Evaluation of WRF for Forecasting Wind Turbine Icing

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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 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.

<table>
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<th>Table 1. PBL and microphysical schemes used in the study</th>
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**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.

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

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 influenced 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 MYJ scheme showed a very high false alarm rate.

Figure 8 shows a comparison of the 8 different icing models with time. It shows almost no difference between the two accretion models, however there is a large difference between the three ablation models.

During cold temperatures, the Kjeller method removes the most ice. When the temperature is above freezing, there is a dramatic loss of ice in the shedding model. During the first half of the month the models show ice during most of the time, however the second half of the month shows very little ice in the shed based models, while the other two models still show large amounts of ice.

The two MVD sizes show an almost 4 times difference in the amount of ice which has accumulated when the droplet size is estimated to be 5 microns larger (upper plot) than in the lower plot.

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).

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

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).