Quantifying the impact of ice accretion on turbine life for Scandinavia using numerical modelling

9th February 2016

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Study purpose

- To demonstrate a more rigorous approach for estimating turbine ice loads using numerical modelling
- Current rules and guidelines provide deterministic inputs, conservatively set
  - Ice mass distribution
  - Number of days 2 blades iced
- This approach has been fed by input data from real Scandinavian site conditions

Source: Fraunhofer

Who is DNV GL Turbine Engineering?

- **>20 years experience in turbine technical analysis**
  - Turbine loads analysis
  - Control algorithm design
  - Mechanical and structural design
  - Bladed industry leading wind turbine simulation software
- **Unique joint services coupled with energy assessment**
  - Energy assessment & turbine site suitability analysis
  - Project life assessment
  - Generic turbine models

The view from our energy colleagues

- DNV GL continue to invest in cold climate energy prediction:
  - Till Beckford – Update to DNV GL's icing map of Sweden and methodology of estimating icing losses

- Our energy analyst colleagues suggested we look into the loading implications of the iced operation that they see in Scandinavian project SCADA data:

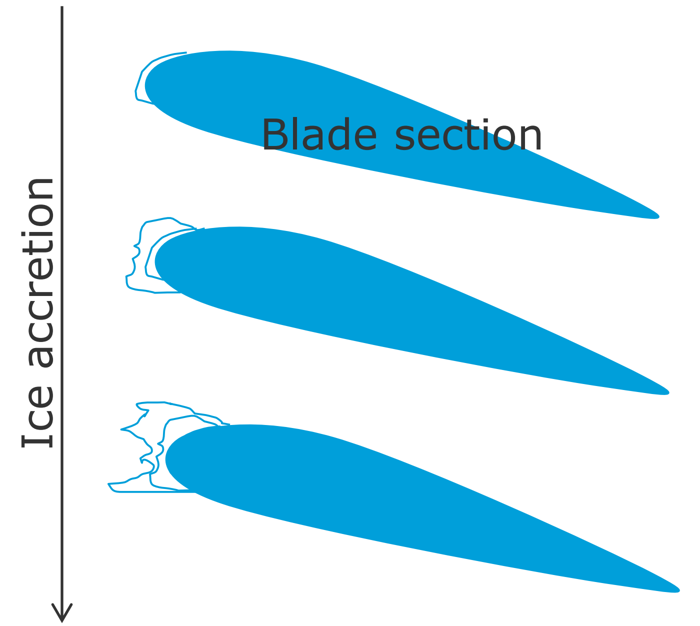
  "Turbines are typically kept operating rather than being shutdown under icing conditions in Scandinavia. This could reduce icing losses particularly in regions where icing is severe, but consequences to turbine life time are not yet known to DNV GL"

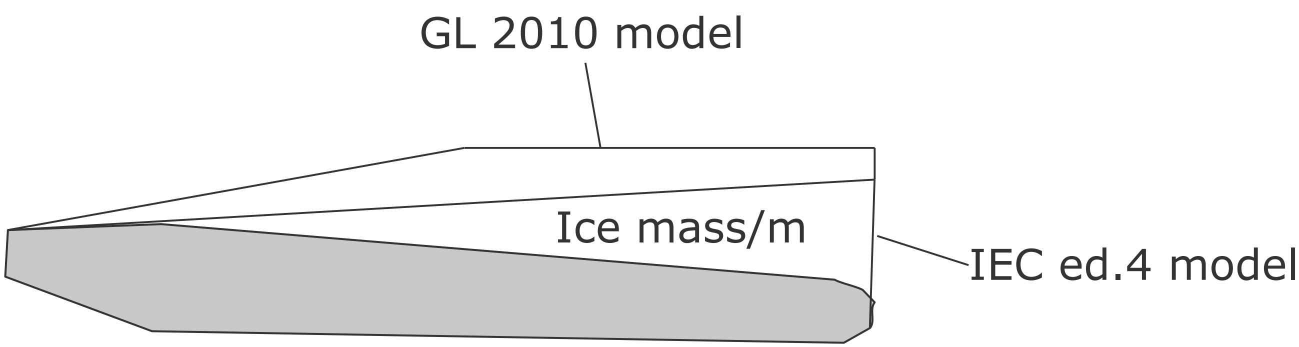
Raises big question:
Are turbine ice-shutdowns being over-ridden? How?
- If so what type of alarms are overridden? – Public safety? Turbine safety?

?

Effect of ice accretion on a cold climate project

- Poor aerodynamics – performance degradation
  - Power/Energy loss
  - Potential stall issues
- Blade mass increase
  - Increase in gravity loading
- Blade asymmetry – rotor mass/aero imbalance
  - Increase in imbalance mass loading
  - Increase in aerodynamic imbalance loading





Standard ice mass distributions

Necessary information when assessing cold climate turbine loads

- Ice severity (mass/metre of blade)
- Ice duration (time spent with ice)
- Correlation between ice severity & ice duration
- Distribution of ice (homogenous/in-homogenous)
- Impact of ice on turbine performance (power degradation)
- Turbine response to iced operation

- What does the SCADA tell us?
  – Power degradation during ice operation
  – Duration of ice operation

Necessary information when assessing cold climate turbine loads

- Ice severity (mass/metre of blade) ✗
- Ice duration (time spent with ice) ✓
- Correlation between ice severity & ice duration ✗
- Distribution of ice (homogenous/in-homogenous) ✗
- Impact of ice on turbine performance (power degradation) ✓ ✗
- Turbine response to iced operation ✗

- What does the SCADA tell us?
  - Power degradation during ice operation
  - Duration of ice operation

Easy to obtain site specific data?

Input SCADA data

- We built upon SCADA analysis performed by our energy analyst colleagues
- Highest altitude sites, most iced operational time

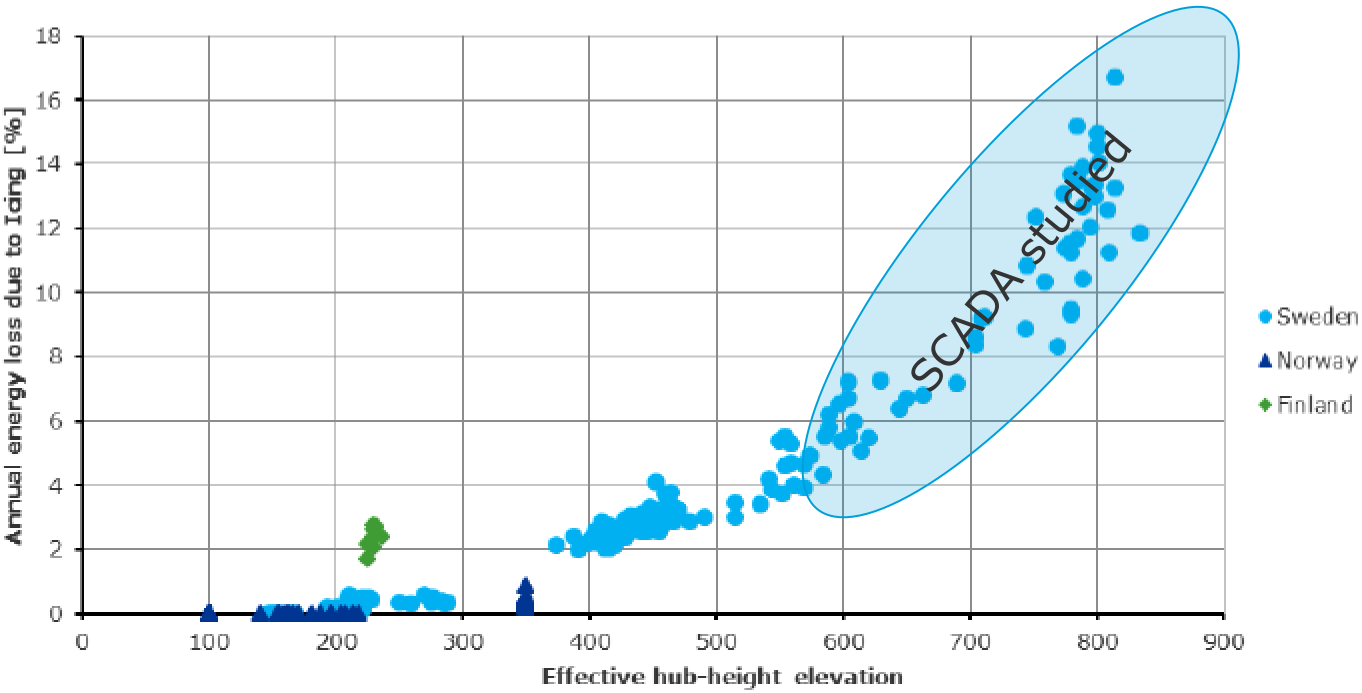
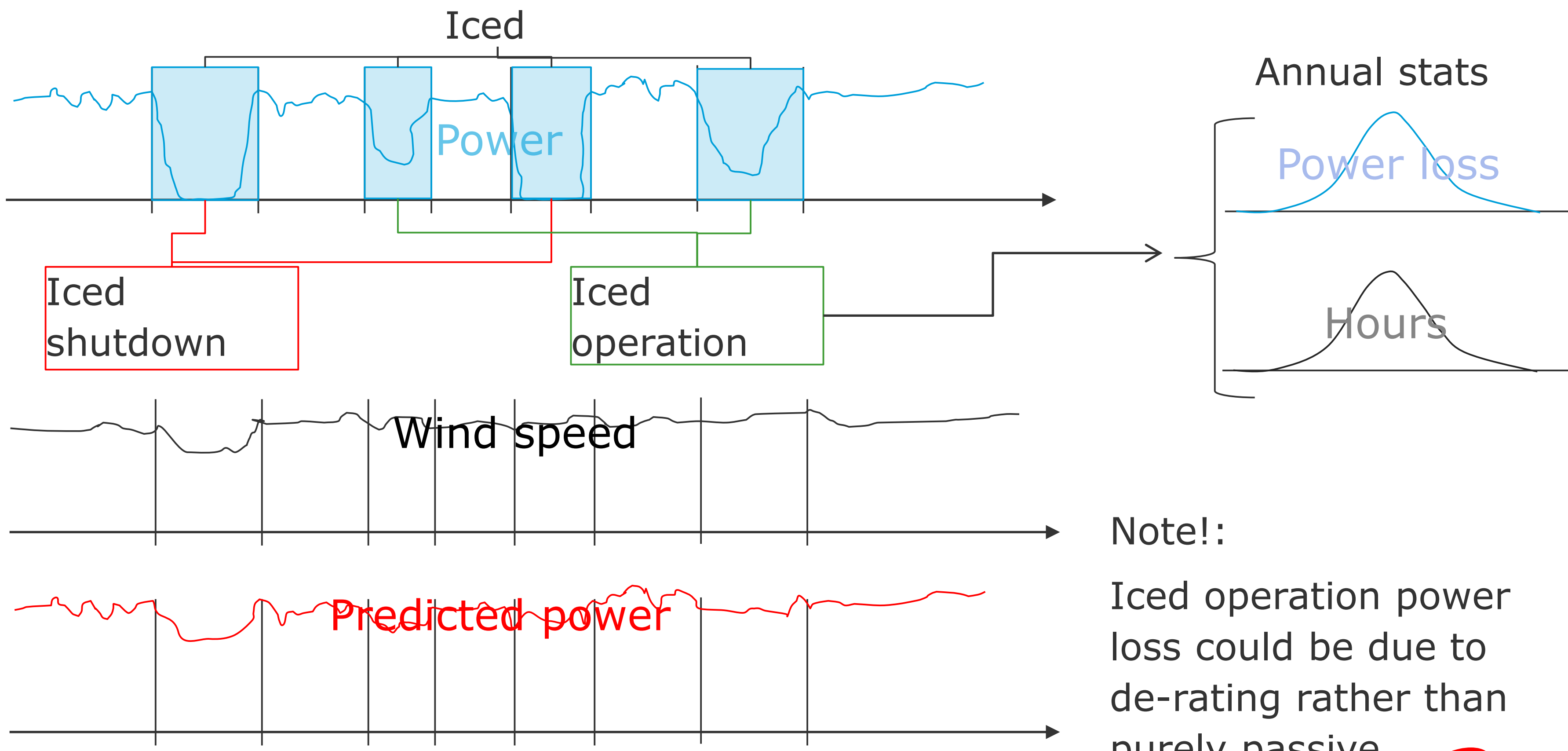


Figure 3-1 Annual production icing loss Vs hub height altitude for each of the wind farms analysed

Source: DNV GL Winterwind 2015… T. Beckford et. al.

Quantification and estimation of energy losses caused by blade icing using SCADA data and pre-construction met. masts in Nordic region

Information from SCADA



Note!:

Iced operation power loss could be due to de-rating rather than purely passive performance loss **?**

Numerical wind turbine model setup

- Generic 2MW VSPR (variable speed, pitch regulated) 75m rotor wind turbine
- Tuned ice vibration alarm set just above filtered 1P nacelle acceleration level from non-iced operation
  - Attempting to recreate a ‘realistic’ case
  - This accounts for the fact that a turbine may not operate with ice above a certain level for integrity reasons

Ice	4m/s	6	8	10	12	14	16	18	20	22	24
Initial	🟢	🟢	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Light	🟢	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴
Medium	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴
Severe	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴

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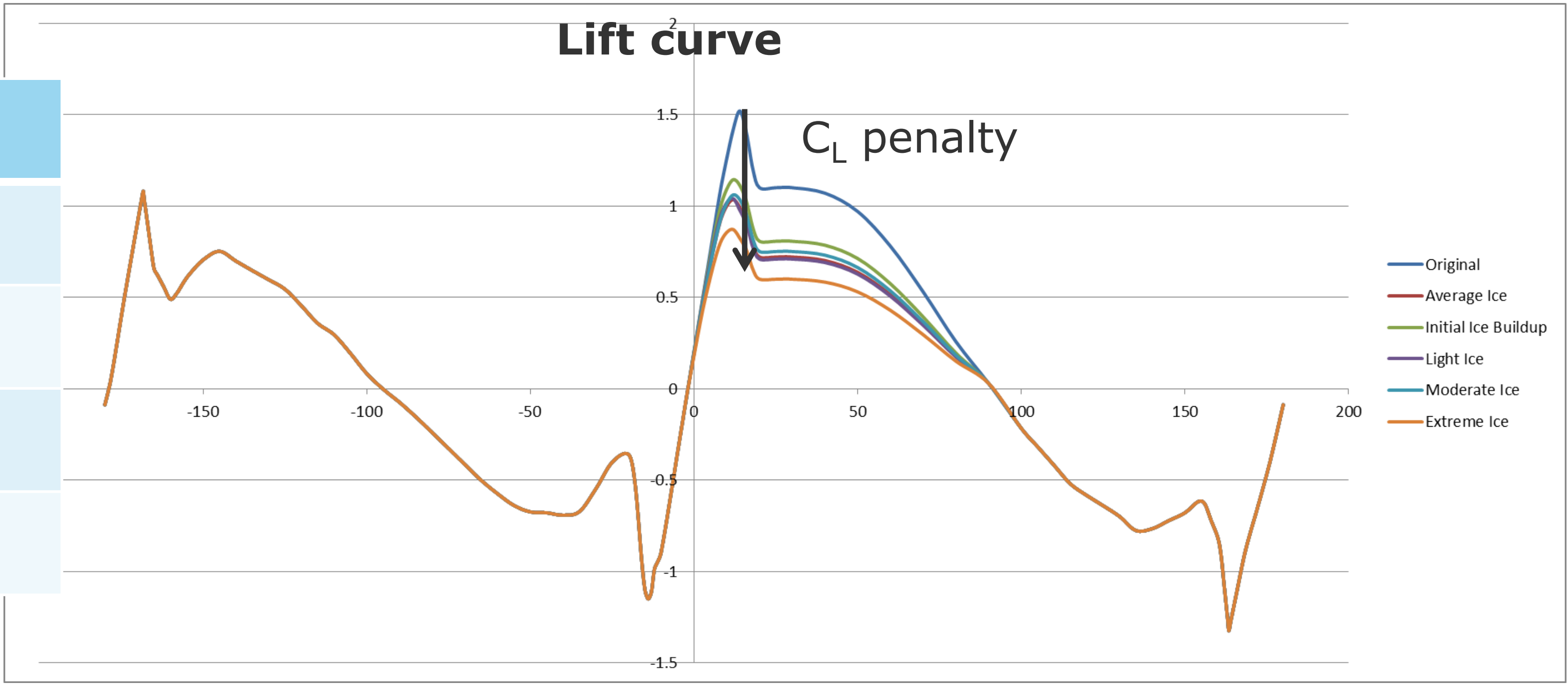
Correlating power loss and ice mass

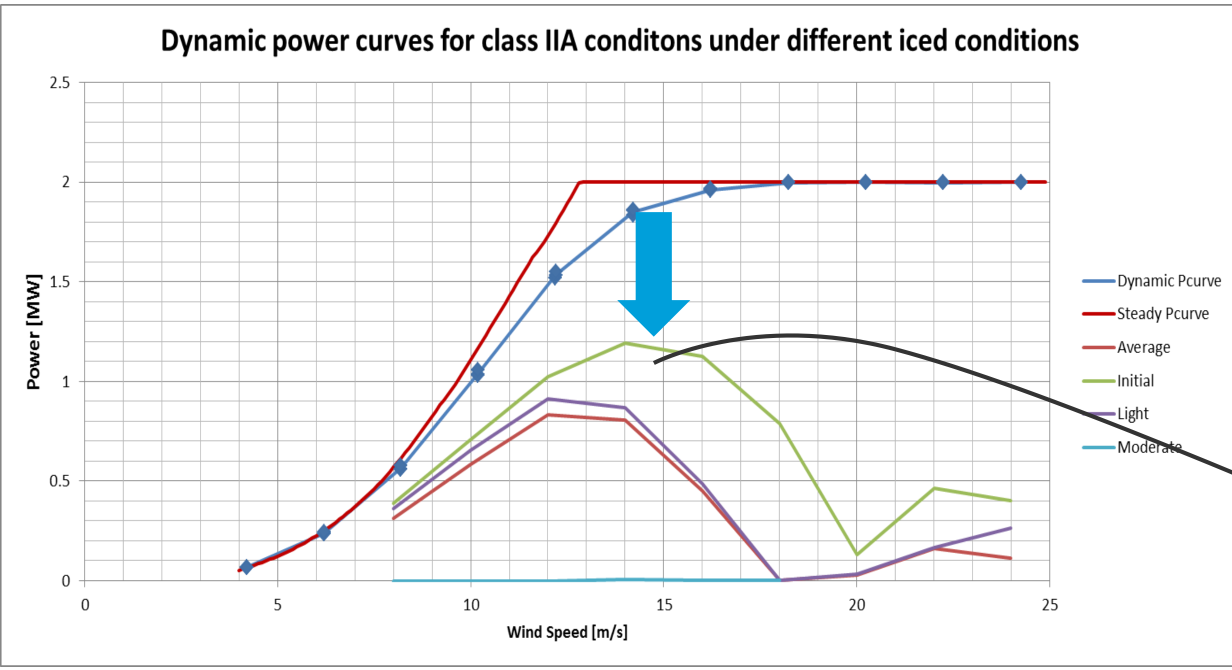
- Ice builds up at the blade leading edge changing the shape of the profile
- The modified blade shape has degraded aerodynamic efficiency
- General assumption: More ice build up ~ More power loss
- Reference: VTT IEC edition 4 sub-committee work in coupling aerodynamic penalty factors with approximate ice kg/m values

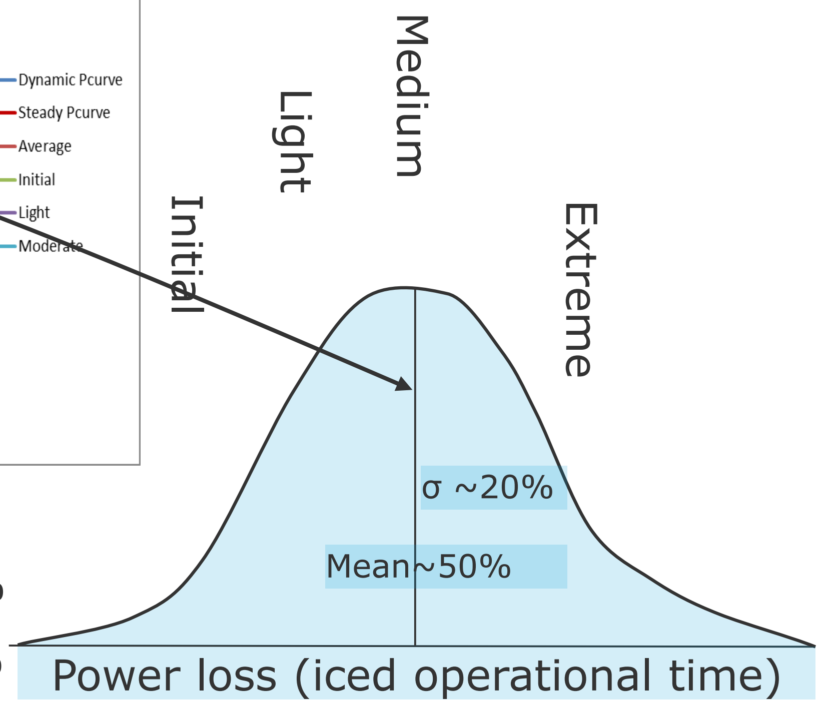
Ice type	Kg/m
initial	0-0.2
Light	0.2-1
Medium	1-3
Extreme	3-5



Calibrating numerical simulations with SCADA data

- Numerical simulations with aerodynamic penalties yield power deficits
- Compare these power deficits with SCADA annual loss values

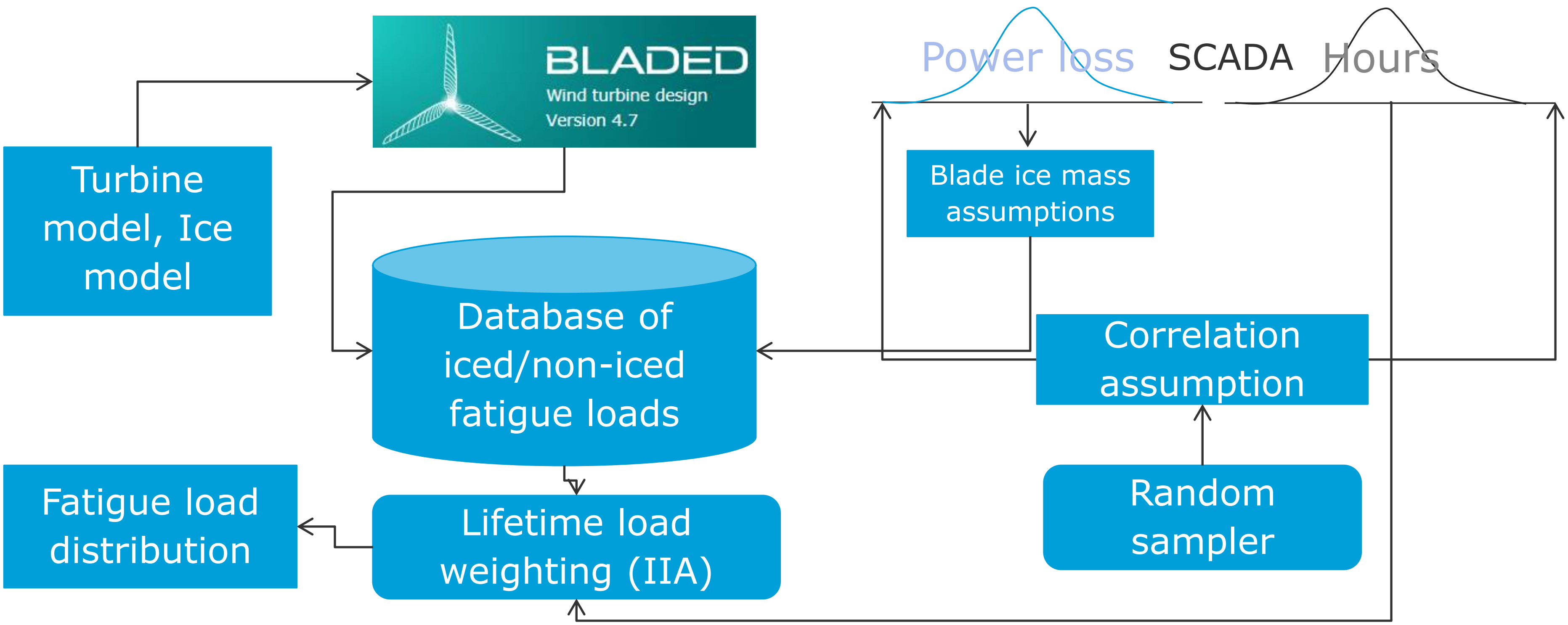




- SCADA statistics across projects:
  - Annual mean iced power degradation: ~50%
  - Annual mean iced standard deviation: ~20%

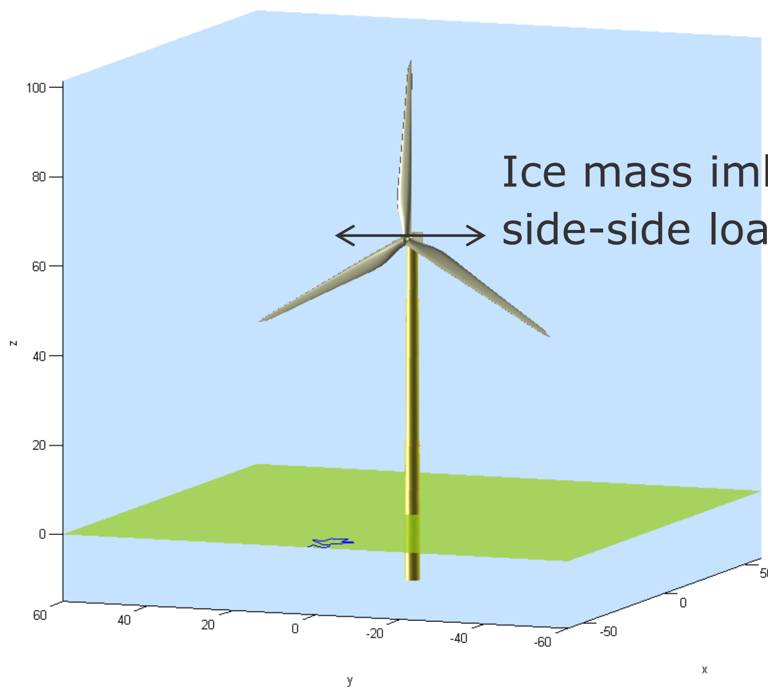
Generating cold climate fatigue loads distributions

- Fatigue IEC simulations run to represent non-iced and iced operation
- Proposed IEC edition 4 ice model used (aerodynamic penalty + ice mass)
- Monte-Carlo sampling of SCADA distributions (assumed normal)
- Correlation between SCADA distributions a user variable
- Iced/non-iced simulations combined to generate lifetime loads



Design loads for comparison

Tower base moment	1E7 cycles in 20 years equivalent load
Side-Side	4988 kNm
Fore-Aft	11525 kNm



Ice mass imbalance increases side-side load cycles

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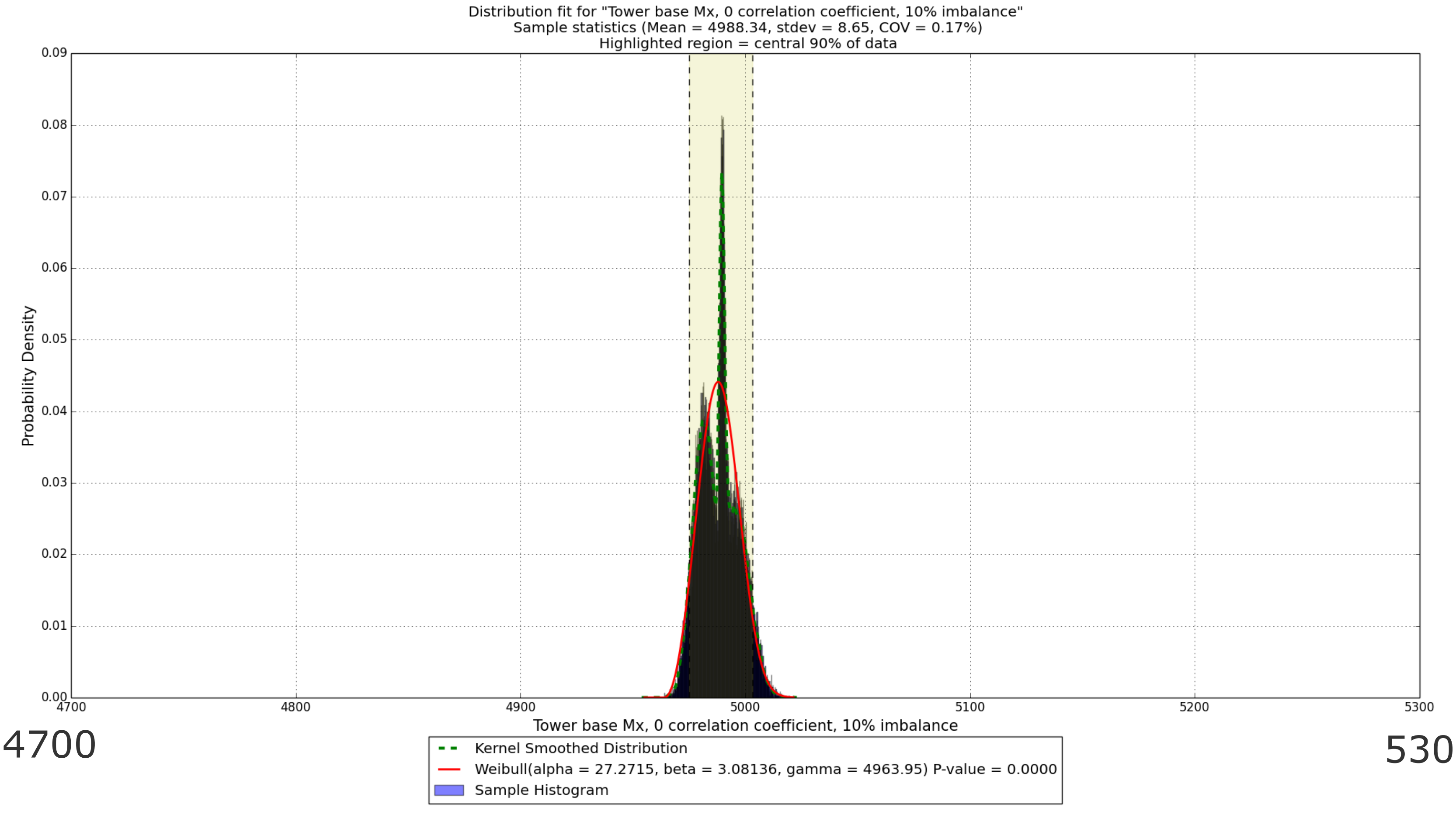
Histogram plots of tower base side-side (0 correlation)
Mass imbalance trend: 10%

Distribution mean: 4988 kNm



4700

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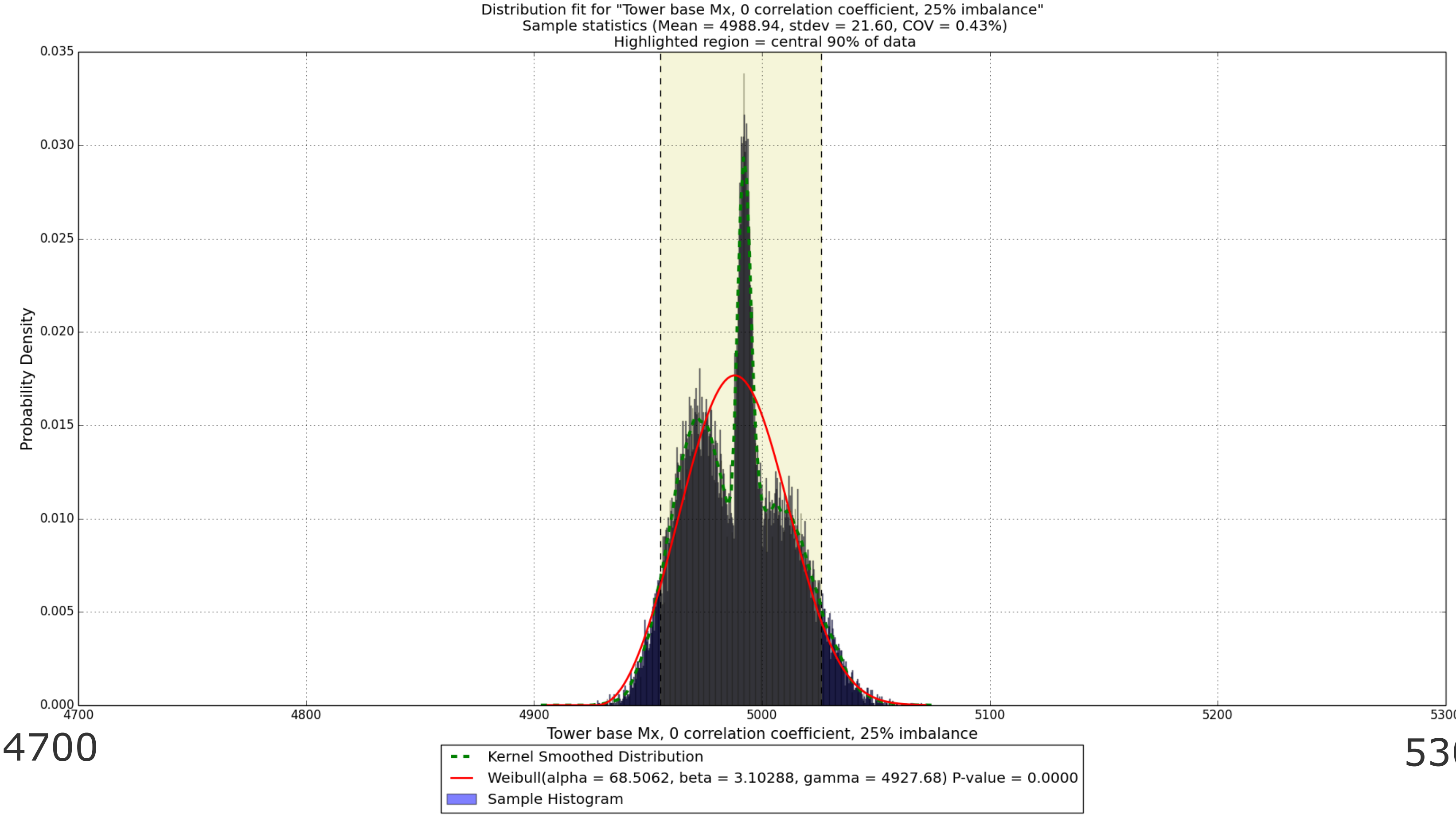
Mass imbalance trend: 25%



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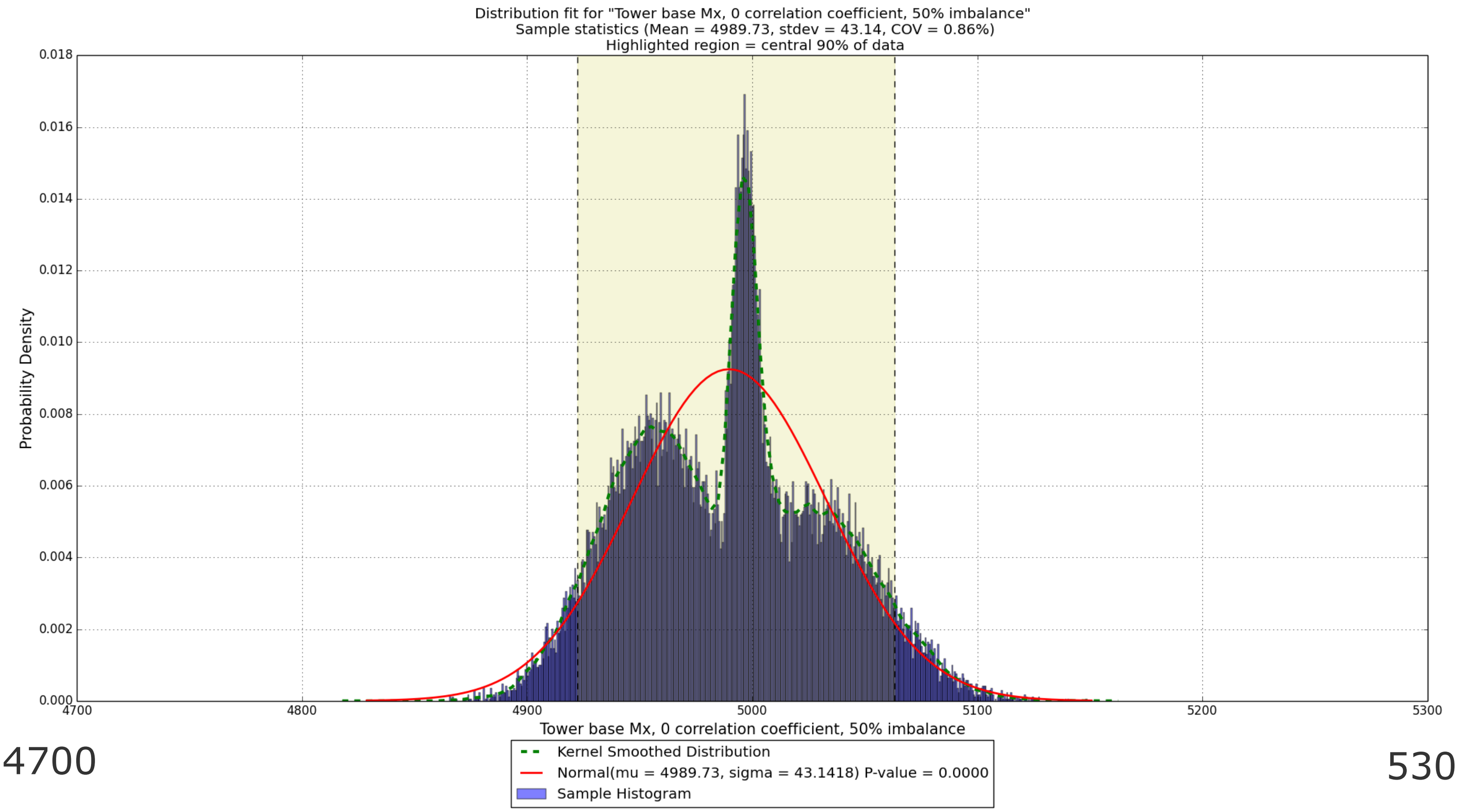
Mass imbalance trend: 50%



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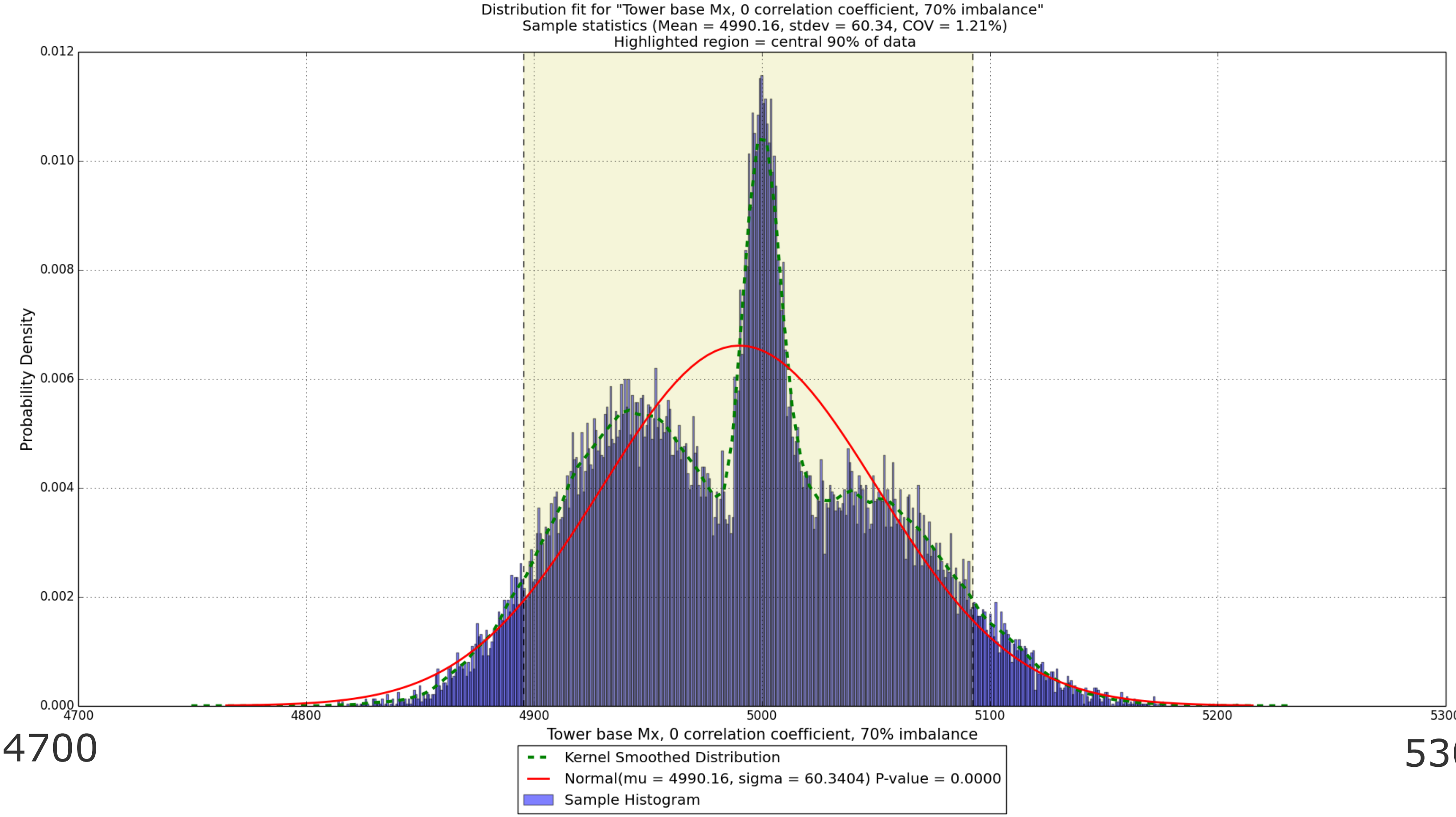
Mass imbalance trend: 70%



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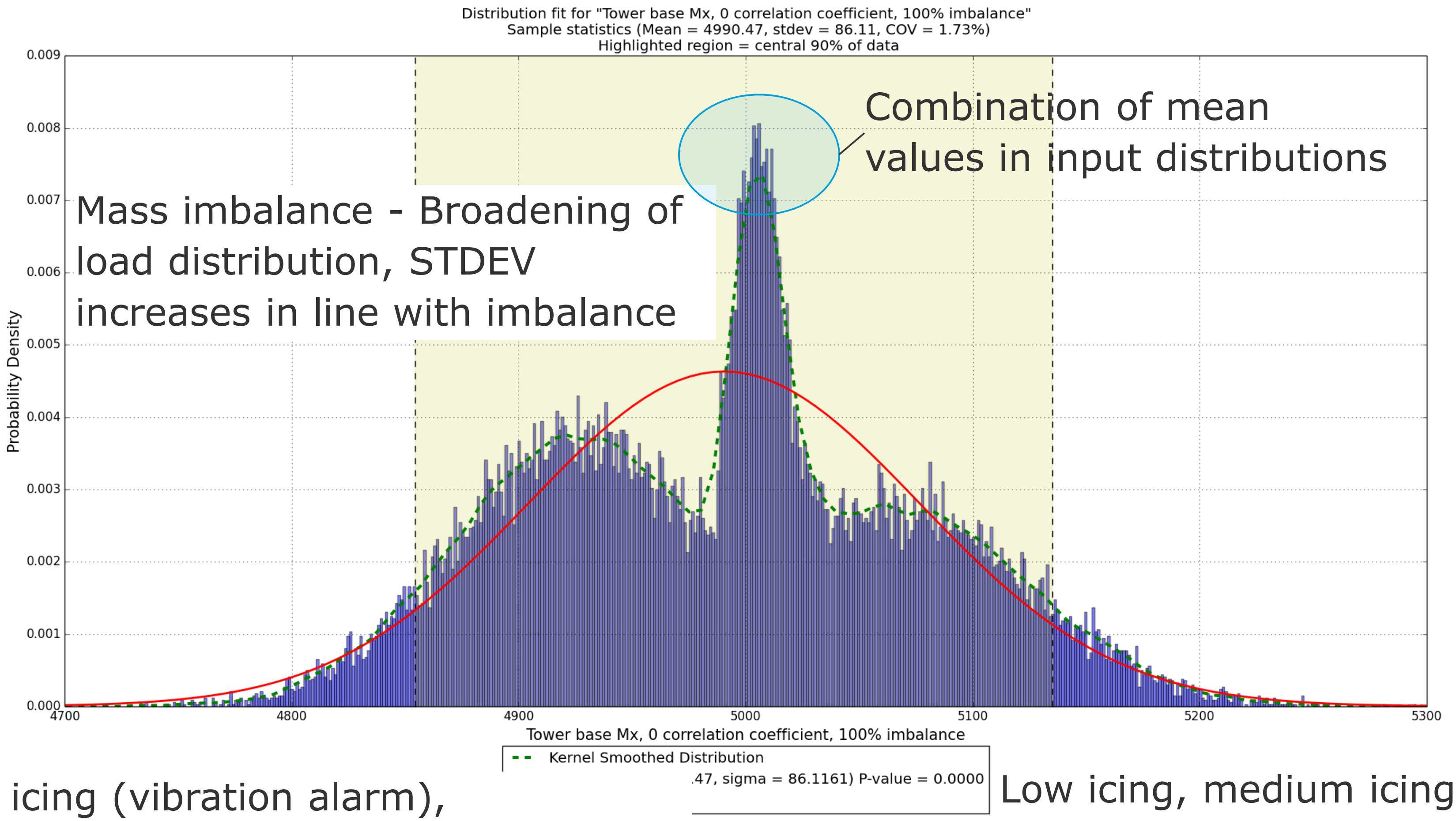
Mass imbalance trend: 100%

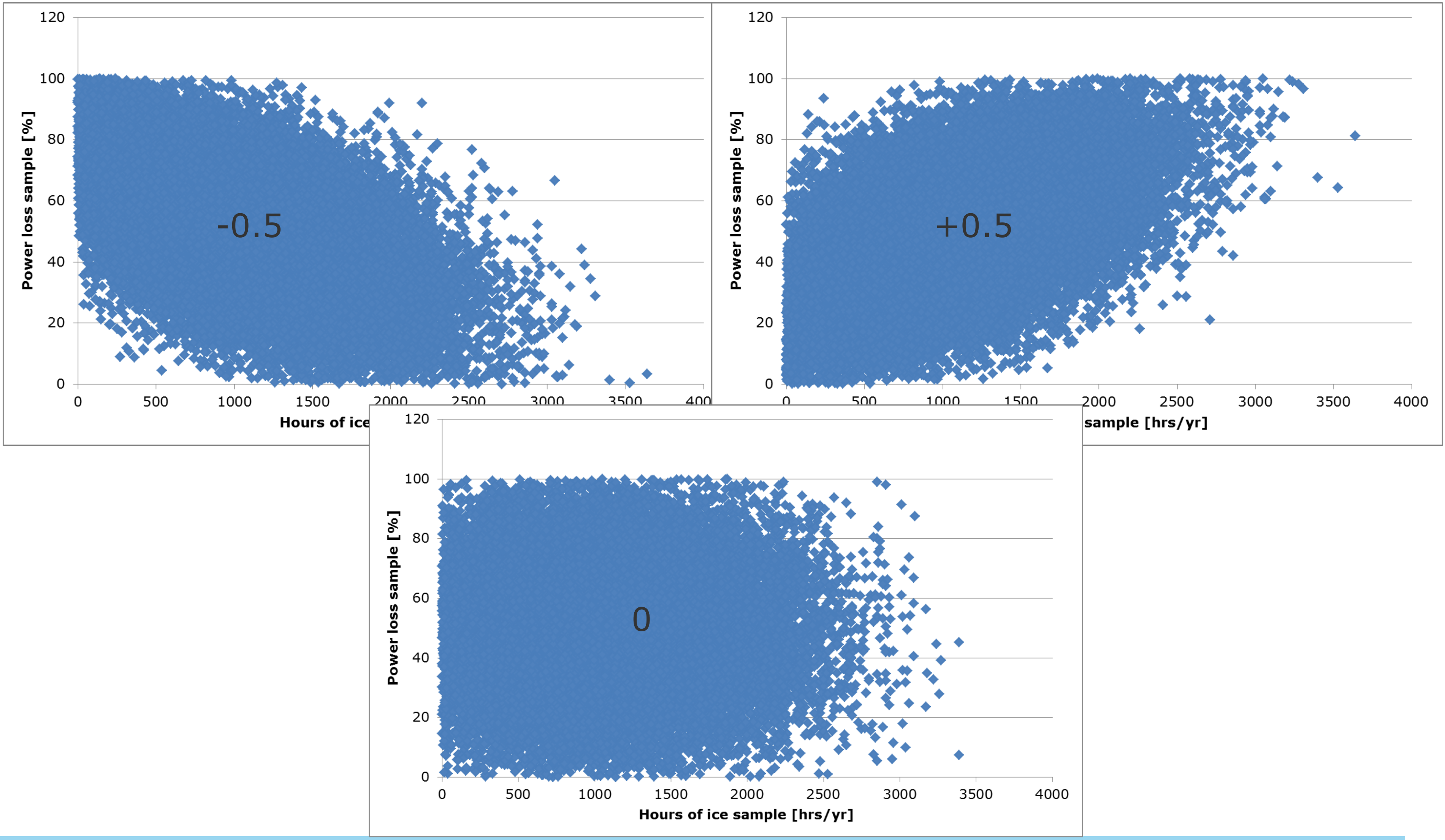


High icing (vibration alarm),

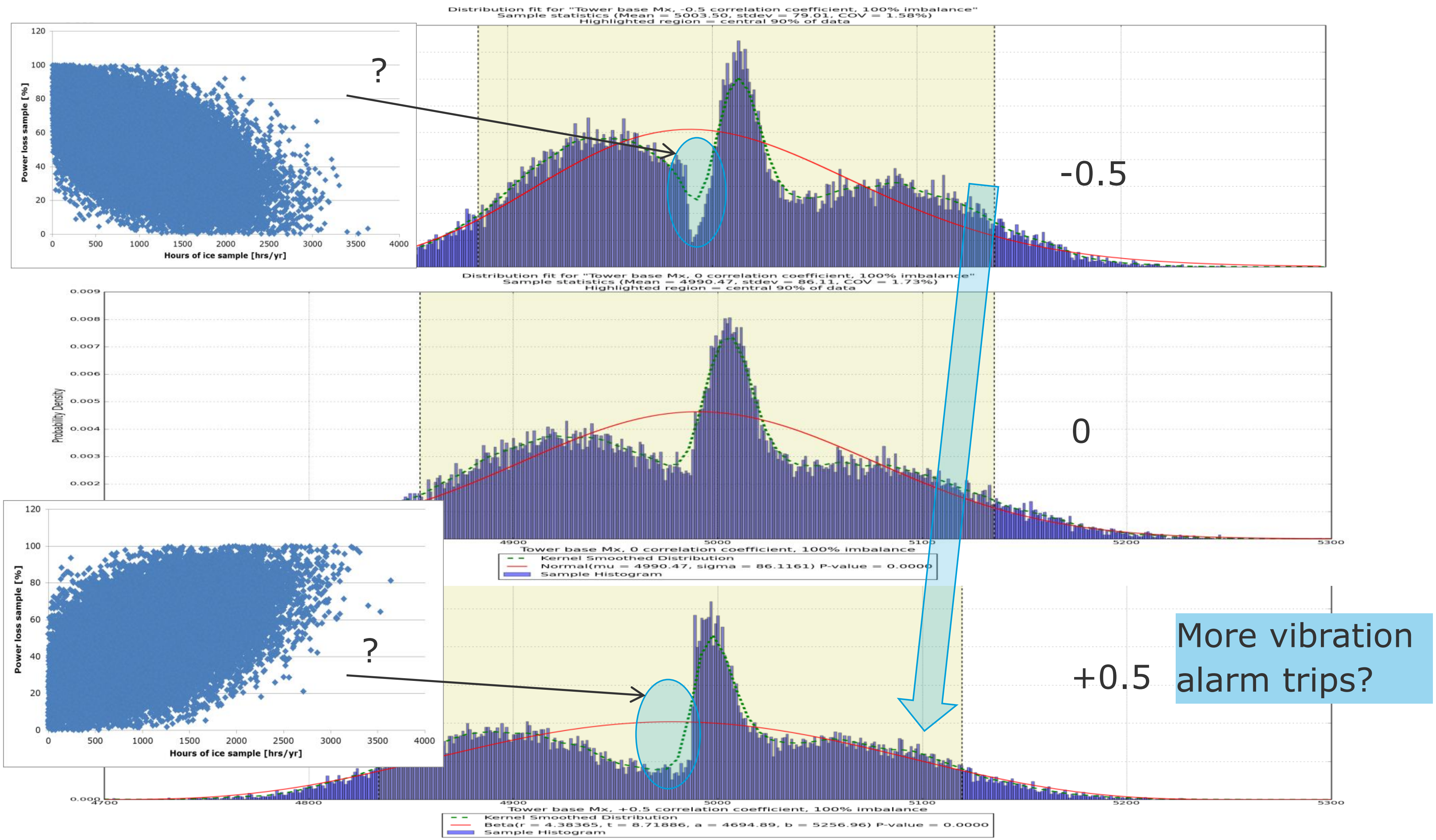
Low icing, low hours

Low icing, medium icing, high hours

Correlations tested



Histogram plots of tower base side-side Correlation trend, 100% imbalance



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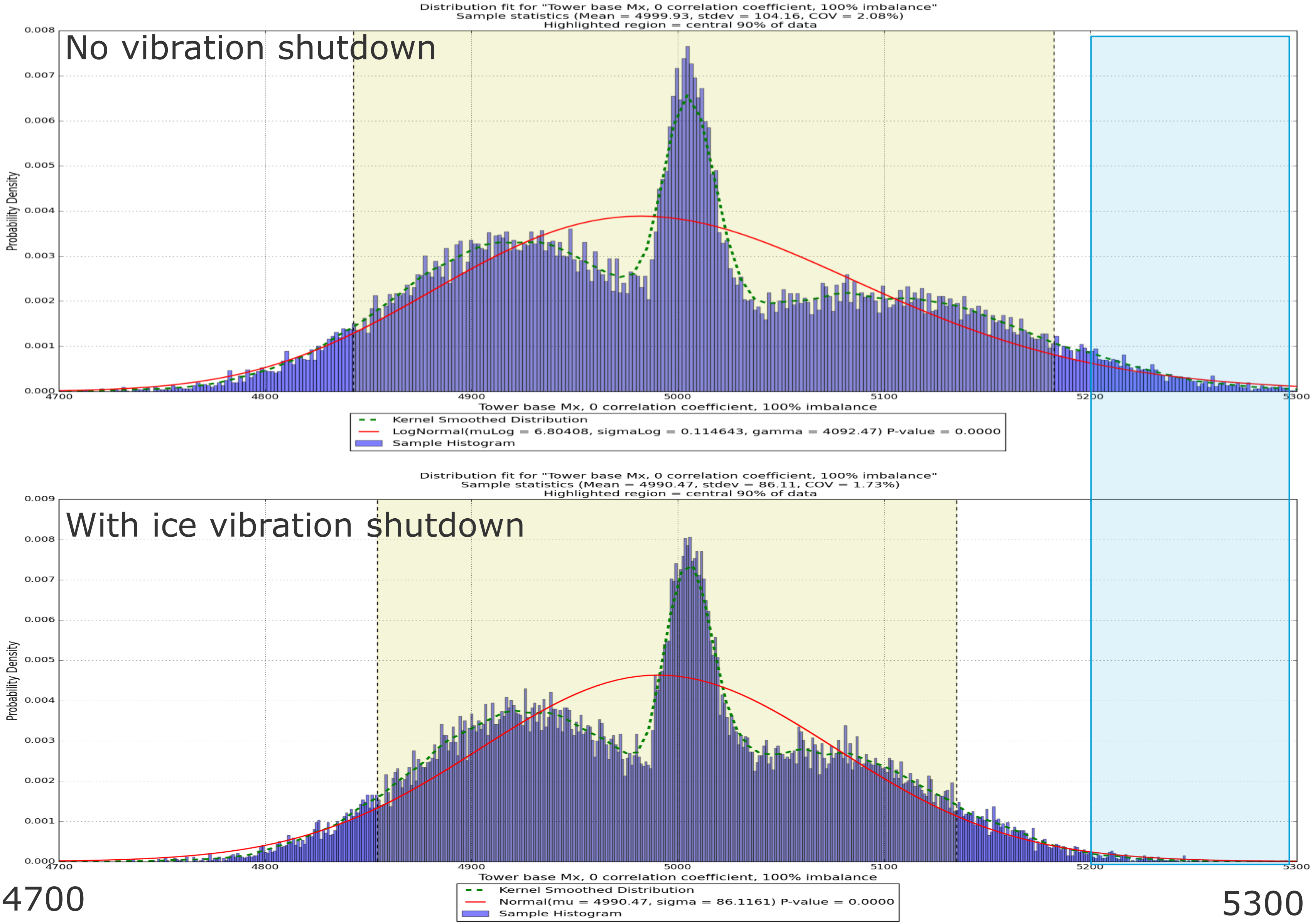
What happens if the vibration alarm is taken away?



Summary observations

- Results show that operating in ice generally isn't a big problem for loading for this particular turbine model
- Loss of aerodynamic performance generally seems to counter the effect of ice imbalance
- The sensitivity to ice loading is highly turbine specific:
  - Blade aerodynamic design
  - Stall margin
  - Control design & operational strategy
  - Tower frequency proximity to 1P
  - Turbine ice detection systems

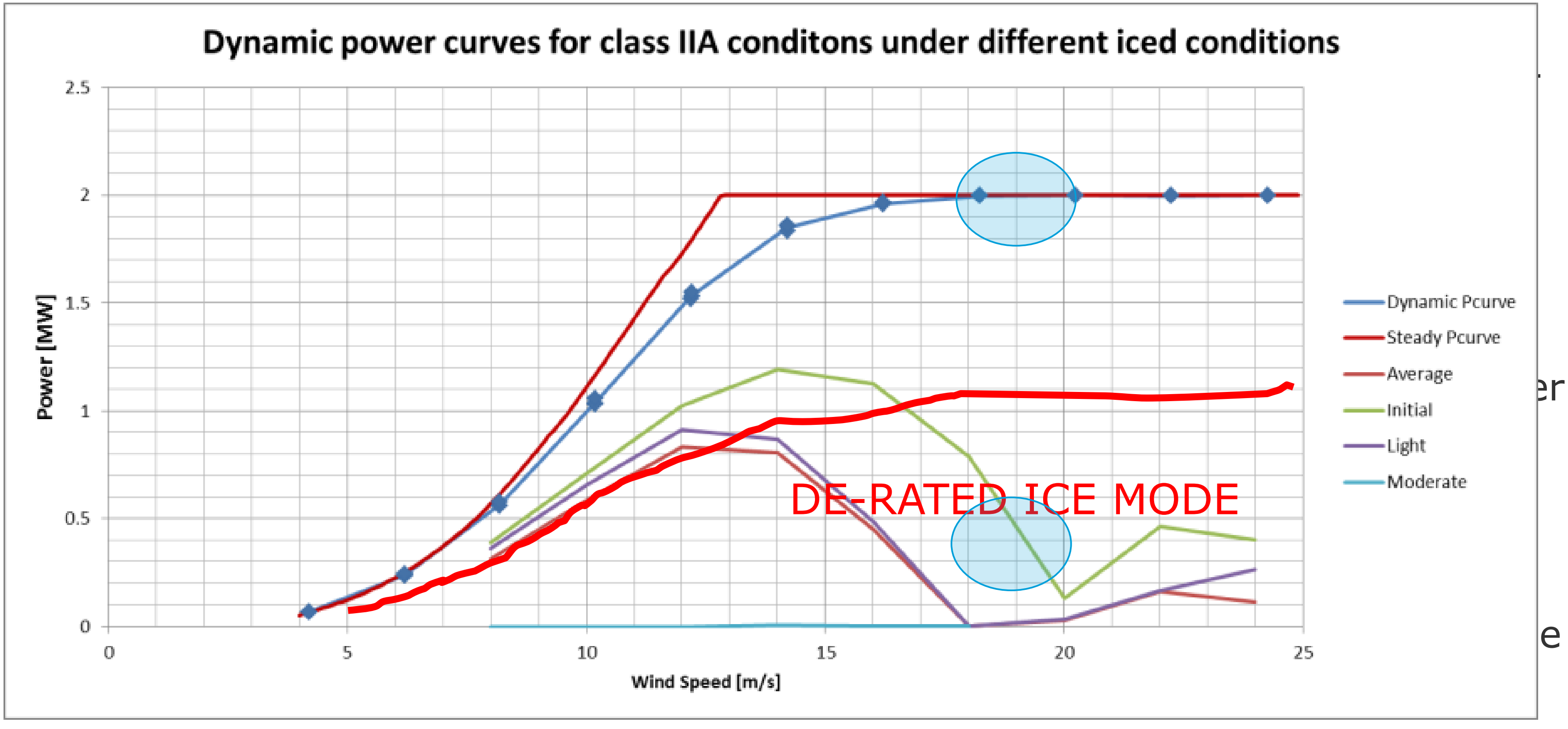
- But 'Dumb' ice operation introduces the unknowns associated with stall!
  - Ice induced stall can even occur in light ice build up
  - Potential for stall induced vibrations if low-damping

The vicious cycle of ice induced stall

- Modern wind turbine control systems are (generally) designed to operate in un-stalled conditions
- Adding ice, reduces the angle of attack at which the blade stalls
- If the blade stalls due to ice the turbine power will degrade
- The control system will try to increase power by decreasing blade pitch
- Reducing blade pitch increases angle of attack and makes the blade push further into stall, making the situation worse!

- To recover from stall, the pitch should be increased but this is not obvious to the standard controller
- Design of a de-rating strategy (reduction in desired power) for icing scenarios would help to generate more power than trying to generate full rated power the entire time

Derating control strategy solution



- Design of a de-rating strategy (reduction in desired power) for icing scenarios would help to generate more power than trying to generate full rated power the entire time
- Increased Energy, Lower load uncertainty

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Summary

- Method demonstrated SCADA data coupled with numerical simulation results to generate a distribution of estimated tower base fatigue load histograms

- The method shows promise for statistically assessing the impact that iced operation may have on a turbine design

- More refinement of the input data would help!

- Numerical modelling is the best way to foresee potential issues prior to building anything!

- Ice induced stall appears to be very likely from our study of turbine blades
  - Advanced ice-control could prove vital to avoiding potential damage from ice-induced stall states & yield more energy!
  - Is this already widely adopted ?

Thank you for your attention

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