ENERGY

DNV GL's empirical icing map of Sweden and methodology for estimating annual icing losses

An update with further Nordic data

Till Beckford
10 February 2016

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Contents

- Experience from operational data
- Analysis of pre-construction data
- A long-term adjustment example

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Experience from operational data

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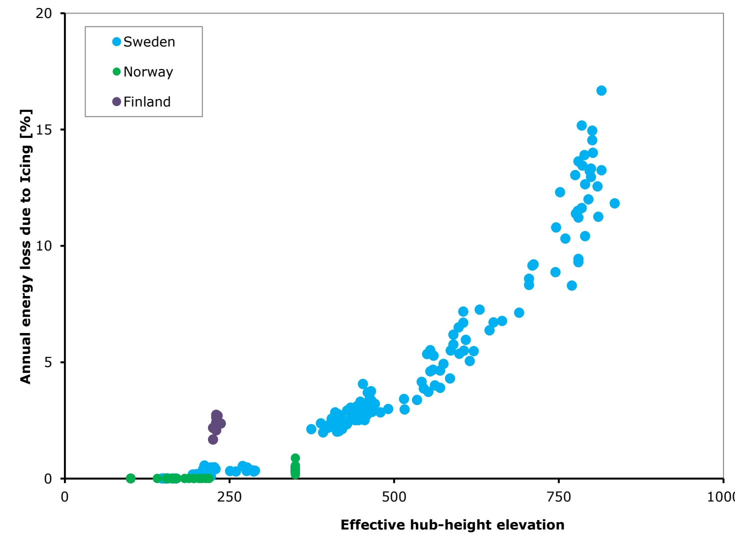
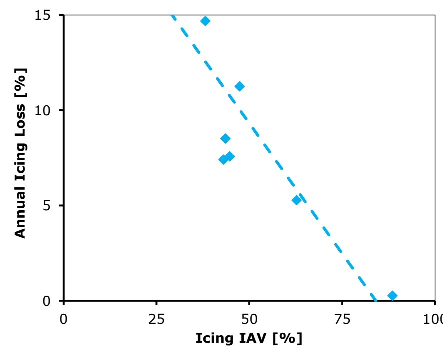
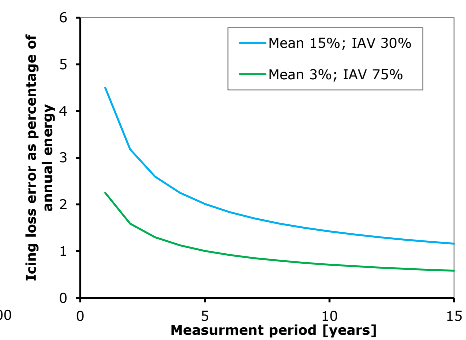
Previously at Winterwind...

- Analysed SCADA data from 18 wind farms in the Nordic region
- Strong relationship between elevation and annual icing loss
- A single Swedish climatology observed
- High inter-annual variability







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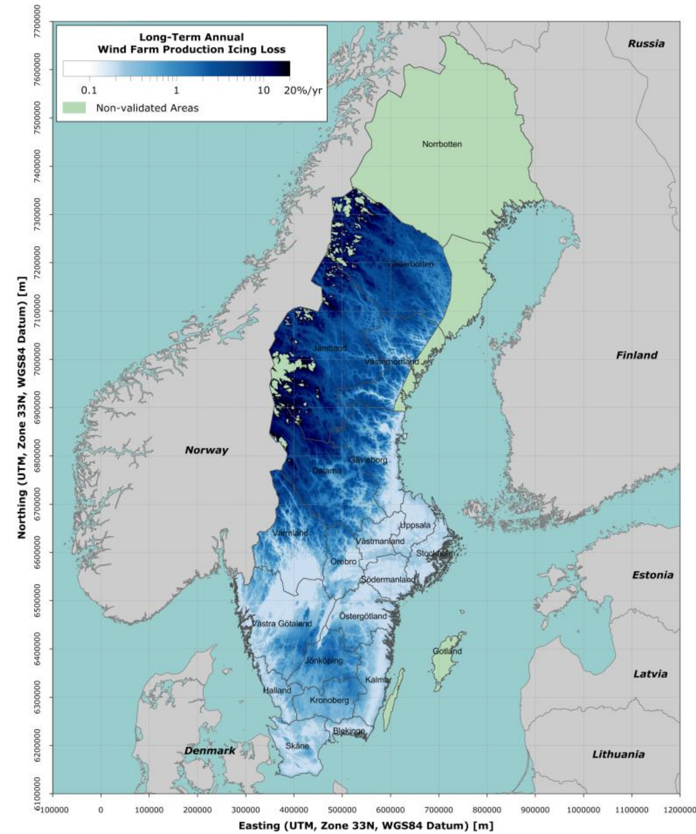
Previously at Winterwind…

- DNV GL Icing map of Sweden
  – Based on empirical data
- Geographical coverage limited by:
  – Data availability
  – Appreciation of other factors driving icing: cloud base height, Arctic weather systems, Gulf stream effects
- Questions:
  – What happens in the north of Sweden?
  – Can maps for Norway and Finland also be derived?



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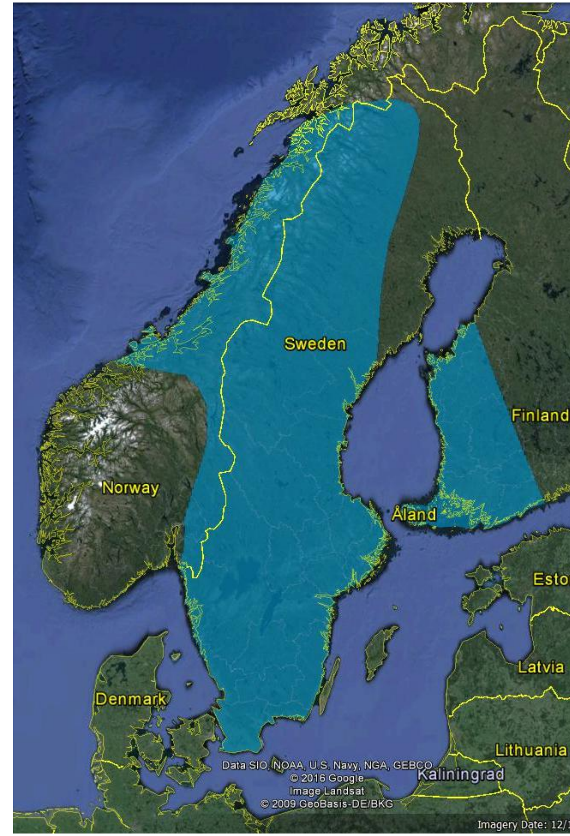
New data analysed in 2015/2016

- Data from 2 new wind farms in Sweden
  - Farm 1:
    - 15+ turbines
    - ~2 years of data
  - Farm 2:
    - 5+ turbines
    - ~1 year of data
- Additional year of data from 1 previously analysed wind farm
- Total of 20 operational wind farms analysed!



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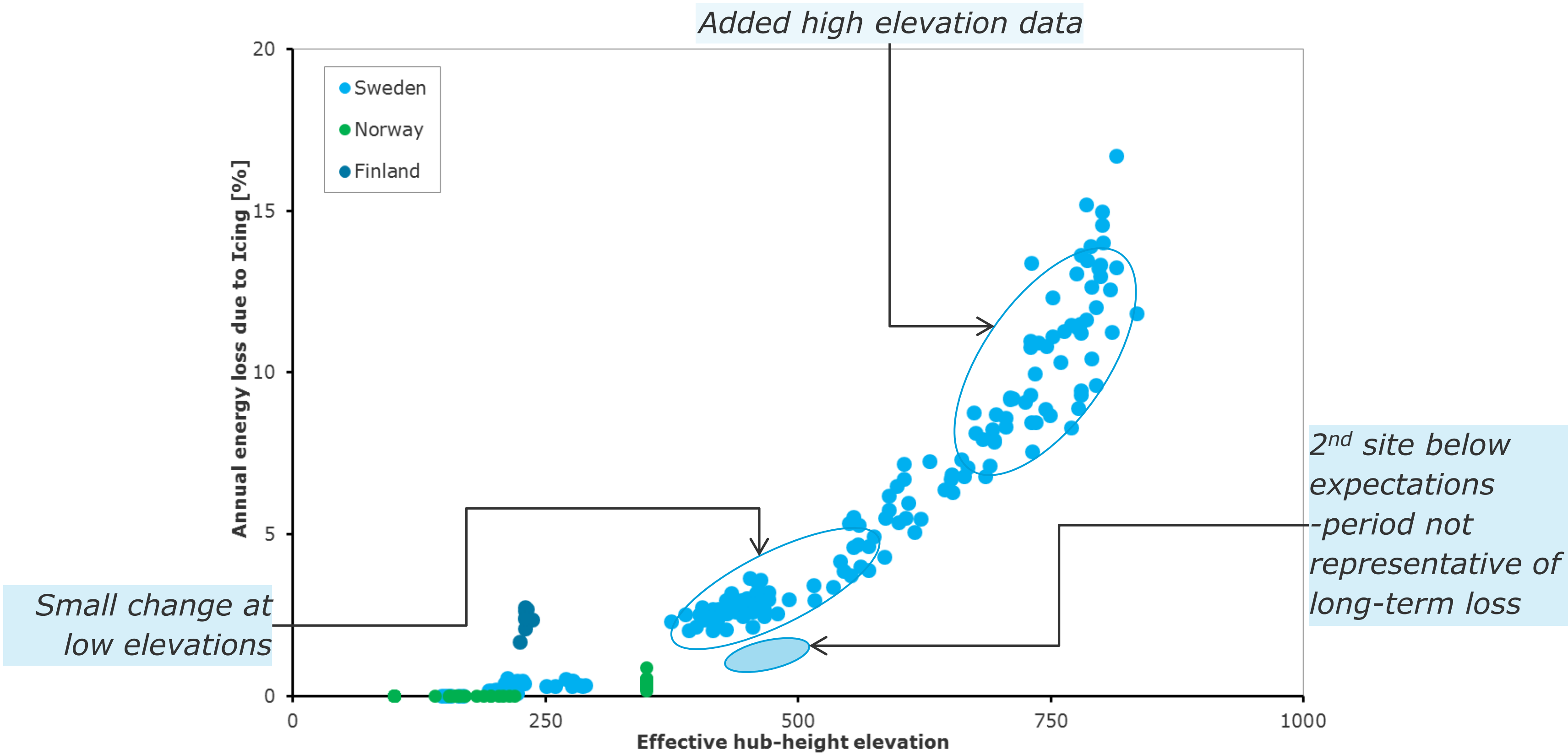
Result - Icing loss vs Elevation



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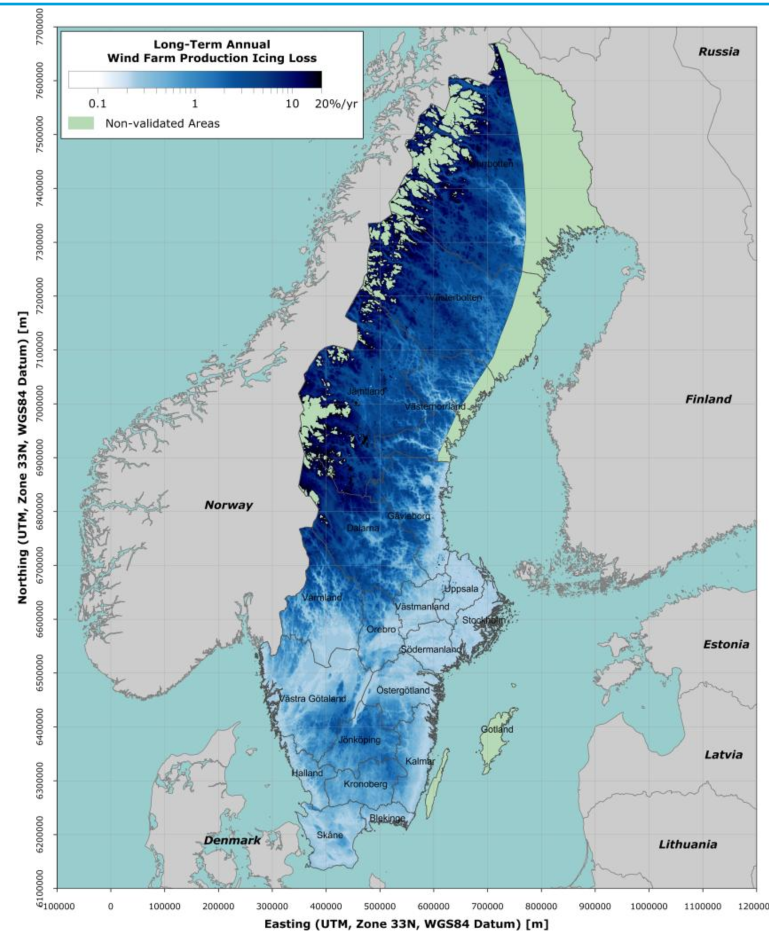
Result – Updated Icing Map of Sweden

- Increased geographical spread
  - Extended into Norrbotten
- Updated elevation trend
  - Small changes in predicted annual icing loss



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Analysis of pre-construction data

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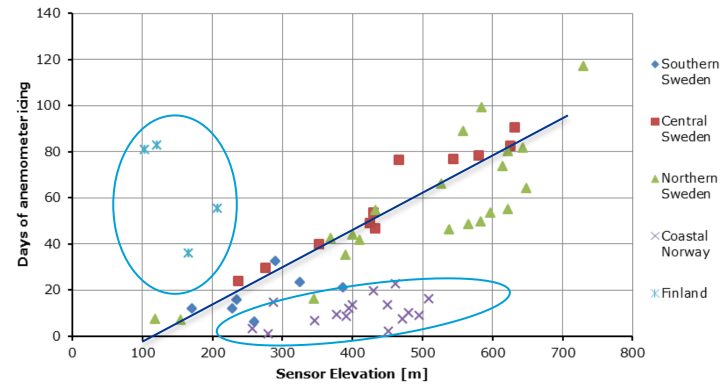
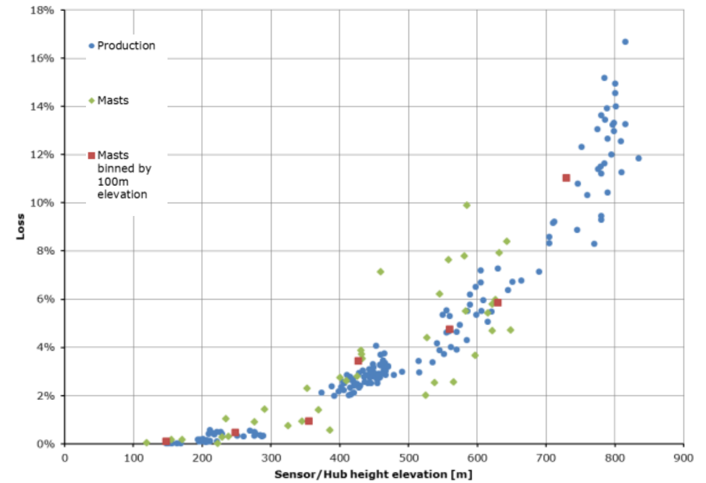
Previously at Winterwind…

- Analysed data from over 60 masts and 450 sensors
- Linear relationship between anemometer icing and elevation
- Developed a methodology to convert anemometer icing into energy loss





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New data 2015/2016

- Added 14 masts
  - 2 in Norway
  - 2 in Finland
  - 10 in Sweden

- Increased geographical spread
  - Northern latitudes better represented

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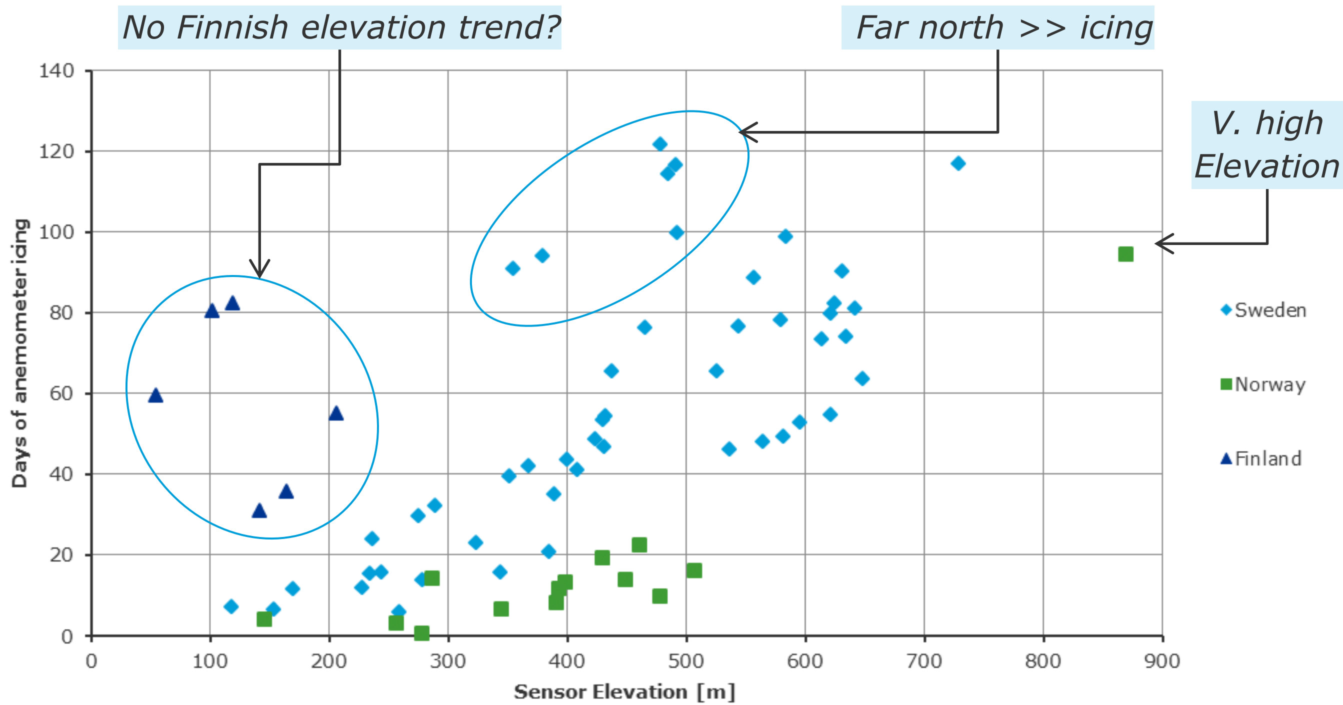
Sensor icing vs elevation



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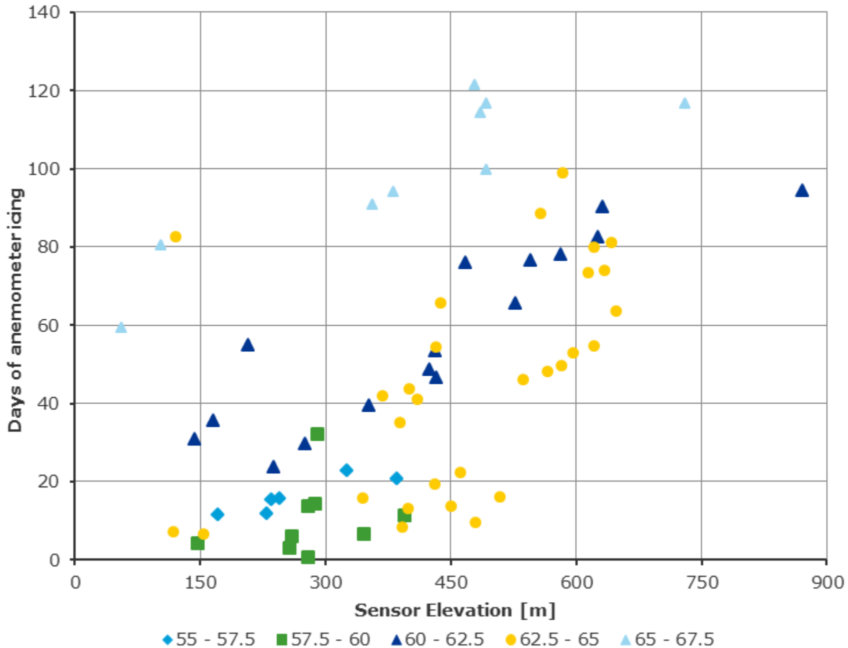
Icing climates – Latitude?



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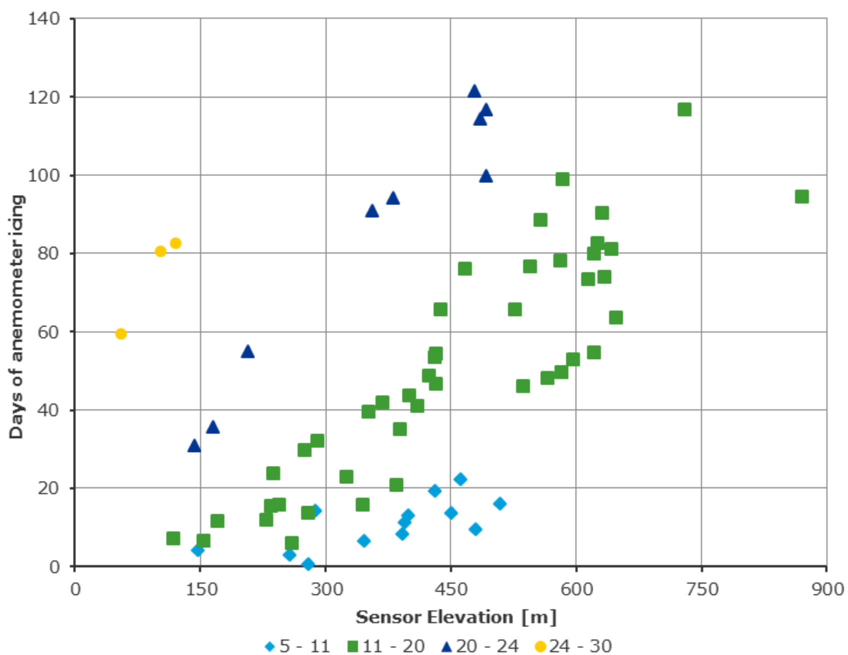
Icing climates – Longitude?



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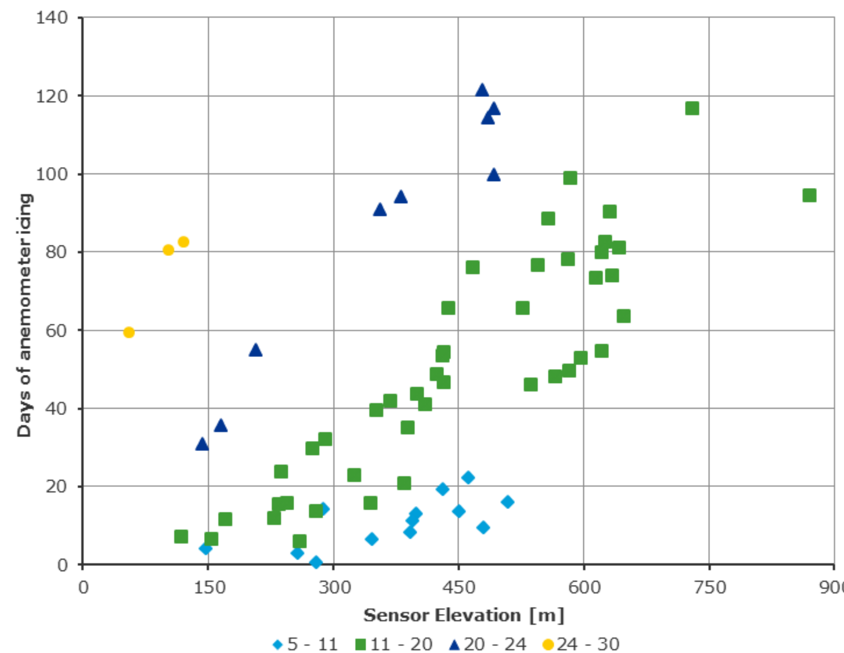
Icing climates

- Different icing zones across the Nordics
- Zones related to longitude
- Elevation the biggest driver within a zone
- What causes the step change between zones?
- Do the same trends exist in energy loss?



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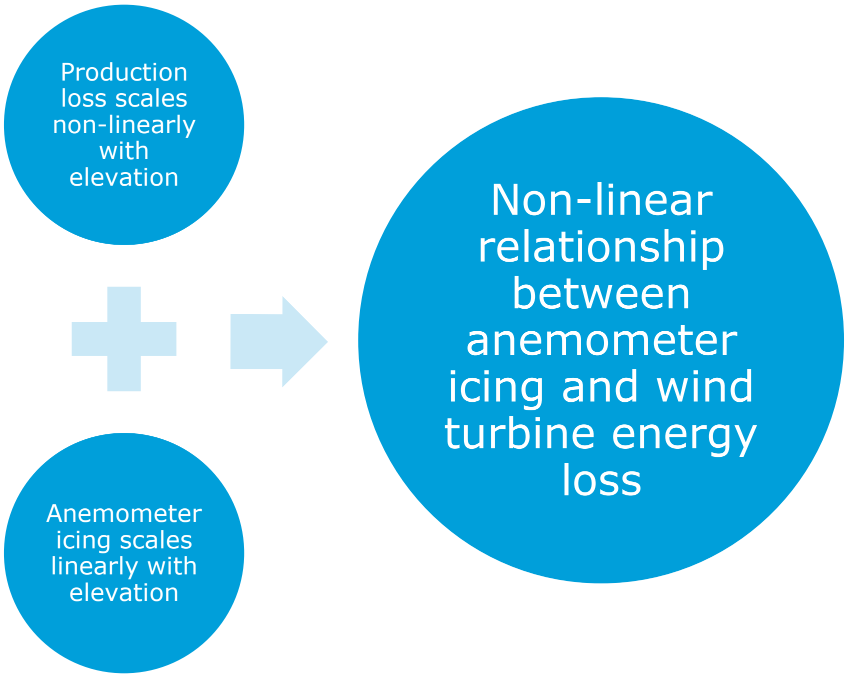
Anemometer icing to production loss, methodology recap



$$Energy\ loss\ due\ to\ icing = k \times time\ spent\ iced^2$$

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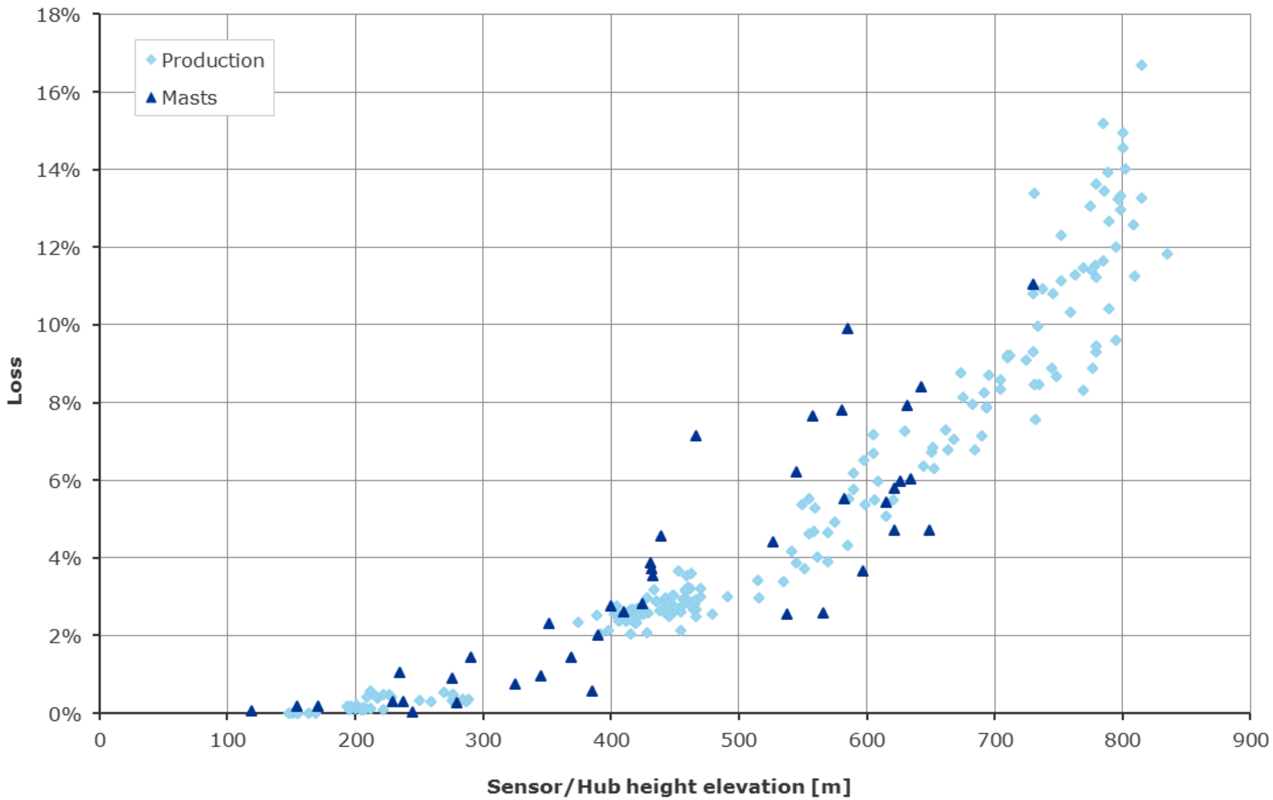
Converting anemometer icing to production loss



- Updated data supports anemometer loss model in Sweden
- Further work needed to reduce scatter
- Not enough data to assess model in Finland and Norway

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A long-term adjustment example

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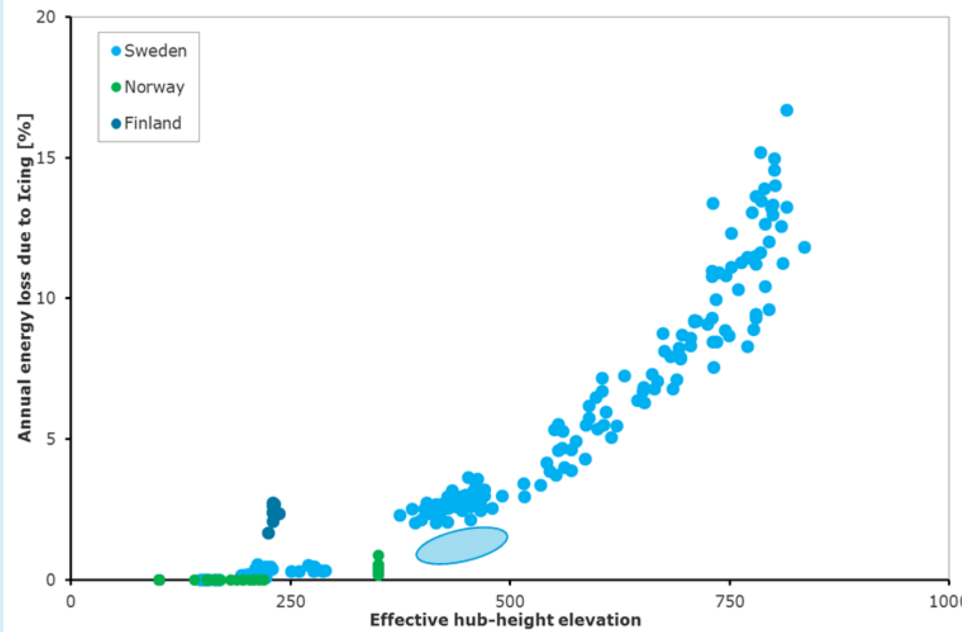
Long-term adjustment

- Can we explain the deviation from the general trend?
- Only 1 winter of data available
  - Was 2014/2015 representative?
  - Can we adjust the data to be representative of a longer historical period?



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Methodology recap

- Based on temperature and humidity data from nearby reference stations
  - Uses a matrix methodology
- Comparison of the frequency of icing conditions during the measured period relative to a longer historical period
- Challenging as reference source must be representative!

% Icing

T\RH	100	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	9	0	0	11	14	0	0	0	0	0	0	0	0	0	16	0	0	2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
3	7.1	27	2.4	0	0	14	0	0	0	22	0	0	0	0	11	0	14	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	52	22	50	24	13	40	0	50	0	20	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0		0	0	0	0	0
1	27	33	21		33	4.6	13	0	40	0	0	0	14	0	0	0	0	0	0	0	0		7.4	0	0	0	0	0	0	0	33		0	50	0	0
0	70	50	70	0	51	67	100	67	0	0	0	0	11	0	0	0	0	0	0	0	67	0	0	0	0	17	0	33	0	0	50	0	0		0	0
-1	71	25	0	60	33	0		0		50	75	0	20	0	0	33	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	33		0
-2	89	28	38	25	0	40	0	0	50	0	64			50	0	20	50	33	0	29	28	0	0	0	0	0	33	0	0		0		0	0	0	
-3	100	33	33	38	50	33	0	0	50	33	0	0	33	0	100	50	0	0	0	0	0	0	0	33	0	0	0		100	0	0	0	100			0
-4	100	50	100	50	57	67	25	33	100	0	0	33	100	100	50		33		67	0	100		33	33	0	50	0		0		0			0	0	
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-6	100	100	97	100	75	75	45	62	100	100	67	0	8.3	0		0	50	0	25	0																
-7		100	100	100	100	100	40	100	67	100		100			1.4						0		0		0				0	0						
-8			100	100	100	91	88	100	67	0	0	0	0	0		100	0		0		0				0	0										
-9				100	100	100	91	80	100	75	100		0	100		18			100					0	100						100					
-10						100	100	100	100	100	100		100			100	100	100		100													100			
-11							100	100	100	90	100	0		0	0	100		0			100			100	0		83									
-12								100	100	90	33	75		100	100	0		8.3																		
-13								100	100	92	100	100					0										0	0								
-14										100	83	100							0		100															
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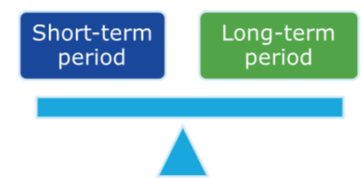

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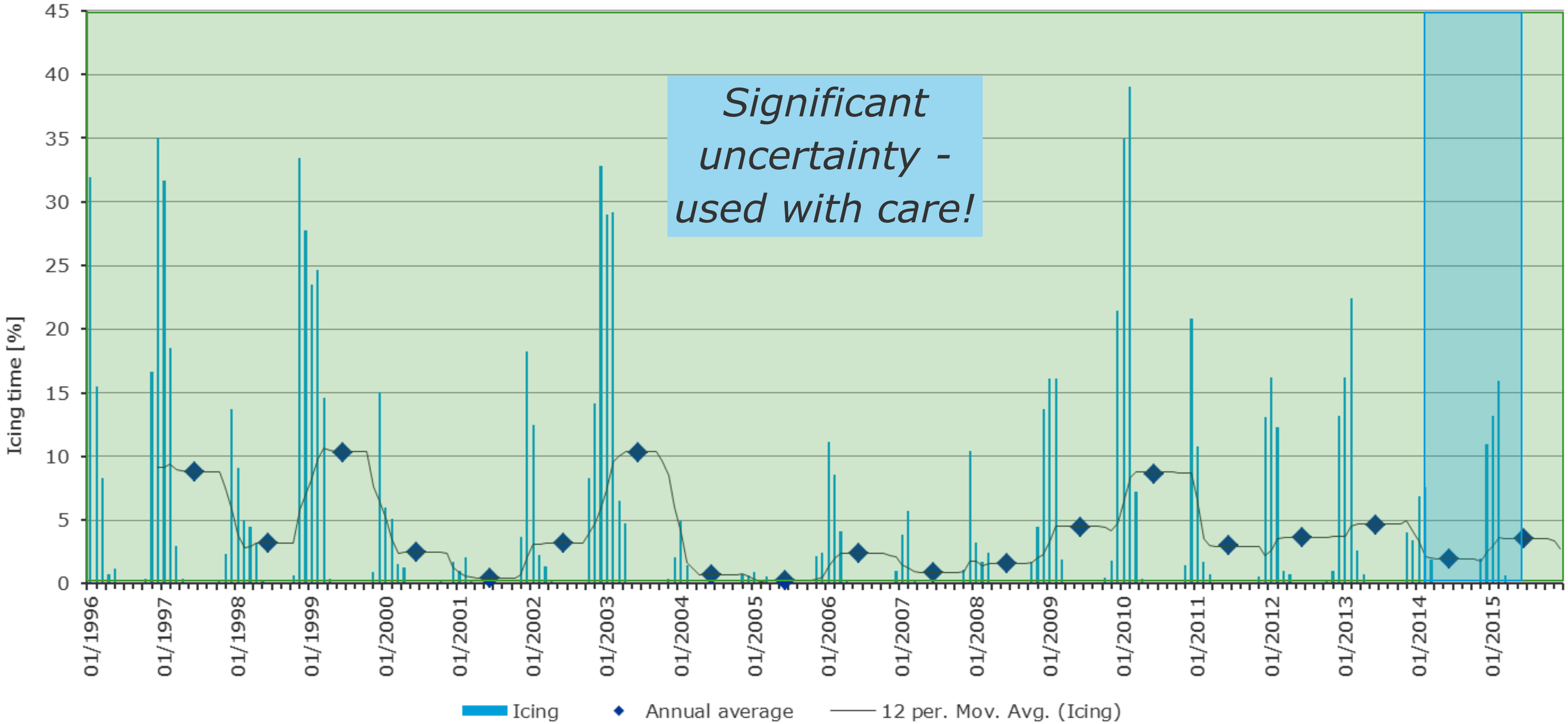
Example operational site

High inter-annual variability – 80%

Suggests upward adjustment of 60%



Significant uncertainty - used with care!

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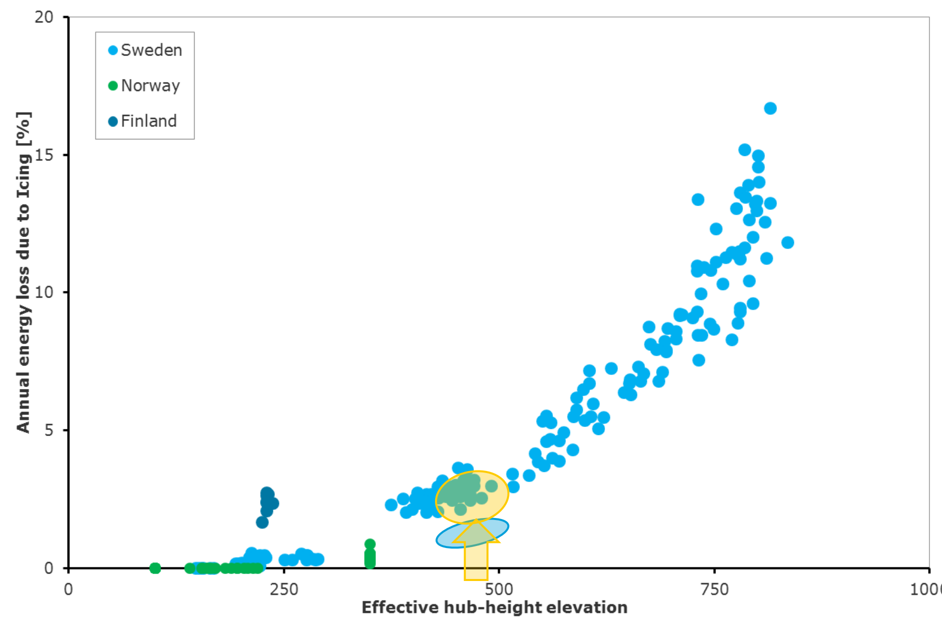
Long-term adjustment

- Methodology suggests a significant upwards adjustment
- Magnitude of adjustment is unclear
  – Method considers time iced, not energy loss
- Methodology is qualitative at present
- There may be other factors to consider



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Conclusions

New operational data

- Elevation trend confirmed – non-linear
- DNV GL Icing Map of Sweden extended north

Further work…

- More data!
  - Finland
  - Norway

Pre-construction analysis

- Elevation trend confirmed - linear
- Identification of climate zones – longitudinal

Further work…

- More data!
  - Finland
  - Norway

Long-term adjustments

- Example of a qualitative adjustment
- Highly dependant of reference data

Further work…

- Long datasets needed
- Refinement of matrix

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Many thanks

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