Creation of a WRF Ensemble for Improved Wind Forecasts at Turbine Height

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Introduction

- Inherent variability of the wind requires more accurate forecasts to optimize wind energy production
- Few evaluations exist of model forecasts for winds at 80m, a height where influence of friction from the earth's surface can vary greatly depending on the time of day, season, and vertical temperature stratification of the boundary layer
- Traditional wind forecasts have focused on the 10m height where standard measurements are made
- More accurate 80m wind forecasts are needed to meet national goals for wind energy production

Data and Methodology

- Weather Research and Forecasting (WRF) model with 10-km horizontal resolution was used to explore improvements in wind speed forecasts at hub height (80m)
- Model configurations run using Global Forecast System (GFS) and North American Model (NAM) analyses for initial and lateral boundary conditions
- Six different planetary boundary layer (PBL) schemes tested:
  - Yonsei University Scheme (YSU) - WRF
  - Mellor-Yamada-Janjic (MYJ) - WRF
  - Quasi-Normal Scale Elimination PBL (QNSE) - WRF
  - Mellor-Yamada Nakanishi and Niino Level 2.5 PBL (MYNN2.5) - WRF
  - Mellor-Yamada Nakanishi and Niino Level 3.0 PBL (MYNN3.0) - WRF
  - Pleim PBL scheme (also called Asymmetric Convective Model (ACM2)) – WRF
- Results were validated using wind speed measurements at 80 m from a meteorological tower at the Pomeroy wind farm in northwestern Iowa and mean absolute error (MAE) was calculated
- Pre-processing tests include:
  - Different PBL Schemes
  - Different Time Initializations
  - Different GFS Perturbations
- Post-processing tests include:
  - Training of the Model
  - Neighborhood Approach
  - Bias Corrections based on wind direction, wind speed, and diurnal cycle

Figure 1

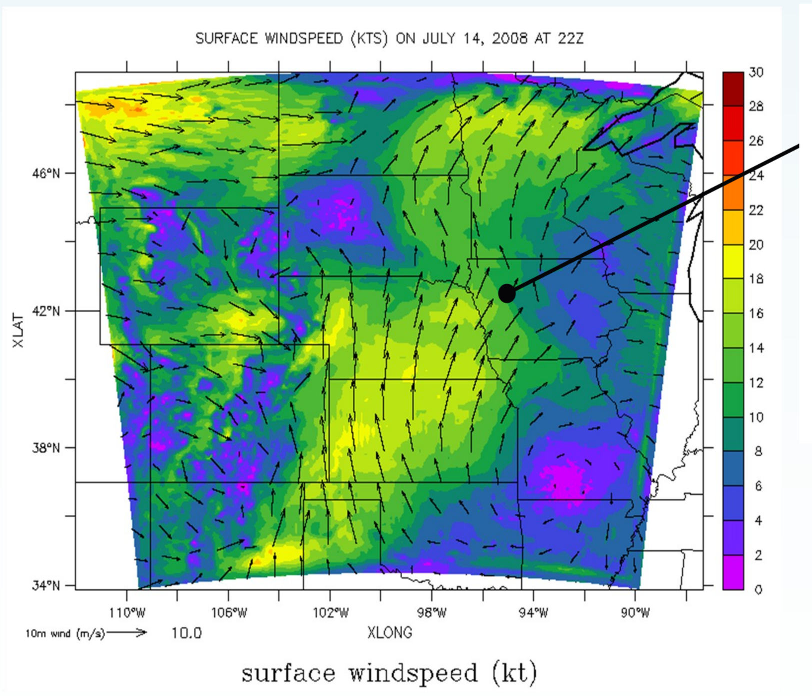

Figure 2

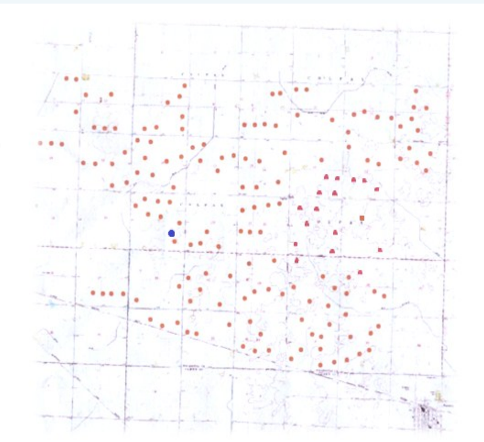

Figure 1: Domain used with an inset (Figure 2) showing the outline of the Pomeroy wind farm where each red dot is a wind turbine and the blue dot is the meteorological tower.

Model Improvement

Table 1 - Time Initialization

Time Initialization	MYNN 3.0 MAE (m/s)	YSU MAE (m/s)	Ensemble MAE (m/s)
18Z	1.88	1.78	1.69
00Z	1.82	1.74	1.63
06Z	1.83	2.07	1.73

Table 2 - Neighborhood Approach

Grid Averaging	MYNN 3.0 MAE (m/s)	YSU MAE (m/s)	Ensemble MAE (m/s)
Point	1.82	1.74	1.63
3x3	1.82	1.72	1.61
5x5	1.82	1.70	1.59
11x11	1.83	1.64	1.59
17x17	1.84	1.62	1.59
21x21	1.85	1.61	1.59

Table 3 - Perturbation of GFS

Perturbation Number	MYNN 3.0 MAE (m/s)	YSU MAE (m/s)	Ensemble MAE (m/s)
2	2.34	2.06	2.05
4	2.18	2.04	1.98
15	2.27	2.18	2.08

Table 4 - 4km vs. 10km

Grid Spacing	MYNN 3.0 MAE (m/s)	YSU MAE (m/s)	Ensemble MAE (m/s)
10 Km	1.82	1.74	1.63
4 Km	2.16	1.79	1.73

Tables 1-4: MAE associated with each different attempt to improve wind speed forecasts during 10 cases in January 2010

Training of the Model

- A 6 member ensemble was developed based on improvement results
- Model trained by calculating MAE for each member during day 1 (hours 6 - 29)
- 3 schemes with the lowest MAE used to predict the wind speed for day 2 (hours 30 - 54)

Table 5 - Results of Training the Model

Model Number	Day 1 MAE	Times Picked
00Z MYJ GFS with a 10km grid spacing	2.51	5
00Z MYJ NAM with a 10km grid spacing	2.61	6
00Z Pleim NAM with a 10km grid spacing	2.58	4
00Z Pleim GFS with a 10km grid spacing	2.36	9
00Z YSU NAM with a 10km grid spacing	2.32	11
00Z YSU GFS with a 10km grid spacing	2.37	10
Ensemble Mean	1.97	
Day 2 Picked ensemble best MAE	**Day 2 Non-Picked ensemble best MAE**	**Day 2 All Member Ensemble best MAE**
5/15	4/15	6/15

Table 6: MAE calculated for the first 24 hour period. The three PBL schemes with the greatest skill were chosen, making up the day 2 Picked ensemble. Times picked indicates the number of times a model is chosen as a member of the day 2 ensemble. Non-picked ensemble incorporates least accurate model for the first 24 hour period.

Bias Correction

Figure 3 - Diurnal Biases

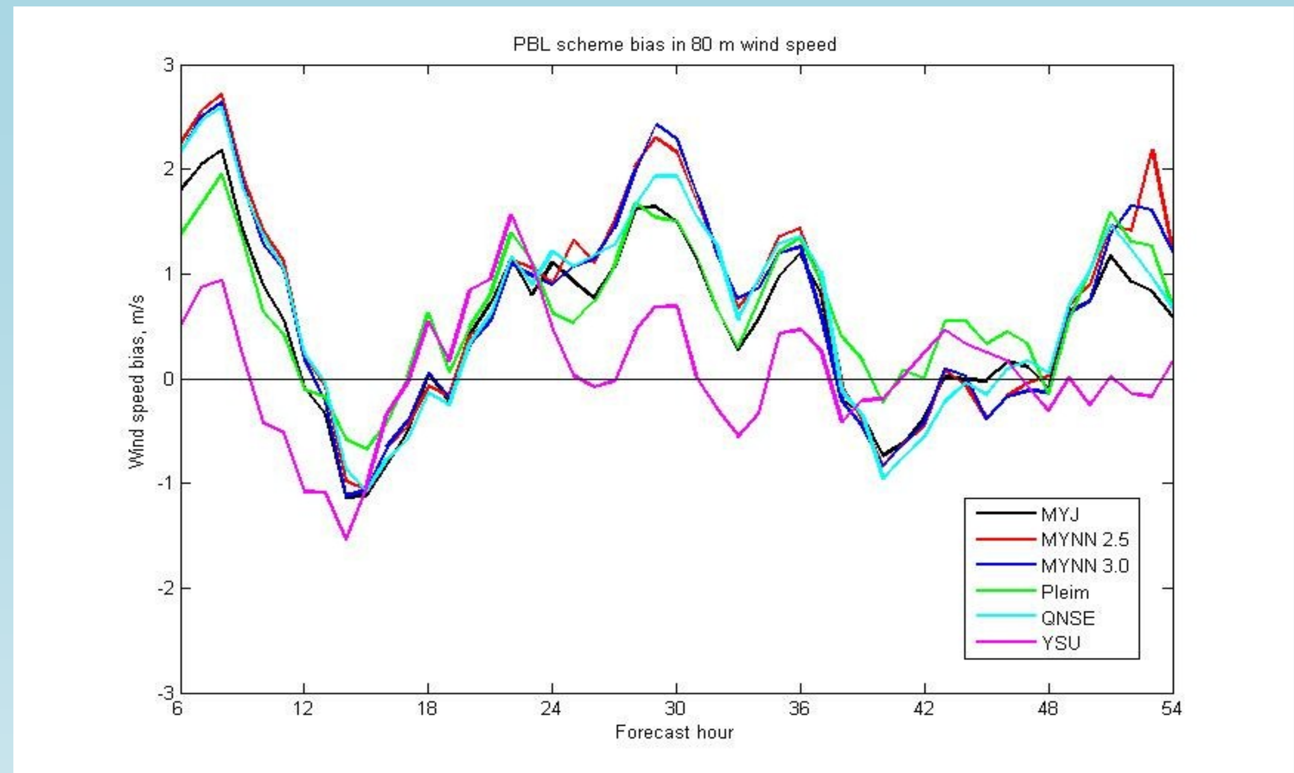

Figure 3: Composites of PBL biases by hour. Each line represents a different PBL scheme. Notice a diurnal bias feature present in the PBL schemes.

Table 6 - Bias Corrections

Bias Corrections	MYJ (m/s)	MYNN 2.5 (m/s)	MYNN 3.0 (m/s)	Pleim (m/s)	QNSE (m/s)	YSU (m/s)	Ensemble (m/s)
No Bias	2.34	2.49	2.41	2.36	2.45	2.28	2.27
Diurnal Cycle	2.29	2.33	2.28	2.27	2.30	2.21	2.18
Wind Direction	2.27	2.27	2.26	2.29	2.28	2.24	2.17
Wind Speed and Direction	2.15	2.16	2.14	2.17	2.17	2.10	2.05
Wind Speed	2.05	2.04	2.01	2.09	2.07	1.99	1.97
Best Improvement	.29 m/s – Wind Speed	.45 m/s – Wind Speed	.40 m/s – Wind Speed	.27 m/s – Wind Speed	.38 m/s – Wind Speed	.29 m/s - Wind Speed	.30 m/s – Wind Speed
% of Improvement	14.1%	22.1%	20.0%	13.0%	18.4%	14.6%	15.2%

Table 7 - MAE associated with different bias corrections developed for each PBL scheme for both 00Z and 18Z initialization times. This example is from the 00Z GFS run. The best improvement was seen with the wind speed bias correction (red box). This case study was done from Oct. 11, 2009 to Nov. 11, 2009.

Table 7 - PBL and Time Initialization Comparison with Bias Correction

	MYJ (m/s)	MYNN 2.5 (m/s)	MYNN 3.0 (m/s)	Pleim (m/s)	QNSE (m/s)	YSU (m/s)	Ensemble (m/s)
GFS 00Z	1.59	1.66	1.66	1.52	1.65	1.57	1.48
GFS 18Z	1.68	1.81	1.72	1.61	1.77	1.63	1.58
NAM 00Z	1.67	1.71	1.69	1.63	1.71	1.57	1.56
NAM 18Z	1.66	1.75	1.74	1.60	1.70	1.63	1.57

Table 8: MAE associated with different PBL schemes using the wind speed bias correction. The best PBL skill was seen with the YSU and Pleim schemes. Ensemble shows better skill than any one PBL scheme alone. The case study was done over three different periods: Aug. 14-28, 2009, Aug. 1-11, 2010, and Sept. 1-11, 2010.

Operational Model

A 6 member ensemble was developed based on the improvement results and bias correction results.

1. 18Z Pleim GFS with a 10km grid spacing
2. 18Z Pleim NAM with a 10km grid spacing
3. 00Z Pleim GFS with a 10km grid spacing
4. 00Z YSU NAM with a 10km grid spacing
5. 00Z YSU GFS with a 10km grid spacing
6. 00Z MYJ GFS with a 10km grid spacing

Table 8 - Operational Model

	18Z Pleim GFS (m/s)	00Z Pleim GFS (m/s)	00Z YSU GFS (m/s)	00Z YSU NAM (m/s)	18Z Pleim NAM (m/s)	00Z MYJ GFS (m/s)	Ensemble (m/s)
No Bias	2.18	2.02	1.77	1.78	2.03	2.12	1.67
Wind Speed	1.72	1.64	1.71	1.68	1.71	1.79	1.52
Best Improvement	.46 m/s	.38 m/s	.06 m/s	.10 m/s	.32m/s	.33 m/s	.15 m/s
% of Improvement over 48 hours	26.7%	23.2%	3.5%	6.0%	18.7%	18.4%	9.9%

Table 9: MAE associated with operational model. Ensemble with wind speed bias correction shows better skill than any one individual scheme (red box) This case study used 25 random cases from summer and fall 2010.

Table 9 - Ensemble Comparison

Ensemble	MAE after Bias Correction (m/s)	MAE Prior to Bias Correction (m/s)	Standard Deviation after Correction (m/s)
GFS 00Z	1.67	1.99	0.74
GFS 18Z	1.66	2.05	0.80
NAM 00Z	1.68	1.91	0.67
NAM 18Z	1.70	1.93	0.73
Deterministic Forecast	1.70	1.77	- - -
Operational Model	1.52	1.67	0.98

Table 10: MAE of operation model ensemble after wind speed bias correction compared to other six member ensembles tested. The deterministic forecast is the best individual model found from the period studied. Standard deviation (measure of model spread) for each ensemble is also calculated. Best model skill is seen in operational model with wind speed bias correction (red box). This case study used 25 random cases from summer and fall 2010.

Conclusions

- Operational model ensemble developed outperformed other ensembles tested
- Highest wind speed skill was seen in Pleim and YSU PBL schemes
- Wind speed bias correction showed highest model skill of all corrections
- 06Z time initialization (closest to forecast period) showed lowest skill
- GFS initial/boundary conditions showed higher model skill than NAM
- Perturbations of the GFS model give more spread in data than achieved with the six PBL schemes, however, a higher MAE is also created
- Neighborhood approach increases the accuracy of the models (lower MAE), but not significantly
- 10km model runs tend to be more accurate than 4km runs in this study
- Training method to predict wind speed is not a reliable method as conditions change from day to day

Acknowledgements

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