On the Predictability of Hub Height Winds

Wind energy is a major source of power in over 70 countries across the world, and the worldwide share of wind energy in electricity consumption is growing. The introduction of significant amounts of wind energy into power systems makes accurate wind forecasting a crucial element of modern electrical grids. These systems require forecasts with temporal scales of tens of minutes to a few days in advance at wind farm locations. Traditionally these forecasts predict the wind at turbine hub heights; this information is then converted by transmission system operators and energy companies into predictions of power output at wind farms. Since the power available in the wind is proportional to the wind speed cubed, even small wind forecast errors result in large power prediction errors. Accurate wind forecasts are worth billions of dollars annually; forecast improvements will result in reduced costs to consumers due to better integration of wind power into the power grid and more efficient trading of wind power on energy markets.

This thesis is a scientific contribution to the advancement of wind energy forecasting with mesoscale numerical weather prediction models. After an economic and theoretical overview of the importance of wind energy forecasts, this thesis continues with an analysis of wind speed predictions at hub height using the Weather Research and Forecasting (WRF) model. This analysis demonstrates the need for more detailed analyses of wind speeds and it is shown that wind energy forecasting cannot be reduced solely to forecasting winds at hub height. Calculating only the power output from hub height winds can result in erroneous estimates due to the vertical wind shear in the atmospheric boundary layer (PBL). Results show that the accuracy of modeled wind conditions and wind profiles in the PBL depends on the PBL scheme adopted and is different under varying atmospheric stability conditions, among other modeling factors. This has important implications for wind energy applications: shallow stable boundary layers can result in excessive wind shear, which is detrimental for wind energy applications. This is particularly relevant with offshore facilities, which represent a significant portion of new wind farms being constructed. Furthermore, a novel aspect to this study is the presentation of a verification methodology that takes into account wind at different heights where turbines operate.

The increasing number of wind farm deployments represents a novel and unique data source for improving mesoscale wind forecasts for wind energy applications. These new measurements include nacelle wind speeds and the turbines' angle of rotation into the wind (yaw angles). This thesis continues with an extensive description of this new data set and its challenges in data assimilation, focusing on data from the Horns Rev I wind farm. Since wind farm data are such a dense data set there is need to derive representative information from the measurements, i.e., thin the data. Different thinning strategies and their impact on improving wind forecasts for wind power predictions are investigated with the WRF Four-Dimensional Data Assimilation system. The median of the whole wind farm was found to be the most successful thinning strategy. Nacelle winds and yaw angles are a promising data set to improve wind predictions downstream of a wind farm as well as at the wind farm itself: Their impact lasted up to 5 hours and depends on time of the day, forecast lead time and weather situation.

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