

ESTIMATING ENERGY LOSSES CAUSED BY BLADE ICING FROM PRE-CONSTRUCTION WIND DATA (UNDERSTANDING, PREDICTING, ADJUSTING)

WINTERWIND 2015, Piteå

Till Beckford

3 February 2015

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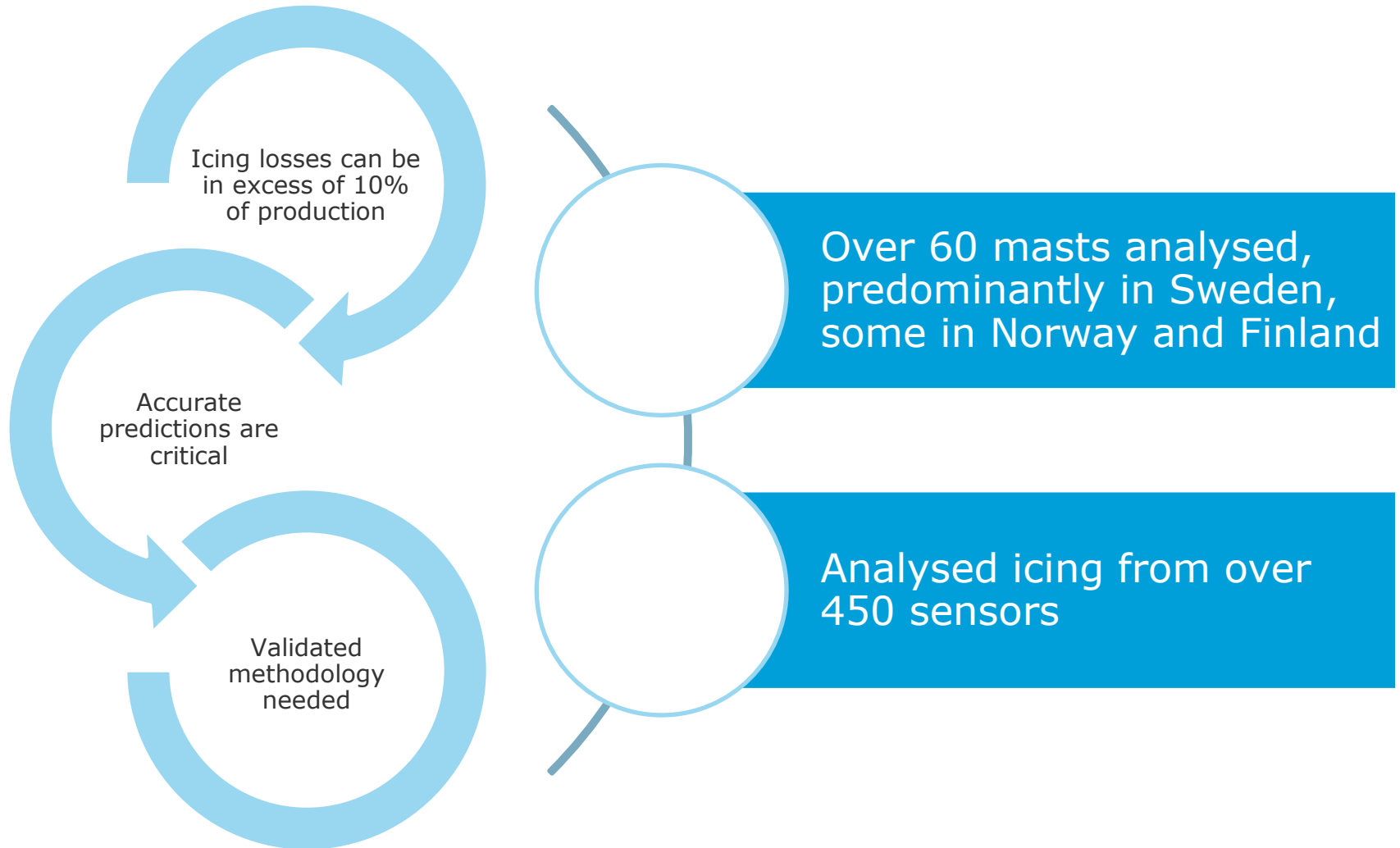


1. Understanding icing in pre-construction meteorological data

2. Predicting icing losses based on pre-construction data

3. Adjusting icing predictions to the long-term expectation

Introduction





1. Understanding icing in pre-construction meteorological data

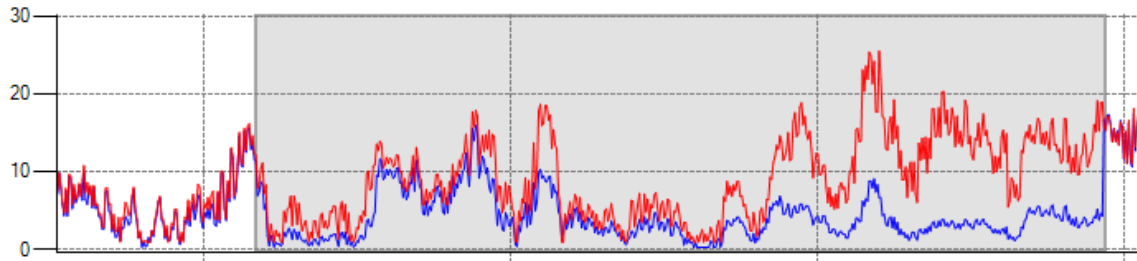
2. Predicting icing losses based on pre-construction data

3. Adjusting icing predictions to the long-term expectation

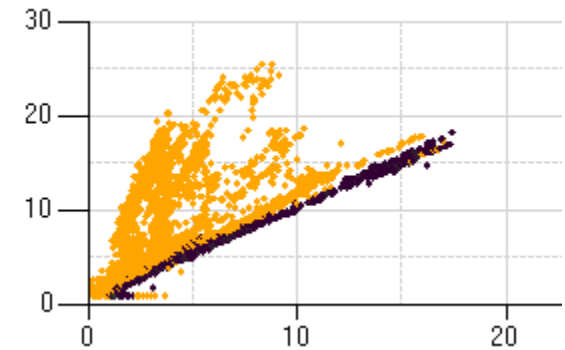
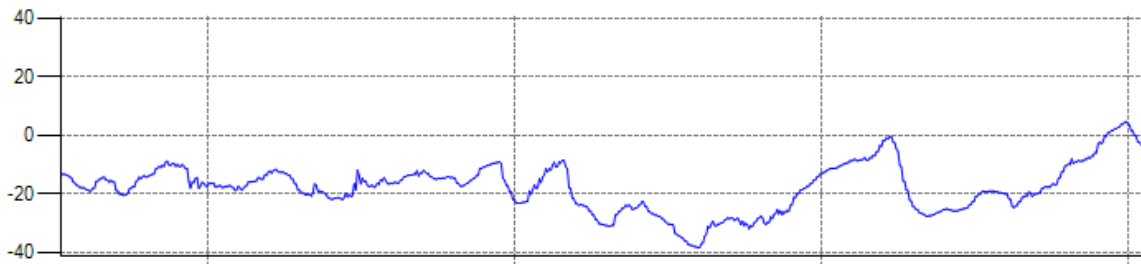
1.2.3. Understanding icing in pre-construction meteorological data

Ice detection

Anemometer Mean



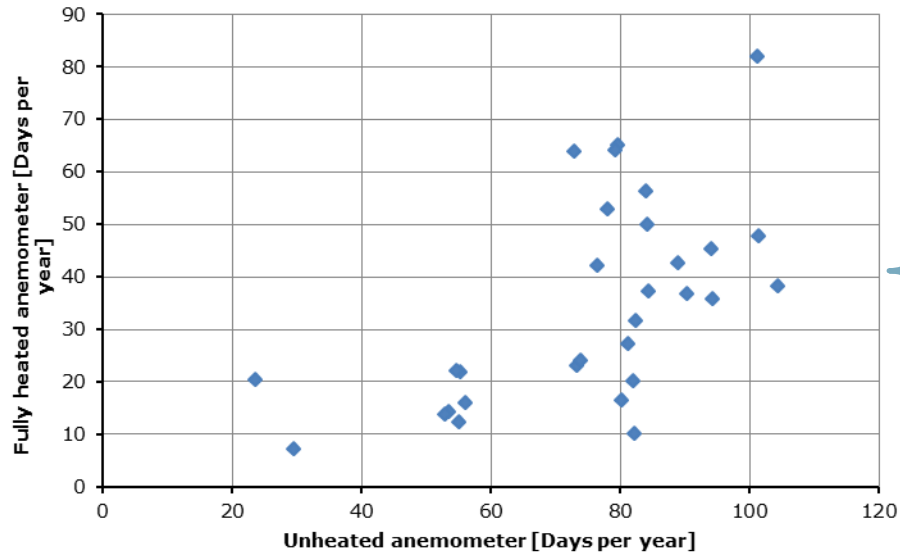
Temperature Mean



1.2.3. Understanding icing in pre-construction meteorological data

Findings - Sensor type

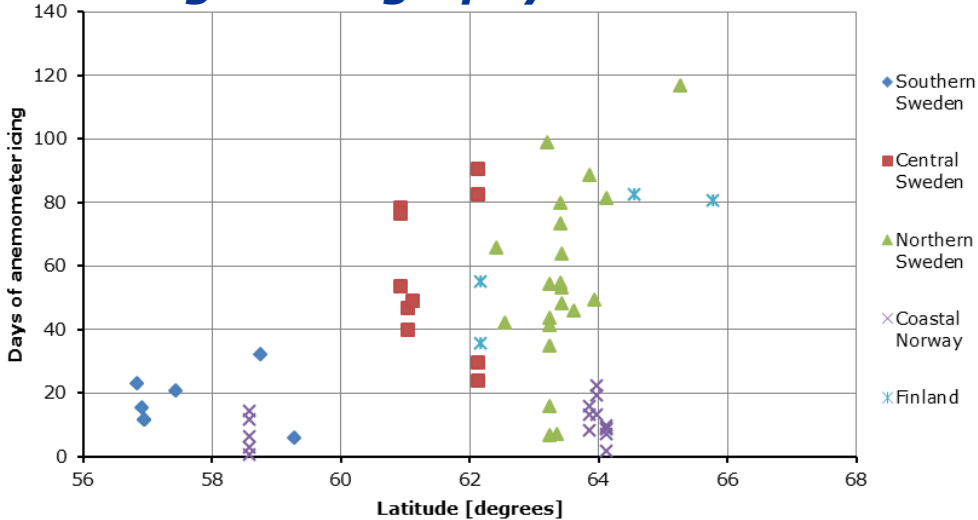
- Partially heated cup anemometer icing \equiv unheated cup anemometer icing
- Wind vane icing \ll cup anemometer icing
- Fully heated cup anemometer icing $<$ unheated cup anemometer icing



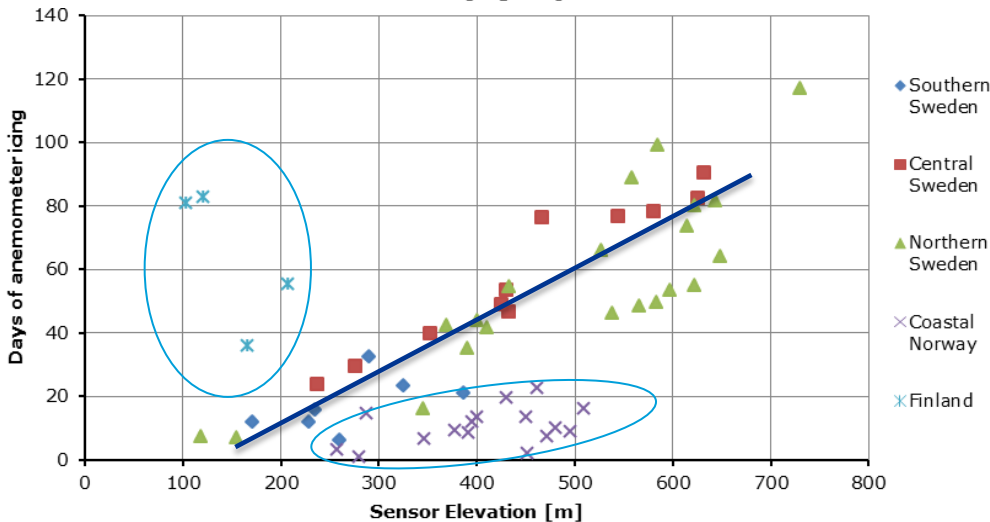
- Benefit is inconsistent
- Largely dependent on the power supply

1.2.3. Understanding icing in pre-construction meteorological data

Findings - Geography



- No correlation
- Large variety of icing within regions



- Linear correlation in Sweden
- Swedish regions lie on same trend
- Norway and Finland have separate icing climates

Contents



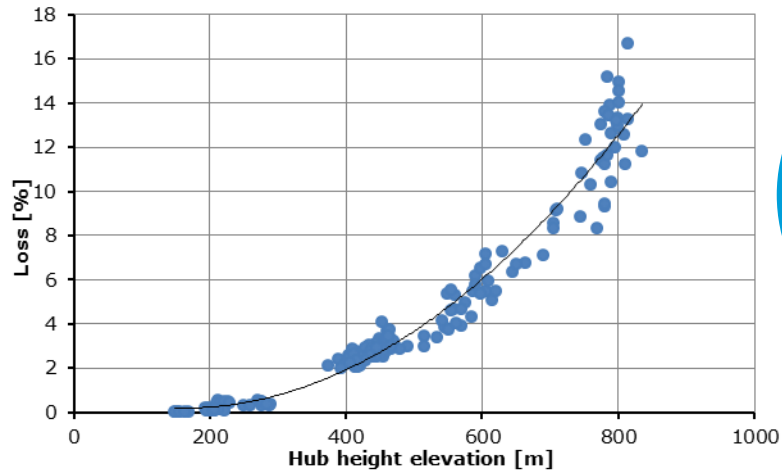
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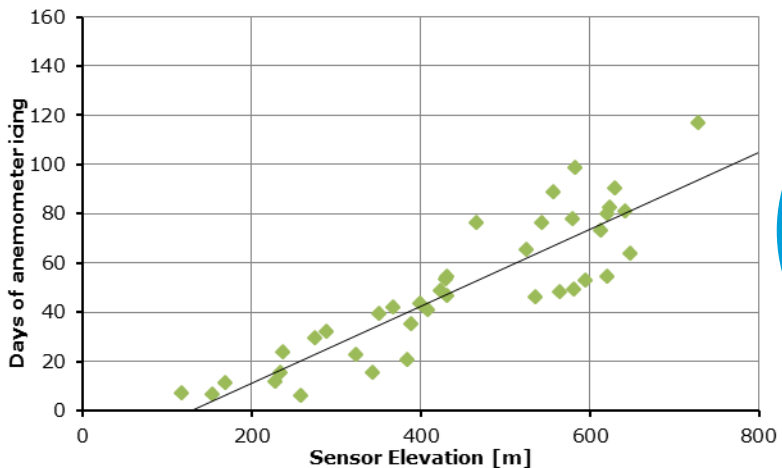
3. Adjusting icing predictions to the long-term expectation

1.2.3. Predicting icing losses based on pre-construction data

Lessons learnt from wind farm and anemometer data



Production loss scales non-linearly with elevation



Anemometer icing scales linearly with elevation



Non-linear relationship between anemometer icing and wind turbine energy loss

1.2.3. Predicting icing losses based on pre-construction data

Methodology

$$\text{Energy loss due to icing} = \text{time spent iced} \times \text{severity of icing}$$

↓
given by
anemometer
data

↓
cannot be directly
measured from
typical met masts

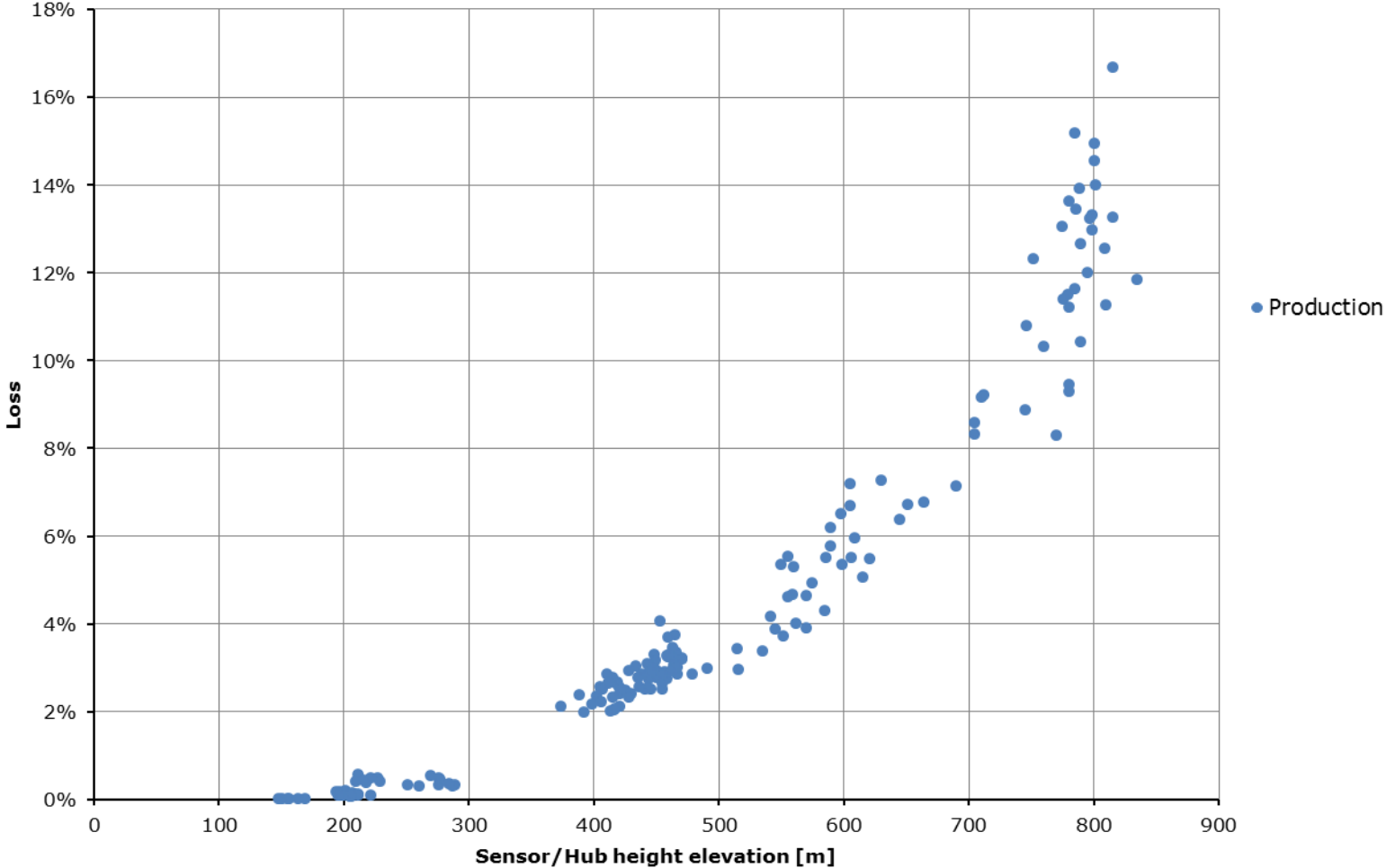
small amount of icing = low severity

large amount of icing = high severity

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

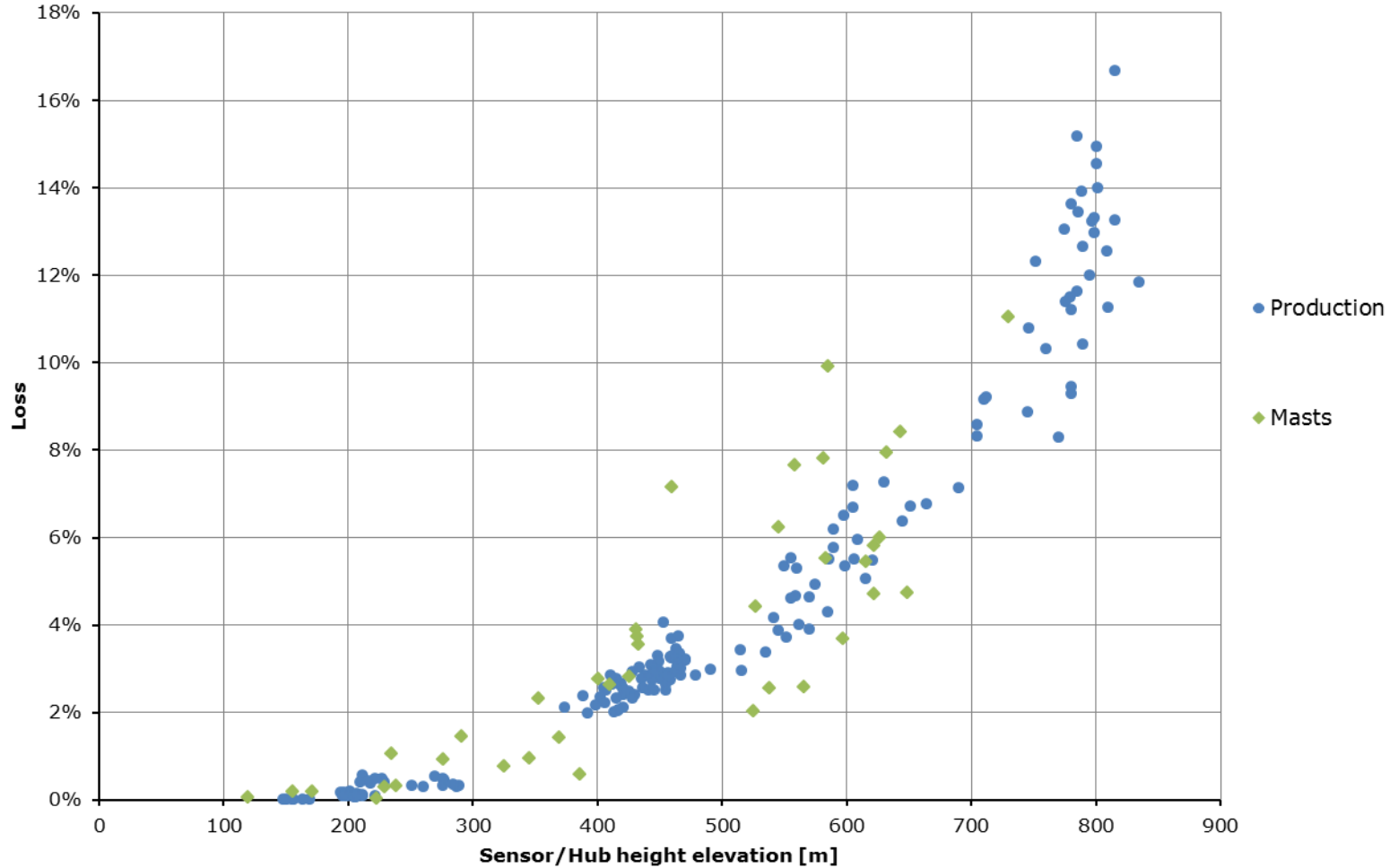
1.2.3. Predicting icing losses based on pre-construction data

Validation



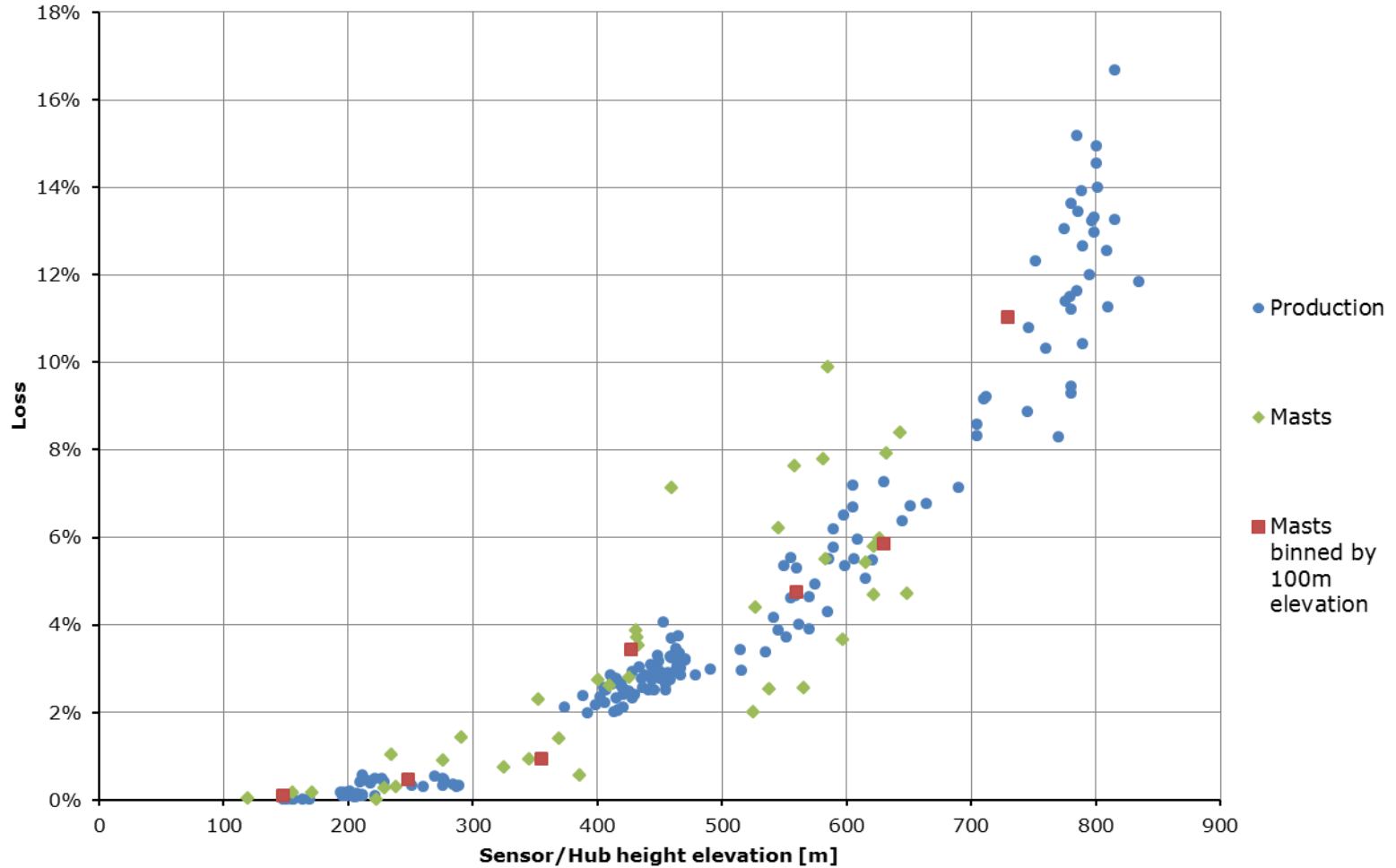
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Validation



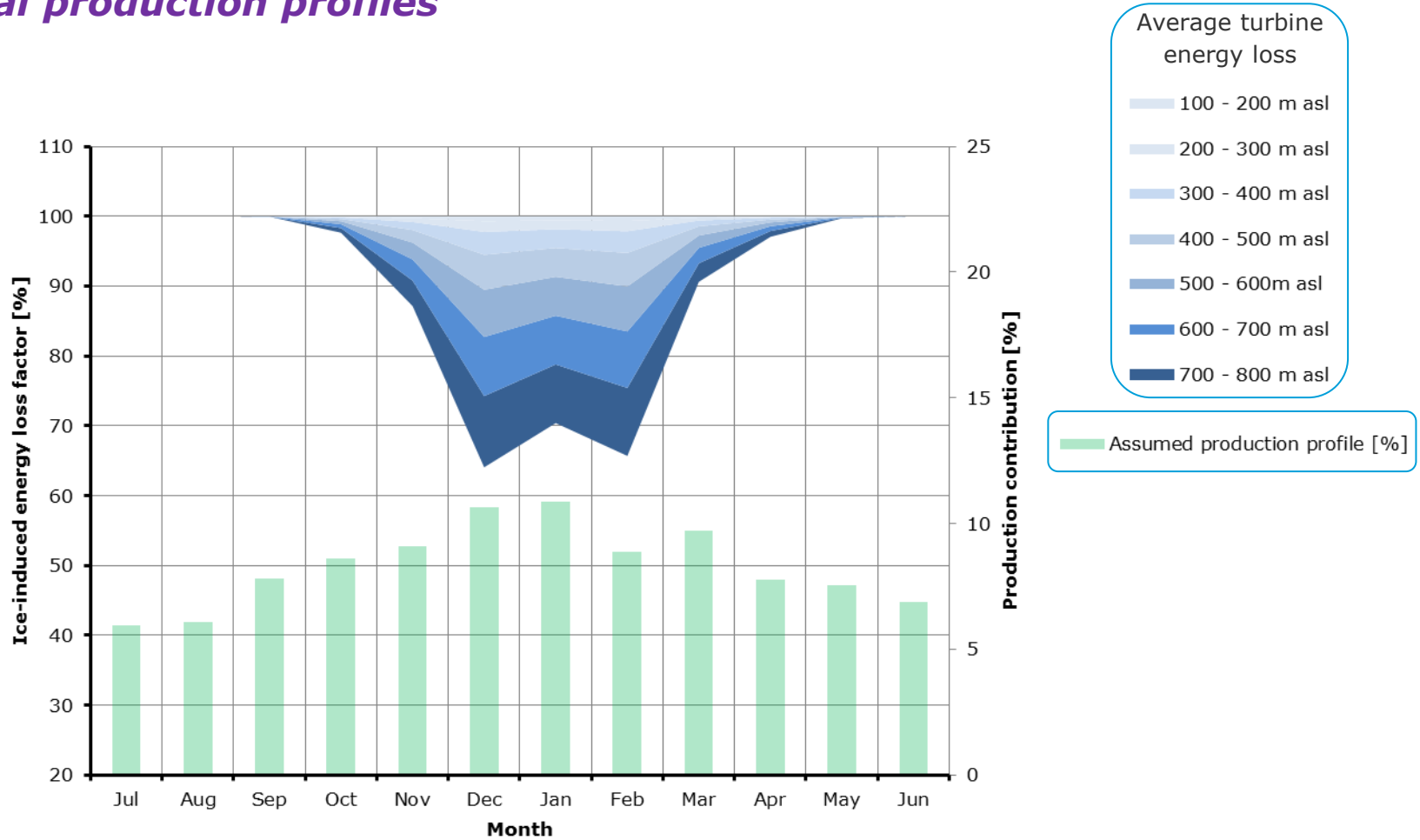
1.2.3. Predicting icing losses based on pre-construction data

Validation



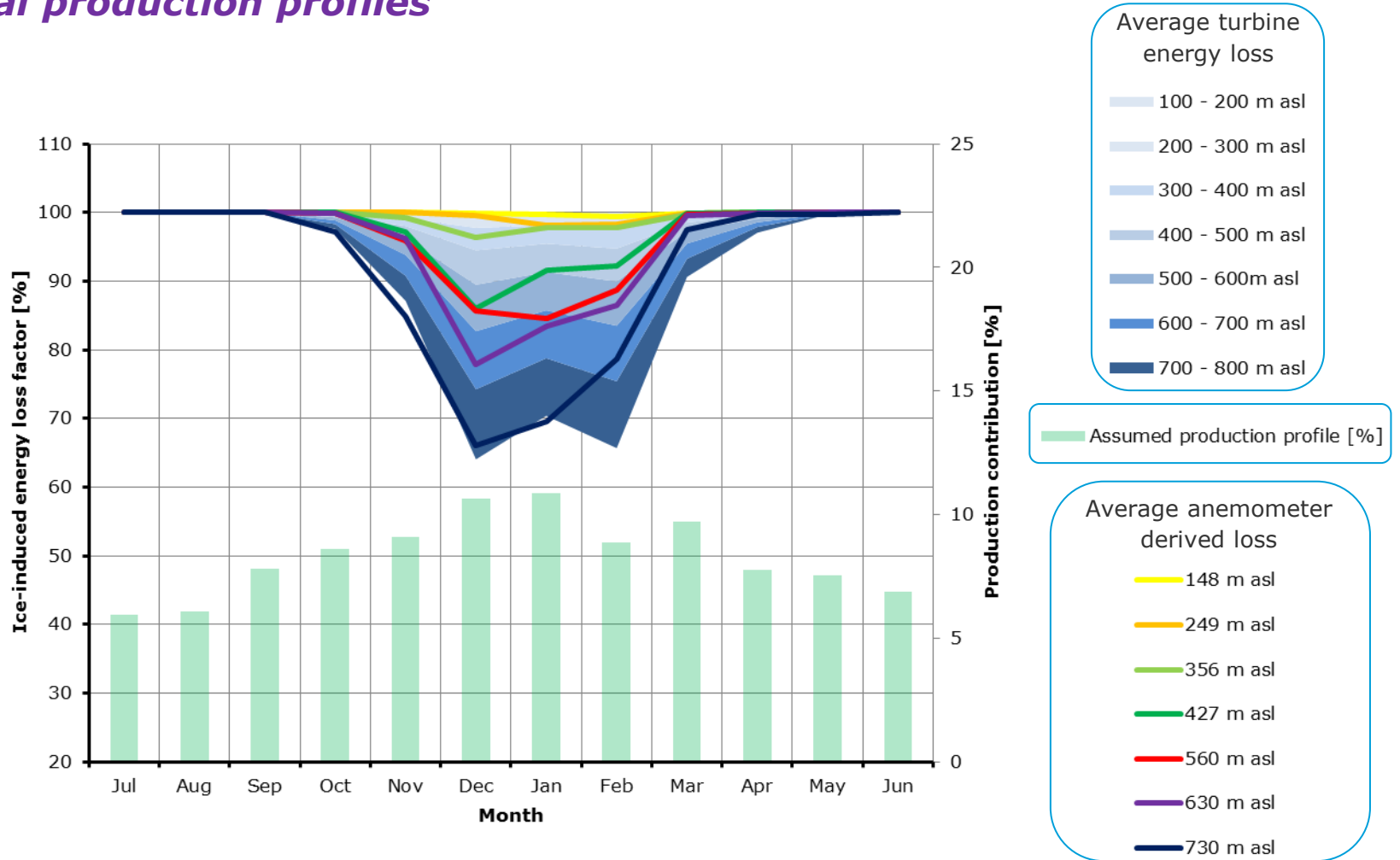
1.2.3. Predicting icing losses based on pre-construction data

Seasonal production profiles



1.2.3. Predicting icing losses based on pre-construction data

Seasonal production profiles





1. Understanding icing in pre-construction meteorological data

2. Predicting icing losses based on pre-construction data

3. Adjusting icing predictions to the long-term expectation

1.2.3. Adjusting icing predictions to the long-term expectation

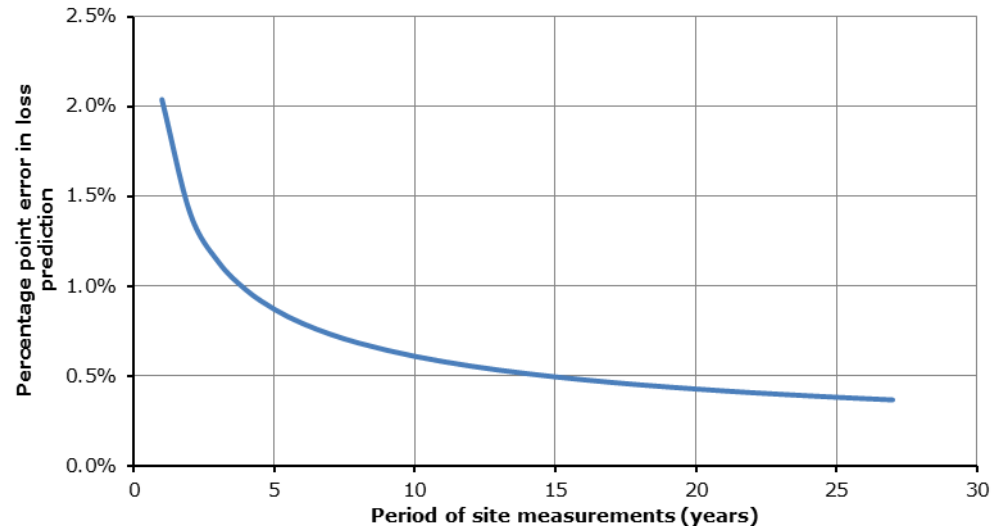
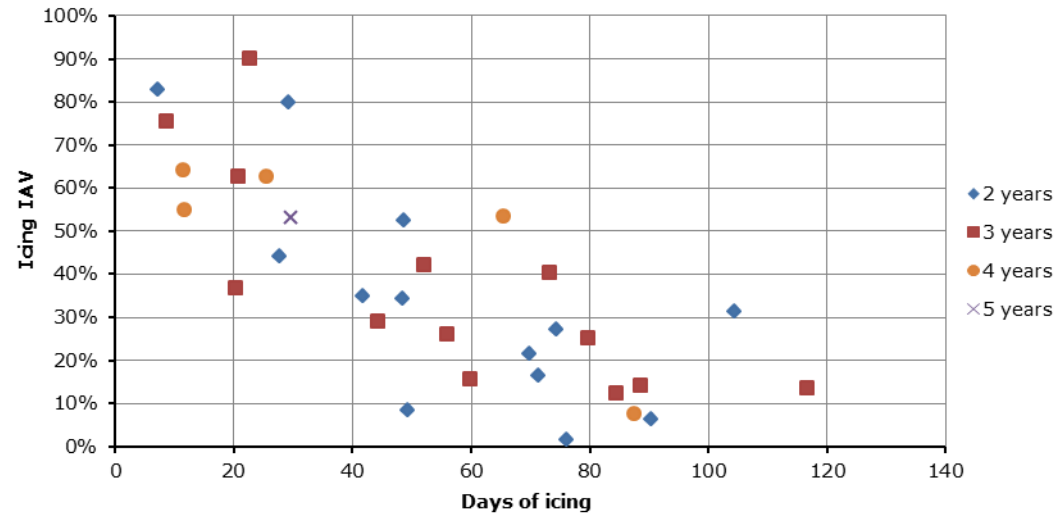
Why?

- Inter-annual variability (IAV) defined as:

- $IAV [\%] = \text{Std Dev} / \text{Mean}$

- Example:

- 55 days/year of measured icing
- $IAV = 35\%$
- Annual loss estimate = 3.4%



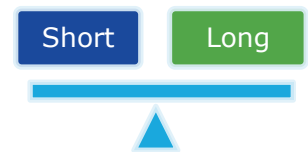
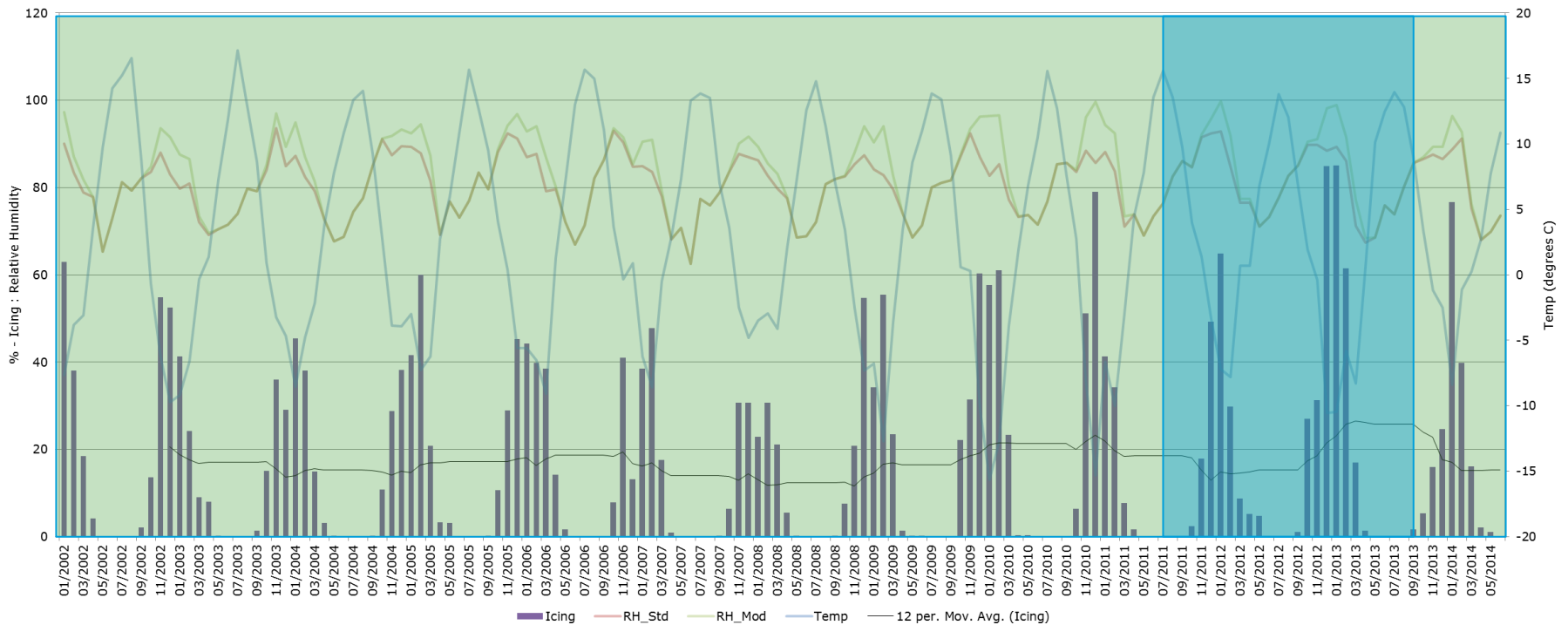
1.2.3. Adjusting icing predictions to the long-term expectation

Icing matrix – site data

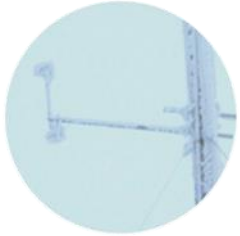
T/RFH	% Icing																																							
	100	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65				
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
4	9	0	0	11	14	0	0	0	0	0	0	0	0	0	16	0	0	2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	50	0	0	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	0	7.4	0	0	0	0	0	0	33	0	50	0	0	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	17	0	33	0	0	50	0	0	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	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	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	0	100	0	0	0	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	0	0	0	0	0	0	0			
-5	100	80	100	100	33	80		50	33	33	0		33		67	0	0	33	0	0	33	0	0	50	100	0	0	0	0	0	0	0	0	0	0	0	0	0		
-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																			
-8			100	100	100	100	91	88	100	67	0	0	0	0		100	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					100	0										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											
-14									100	83	100																													
-15										100	100	100	100	0																										
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1.2.3. Adjusting icing predictions to the long-term expectation

Long-term comparison



Conclusions



Understanding icing in pre-construction meteorological data

- Icing can be reliably identified in pre-construction anemometer data
- Icing is independent of anemometer type, heating is effective but inconsistent
- In Sweden, icing correlates with altitude, not latitude. Norway and Finland have separate icing climates



Predicting icing losses based on pre-construction data

- DNV GL has a validated method for reliably converting anemometer data to the expected annual energy loss
- The seasonal loss profile is also well represented



Adjusting icing predictions to the long-term expectation

- DNV GL has a method to extrapolate historical data and assess the iciness of site measurements relative to the long-term expectations
- Further validation work is under way for the long-term adjustment

Questions?

ESTIMATING ENERGY LOSSES CAUSED BY BLADE ICING FROM PRE-CONSTRUCTION WIND DATA (UNDERSTANDING, PREDICTING, ADJUSTING)

Thanks to Carla Ribeiro and Staffan Lindahl

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