Validating the WRF model using High Resolution Doppler Lidar data from a Uinta Basin, UT 2012 field campaign for wind energy applications

Meghan Mitchell (a), Yelena Pichugina (b, c), Bob Banta (c), Alan Brewer (c), Ravan Ahmadov (b, c), Dustin Swales (b, c)
(a) Texas Tech University
(b) Cooperative Institute for Research in Environmental Sciences, Boulder
(c) National Oceanic and Atmospheric Administration, Boulder

Abstract: Data from the scanning High Resolution Doppler Lidar (HRDL) are used to evaluate the accuracy of the WRF modeled wind flow over complex terrain of the Uintah Basin. Results of the case study and a discussion of discrepancies between modeled and observed winds are presented.

1. Introduction
Models can be important tools for assessing the potential of wind energy sites, but the accuracy of these predictions has not been properly validated. In this study, the High Resolution Doppler Lidar (HRDL) data obtained at high temporal and spatial resolution for heights of modern turbine rotors were compared to output from the Weather Research Forecast (WRF) model to evaluate the performance of the model in producing wind forecasts. The model validation method was based on the qualitative comparison of the wind field images, time-series analysis and statistical analysis of the observed and modeled wind speed and direction, both for case studies and for the whole experiment. The results from this analysis reveal where and when the model typically struggles in forecasting winds at rotor heights, so that in the future the model can be improved to provide better wind forecasts.

2. Study area and the High Resolution Doppler Lidar
The Uintah Basin Winter Ozone Study (UBWOS) field campaign took place in January 23-March 1, 2012 in the Uintah Basin of Northeast Utah, with the intensive studies focused on the month of February. The topography of the Basin—and, consequently, the surface meteorology—is exceedingly complex, and surface measurements do not well characterize the vertical structure of the flow. To provide insight into the temporal and spatial variability of wind flow, and to address other objectives of the experiment, the Doppler lidar HRDL was deployed to the Horse Pool research area.
The HRDL is a pulsed, scanning, remote-sensing instrument that sends out a beam of infra-red light to measure the backscatter from aerosols and particles in the atmosphere and the Doppler-shifted frequency. HRDL transmits a pulse of 2-µm infrared radiation at a pulse repetition frequency of 200 Hz. The precision of radial velocity measurements is about 10 cm s⁻¹, with 30 m range-gate resolution along the beam [2].

During UBWOS the HRDL was deployed to the eastern sector of the basin at the Horse Pool site, at a platform elevation altitude of 1562 m AGL the scanning strategy, developed for the experiment includes sequences of conical and vertical slice scans. The scanning strategy was automatically executed by the HRDL computer, and data were transferred in real time to the NOAA office in Boulder CO for further data analysis. The processing technique [3] uses both types of scan to compute mean wind speed and wind direction profiles from surface up to 1.5-2 km. These profiles, combined in the time-height cross section, reveal both, diurnal and vertical variability of wind properties.

3. **WRF Model**

The WRF model used in the study is a next generation meteorological model developed extensively for operational and research applications worldwide (http://www.wrf-model.org). The WRF model coupled with chemistry was successfully applied to simulating meteorological and chemistry variables over the Uinta Basin (UB) during UBWOS-2012 field campaign [1].

The WRF model was run on two nested domains with 12 and 4 km resolutions, respectively. The inner domain centered over the study area is shown in Figure 2. For boundary and initial conditions of the meteorological fields the North American Mesoscale analysis fields (www.emc.ncep.noaa.gov) were used. The 12 km resolution outer domain simulations were initialized every day at 00UTC, where 6 hours for each day were used a spin-up time period. The inner domain simulations were conducted by nesting down from the WRF output for the outer domain.

![Topography of the WRF domain (4 km resolution inner domain). Terrain heights are color coded according to the color scale at the bottom of the Fig. The “h” marks Horse Pool site.](image)

4. **Results. Case study**

An example of a comparison of the observed and modeled wind speed on February 26, 2012 is presented in Figure 3. The selection of this day for the case study was based primarily on two factors: the strong
winds and high variability in the wind speeds and wind directions, and the significant underperformance of the model during nighttime hours.

Figure 3. Time-height cross sections of the (a) observed and (b) modeled wind speed, (d) observed and (e) modeled wind direction, and (e) wind speed and (f) direction difference that are color coded according to the scale at the right side of each panel. Data are shown for 26 February 2012. The two white solid lines outline the heights of 50-150 m AGL and the dashed white line indicates the height of 100 m AGL.

The observed winds were stronger on the evening of February 26, gradually slowing throughout the morning and remained weak (< 4 m s\(^{-1}\)) from the local afternoon till evening (~1500-2400 UTC) of February 27. The model appears to capture the overall trend of the wind speeds with faster winds between 00-04 UTC and much slower winds between 1600 UTC. However, the modeled wind speeds in the rotor layer are much slower than the observed wind speeds during the period of 700-1400 UTC. The bias in measured and predicted wind speed is shown on the bottom panel (c) illustrating significant discrepancies during evening-morning transition hours, the largest difference of 10 m s\(^{-1}\) occurring ~800 UTC. The observed northwesterly wind direction (brow color) in the late evening/overnight gradually turned to southwesterly (yellow) in the next day morning, and more southerly towards the afternoon and evening hours. The modeled wind direction appears to follow the same trend somewhat but with more pronounced differences during the local afternoon and evening hours of February 26 (Fig. 3 e). Several periods of significant (~60-70\(^{\circ}\)) deviations between measured and predicted wind directions found for periods around 800 and 1900 UTC, the largest happening at 00 UTC on February 27.

5. Results. Statistical Analysis of the entire datasets

As major standard metrics for the assessment of the model performance we use the experiment mean bias, root mean square error (RMSE), and correlation coefficient (R) between measured and modeled wind speed and wind direction. Figure 4 shows experiment mean profiles of these statistics for (left panels) wind speed and (right panels) wind direction. The positive bias values for both variables indicate that the model, on average, was overestimating the wind speed and direction The largest wind speed bias (~0.75 m s\(^{-1}\)) is found at heights below the rotor layer (the shaded region) and at 500 m AGL. Within the rotor layer the bias was 0.4-0.6 m s\(^{-1}\) which is significantly smaller than reported in offshore wind [3] biases found between lidar observed and forecasted by several National Weather Prediction (NWP) models. The
wind speed RMSE gradually increases from 1.8 near the surface to 2.9 at 500 m AGL. The correlation coefficient was between 0.81 and 0.82 in the rotor layer indicating there is a strong positive correlation between the observed and modeled wind speeds.

![Figure 4](image)

Figure 4. Profiles of experiment-mean statistics between measured and modeled (a-c) wind speed and (a1-c1) wind direction. In all plots, symbols indicate heights of lidar measurements and shaded area indicates the presumptive turbine rotor layer of 50-150m.

The wind direction bias indicates that the model predicted more northwesterly winds compared to the observed directions, with the largest value of ~ 16 degrees within the rotor layer. The wind direction root mean square error is around 82-87° in the rotor layer. The correlation coefficient was around 0.4 in the rotor layer meaning there is a weak positive relationship between the observed and modeled wind directions.

6. Conclusions

Overall the WRF model was able to capture the general trend of the wind field in the turbine rotor layer with the forecasting uncertainty of 2-2.5 m s\(^{-1}\). However, several cases of large discrepancies between modeled and observed winds were found mostly during evening-morning transitional periods of increased winds and frequent Low Level Jet (LLJ) profiles. The larger wind speed discrepancies (~10 m s\(^{-1}\)) were observed on February 26. During this case, WRF forecasted wind speed drops below cut-in wind speed for generic turbines, whereas the observed wind speed was stronger. This issue is especially important to the wind industry. There could be a number of reasons the model forecasted wind field was different during this hour and further investigation of this should be done to conclude why the model struggled at this time and what type of atmospheric event caused the difference between the modeled and observed winds.

Acknowledgements

The study was supported by the SOARS program and conducted at the NOAA Chemical Science Division.

References
