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Wind over complex terrain – Microscale modelling with two types of mesoscale winds at Nygårdsfjell

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ABSTRACT

Nygårdsfjell, a complex terrain near Norwegian-Swedish border, is characterized by its significant wind resources. The feasibility of using mesoscale winds as input to microscale model is studied in this work. The main objective is to take into account the actual terrain effects on wind flow over complex terrain. First set of mesoscale winds are modelled with Weather Research and Forecasting (WRF) numerical tool whereas second set of mesoscale winds are taken from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) data system. WindSim, a computational fluid dynamics based numerical solver is used as microscale modelling tool. The results suggest that the performance of microscale model is largely dependent upon the quality of mesoscale winds as input. The proposed coupled models achieve improvements in wind speed modelling, especially during cold weather. WRF-WindSim coupling showed better results than MERRA-WindSim coupling in all three test cases, as root mean square error (RMSE) decreased by 70.9% for the February case, 61.5% for October and 14.4% for June case respectively. Raw mesoscale winds from the WRF model were also more correct than the mesoscale winds from MERRA data set when extracted directly at the wind turbine by decreasing the RMSE by 62.6% for the February case, 62.7% for October and 23.7% for June case respectively. The difference of RMSE values between the mesoscale winds directly at wind turbine versus the coupled meso-microscale model outputs are not conclusive enough to indicate any specific trend.

1. Introduction

The most critical factor in wind farm performance is the wind speed itself. Consequently, the accurate prediction of wind speed is a key research field for the industry as well as the academics. Until recently, meteorological institutes all over the world have undertaken wind prediction research. However, due to rapid expansion in wind farm industry and its introduction into conventional grid, there is a need to build a bridge between the meteorological researches regarding the wind speed prediction and its direct application into wind industry.

Meteorological models have proven themselves very useful in predicting various environmental variables, mostly because they are equipped with the possibility of wide range of configurations. This diversity also poses a challenge to find the right set of configurations and the numerical and physical schemes that are also dependent on the multidimensional and nonlinear interactions [1]. The first and the foremost challenge is to find the correct combination of configurations of the model to use in a specific area. Having said that, the best configuration for one area might well not be suitable to other areas [2]. Changes in the configuration of these models provide understanding of how the models react to it and how it effects their output. It also narrows down the most sensitive parameters to the model [3] [4].

Meteorological models are not good to resolve physical processes on all scales and the atmospheric processes can occur in range of 10^{-2} meters to 10^{8} meters spatially and 10^{-1} seconds to 10^{8} seconds temporally [5]. So unresolved physical processes are handle by physical parameterization schemes. However, the down side of using these schemes is that these parameterization schemes are based on assumptions and approximations so in the event of these assumptions and approximations going wrong results in introducing errors in the model [6]. Topography also plays a crucial role on the climate of the region. Orographic features may substantially affect the regional climate by influencing the dynamics of the atmospheric circulation and the interaction between the

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atmosphere and the land [7] [8]. On a micro scale, the local terrain plays a vital role influencing the surrounding atmospheric circulation. Increasing the resolution of simulation domain will make it possible for the model to capture the complex terrain effects on wind flow. However, the improvement in results may not justify the high computational costs [9].

The Nygårdsfjell wind farm is located in a valley at approximately 420 m above sea level surrounded by mountains in the north and south near the Norwegian-Swedish border. Majority of the winds are suspected to be originating from Torneträsk lake in east which is covered with ice during the winter time. The air closest to the surface on surrounding mountains gets colder and denser. The air then slides down the hill and accumulates over the lake. The air then spills out westward towards Ofotfjord through the broader channel that directs and transforms it into speeding winds. Previous study at Nygårdsfjell wind farm indicated high wind events particularly during the winters. These events consist of wind speeds between 12 and 24 m/s and one of them lasted up to four and a half days uninterruptedly. Majority of these high winds are coming from East of the wind farm [10].

In this study, an attempt is made to couple two types of mesoscale winds with computational fluid dynamics (CFD) based microscale model to better estimate the wind circulations over the complex terrain at Nygårdsfjell wind farm. The method is expected to provide better understanding of wind flow over complex terrain of Nygårdsfjell. The quality of input mesoscale winds are expected to have direct influence on microscale model output. The mesoscale winds are taken from WRF and MERRA, whereas WindSim is used as microscale model. This is not the preferred method of meso-microscale model coupling, but this method is evaluated as it was expected to be easier to implement and to check if it could still give valuable results. The proposed method is applied to three selected cases due to resource constraints. The cases are taken from the previous research work at the Nygårdsfjell wind farm [10]. The objective was to model high wind events over different seasons. The intention of the work is to introduce a potentially promising method that is recommended to be tested on larger data sets. Measured data is compared with the coupled model output in terms of RMSE.

The outline of the paper is as follows: Description of the data set is given in section 2. Section 3 explains the model configurations and simulation setup of WRF and WindSim followed by Section 4 discussing various coupling methods of mesoscale winds with microscale model. Results are discussed in section 5, whereas conclusion is made in section 6.

2. Data sets

Primarily two types of mesoscale winds are used as input to WindSim model. First set of mesoscale winds are generated by WRF simulations. The data is generated by setting up WRF simulations centered around the Nygårdsfjell wind farm as explained in section 3.

The second set of mesoscale winds are taken from the Modern-Era Retrospective Analysis for Research and Applications (MERRA), provided by NASA [11–13]. MERRA reanalysis data reconstruct the atmospheric state by integrating data from different sources such as conventional and satellite data [14]. MERRA uses a three-dimensional variational (3d-Var) analysis algorithm based on the Grid-point Statistical Interpolation scheme [15]. It provides worldwide grid of wind data at a spatial resolution of 1/2° latitude and 2/3° longitude that translates to approximately 27 km × 57 km grid size with hourly temporal resolution since 1979. The wind data is based on the northward and eastward wind components at three different heights (2, 10 and 50 m) above ground level (a.g.l) that can be utilized to obtain the wind speed and the corresponding direction at the hub height. The focus of the research is not to carry out a detail technical evaluation of the data generating strategy of MERRA but rather focus on the usage of MERRA data in the wind energy industry. In-depth details are provided in Ref. [15,16]. In this research work, MERRA dataset is extracted at the nearest available point for its use in microscale modelling.

Measured dataset is taken from three 2.3 MW Siemens wind turbines (SWT-2.3-93) with hub height of 80 m that were installed at Nygårdsfjell during the fall of 2005. The data is filtered and analyzed for the high wind events and three test cases are selcted in June 2008, October 2008 and February 2009.

3. Model setup

WRF model is run at the super computing facility of Texas Tech University, USA whereas WindSim simulations are done in collaboration with Narvik University College. The author followed the user manual of the WindSim for setting up the model and running the simulations. The model configurations are given in the following.

3.1. WRF

One set of mesoscale winds are generated by running the WRF model at the Nygårdsfjell wind farm. WRF version 3.5.1 of the Advanced Research (ARW) solver which is a widely used mesoscale model developed by the National Center for Atmospheric Research (NCAR) is used. It is a successor to NCAR Fifth-Generation meso-scale Model (MM5). WRF offers multiple physics options that can be combined in different ways. The options typically range from simple and efficient to sophisticated and more computationally costly and from newly developed schemes to the well-tried schemes. WRF has a wide set of physical parameterization schemes available for micro physics, radiation (long wave and short wave), cumulus and related to the boundary layer: surface layer, planetary boundary layer (PBL) and land surface model. Physical parameterization schemes interact non-linearly with each other and with the dynamical core of the model, and these complex relationships make the interpretation of model deficiencies very challenging.

For current analysis, mesoscale winds from the WRF model are generated by using the PBL scheme; local closure turbulent kinetic energy scheme Mellor-Yamada-Janjić along with the short/long wave radiation scheme Goddard. The selected PBL settings may not be optimal for this site, but are similar to previous settings that have been used with success in other research work [17–19]. The initial and boundary conditions supplied to the WRF model were taken from the ERA-Interim data sets from the European Center for Medium-Range Weather Forecasts, with spectral resolution of approximately 80 *km* on 60 vertical levels with 6 h of temporal sampling. Land use and topographical properties are acquired from the US Geological Survey. The simulation domains are shown in Fig. 1. The parent domain (d01) has a spatial resolution of 18 × 18 km, covering most of the north Norway. The inner nested domains (d02 and d03) have spatial resolutions of 6 × 6 km and 2 × 2 km respectively. The vertical resolution of the model consists of 51 levels. All domains are centered around the wind turbine location: Latitude = 68° 30″ 27′; Longitude = 17° 87″ 27′. Interaction protocol feedback from nest to its parent domain is selected. All the results discussed in this paper lie within the inner most domain that is d03 and are converted to hourly temporal resolution to be consistent with other models.