Evaluation of WRF for Forecasting Wind Turbine Icing

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Introduction

The growth of ice on a wind turbine can pose many problems. Icing can create a potential safety risk due to ice shedding (fig. 1), lead to production losses which reduce profits (fig. 2), and can increase loads, thereby reducing the turbine lifetime. The ability to forecast turbine icing (fig. 3) could help to minimize these risks both by identifying sites prone to icing during the planning phase, and estimating production losses in the short term.

For this study we examine icing events at a site in Northern Sweden (fig. 4), using WRF and a variety of icing models, in a hind-cast setup for the month of January 2011. The WRF simulated temperature was evaluated against GDAS data over the entire 10 km domain. For evaluating the icing model we utilized production data from 43 of the 47 turbines in the wind park. We utilized the production to estimate observed icing by identifying times when the observed power deviated from the generic power curve by more than 20% and the temperature was below freezing temperature. We then created three observational data-sets depending on how many of the turbines showed the icing signal (all, majority, or any).

We found that WRF does a reasonable job capturing the occurrence of icing found at this site, using the Thompson MP Scheme. We also found that both icing occurrence and amount is highly sensitive to the PBL and microphysics schemes used.

Icing Forecast System

The WRF model was used to provide meteorological input to the icing models. The model was run over 2 domains at 30 km and 10 km resolution respectively (fig. 3). The outer domain was nudged using the NCEP FNL data-set, which was also used for the input and boundary conditions. Nine sensitivities testing three combinations each of the microphysics and PBL schemes in the model (Table 1).

Meteorological Setup

The WRF model was used to provide meteorological input to the icing models. The model was run over 2 domains at 30 km and 10 km resolution respectively (fig. 3). The outer domain was nudged using the NCEP FNL data-set, which was also used for the input and boundary conditions. Nine sensitivities testing three combinations each of the microphysics and PBL schemes in the model (Table 1).

Table 1. PBL and microphysical schemes used in the study

<table>
<thead>
<tr>
<th>Microphysics</th>
<th>SUNY-Lim (13)</th>
<th>Thompson (5)</th>
<th>WSM5 (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBL</td>
<td>MVG (2)</td>
<td>MKN2 (5)</td>
<td>YSU</td>
</tr>
</tbody>
</table>

Icing Model

Collision Efficiency: Percentage of mass flux which impacts the object. A function of wind speed, droplet size (MVD) and object size. Current model is based on flow around a cylinder (Term α, from Makkonen, 2000).

Ice Ablation: Melting/evaporation, sublimation or shedding of ice

Kjeller Model: Evaporation / sublimation based on cloud droplets, additional energy from short and long wave radiation budgets, multiplier used to approximate shedding.

DTU Model: Similar to Kjeller with more advanced heat transfer coefficient calculation for airfoil, inclusion of temperature impact on energy budget, no shedding.

Time: Sheding only model, removes all ice when temperature is 0.5 degrees above freezing

WRF Model Evaluation

The 80m Temperature simulated by the WRF model was evaluated against GDAS data using the MET model evaluation tool. Results shown in Fig. 7 and Table 2, show that both the PBL and microphysical scheme influence the model results.

Table 2. Evaluation of events where the temperature was below 0.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>MKN2</th>
<th>YSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVG</td>
<td>0.92</td>
<td>0.85</td>
</tr>
<tr>
<td>SUNY-Lim</td>
<td>0.87</td>
<td>0.8</td>
</tr>
</tbody>
</table>

The Thompson and YSU schemes showed the warmest temperatures, while WSM5 & MKN2 were consistently the coldest. All model runs did a reasonable job estimating freezing temperatures, but the MY2 scheme showed a very high false alarm rate.

Ice Model Evaluation

Figure 9 shows the model evaluated against our best guess for observed icing on the turbine.

The choice of both the microphysics scheme and PBL scheme are key to model results. SUNY-Lim performs the poorest job capturing the low level clouds needed to generate icing at wind turbine heights, while Thompson does the best. The MKN2-PBL scheme shows the earliest onset of icing, while the YSU scheme being the warmest melts ice too quickly at times.

When evaluating the icing models, the tshed ablation model performs the best capturing the lce of ice on the majority of the turbines at the end of the period.

References