Wind Ramp Events at an Iowa Wind Farm: a Climatology and Evaluation of WRF Ensemble Forecast Skill

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Introduction

- Rapid changes in wind speed that lead to extreme changes in wind power output, known as ***wind ramp events***, cause considerable problems for the wind energy industry
- Because ramp events occur on short time scales, forecasting is difficult
- Rapid wind changes from the cut-in speed to the rated wind speed on the wind turbine power curve cause the biggest problems

Data and Methodology

- Weather Research and Forecasting (WRF) model with 10-km horizontal resolution was integrated for 54 hours starting at 00 UTC to simulate ramp events (validated from 06-54 hours)
- Global Forecast System (GFS) analyses used 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
- Sixty cases spanning 120 days were validated using hourly wind speed measurements at 80m from a meteorological tower at the Pomeroy wind farm in northwestern Iowa
- Event defined as a ramp if change in wind power was 50% or more of total capacity in four hours or less, approximated (based on wind turbine power curve) using any wind speed change of more than 3 m/s within the 6-12 m/s window (where power production varies greatly)

Figure 1

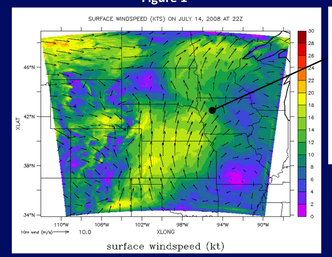

Figure 2

Figure 1: Domain used with inset (Fig. 2) showing outline of Pomeroy wind farm where red dots are wind turbines and the blue dot is the meteorological tower.

Acknowledgements

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Number of Ramp Events

Table 1 - Number of Ramp Events (Day 1)

PBL Scheme	MYJ	MYNN 2.5	MYNN 3.0	Pleim	QNSE	YSU	Obs
Ramp Up	23	29	27	19	26	16	35
Ramp Down	23	28	21	14	28	13	31
Total Ramp Events	46	57	48	33	54	29	66

Table 1: Number of ramp events during day 1 (06-30 hours after model start up). All six PBL schemes showed a lower number of ramp events than observations. The MYNN 2.5 PBL scheme showed the most ramp events of any PBL scheme while the YSU scheme showed the fewest.

Table 2 - Number of Ramp Events (Day 2)

PBL Scheme	MYJ	MYNN 2.5	MYNN 3.0	Pleim	QNSE	YSU	Obs
Ramp Up	17	25	24	17	26	11	37
Ramp Down	19	22	16	20	23	11	35
Total Ramp Events	36	47	40	37	49	22	72

Table 2: Number of ramp events during day 2 (30-54 hours after model start up). All six PBL schemes showed a lower number of ramp events than observations. Also note that fewer ramp events are forecasted during the day 2 period compared to day 1, even though more observed ramp events are seen. ***Of note, observed events were found to occur from a wide range of conditions including thunderstorms, frontal passages, PBL growth/decay, LLJ, and, in many cases, no obvious mechanism was seen but unstable lapse rates may have assisted.***

Amplitude of Ramp Events

Table 3 - Avg. Amplitude of Ramp Events

PBL Scheme	MYJ (m/s)	MYNN 2.5 (m/s)	MYNN 3.0 (m/s)	Pleim (m/s)	QNSE (m/s)	YSU (m/s)	Obs (m/s)
Ramp Up (Day 1)	4.50	4.62	4.75	4.85	4.60	4.67	4.53
Ramp Up (Day 2)	4.54	5.16	5.2	4.56	4.69	4.73	4.01
Ramp Down (Day 1)	3.74	4.62	4.20	4.60	4.31	4.17	4.34
Ramp Down (Day 2)	3.83	4.28	4.46	4.27	4.59	4.43	4.21

Table 3: Average amplitude of ramp events divided into ramp up/down events on day 1 and day 2. Simulated ramp up events have higher amplitudes than ramp down events for all six PBL schemes. Observations show little difference between the amplitudes of ramp up and down events.

Duration of Ramp Events

Table 4 - Avg. Duration of Ramp Events

PBL Scheme	MYJ (hr)	MYNN 2.5 (hr)	MYNN 3.0 (hr)	Pleim (hr)	QNSE (hr)	YSU (hr)	Obs (hr)
Ramp Up (Day 1)	3.30	3.14	3.48	3.05	3.46	3.31	2.34
Ramp Up (Day 2)	3.76	3.76	3.83	3.59	3.69	3.91	2.08
Ramp Down (Day 1)	3.13	3.71	3.76	3.36	3.39	3.62	2.32
Ramp Down (Day 2)	3.74	3.73	3.88	3.70	3.61	3.27	2.31

Table 4: Average duration of ramp up/down events on day1 and day 2. Ramp durations are longer on day 2 for both ramp up and ramp down events compared to day 1. All six PBL schemes over-predict duration during both ramp up and ramp down events. Observations show little difference between the duration of ramp up and down events during any time period.

Ramp Event Diurnal Cycle

Figure 3 - Diurnal Cycle of Ramp Up Events

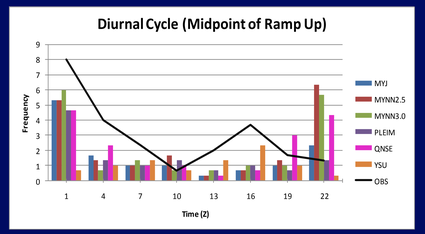

Figure 3: Three hour averaged diurnal cycle of ramp up events using the midpoint of the ramp event. Observed ramp up events occur most frequently around 01Z. Model ramp up events occur most frequently between 22Z and 1Z.

Figure 4 - Diurnal Cycle of Ramp Down Events

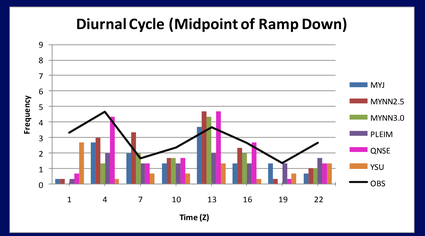

Figure 4: Three hour averaged diurnal cycle of ramp down events using the midpoint of the ramp event. Any trends in frequency are small for both observed and model events.

Model Error

Table 5 - Model Error

PBL Scheme	Ramp Type	Obs. Total Events	Model Total Events	Hits	False Alarm	Miss	MAE (hr)	Bias (hr)	POD	FAR	Threat Score
MYJ	Up (Day 1)	35	23	17	6	18	3.47	-1.24	0.49	0.26	0.41
	Up (Day 2)	37	17	13	4	24	1.85	-1.23	0.35	0.32	0.32
	Down (Day 1)	31	20	8	12	23	1.88	0.63	0.26	0.60	0.19
	Down (Day 2)	35	19	12	7	23	1.42	-0.42	0.34	0.37	0.29
MYNN 2.5	Up (Day 1)	35	29	19	10	16	2.68	-1.74	0.54	0.34	0.42
	Up (Day 2)	37	25	15	10	22	2.33	-1.20	0.41	0.40	0.32
	Down (Day 1)	31	28	11	17	20	1.64	-0.73	0.35	0.61	0.23
	Down (Day 2)	35	22	11	11	24	1.55	-0.27	0.31	0.50	0.24
MYNN 3.0	Up (Day 1)	35	27	17	10	18	2.88	-1.71	0.49	0.37	0.38
	Up (Day 2)	37	24	16	8	21	2.75	-1.13	0.43	0.33	0.36
	Down (Day 1)	31	21	9	12	22	1.89	-0.56	0.29	0.57	0.21
	Down (Day 2)	35	16	8	8	27	1.50	0.25	0.23	0.50	0.19
Pleim	Up (Day 1)	35	19	10	9	25	3.10	-1.30	0.29	0.47	0.23
	Up (Day 2)	37	17	12	5	25	2.33	-1.83	0.32	0.29	0.29
	Down (Day 1)	31	14	9	5	22	2.22	0.44	0.29	0.36	0.25
	Down (Day 2)	35	20	12	8	23	2.00	0.50	0.34	0.40	0.28
QNSE	Up (Day 1)	35	26	18	8	17	3.56	-2.56	0.51	0.31	0.42
	Up (Day 2)	37	26	15	11	22	1.73	-1.20	0.41	0.42	0.31
	Down (Day 1)	31	28	11	17	20	1.27	-1.00	0.35	0.61	0.23
	Down (Day 2)	35	23	12	11	23	1.33	-0.22	0.34	0.48	0.26
YSU	Up (Day 1)	35	16	8	8	27	3.25	-0.25	0.23	0.50	0.19
	Up (Day 2)	37	11	8	3	29	2.50	0.25	0.22	0.27	0.20
	Down (Day 1)	31	13	9	4	22	1.33	-0.22	0.29	0.31	0.26
	Down (Day 2)	35	11	9	2	26	1.33	-0.89	0.26	0.18	0.24

Table 5: Model error associated with ramp events for each PBL scheme. Probability of Detection (POD), False Alarm Rate (FAR) and Threat Score were calculated. The Bias and Mean Absolute Error (MAE) show the timing error associated with each PBL scheme . A hit means the model correctly predicted the ramp event within +/- 6 hours. With the exception of the YSU and Pleim schemes, the POD is higher for ramp up events as opposed to ramp down events and FAR is higher for ramp down events.

Conclusions

- All six PBL schemes underestimate number of ramp up and ramp down events compared to observations
- Observed events come from large variety of causes, and in many cases, no obvious cause is present although unstable lapse rates may play a role
- Model ramp up events have higher amplitudes than ramp down events for all six PBL schemes. Observations show little difference between these amplitudes
- Longer model ramp duration during day 2 in both ramp up and ramp down events (except YSU) when compared to day 1 — result not pronounced in observations
- Peak frequency of observed ramp up events occurs around 01Z while model ramp up events occur most frequently between 22Z and 1Z
- No large trends in frequency occur in both observed and model ramp down events.
- Except for YSU and Pleim, the POD is higher for ramp up events than ramp down events.
- Except for YSU and Pleim, FAR is higher for ramp down events than ramp up events