The Wind Power Application Research Based on The Fusion of Deterministic and Ensemble Prediction

Shi Lan  Xu Lina  Hao Yuzhu
lan_shi@sina.com
Inner Mongolia Meteorological Service Center, China
15 September 2016
Targets

How to make use of the existing resources to improve the accuracy of wind speed forecast of wind farm, to supporting wind power prediction for local large-scale wind power integration?

Present conditions:

• The running mesoscale numerical forecast model is not enough to support local large-scale wind power prediction in the accuracy and stability aspects.

• The development of ensemble prediction with high resolution is limited by computing resources, operating conditions and so on.

• The existing ensemble forecast has low spatial and temporal resolution (3h), and each member has a large difference in forecast wind speed.

Research targets:

• Based on the characteristics of ensemble forecast (the uncertainty of the weather forecast is estimated quantitatively, the single forecast is transformed into probability forecast) and application requirement, a fusion product of wind farms’ wind speed forecast is designed and studied.
  - 0-72h wind speed forecast for wind power prediction is provided.
  - 0-72h wind speed distribution for wind power prediction is provided.
Contents

1. Background of the study area
2. Data
3. Solution design
4. Modeling and verification
5. Conclusions and discussions
1. Background of the study area

The study area is located in the hilly region of the north of China. The terrain is higher in the north and lower in the south. The average elevation is about 1560m. The elevation difference is about 200m. The wind tower is located near the center of wind farm.
2. Data

2.1 Observed data

2.2 Forecast data

The forecast point is interpolated and statistically fitted to the position of the wind tower, and then to model and analyze.
2. 1 Observed data

• Source
  - Wind speeds on 70m high from the wind tower in the wind farm

• The data interval
  - 1 hour

• The data length
  - The method study period: Method comparison and selection in the process of fusion, such as interpolation method, correction method, and so on.
    00:00 1 June 2016 – 23:00 18 June 2016
  - The period of model training and verification:
    00:00 27 June 2016 – 23:00 18 July 2016
### 2.2 Forecast data

<table>
<thead>
<tr>
<th>Model</th>
<th>ECMWF Global Ensemble Forecast</th>
<th>BJ-RUC</th>
<th>MM5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Time 08h, 20h</td>
<td>08h, 20h</td>
<td>08h, 20h</td>
</tr>
<tr>
<td>Time Resolution</td>
<td>Time Resolution 3h (0-72 hours) 6h (78-240 hours) 12h (252-360 hours)</td>
<td>1h (0-100 hours) 1h (0-100 hours)</td>
<td></td>
</tr>
</tbody>
</table>
| Spatial Extension | Spatial Extension Surface: 40°E-180°E, 10°S-70°N  
Upper-lever: 0°E-180°E, 20°S-90°N       | 96.45-127.53°E 37.20-54.58°N  
Upper-lever: 92.22-122.06°E 35.19-54.24°N |           |
| Spatial Resolution | Spatial Resolution Surface: 0.5°*0.5°  
Upper-lever: 1°*1° | 9km         | 9km       |

- The height layer of model forecast product:
  - ECMWF: 100m (Spatial downscaling by statistical fitting)
  - BJ-RUC: 70m
  - MM5: 70m

- **ECMWF**: European Centre for Medium-Range Weather Forecasts
- **BJ-RUC**: Beijing-Rapid Update Cycle mesoscale numerical model running locally
- **MM5**: Mesoscale Model5 mesoscale numerical model running locally
3. Solution design

3.1 Interpolation method selection
   Bilinear interpolation

3.2 Statistical correction of forecast data
   Nonlinear least square method (NLS)

3.3 Calibration of probability matching technique
   Bayesian Model Averaging (BMA)

3.4 Time downscaling
   Autoregressive Integrated Moving Average (ARIMA)

3.5 The fusion of three numerical forecast products
   Bayesian Model Averaging (BMA)
4. Modeling and verification

By using the comparative experiment of the study period, the optimal scheme is selected to set up the model and verify.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMWF ensemble forecast</td>
<td>ECMWF</td>
</tr>
<tr>
<td>BJ-RUC numerical forecast</td>
<td>BJ-RUC</td>
</tr>
<tr>
<td>MM5 numerical forecast</td>
<td>MM5</td>
</tr>
<tr>
<td>Statistical correction of wind speed</td>
<td>NLS</td>
</tr>
<tr>
<td>Product of probabilistic calibration</td>
<td>BMA</td>
</tr>
<tr>
<td>Single value forecast of time downscaling</td>
<td>ARIMA</td>
</tr>
<tr>
<td>The fusion product of wind speed forecast</td>
<td>FUSION</td>
</tr>
</tbody>
</table>
4. Modeling and verification

- **Sliding training**
  - Training period : First 13 days
  - Verification period : 72h forecast

<table>
<thead>
<tr>
<th>Training period</th>
<th>Verification period</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 Jun - 9 Jul</td>
<td>10 Jul - 12 Jul</td>
</tr>
<tr>
<td>28 Jun - 10 Jul</td>
<td>11 Jul - 13 Jul</td>
</tr>
<tr>
<td>29 Jun - 11 Jul</td>
<td>12 Jul - 14 Jul</td>
</tr>
<tr>
<td>30 Jun - 12 Jul</td>
<td>13 Jul - 15 Jul</td>
</tr>
<tr>
<td>1 Jul - 13 Jul</td>
<td>14 Jul - 16 Jul</td>
</tr>
<tr>
<td>2 Jun - 14 Jul</td>
<td>15 Jul - 17 Jul</td>
</tr>
<tr>
<td>3 Jun - 15 Jul</td>
<td>17 Jul - 18 Jul</td>
</tr>
</tbody>
</table>
4. Modeling and verification

- Bilinear interpolation from ECMWF to the wind farm
4. Modeling and verification

- Nonlinear least square method correction of ECMWF forecast members
4. Modeling and verification

- Calibration of probability matching technique for the NLS correction

**BMA contrast in training period**

- OBS
- ECMWF
- NLS
- BMA

**BMA contrast in verification period**

- OBS
- ECMWF
- NLS
- BMA

Single value forecast
4. Modeling and verification

- Calibration of probability matching technique for the NLS correction
4. Modeling and verification

- **ARIMA time downscaling of the result BMA**
4. Modeling and verification

- **Test indexes**
  - Correlation coefficient (R)
  - Mean absolute error (MAE)
  - Root mean square error (RMSE)

<table>
<thead>
<tr>
<th>Training</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>BMA</td>
</tr>
<tr>
<td>MAE</td>
<td>BMA</td>
</tr>
<tr>
<td>RMSE</td>
<td>BMA</td>
</tr>
</tbody>
</table>

The best result of single value forecast:
4. Modeling and verification

• Fusion of three numerical model forecast

- BJ-RUC&MM5: The Average of corrected wind speed of BJ-RUC and MM5

<table>
<thead>
<tr>
<th></th>
<th>FUSION</th>
<th>ECMWF</th>
<th>Improved percentage</th>
<th>BJ-RUC&amp;MM5</th>
<th>Improved percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0.513</td>
<td>0.468</td>
<td>8.7%</td>
<td>0.147</td>
<td>249.5%</td>
</tr>
<tr>
<td>MAE</td>
<td>1.193</td>
<td>1.371</td>
<td>13.0%</td>
<td>1.671</td>
<td>28.6%</td>
</tr>
<tr>
<td>RMSE</td>
<td>1.540</td>
<td>1.7</td>
<td>9.4%</td>
<td>2.244</td>
<td>31.4%</td>
</tr>
</tbody>
</table>

*Muti-model fusion forecast and OBS contrast*
4. Modeling and verification

- Comparison of MAE in different forecast ahead

MAE do not increase with downscaling and the extension of the forecast ahead
5. Conclusions and discussions

• Conclusions

- Through the statistical correction on the three numerical products, calibration of probability matching technique to ECMWF by using BMA method and time downscaling, the fused wind speed forecast product of wind farm based on the three numerical products is generated. This forecast idea is feasible and effective for the improvement of existing numerical forecast’s accuracy.

- Fusion forecast has obvious effect on improving the accuracy of the existing numerical forecast products. MAE is not increases with downscaling and the extension of the forecast ahead, which are all below 2m/s. In verification period, compared with the existing deterministic forecast, MAE is reduced by 28.6% and RMSE is reduced by 31.4%; Compared with the ECMWF ensemble forecast, MAE is reduced by 13% and the RMSE is reduced by 9.4%.
5. Conclusions and discussions

- **Discussions**
  - The fusion of the existing numerical forecast products, is an effective way to improve the forecast accuracy of province whose computing resources are limited. Less number of study area selected and the study period is short in this study, more wind farms will be selected, and multi model ensemble forecast products will be fused next step. This method will be refined in order to promote and apply in all wind farms serviced.
  - There are some defects on extracting the turning point of wind speed in this method, Bayesian estimation of quantile regression will be attempted to study next step.
Thank You!

16th EMS Annual Meeting, Trieste, Italy, 15 September 2016