IceWind Inter-comparison of Icing Production Loss Models

- ## DTU Wind Energy

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- ## Kjeller Vindteknikk

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- ## WeatherTech Scandinavia

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 - Magnus Baltscheffsky

IceWind

- Nordic Project supported by Top-Level Research Initiative (TFI)

- Improved forecast of wind, waves and icing

- 13 Project partners

- Work Package 1: Wind turbine icing

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

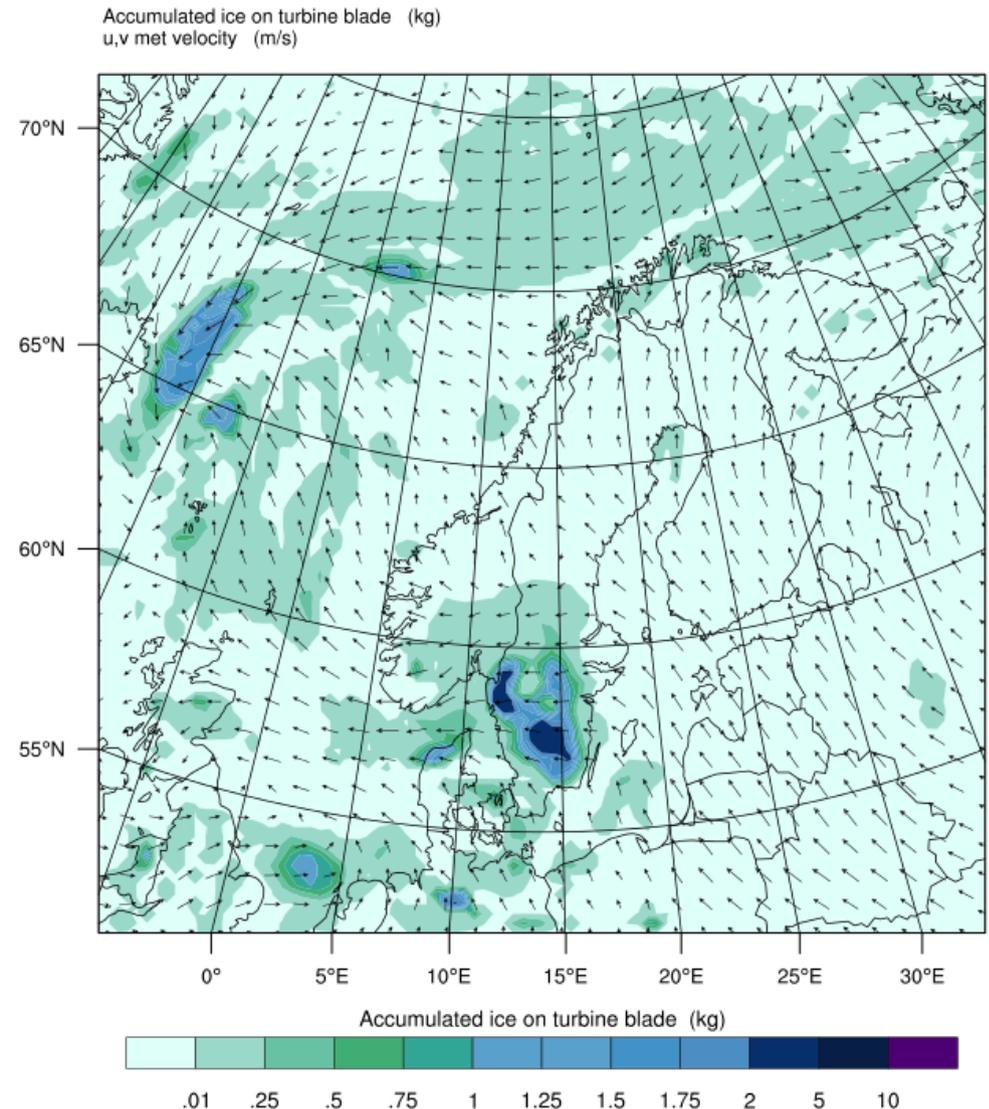Power Deviation from Power Curve Using Nacelle Wind Speed
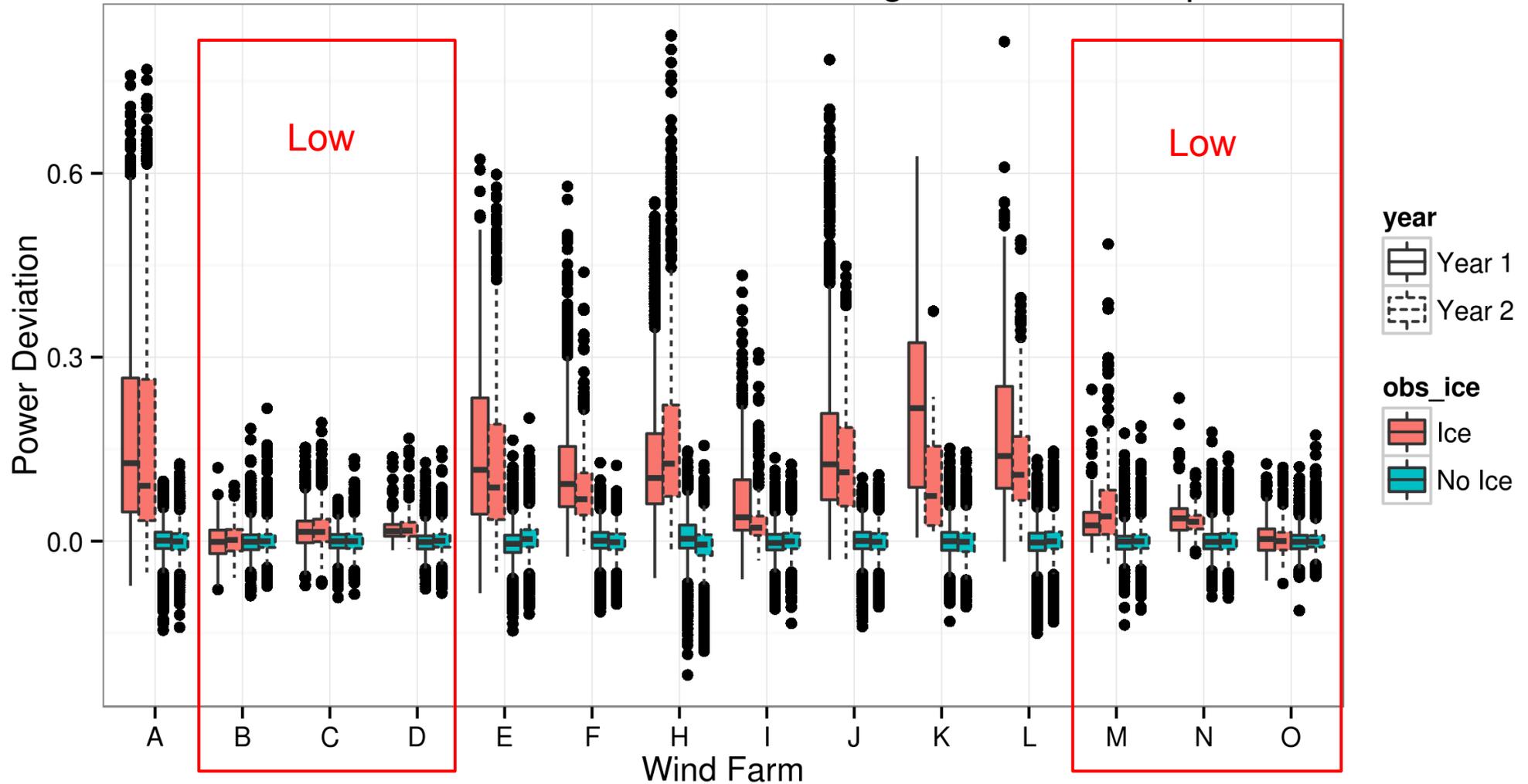
- Note 2 regimes in different wind farms
- Similar results from both years

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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
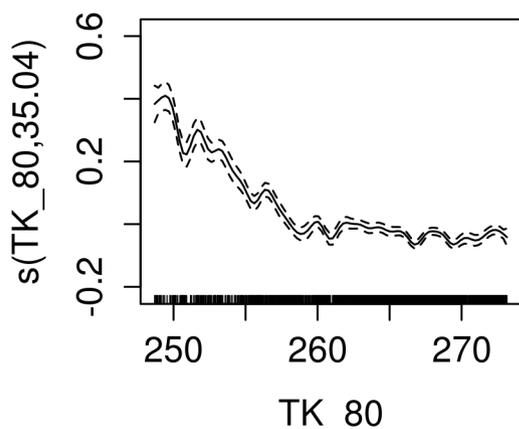
Turbine Icing @ 80m

Init: 2012-12-16_00:00:00
Valid: 2012-12-17_17:00:00

Accumulated ice on turbine blade   (kg)
u,v met velocity   (m/s)

Accumulated ice on turbine blade (kg)

.01   .25   .5   .75   1   1.25   1.5   1.75   2   5   10

WRF model data

- 3D Representation of the atmosphere

- Data interpolated to 40, 80, 120, 160 and 200 m AGL

Ice Accretion (kg)   Init: 2012-12-16_00:00:00

Accumulated ice on turbine blade (kg)

.4   1.2   2   2.8   3.6   4.4
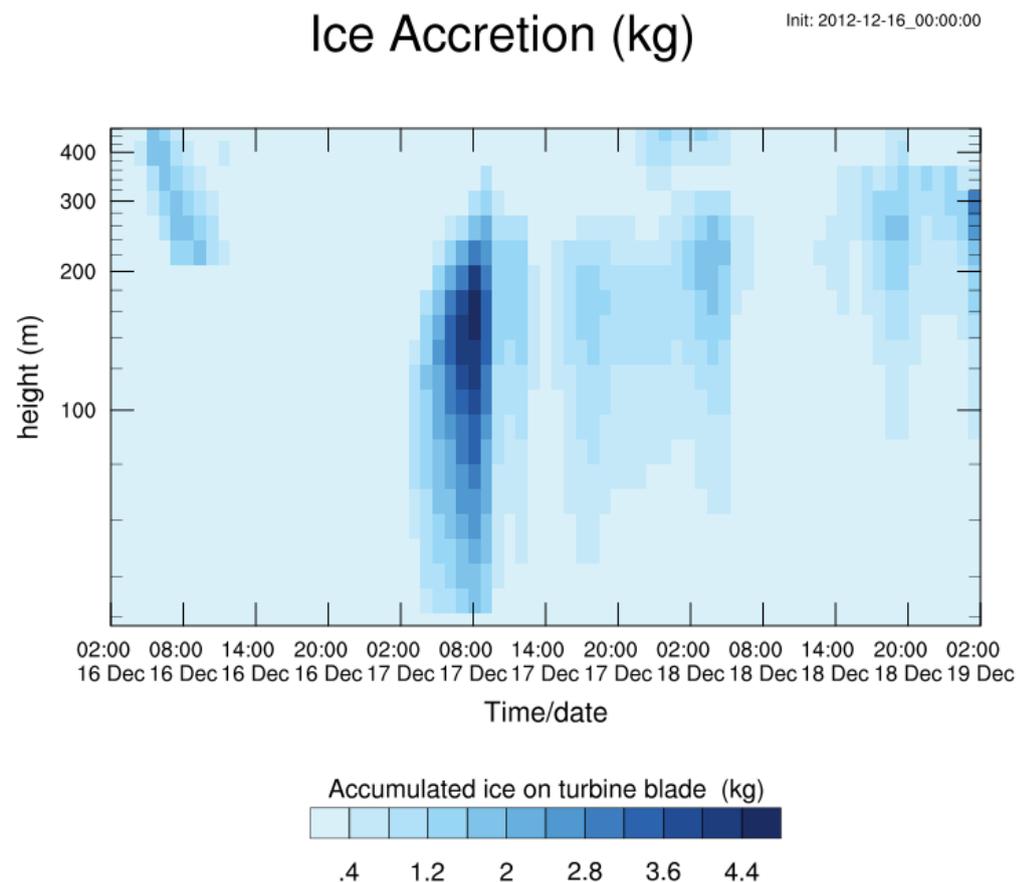
Production Loss Models

DTU model
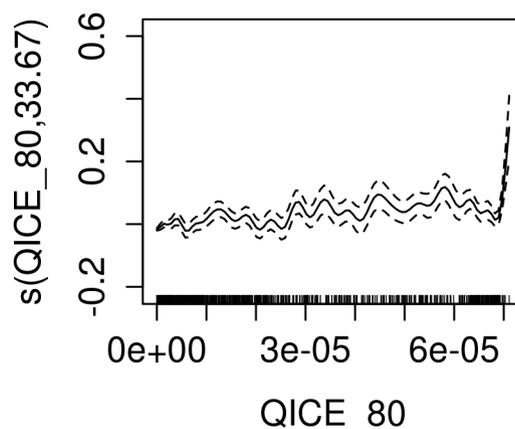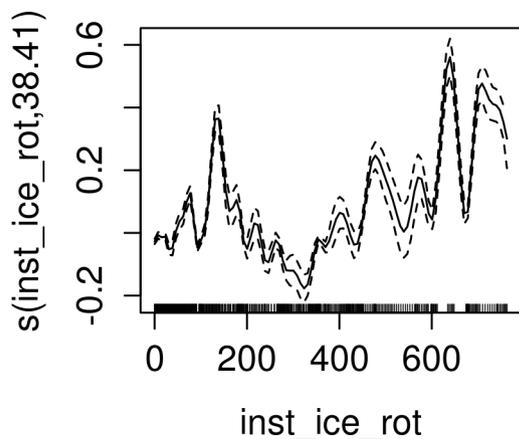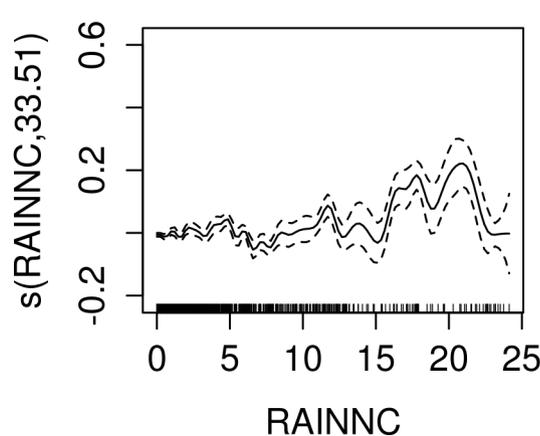

- Mixed model
  - Fits separate models for forecast ice / no ice conditions
- Generalized Additive Model
- Utilizes results from WRF and iceBlade
  - IceBlade modified to include cloud ice for WSM5 microphysics
- Fit separately for each farm in this study with consistent variables

Kjeller Model

- 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
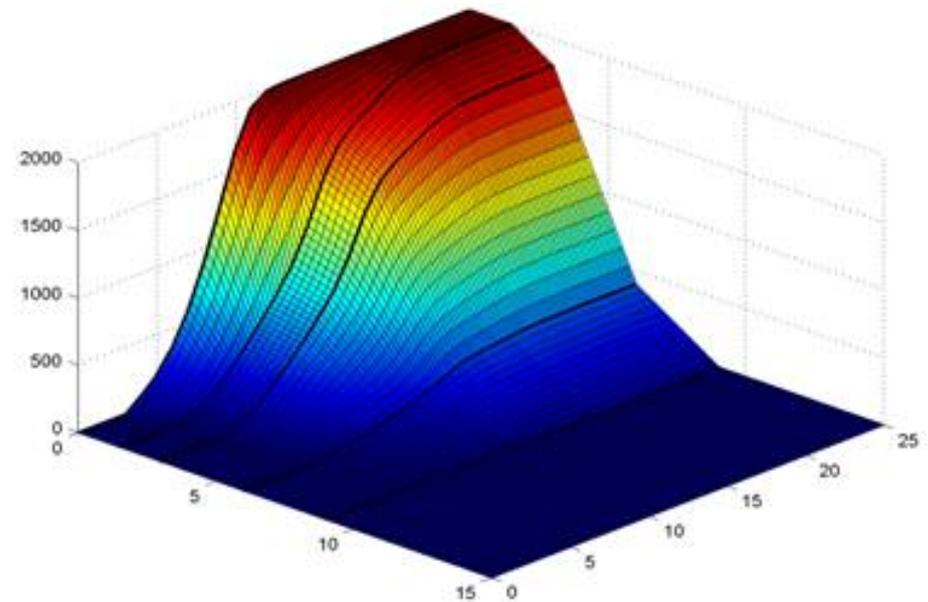
VTT
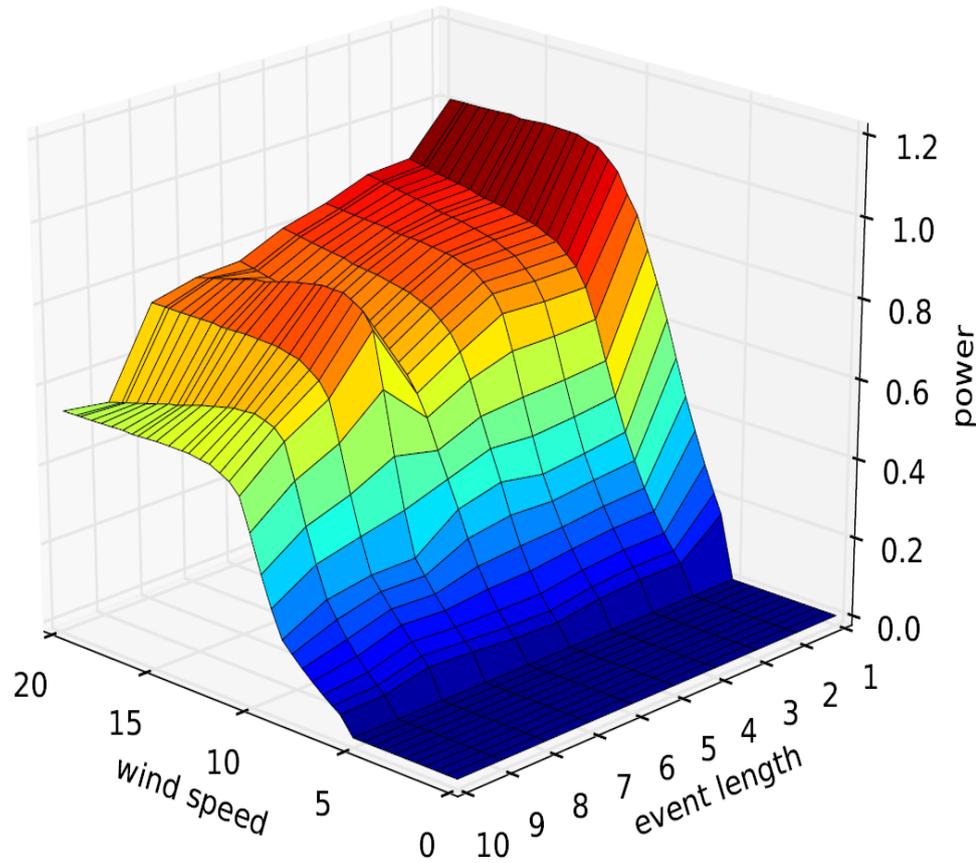
- Based on statistical analysis of power loss observations

- 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
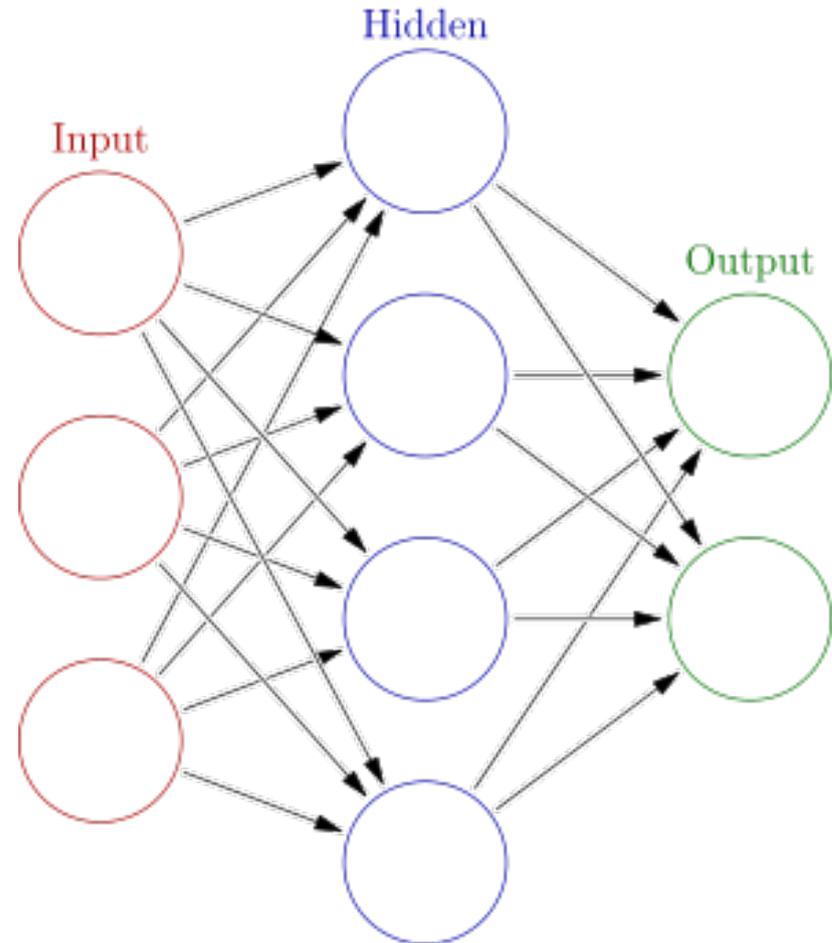
# Results

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)

Gross Power RMSE
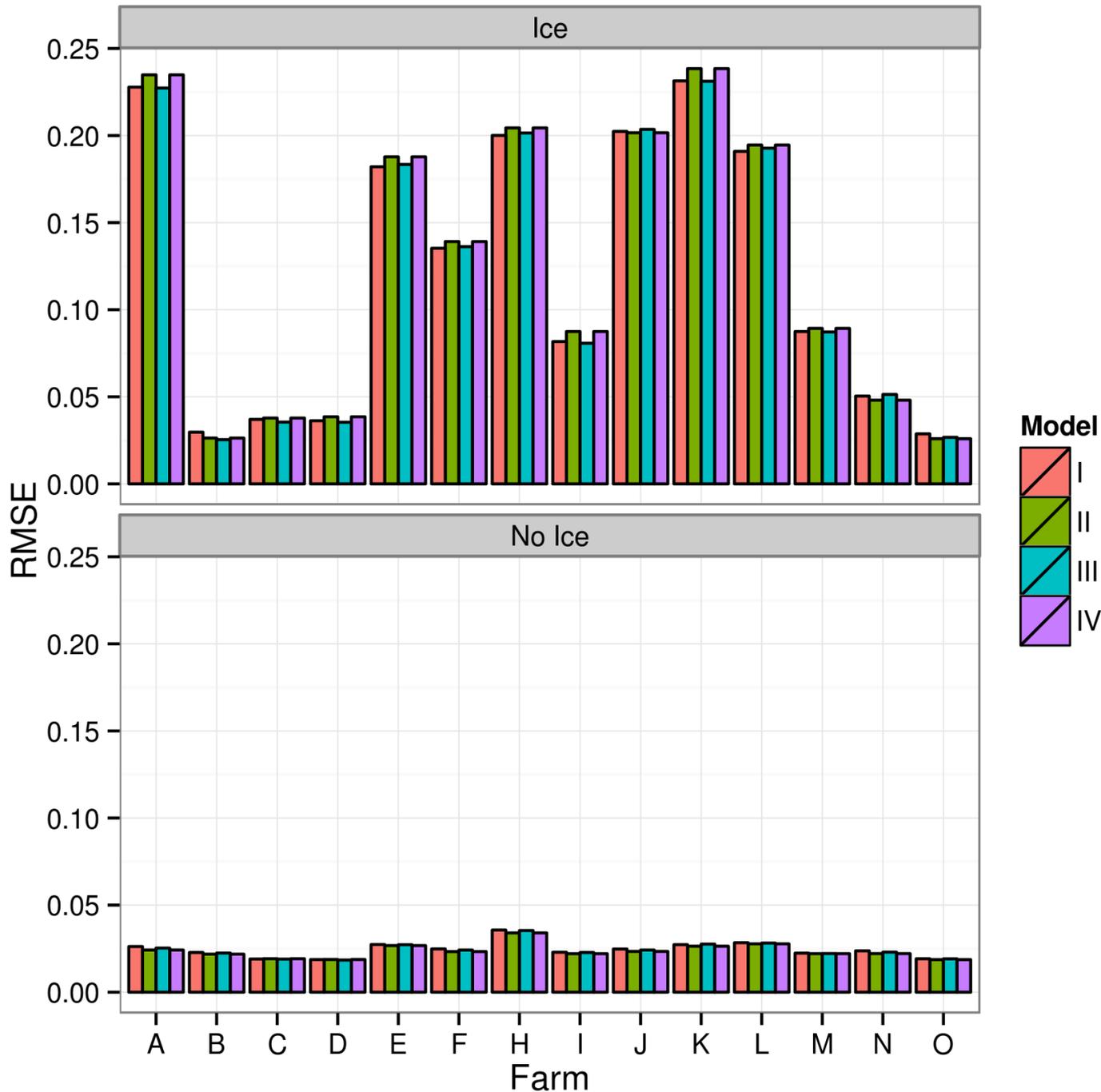
- Power curve fit to nacelle wind speed

- Gross estimates similar across models

- Much larger errors for observed icing cases

- Error pattern similar to impact of icing from boxplot
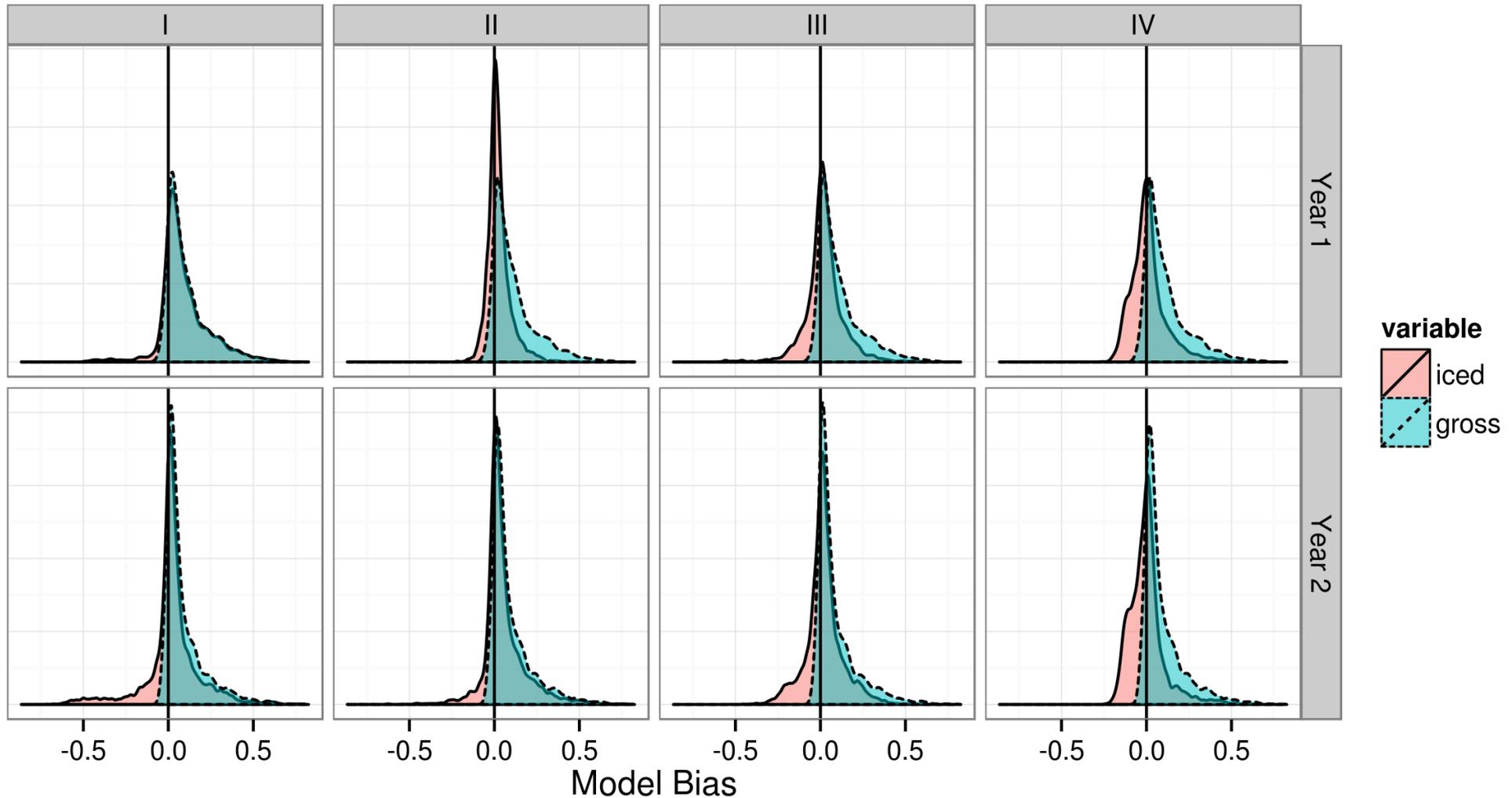
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Distribution of Gross Power Bias
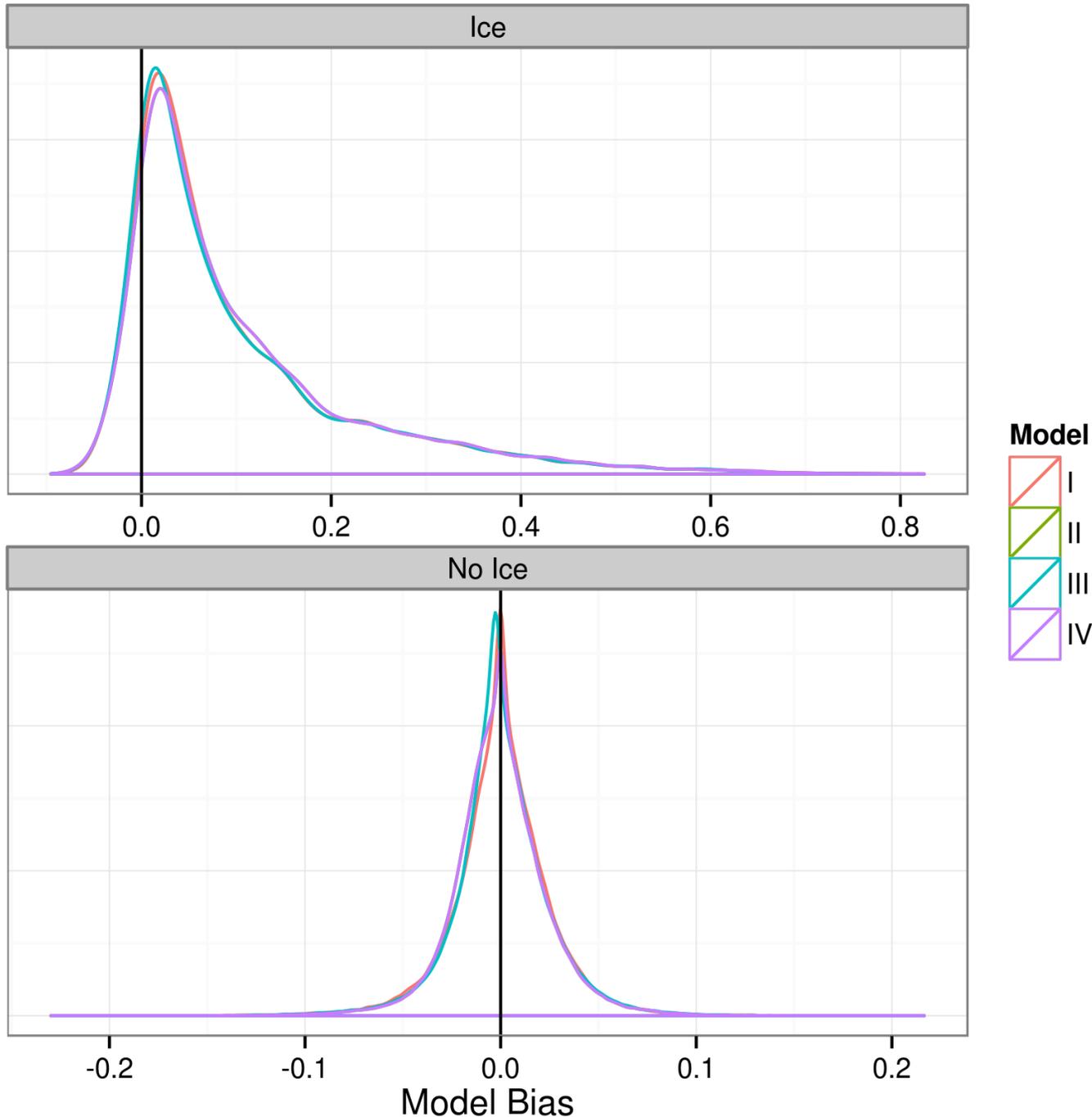
- Peak near zero for all models

- Symmetrical bias for no ice

- Ice condition skewed positive signifying higher estimated power than observed

- No large deviation across models
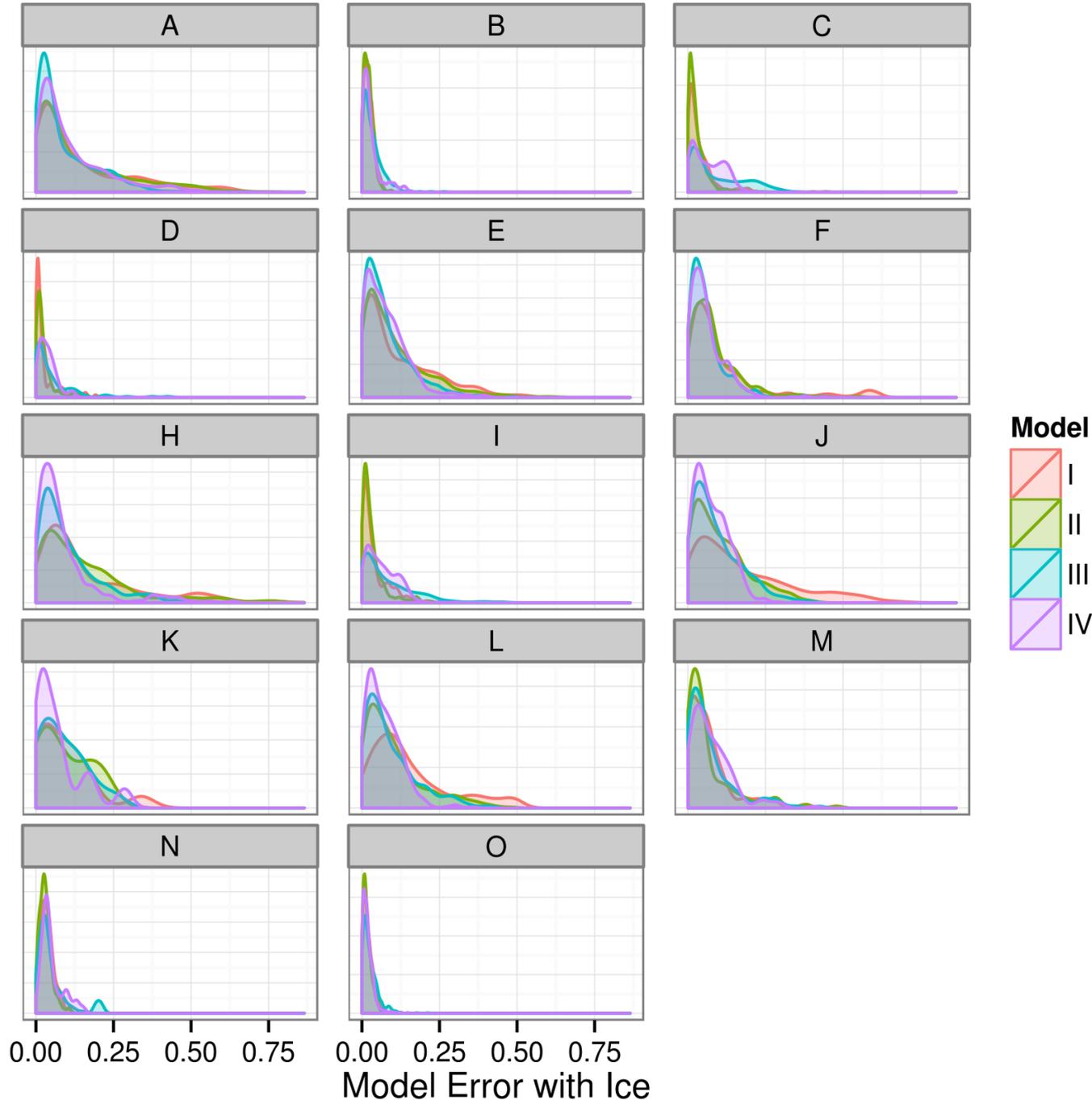
Iced vs Gross Error for Iced Times
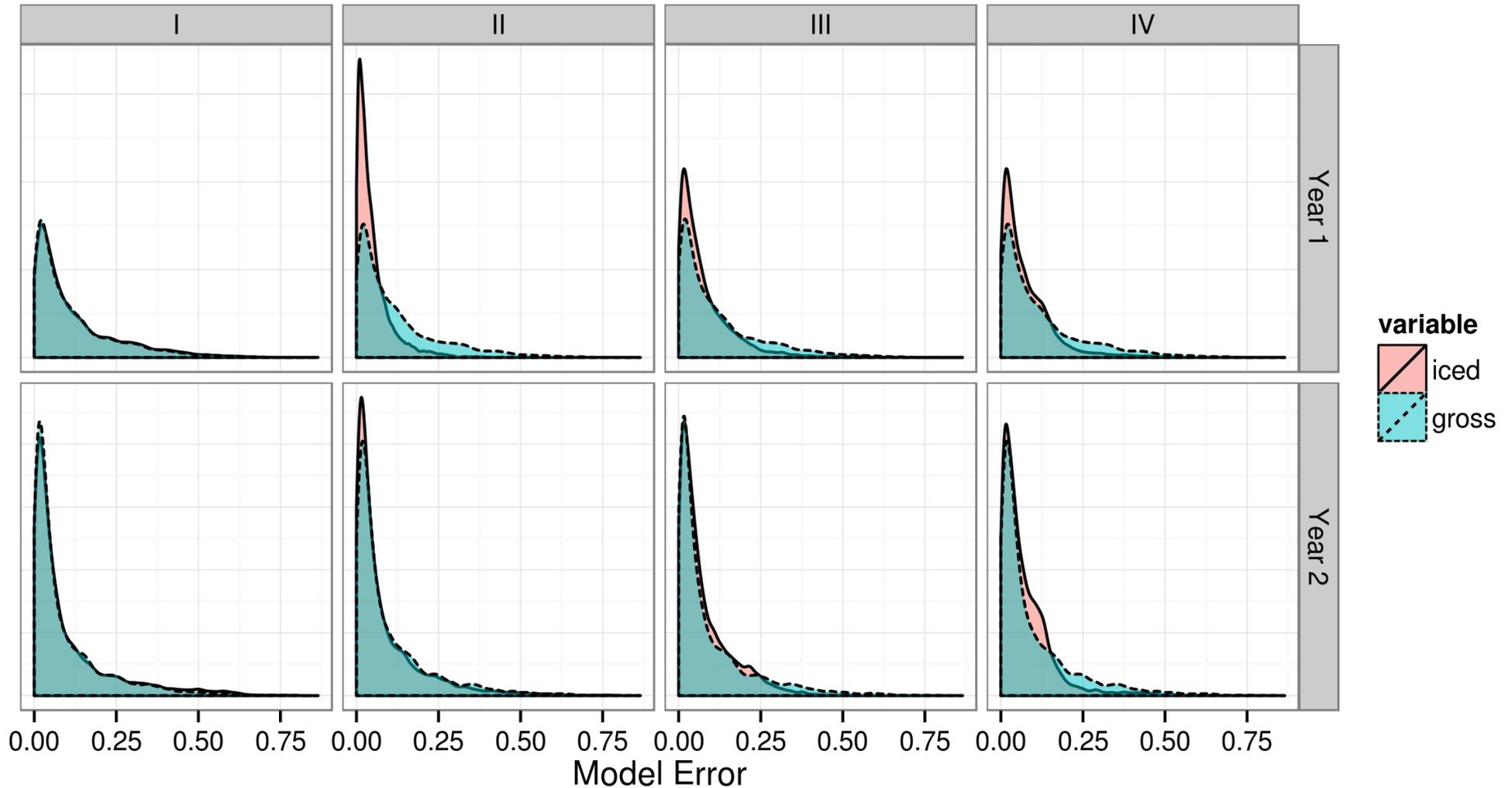
- Large improvement in year 1 for Models II, III and IV
- Much smaller improvement in year 2

Iced vs Gross Bias for Iced Times

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

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Modeled Error for Year 2 Iced Times at Each Wind Farm

- 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

Model RMSE by Year
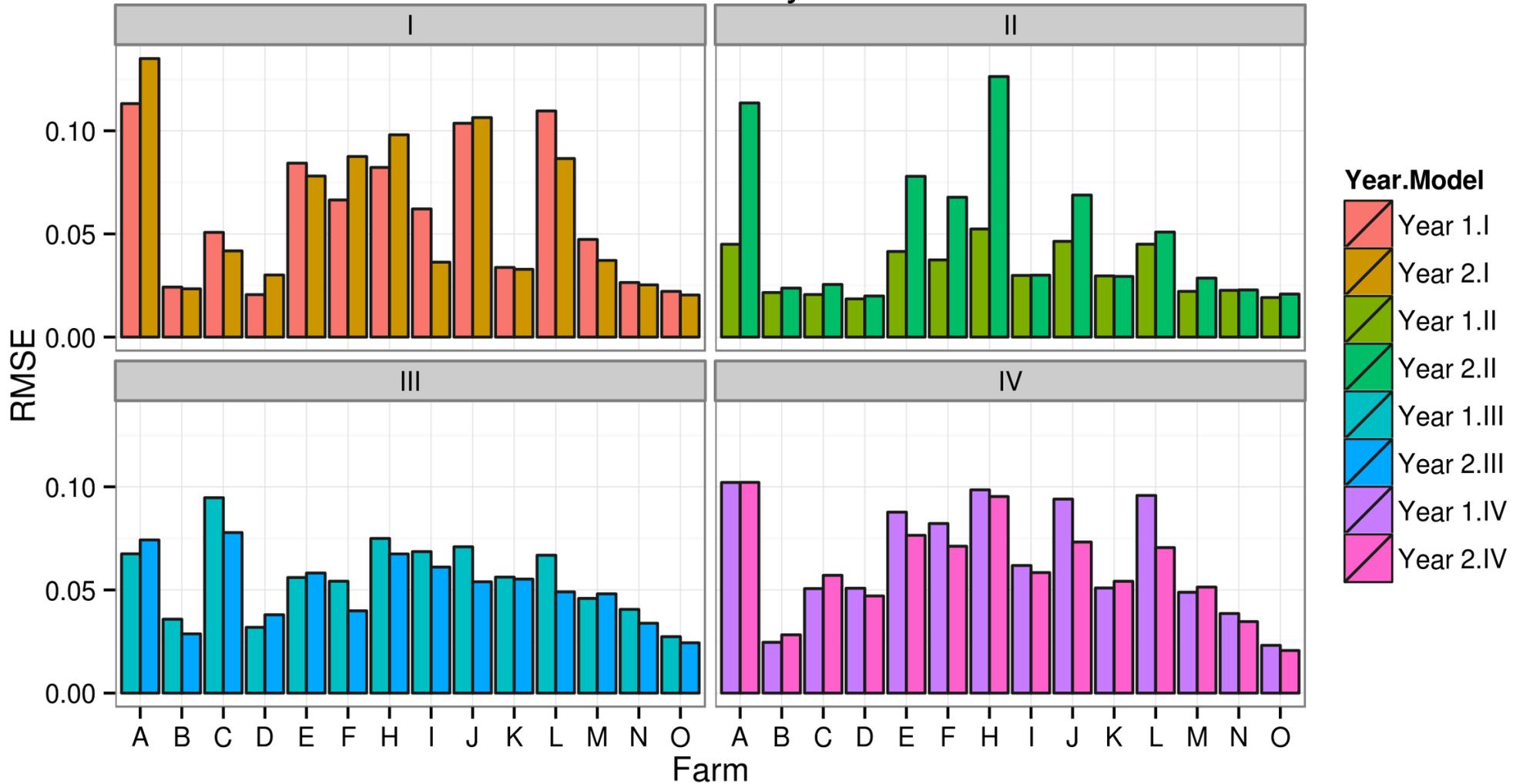
- Colors signify years
- Model II appears to have over fit model to year 1
- Models III and IV shows larger errors at sites with less icing than other models

Change in Model Mean Bias (Iced - Gross)
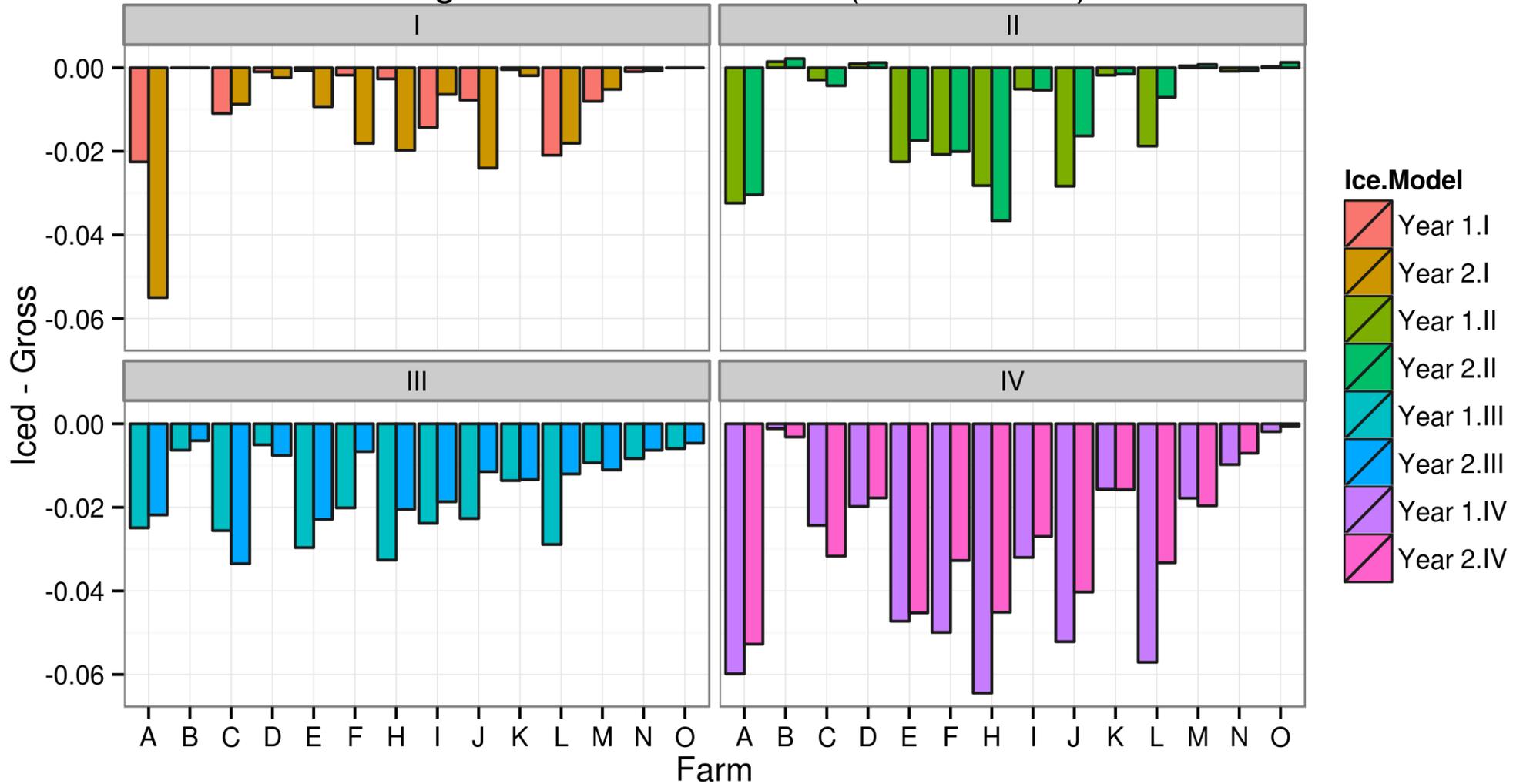
- Using any ice model almost always reduces bias
- Bias reduced more for sites with large amounts of ice
- Not a large change from year to year

Change in Model RMSE (Iced - Gross)
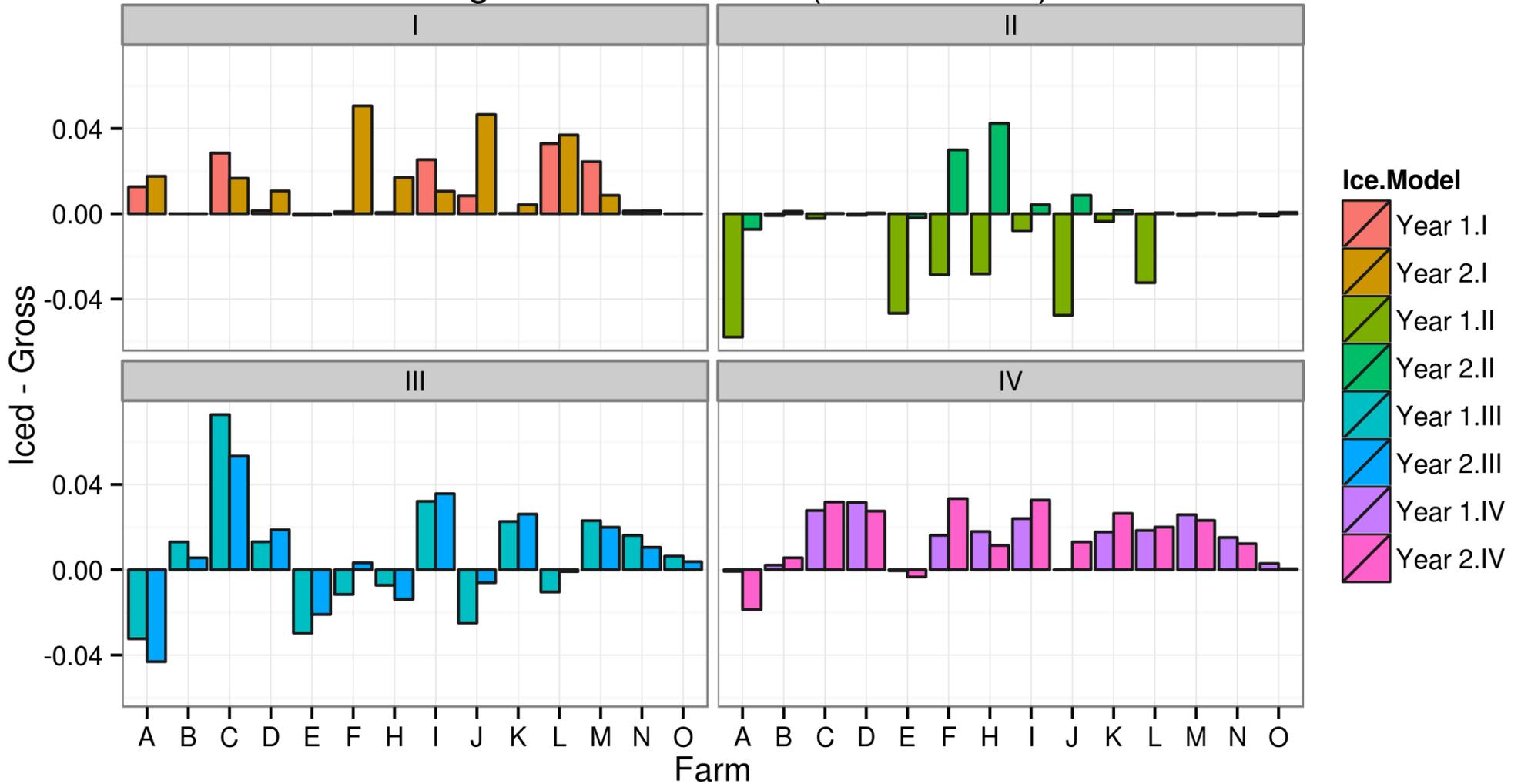
- Iced RMSE often worse than Gross, due to the decrease in performance for non-iced times

- Depending on agreement, bias correction may offset increased error

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