Forecasting Production Losses at a Swedish Wind Farm

WinterWind 2013

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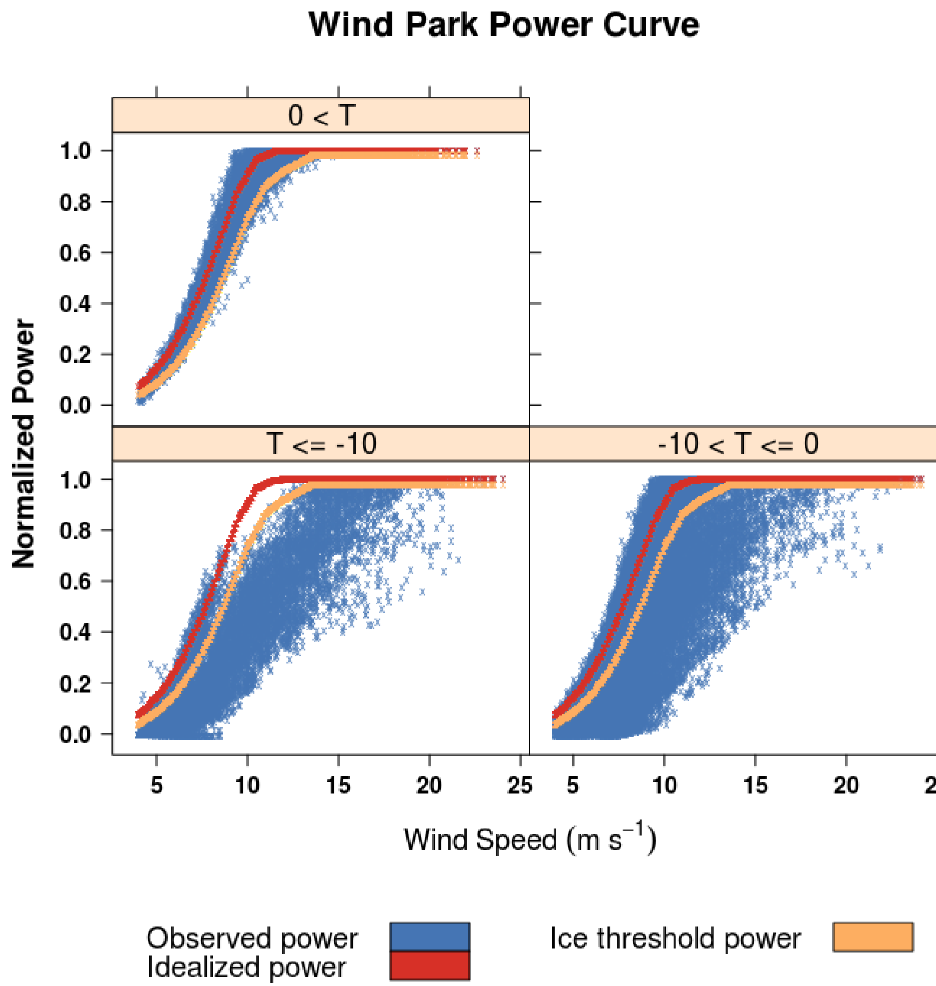
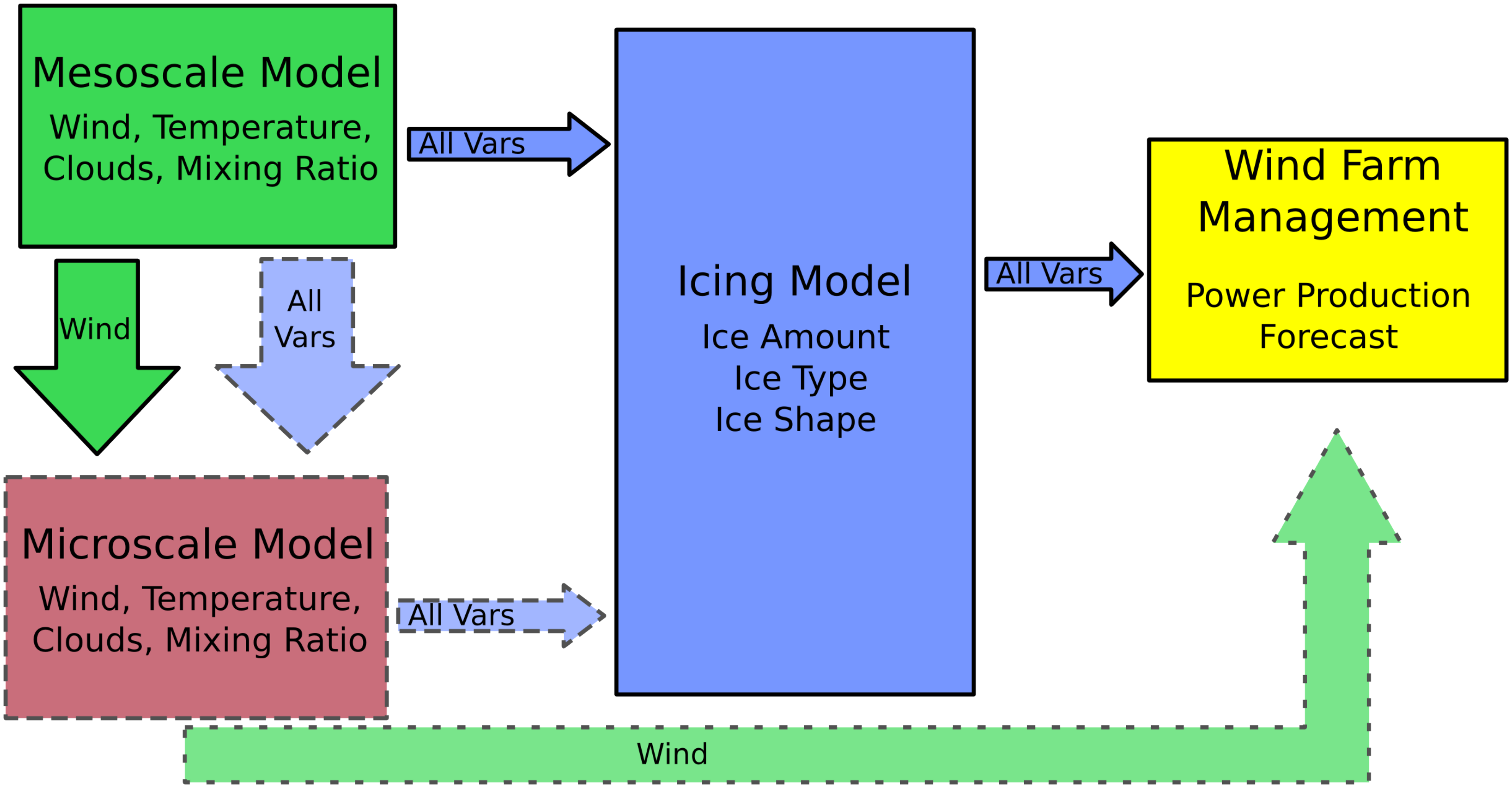
Motivation

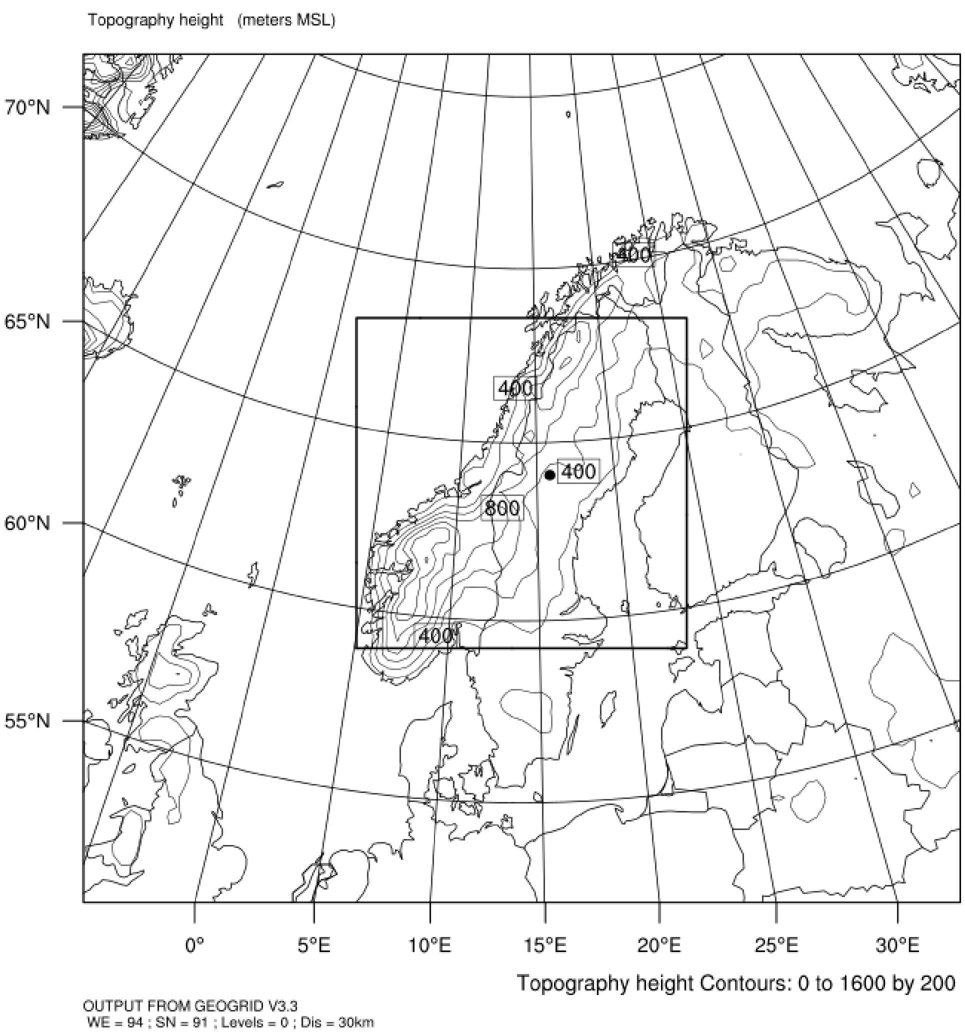
- Site location
- Wind park planning
- Energy market pricing



Production Forecast Model



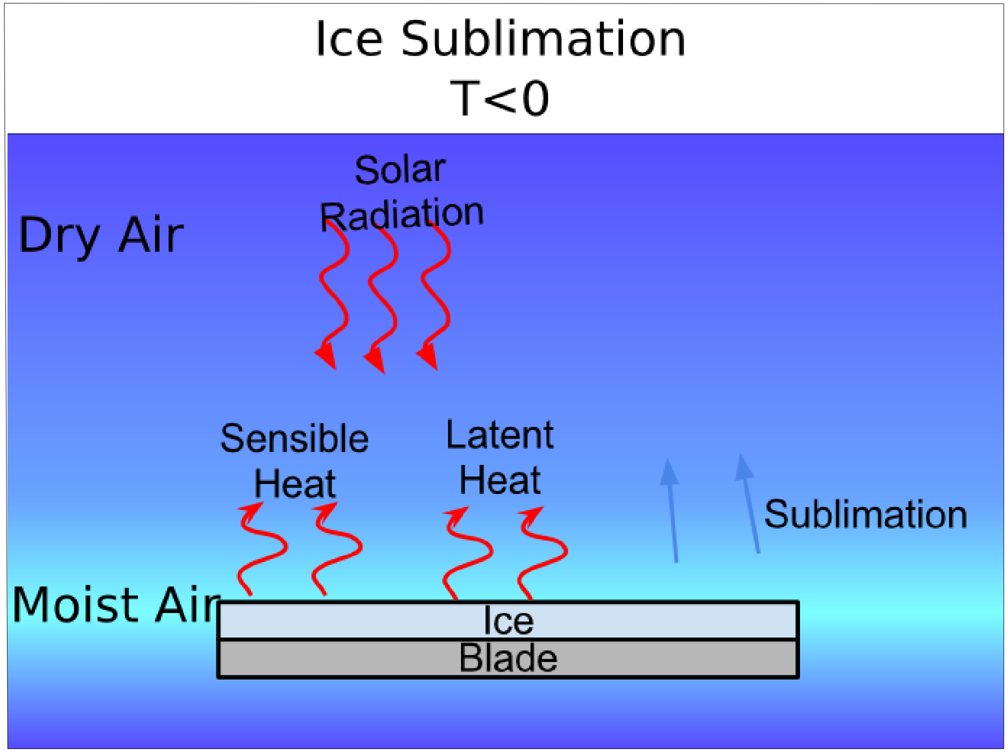
Inputs



- Observational data
  - Located in central Sweden
  - Approximately 50 Vestas V90 turbines
  - Grouped into 3 parks
  - Observations from January 2011
  - Temperature, wind speed , wind direction from hubs of each turbine, production & turbine normal operation time
- WRF mesoscale simulation
  - 27 km & 9 km nests
  - Thompson microphysics & MYNN2 PBL
    - Best performing of 9 sensitivities
  - FNL for initial & boundary conditions
  - Grid nudging on the outermost domain
  - 63 vertical levels

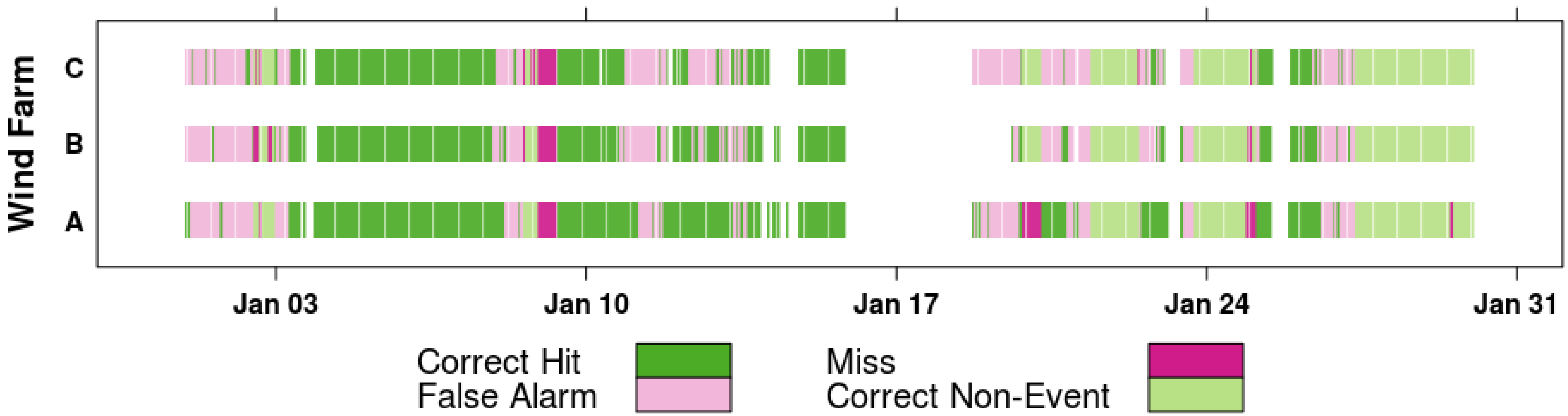
Icing model

- Modified Makkonen model
  - Cylinder moves at blade relative velocity
    - Diameter 0.144 m
    - Located at 75% of blade length
  - Heat transfer coefficient for airfoils
  - Blade always at 80m hub height
  - Utilize all 4 WRF hydro-meteor types (QCLOUD, QRAIN, QICE, QSNOW)



- Sublimation & shedding included
  - Sublimation based on humidity gradient & radiation balance
  - Shedding set to 100% when T > 1º Celsius

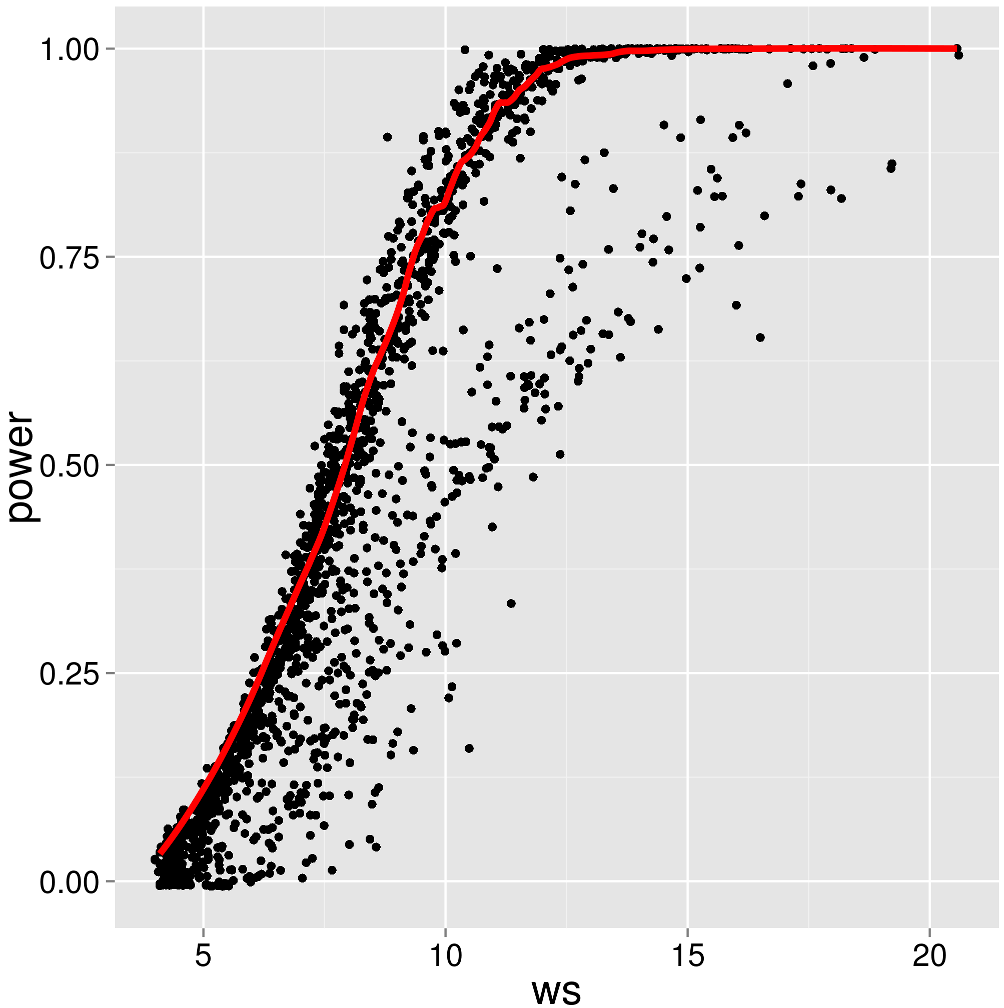
Ice duration evaluation



- Timeseries comparing model icing periods to periods when any turbine was iced in a given farm.
- Compared with persistence & threshold method for several skill scores and this method outperformed both
- For more details see paper submitted to Journal of Applied Meteorology & Climatology "*Forecast of Icing Events at a Wind Farm in Sweden*"

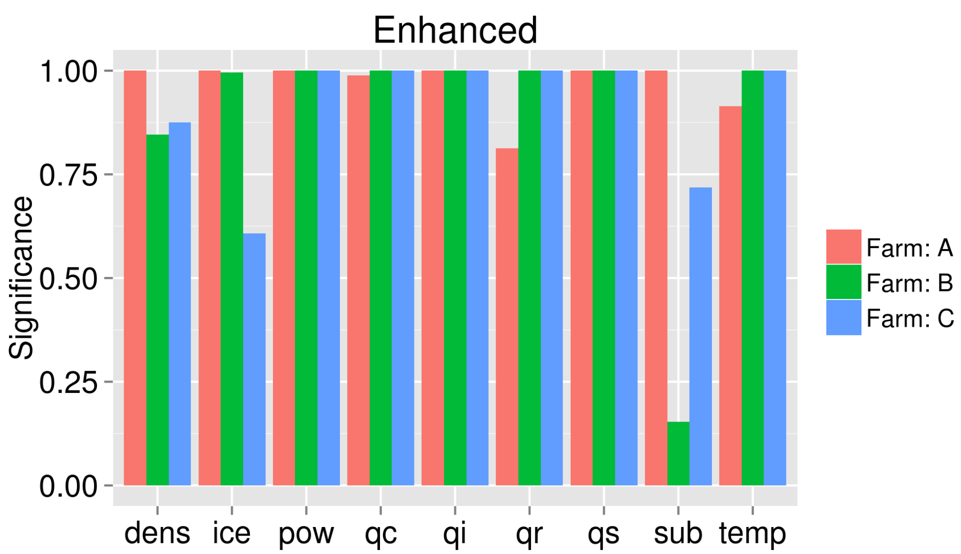
Production loss model

- Fit smoothing function to power curve
  - Wind farm average values
  - Only for temps above freezing
  - Red line in the plot
- Calculate power difference
  - Deviation from modeled power
- Investigate potential predictors for power difference
  - Ice Model outputs
  - WRF Hydrometeors
- Fit test models for all farms
  - Make use of entire dataset
  - Maximize adjusted R^2

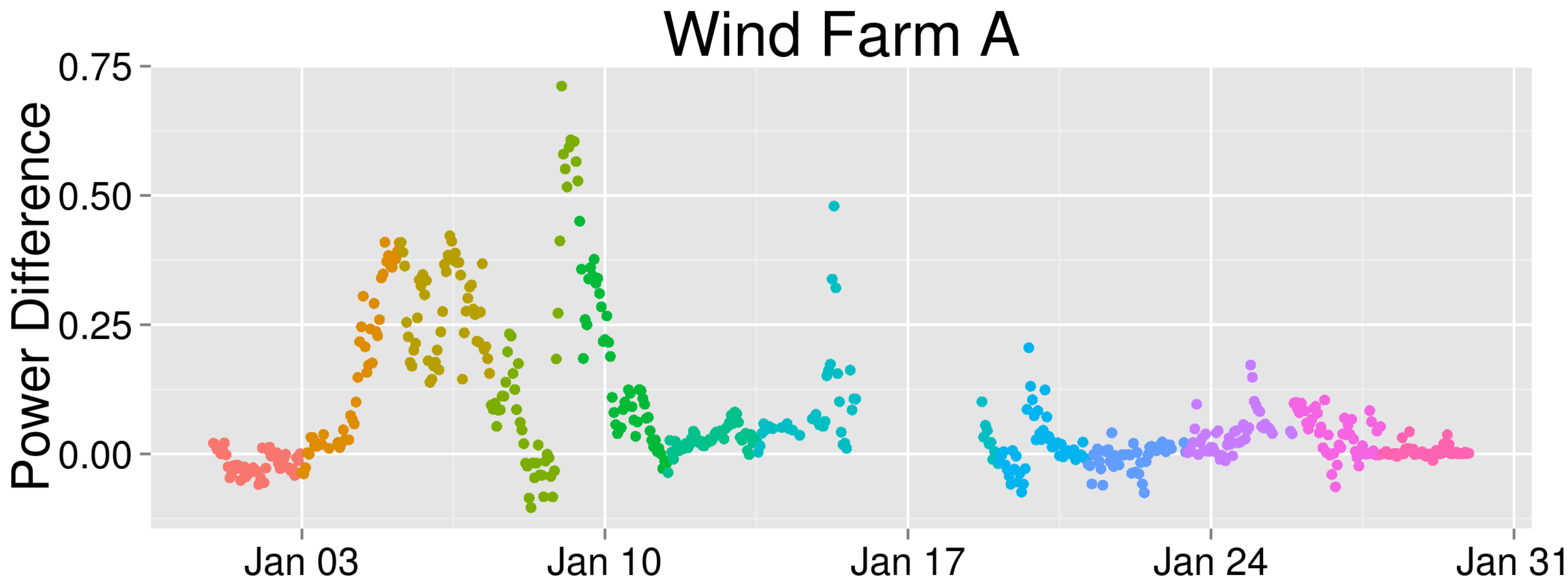


Model Parameters

- Threshold
  - Model qall > 1e-3
  - Set power to 0
  - Use power curve all other times
- Ice only
  - Forecasted power
  - Accumulated mass
  - Average ice density
  - Sublimation
  - Temperature
- Enhanced
  - Ice only parameters
  - Square root of all 4 hydrometeors

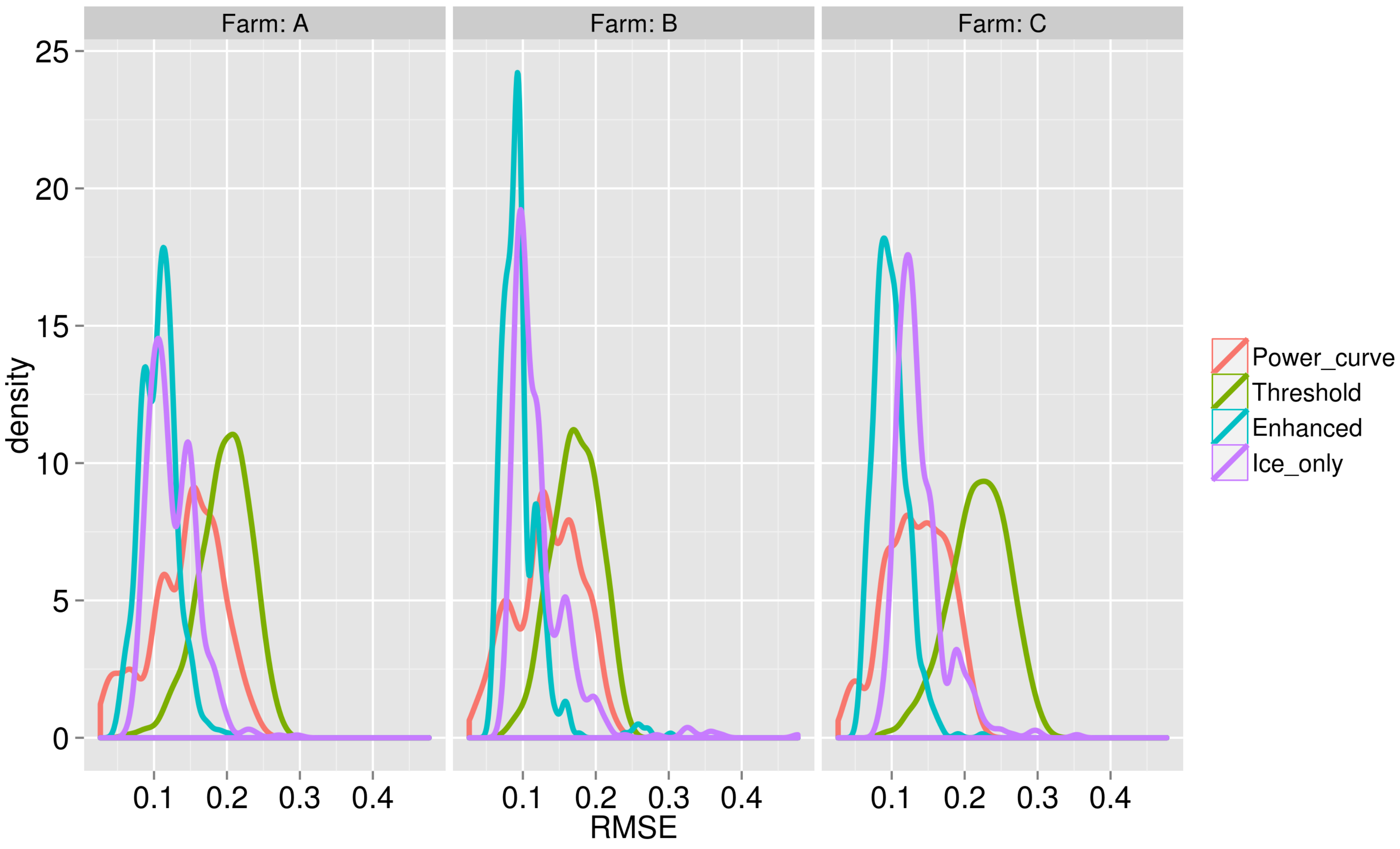


K-fold cross validation



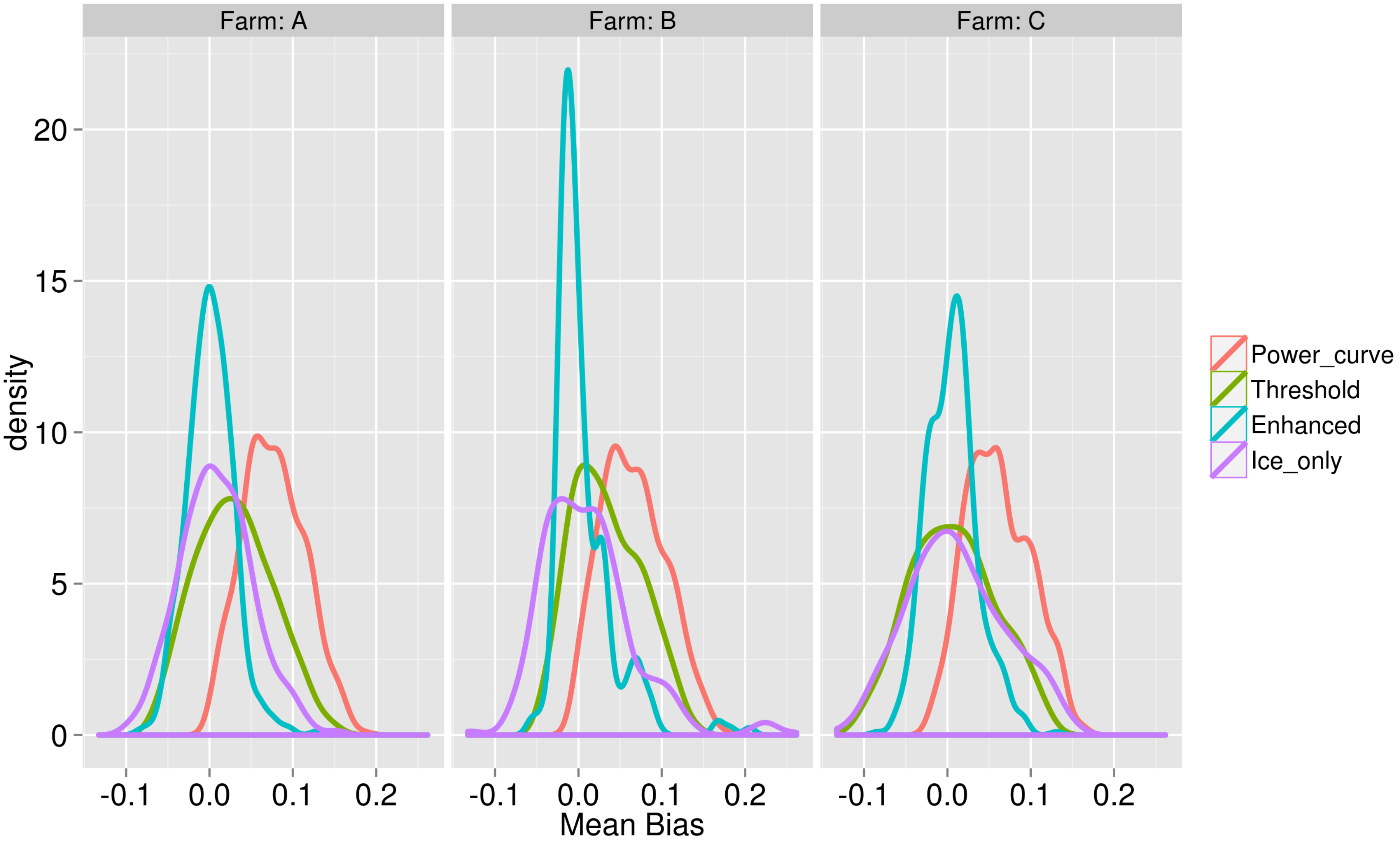
- Cut into 12 pieces
- Fit 8 pieces (training), and forecast remaining 4 (test)
- Calculate RMSE & mean bias of mean farm power forecast (test)
- Monte Carlo approach with 495 different model fits

RMSE



Farm: A
Farm: B
Farm: C
density
25
20
15
10
5
0
0.1
0.2
0.3
0.4
RMSE
Power_curve
Threshold
Enhanced
Ice_only

Bias



Farm: A
Farm: B
Farm: C
density
20
15
10
5
0
-0.1
0.0
0.1
0.2
Mean Bias
Power_curve
Threshold
Enhanced
Ice_only

Conclusions

- Combination of WRF output parameters & icing model parameters works best for all 3 wind parks
- Both bias and RMSE of hourly production estimates can be improved using this approach
- Both statistical approaches show improvement over the threshold based method
- For this site the icing model output was a secondary feature, with the cloud outputs from WRF performing as well as the icing model.
  - We propose this is due in part to the very cold temperatures during icing, so the physical icing model does not have as much impact.

This work was supported financially by the Top-Level Research Initiative (TFI) project, Improved forecast of wind, waves and icing (IceWind), Vestas, and the Nordic Energy Industry.

Future Work

- Apply this method to other sites and longer periods
  - Investigate possible time lags using time series analysis
- Ensure the modified Makkonen model is representing the turbine icing correctly
  - Develop relationships between the two if required
- Enhance the formulation of ice removal mechanisms
- Evaluate performance using forecasted winds

Questions???