# P501 NUMERICAL SIMULATION OF WIND POWER POTENTIAL IN UPSTATE NEW YORK

Robert Ballentine *, Scott Steiger and Daniel Phoenix
State University of New York at Oswego

## 1. INTRODUCTION

Consistent with the national goal of moving away from our dependence on carbon-based fuels, there is considerable interest in New York State in developing wind power especially in areas with highest potential. The purpose of this research is to simulate low-level winds over upstate New York by running the Weather Research and Forecasting (WRF, Skamarock, et al 2005) model every day on a high-resolution (1.333 km) domain. Using the standard wind speed-versus-power generation curve for a GE 1.5 MW wind turbine, we can estimate the monthly and seasonal average wind power potential at all of our grid points (covering much of upstate New York and adjacent Lake Ontario). To determine the accuracy of WRF wind predictions, we are comparing winds simulated by WRF at 10 m AGL with hourly observations at three regularly reporting sites near Lake Ontario.

### 1.1 *Brief Description of Wind Power Sites*

As of November 2009, New York State had more than 1200 MW of wind generating capacity from sites such as Horizon Wind Energy's Maple Ridge Wind Farm in Lewis County and farms operated by Noble Environmental Power in Clinton, Franklin and Wyoming Counties. Several European countries (e.g., Denmark and the United Kingdom) are developing shallow offshore wind resources. With the strong prevailing winds near the Great Lakes, New York State ranks 15th in the nation with over 7000 MW of wind power potential according to the American Wind Power Association. Recently, the New York Power Authority (NYPA) called for proposals to install up to 500 MW of power from offshore wind turbines on Lake Ontario and Lake Erie.

An important question is how far offshore should turbines be located to produce the greatest amount of power at the lowest startup and maintenance cost. One of our wind power cross sections will show how wind power over Lake Ontario compares with that near the Maple Ridge wind farm on a seasonal basis.

* *Corresponding author address:* Robert J. Ballentine, SUNY Oswego, Dept. of Earth Sciences, Oswego, NY 13126, robert.ballentine@oswego.edu

## 2. METHODOLOGY

### 2.1 *Grid Arrangement*

We are running the ARW-core of WRF on a doubly-nested grid (Fig. 1) to ensure that both large-scale meteorological forcing and local geographical effects are well-represented. The grid spacings of the large, intermediate and fine grids are 12 km, 4 km and 1.333 km respectively. We use 33 sigma levels where the lowest levels correspond to 10m, 40m and 80m above ground under typical meteorological conditions. We employ the Noah LSM and Yonsei PBL schemes.

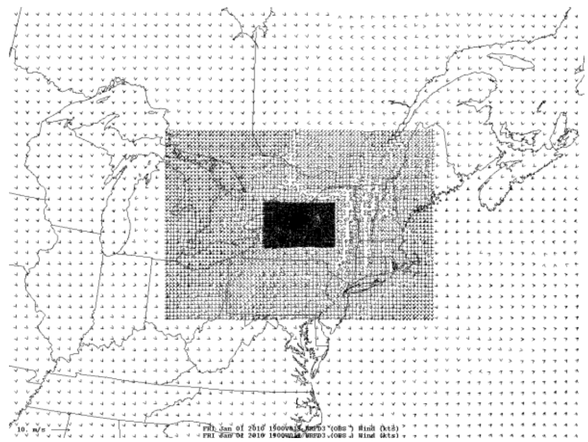

Figure 1. Domain configuration for WRF wind study. Grid points are shown with minimum 'depictables' for this display using GARP.

### 2.2 *Initial and Boundary Data*

We have been running WRF out to 24 hours every day since February 18, 2009 on a dual quad-core Dell Precision Workstation. Initial conditions and boundary values for the large domain are obtained using twelve contiguous 'tiles' from the 0000 UTC run of the operational North American Mesoscale (NAM) model available online from the National Centers for Environmental Prediction.

### 2.3 *Wind Power Calculations*

The wind speed predicted by WRF each hour at 80 m AGL is used in a formula that represents theoretical power generation by the GE 1.5 MW SLE turbine. No power is produced for winds less than 3.5 m/s while separate cubic polynomials are used to fit the GE power curve between 3.5 and 10 m/s and between 10 and 14 m/s. Power output is held constant for wind speeds above 14 m/s, but drops to zero for winds above 25 m/s since the turbine is supposed to be shut down. Plots of wind power potential on the fine grid, averaged over all hours for each of three seasons, are discussed in Section 3.

## 3. RESULTS

### 3.1 *Seasonal Wind Power on the Fine Grid*

For the three seasons studied so far, WRF predicts wind power maxima over Lake Ontario, the Tug Hill Plateau (T in Fig.2), northeastern Otsego County (S), Madison County (M), southern Cayuga County (C), southern Ontario County (O), and Wyoming County (W) in the southwest corner of the fine-grid. We see from Fig. 2, that WRF predicts a potential for up to 600 kW of average power (red contour border) over Lake Ontario within a 'reasonable' distance (e.g., 25 km) from the shoreline.

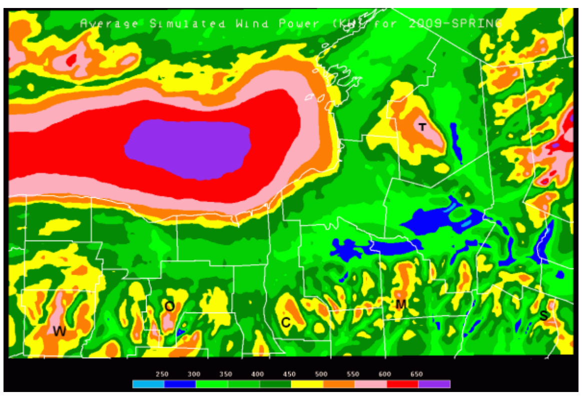


Figure 2. Average wind power simulated by WRF (kW) for Spring 2009 (March, April and May).

WRF simulations suggest that wind power values comparable to those along the Tug Hill (e.g., Maple Ridge Wind Farm) and over Ontario and Wyoming Counties could be attained over Lake Ontario at locations very close to the southern shoreline. Such values are also predicted off the eastern shoreline, but at a distance considerably farther offshore.

Summer 2009 was the weakest of the three seasons with a potential for up to only 300 kW of power within a reasonable distance from the shoreline (Fig. 3). The potential wind power over the Tug Hill exceeds the predicted power near the lake shore anywhere within our fine grid. Turbines would need to be installed at least 25 km offshore for power generation to reach Tug Hill levels. For all of the traditional 'hot spots' in the hills south of Lake Ontario, the power potential is less than that for the Tug Hill especially in Cayuga and Madison Counties.

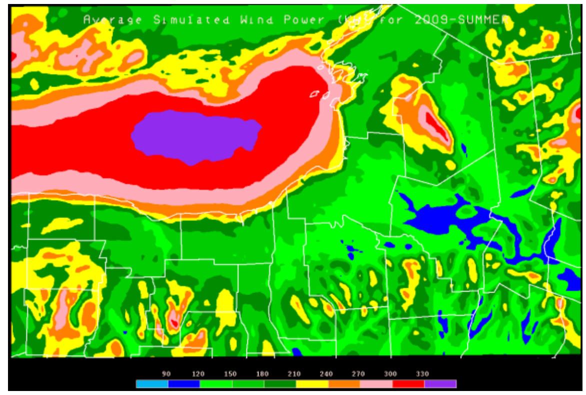


Figure 3. Average wind power simulated by WRF (kW) for Summer 2009 (June, July and August).

For Autumn 2009 (Fig. 4), WRF predicts average power potential of up to 500 kW over Lake Ontario within a reasonable distance from the eastern shore. In contrast to Spring 2009, the potential over the lake close to the shoreline actually exceeds the potential over the Tug Hill (just over 400 kW) and all of the southern 'hot spots' except in Ontario and Wyoming Counties where the potential is just over 450 kW.

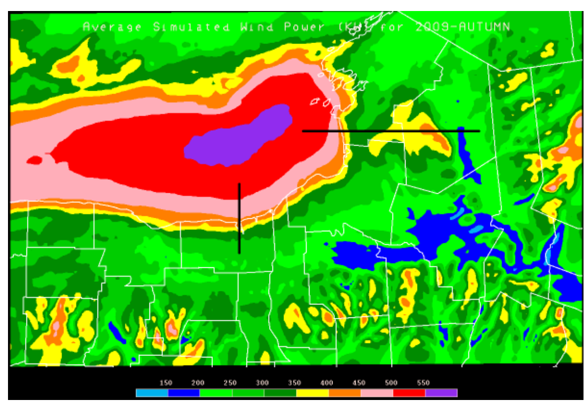


Figure 4. Average wind power simulated by WRF (kW) for Fall 2009 (September, October, November).

### 3.2 *Wind Power Cross Sections*

Since there appears to growing interest in offshore wind power in New York State, we will examine both west-to-east and north-to-south cross sections of wind power simulated by WRF. The locations of these cross sections are shown by the heavy black lines in Fig. 4. The first runs eastward through the Tug Hill Plateau and the second extends southward over Sodus Bay into Wayne County.

The west-east cross section (Fig. 5) shows a decline in power potential as we move from the lake toward the eastern shore. For each season, power potential increases over land with a slight decrease in extreme western Lewis County where the terrain levels off followed by another steady increase to the summit of the Tug Hill along model grid Row 101. Power potential decreases sharply as we approach the Black River Valley (near the right edge of Fig. 5).

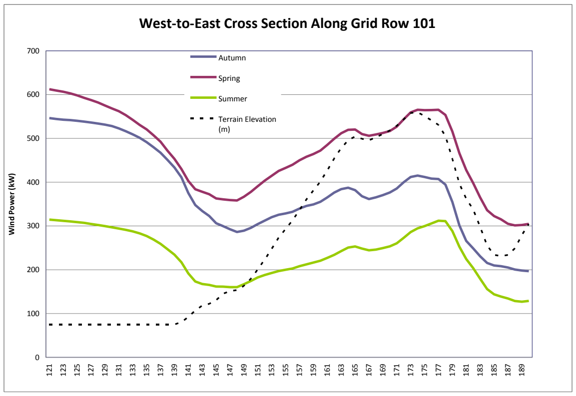


Figure 5. Wind power (kW) simulated by WRF along the 92-km long west-to-east line of Grid Row 101 shown in Fig. 4. Terrain elevation (dashed) in meters using the same scale as that used for wind power.

The north-south cross section through Sodus Bay (Fig. 6) shows a gradual decrease in wind power potential from a maximum well offshore of the lake to a minimum a few km inland. The largest wind power

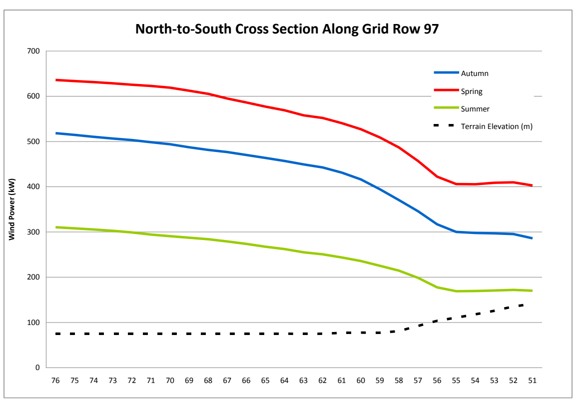


Figure 6. As in Fig. 5 except along the 33-km long line of Grid Column 97.

decrease is predicted by WRF just inland from the south shore. The model suggests that no significant increase in power should be expected over the slightly elevated terrain just south of the lake in Wayne County.

### 3.3 ***Verification of WRF Wind Predictions***

Wind speeds reported at Fulton, NY (KFZY), Watertown, NY (KART), and Oswego, NY (OSGN6) are compared (every 3 hours, e.g., 00Z, 03Z, etc) with

| | All Winds | | | Winds ≥ 4 m/s | | |
|---|---|---|---|---|---|---|
| | %err >2m/s | %pos error | %neg error | %err >2m/s | %pos error | %neg error |
| FZY Spring | 38.0 | 29.6 | 8.4 | 32.7 | 11.7 | 21.1 |
| FZY Fall | 42.7 | 40.9 | 1.8 | 22.3 | 15.8 | 6.5 |
| ART Spring | 29.1 | 20.5 | 8.7 | 25.6 | 7.2 | 18.4 |
| ART Fall | 42.8 | 27.6 | 15.2 | 46.3 | 8.2 | 38.1 |
| OSGN6 Spring | 32.5 | 11.6 | 20.9 | 42.6 | 7.5 | 35.1 |
| OSGN6 Fall | 27.4 | 18.1 | 9.3 | 26.1 | 6.6 | 19.5 |

Table 1. Percentage of WRF 10-m wind speed errors exceeding 2 m/s. Positive error for WRF speed too high; negative for speed too low. Right half of Table for wind speed sufficient to produce significant power.

WRF predictions at 10 meters AGL. WRF errors are summarized in Table 1. Signed wind speed errors are computed by subtracting the observed speed from the forecast speed. As an example, for KFZY during spring 2009, WRF absolute errors exceeded 2 m/s (for observed wind speed at least 4 m/s) 32.7% of the comparison hours. Of these, 21.1% of the errors were negative (WRF underforecast) while 11.7% were positive (WRF overforecast). From Fig. 7, we see that the average WRF negative bias error increases with increasing wind speed.

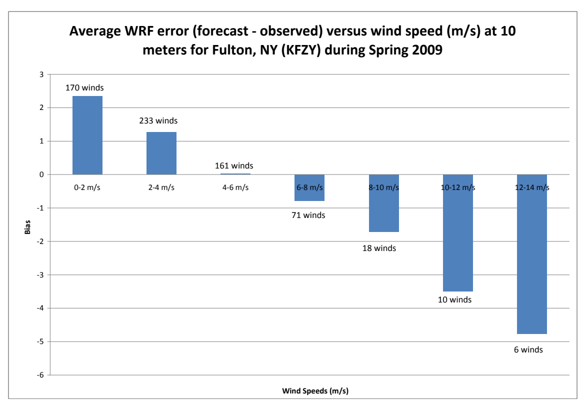


Figure 7. Average WRF wind speed error for speed categories. Numbers beneath each bar give the number of comparison hours for that wind speed bin.

We see from Table 1 that except for KFZY during fall 2009, WRF underpredicted more often than it overpredicted 10-m wind for speeds necessary for power generation. At Watertown this trend is more pronounced during fall while at Oswego, it is stronger in spring. Sensitivity tests will be run with other PBL and LSM schemes to determine if the WRF prediction of wind speed can be improved. Although it seems likely that WRF also has a negative bias for wind speed at hub height, we do not yet have access to tower data to verify WRF 80-m predictions. We plan to request tower data from wind energy companies for the purpose of further model verification. We will also explore new technologies for mobile field studies using portable low-level wind measuring equipment.

In an effort to evaluate WRF predictions at higher elevations, we used the tethersonde tracking system purchased in 2008 with funds from NSF. The balloon was launched from the SUNY Oswego campus at 1915 UTC on 10 October 2009. The wind at 2000 UTC was 6.5 m/s from 250 degrees at an elevation of approximately 160 m. The WRF wind (20-hour forecast verifying 20Z) was 5.6 m/s from 285 degrees. Unfortunately, we have been unable to make further launches due to damage to the balloon. However, we expect to make more launches with a replacement balloon starting in Spring 2010.

## 4. DISCUSSION

### 4.1 *Influence of Terrain*

As expected, WRF predicts good potential for onshore wind power (e.g., averaging at least 30% of rated power) near the peaks of hilly areas. This is especially true for those hills where there is a large gradient in terrain elevation such as shown in Fig. 8 in Lewis County (Maple Ridge) and Wyoming County.

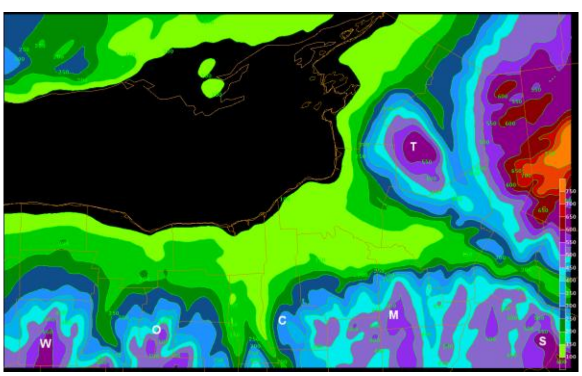


Figure 8. Terrain elevation (m) over the fine grid. White letters indicate significant wind power 'hot spots' over land indicated by the WRF simulations.

WRF indicates that wind power potential is good in portions of Herkimer and especially in Hamilton County along the eastern border of the fine grid. While there is high terrain and steep terrain gradients in these locations, it is not likely that wind turbines will be permitted there because these areas are within the Adirondack Park and Forest Preserve. Ideally, wind turbines should be located over cleared land or in shallow water rather than in forests.

### 4.2 *Offshore versus Onshore Wind Power*

Which is more cost effective, onshore wind power or offshore wind power installed in shallow bodies of water? WRF suggests that except during summer, there is at least as much potential just off the eastern and especially southern shores of Lake Ontario as there is over the Tug Hill. For December 2009 (Fig. 8) and late February 2009 (not shown), the average power simulated by WRF is considerably greater (up to 56% of capacity within 15 km of the shoreline as compared to barely 43% of capacity over the Tug Hill). We also find that the average power predicted by WRF *over land* within a narrow strip about 10 km wide adjacent to the shoreline exceeds that over the

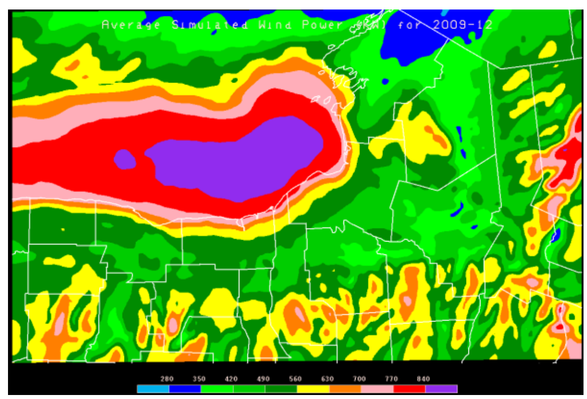


Figure 9. Average wind power simulated by WRF (kW) for December 2009.

Tug Hill all the way from Rochester, NY nearly to Watertown, NY. Although our results for winter are incomplete, the plot in Fig. 9 suggests that power potential along the coastal strip of Lake Ontario (and presumably the other Great Lakes) both onshore and offshore is at least as great in winter as for any of the hilly locations over land. In contrast, the WRF simulations for summer (Fig. 3) suggest that power potential is less along the onshore coastal strip than over the hills. Since the air in the lowest few hundred meters is usually more unstable over the lake in winter as compared to spring and summer, it is possible that the lake influence on wind speed extends somewhat farther inland during the cold season. There is some question as to how well WRF handles the influence of the lake on winds just onshore. For December 2009, the WRF speed bias for winds of at least 4 m/s at OSNG6 was positive for 15.2% of the hours and negative (underforecast) for 20.7% of the hours - not much different. For spring 2009, the bias at OSGN6 (from Table 1) was 7.5% positive and 35.1% negative. This suggests that WRF may have problems predicting high enough wind speeds in the coastal strip during the stable season and less trouble during the unstable season. We will continue model verification during 2010 for cities close to the shoreline.

Some possible concerns about installing wind turbines on Lake Ontario include damage to the turbine and its supporting structure due to migrating ice flows and winds up to 80 mph in winter, the cost of cables to transmit electric power onshore, the cost of travel for maintenance, harm to birds and other wildlife, disruption of shipping lanes, restriction of fishing and other recreational activities. Some people may oppose turbines on the lake because they diminish the natural scenic beauty including the famous sunsets as viewed from the eastern shore.

Even if these challenges can be overcome, is there enough power potential over the lake to justify the extra cost of construction and maintenance? According to Windustry.org, the cost of commercial turbines over land ranged from $1.2 to $2.6 million per megawatt capacity in 2007. It has been difficult to find cost estimates for erecting and maintaining turbines on the Great Lakes, but we suspect that the support structures will need to be very rugged.

**5. CONCLUSIONS**

WRF running on a doubly-nested, high-resolution fine grid appears capable of representing the effects of large-scale meteorological conditions and irregular terrain. However, a comparison with WRF-simulated winds at 10 meters and winds reported at stations near Lake Ontario indicates that the model tends to underestimate wind speed especially when the lake is colder than the air above.

Using winds simulated each hour at 80-m, WRF predicts the greatest wind power potential over the interior of Lake Ontario where turbines are not likely to be installed. However, there appears to very good potential (about 34% of capacity for all the months studied so far), over the shallow waters close to the shoreline. This includes the summer months where the average wind power for this region is only about 20% of capacity.

Over land, WRF predicts the greatest potential near the peaks of hills having a steep terrain elevation gradient such as the Tug Hill. For all months studied so far, the average simulated power over the Tug Hill is about 31% of capacity while the average in the narrow strip of land adjacent to the coast is about 26% of capacity. Except for summer, the potential is greater just inland from the south shore than just inland from the east shore of the lake.

We plan to keep running WRF every day for at least another year in order to expand our wind power climatology. We will carry out sensitivity tests with different physical parameterizations to determine if the underforecast error can be reduced. We will also determine if running with more vertical levels makes any difference in the accuracy of wind predictions. We will investigate a few of the rare cases where the model winds were much different than those reported at stations near the lake to determine the source of these large errors.

**6. REFERENCES**

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang and J. G. Powers, 2005: A description of the Advanced Research WRF Version 2. NCAR Tech. Note, ncar/TN-468+STR, 88 pp.

**6. ACKNOWLEDGEMENTS**

This research was supported by grant DE-FG26-08NT01994 from the Department of Energy. We acknowledge the National Centers for Atmospheric Research (NCAR) and collaborators for development of the WRF model, and the National Centers for Environmental Prediction (NCEP) for providing access to operational model forecast tiles which we are using to provide initial and boundary data. We are grateful to the Office of Research and Sponsored Programs at SUNY Oswego for purchase of the computer used to run WRF.