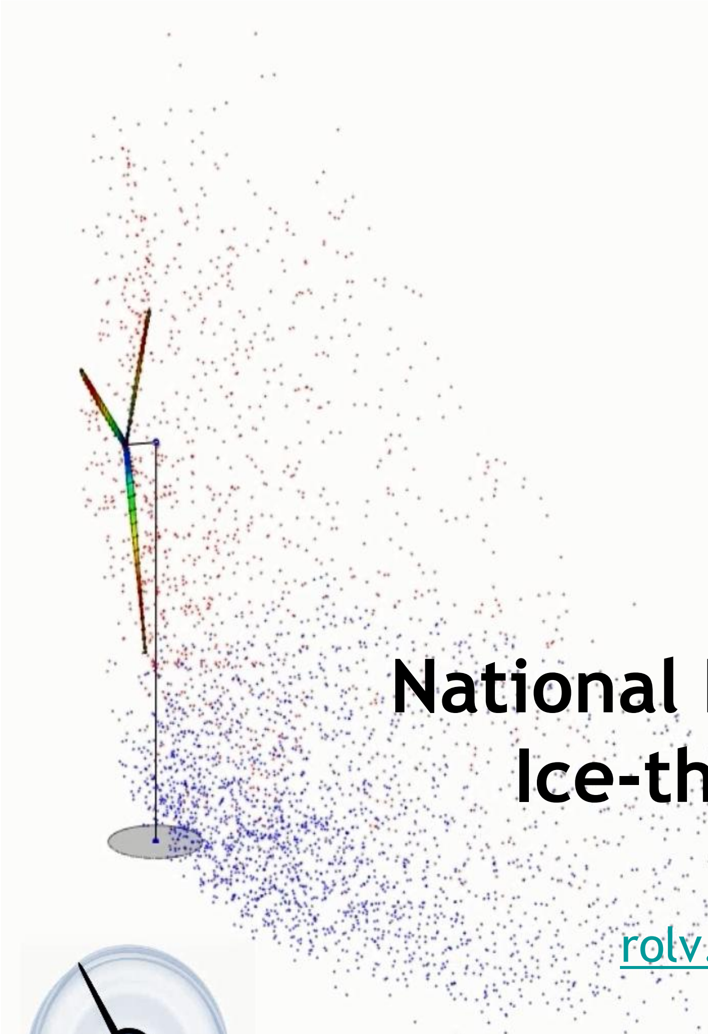

Roger Flage, IRIS
Bushra Butt, NVE

National Norwegian Guidelines: Ice-throw hazard (2018)

Rolv Erlend Bredesen
rolv.bredesen@vindteknikk.no

The goal of the project is to prepare easily understood and relevant advise for wind farm concessionaires (owners/operators) and to the general public:

- 1) How to communicate the risk of injury and damage to the general public caused by ice throw and ice fall.
- 2) Relevant measures handling the risk of injury and damage.
- 3) Clarify the criminal and compensatory liability for incidents involving injury.

- The Norwegian Guideline is meant as a supplement to the IEA Wind Task 19's internationally harmonized guidelines regarding ice throw risk assessments

Summary of available background knowledge and guidelines

- New studies
  - IceThrower!
  - [Enercon study]!
  - Austrian study!
- Current knowledge and the way forward in state-of-the-art risk assessments has been reviewed
  - Peer-reviewed article
  - WindEurope presentation
  - WindEurope audio

WindEurope Conference & Exhibition 2017 IOP Publishing
IOP Conf. Series: Journal of Physics: Conf. Series **926** (2017) 012001 doi:10.1088/1742-6596/926/1/012001

Understanding and acknowledging the ice throw hazard - consequences for regulatory frameworks, risk perception and risk communication

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Abstract. This study attempts to provide the necessary framework required to make sufficiently informed decisions regarding the safety implications of ice throw. The framework elaborates on how to cope with uncertainties, and how to describe results in a meaningful and useful manner to decision makers. Moreover, it points out the moral, judicial and economical obligations of wind turbine owners such that they are able to minimize risk of ice throws as much as possible. Building on the strength of knowledge as well as accounting for uncertainty are also essential in enabling clear communication with stakeholders on the most important/critical/vital issues. With increasing empirical evidence, one can assign a higher confidence level on the expert opinions on safety. Findings regarding key uncertainties of ice risk assessments are presented here to support the ongoing IEA Wind Task 19's work on creating the international guidelines on ice risk assessment due in 2018 (Krenn et al. 2017)[1-6]. In addition the study also incorporates the findings of a Norwegian information project, which focuses on the ice throw hazard for the public (Bredesen, Flage, Butt, Winterwind 2018)[7-9]. This includes measures to reduce damage and hazard from wind turbines for the general public. Recent theory of risk assessment questions the use of risk criteria for achieving optimum risk reduction and favours the use of the ALARA (as low as reasonably achievable) principle. Given the several practical problems associated with the ALARA approach (e.g. judicial realization), a joint approach, which uses a minimum set of criteria as well as the obligation to meet ALARA is suggested (associated with acceptable cost). The actual decision about acceptance criteria or obligations is a societal one, thus suggestions can be made at best. Risk acceptance, risk perception and risk communication are inextricably linked and should thus never be considered separately. Risk communication can shape risk perception, which again is vital for defining risk acceptance. Moreover, risk communication should be seen as an opportunity to demonstrate trustworthiness and an open, responsible and caring attitude. It is important for the wind industry to avoid accidents: In Winterwind 2017 (Ronsten)[10], the importance for the wind power community to proactively take safety measures for passers-by and service personnel was emphasized: Establishing good practices and communication routines is key to avoid accidents. Visually attractive ways of presenting the risk of ice throw are recommended.

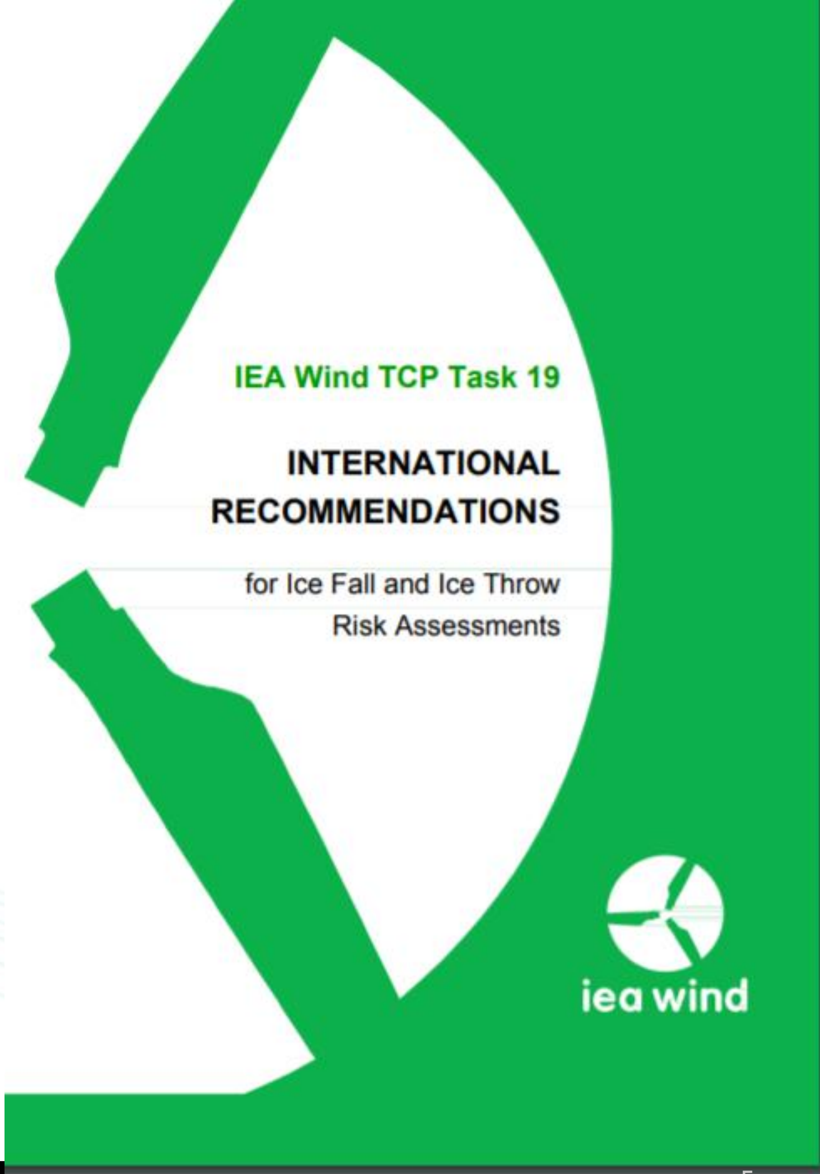
Official Norwegian Documents

- Norwegian guideline:
  https://www.nve.no/nytt-fra-nve/nyheter-konsesjon/ny-veileder-for-handtering-av-faren-for-iskast-fra-vindturbiner/

- Norwegian Framework for wind power, report on icethrow:
  https://www.nve.no/Media/6951/iskast.pdf

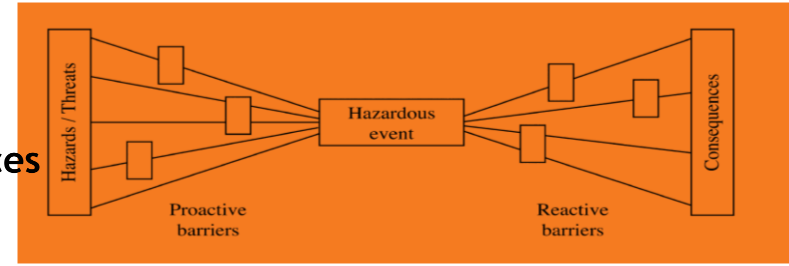
New IEA Wind (task 19) guideline:

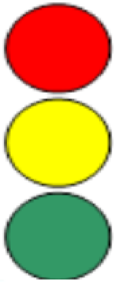
https://community.ieawind.org/task19/home



IceRisk assessment -Are the relevant risks controlled?

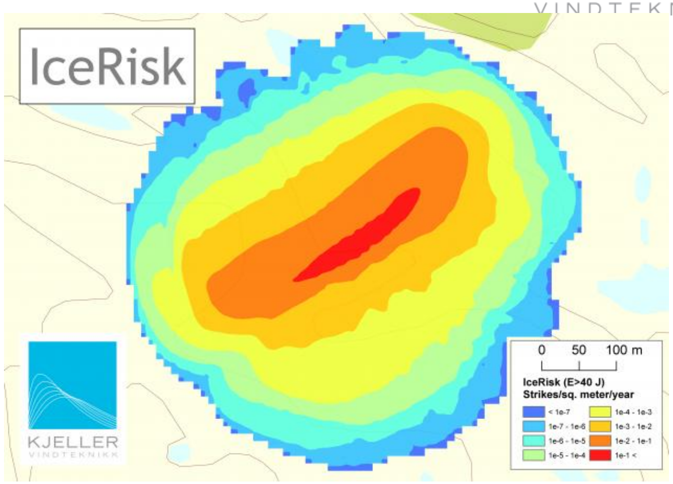
- Evaluate the **extent of icing**
- Assess the risk of icethrow/fall
  - Register the use of area that may be exposed to ice throw in the area
  - Who is at risk?
  - **Describe the causal and consequence picture**
    - Relevant initiating events, causes and **consequences**
    - barriers mitigating the risk, barrier failure
  - **Describe the uncertainty**
    - e.g. likelihood of described event and associated consequence occurring
    - Probability maps
  - Assess the confidence in and the quality of the performed analysis
    - e.g. using strength of knowledge indices: (high/medium/low),
    - e.g. Sensitivity on critical assumptions (NUSAP elements with radarcharts)
- Evaluate the identified risk with acceptance critera
- **Assess whether and what measures should be taken**





Prevalent approach for ice risk assessments

- 1) Mathematical trajectory/calculation model
  - Turbine parameters:
    - Hub height
    - Rotor diameter
    - Operational mode
  - Topography
  - Physical parameters
    - Air density
    - Vertical wind profile
    - Radial distribution of ice on blades
    - No. of relevant fragments
- 2) Wind and Icing data
  - Wind statistics representative for periods when icing and melting may occur
  - Estimation of amount of ice fragments

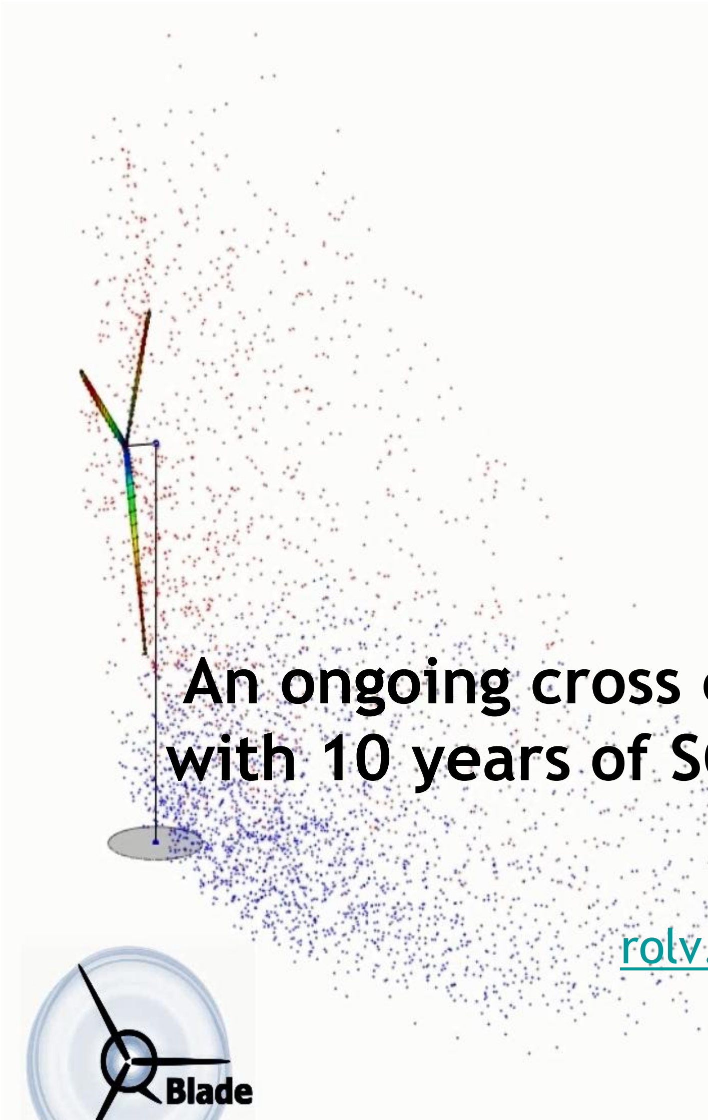


- 3) Risk assessment
  - Probability of Persons present
  - Calculation of actual risk level
  - Threshold for accepted risk levels
  - Safety measures
  - Consideration of uncertainties

It is recommended to make realistic assumptions on the input parameters

- mathematical trajectory model
- wind speed data
- size and shape of used ice fragments

- Unless the uncertainty is specified it is recommended to make **conservative assumptions for the following parameters:**
  - Number of ice fragments
  - Likelihood / exposure of people
  - Vulnerability / probit function
  - Thresholds for accepted risk level
  - Effectivity of measures



An ongoing cross comparison of the Icethrower database with 10 years of SCADA and meteorological forecast data.

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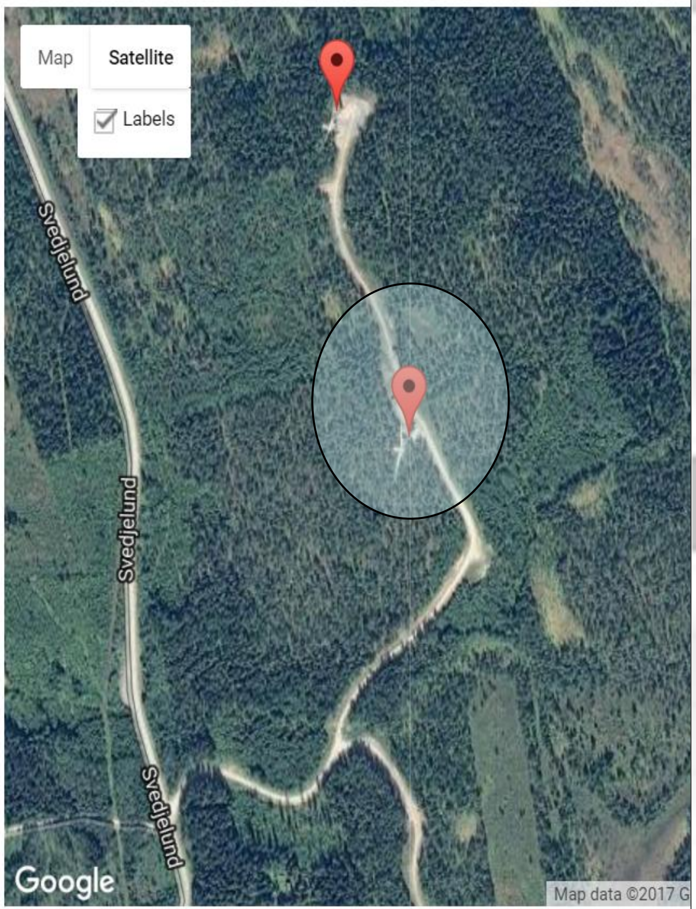
What and why

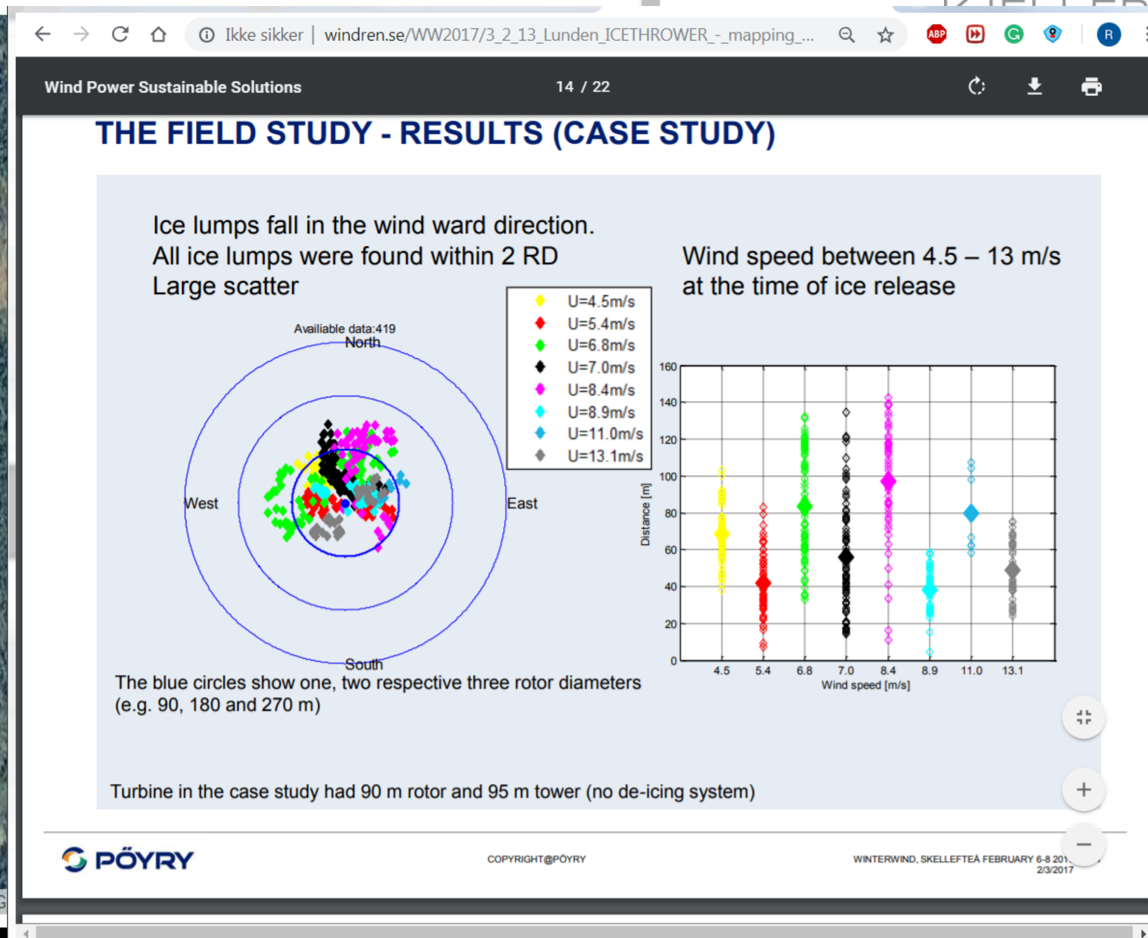
- A cross comparison of the IceThrower database with 10 years of SCADA and meteorological forecast data.
- The aim of this presentation is to increase the strength of knowledge and to describe key uncertainties in ice risk assessments.

- Ice Thrower database compiled by Pöyry
- SCADA data courtesy of Dala Vind
- Meteorological simulation and analysis by Kjeller Vindteknikk

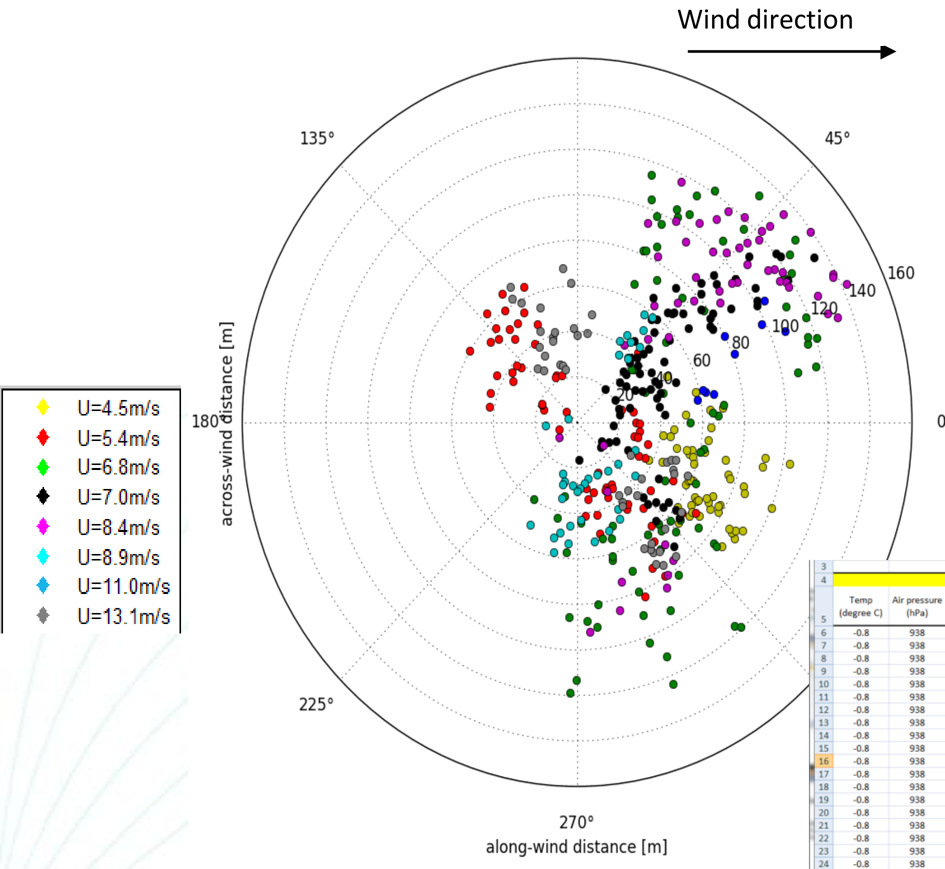
Thorough IceThrower collection study performed in forrested terrain (Event A-H), Report by Pöyry.

Klicka på ett verk i kartan för att komma till respektive verk





417 ice pieces collected within 140 m from the IceThrower database for the considered V90 turbine (tipheight of 140 m).



IceThrower database on collected ice debris: lenght,width, mass, position, time and meteorological conditions

Note: the time of ice throw and the associated values are only reported as daily mean values.

Coordinate system | RT90 2,5 gon V

	Observation				Time of ice throw				At the time of ice throw							Turbine coordinate		Location of im
No	WTG ID	Year	Month	Day	Time	Year	Month	Day	Time	Op. mode	Wind speed (m/s)	Direction (degree)	Nacell direction (degree)	Temp (degree C)	Air pressure (hPa)	Rotation speed (rad/s)	X-coordinat	Y-coordinat	X-coordinat
1	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127076
2	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127082
3	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127082
4	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127082
5	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127086
6	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127086
7	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127088
8	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127091
9	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127091
10	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127091
11	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127091
12	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127106
13	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127106
14	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127106
15	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127116
16	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127116
17	5	2013	12	11	10:00	2013	12	10	N	R	13.6	252	252	-0.8	938	14.6	7127076	1624359	7127054

			Turbine coordinate		Location of impact		Throwing distance	Ice properties								
Temp (degree C)	Air pressure (hPa)	Rotation speed (rad/s)	X-coordinat	Y-coordinat	X-coordinat	Y-coordinat	(m)	Ice type	Mass (kg)	Origin	Shape	Density (kg/m3)	Area (m3)	Lenght (cm)	Width (cm)	
-0.8	938	14.6	7127076	1624359	7127076	1624359	0.0	N	N	1,2,3	N	N	N	50	10	SRL53
-0.8	938	14.6	7127076	1624359	7127082	1624360	6.1	A	N	1,2,3	N	N	N	30	10	SRL54
-0.8	938	14.6	7127076	1624359	7127082	1624361	6.3	A	N	1,2,3	N	N	N	5	3	SRL55
-0.8	938	14.6	7127076	1624359	7127082	1624361	6.3	A	N	1,2,3	N	N	N	5	3	SRL56
-0.8	938	14.6	7127076	1624359	7127086	1624362	10.4	A	N	1,2,3	N	N	N	30	10	SRL57
-0.8	938	14.6	7127076	1624359	7127086	1624364	11.2	A	N	1,2,3	N	N	N	20	5	SRL58
-0.8	938	14.6	7127076	1624359	7127088	1624357	12.2	A	N	1,2,3	N	N	N	20	5	SRL59
-0.8	938	14.6	7127076	1624359	7127091	1624357	15.1	A	N	1,2,3	N	N	N	70	5	SRL60
-0.8	938	14.6	7127076	1624359	7127091	1624356	15.3	A	N	1,2,3	N	N	N	12	5	SRL61
-0.8	938	14.6	7127076	1624359	7127091	1624356	15.3	A	N	1,2,3	N	N	N	15	10	SRL62
-0.8	938	14.6	7127076	1624359	7127091	1624355	15.5	A	N	1,2,3	N	N	N	9	5	SRL63
-0.8	938	14.6	7127076	1624359	7127106	1624345	33.1	A	0.31	1,2,3	N	N	N	10	5	SRL64
-0.8	938	14.6	7127076	1624359	7127106	1624345	33.1	A	N	1,2,3	N	N	N	10	5	SRL65
-0.8	938	14.6	7127076	1624359	7127106	1624345	33.1	A	N	1,2,3	N	N	N	25	10	SRL66
-0.8	938	14.6	7127076	1624359	7127116	1624342	43.5	A	N	1,2,3	N	N	N	40	20	SRL67
-0.8	938	14.6	7127076	1624359	7127116	1624342	43.5	A	N	1,2,3	N	N	N	50	10	N
-0.8	938	14.6	7127076	1624359	7127054	1624375	27.2	A	0.55	1,2,3	N	N	N	10	13	N
-0.8	938	14.6	7127076	1624359	7127054	1624375	27.2	A	N	1,2,3	N	N	N	10	13	N
-0.8	938	14.6	7127076	1624359	7127054	1624379	29.7	A	N	1,2,3	N	N	N	15	5	N
-0.8	938	14.6	7127076	1624359	7127054	1624379	29.7	A	N	1,2,3	N	N	N	15	5	N

Info | DV | VF 1 | VF 2 | VF 3 | VF 4 | VF 5 | VF 6 | SK | Explanation

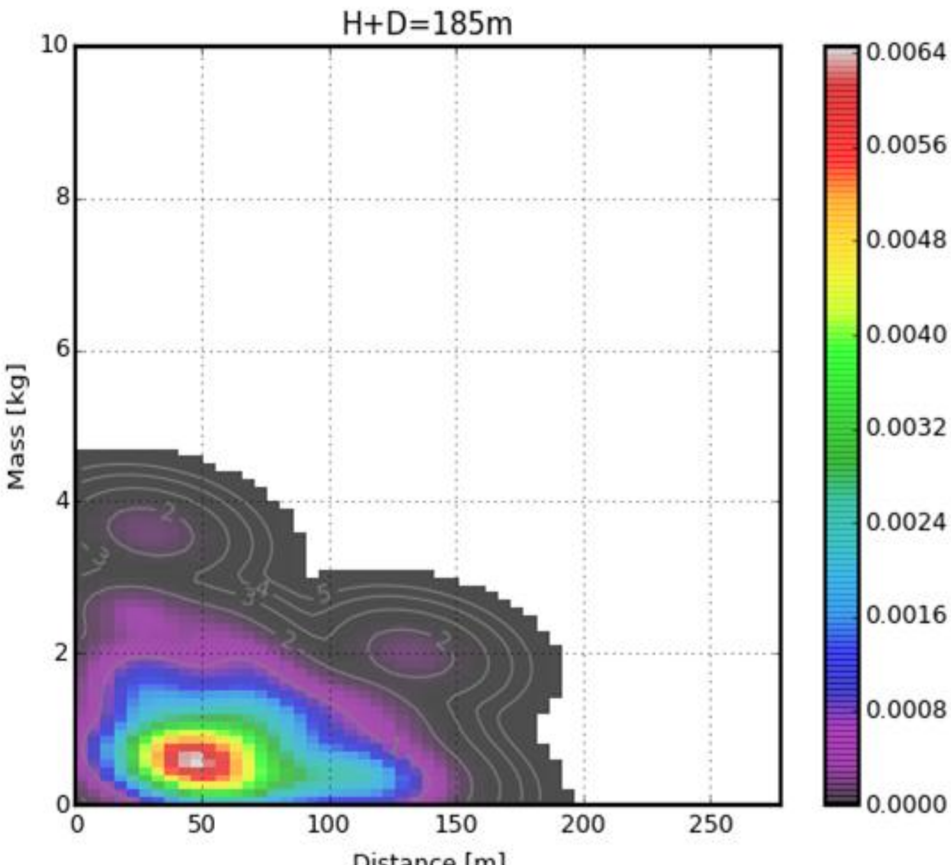
Klar 85 %

Mass of uncrushed pieces vs distance

At distance H+D/2=140 m the likelihood of finding 0.5 kg pieces are reduced by 1 order.

Sharp gradient in range outside 150 m. Decadal decay contours in grey.

Histogram calculated using kernel density estimation (KDE)

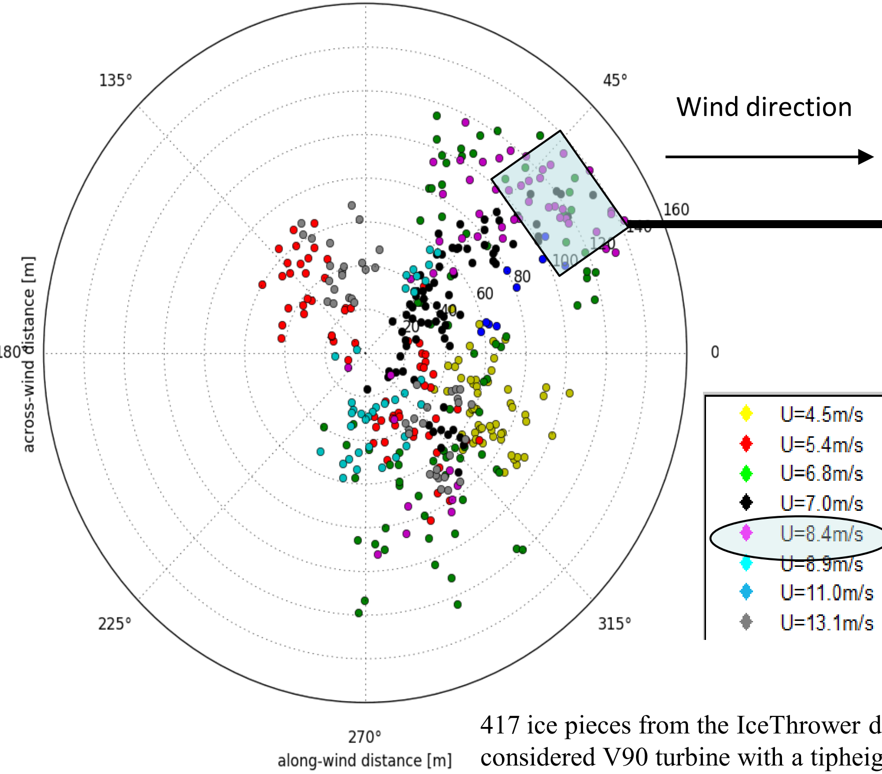


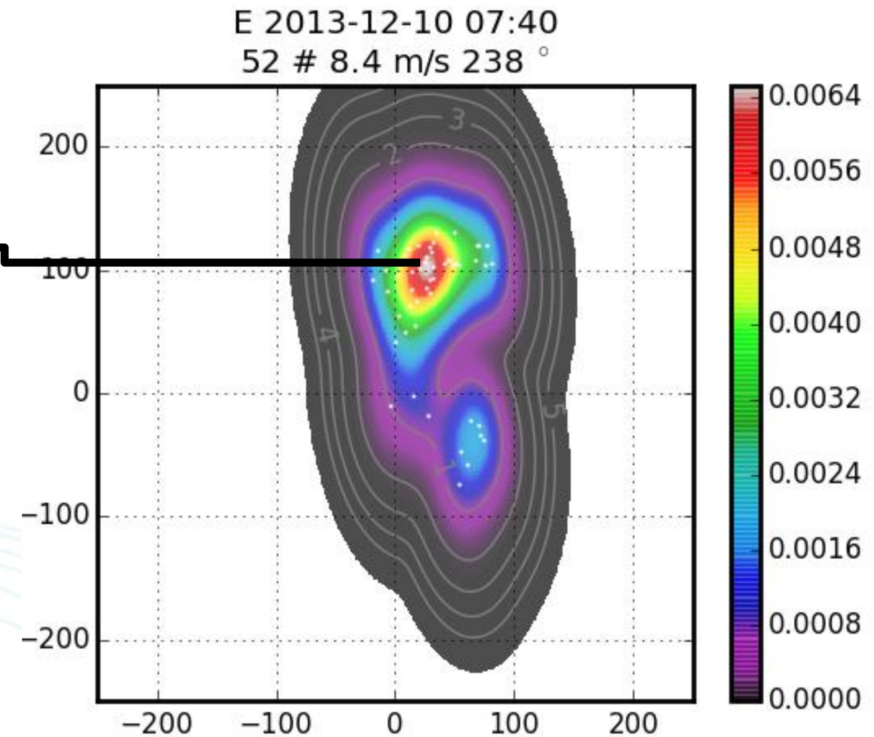
Density estimation and uncertainty, episode E.

20 strikes in a 40 m x 40 m region at 120 m distance:

0.0125 strikes per square meter for the episode

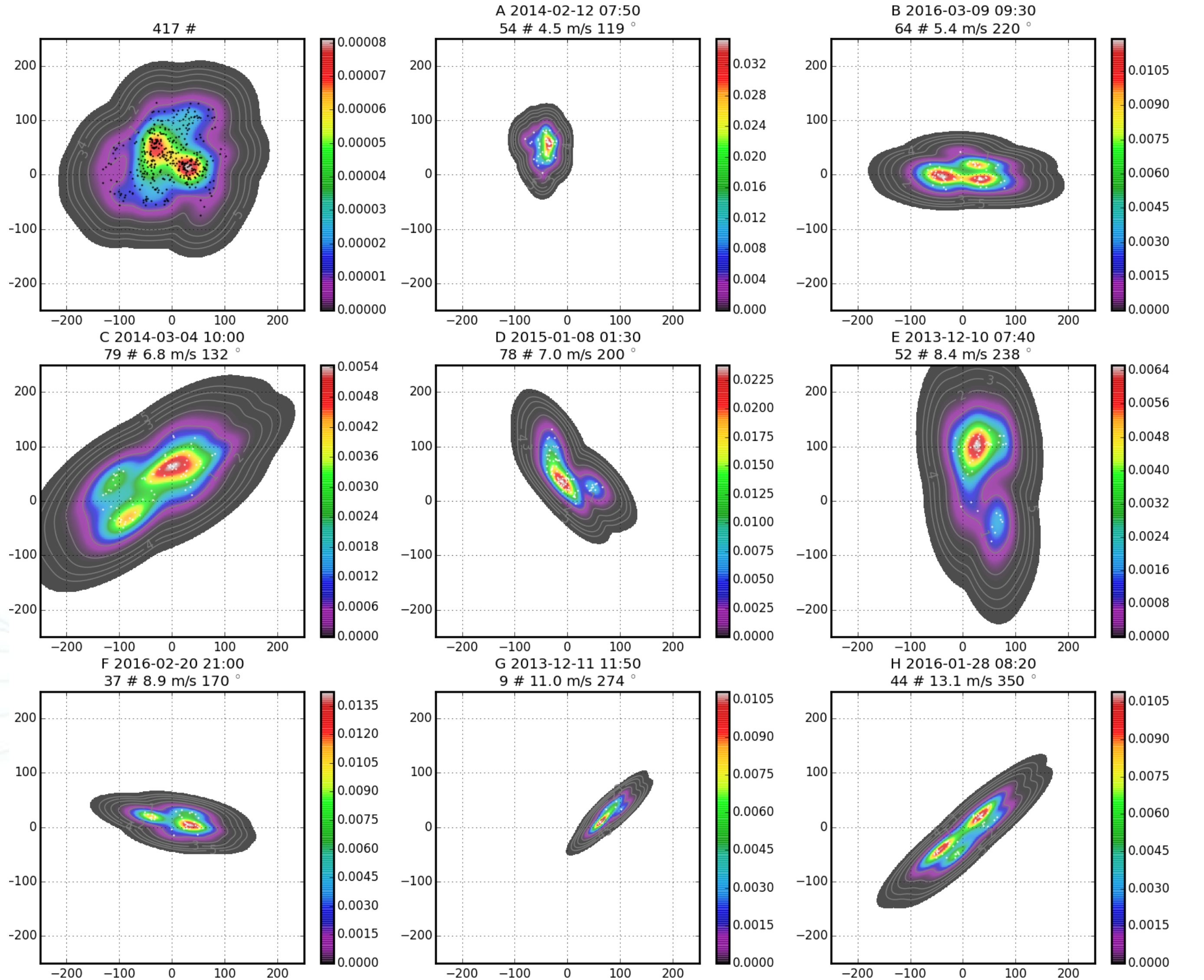
KDE averaging reduces upper limit to: 0.0064 strikes/square meter/episode, but shows uncertainty





417 ice pieces from the IceThrower database for the considered V90 turbine with a tipheight of 140 m.

Strike probability map of 417 # collected pieces

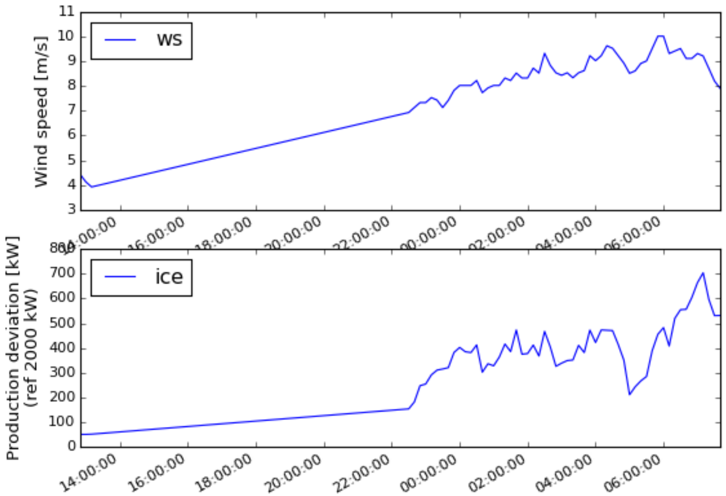


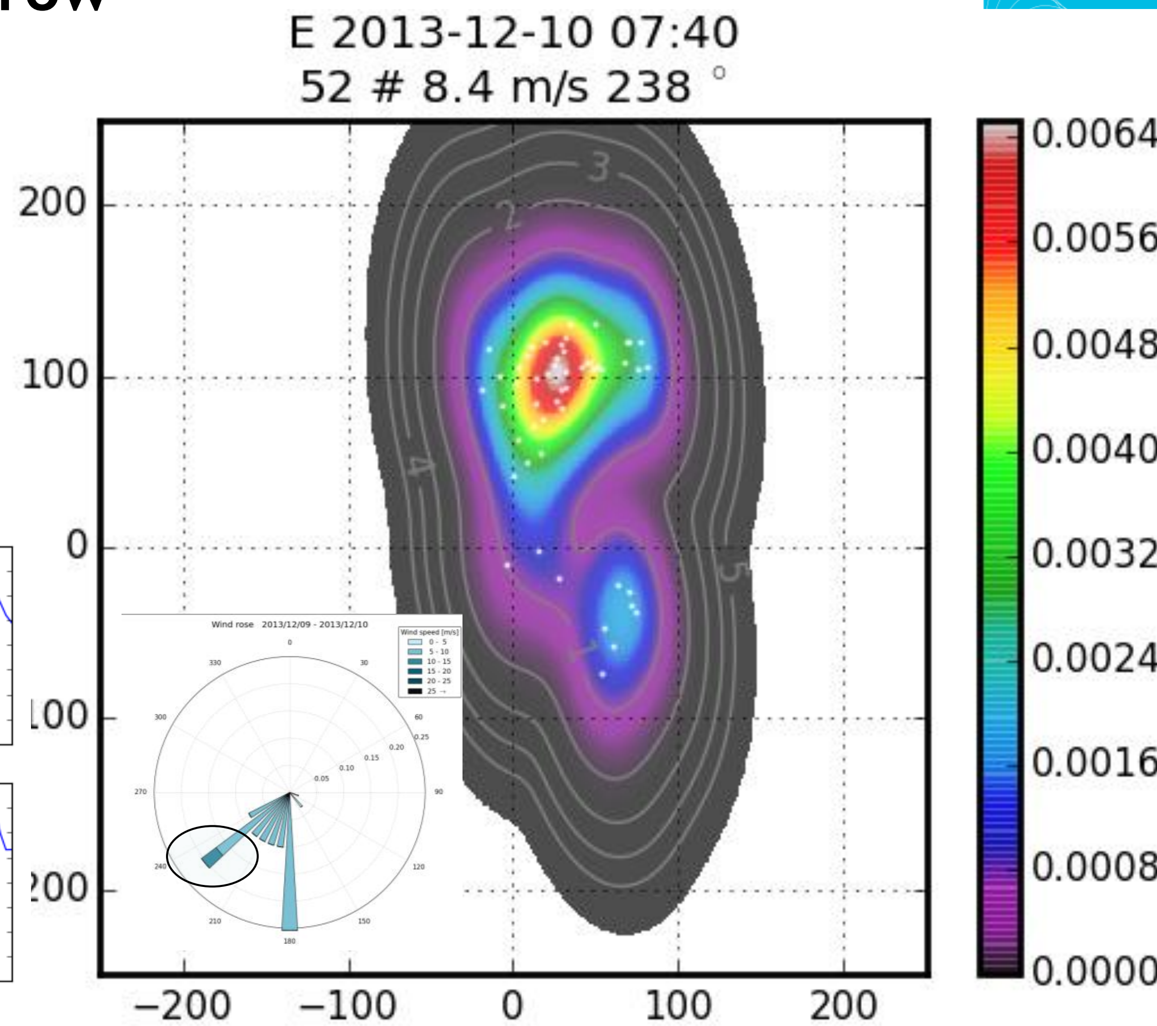
Only C, D, and E exceed 200 m.

4 episodes from 2013/2014 winter

Case E - downwind throw

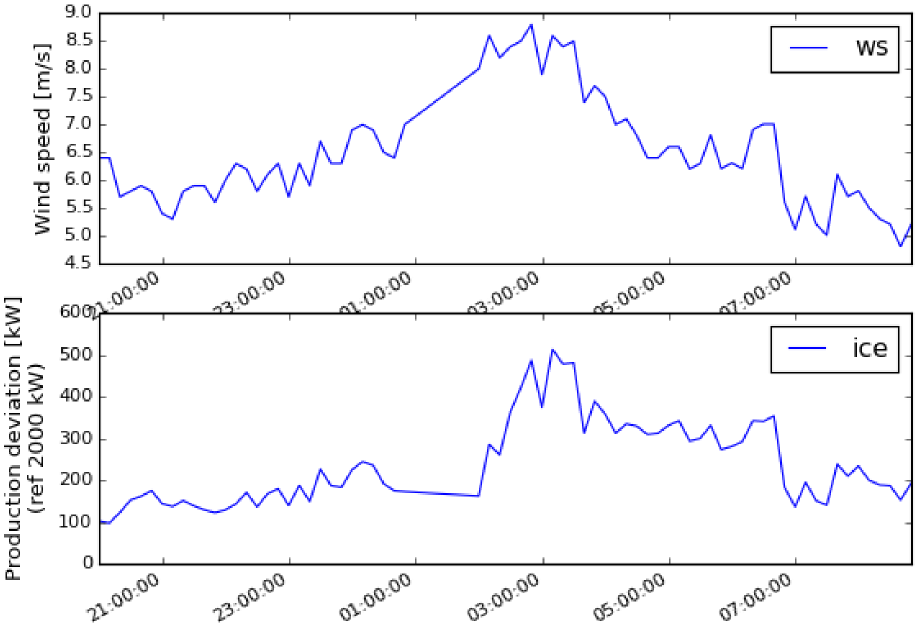
- Only datapoins with detected ice shown
- Wind speed was below 10 m/s
- Wind direction by proxy from KVTMESO simulation
- Wind direction increasing with time and "production loss"
- Max deviation in production loss 700 kW (of 2 MW)

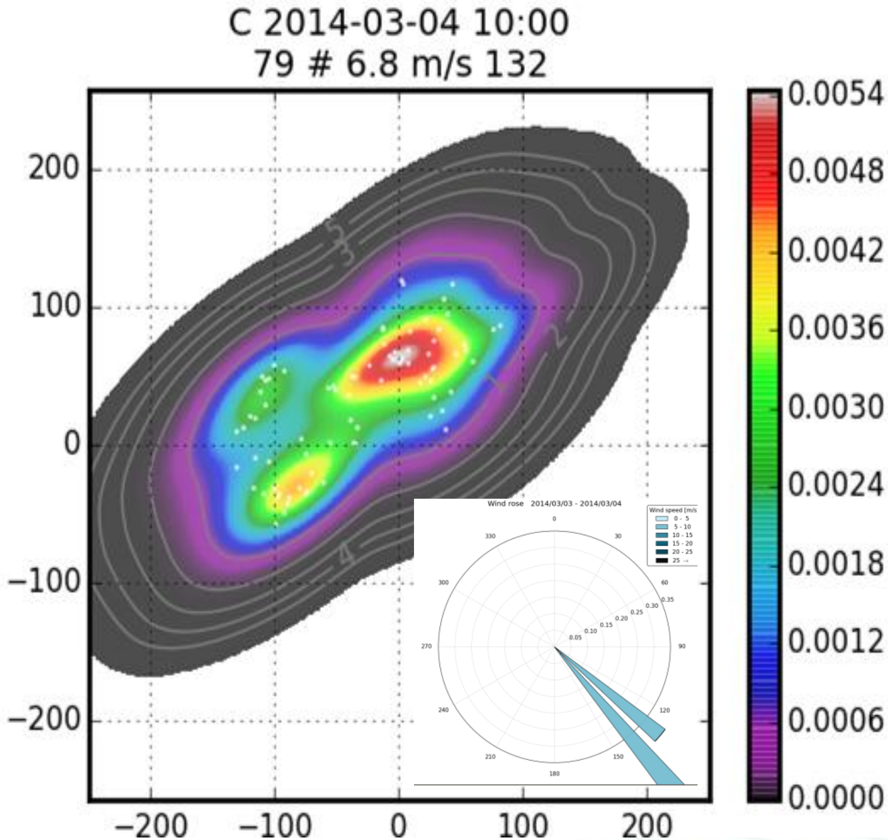




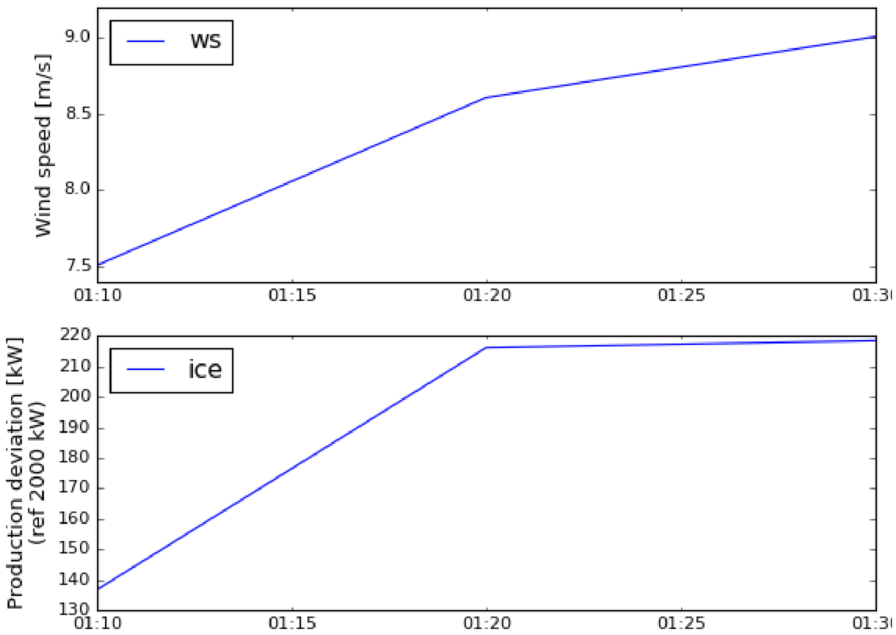
Case C:
Wind speed around 8.5 m/s at period of highest production deviation (500 kW/2000 kW)

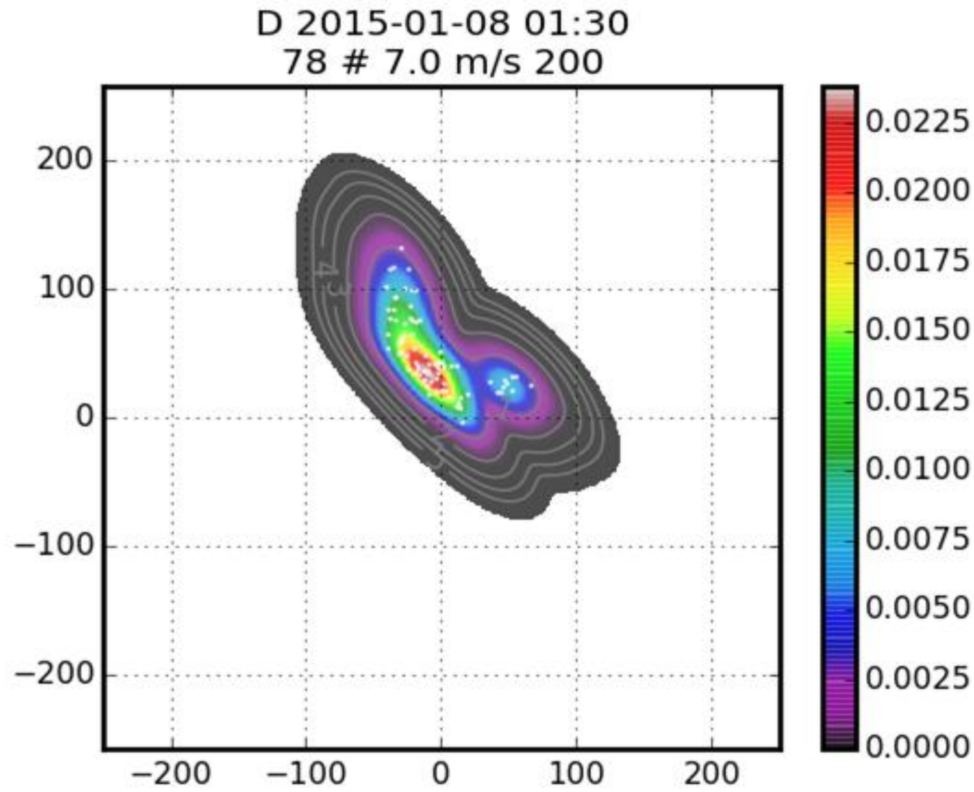
- Left:Wind speed and production loss signal





Case D: minimal production loss
80 pieces thrown. 90 minute duration total.

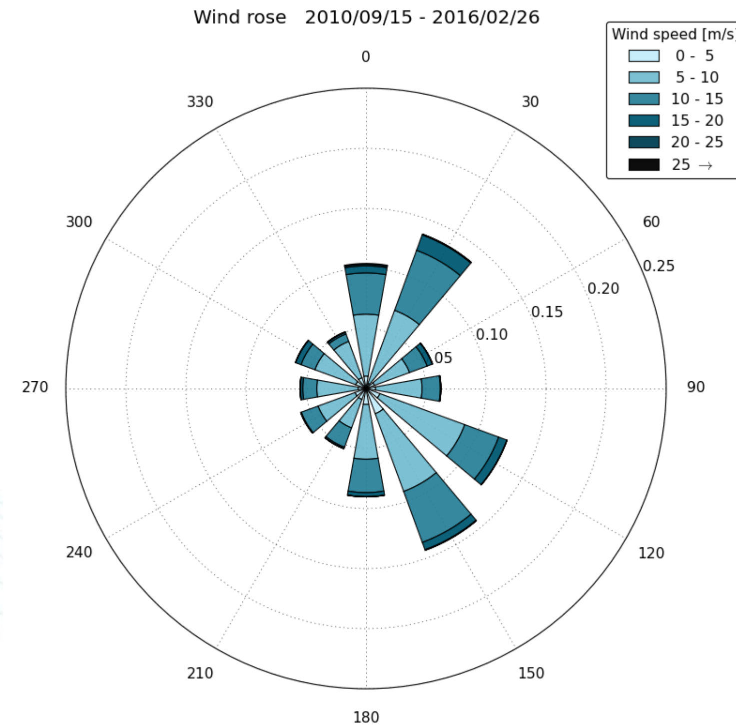




Scaling of number of pieces, and wind statistic

- ~1000-2000 ice pieces per year has been observed from a turbine in a similar icing class (Guideline).
- Case E - 50 ice pieces over 9 hour episode?
- Case D – 80 ice pieces over 20-90 minutes?
- Case C - 80 ice pieces over 6 hour episode?
- Did ice accrete only during these hours?

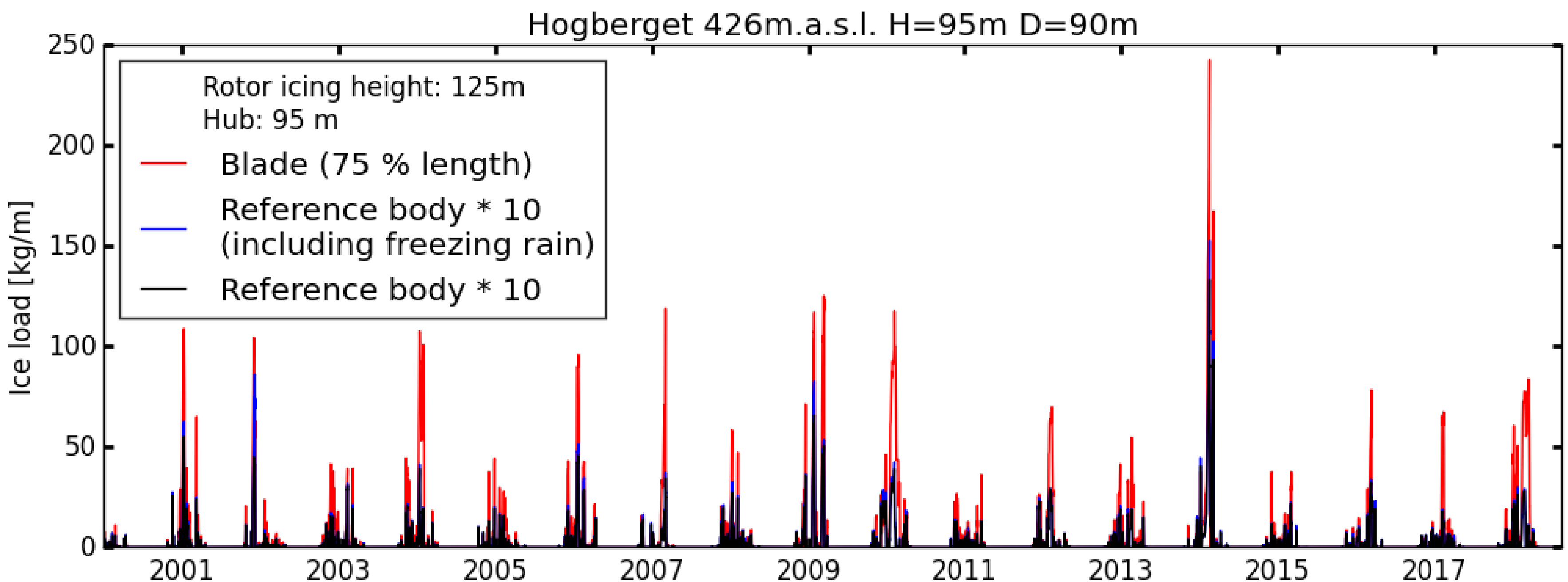
- Even with missing documentation of episodes, no ice piece has been found on surrounding ski-track
- Task 19 ice loss method on SCADA data indicates icing 9 % of the time. Weibull wind parameters for instrumental icing is C=8.0, k = 2.7
- 2.8 % icing loss in total for this site.



Meteorological simulation of ice accretion shows maximum for 2014 winter.

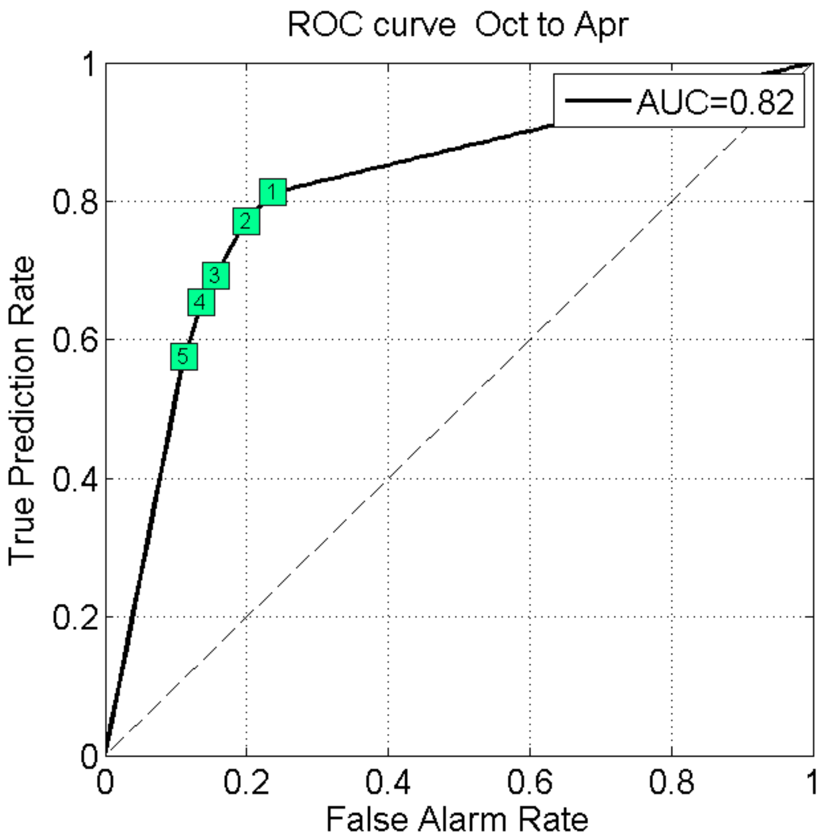
- No calibration or sensitivity study performed on these results.

  *No performance penalty on blade, repeated cycles:



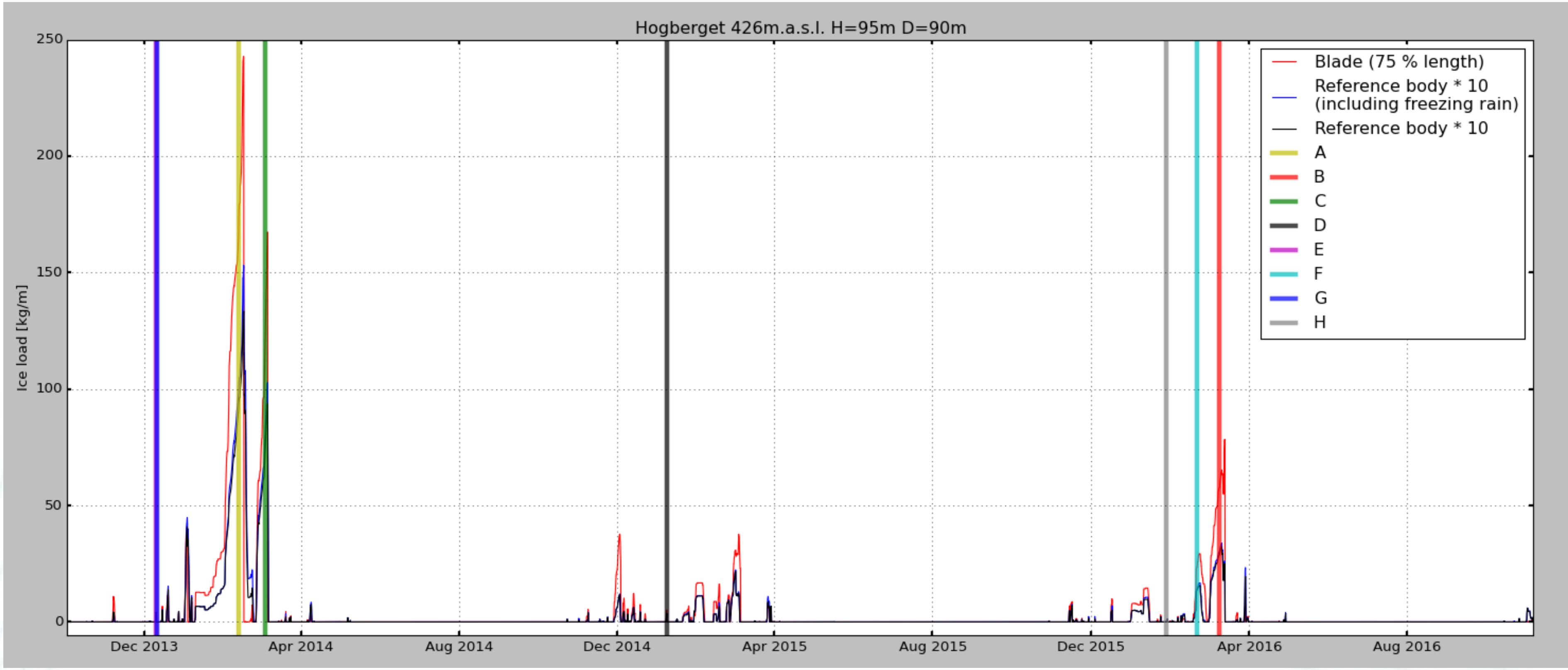
Quality of meteorological simulation using ROC metric: 80 % hit rate for all hours with icing (20 % false alarm rate)

- Task 19 IceLoss method as proxy for hours with icing (production loss from SCADA)
- Area under curve score of 0.82,
- Simulated ice amounts on a reference cylinder
  - 1: 10 g/m
  - 2: 50 g/m
  - 3 :100 g/m
  - 4: 150 g/m
  - 5: 200 g/m
- Note that score is influenced by duration of events



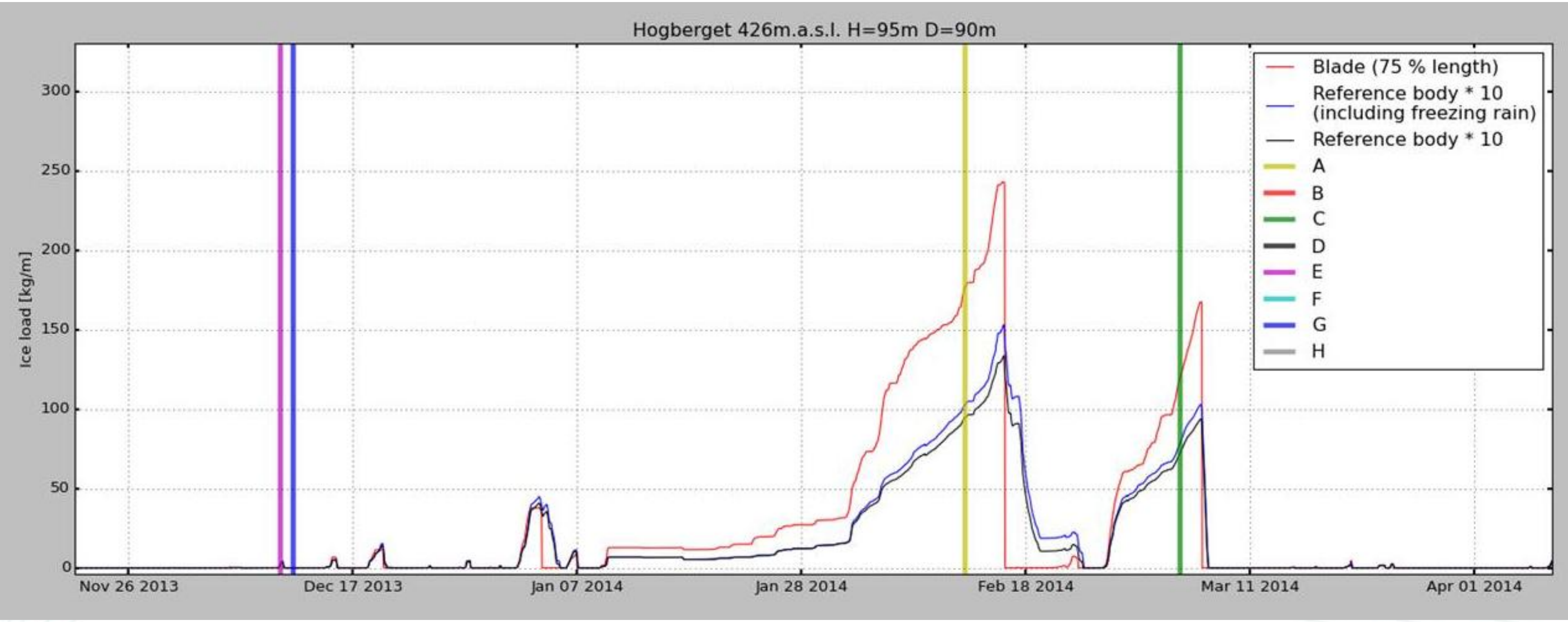
Intermittent icing, 4 clear episodes, 4 barely detected.
Not all episodes inspected

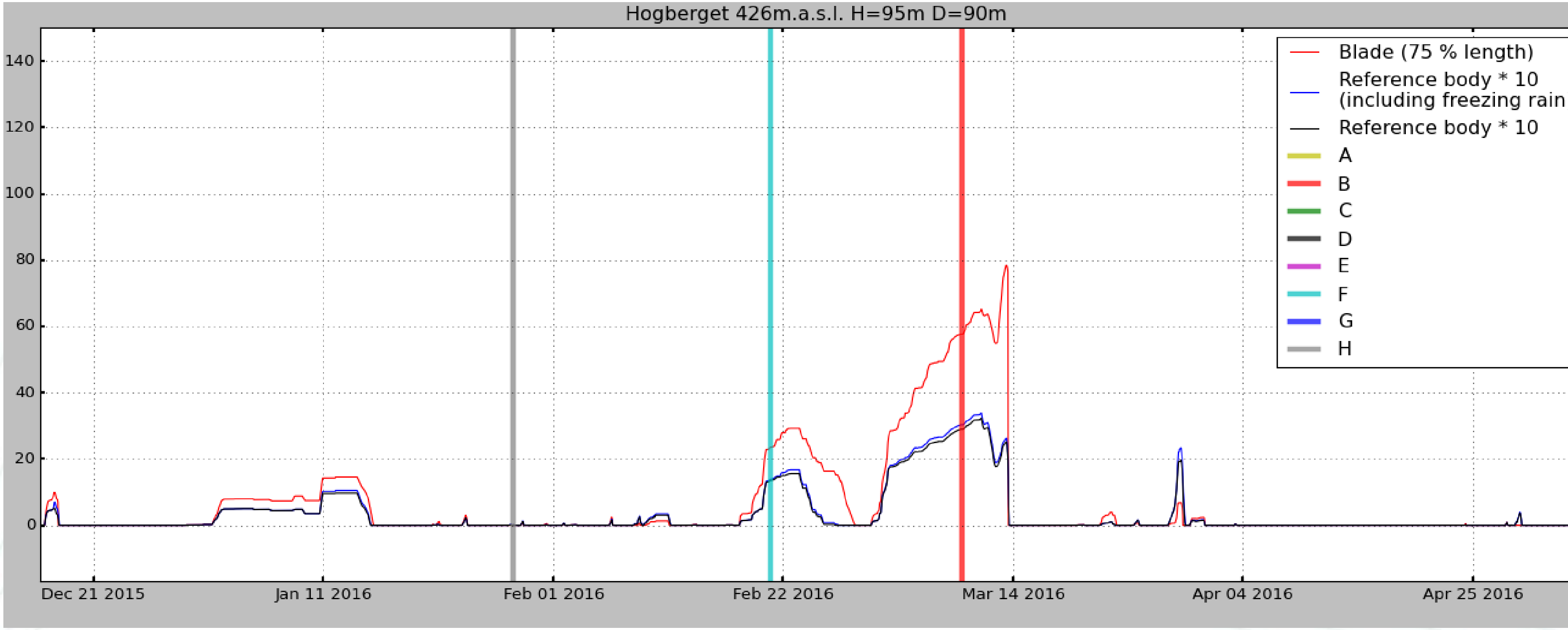
KJELLER VINDTEKNIKK



Both shorter and longer periods, inspection too early?

- Mechanical shedding is not modeled





Hogberget 426m.a.s.l. H=95m D=90m
140
120
100
80
60
40
20
0
Dec 21 2015
Jan 11 2016
Feb 01 2016
Feb 22 2016
Mar 14 2016
Apr 04 2016
Apr 25 2016
Blade (75 % length)
Reference body * 10
(including freezing rain
Reference body * 10
A
B
C
D
E
F
G
H

Further work

- Extract wind conditions for each episode from both SCADA and KVTMESO
- Quantify the error for each episode, calibrate number, size, and form factor distribution

Thank you for your attention!

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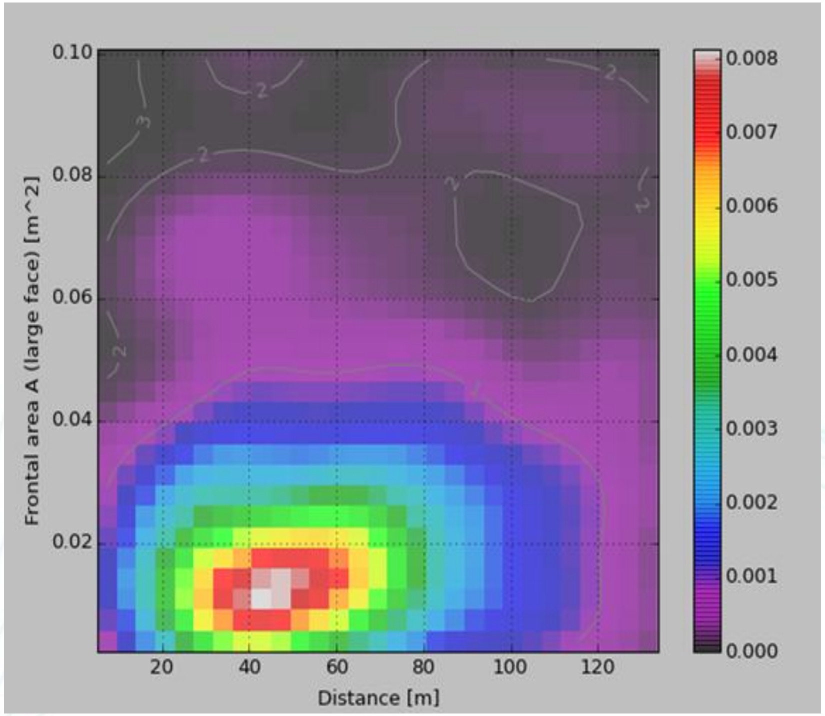
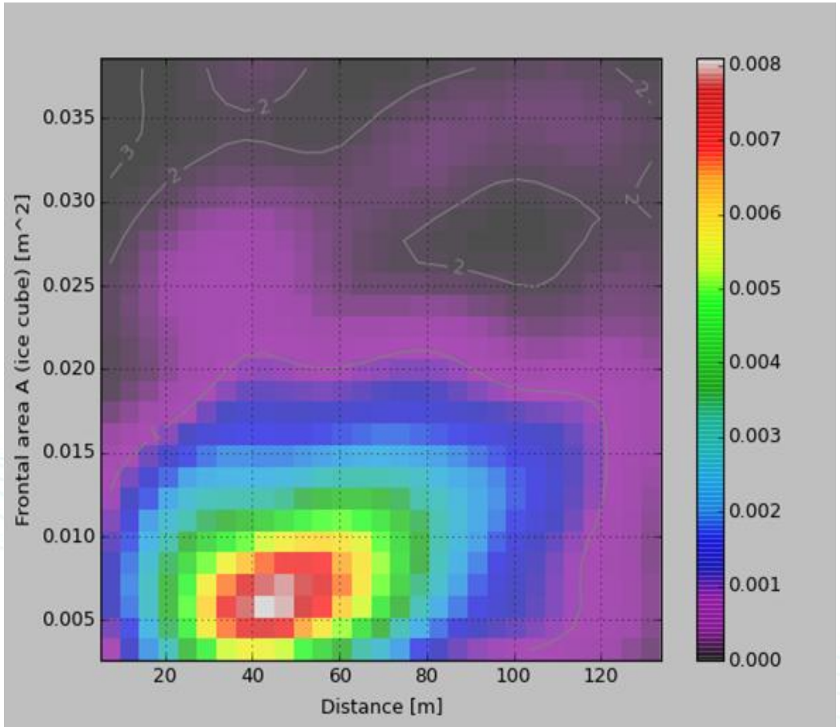
Bonus slides

Form factor, Cd *A /M, using largest face is 250 % higher than the average face

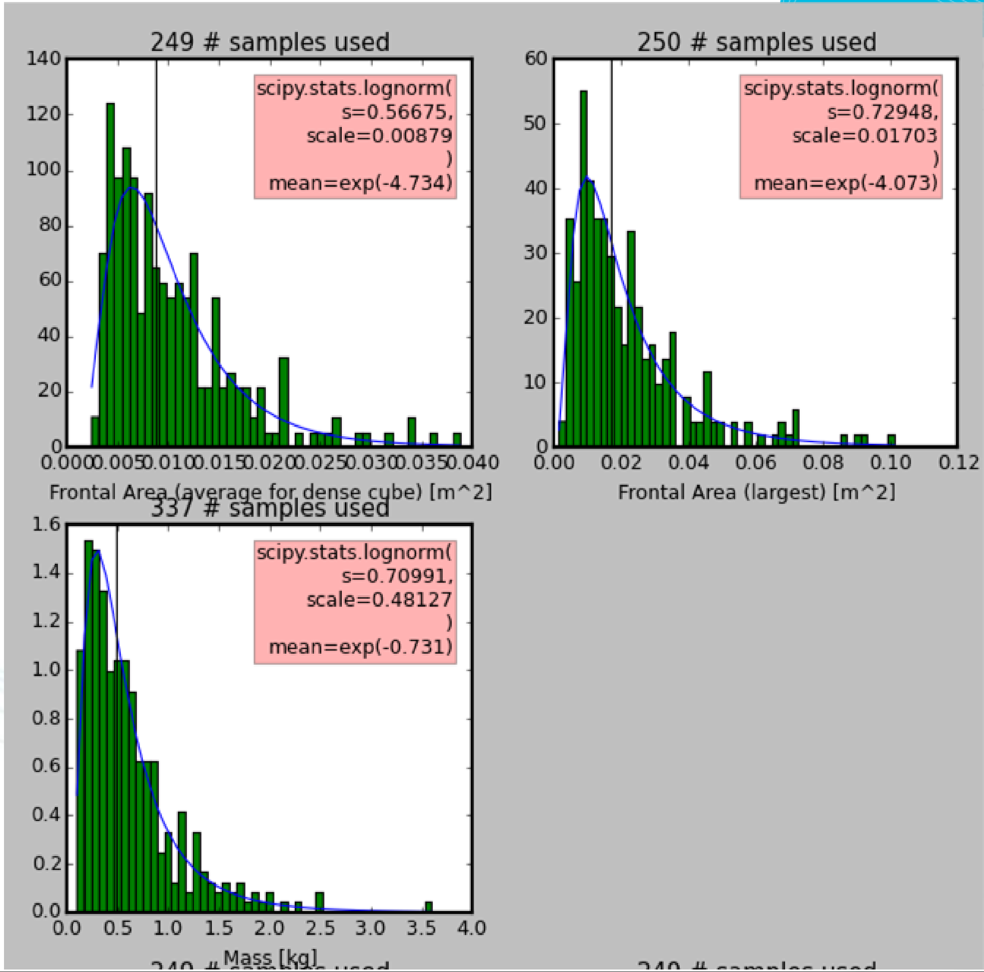
Histogram on largest face/average area of ice piece as function of distance





KJELLER VINDTEKNIKK

Area ice piece distribution

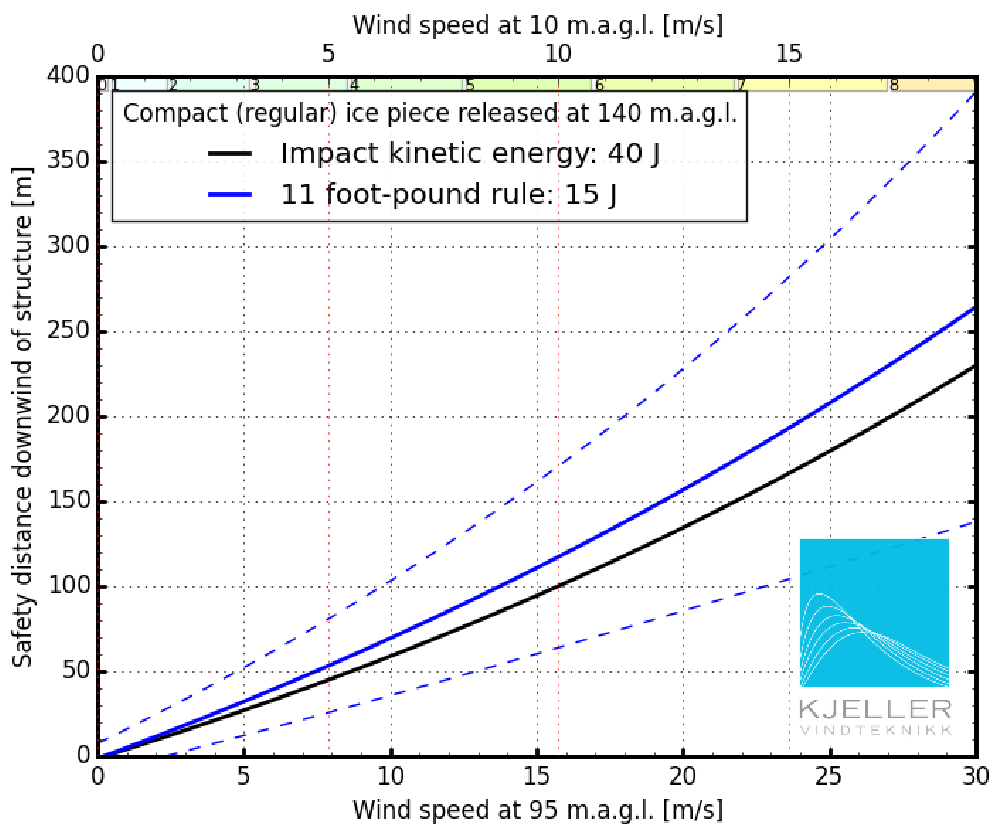


Stopped turbine analysis
Strong Breeze (Beufort 6)- 40-50 km/h at 10 m.

15 J – Protection against serious injury

40 J Limit for casualty

Dashed line gives
uncertainty using 3
standard deviations



Austrian field study:
Double detection system - idling turbine
Ice fall at (H+D) distance for 12 m/s wind

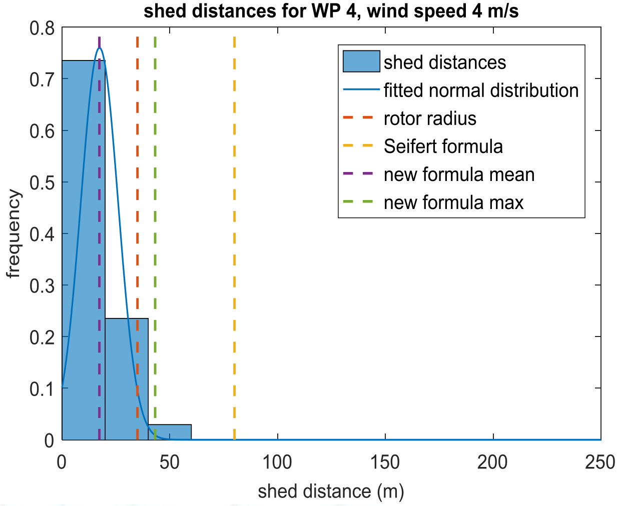


Figure: Shed distances for 4 m/s mean wind speed, 65 m hub height and 70 m rotor diameter

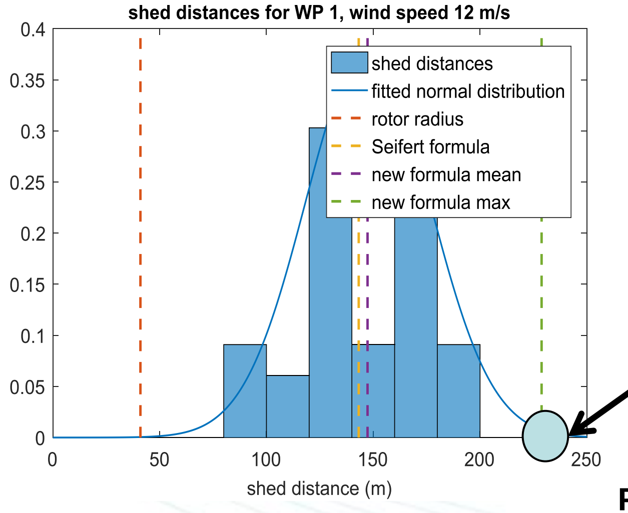
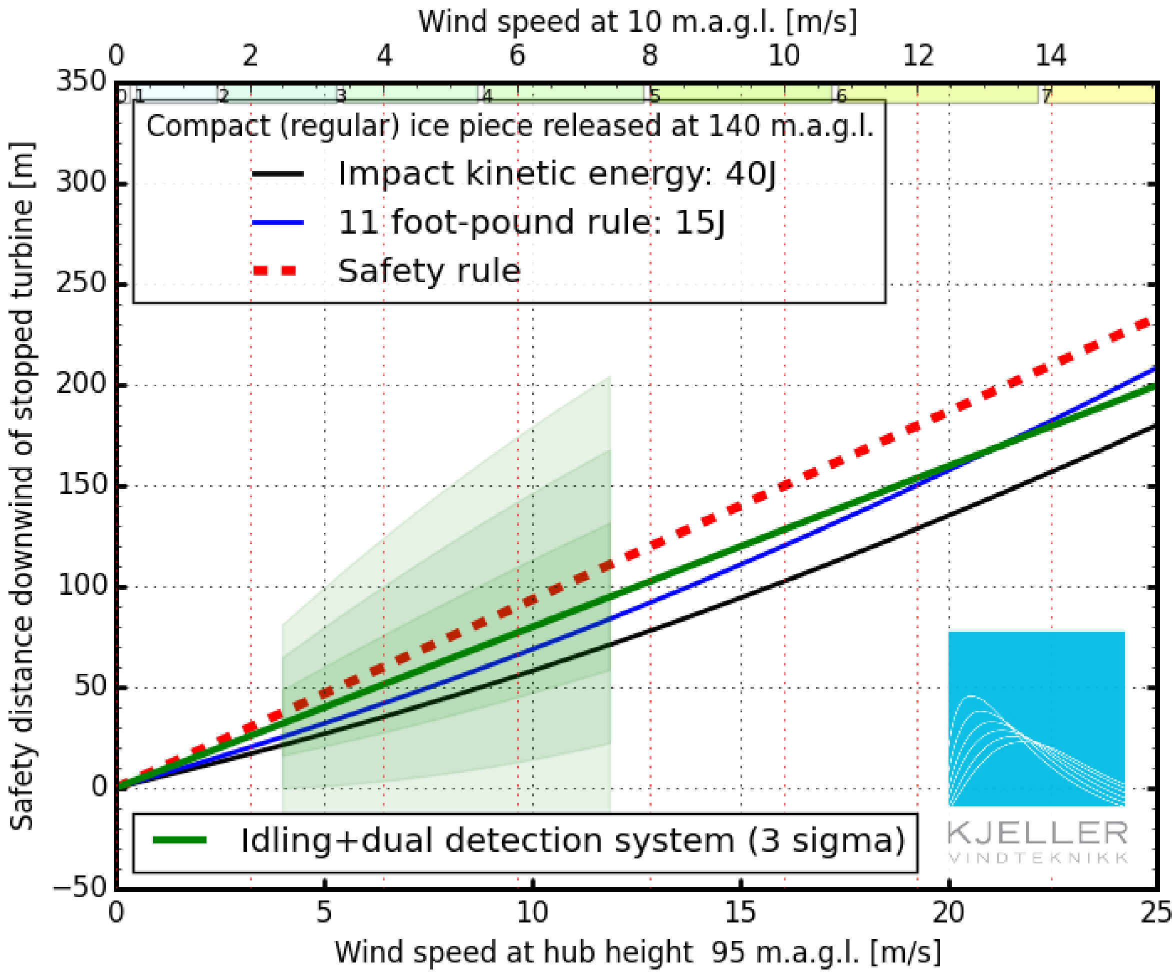


Figure: Shed distances for 12 m/s mean wind speed, 138 m hub height and 82 m rotor diameter

Figure: Ice piece with the highest recorded shed distance of 225 m from a turbine with 138 m hub height and 82 m rotor radius. The length of this piece was 38 cm, the width 16 cm and the thickness varies between 3 and 8 mm. It was pure glace ice with a weight of 240 g.

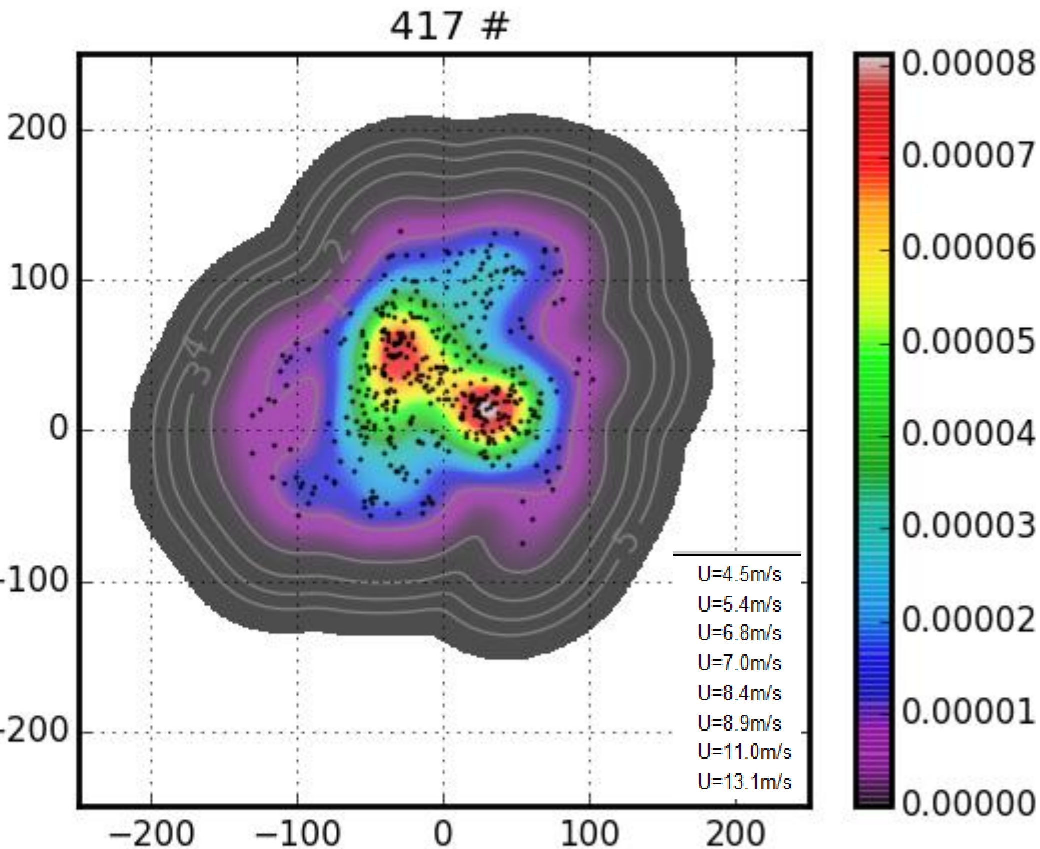
Comparison with Austrian study in Green, 3 standard deviations for IceThrower turbine

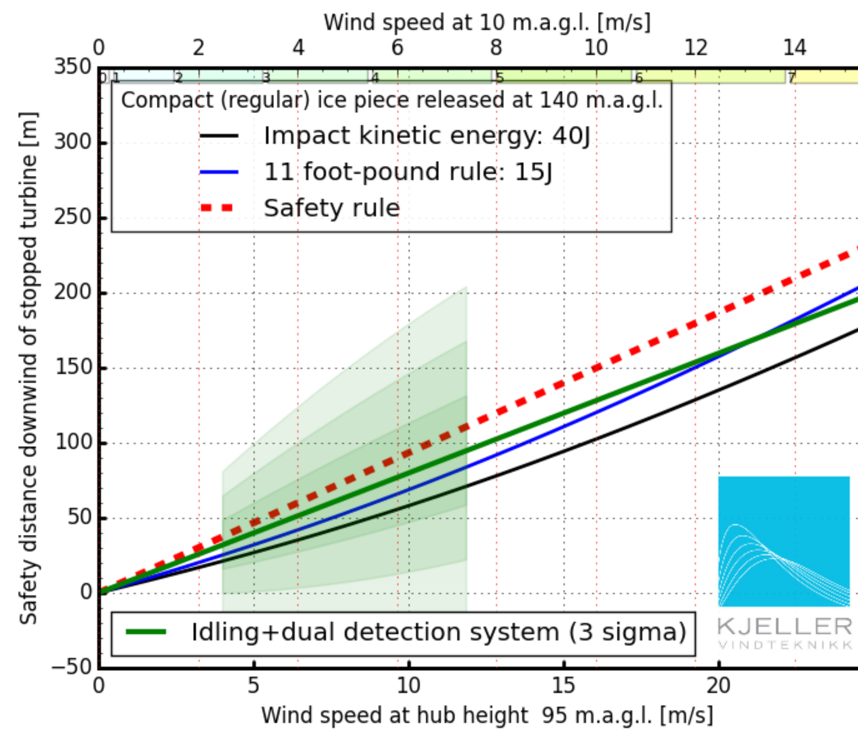
- Expected distance for ice shed from 100 m +- 30 m for 12 m/s hub winds.
- Note that turbines in green is supposed to stop when ice is detected!



200 m is expected bound for stopped turbine for wind speeds below 13 m/s. Winds speed below 20 m/s for iced turbine conditions at this location

KJELLER VINDTEKNIKK





Comparison of A/M distributions

INTERNATIONAL RECOMMENDATIONS FOR ICE FALL AND ICE THROW RISK ASSESSMENTS

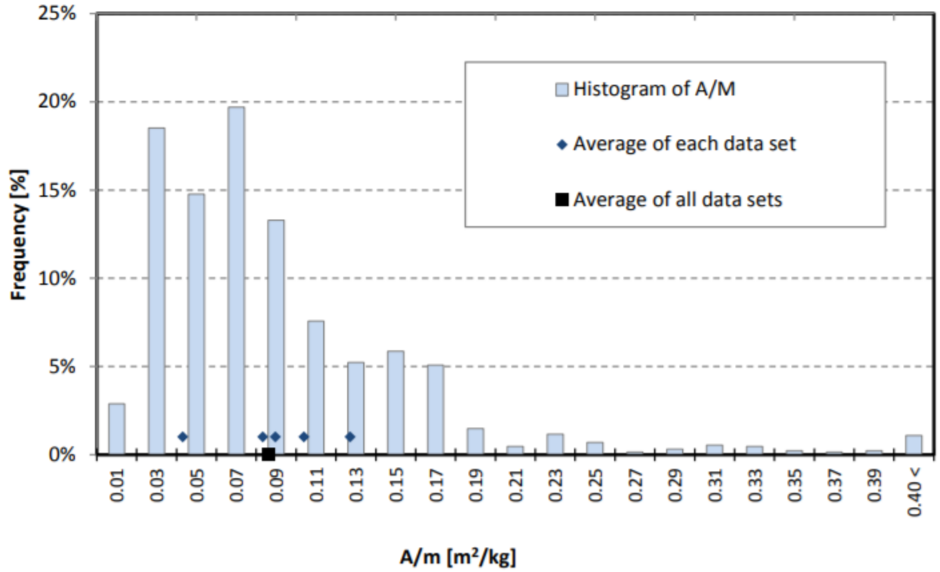
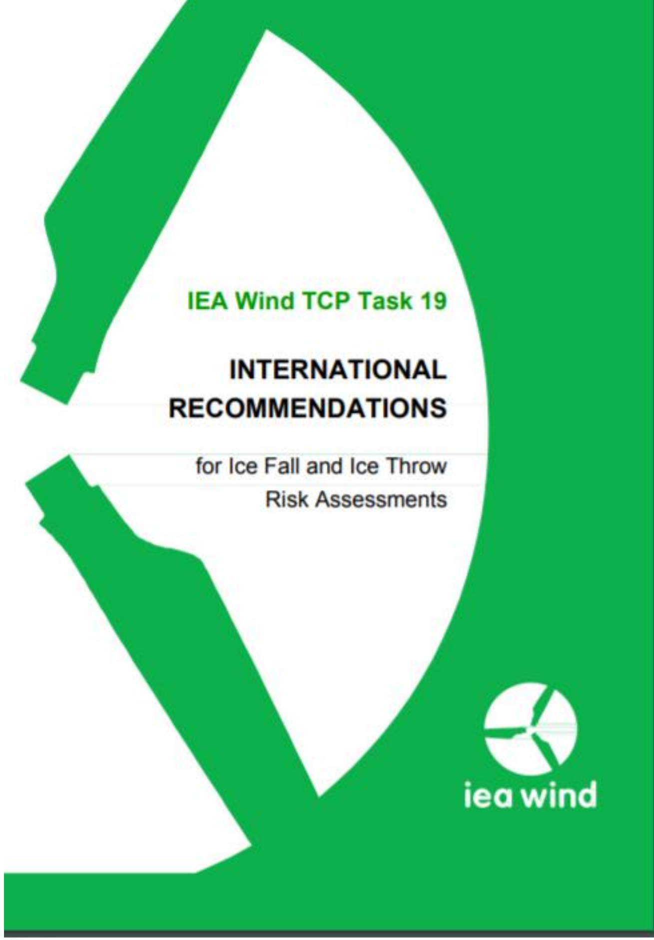
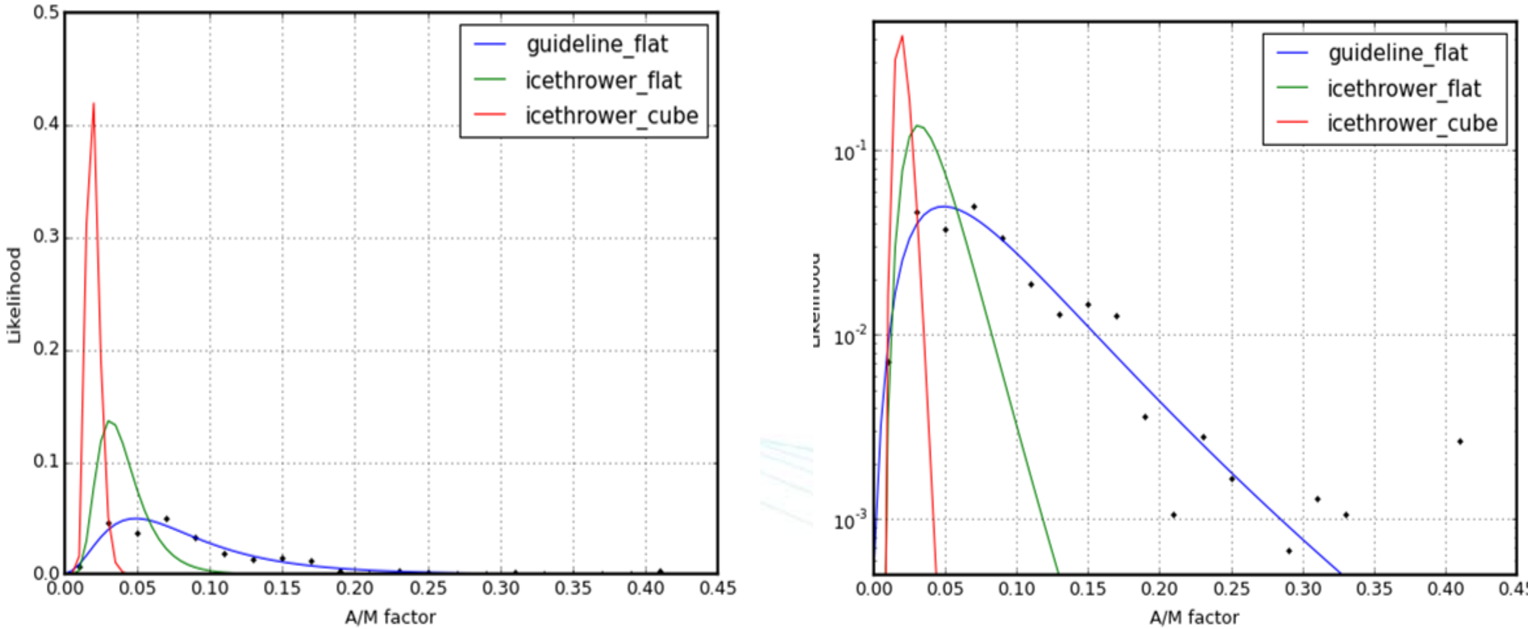


Figure 4: A/m histogram (columns) and average values for merged data set and individual data sets (cross).



Larger / more compact ice pieces in icethrower

Linear and log scale, same area under curve.



Test of shape distributions

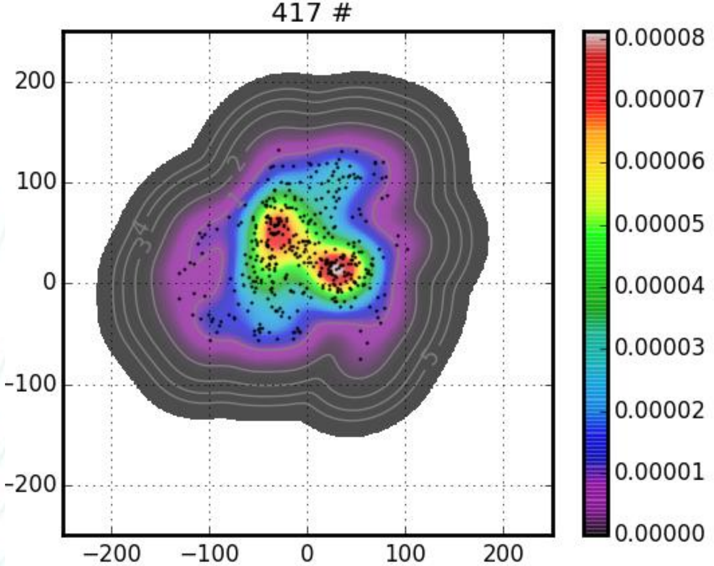
for 4 representative long-term wind conditions (from KVTMESO)

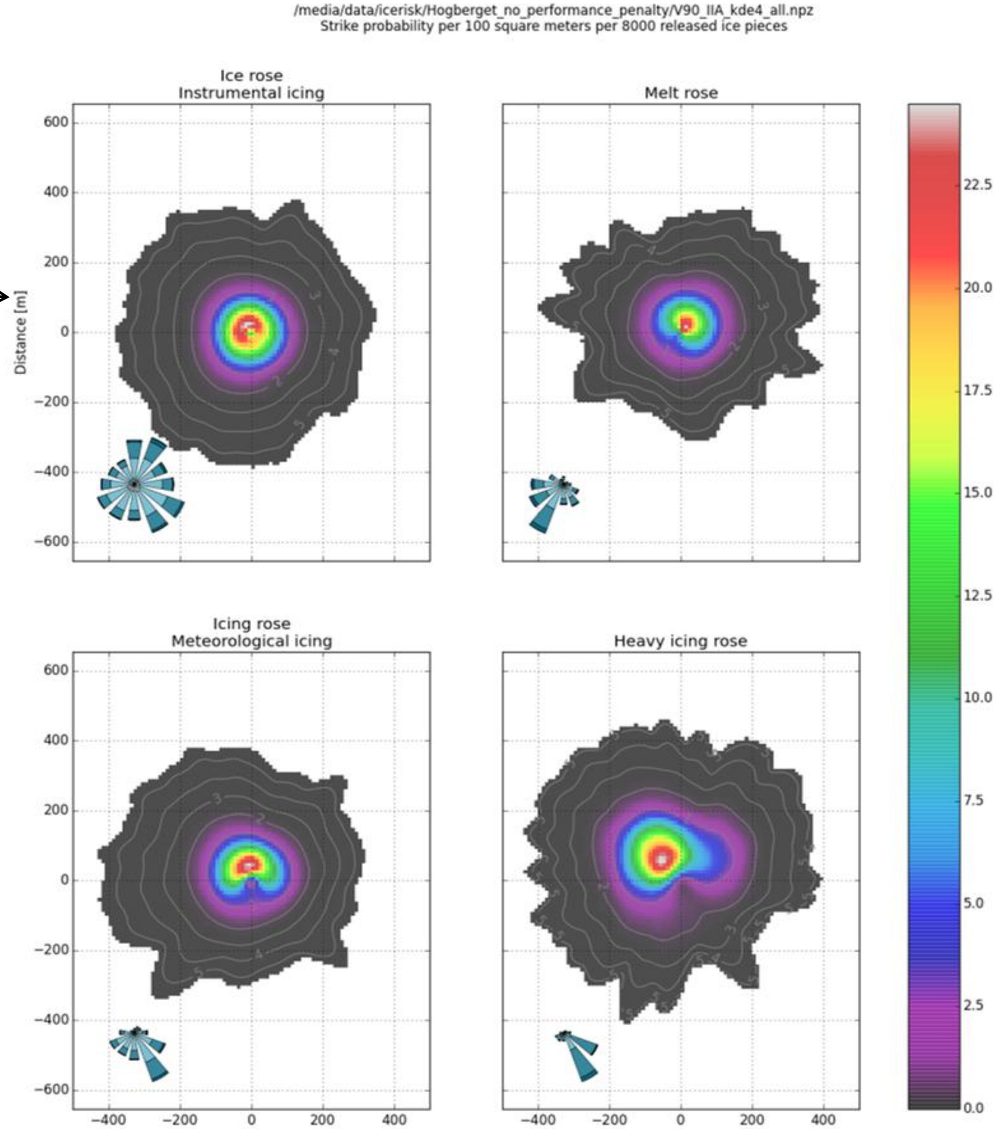
- Instrumental icing
- Melting conditions
- Meteorological icing
- Strong meteorological icing

Simulated strikes of ice pieces per 100 square meters

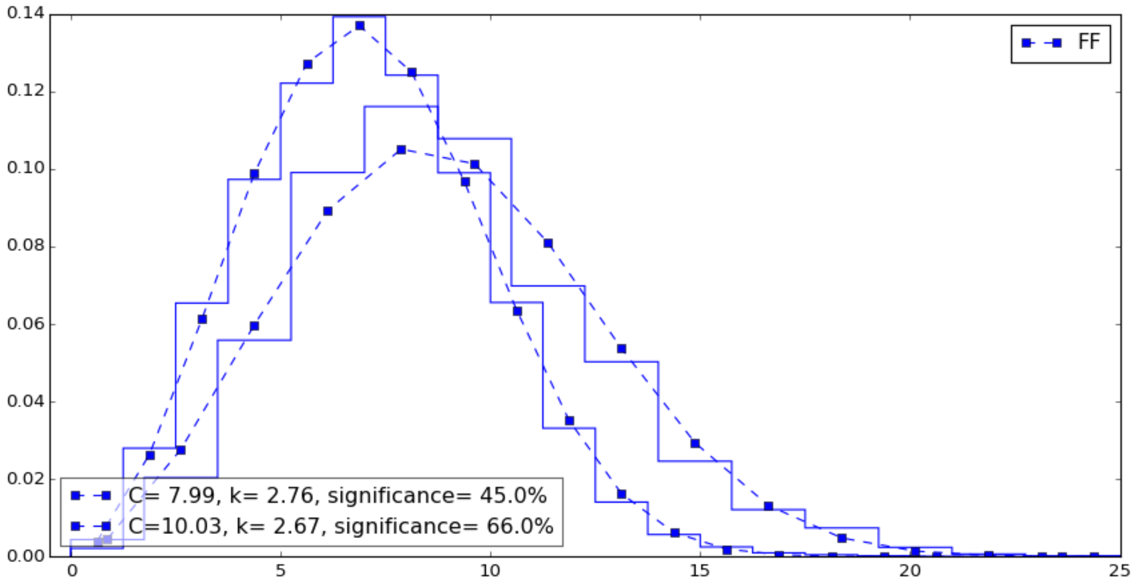
Guideline A/M flat distribution (8000 pieces, wind speed uncalibrated).

Average 8 episodes (per m2)



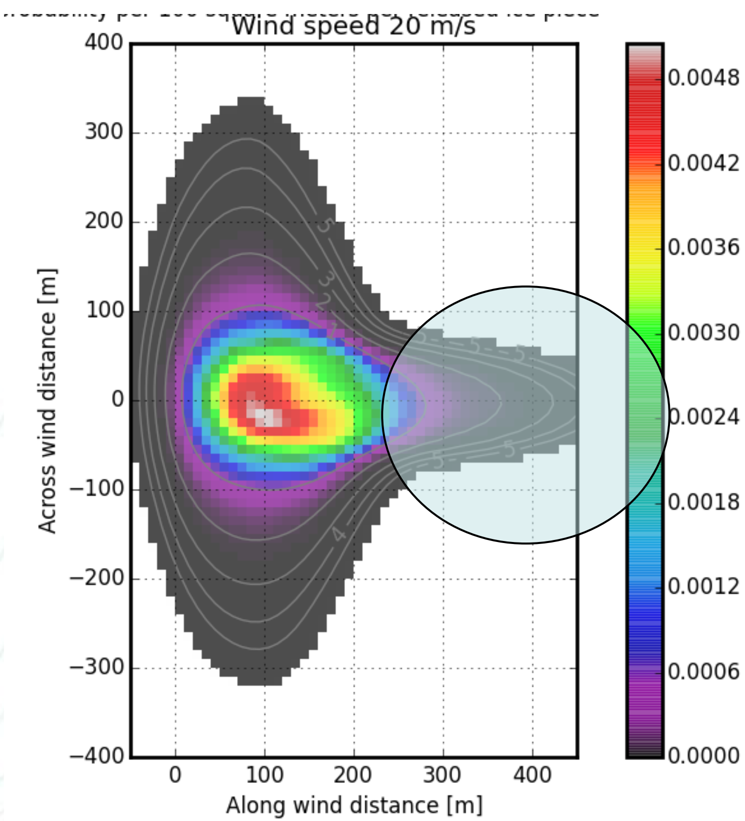


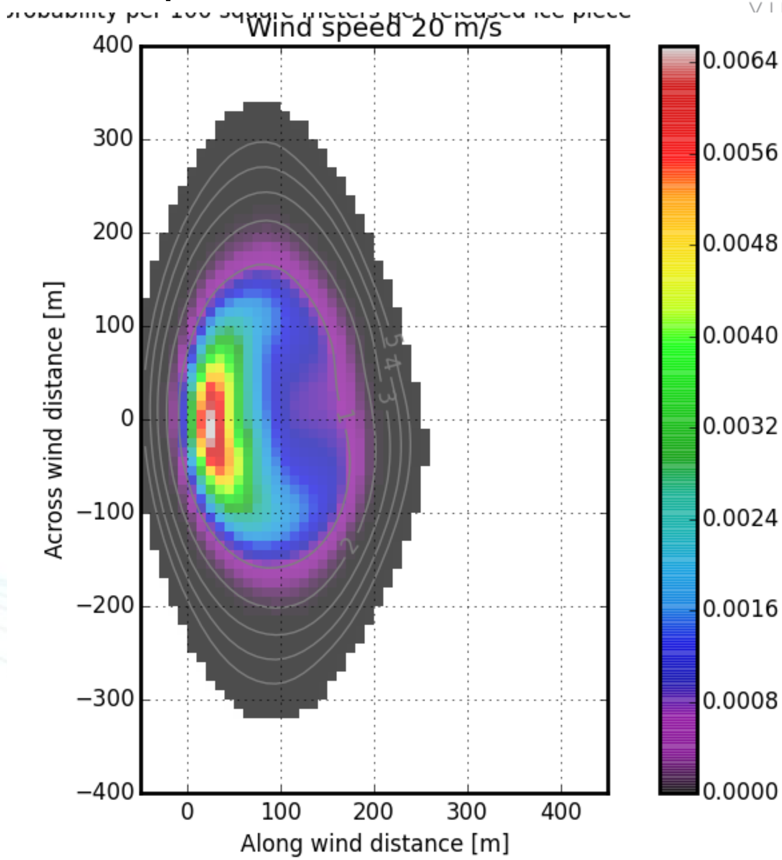
SCADA:
Averge wind, and average wind for instrumental icing



Fix the tail of the distribution
Form factor by largest face, 20 m/s wind
Guide line fit (left) , Ice Thrower fit (right)

Strike probability per released piece per 100 square meter





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