Using Reanalysis Data for the Prediction of Seasonal Wind Turbine Power Losses Due to Icing

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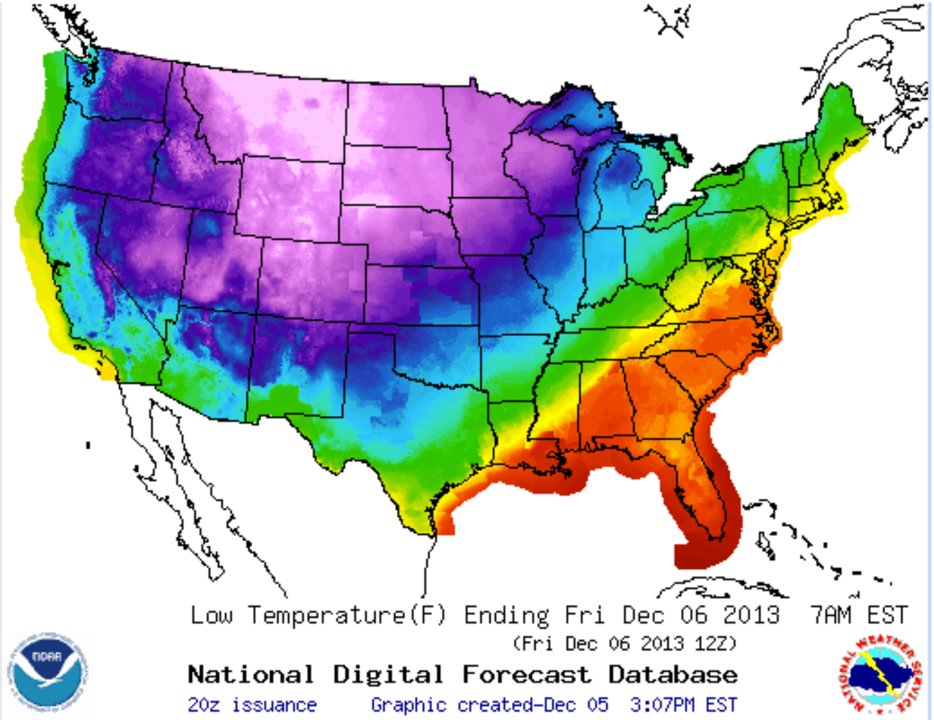
Why Should We Care?

- Icing causes changes in the aerodynamics of turbine blades, thereby reducing energy output.
- In cold climate areas (Baring-Gould et al. 2012) reduced energy output due to icing can be significant.
- Long-term feasibility, siting, and financing studies of new turbine locations require estimates of % annual losses due to icing.



What's Wrong With What We Use Now?

- Typically, a constant value, as a percent of the expected annual energy production, is used for future estimates of icing losses (**industry method**)**.

- The reduction in energy output is highly variable between seasons, locations, and even icing events.

- Need to develop a method to more accurately predict icing losses and compare with the typical constant value.

Icing Determination

- Ideally, liquid water content (LWC) and droplet size distribution (DSD) used with temperature and wind speed.
    - LWC and DSD are difficult to measure in operational environments
- Relative humidity (RH) to be used as a proxy.

Icing Determination

- Fikke et al. (2007) use RH > 95 % and T < 0 °C.

- Baring-Gould et al. (2012) suggest that using a high RH can overestimate frequency of icing events.

- Cattin et al. (2008) showed the calculation of RH where saturation vapor pressure is determined with respect to ice for low temperatures, improved icing detection by 10%.

Study Location

- 900-kW turbine located in Petersburg, ND.
- Operational since July 2002.
- Meteorological tower with anemometers at three heights.
- Four MERRA grid points surrounding turbine location.

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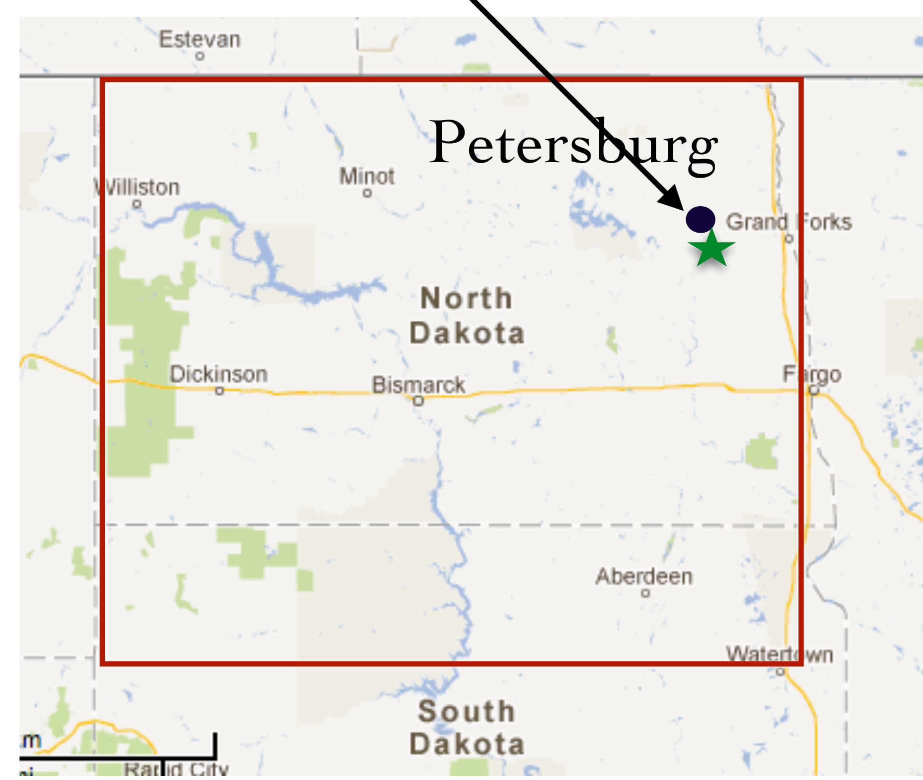

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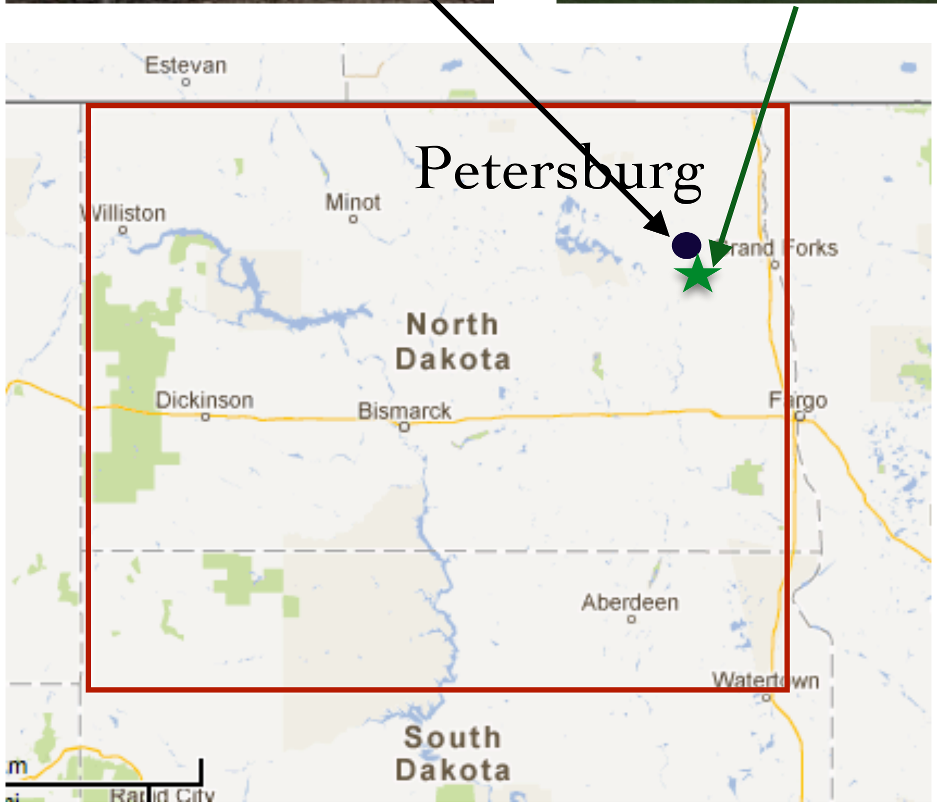

Methods to Determine Icing

- Three methods of determining required atmospheric variables at the turbine location and height.

Method	Wind Speed	Specific Humidity	Temperature
1	MCP Analysis + Terrain Model	Interpolated	Interpolated
2	MCP Analysis + Terrain Model	10 m Value	10 m Value
3	MCP Analysis + Terrain Model	Boundary Layer Similarity	Boundary Layer Similarity

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MCP/Terrain Model

- Measure-Correlate-Predict (MCP)
  - Linear regression of two-year anemometer data to fit MERRA data.
  - Produces a longer-term wind speed dataset.
- Industry software used to translate to turbine location and height using terrain flow model.

Determining **Observed** Icing Losses

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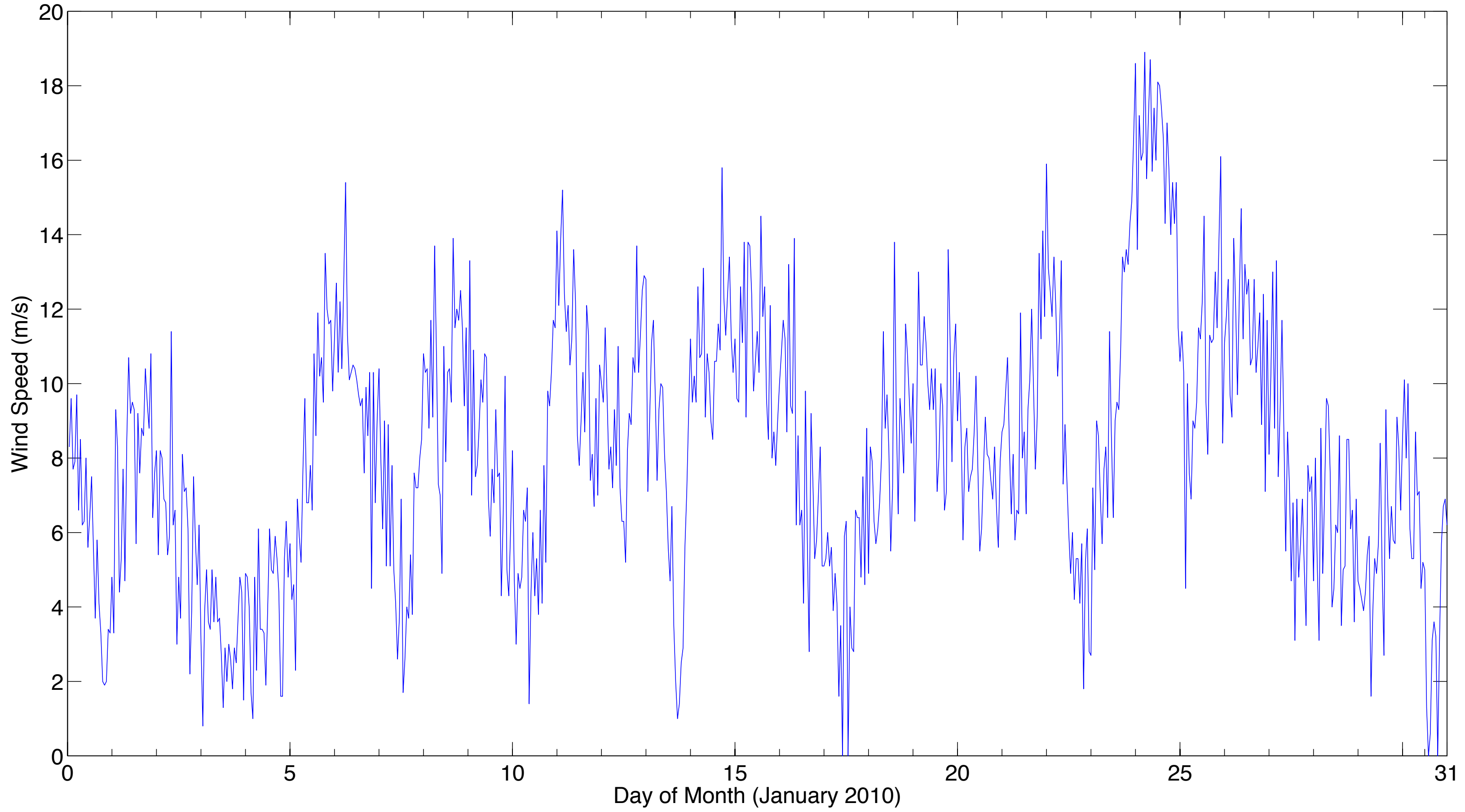
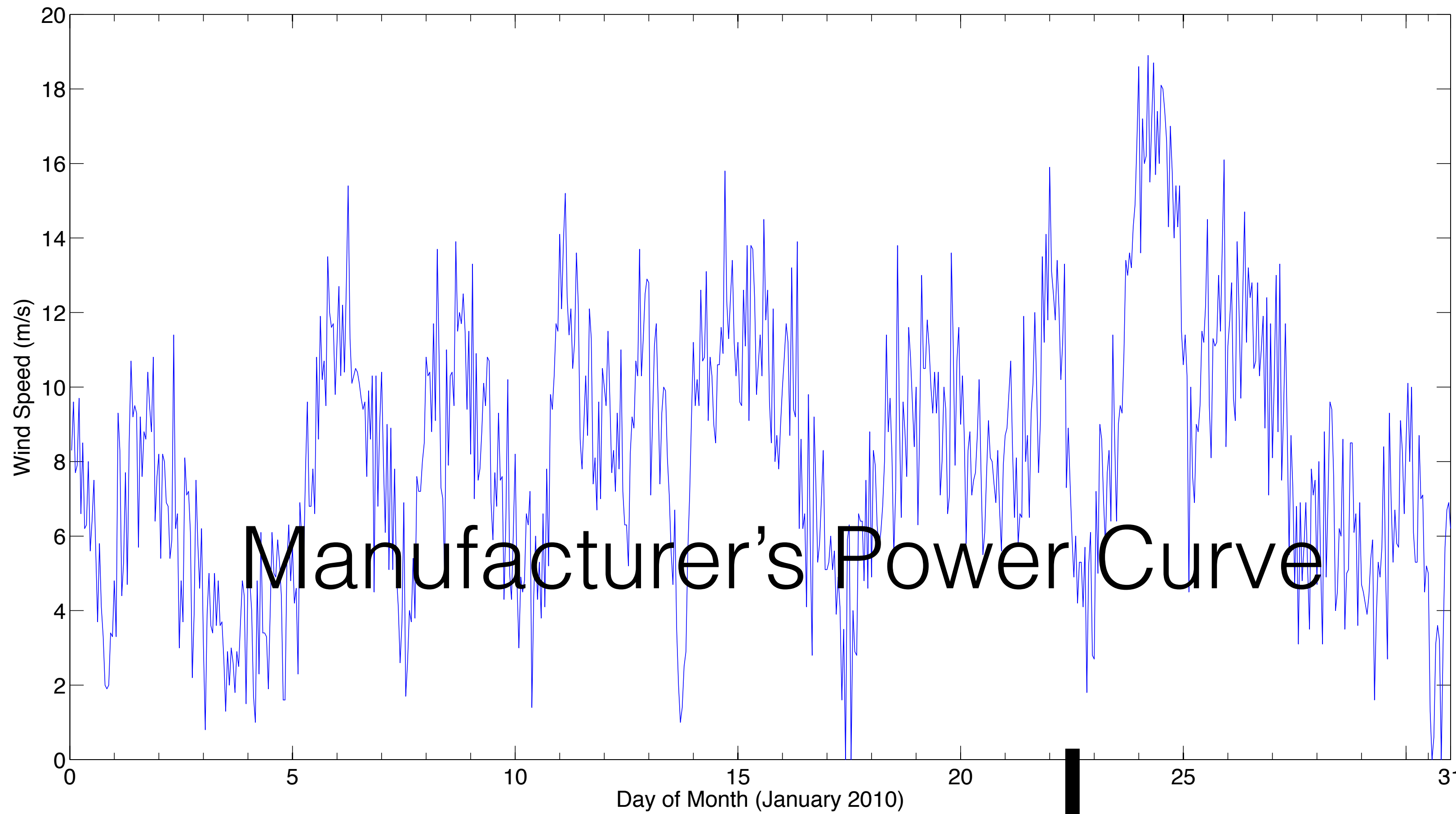
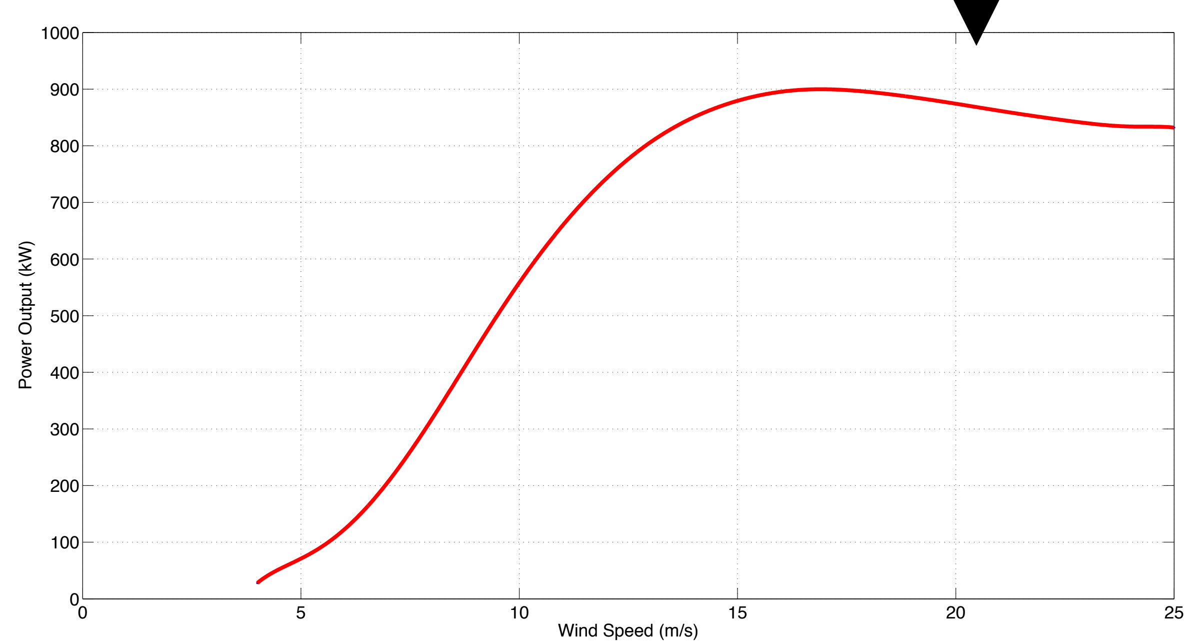


Wind speed at turbine height

Determining **Observed** Icing Losses



Manufacturer's Power Curve



Determining **Observed** Icing Losses

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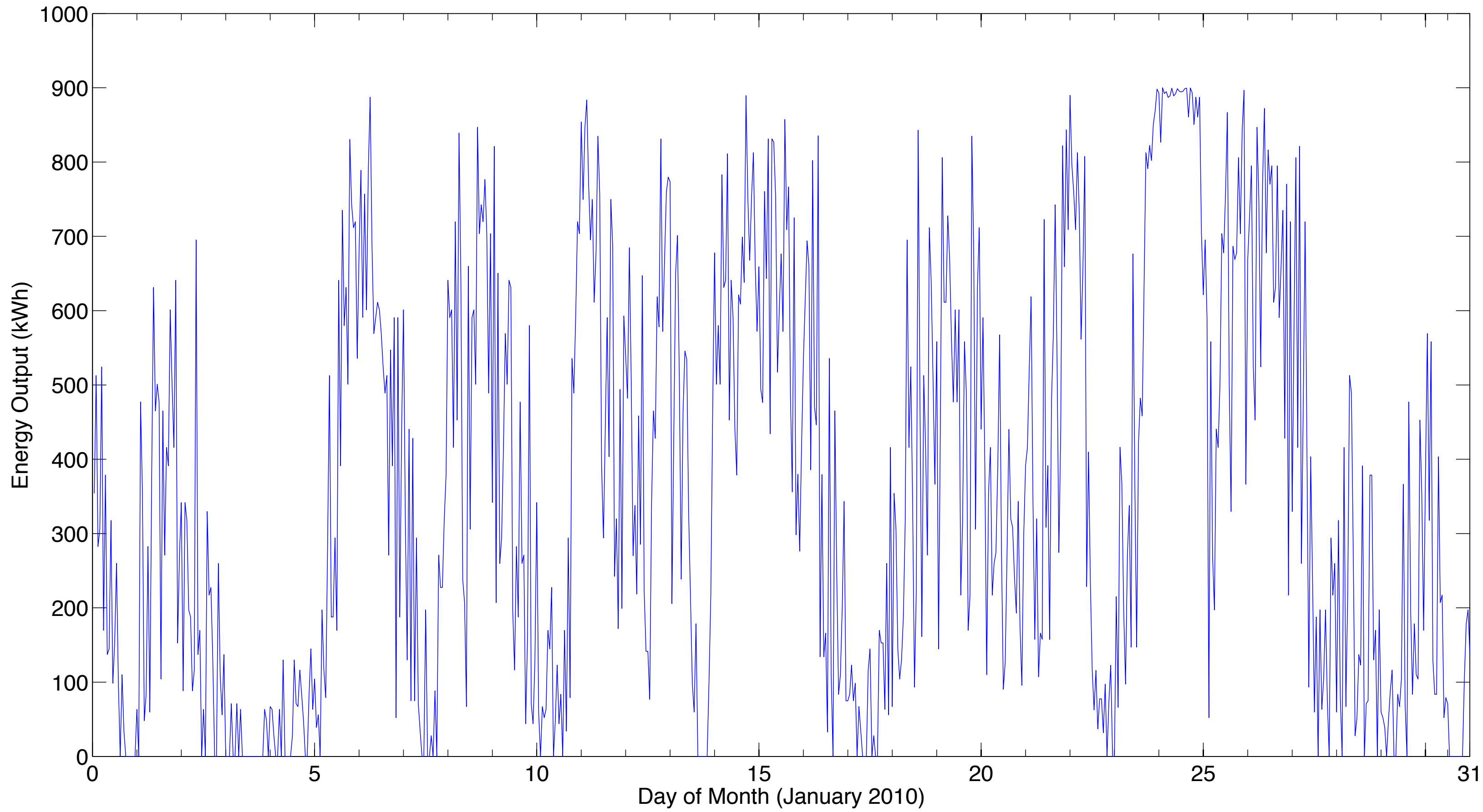
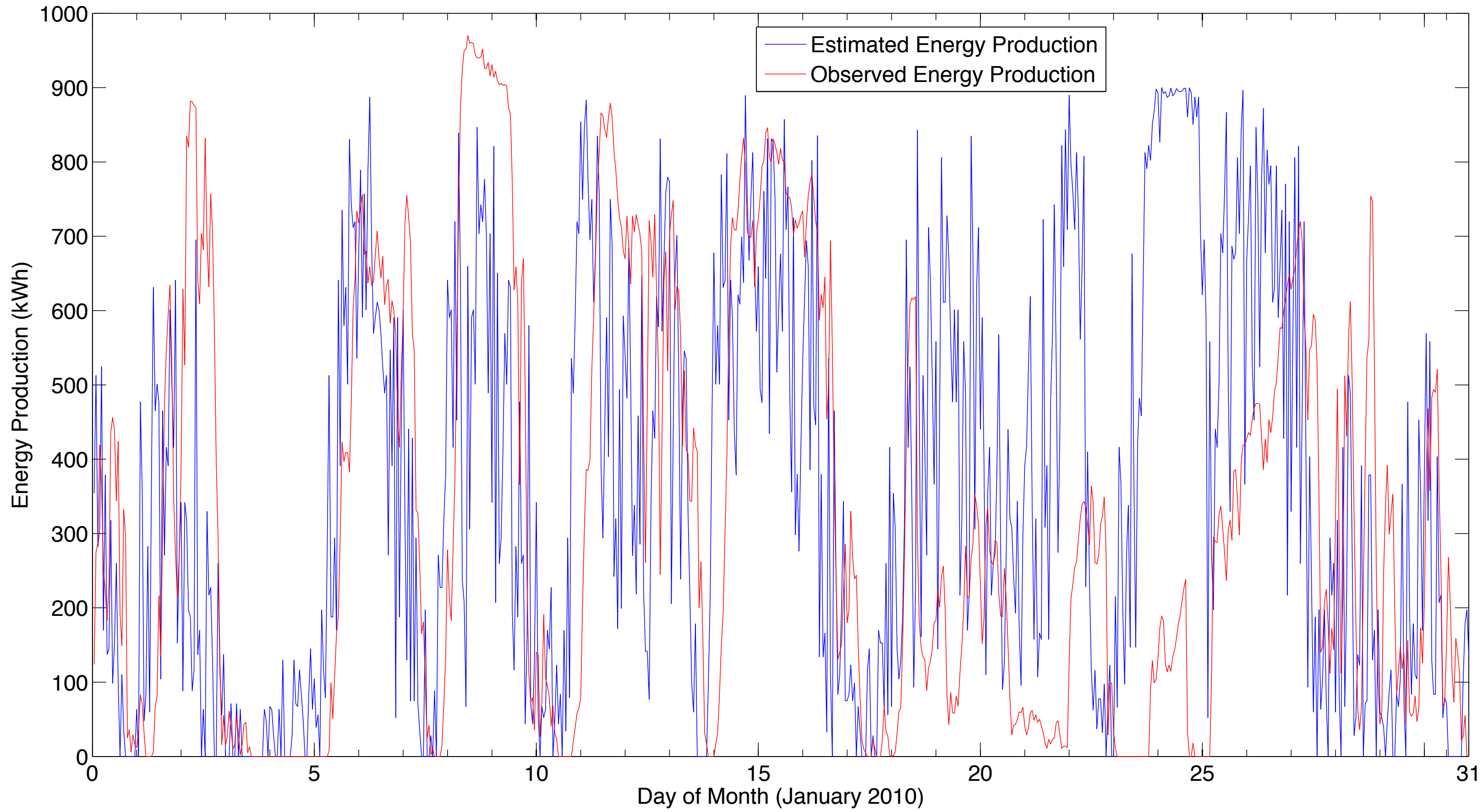
Estimated Energy Production



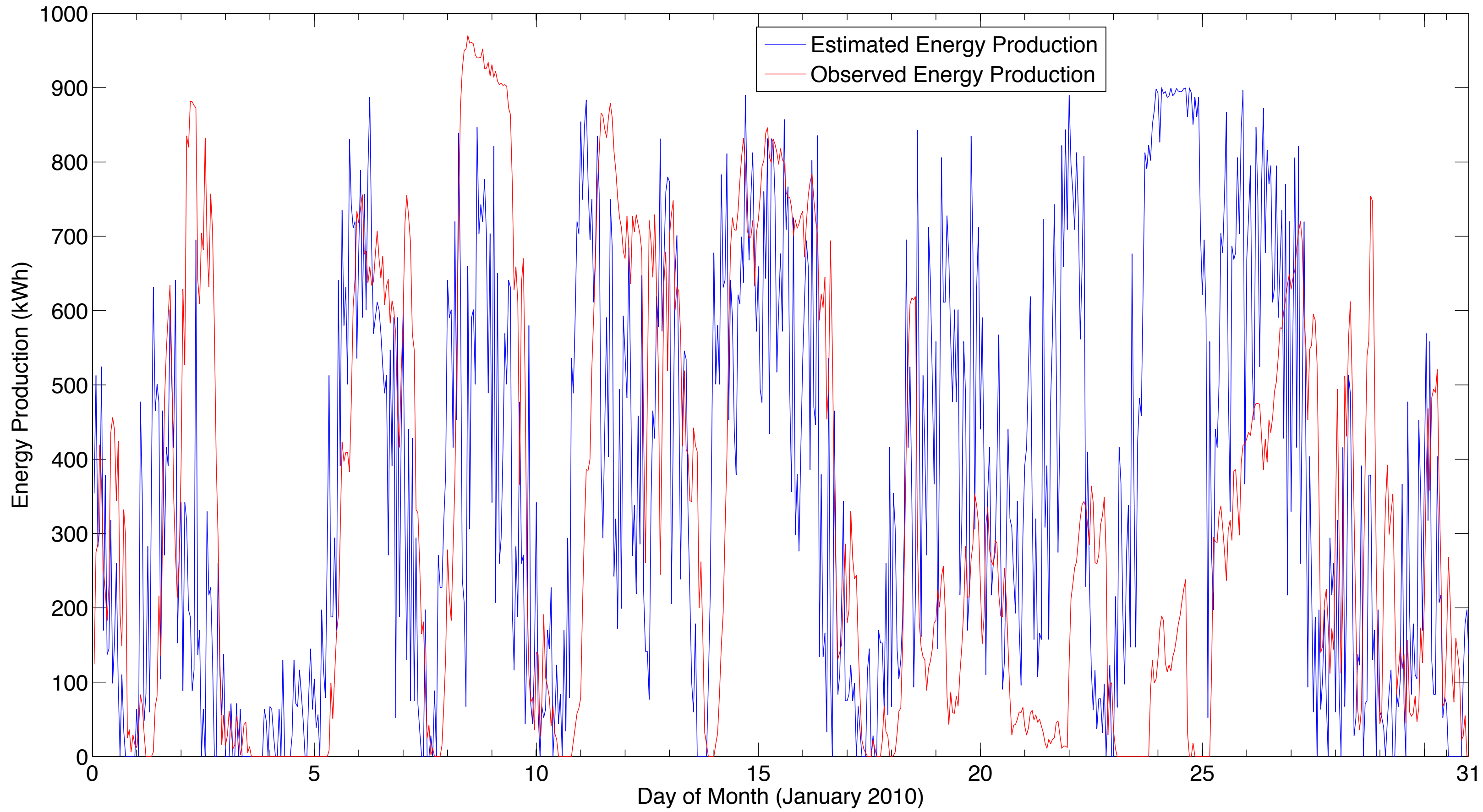
Determining **Observed** Icing Losses

Compare to Observed Production Data



Determining **Observed** Icing Losses

Observed Less than 80% of Estimated?



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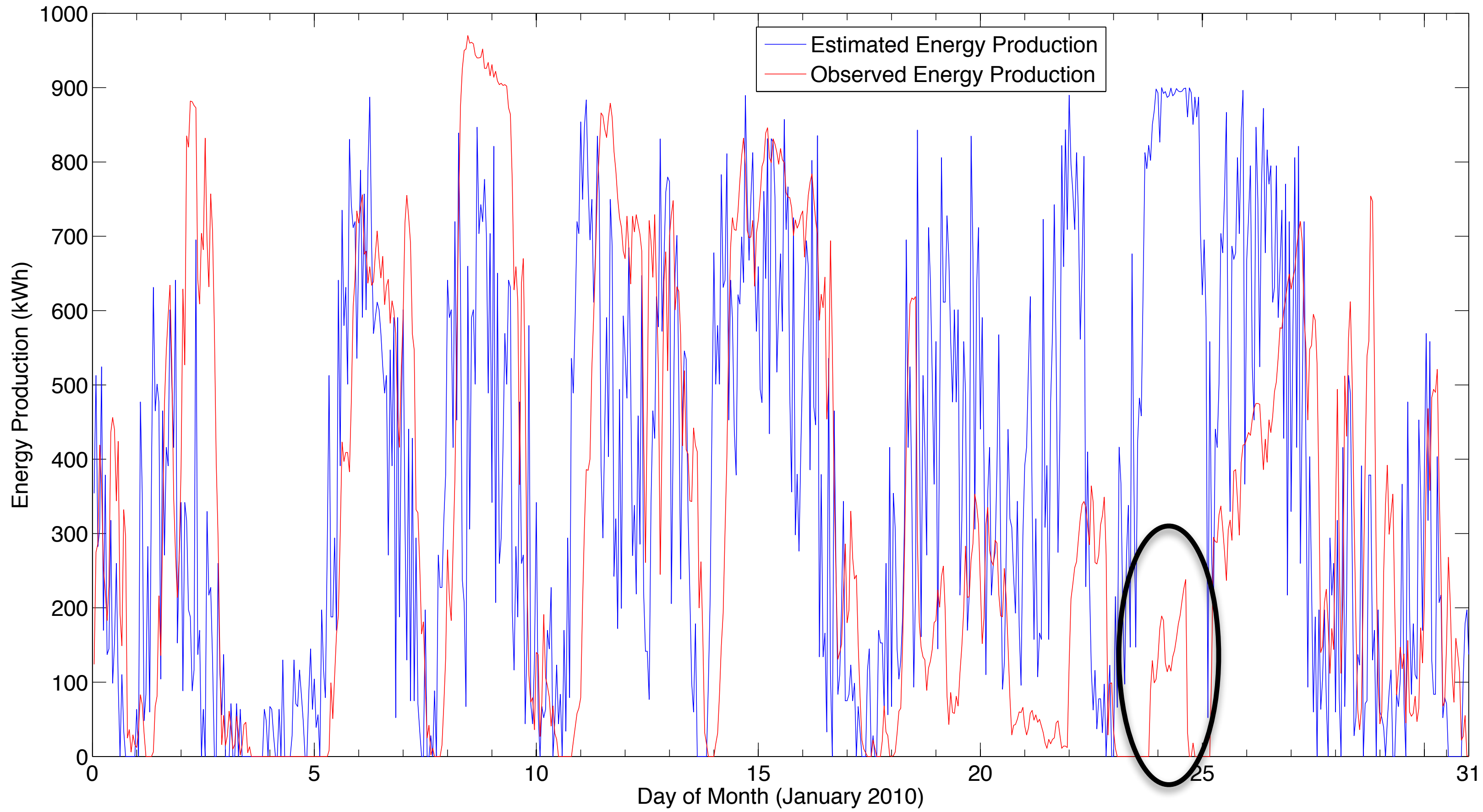

ICING!!

Determining **Observed** Icing Losses

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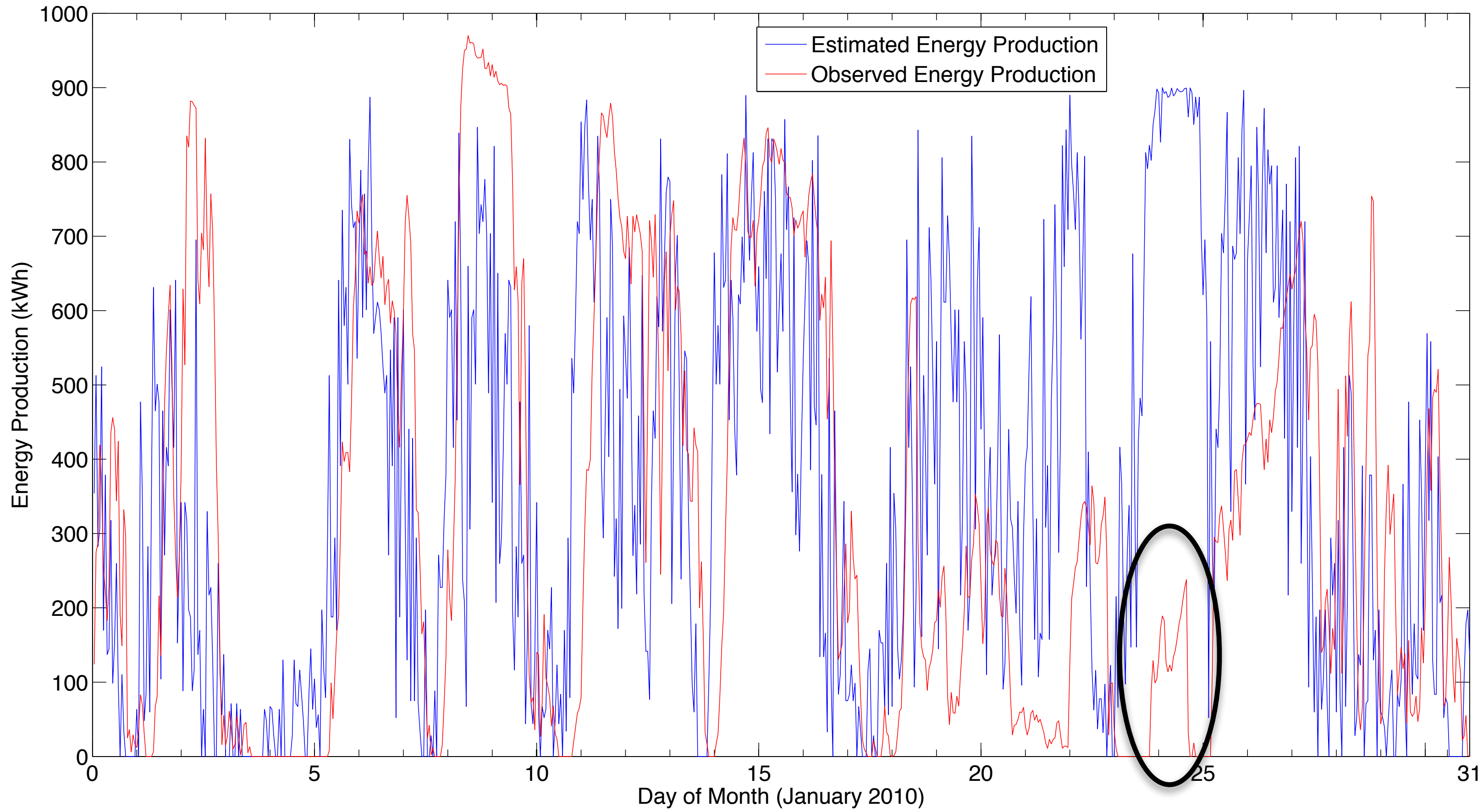

Difference is observed icing loss.

Determining **Observed** Icing Losses

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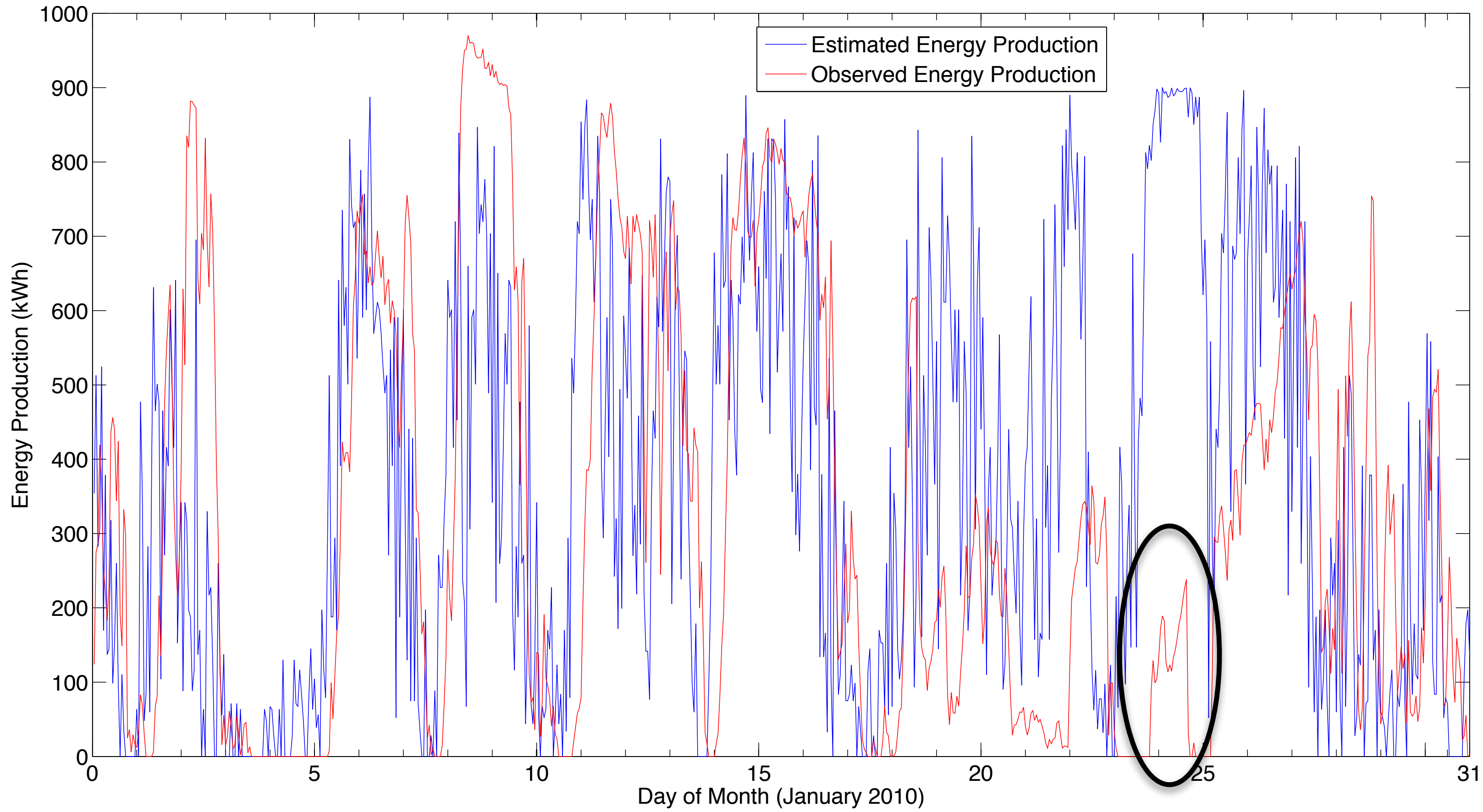
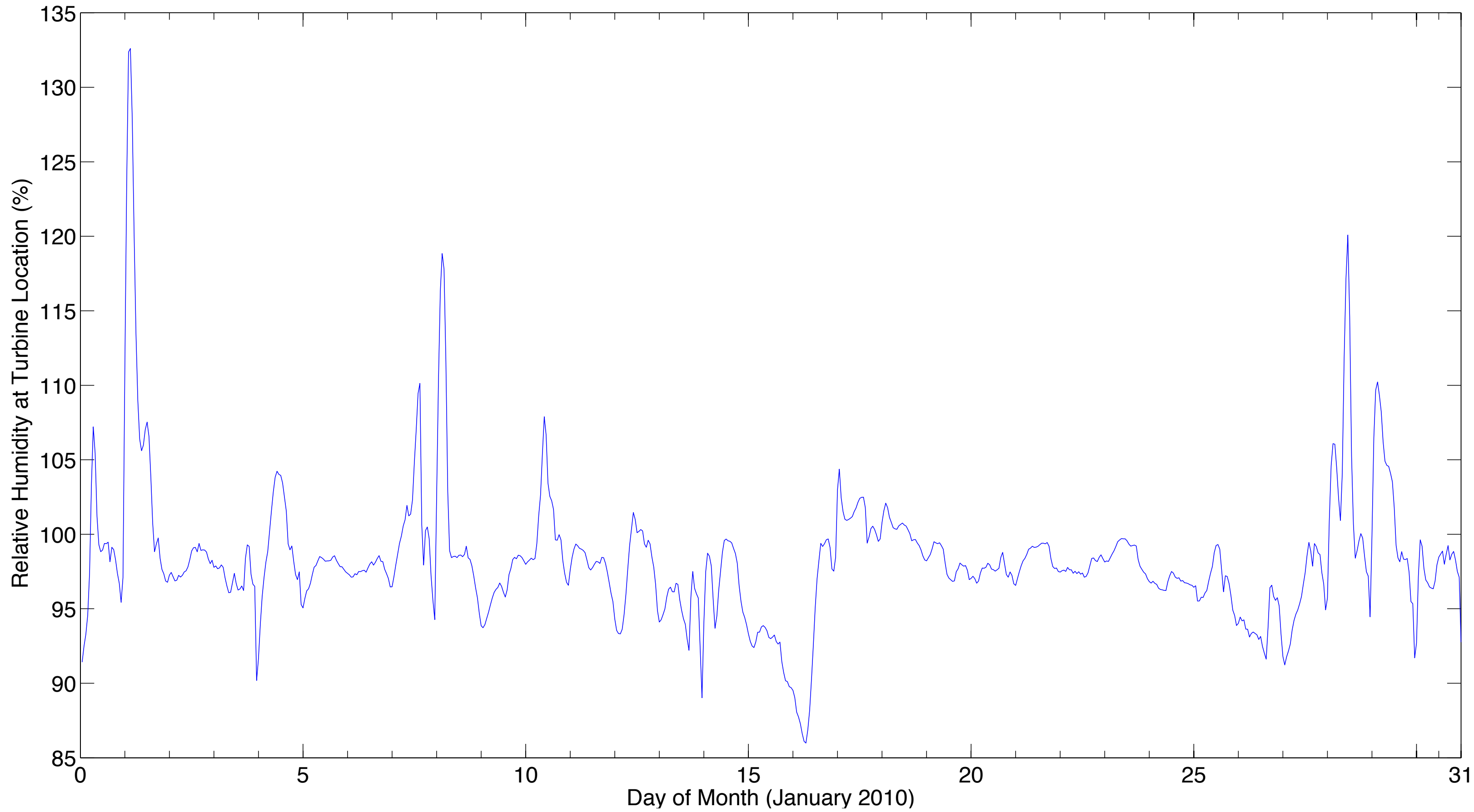


Difference is observed icing loss.

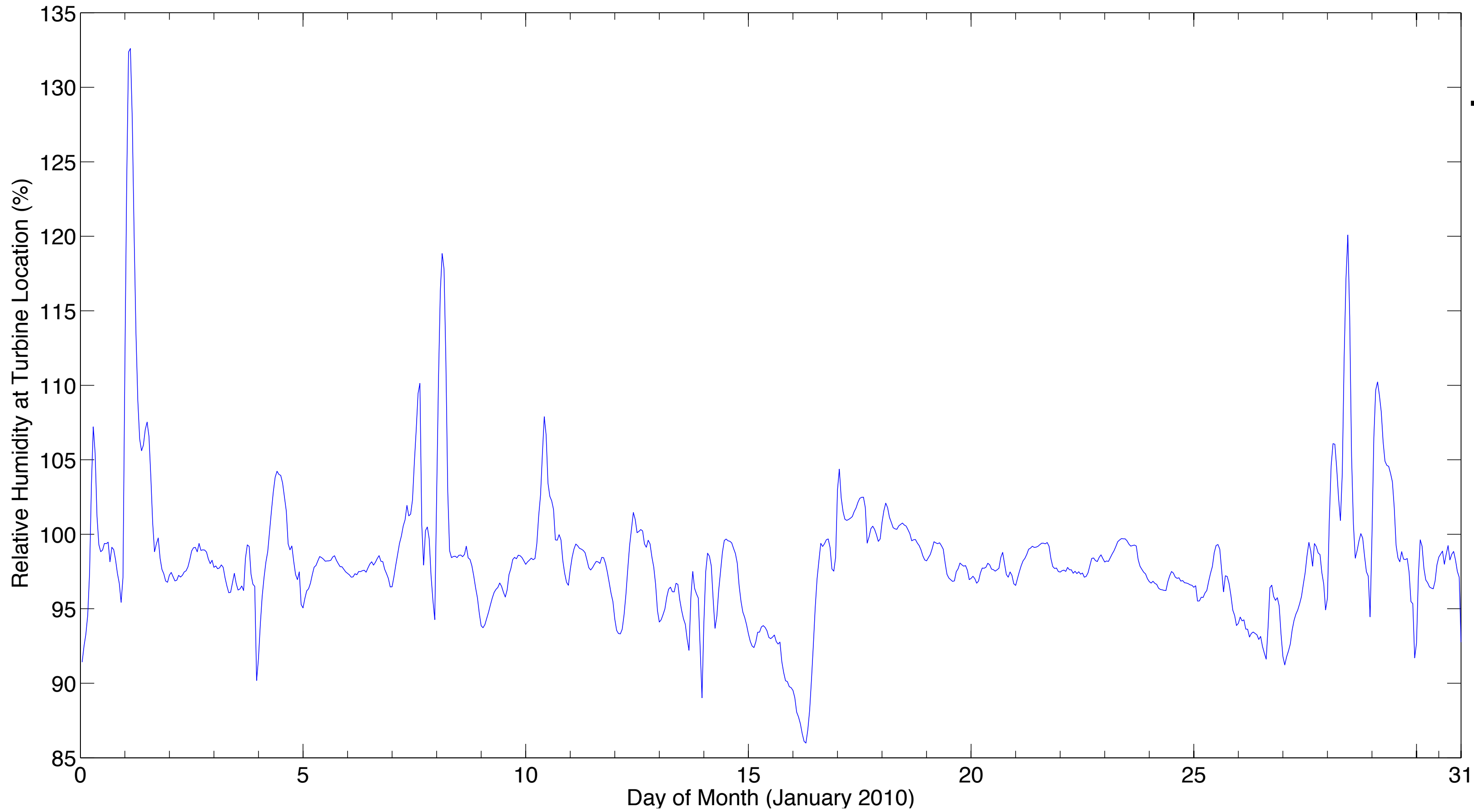
Sum over entire season.

Determining **Predicted** Icing Losses



Determining **Predicted** Icing Losses

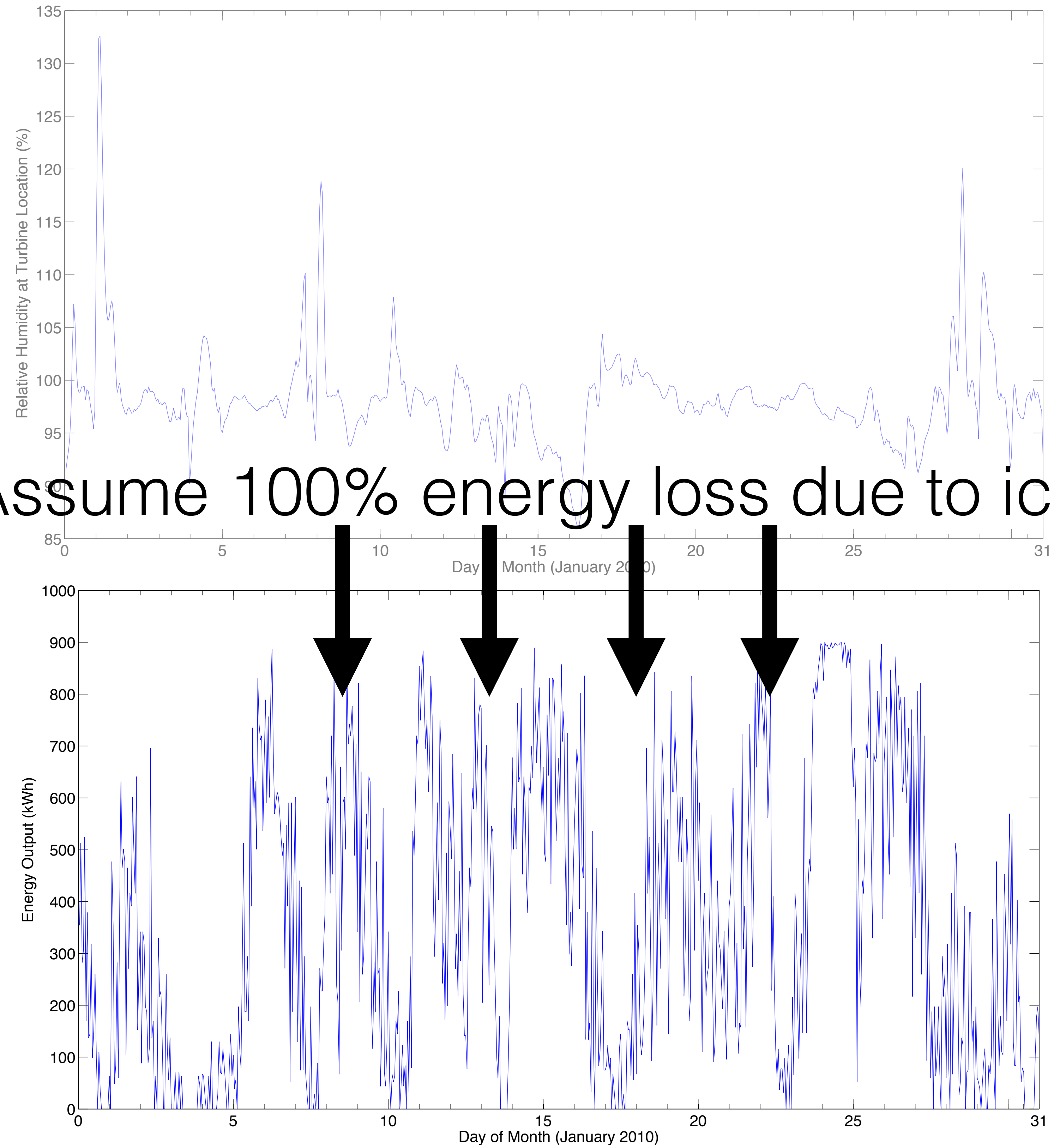
Calculated RH greater than threshold?



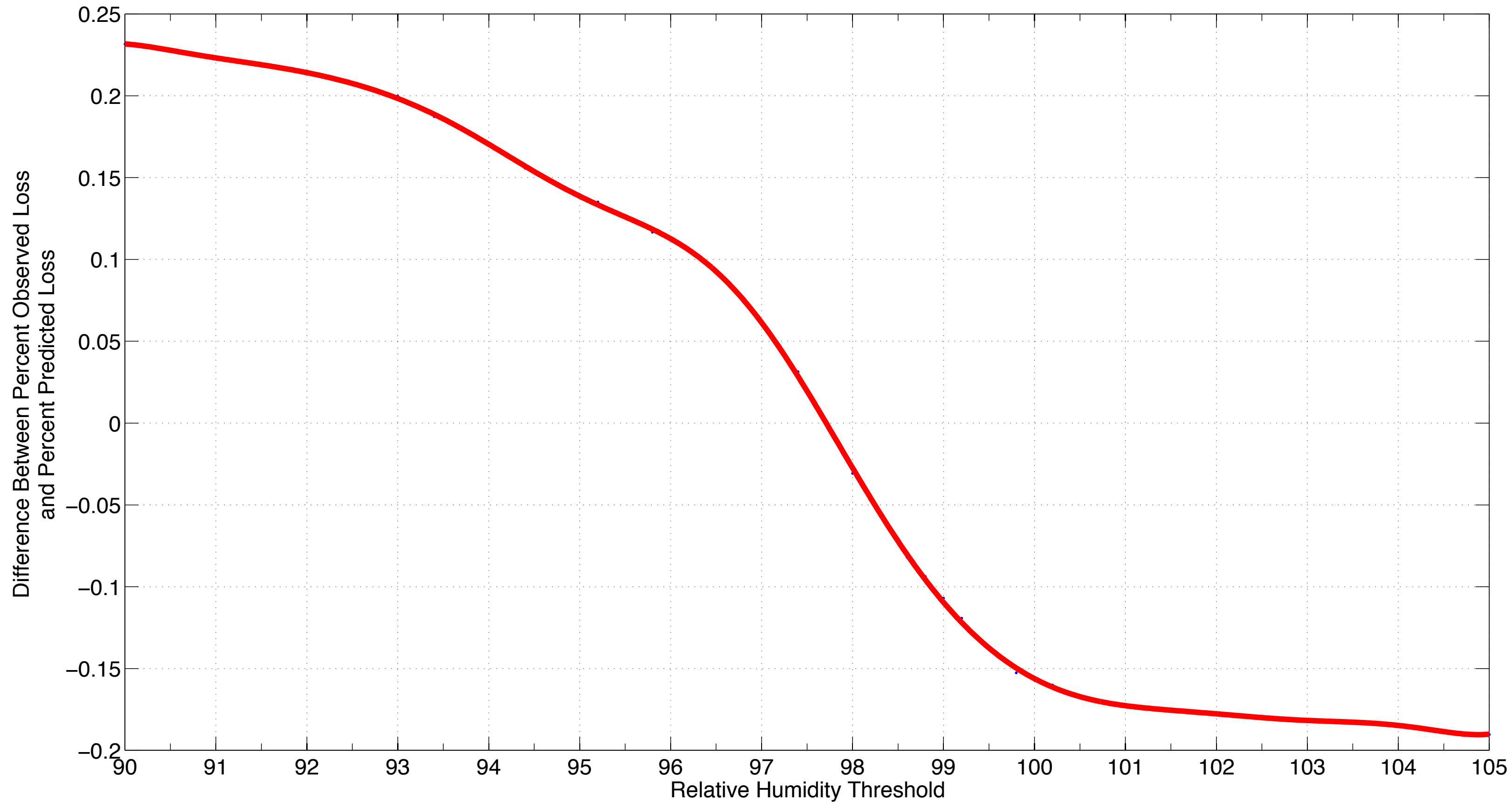
T < 0 °C

RH Threshold varies from 90% to 105%

Determining **Predicted** Icing Losses



Best RH Threshold?



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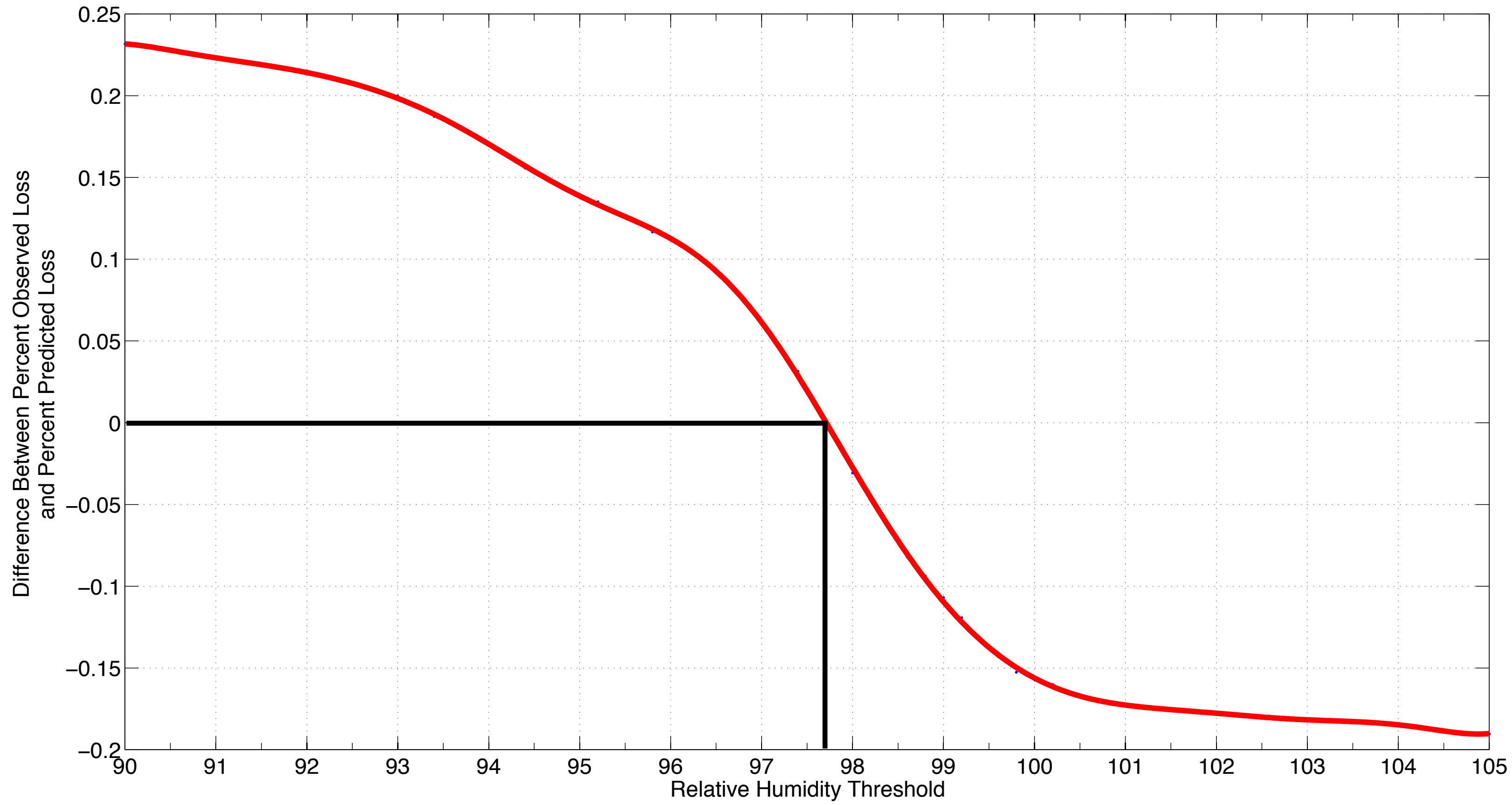
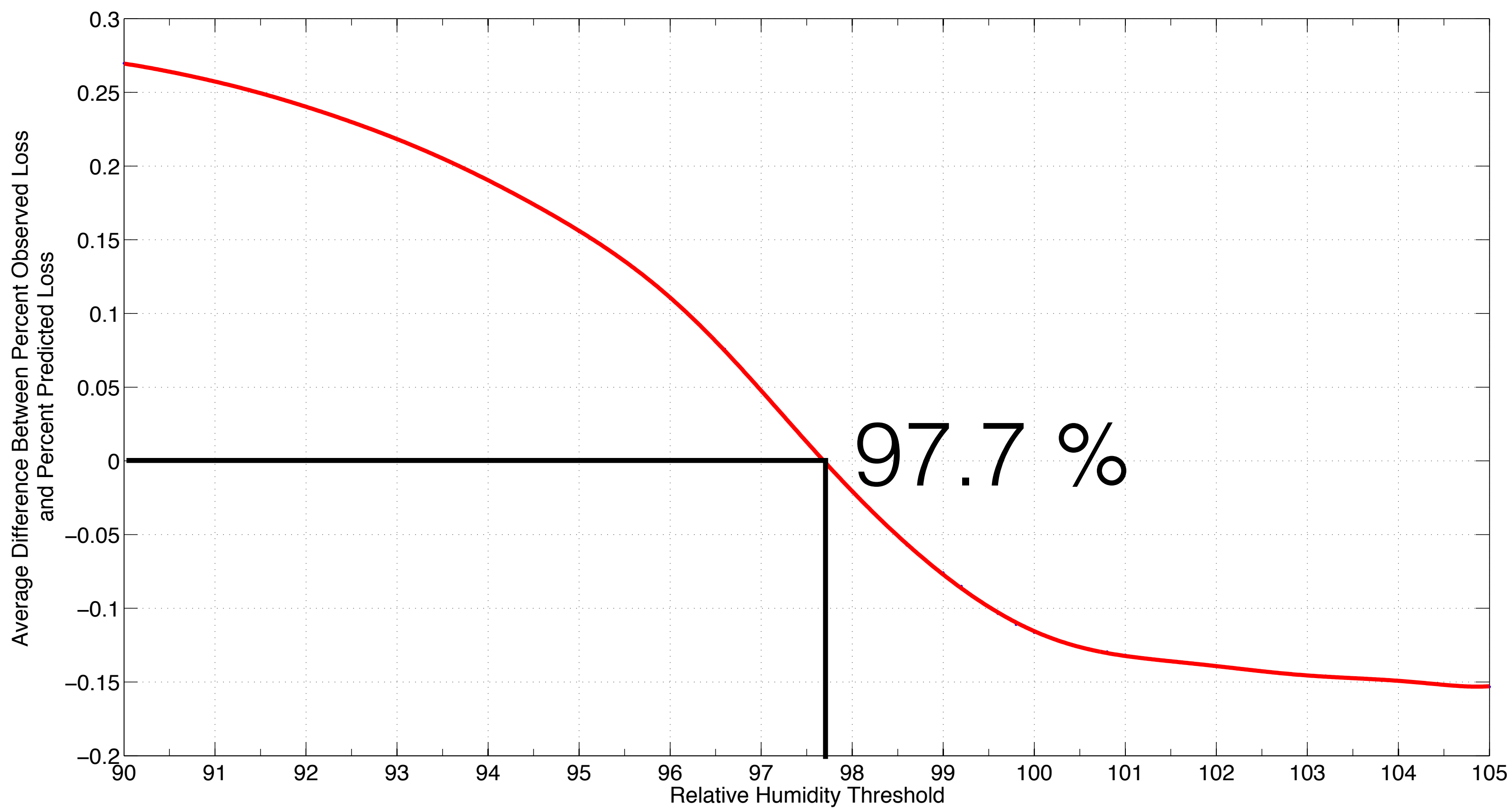


For Season ending March 2010

Best RH Threshold?



Average for all eight seasons - Oct-Mar, 2002-2010

Testing of Methods

- Three winter seasons (2010 - 2013).
- Include remaining six months of ice-free energy production data to generate observed and predicted **annual** loss due to icing.

How Did We Do?

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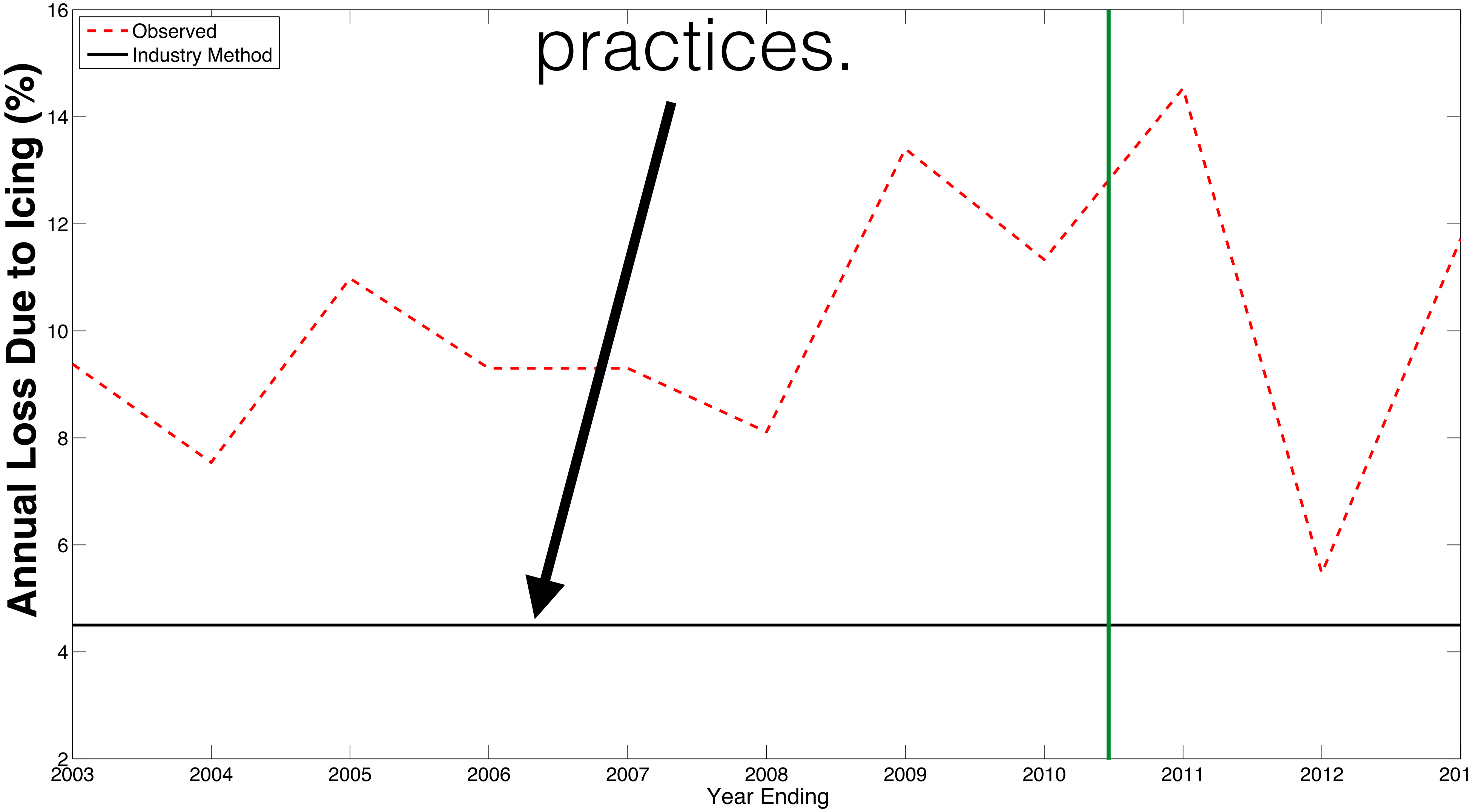
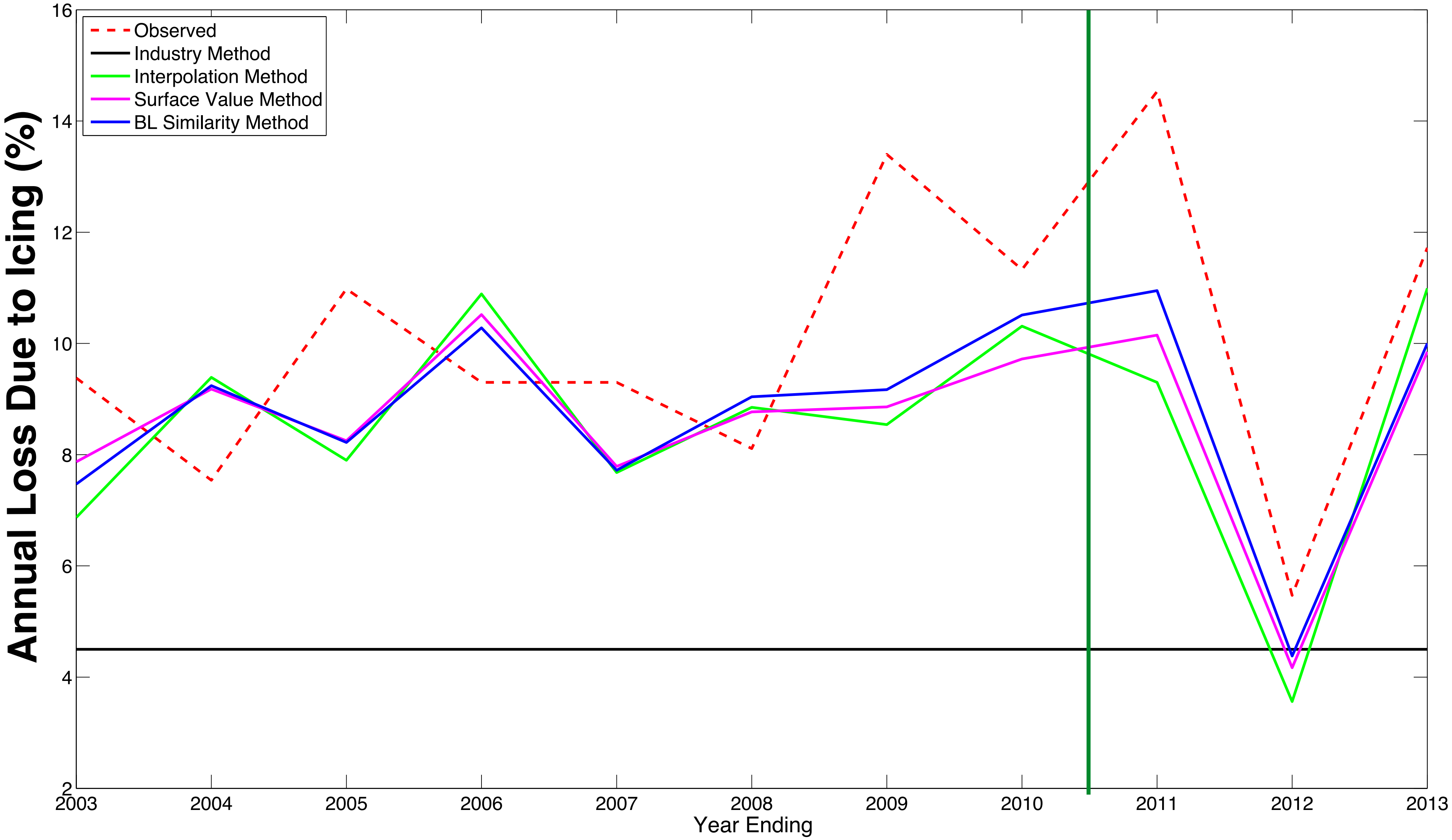
Provided by EAPC, calculated using standard industry practices.



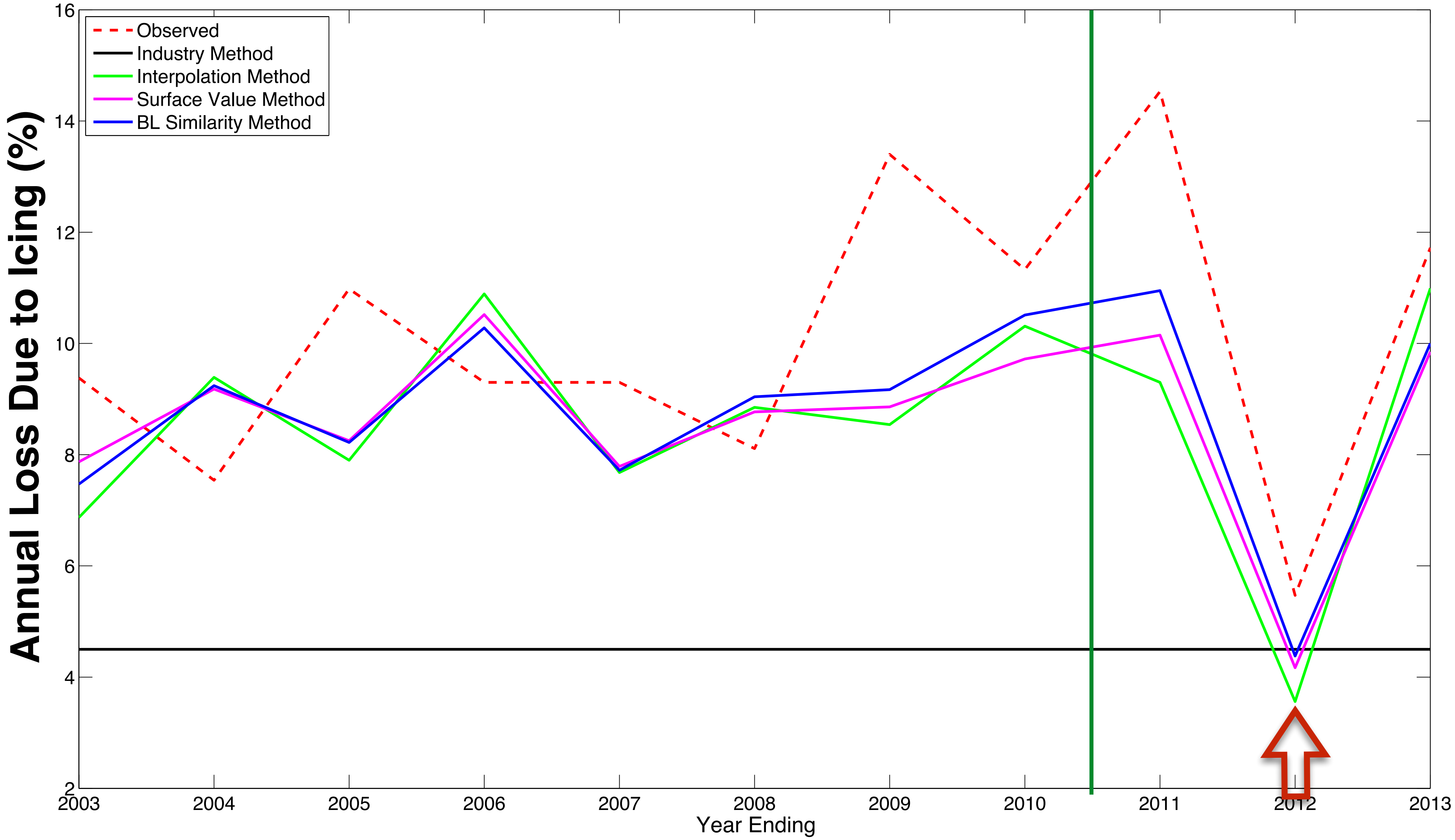
Training Years

Test Years

How Did We Do?


Observed
Industry Method
Interpolation Method
Surface Value Method
BL Similarity Method
Annual Loss Due to Icing (%)
16
14
12
10
8
6
4
2
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year Ending

How Did We Do?



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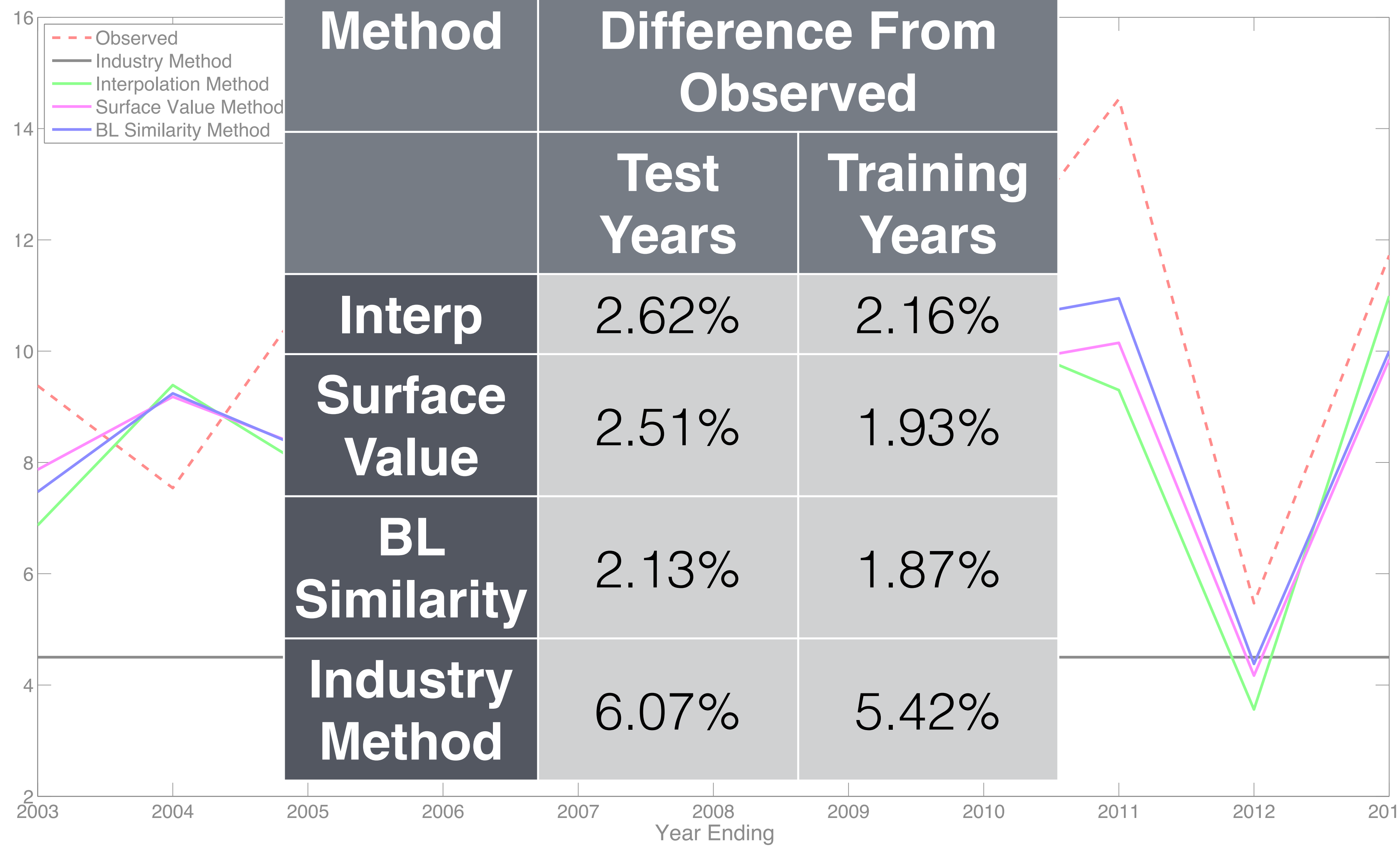

Method	Average Absolute Difference From Observed	
	Test Years	Training Years
Interp	2.62%	2.16%
Surface Value	2.51%	1.93%
BL Similarity	2.13%	1.87%
Industry Method	6.07%	5.42%

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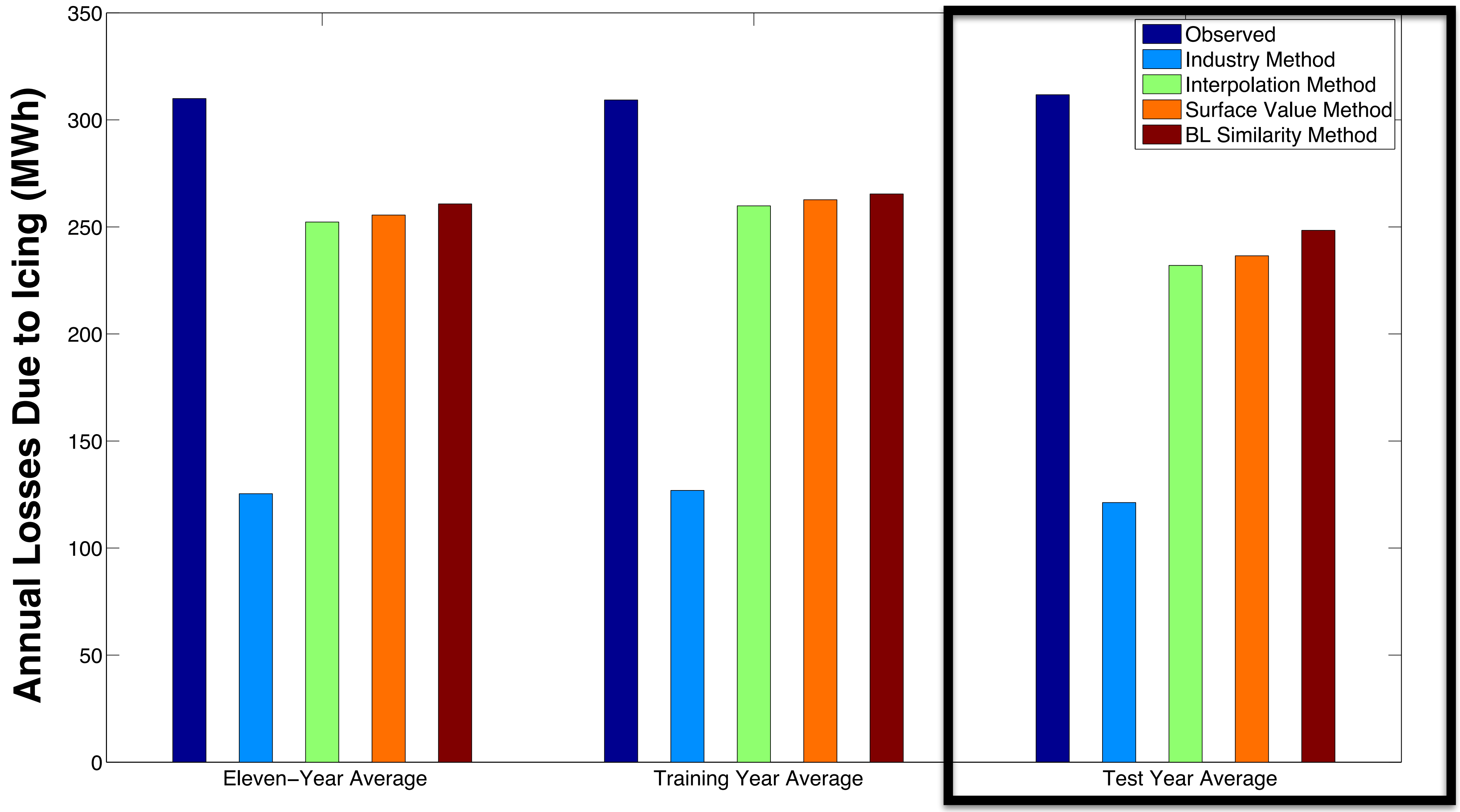
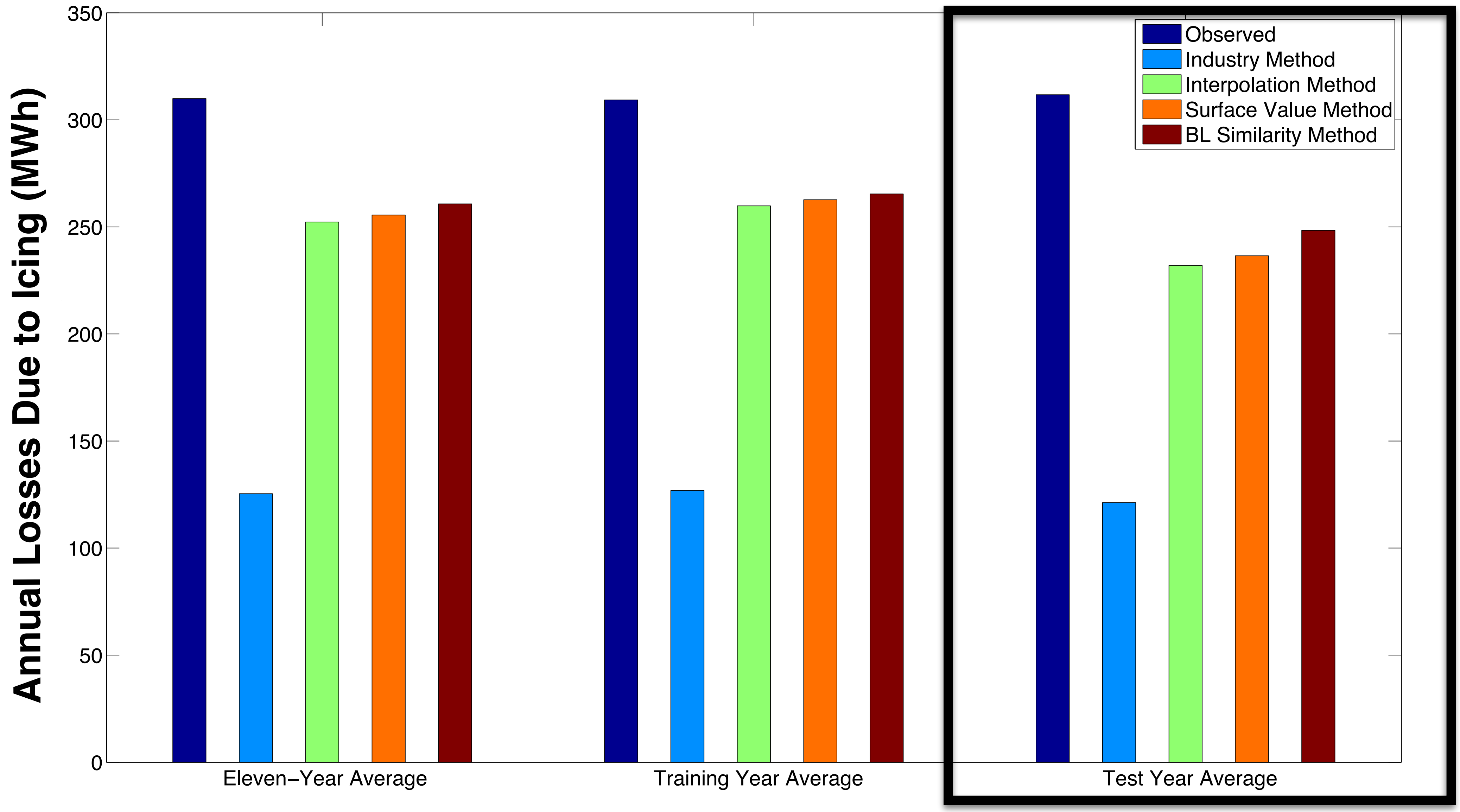


Annual Losses Due to Icing (MWh)
350
300
250
200
150
100
50
0
Observed
Industry Method
Interpolation Method
Surface Value Method
BL Similarity Method
Eleven−Year Average
Training Year Average
Test Year Average

How Did We Do?

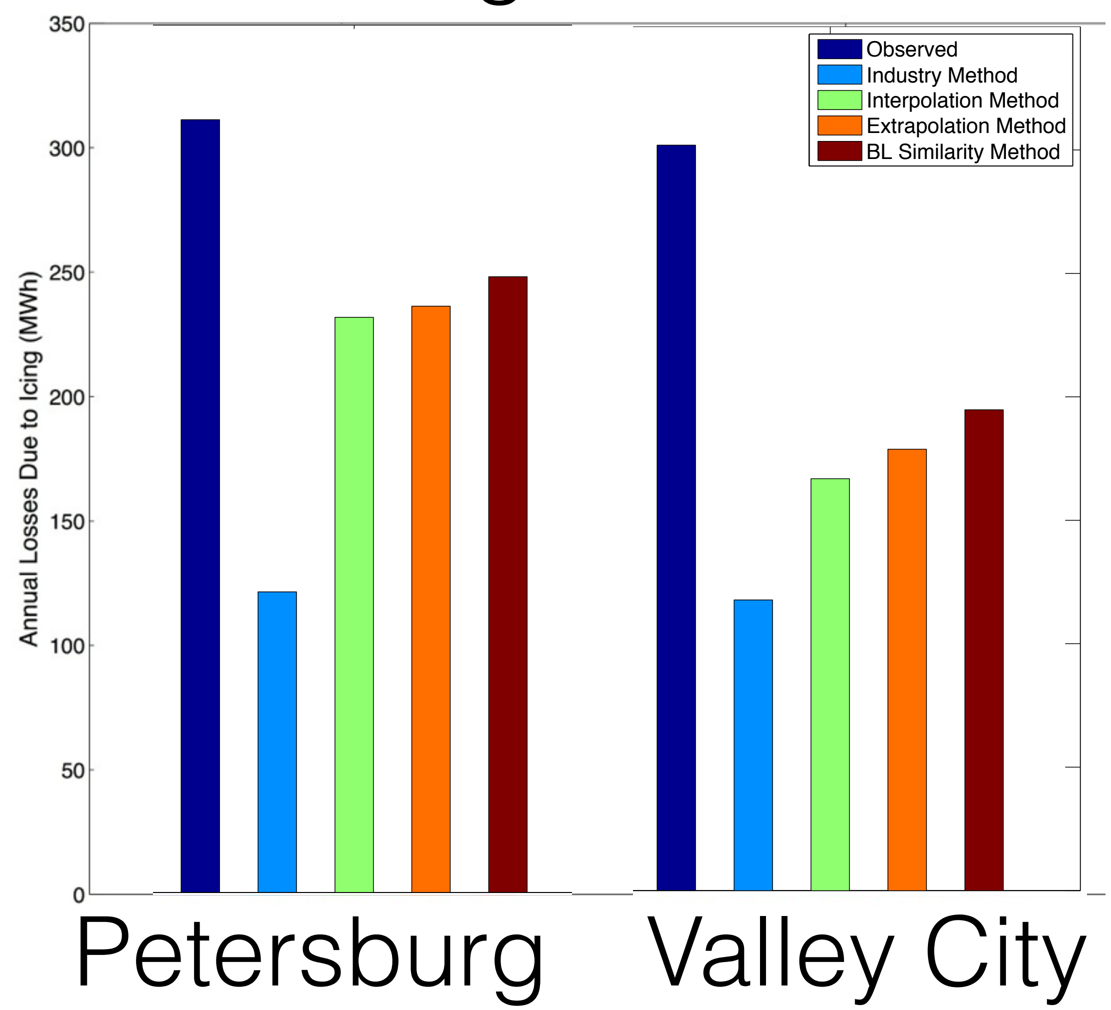


Assume $30/MWh and 50 turbine wind farm:

OBS - $465,000
IND - $182,000
BL - $372,000

Regional Applicability of Results

- Preliminary analysis of second location without training data but using same RH thresholds.



- Provided the data exists, these methods could be applied to any location and with dense enough network, could develop icing climatology maps.

Conclusions

- Using **industry method** (constant value) for icing loss:
  - Severely under-estimates % annual losses (**over 6% difference** from observed)
  - Predicted energy lost due to icing is **~ 60% lower** than observed.
  - Under-predicting financial losses (large wind farms)!
- **Reanalysis methods** are better predictors of icing losses than the constant value.
  - **Difference** from observed % annual losses is **2.1% - 2.7%**.
  - Predicted energy lost due to icing **16% to 19% lower** than observed.