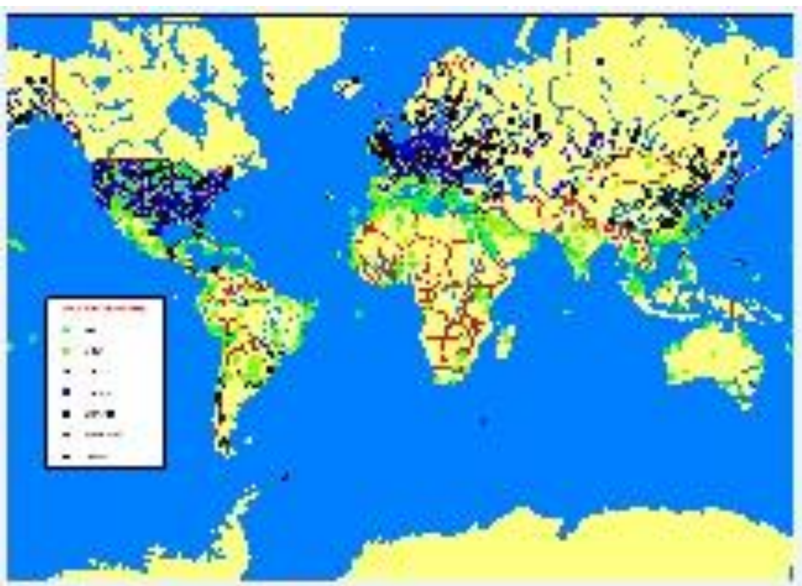
Business from technology



Wind Power Icing Atlas – tool for financial risk assessment

Winterwind 2014

Sundsvall 11-12.2.2014

Ville Lehtomäki, Timo Karlsson, Simo Rissanen
VTT Technical Research Centre of Finland

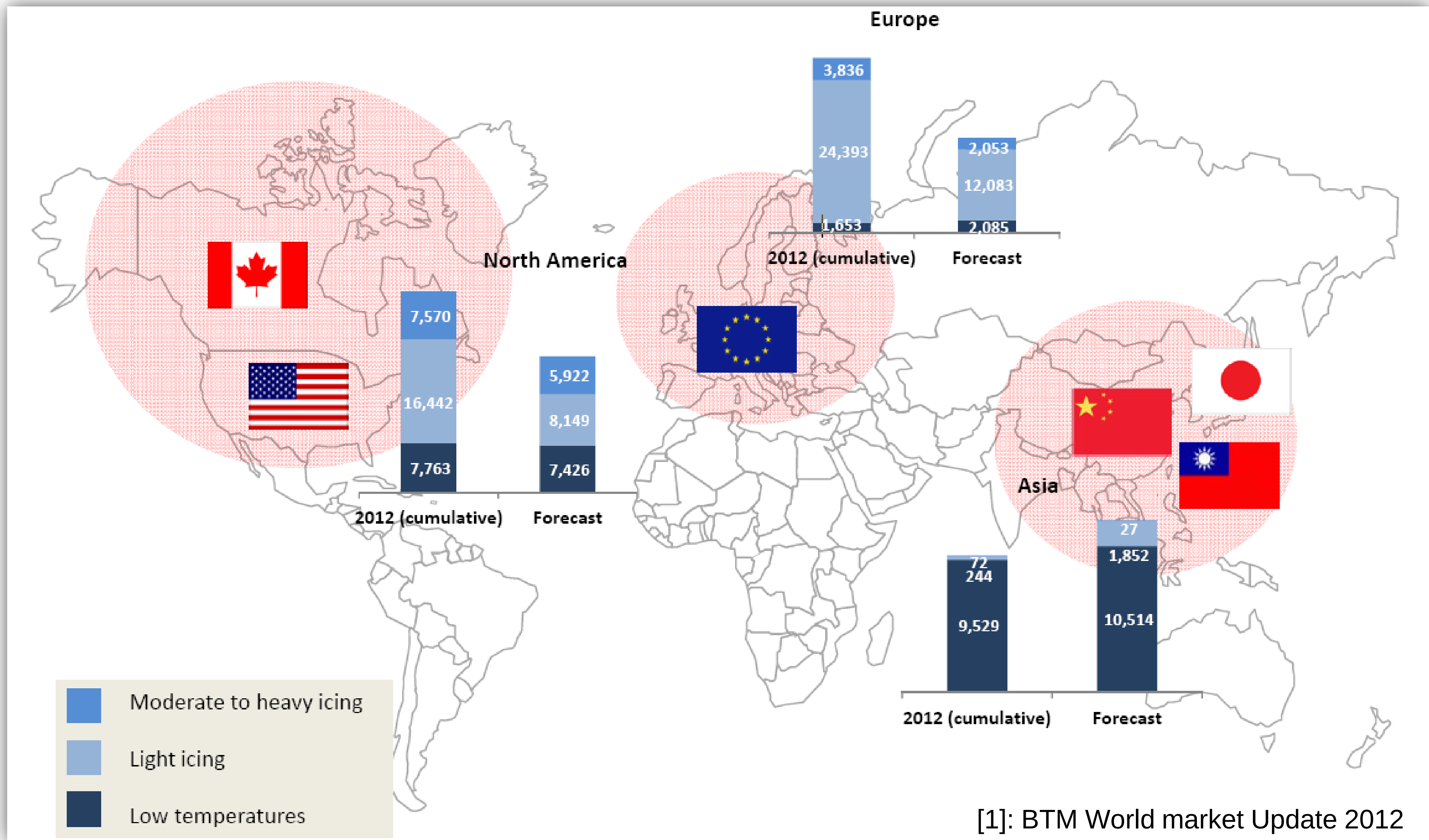
Outline

- Motivation from market potential & customer interviews

- Wind Power Icing Atlas (WIceAtlas)
  - Main benefits
  - Validation results
  - Case example: 20 x 3MW site in North Sweden

- Conclusions

Cold Climate (CC) wind energy market potential [1]



[1]: BTM World market Update 2012

Total installed and forecasted capacity in Cold Climates [9]

Cumulative installed capacity by end of 2012 [MW]			Forecasted capacity 2013-17 [MW]		
Low temperature	Light icing: safety risk, some economic risk	Moderate to heavy icing: economic and safety risk	Low temperature	Light icing: safety risk, some economic risk	Moderate to heavy icing: economic and safety risk
18,945	41,079	11,478	20,025	22,083	8,003
Total 69,000 (*)			**Total 45,000 – 50,000**		

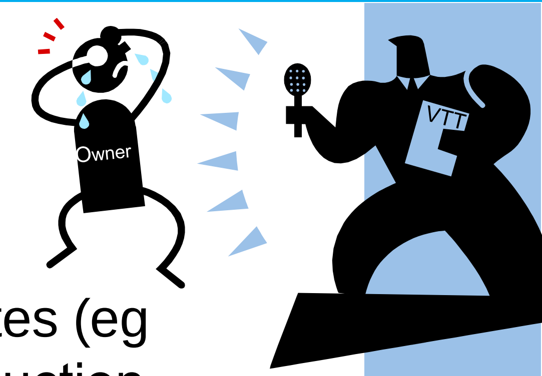
(*) The total capacity is less than the sum of individual capacities because some of the sites have both low temperatures and icing conditions.

30GW of new installations to icing conditions by 2017

- Compare: new offshore 29GW by 2017!

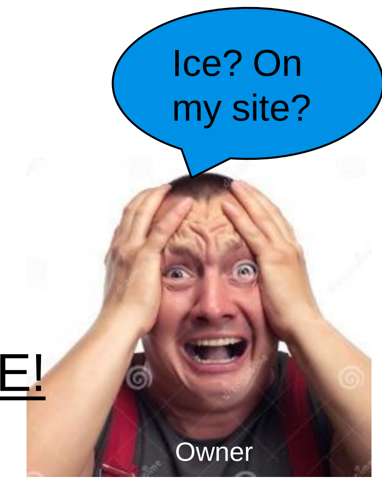
[9]: BTM World market Update 2012

CC Market Observations



- We have interviewed many wind farm owners in icing climates (eg Canada, Sweden, Czech…) suffering from ice induced production losses -> financial consequences

- Root cause:
  - insufficent ice assessment (wrong or no ice instruments, too optimistic "gestimation" of AEP losses in finance phase etc.)
  - ➢ MOST RISKS COULD HAVE BEEN ASSESSED IN ADVANCE!

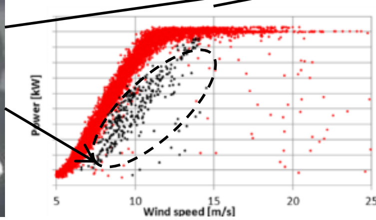


- Icing severity varies significantly from one year to another (mean icing ±200% vs mean wind ±15%)

➢ **Market demads for <u>simple</u> & <u>robust</u> tool for ice assessment!**

The Challenge of ice assessment

What is the connection???



OR

1. AEP losses from icing are often very difficult to estimate before turbine installation

2. Typical shortcomings of on-site measurements (1yr is too short) and mesoscale weather models
   - Both demanding & expensive

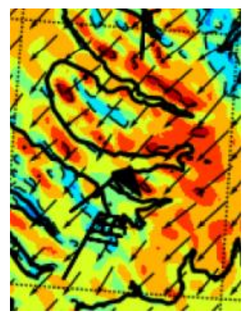


Table. Measurements from met mast and turbine AEP losses [10]

Site	Winter	Met Ice	P-loss	IEA class
	2010	3.1%	**2.5%**	3
	2011	1.8%	**0.5%**	2
	2012	3.0%	**2.1%**	3
	2013->		**???**	
	11-12	2.2%	**1.5%**	2
	12-13	4.7%	**5.0%**	3
	2013->		**???**	

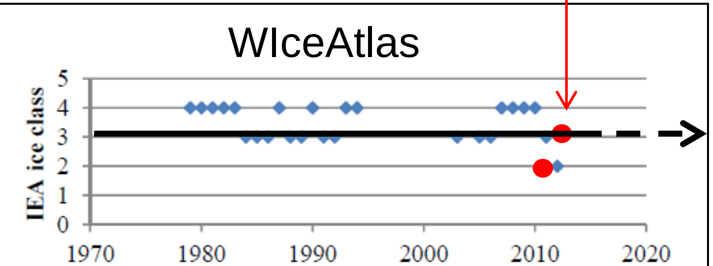


Figure 6: IEA ice class per year for RaR based on local airport cloud base height and temperature. [2]

- **Need: assess future iced AEP losses from long-term historical data <u>simply</u> yet <u>robustly</u>**
  - **And the solutions is…**

[2]: Recommended Practices for Wind Energy in Cold Climates, IWAIS 2013

Wind Power Icing Atlas (WIceAtlas)

Icing events: Iced wind turbine rotor -> **BUSINESS RISK!**

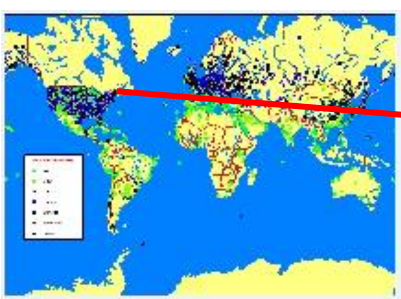
WIceAtlas will tell the -€€€ effects for power production!

- **Typical ΔAEP 3-5% = 20-30k€/turbine/year**

Wind Power Icing Atlas

- Is an icing database based on long-term +20yrs of measurements and observations from meteorological stations globally
  - ***To answer: How large are yearly variations of icing?***
- +4000 stations globally and increasing
  - ***To answer: Where are the icing risks likely to happen?***
- Method: Low level clouds + low temperatures = icing <-> IEA Ice Class
  - ***Simple & robust method: Ice detected as on/off criteria (see [5] for details why this is sufficient)***

➢ *Estimate next 20yrs iced production losses!*



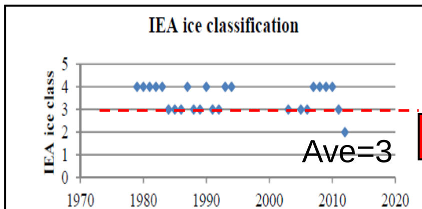


Figure 6: IEA ice class per year for RaR based on local airport cloud base height and temperature.

*: not stop turbine with iced blades
**: stop turbine with iced blades

IEA ice class	Duration of Meteorological icing [% of year]	Duration of Instrumental icing [% of year]	Production loss [% of AEP]
5	>10	>20	>20
4	5-10	10-30	10-25
3	3-5	6-15	3*-12**
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0-0.5

Wind Power Icing Atlas -Main Benefits-

IEA ice class	Duration of Meteorological icing [% of year]	Duration of Instrumental icing [% of year]	Production loss [% of AEP]
5	>10	>20	>20
4	5-10	10-30	10-25
3	3-5	6-15	3*-12**
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0-0.5

*: not stop turbine with iced blades
**: stop turbine with iced blades

- Main benefits before and during site assessment:
  1. <u>Unique, EARLY site IEA ice classification</u> to
     a) design proper measurement campaign to increase data availability and quality and
     b) quantify financial risks based on +20 years of historical observation data
  2. Inexpensive and fast delivery of results
     - Now results as quickly as in 1-2 weeks
     - Future goal: online, immediate answer eg mobile app

- Currently sold as ice assessment service
- See [5] why on-off criteria and icing duration are most important!

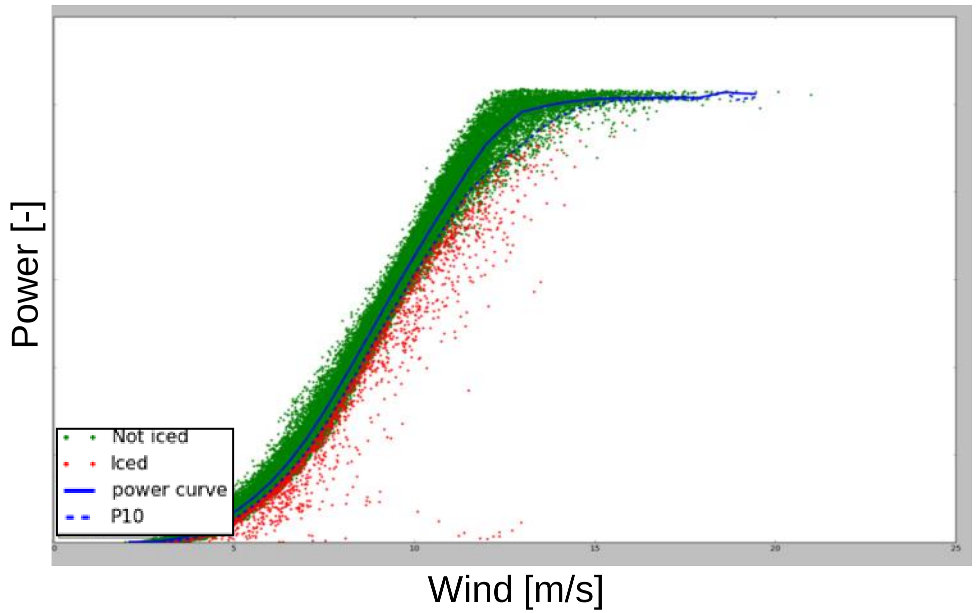
Validation of WIceAtlas

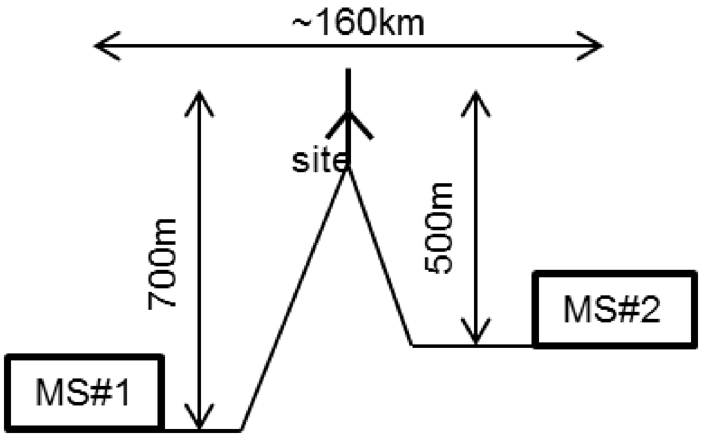
- List of validation cases:
  1. Case France (turbine AEP)
  2. Case Canada (meteorological AND turbine AEP)
  3. List of other meteorological references

Validation of WIceAtlas
Case France (1/2)

- Wind farm in France with infrequent icing challenges at high altitudes
- 3 years on production data -> P-loss method: <0°C & < P10* ref power

- WIceAtlas: Selected two meteorological stations (MS#1,2) nearby

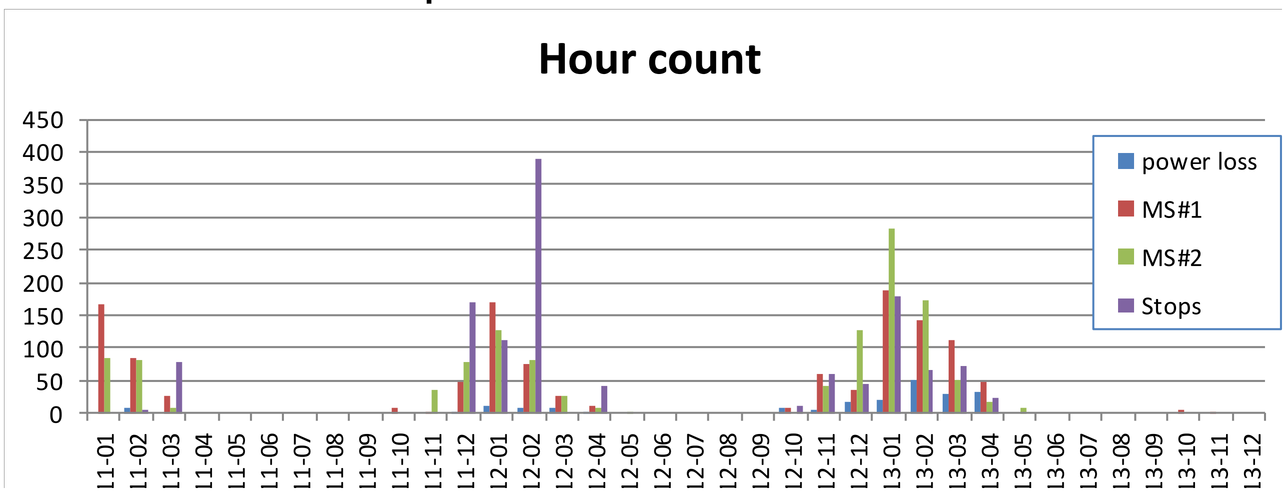




*: P10 = 10th percentile

Validation of WIceAtlas
Case France (2/2)

- Calculated monthly values for:
  - Power loss
  - In-cloud icing from WIceAtlas Met Station #1,2 (MS#1, MS#2)
  - Stops



Correlation test

Table. Correlation between WiceAtlas vs site

	P-loss	MS#1	MS#2	Stops
P-loss	1	0.89	0.79	0.78
MS#1	0.89	1	0.89	0.90
MS#2	0.79	0.89	1	0.81
Stop	0.78	0.90	0.81	1

➢ Good correlation from MS#1 & 2 to site power loss measurements (table values > 0.79)

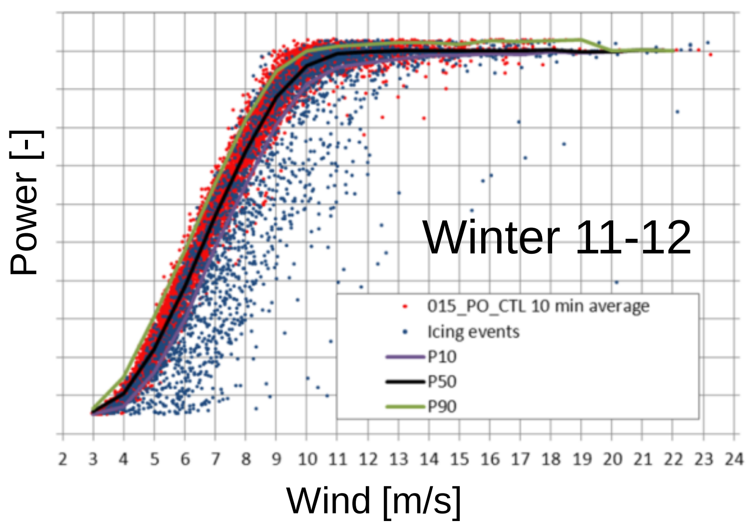
➢ For this site, WIceAtlas can be used to assess long-term icing!

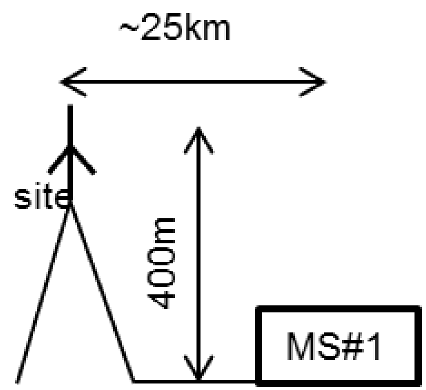
Validation of WIceAtlas Case Canada

- TechnoCentre R&D wind farm in Riviere-au-Renard, Quebec with 2 x Senvion (REpower) MM92 2MW turbines with frequent icing conditions
- 2 years on production data -> P-loss method: <0°C & < -15% ref power
- WIceAtlas: Selected one meteorological stations (MS#1) nearby
  - MS#1 results in same ball park
  - **Next 20yrs on average = IEA class 3**
  - **IEA class 3 = 3…12% AEP losses**

Table. Measurements from met mast and turbine AEP losses [2]

Winter	MS#1	Site Met Ice	P-loss	IEA class
11-12	4.1%	2.2%	**1.5%**	2
12-13	2.1%	4.7%	**5.0%**	3





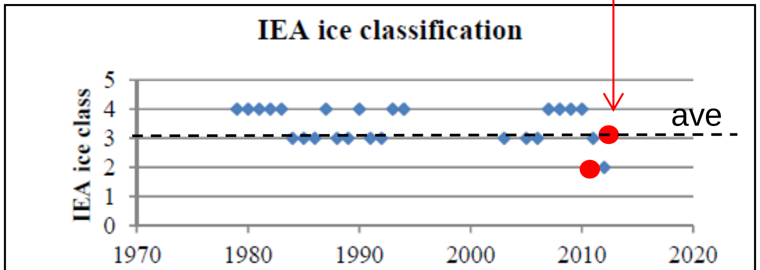


Figure 6: IEA ice class per year for RaR based on local airport cloud base height and temperature. [2]

Validation of WIceAtlas
List of other references

Makkonen IWAIS2013 [3]

- 326m tower in S FIN with severe icing event in Jan1996, *t*=170h!

Table. Measurements vs WIceAtlas MS#1 results [3]

Height (m agl)	meas. (kg/m)	MS#1 (kg/m)
298	6.8	4.51
265	6.2	4.37
210	3.3	4.13
160	2.9	3.86
110	1.6	3.48
55	0.6	1.42

- Used simple ice formula [3]:

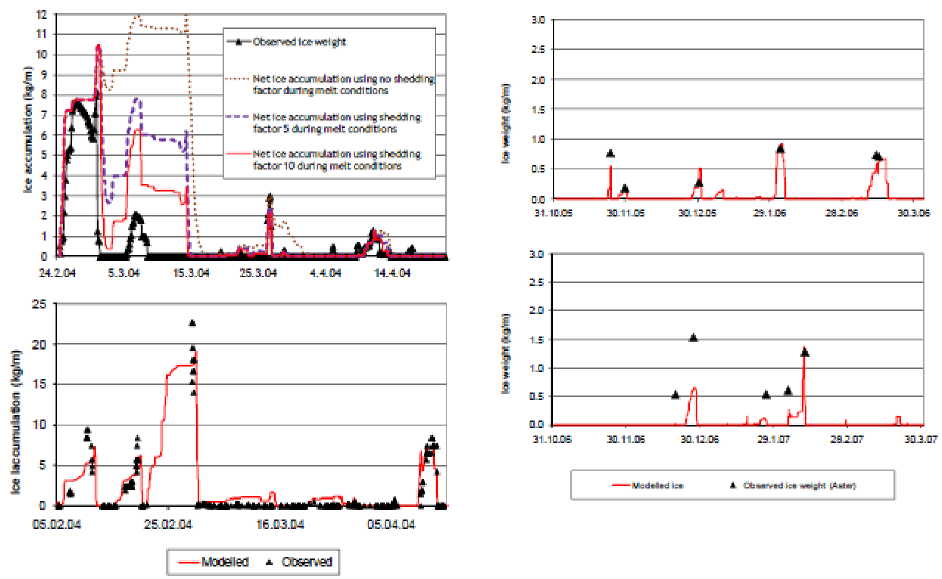
$$M = cVt$$

Where *c* is constant 0.055, *V* is MS#1 wind speed and *t* is time with low level cloud

➢ WIceAtlas produced surprisingly accurate result for extreme events!!

Harsveit IWAIS2009 [4]

- Sites in NOR & UK with ice measurements
- Compare measurements to met stations



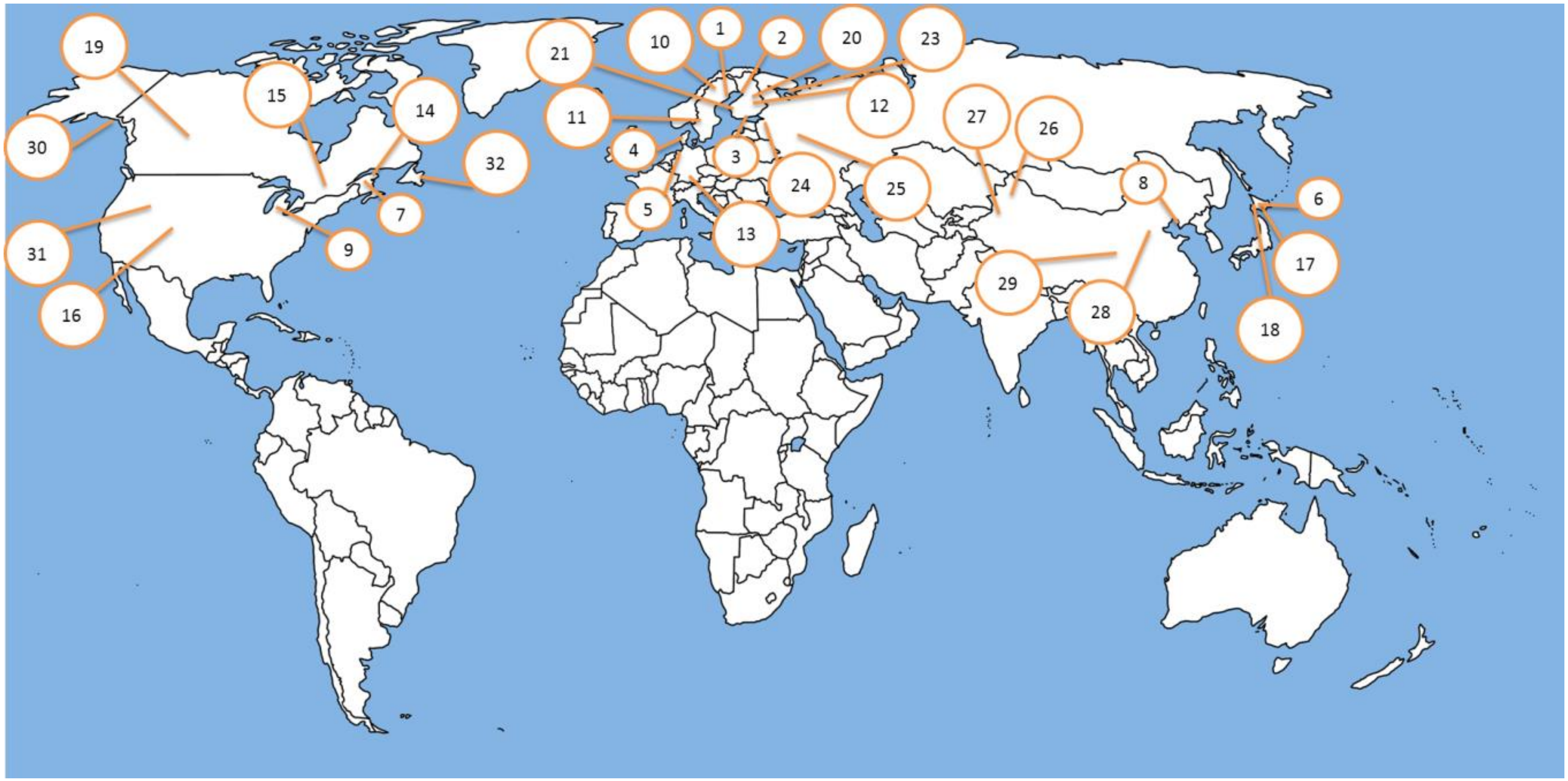
➢ WIceAtlas produces reliable results from many different icing cases!

➢ **Conclusion: WIceAtlas is reliable from meteorology perspective!**

Demo: The power of WIceAtlas

- Data from 32 measurement stations during 1979-2010
- Extracted data:
  - Ambient temperate at ground level
  - Relevant (cloud) heights for wind energy: 50,150 & 250m agl
  - Result: vertical icing profile
- By product: very rough icing atlas of the world!

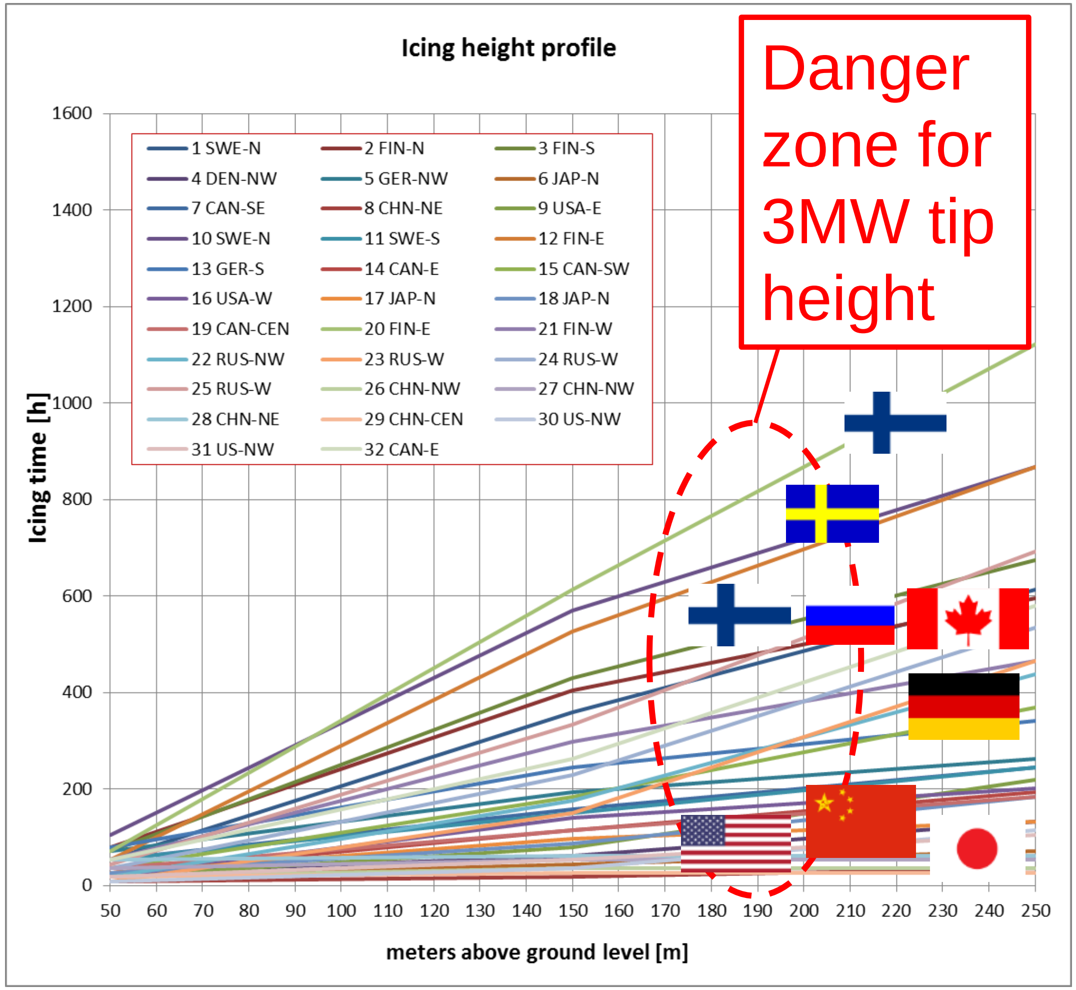
Selected points & locations



Name
1 SWE-N
2 FIN-N
3 FIN-S
4 DEN-NW
5 GER-NW
6 JAP-N
7 CAN-SE
8 CHN-NE
9 USA-E
10 SWE-N
11 SWE-S
12 FIN-E
13 GER-S
14 CAN-E
15 CAN-SW
16 USA-W
17 JAP-N
18 JAP-N
19 CAN-CEN
20 FIN-E
21 FIN-W
22 RUS-NW
23 RUS-W
24 RUS-W
25 RUS-W
26 CHN-NW
27 CHN-NW
28 CHN-NE
29 CHN-CEN
30 US-NW
31 US-NW
32 CAN-E

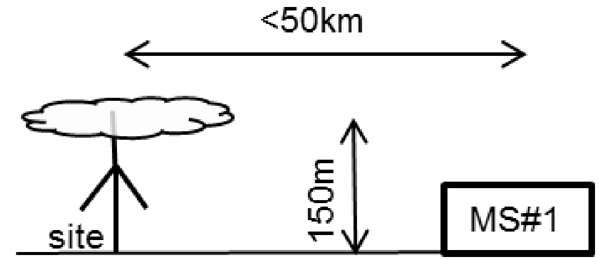
Rough Global Icing Atlas for Wind Energy

- Large geographical variations visible
- Scandinavia is ranked no1 ☺ Points no20 & 10 (FIN,SWE) with largest icing durations
- Icing duration typically triples 100m -> 200m!
- We have this same data for +4000 stations globally! -> Quick & easy to analyse

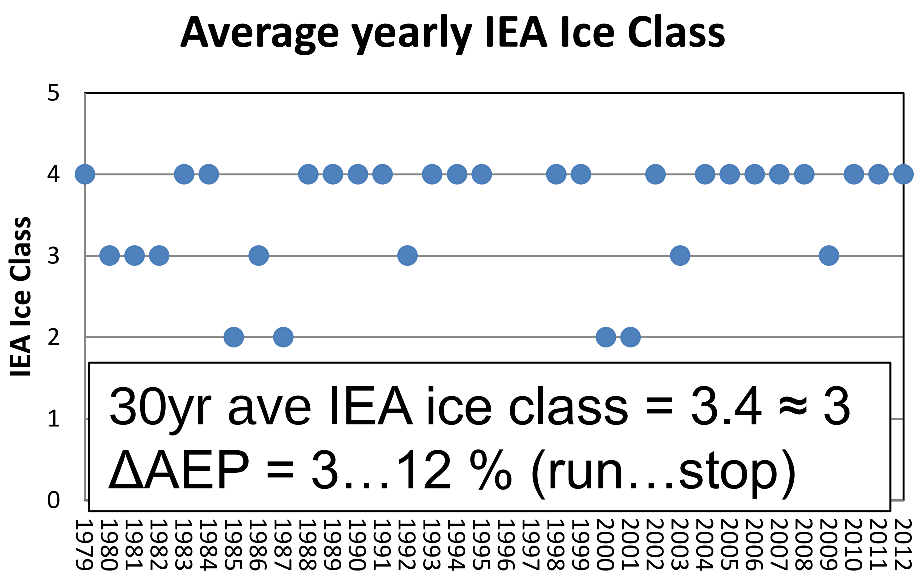


Site	Ice Class
1 SWE-N	3
2 FIN-N	3
3 FIN-S	3
4 DEN-NW	2
5 GER-NW	2
6 JAP-N	2
7 CAN-SE	2
8 CHN-NE	1
9 USA-E	2
10 SWE-N	4
11 SWE-S	2
12 FIN-E	4
13 GER-S	2
14 CAN-E	2
15 CAN-SW	2
16 USA-W	2
17 JAP-N	2
18 JAP-N	2
19 CAN-CEN	2
20 FIN-E	4
21 FIN-W	3
22 RUS-NW	2
23 RUS-W	2
24 RUS-W	2
25 RUS-W	3
26 CHN-NW	1
27 CHN-NW	2
28 CHN-NE	2
29 CHN-CEN	1
30 US-NW	1
31 US-NW	2
32 CAN-E	3

Example: 20 x 3MW site in North Sweden



- 3MW, hub at 110m, rotor D=120m -> Focus: icing below 150m agl
- Assume capacity factor $C_f = 0.35$ (good windy site)



IEA ice class	Duration of Meteorological icing [% of year]	Duration of Instrumental icing [% of year]	Production loss [% of AEP]
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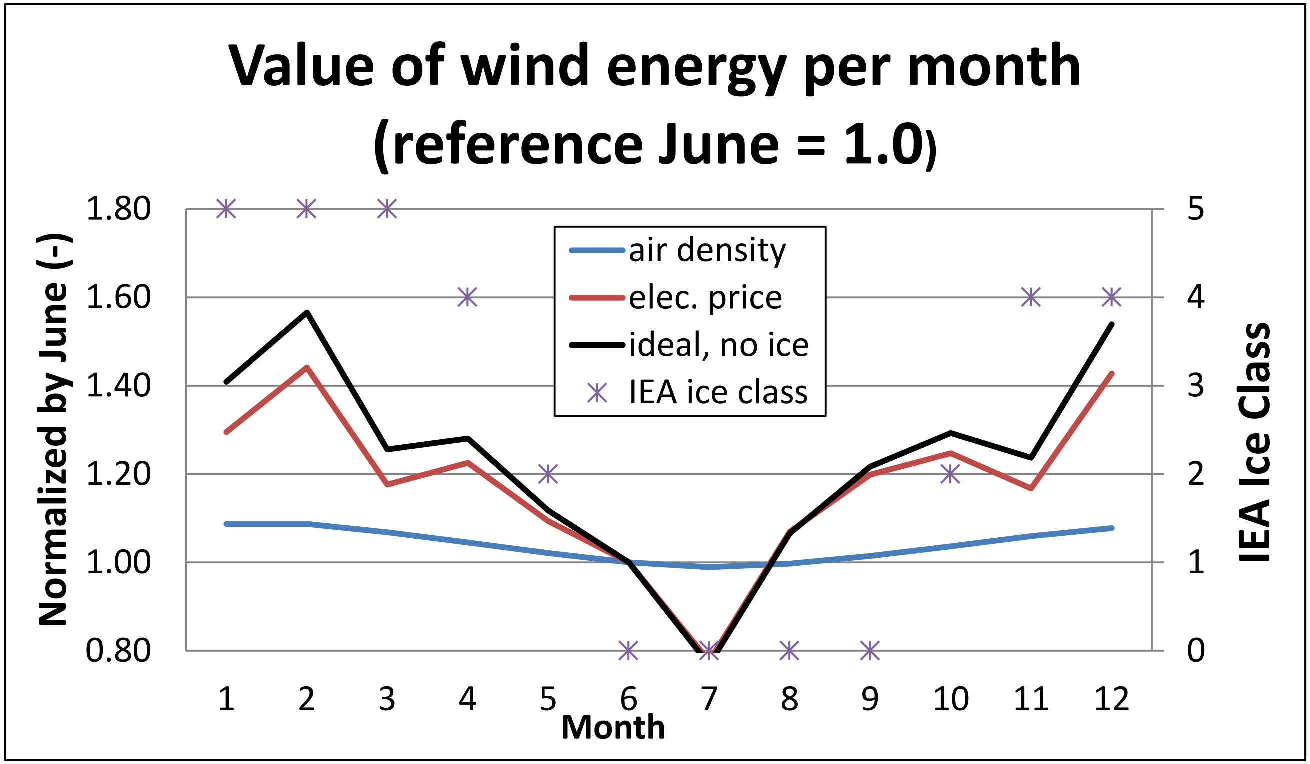
1	0-0.5	<1.5	0-0.5

*: not stop turbine with iced blades
**: stop turbine with iced blades

- 1yr site ice assessment measurements done in eg 1987 would have ended up in ice class 2: **Underestimate AEP losses!**
- **ΔAEP=3…12 % <u>per year</u>, rough numbers, we can do better!**

Example: 20 x 3MW site in North Sweden -Monthly value-



IEA ice clas s	Duration of Meteorological icing [% of year]	Duration of Instrumental icing [% of year]	Production loss [% of AEP]
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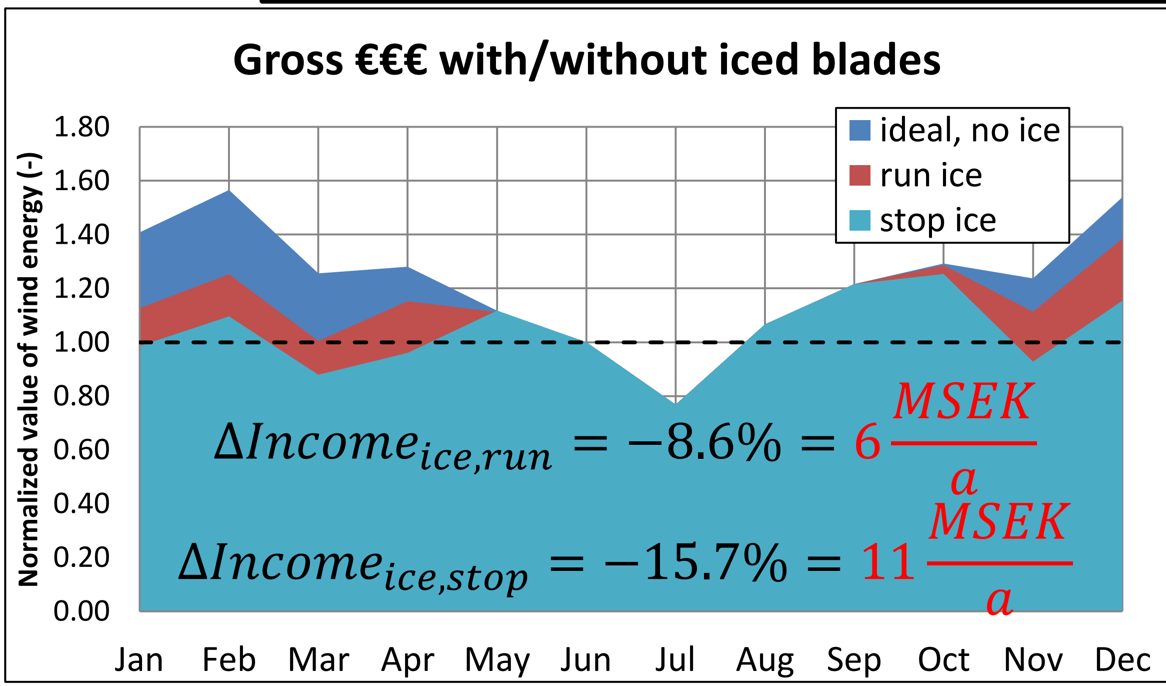
**: stop turbine with iced blades

- Winter wind is VERY VALUABLE in €, on average 1.3…1.5 x summer!
- But at same time, very high risk of ice in winter!
- OBS! Wind speed not included (might be higher in winter…)

Example: 20 x 3MW site in North Sweden

- Income from wind depends on:
  - AEP (wind speed + air density) and electricity price
  - Calculate monthly iced income more accurately than yearly IEA Ice Class table:

$$Income_{ice} = Monthly\ potential_{no\ ice} \cdot \rho_{air} \cdot €_{elec} \cdot Loss_{ice}$$



Long term AEP losses between 6…11 MSEK (0.6-1.1M€) per year!

Conclusions

- Root cause of ice problems: insufficient ice assessment
- Typical 1-2yr site resource (ice) assessment NOT able to see large yearly variations -> BIG BUSINESS CASE UNCERTAINTY!
- Simple & robust ice risk assessment: VTT's Wind Power Icing Atlas
  - Main benefit: Unique, EARLY site IEA ice classification
  - Evaluate the -€€€ effect on project lifetime

VTT - 70 years of **technology for business and society**

Ville Lehtomäki
ville.lehtomaki@vtt.fi
Phone: +358 40 176 3147

References

[1]: BTM World Market Update 2012, Navigant Research

[2]: Recommended Practices for Wind Energy in Cold Climates: Resource Assessment and Site Classification, N. Clausen et al, IWAIS 2013

[3]: Icing of a 326 m Tall Tower - A Case Study, Makkonen et al., IWAIS2013

[4]: Using Metar - Data to Calculate In-Cloud Icing on a Mountain Site near by the Airport, Harstveit, K., IWAIS2009

[5]: Simple methodology to map and forecast icing for wind power, Lehtomäki, V. et al. WinterWind 2014