Forecasting of Wind for Energy in Southern Idaho

Kevin Nuss, Paul Dawson, and Todd Haynes
Boise State University College of Engineering

1. Introduction

As part of a research project aimed at improving forecasted wind speeds for the purpose of making wind energy more usable, various physics options in WRF were investigated. These were compared to readings from a Triton sodar placed on the site of an operational wind farm in southwest Idaho, on the Snake River plain. The initial set of experiments was done using data from December 20, 2008 to March 20, 2009 when the sodar was operational. After version 3.1 of WRF was released, additional sets of forecasts were run to evaluate some of the new physics options.

Some of the many additions to WRF 3.1 were not of interest for wind forecasting because they dealt with options particular to long runs, urban canopies, sea ice, or climate related simulations. Forecasting needed for wind farms tends to focus on relatively small rural areas and have short forecast lengths. Accurate temperature and precipitation is not a necessity other than for its effect on wind. And since the energy available to wind turbines is a function of the cube of wind speed, highly accurate wind forecasts are needed by power companies to manage supply and demand on power grids, which have no storage capability.

The research reported in this paper evaluates three of the new planetary boundary layer options and the two new surface layer options introduced in version 3.1 of WRF.

2. Methods

As part of the overall research, additions were made to the WRF source code to help provide wind speeds averaged over short periods of time rather than instantaneous wind speed at the WRF output intervals. These changes accumulate wind speed totals from every time step so an average can be calculated. Since vertical coordinates in WRF are based on atmospheric pressure rather than fixed heights, wind speeds were interpolated to fixed heights before being accumulated. The fixed heights and averaging intervals are configurable in WRF’s namelist input file. An averaging interval of 10 minutes and fixed heights of 40, 50, 60, 80, 100, 120, 140, 160, 180, and 200 meters were used to match the output from the sodar. We were particularly interested in the 80-m wind speeds at the wind turbine hub heights.

Rapid Update Cycle (RUC) data from National Centers for Environmental Prediction (NCEP) was used to initialize the model runs, RUC initialization limited the forecasts to 9 hours. For the purposes of comparing physics options, 198 evenly spaced forecasts were performed over 91 days. Each run creates a forecast over a 9 hour period of time and begins 11 hours after the beginning of the previous run. This spacing created runs that occur at varying times of day. The data from the sodar is not present for every time period and is occasionally of too poor quality to use, so the calculated errors are from varying numbers of comparisons.

The sodar is a Triton model made by Second Wind, Inc. It is located near Mountain Home, Idaho at a location where the elevation about 970m. The site is on a large river valley with foothills rising to the north. The soil is sandy, the vegetation is shrub land or agricultural, and the climate is dry. The terrain could be characterized as moderately complex.

The model contains three square domains, with the innermost, d03, centered in the middle domain, d02, which is centered in the outer domain, d01. Grid cell sizes are 9km, 3km, and
1km and grid dimensions are 52 by 52 (d01), 36 by 36 (d02), and 30 by 30 (d03). In previous tests of boundary layer options for this area of interest, larger grid dimensions did not significantly improve the forecasts.

Vertical coordinates were chosen so as to have approximately 30 meter spacing near the surface and gradually increased spacing higher up. Some previous research at another location showed that this vertical resolution provided good results in forecasting winds at wind turbine heights. The 44 eta levels that were used were: 1.0000, 0.9960, 0.9920, 0.9880, 0.9840, 0.9797, 0.9742, 0.9675, 0.9596, 0.9505, 0.9399, 0.9269, 0.9115, 0.8937, 0.8735, 0.8460, 0.8300, 0.8120, 0.7920, 0.7680, 0.7360, 0.7020, 0.6660, 0.6290, 0.5915, 0.5536, 0.5153, 0.4773, 0.4400, 0.4040, 0.3695, 0.3375, 0.3085, 0.2645, 0.2305, 0.2035, 0.1792, 0.1539, 0.1272, 0.0995, 0.0713, 0.0429, 0.0145, 0.0000. The top of the model was at 100 hPa.

Fixed length time steps of 54, 18, and 6 seconds were used for domains d01, d02, and d03 respectively. The Lin et al. scheme of microphysics (mp_physics=2), the RRTM scheme for longwave radiation (ra_lw_physics=1), the Dudhia scheme for shortwave radiation (ra_sw_physics=1), and the 5-layer thermal diffusion scheme (sf_surface_physics=1), using 5 soil layers (num_soil_layers=5), were used. These same physics options were used for all three domains and all forecasts. Among the dynamics options, diffusion (diff_opt=1) and 2d deformation (km_opt=4) were chosen. The research is oriented toward operational wind forecasts, so vertical velocity damping (w_damping=1) was chosen. The above physics and dynamics options are described more fully in the WRF user's guide (Wang et al., 2009) and the technical note describing WRF (Skamarock et al., 2008).

For this paper, the bias for a particular forecast hour is defined as average error for that forecast hour over all 198 forecast runs. And error is defined as the 80-m reference wind speed from the sodar minus the predicted, interpolated 80-m horizontal wind speed from WRF. A negative bias indicated that the forecasted speed was too high. Mean absolute error (MAE) and root mean squared error (RMSE) are described in (Madsen et al., 2004) and have the commonly used definitions. Similar analysis was performed for other heights, but only the 80-m data is presented here.

A nonstandard method labeled “Mean Absolute Bias Corrected Error” (MABCE) was also used to evaluate model output. After the bias for each forecast hour was calculated for a set of runs, that bias was removed from each forecasted wind speed before the mean absolute error was calculated. Similarly, “Root Mean Squared Bias Corrected Error” (RMSBCE) was also calculated but is not shown.

As an example of MABCE calculation for the QNSE/QNSE options: after the 198 forecasts were complete, a bias was calculated for forecast hour 5 using all of the hour 5 forecasts that had a corresponding reading from the sodar. All the hour 5 forecasted wind speeds were then adjusted by that bias amount before MAE was calculated for hour 5, giving MABCE.

The MABCE is used because the bias can be and will be removed during any post processing of the model output. Removing the bias from the same forecasts used to calculate that bias artificially assumes that the bias is identical to the long term bias of the planetary boundary layer scheme being tested. Ideally, a set of longer term sodar measurements would be used to first calculate a seasonally adjusted bias and then apply that bias to future forecast runs. Since the bias changes significantly with forecast hour, a different bias is calculated and used for each forecast hour.

Below are the six combinations of planetary boundary layer (PBL) and surface layer (SL) physics tested in this study:

**MYJ/ETA/3.0:** Uses the Mellor-Yamada-Janjic PBL scheme with the Eta Similarity SL scheme, both from version 3.0 of WRF. In a previous study, this combination gave the best results for the study area.
**MYJ/QNSE**: Uses the older Mellor-Yamada-Janjic PBL scheme but with the new Quasi-Normal Scale Elimination SL scheme.

**QNSE/QNSE**: Uses the new Quasi-Normal Scale Elimination PBL scheme with new Quasi-Normal Scale Elimination SL scheme.

**MYNN2.5/ETA**: Uses the new Mellor-Yamada Nakanishi Niino Level 2.5 PBL scheme with the older ETA SL scheme.

**MYNN2.5/MYNN**: Uses the new Mellor-Yamada Nakanishi Niino Level 2.5 PBL scheme with the new Nakanishi Niino SL scheme.

**MYNN3/MYNN**: Uses the new Mellor-Yamada Nakanishi Niino Level 3 PBL scheme with the new Nakanishi Niino SL scheme.

The above descriptions come from the ARW Version 3 Modeling System User's Guide April 2009 (Wang et al., 2009).

### 3. Results

#### Figure 1: Wind Speed Bias

The graph in Figure 1 shows bias for each forecast hour. Early forecast hours have a positive bias, which reflects a bias within the RUC data used to initialize the model. Over a couple hours of model simulation time, that initial positive bias from the initialization data became negative. This implies that all the tested physics combinations have a negative bias for this model resolution and location. As the simulation evolved, the initialization bias was replaced by the model bias.

In the graph in Figure 2, the mean absolute error (MAE) displays a fairly consistent error range between 2 and 2.65 m/s, which seems to indicate good overall quality in the RUC data used for initialization and boundary conditions. Since the MAE levels off and does not increase as the forecast hour increases, the model seems to demonstrate some skill in its general forecasting abilities. Otherwise, error would increase over time.

#### Figure 2: Mean Absolute Error (MAE)

Perhaps some error is caused by subscale processes whose details are not captured in the model. If the details were captured but just miscalculated, there would probably be a consistent bias that could be removed. The mean absolute bias corrected error (MABCE), shown in Figure 3, only shows minimal improvement. And obviously, the quality of the RUC data used to initialize the model and provide lateral boundary conditions plays a critical role in determining the outcome of a forecast.
Though they are not shown, graphs of the root mean squared error and root mean squared bias corrected error show the same pattern.

It is interesting to note that the bias and error graphs show a lack of smoothness over forecast hours. This may indicate that several unusually good forecasts are affecting the results. Bias and error for forecast hours six and seven should otherwise have similar error values as surrounding hours. A larger sample of forecasts could be used to test whether this variability is reduced with sample size or whether there may be some other time dependent component.

4. Conclusion

All of the tested physics options showed a good degree of skill in predicting wind speeds. None stood out as especially good or bad for the data analyzed but seemed to track closely with previous schemes provided in version 3.0 of WRF.

Since all of the planetary boundary layer and surface layer scheme combinations that were tested showed roughly similar results, it seems that remaining error in the forecasts is caused by other factors.

Future work can take the best of these schemes and vary other factors such as vertical and horizontal resolution, radiation schemes, assimilated data, and seasonal factors. The research, of which this reported study is a part, is investigating the use of other high resolution fluid dynamics programs such as Fluent and CALMET for obtaining a higher degree of vertical and horizontal resolution. Using the large eddy simulation options within WRF is also a part of that research.

5. Acknowledgements

The study presented here is part of a wind and power forecasting grant provided by Bonneville Power Administration. It is funded under BPA Contract 00039902, administered by John Pease. That research is also supported by Doug Taylor at John Deere Wind Energy, Kurt Meyers at INL, various folks at Idaho Power Inc.

6. References

