# Icewind Inter-comparison of Icing Production Loss Models

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- WeatherTech Scandinavia
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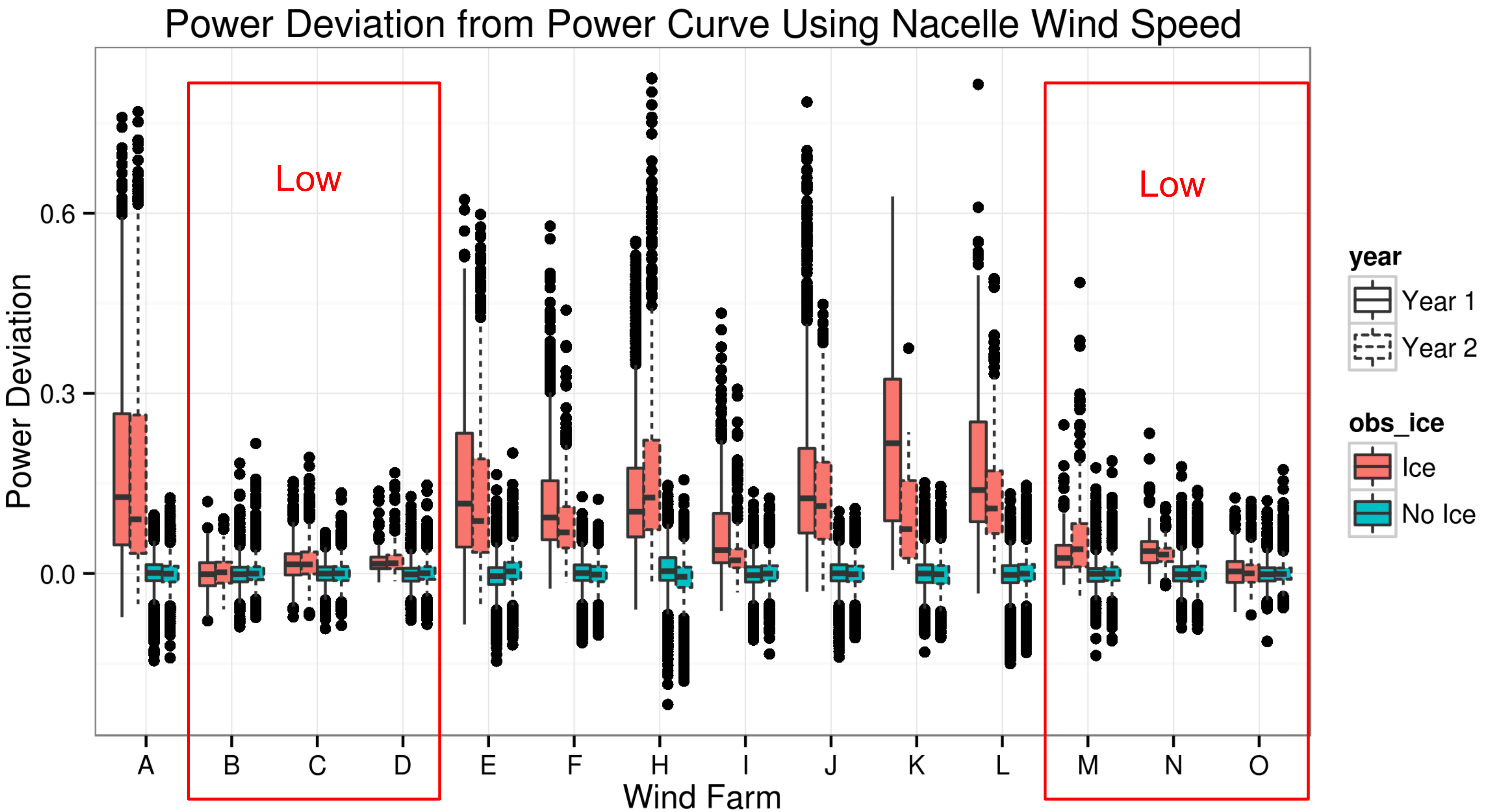
Top-level Research Initiative

# Observations

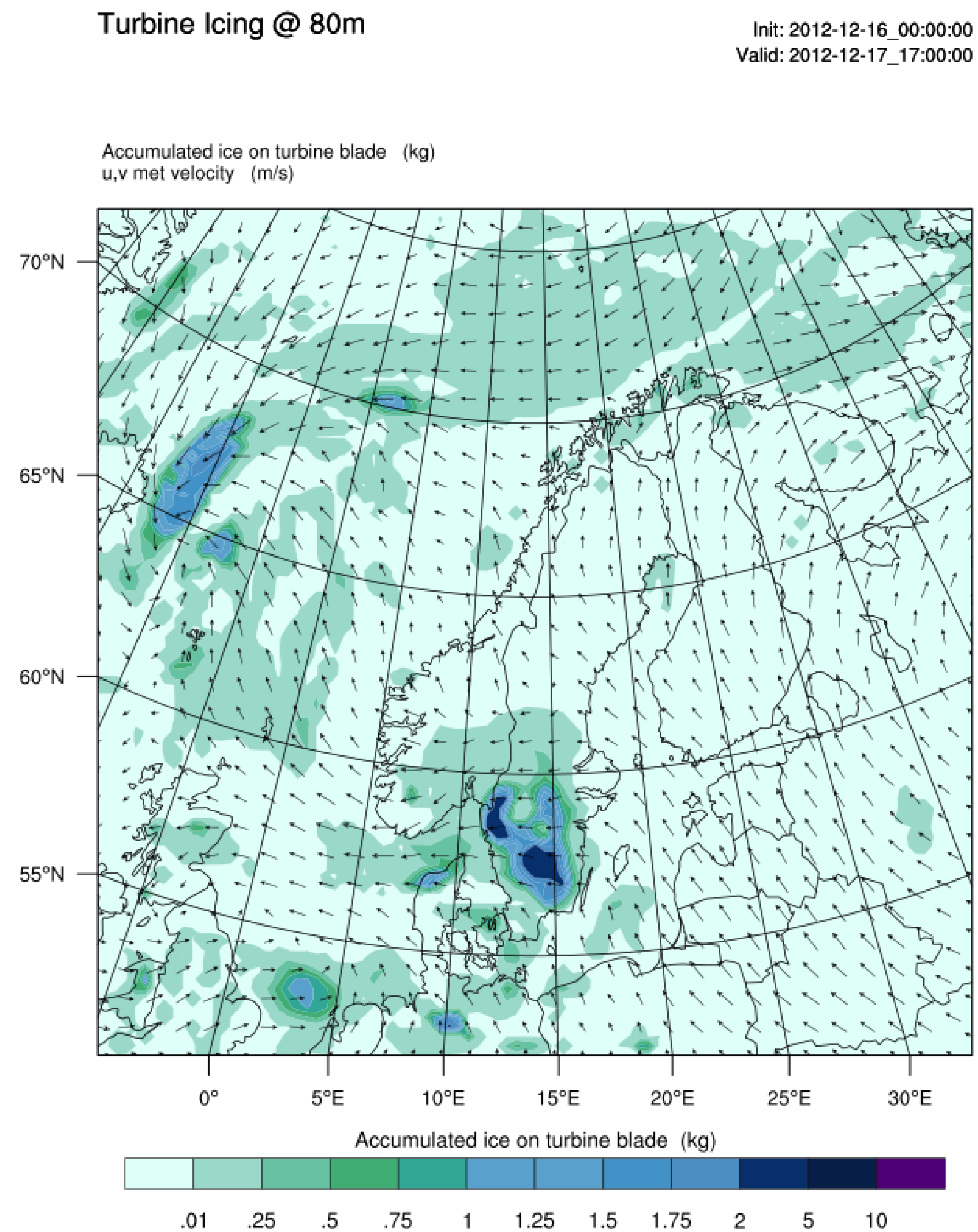
- Selected data from 15 wind farms
  - Averaged to wind farm values, not turbine specific
  - 2 years of data (June 2010-June 2012)
  - Observed icing times from automated approach classifying production loss
  - Data removed when turbines not operating optimally




- Note 2 regimes in different wind farms
- Similar results from both years

# WRF model data

- Provided by Vestas at 3 km
- WSM5 microphysics
- 6 hour spin up cycle
- Provided Fields
  - Wind Speed
  - Temperature
  - Pressure
  - 4 Cloud types
  - Precipitation rate
  - Specific humidity
  - Shortwave radiation
  - Longwave radiation

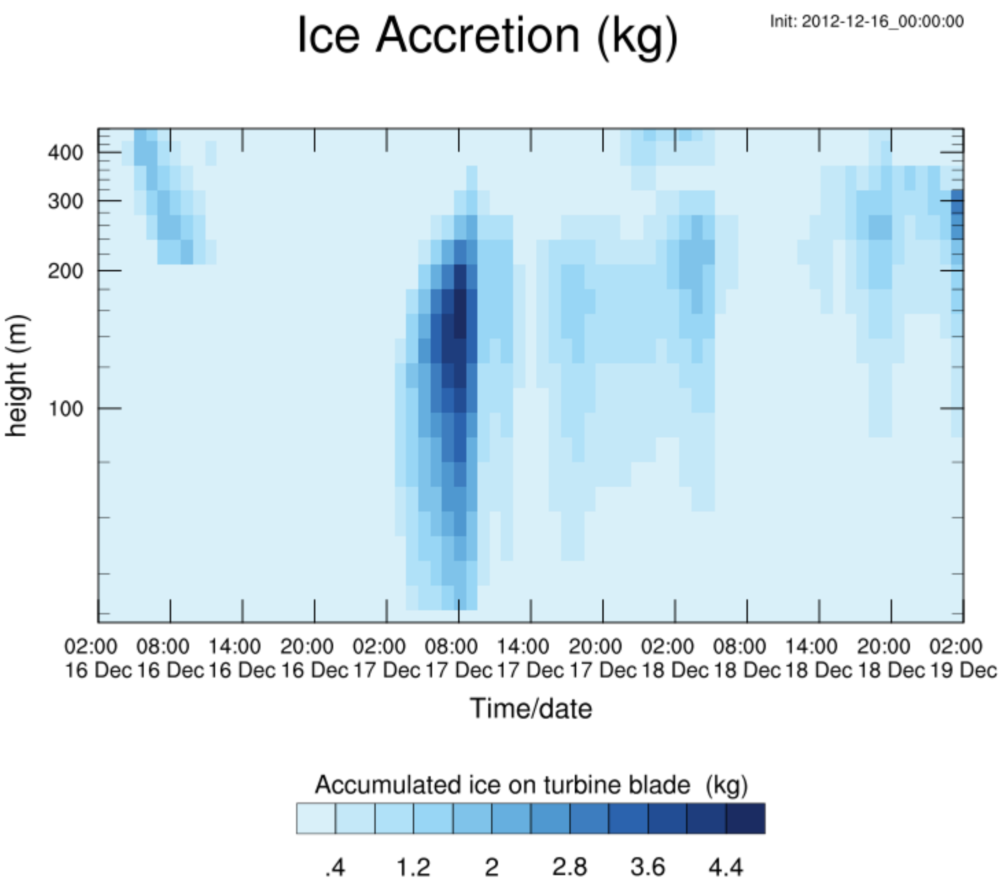


Vestas

DTU

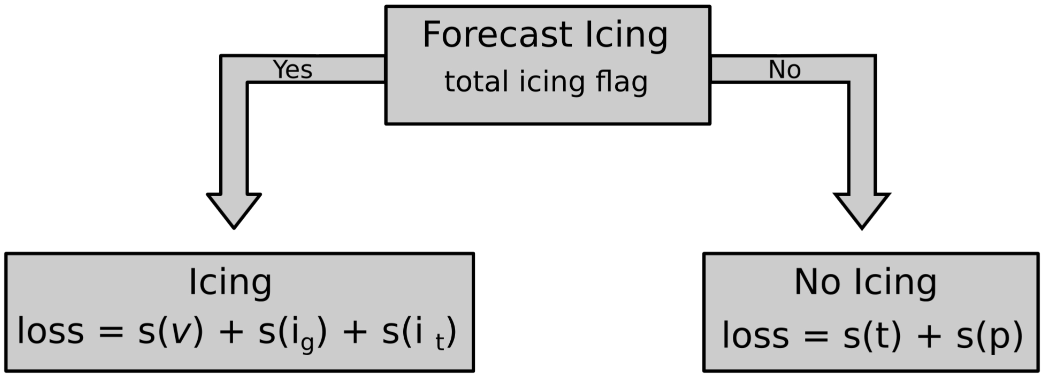
# WRF model data

- 3D Representation of the atmosphere
- Data interpolated to 40, 80, 120, 160 and 200 m AGL



# Production Loss Models

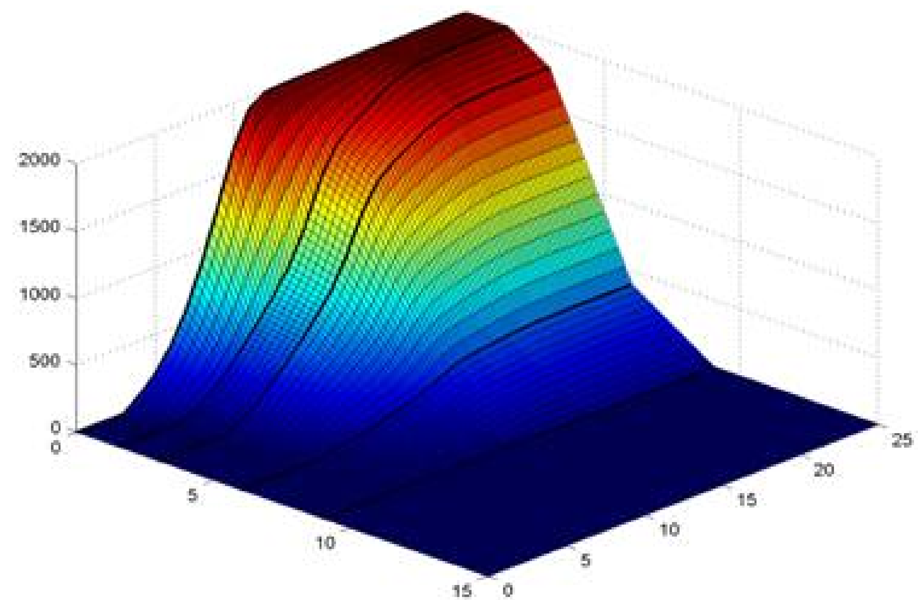
# DTU Wind Energy



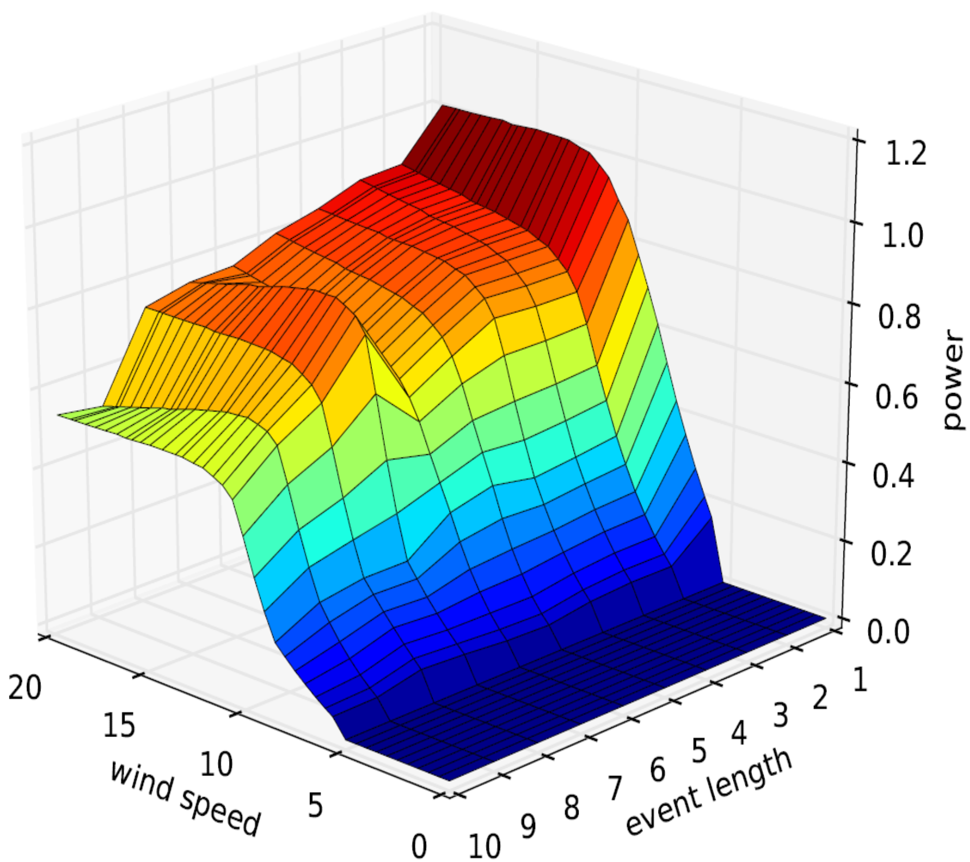

- Mixed model
  - Fits separate models for forecast ice / no ice conditions
- Generalized Additive Model
- Utilizes results from WRF and iceBlade
  - IceBlade modified to include cloud ice for WSM5 microphysics
- Fit separately for each farm in this study with consistent variables

# Kjeller Vindteknikk

- Two-parameter power curve
  - Suggested by wind tunnel results
  - Ice mass and wind speed
  - Tuned and validated using operational data
- Uses a standard cylinder for ice mass modeling
- Assumes power yield of 0 at approximately 9 kg/m



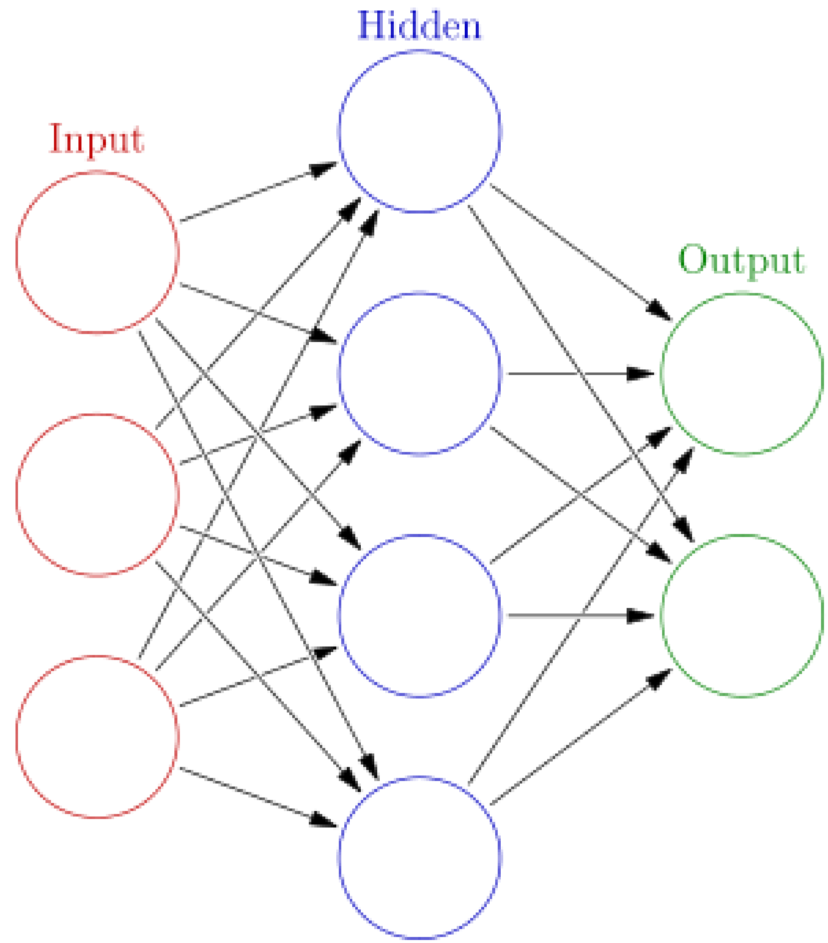
# VTT




- Based on statistical analysis of power loss observations
- Produces an estimate for power loss due to rotor icing
  - Based on wind speed and length of icing event
- Independent of icing or production forecasting methods
- Requires external icing forecast
  - Used iceBlade accumulated icing for this comparison

# WeatherTech Scandinavia

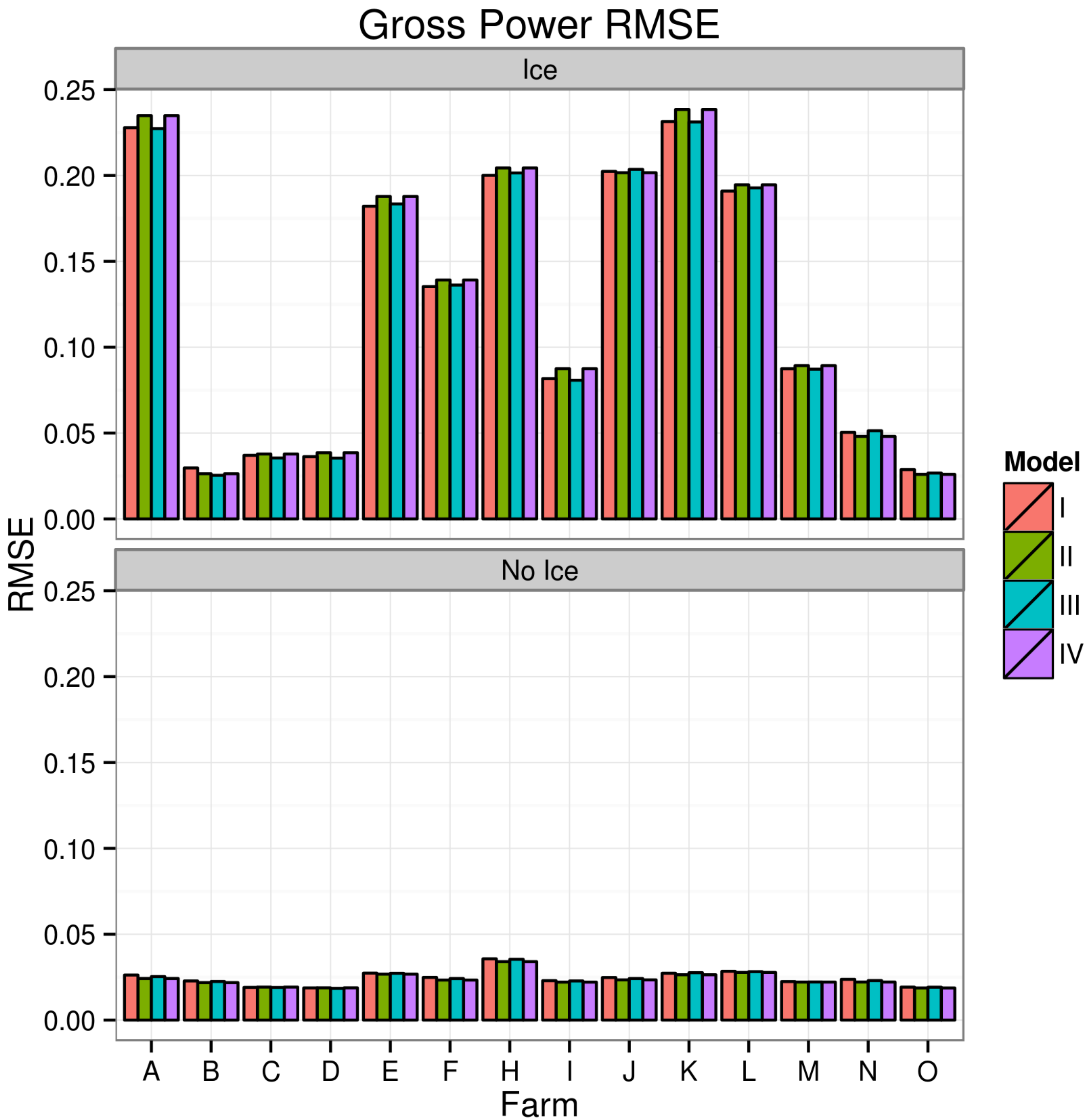
- WICE – WeatherTech Ice Model
- Artificial Neural Network
  - Trained with observed clean & iced production
- Tested for different turbines & locations
- Either forecast or assessment tool



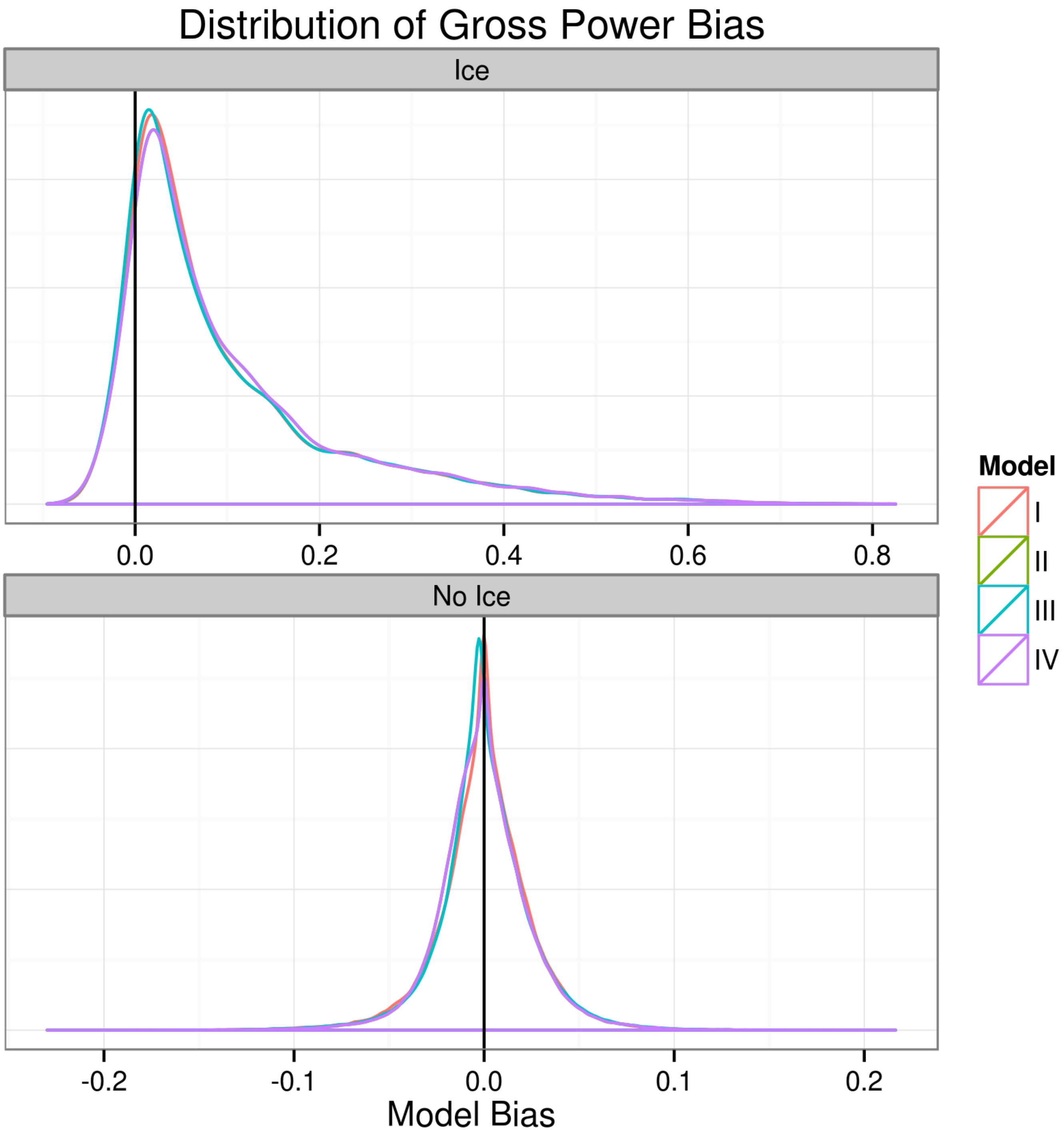
# Results

# Terminology

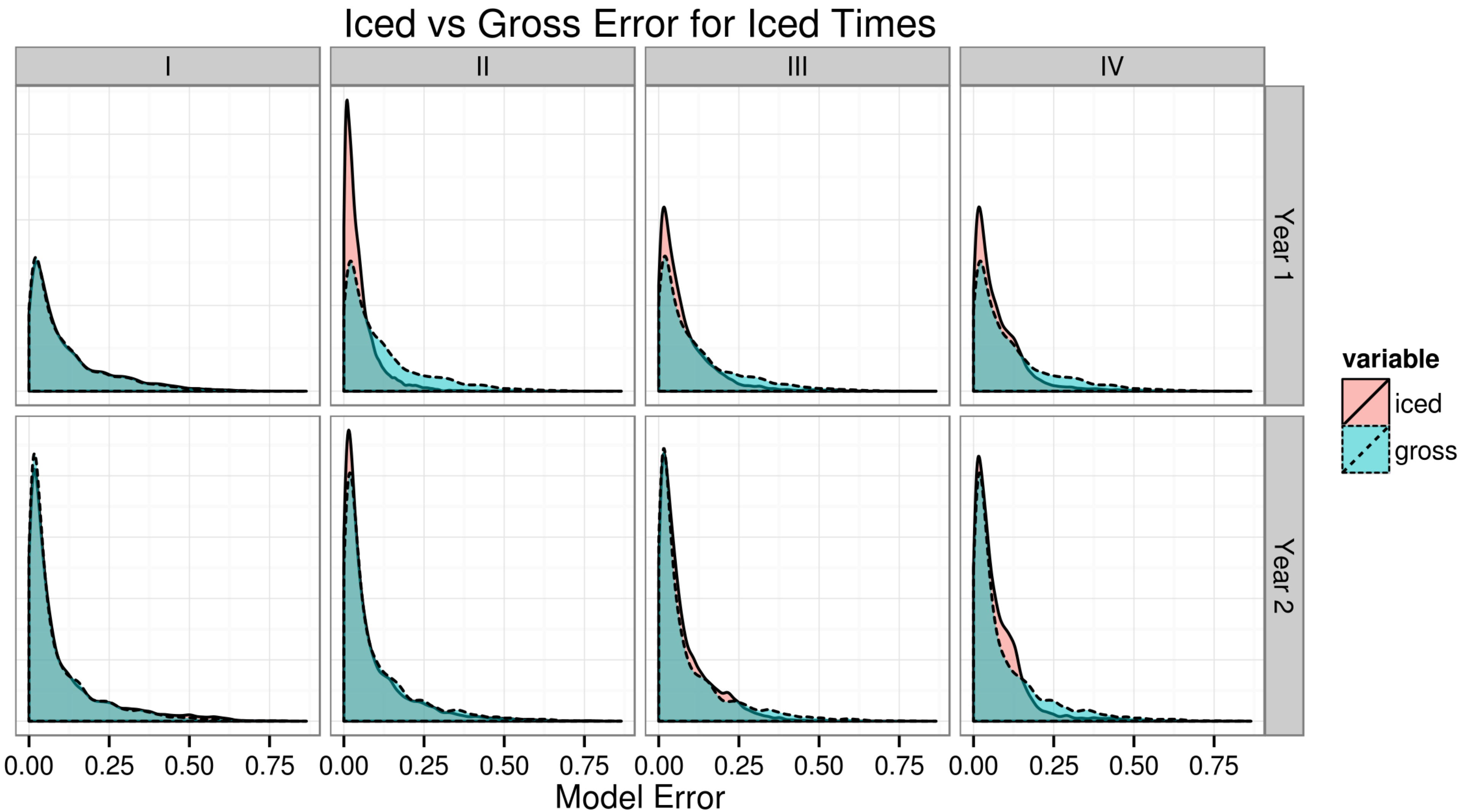
- 2 Years (defined June – May)
  - Year 1 Used to fit statistical models
  - Year 2 Evaluation year
- 2 Power estimates
  - Gross: power estimate without icing
  - Iced: power estimate with icing
- 2 Observed Conditions
  - Ice: times when observations suggest icing
  - No Ice: times without icing
- 14 Farms (Labeled A-O, ex. G)
- 4 Models (Labeled I-IV)



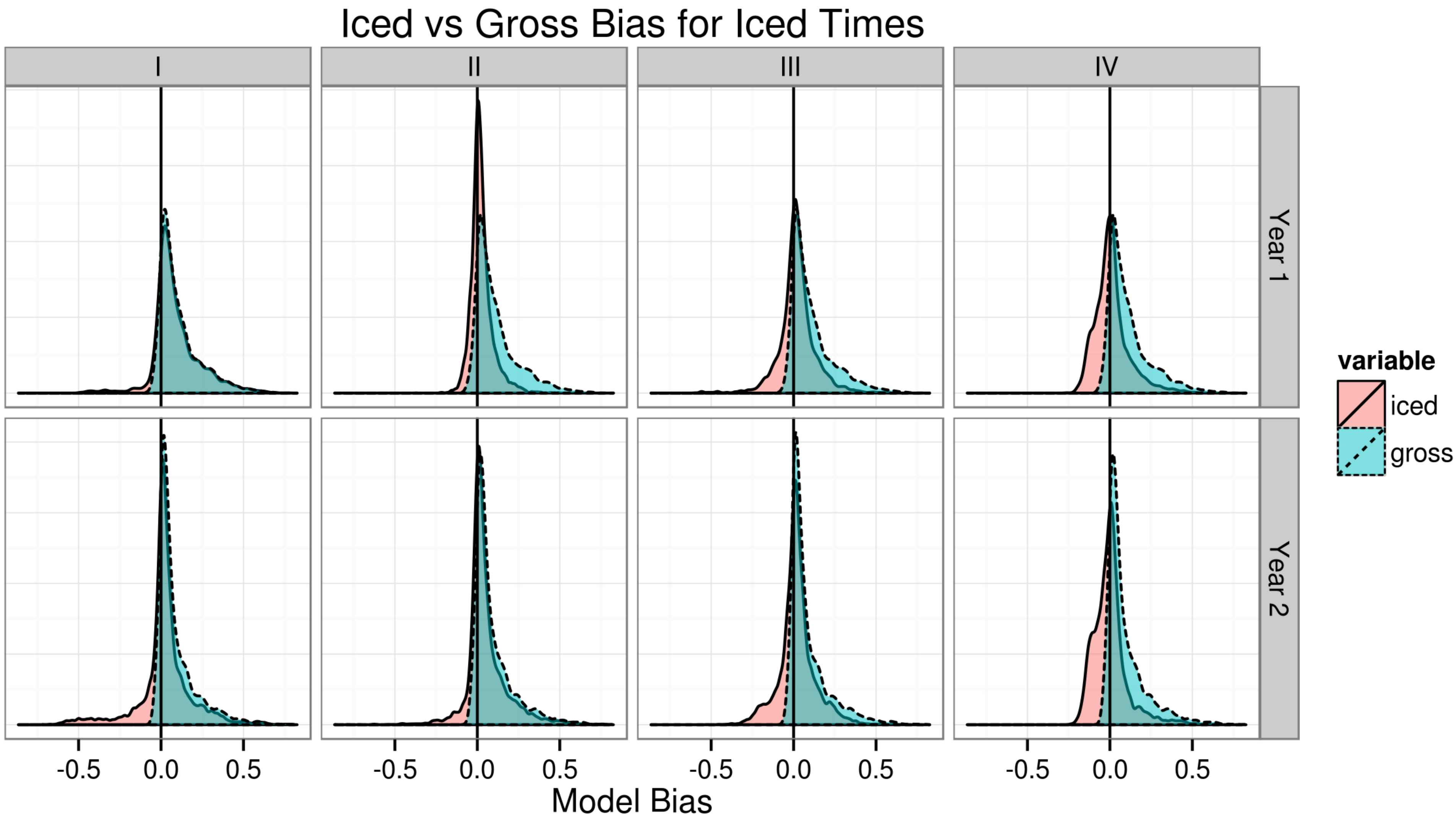

- Power curve fit to nacelle wind speed
- Gross estimates similar across models
- Much larger errors for observed icing cases
- Error pattern similar to impact of icing from boxplot



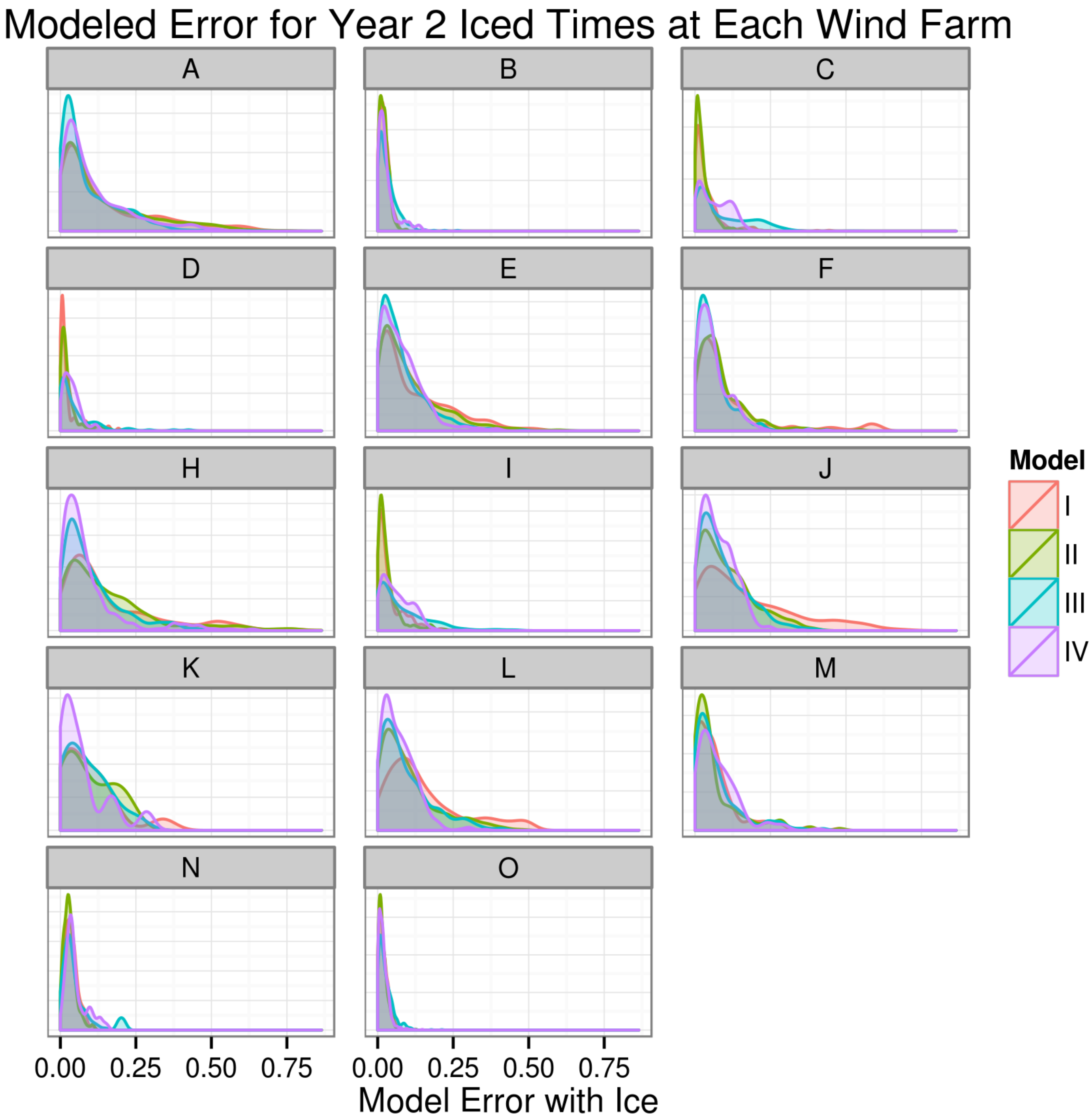

- Peak near zero for all models
- Symmetrical bias for no ice
- Ice condition skewed positive signifying higher estimated power than observed
- No large deviation across models



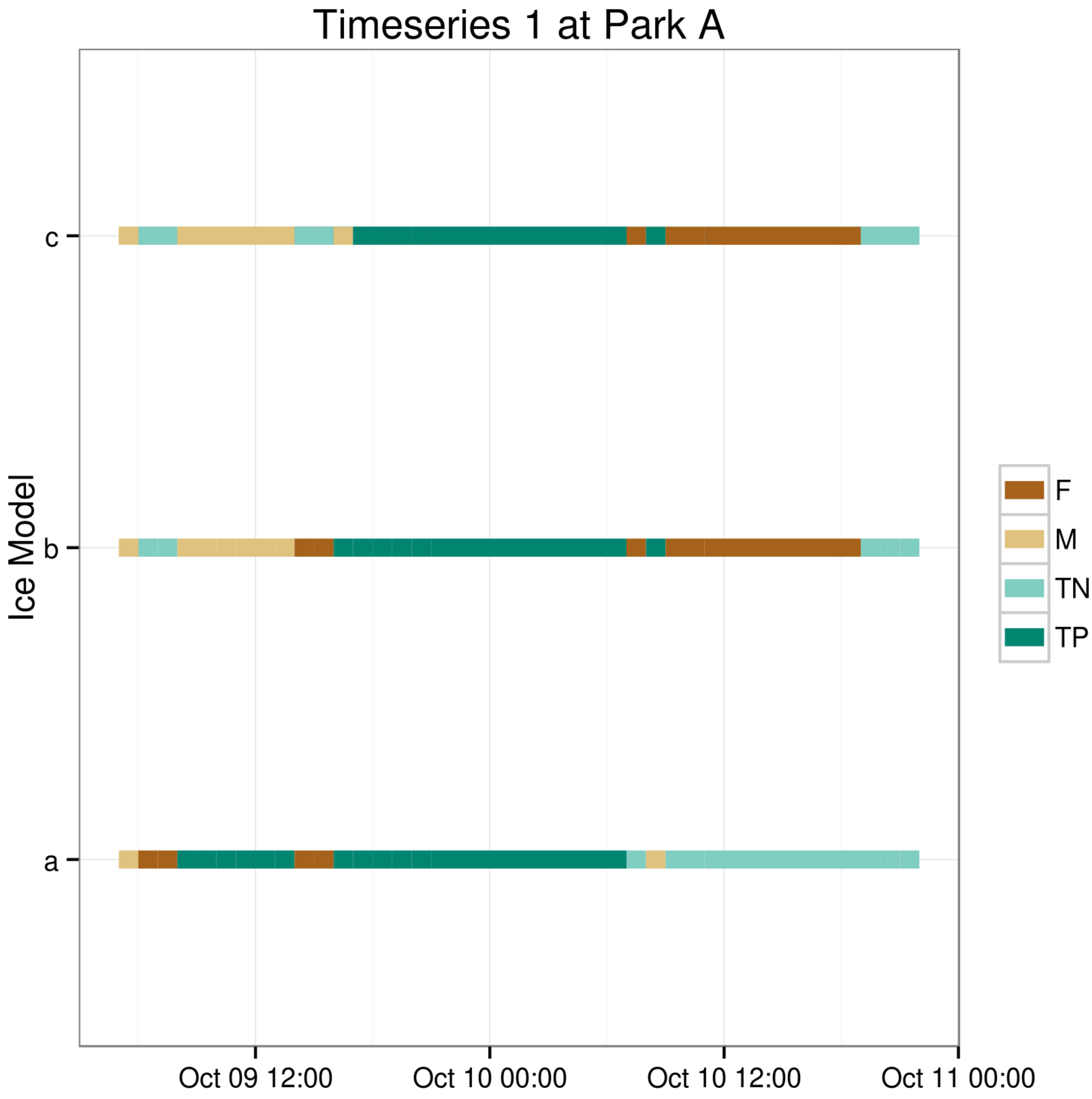

- Large improvement in year 1 for Models II, III and IV
- Much smaller improvement in year 2



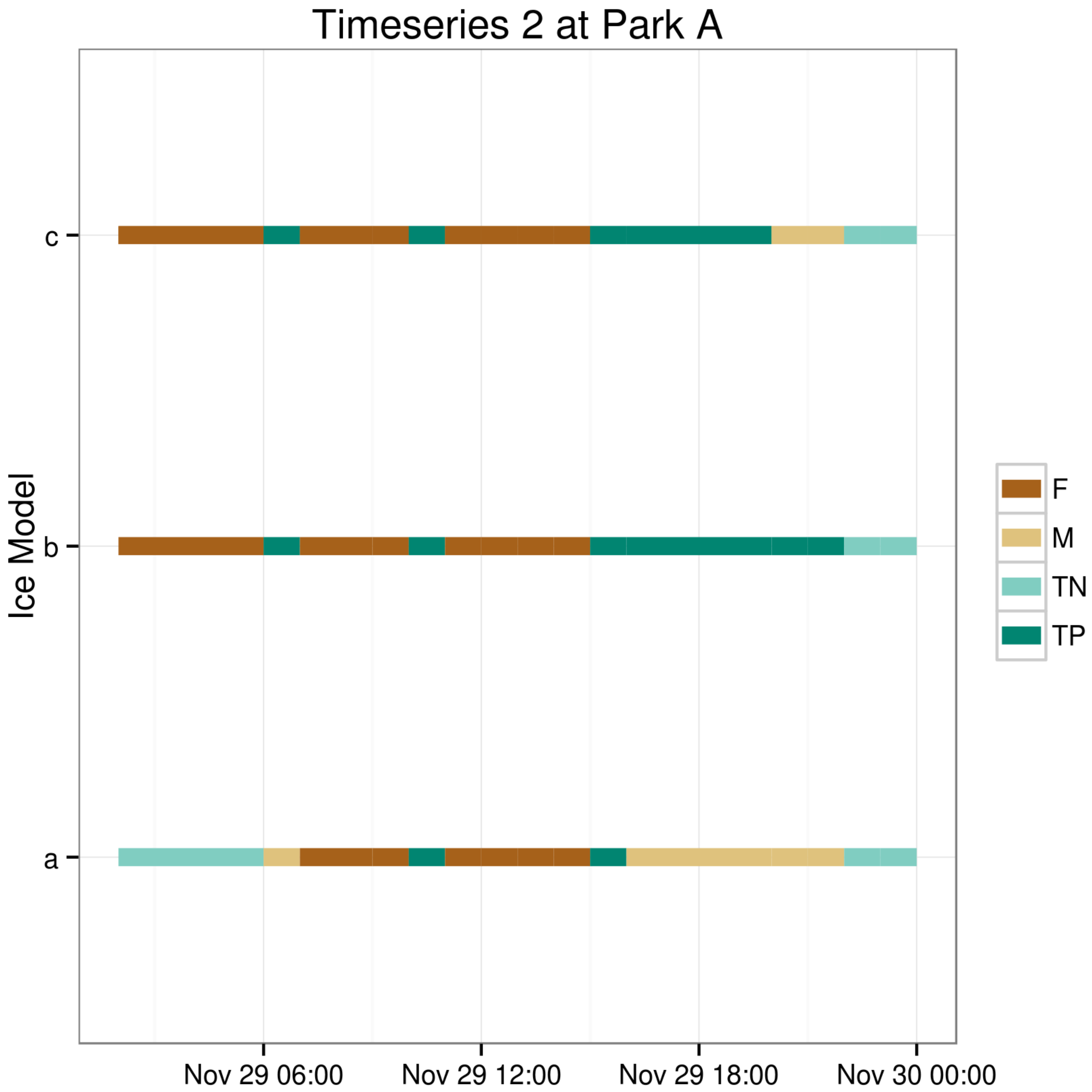

- General shift of positive bias to negative
- Year 2 shows larger shift of bias from positive to negative




- Reasonable performance from all models
- Large differences between models at most sites
- Can pick out sites with low ice impact
- Model III and IV slightly outperform other models at several sites




- Only a captures first event
- C captures the start of second event best
- Both b & c miss the end of the icing event




- b & c both show one long event at the beginning of the period
- a overruns the end of the event
- a also misses the first short event
- Differences may be due to errors in observations

# Conclusions

- Models perform similarly
- Differences appear mostly due to park conditions
- Large improvements still possible
  - Longer periods for model fit to reduce over fitting
  - WRF runs customized for icing
  - Ice ablation methods & relationship to power
- Agreed upon metric is needed to help improve the models
  - Bias was improved at most sites
  - RMSE was not improved as much
- Using human input could improve these models, need judgment on when to apply them

# Where to go from here

- Study focusing on AEP evaluation, with inter-annual variability
- Development of ice ablation models to improve ending of icing events
- Investigation of ice roughness and how it changes through icing events and impacts power loss
- Evaluate LWC and MVD input parameters for the cloud models to determine optimal setup