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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 where 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. 2). 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 Model Setup

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 all/air, inclusion of temperature impact on energy budget, no shedding.

TShed: Shedding only model, removes all ice when temperature is 0.5 degrees above freezing

Fig. 4. Illustration of how droplet size impacts the trajectory of a particle in flow around an obstacle (Makkonen, 2000).

Ice Model Evaluation

Ice Accretion: Growth of ice, function of the heat balance between the heat released via the phase change and other components of the total heat balance.

Fig. 5 shows the balance required between the mass flux and temperature to maintain each type of icing.

Makkonen: ISO standard model for calculating ice accretion on structures (Makkonen, 2000).

Brakel: Asymptotic model, advanced features: Type of icing, amount of water during glaze icing, ability to represent heating from below (Brakel et al. 2000).

We examined this parameter at several locations, and found that the shape of the plots varied mostly due to the site location. However the SUNY-Lin scheme always produced the lowest values.

Table 1. PBL and microphysical schemes used in the study

<table>
<thead>
<tr>
<th>Microphysical</th>
<th>SUNY-Lin</th>
<th>Thompson</th>
<th>WMS</th>
<th>WMSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBL</td>
<td>MV2</td>
<td>MYNN2</td>
<td>YSU</td>
<td></td>
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</tbody>
</table>

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.

The Thompson and YSU schemes showed the warmest temperatures, while WMSM & MYNN2 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.

Fig. 7. Observed vs WRF simulated temperature at 80m for the nine sensitivity simulations.

Fig. 6. Comparison of WRF cloud amount at 80m with the total precipitation at the ground. Colors indicate dominant hydromete type.

Due to the linear increase in cloud amount with precipitation we do not feel the icing model needs precipitation included as a separate input.

Fig. 8. Comparison of WRF cloud amount at 80m with the total precipitation at the ground. Colors indicate dominant hydromete type.

The choice of both the microphysics scheme and PBL scheme are key to model results. SUNY-Lin and Shedd perform well at capturing the low level clouds needed to generate icing at wind turbine heights, while Thompson does the best. The MYNN2-PBL scheme shows the earliest onset of icing, while the YSU scheme being the warmest melts ice too quickly at times.

Fig. 9. The change in total cloud mining ratio with height, at a nearby wind farm in Sweden.

Fig. 9 Shows the model evaluated against our best guess for observed icing on the turbine.

Fig. 10. Timeseries of ice amount at the leading edge of a wind turbine blade using different icing models. All icing figures are used from data from the Thompson / MYNN2 simulations.

Fig. 5. Illustration of the impact of changes to temperature or mass flux on the type of icing experienced by a turbine blade.

Fig. 6. Illustration of the energy (red) and mass (blue) fluxes for ice undergoing ablation via melting or sublimation.