Turbine-specific pad-level ice loss assessment

Advantages, accuracy, and challenges

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Value drivers for improving ice prediction

- Cold climate presents about 10% of the market.
- Production loss due to icing has large impact on business case (cost of energy).
- Active mitigation comes with a price.

- So far the total park production loss has been estimated.
- Knowledge about intra-park variability presents opportunities.

*Ice Assessment** enables more precise and accurate business case analysis
- Large differences in conditions exists within a park.

Example:
- Determine if IPS (Ice Protection System) is needed for all turbines in a park and by this reduce cost

*Product name for turbine specific pad-level ice loss estimate

Production loss

What we observe and attempt to predict for the lifetime

- Production data analysis
- Task19 or equivalent approach

	Ice Loss (%AEP)
Subtotal	9,1 %
2010-2011	7,0 %
2011-2012	5,0 %
2012-2013	14,0 %
2013-2014	13,5 %
2014-2015	9,3 %
2015-2016	6,3 %

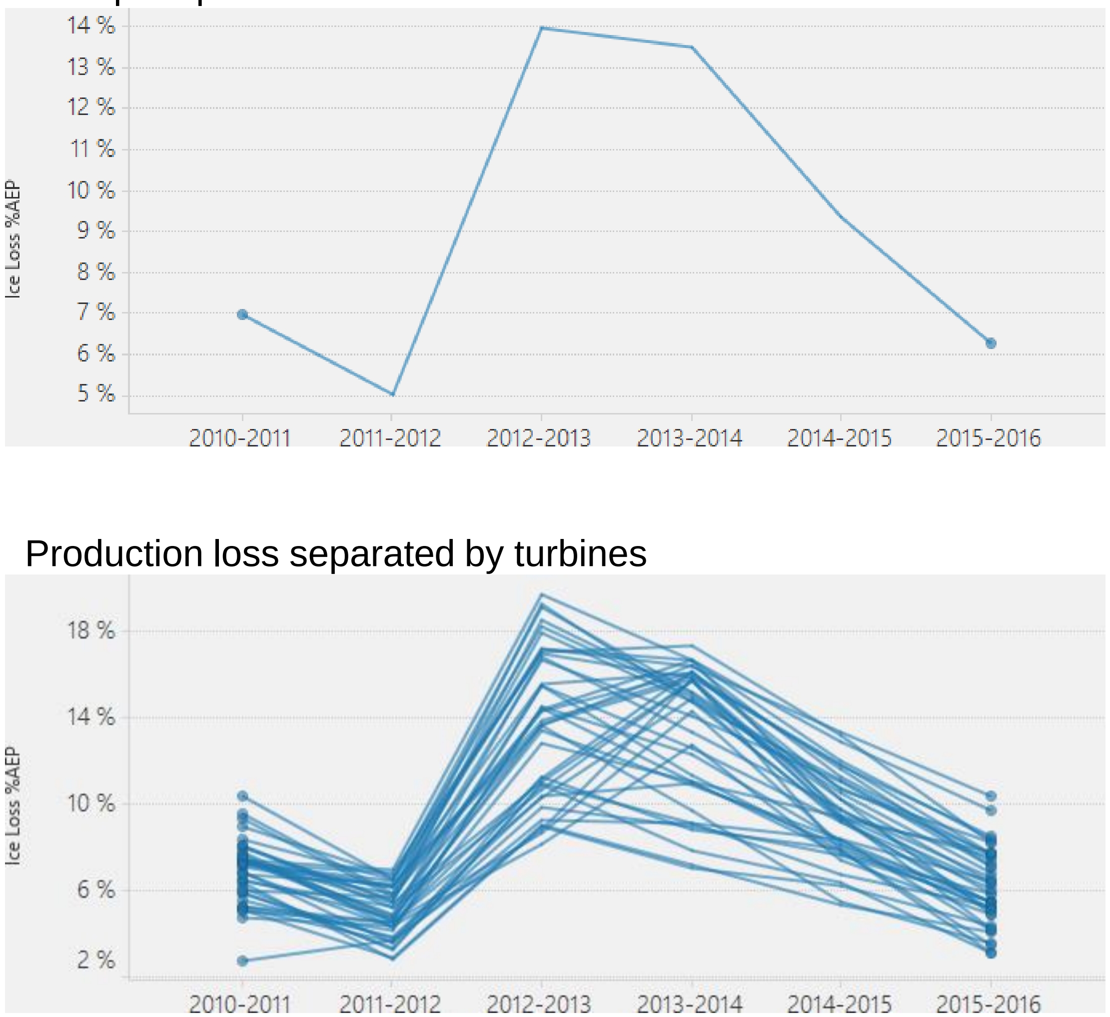
- Park, Average

- Variability by years
- Intra-park variability (individual turbines)

Observations from one wind farm

Total park production loss

Production loss separated by turbines



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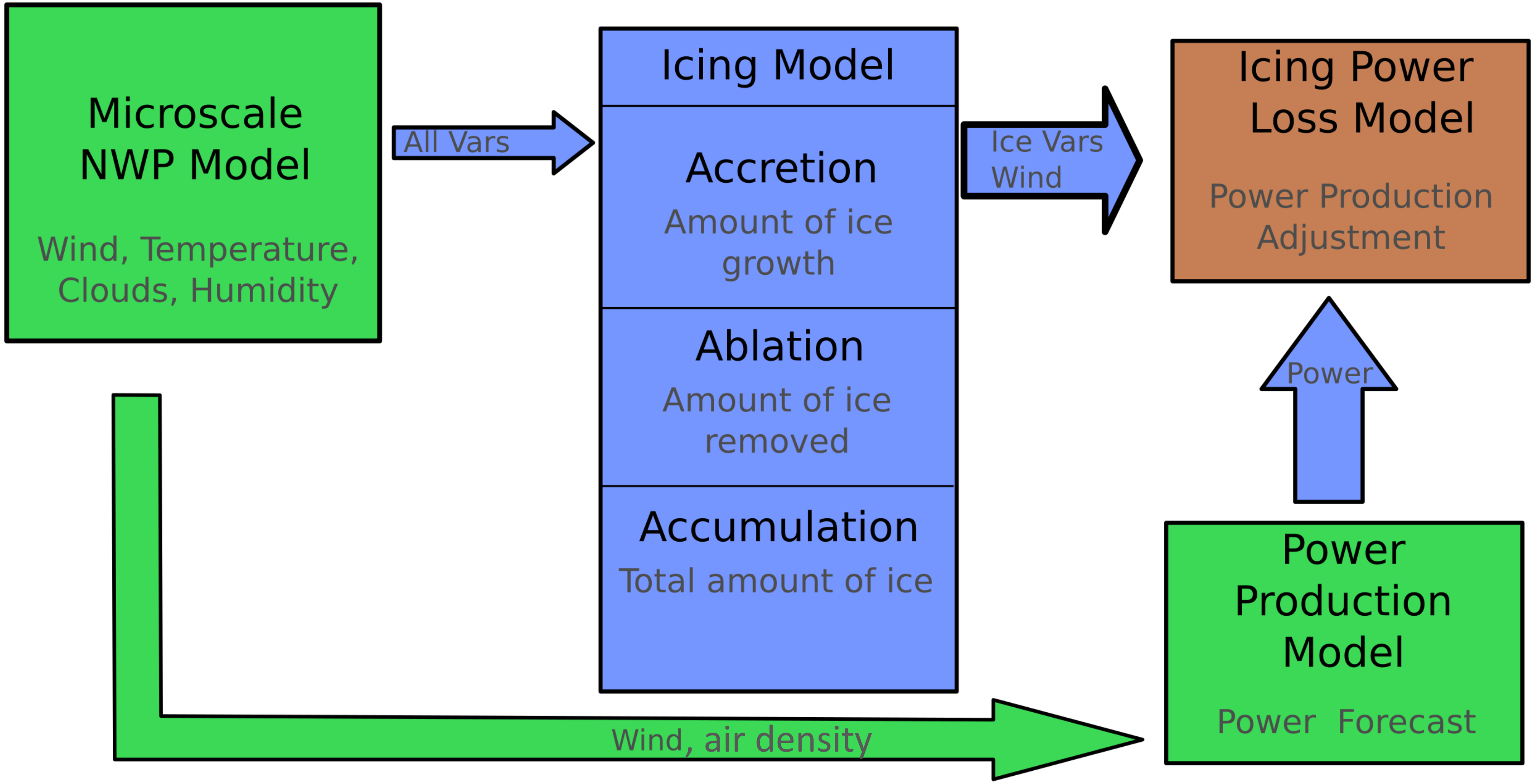
Ice Assessment methodology

Process and techology



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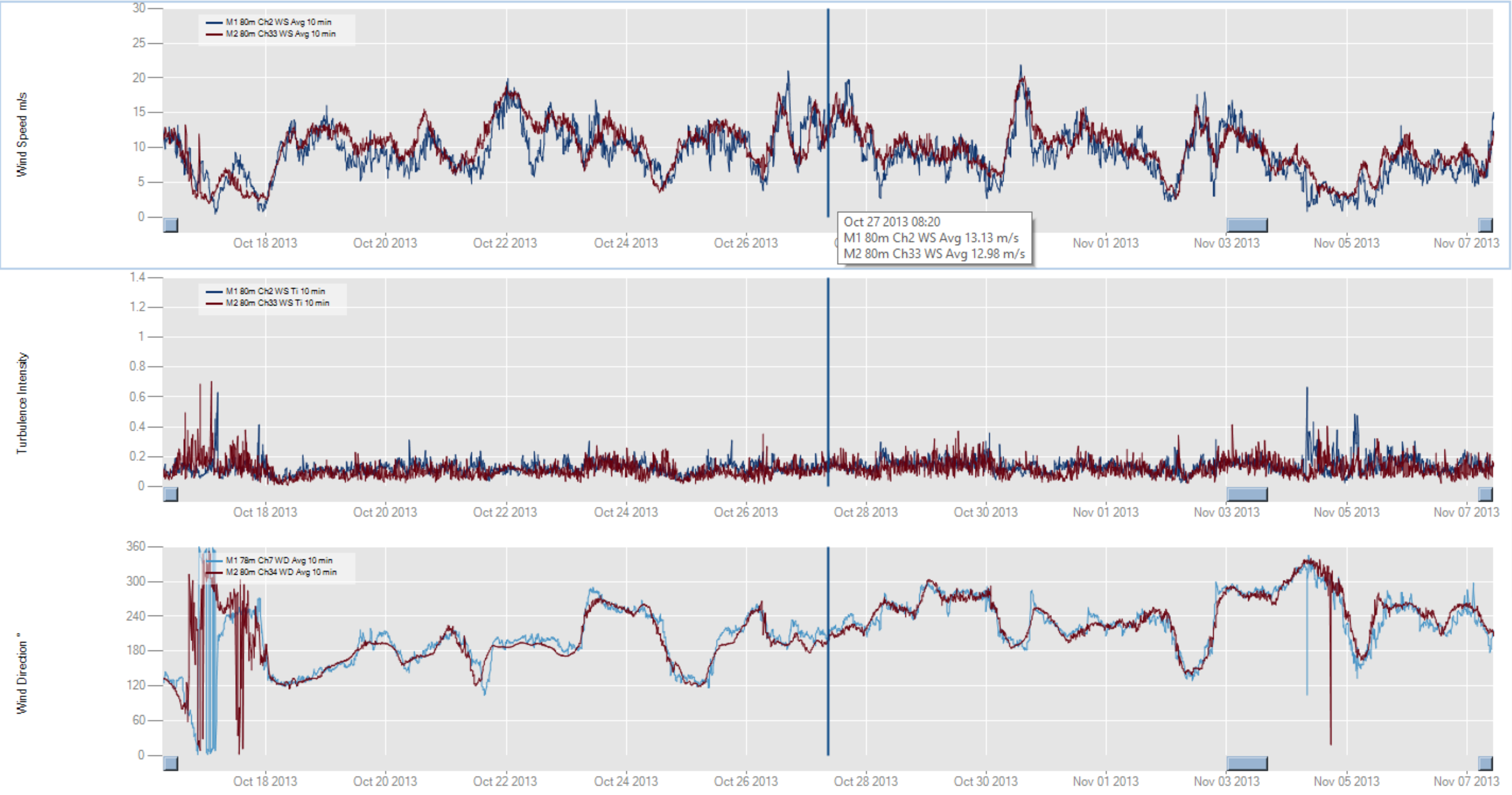
Technology 1: Microscale weather modelling (WRF-LES)

Lack of ice-specific observation; complemented with validated numerical weather models

Modelled
vs.
Observed
(somewhere in Scotland)

Or maybe
Modelled
vs.
Observed



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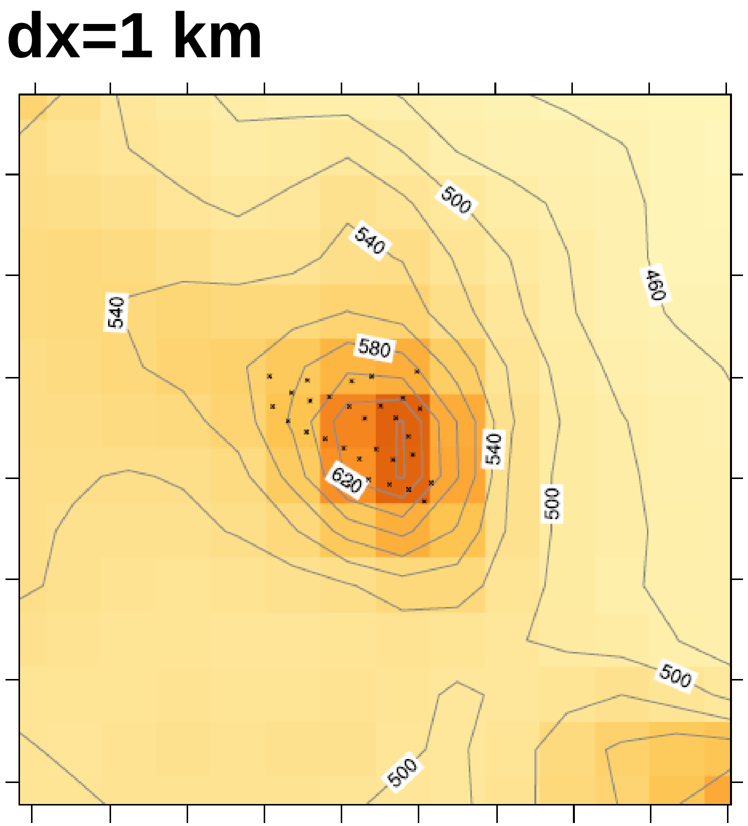
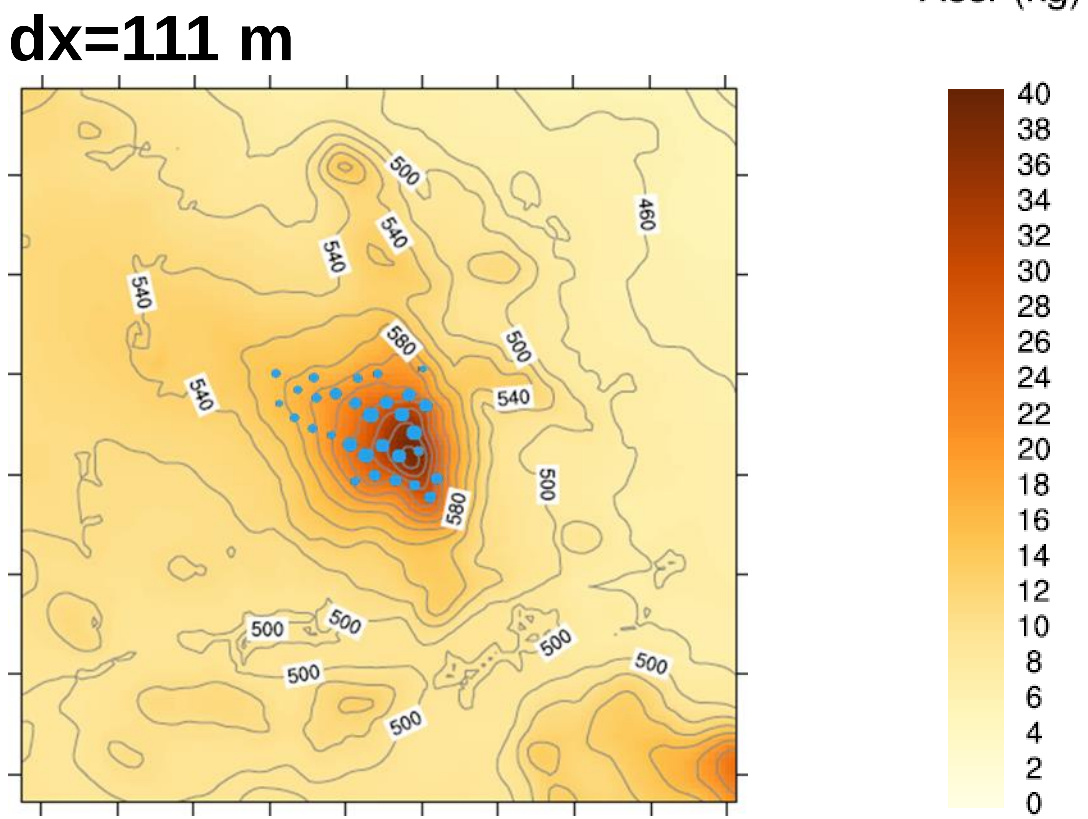
Technology 1: Microscale weather modelling (WRF-LES)

Increasing precision
- More accurate terrain
- Additional physical and weather features

What to see in the plots below?
- Higher terrain – more ice accretion
- Production losses vary a lot between WTG's
    - Size of blue circles proportional to loss





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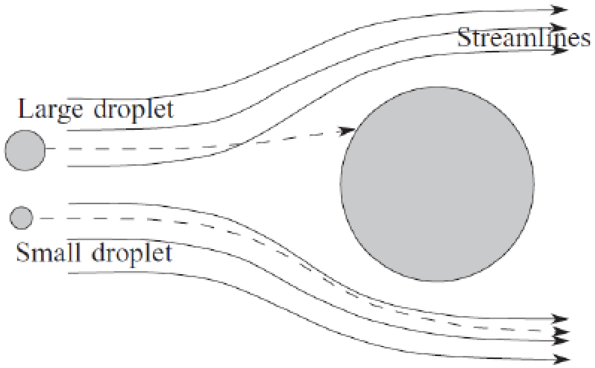
Technology 2: iceBlade ice accretion model (Davis et al. 2014)

- Rate of ice mass growth on a rotating cylinder (not designed for wind energy; Makkonen 2000)

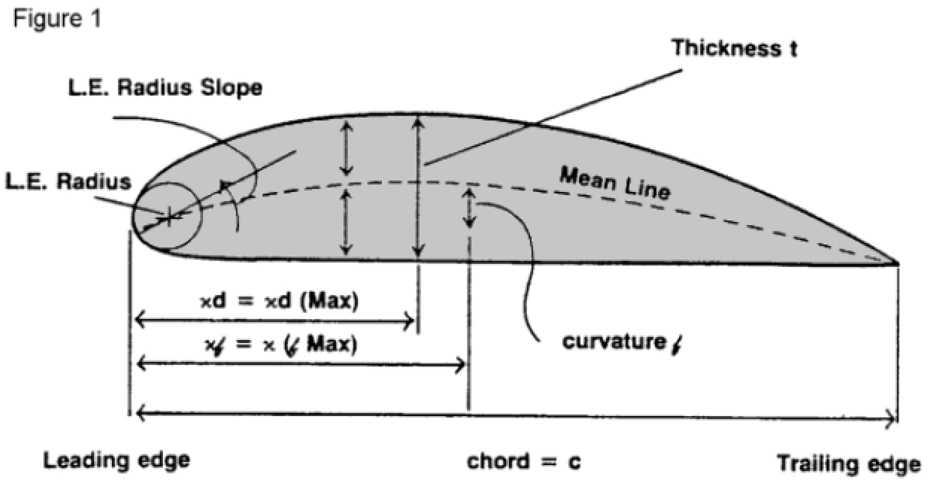
$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V$$

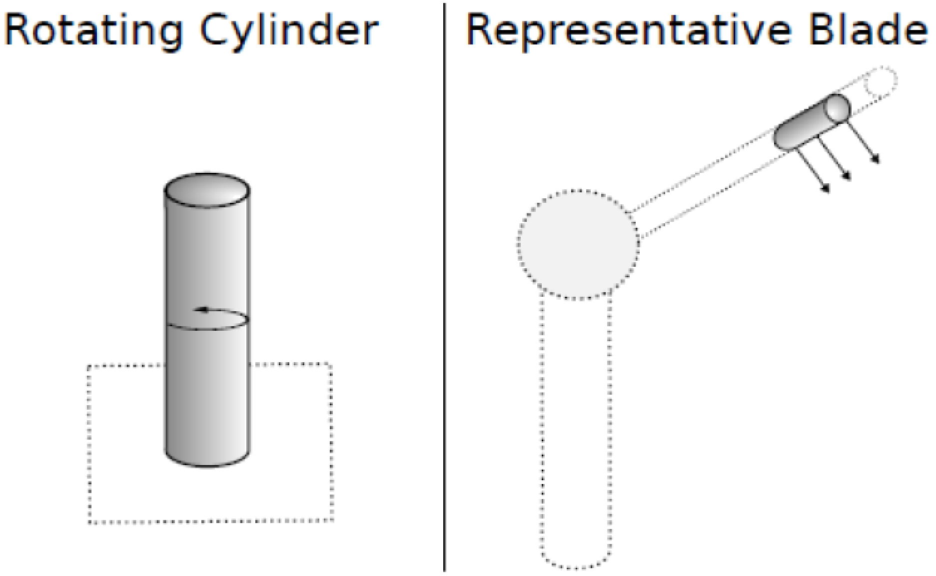
- Empirical equations (Scaled 0 to 1):
  - Collision efficiency (α_1)
  - Sticking efficiency (α_2)
  - Freezing efficiency (α_3)



Homola, M. C., T. Wallenius, L. Makkonen, P. J. Nicklasson, and P. A. Sundsbø, 2010: The relationship between chord length and rime icing on wind turbines. Wind Energy, 13, 627–632, doi:10.1002/we.

- Enhanced for wind turbines (Davis et al; 2014)





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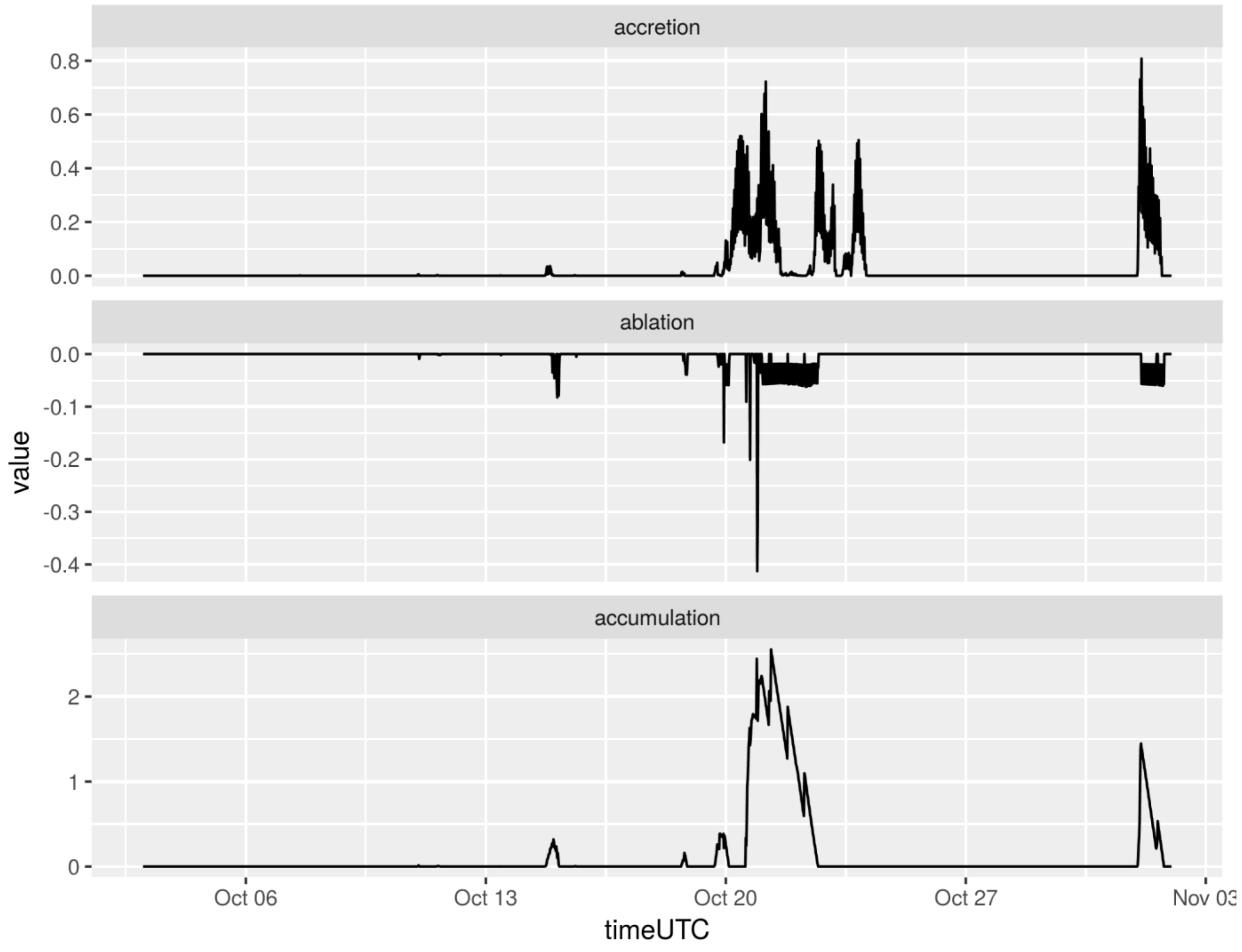
Technology 2: iceBlade ice ablation and accumulation model (Davis et al. 2014)

- Ablation
  - Total shedding when temp above 0 for 30 minutes
  - Sublimation from Thompson microphysics
  - Empirical wind erosion

- Accumulation
  - Combine Accretion and Ablation
  - Limit max ice amount



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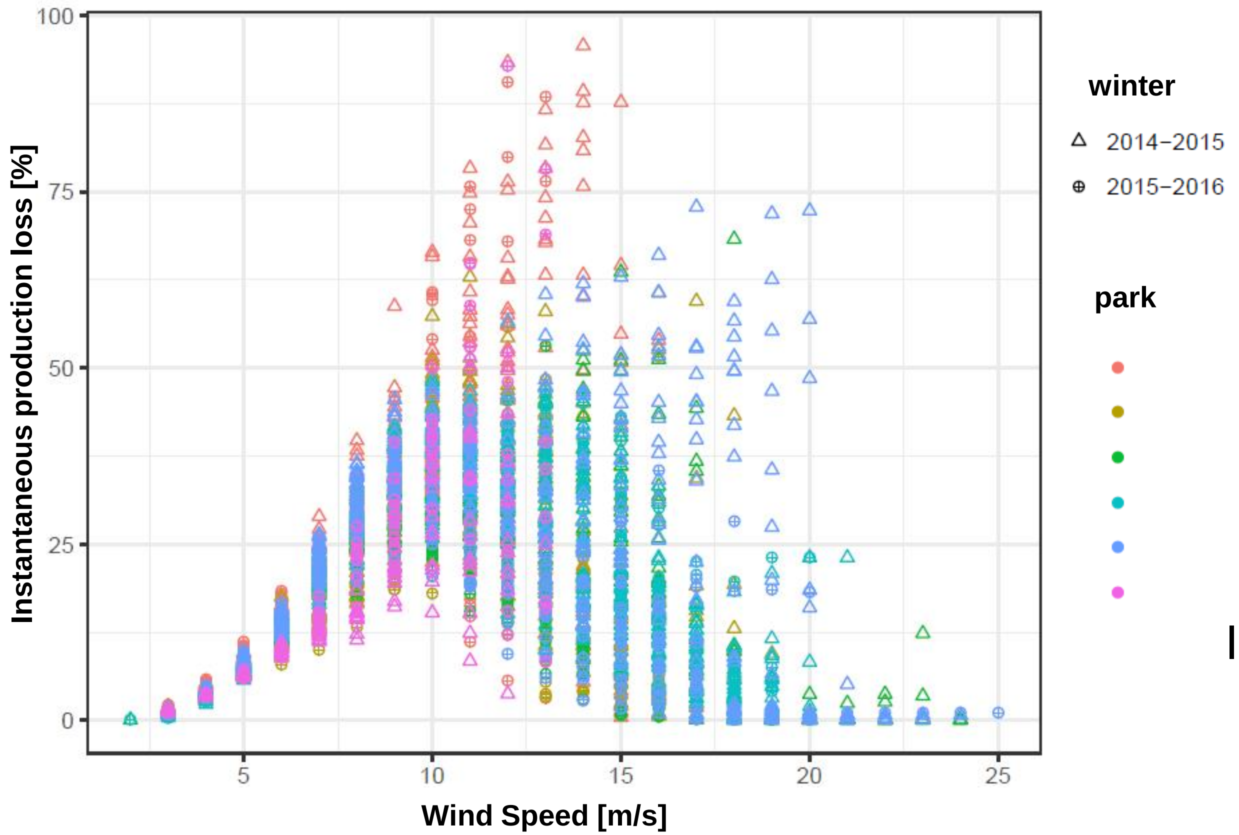
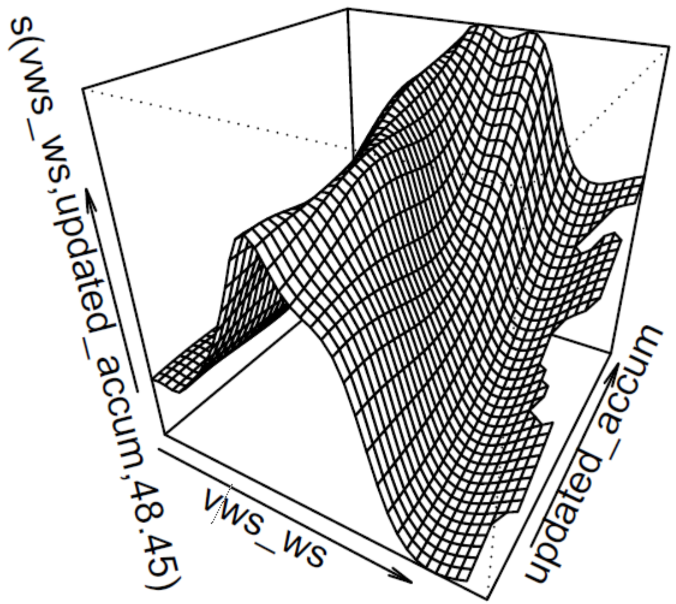
Technology 3: Production loss calculation

Multi-parametric power loss curve derived statistically combining:

- Observed performance degradation of turbines when ice is present on the blades
- Predicted ice-related conditions on future projects where performance data is not yet available
- Different ice-affected power curve for every Vestas turbine type



iceBlade
Ice accumulation



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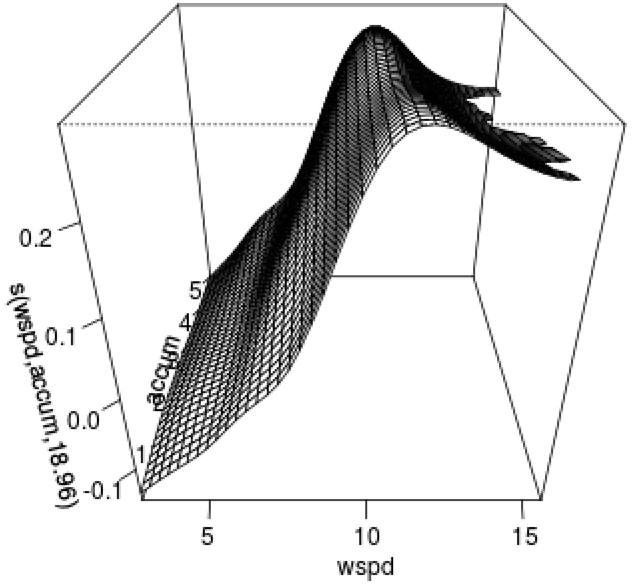
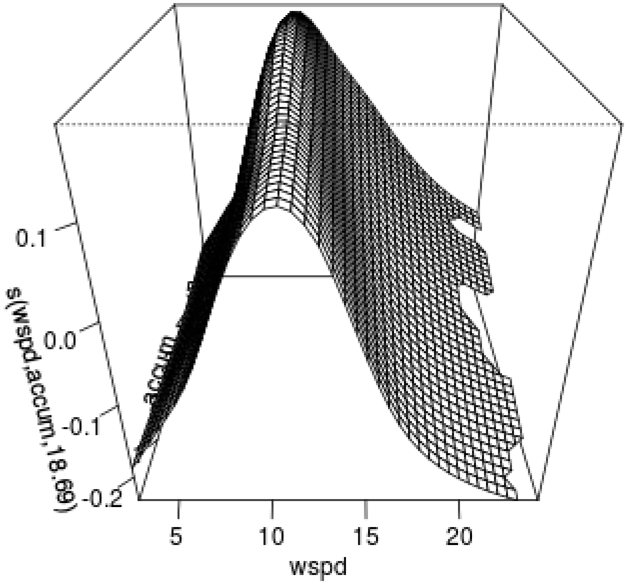
Technology 3: Production loss calculation

“Loss surfaces”



Active icing

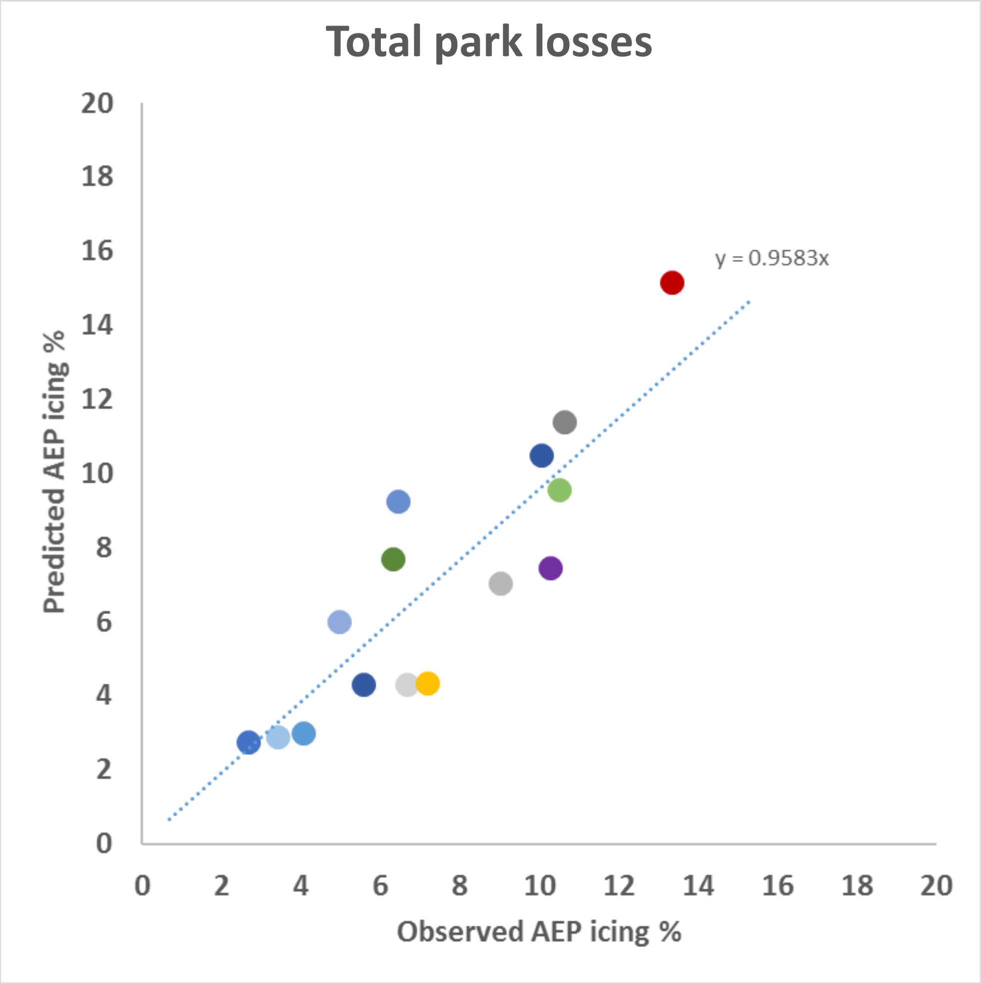


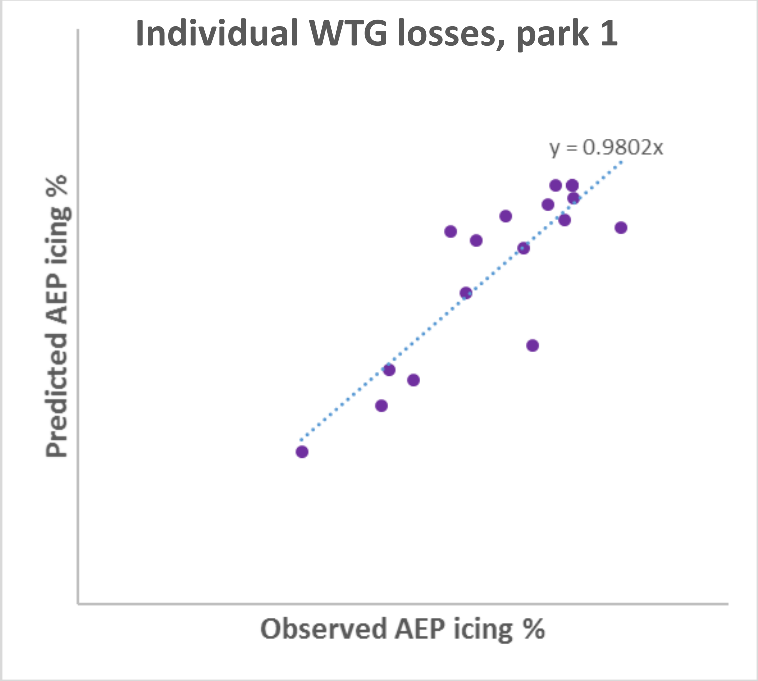
Passive icing

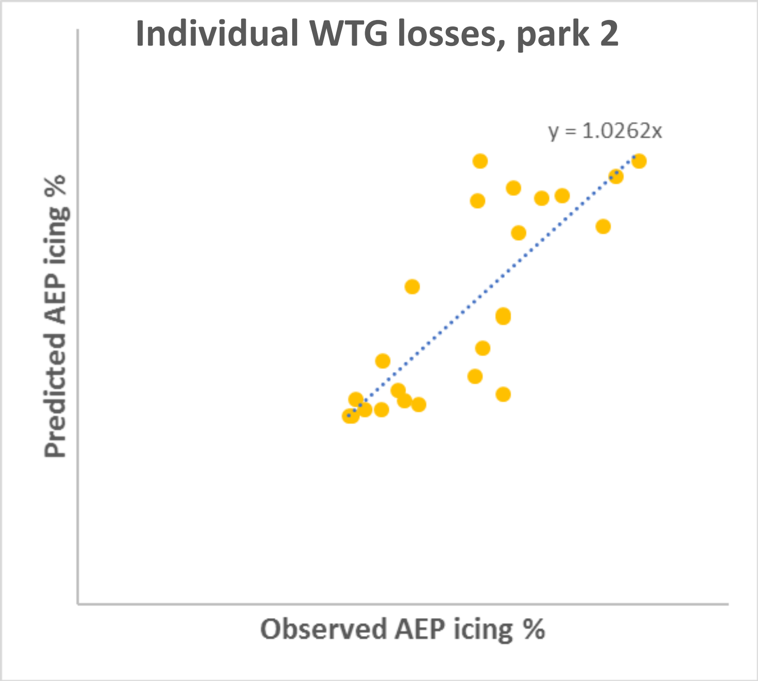
Based on a generalized linear model and training dataset of a number of wind farms and winter seasons

Validation

We want to predict absolute park losses and relative intra-park variability



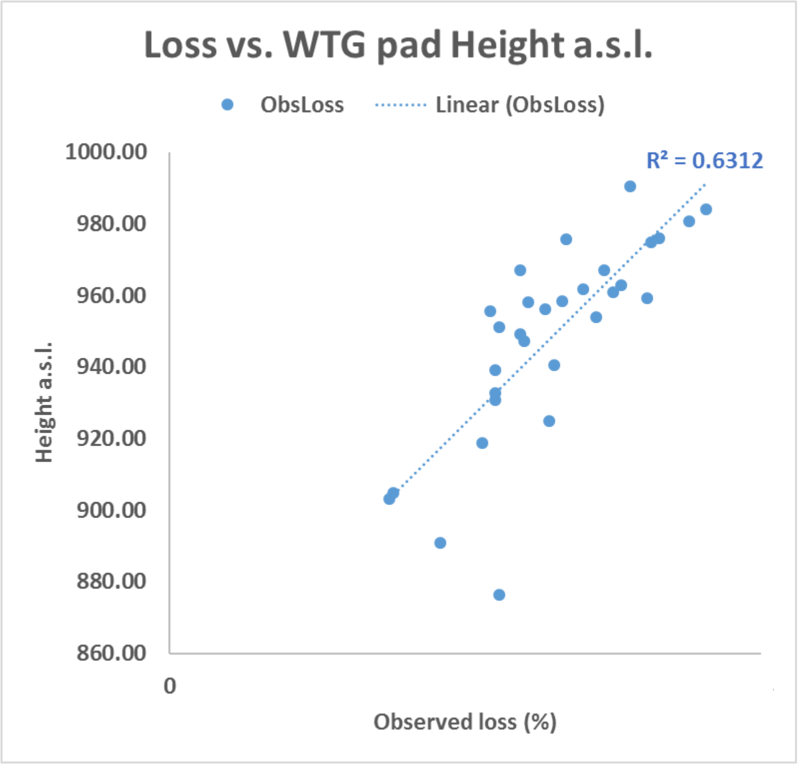


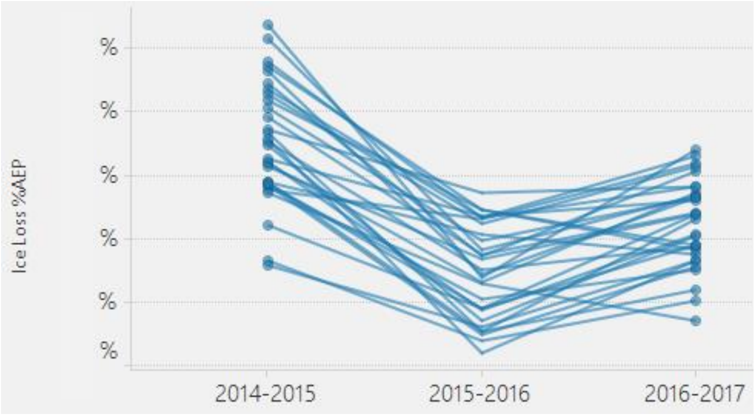


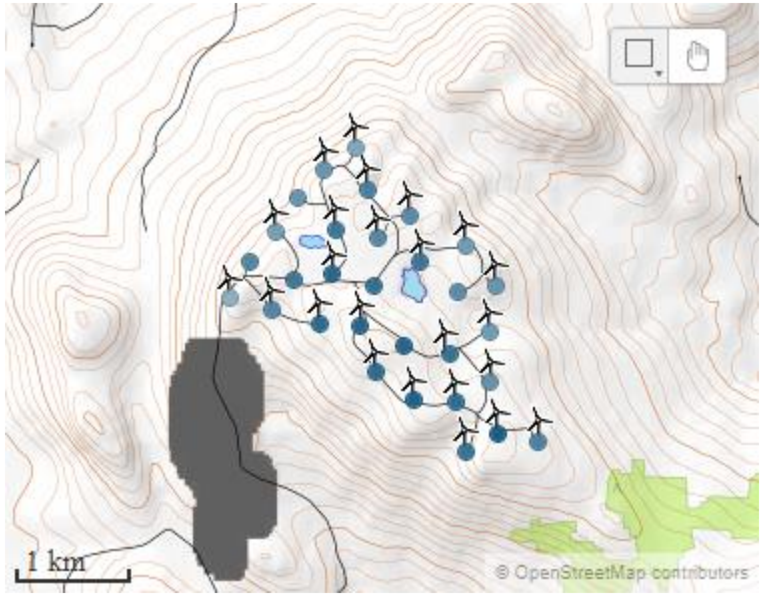
What causes the intra-park variability

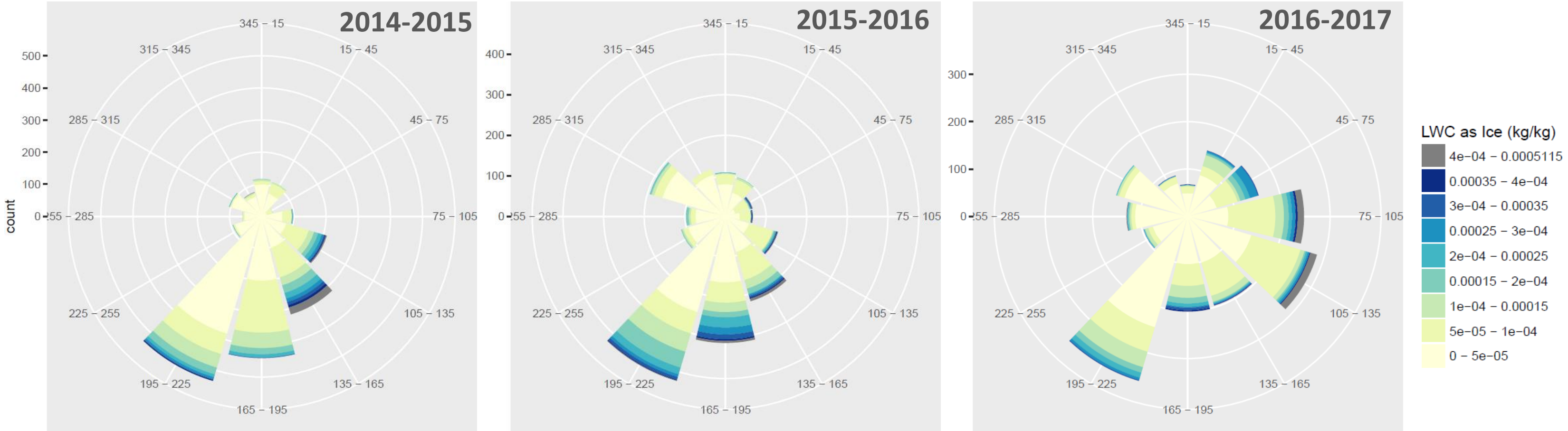
What we can see in the data and what we see but not understand

- Height explains about 60%
- Ice rose interpretation desired









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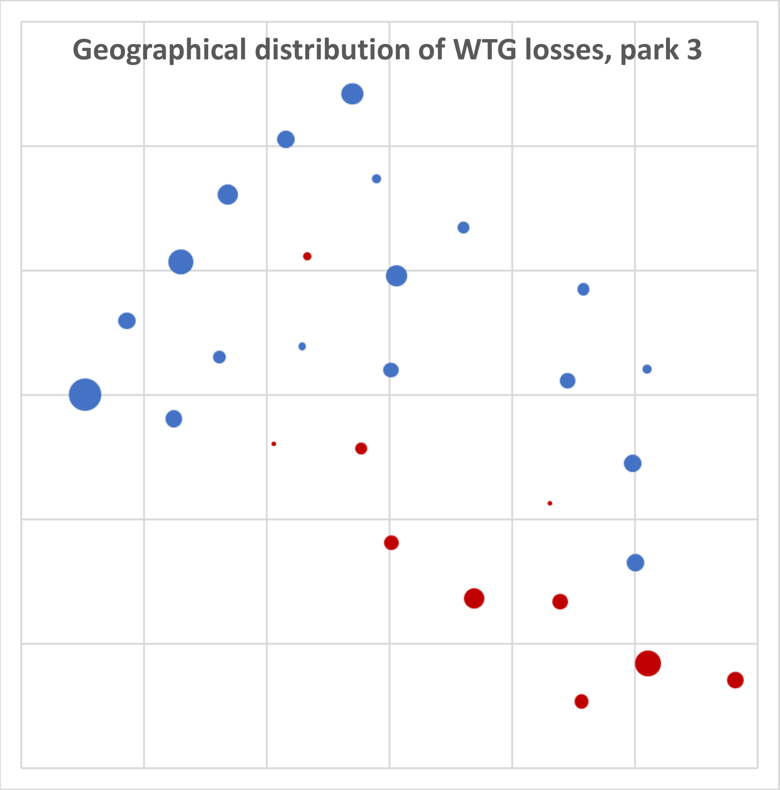
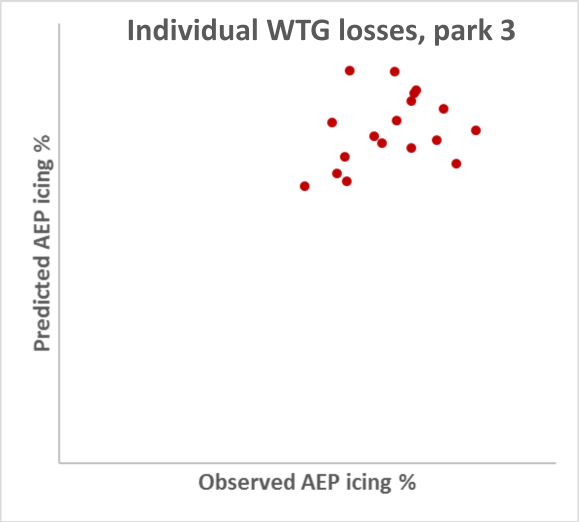
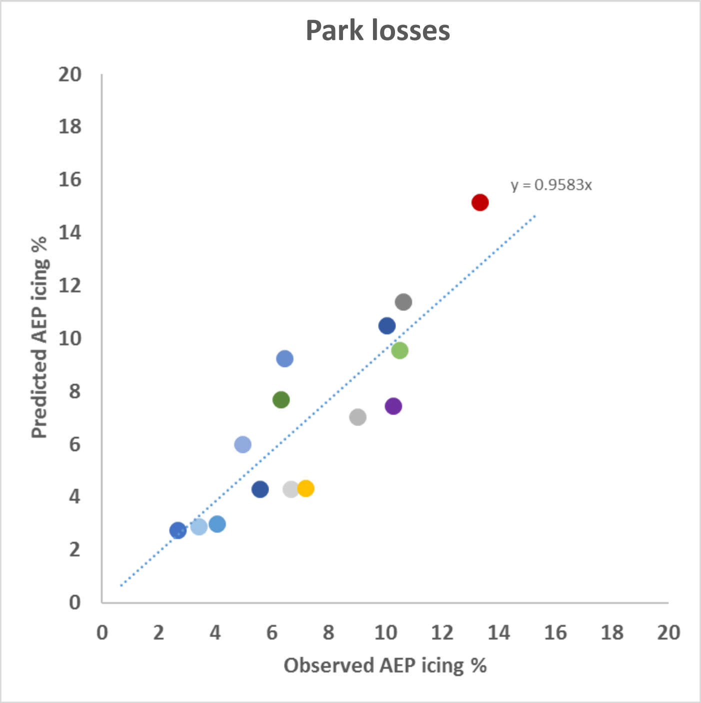
Future work, Challenges







Comprehensive analysis of factors affecting the remaining errors

What predictors should be added into the statistical model?

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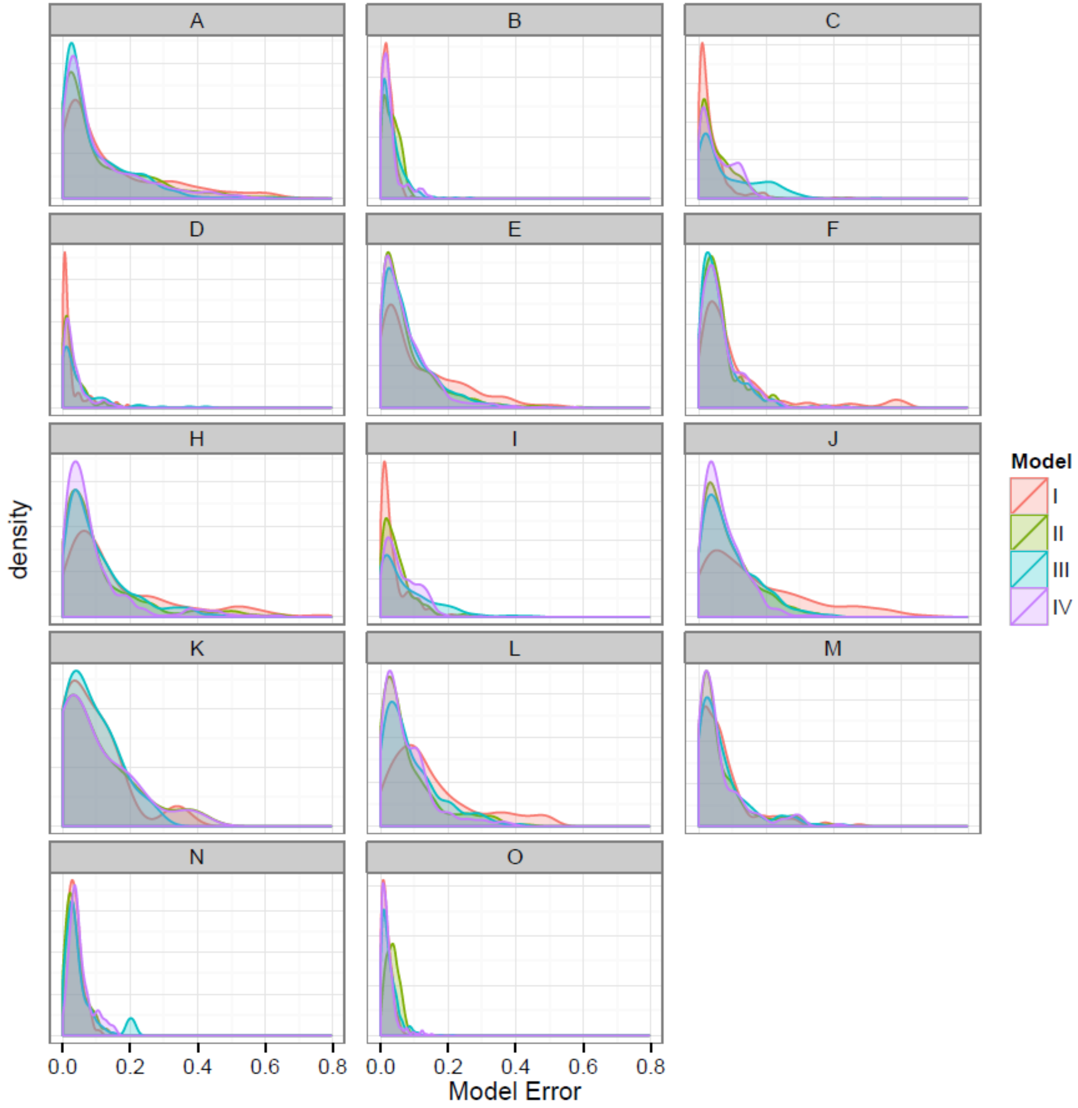
Developable platform

Lessons will be learned through future use

- Enhancing weather model capabilities regarding icing conditions
  - It is a specific problem requiring dedicated research
  - Data needed for fundamental understanding and model improvement
    - Systematic (like AI analysis of camera pictures)
    - Relevant quantities: LWC, droplet size distribution, cloud base height, visibility
    - Individual components of the chain (wind,icing) → (power,loss) must be further validated
- Further improvement of the learning: ice loss models learn from direct ice observations, not just power loss
  - Statistically
  - Physically
    - Iced blade aerodynamics, 3D CFD
    - Understanding ablation



Performance of 4 different ice loss models. All are driven by the same weather model input (Davis, 2014)

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