear model, the estimated accuracy benefit on MWS is therefore 70% * 2% = 1.4%. For a typical energy analysis, the corresponding benefit on energy uncertainty would be approximately 3%.

Conclusions

CFD has oft been cited as the remedy to the weaknesses of linear models, but these claims have been met with industry scepticism in the face of the scarce validation published to date. With an increasing commercial application of CFD at DNV GL and elsewhere, large-scale validation is now possible.

The results of this extensive, two-year validation project show that the CFD analysis process and engineering expertise developed at DNV GL add significant value to energy production assessments. This benefit is bound to increase as our CFD methods continue to mature. Moreover, engineering judgment can provide additional value on a site-specific basis.

Though this study focused on multi-mast sites, the outcome gives confidence that CFD can also reduce uncertainty on single-mast sites where model performance is not as easily assessed.

References