Verification of the NCAR-Xcel Ensemble-RTFDDA system for Wind Energy Prediction

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Motivations

- Since April 2010, E-RTFDDA implemented for Xcel energy, to support wind power forecasting
- Extends the predictability of the mesoscale weather processes, improves the wind and power trend prediction from the single deterministic model forecasting and provides probabilistic information for the timing and magnitude of wind

Outline

1) E-RTFDDA Modeling System
2) Verification of SPD at three wind farms
3) Evaluation of WRF physics settings
4) Statistical bias correction/Calibration
RTFDDA - 4D Continuous DA and Forecasting

Regional-scale model, based on WRF

4 cycles a day
- 6-hour FDDA analysis
- 48 hour forecast

All WMO/GTS
GOES
Radar
WRF
Weather observations
Cold start
FDDA
Forecast
RTFDDA ➝ E-RTFDDA

Ensemble-RTFDDA System

- Boundary UC
- Physics UC
- Obs UC
- Analysis UC
- External forcing UC

Ensemble Generator + Filter

RTFDDA Members

Probabilistic Forecasting products

*UC: uncertainties

Perturbations
Observations

RTFDDA

48h fcst
Post processing
Xcel E-RTFDDA Model Domains

D1: 30 km
D2: 10 km

30 members, 6h cycle, 48h forecast

37 vertical levels with 12 levels in the lowest 1-km
30 members, 6h cycles, 48h forecasts

<table>
<thead>
<tr>
<th>E#</th>
<th>LBC</th>
<th>WRF Members (15)</th>
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<tbody>
<tr>
<td>1</td>
<td>NAM</td>
<td>Control: WRF baseline physics</td>
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<tr>
<td>2</td>
<td>GFS</td>
<td>Control: WRF baseline physics</td>
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<tr>
<td>3</td>
<td>NAM</td>
<td>SLAB land surface</td>
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<tr>
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<td>NAM</td>
<td>MYJ PBL</td>
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<tr>
<td>5</td>
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<td>MYJ PBL + GD Cumulus</td>
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<td>9</td>
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<tr>
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<td>13</td>
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<td>GFS</td>
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<tr>
<td>15</td>
<td>GFS</td>
<td>KF cumulus in 3.3 km grid</td>
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<td>20</td>
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<td>Goddard microphysics</td>
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<td>GFS</td>
<td>Betts-Miller cumulus</td>
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<td>GFS</td>
<td>Reisner 3-ice microphysics</td>
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<td>CCM2 radiation</td>
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<td>GFS LBC Phase-uncertainty 1</td>
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<td>Symmetric perturb to Member 25</td>
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<td>30</td>
<td>GFS</td>
<td>Symmetric perturb. to Member 29</td>
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Xcel Wind Farms

- 3 wind farms: COL1, TX1 and MN1
- Hub-height wind speed
- Over the year 2011
Statistics of the ensemble mean

• Over the year 2011
• 0-24h forecast
• Ensemble mean

Under-estimation of wind-speed
Overall good correlation
Better statistics than deterministic run
TX1, MN1: underestimate higher winds
Ensemble Verification

**COL1**

**TX1**

QQ plot for wind speed (WLDR)

- **Smooth Abs. Error/Sdev (m/s)**
  - Forecast Time (0Z cycle)
  - 00 06 12 18 24 30 36 42 48
  - 0.0 2.0 4.0 6.0

- **Hub Height Wind Speed (m/s)**
  - Forecast Time (0Z cycle)
  - 00 06 12 18 24 30 36 42 48
  - 0 3 6 9 12 15 18

- **Forecast wind speed**
  - 0 3 6 9 12 15 18

- **Observed wind speed**
  - 0 3 6 9 12 15 18
Ensemble Verification

ROC for 24h fcst

Reliability plot for 24h fcst
Verification of Ensemble Members

All forecast

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<th>Standard Deviations (Normalized)</th>
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<td>0.2</td>
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<td>0.3</td>
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<td>1.0</td>
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1 - SPD

Systematic RMSE

Unsystematic RMSE

18h to 24h fcst

Hub Height Wind Speed (m/s)

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Low differences for COL1. Low NAM/GFS differences. GFS better for MN1 and TX1. Lowest underestimation for WRF for MN1 and TX1.
For COL1, YSU/BOU lowest errors/MYNN highest. For TX1, MYJ lowest errors/BOU highest. YSU (daytime) and MYJ (nighttime) lowest errors on average. Low differences for the Microphysics/Cumulus schemes (not shown).
This correction is applied independently at each observation location, for a given forecast time and for each member.

**Apply Quantile Regression on the ANKF corrected ensemble**

Fitting SPD quantiles using QR conditioned on:

- Ranked forecast ensemble
- Ensemble mean
- Ensemble median
- Ensemble standard deviation
- Persistence

(work by: Luca Delle Monache)

(work by: Tom Hopson)
Verification after Correction/Calibration

**CORR**

**RMSE**

Wind Speed Frequency

Systematic RMSE
Summary

- E-RTFDDA system has been developed for Xcel Energy for Wind Power forecasting since April, 2010. This study investigates the wind forecast characteristics at Wind Farms and post-processing approaches. It is found that:

1. Underpredict hub-height (60 – 80m AGL) wind speeds at all the farms and underestimate strong wind events (low-level jet at TX1);

2. Ensemble underdispersive, lack resolution, but good skill;

3. Differences between NAM and GFS LBC are small. WRF members show lower errors than MM5.

4. On average, YSU and MYJ perform the best.

5. Applying a statistical bias correction (ANKF) and a quantile regression improves the forecasts: lower bias, better spread and skill;

6. Future work: improve statistical bias correction and verification of the ramp events…
Thank you...

QUESTIONS?
Step 1: Determine climatological quantiles

Step 2: For each quan, use "forward step-wise cross-validation" to iteratively select best subset
Selection requirements:
1. QR cost function minimum,
2. Satisfy binomial distribution at 95% confidence
If requirements not met, retain climatological "prior"

Regressors set:
1. reforecast ens
2. ens mean
3. ens stddev
4. persistence
5. LR quantile
(not shown)

Step 3: Segregate forecasts into differing ranges of ensemble dispersion and refit models (Step 2) uniquely for each range

Final result: "sharper" posterior PDF represented by interpolated quans
Forecast of ramp events: TX1

3h Duration ramp (3h forecast)

<table>
<thead>
<tr>
<th>Observation</th>
<th>Up</th>
<th>Neutral</th>
<th>Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up</td>
<td>16%</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>Neutral</td>
<td>12%</td>
<td>14%</td>
<td>11%</td>
</tr>
<tr>
<td>Down</td>
<td>6%</td>
<td>11%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Percent Correct: 45%

(work by: Matt Pocernich)
ROC Score against forecast lead time for different event probability thresholds.
CEDC.SPD.00.MOD (reference forecast: Sample climatology)

Brier Score by forecast lead time.
WLDR.SPD.12.MOD

- > 4.0
- > 10.0