Icethrow from wind turbines

Assessment and risk management

IEA Wind Task 19, Winterwind 2017

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What is in-cloud icing?

- If temperatures are below 0° C and the structure is located inside a cloud (above cloud base height) we get in-cloud icing.
- The ice accretion rates increases with the relative windspeed and the moisture content of the cloud.
- Because the blade of a wind turbine moves fast there is an elevated hazard associated with ice throw and fall from turbines located in icing conditions.

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Examples of ice debris from wind turbine blades

Icepiece found 25 m from tower of turbine. Kjøllefjord, Norway 29.march 2008.

Source: Statkraft

Source: Seifert 2002

How far can the ice be thrown?

- Maximum throw distance (screening) : 1.5 x (D + H). ~ 350 m.
- Ice debris have so far not been found at this distance.
- Ice pieces have been found at 68 % of the maximum throw distance.
  - 1.4 x tip height (Cattin). 1000 icepieces with 3 % above tip height
  - 1 x Tip height (Lunden, 2017). 500 icepieces total.

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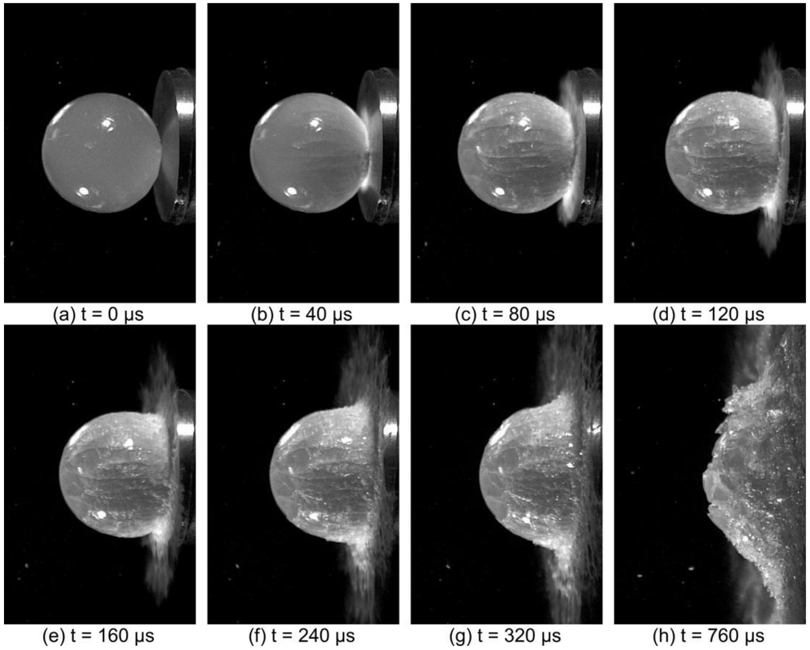
How dangerous is the ice.

- An impact kinetic energy of more than 40 J is considered fatal.
- 40 J correpsonds to a 0.2 kg ice piece with density 500 g/dm^3 falling from an elevation of 30 – 50 m.
- Because of the turbine height all ice pieces larger than approximately 0.2 kg are potentially fatal.



When do we have dangerous ice amounts?

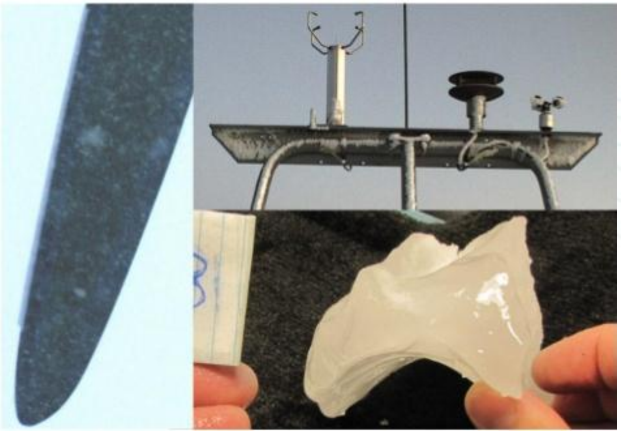
- **Typically 10-20 times more ice on a blade than on the reference object.**
- **Relation between ice on reference body at hubheight and accumulated ice on a wind turbine blade (ref. estimated using ISO12494).**
- **Dangerous ice amounts for icing above 0.5 kg/m on a reference object?**

TechnoCentre éolien
Wind Energy TechnoCentre

Pictures presented by Wadham-Gagnon, M., (2013). Ice profile Classification Based on ISO 12494. TechnoCentre éolien (Wind Energy TechnoCentre). Winterwind 2013.

Ice Class Rime 1 (ICR1) – 0 to 0.5 kg/m

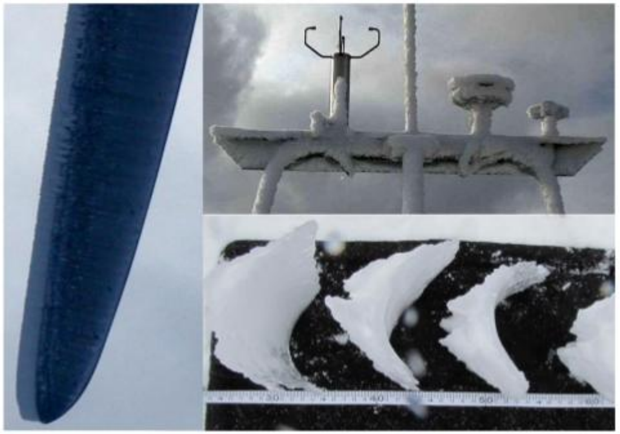
Ice Class Rime 2 (ICR2) – 0.5 to 0.9 kg/m



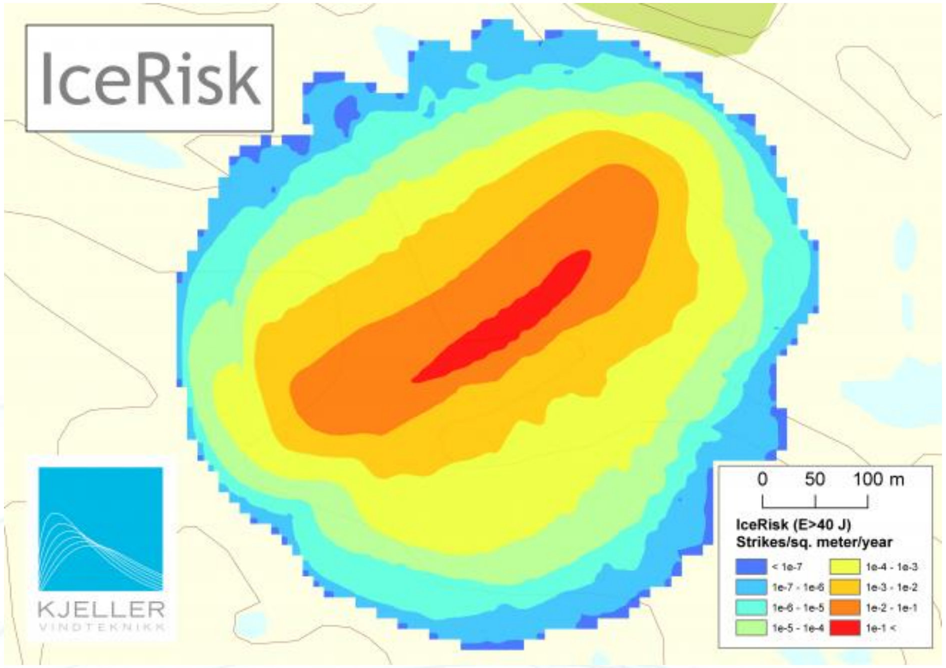
Ice Class Rime 3 (ICR3) – 0.9 to 1.6 kg/m

Ice Class Rime 4 (ICR4) – 1.6 to 2.8 kg/m

Ice Class Rime 5 (ICR5) – 2.8 to 5.0 kg/m



What is the probability of icethrow ?



- The probability depends on the local icing conditions (accreted ice amounts)

Example: 210 m from this wind turbine the probability is 10^{-6} per year to be struck by dangerous ice.

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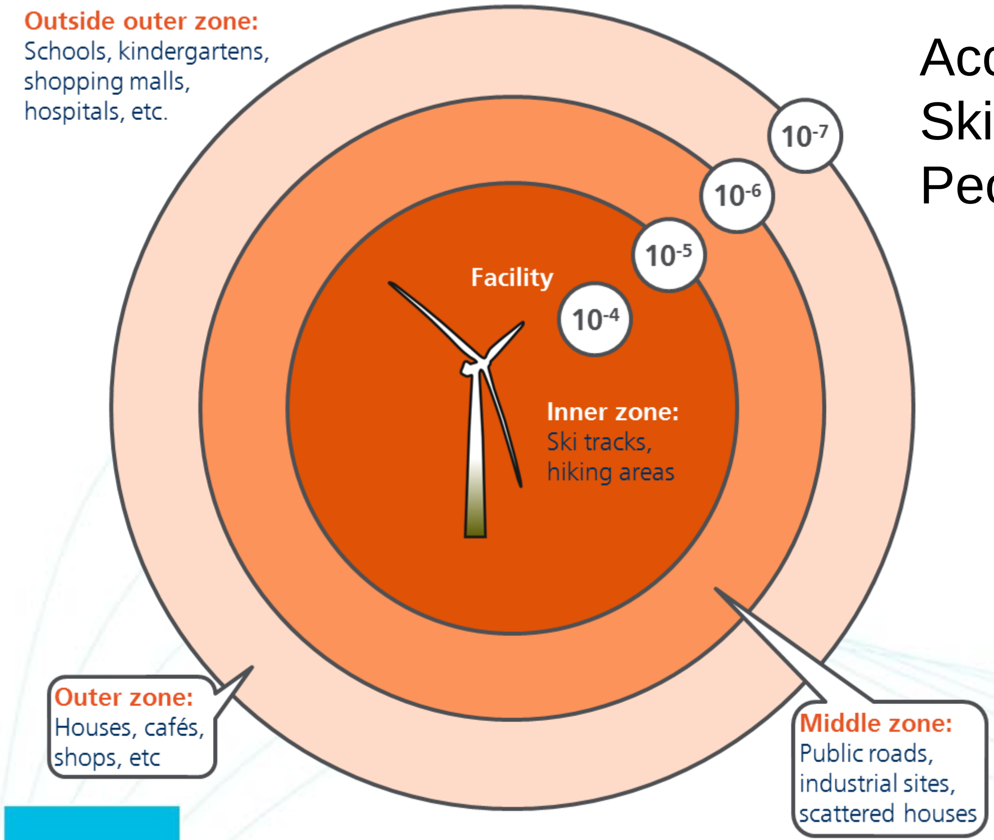
How large risk can we accept?



Acceptable risk:
Ski tracks < 10-4
People walking along public road < 10-5

Localizied Individual Risk metric: LIRA is the probability that an average unprotected person, permanently present at a specified location, is killed in a period of one year due to an accident at a hazardous installation

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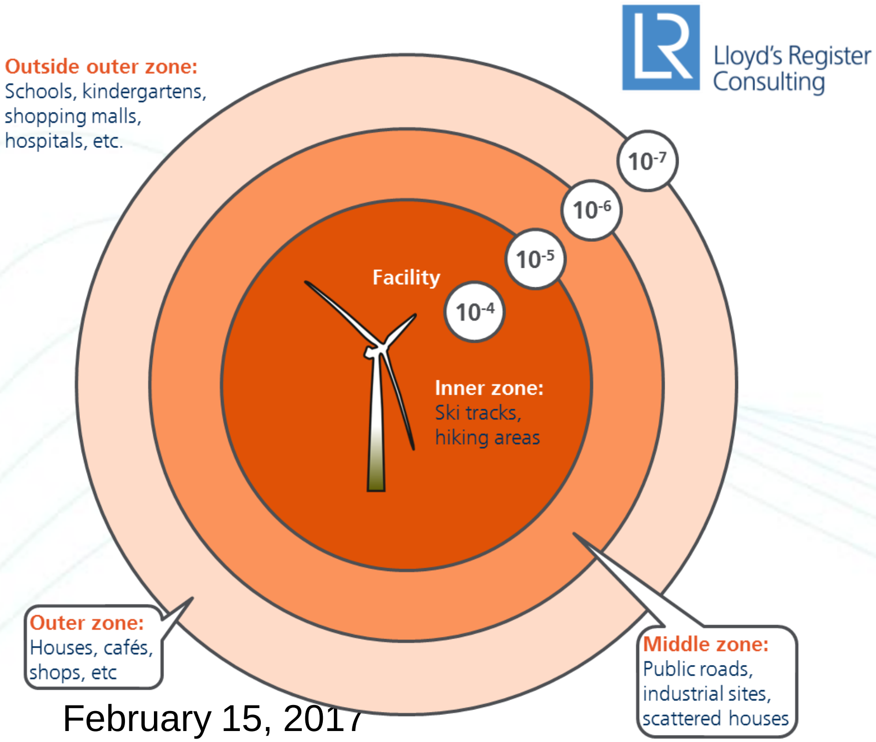
Suggested risk acceptance criteria for third person

- Risk = probability of event * severity of the consequence



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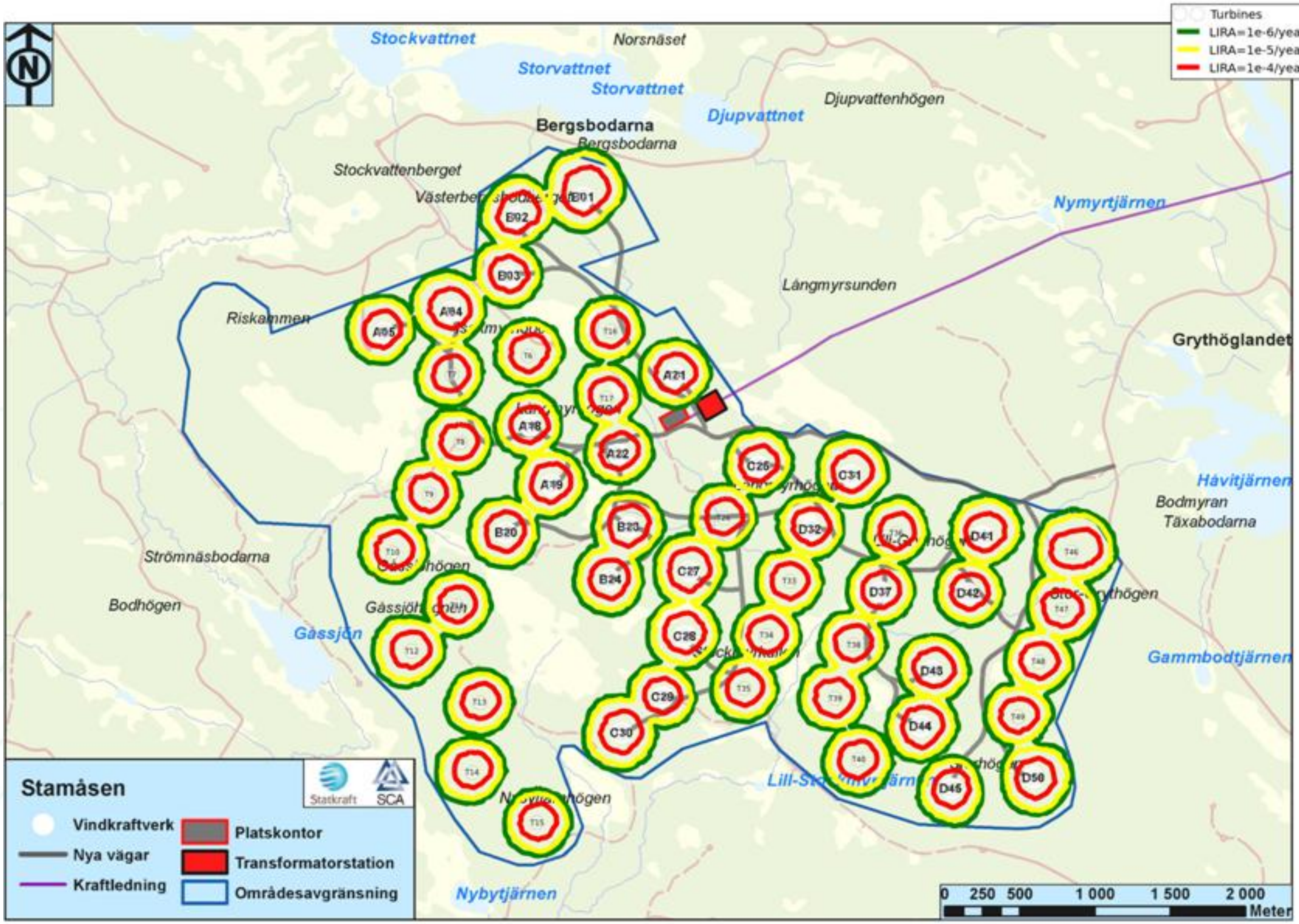
Yellow LIRA contour: Public road /scattered houses excepted



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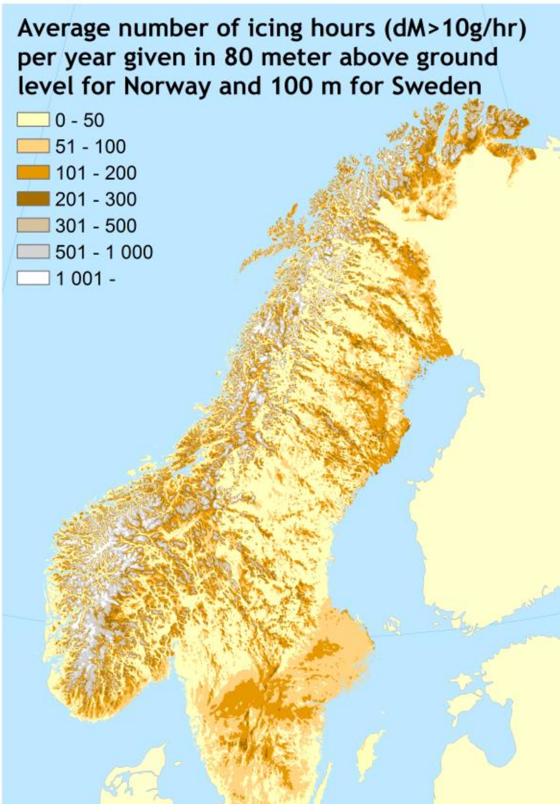
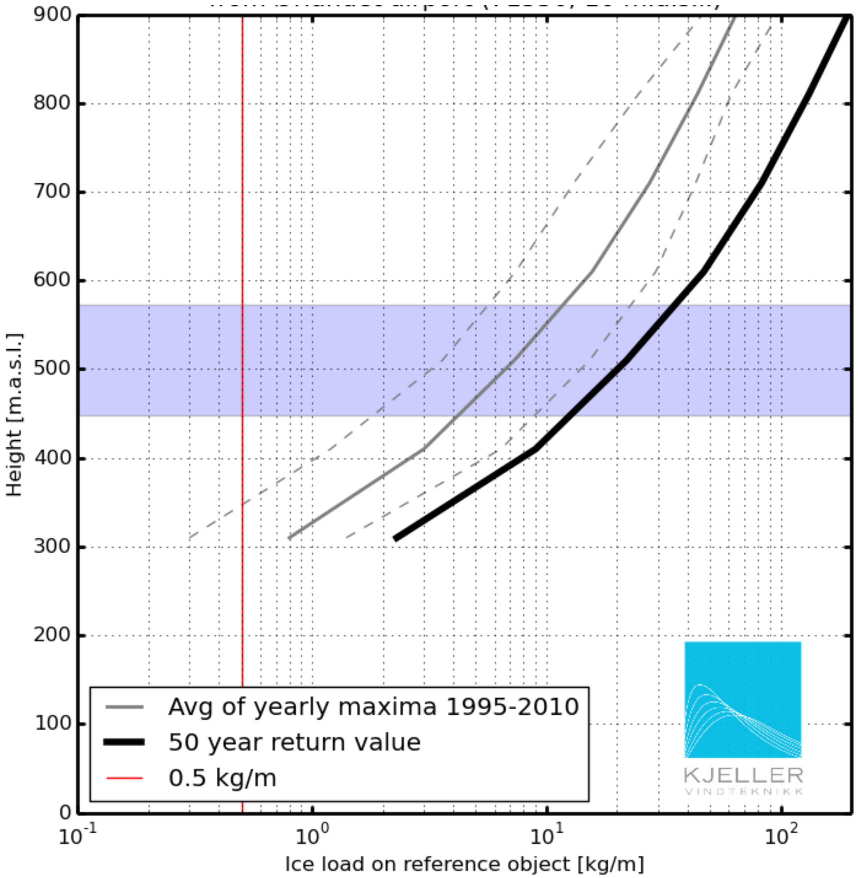
Where do we have icing?



Icing map of Norway
www.nve.no

The map shows frequency
not ice amounts



Icing increases exponentially with height above sea level.
50 ton / year thrown from highest turbine
10 ton / year from lowest turbine

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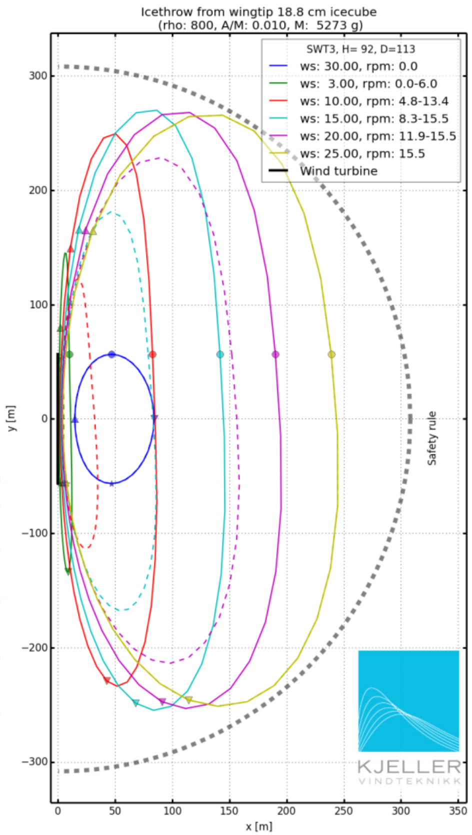
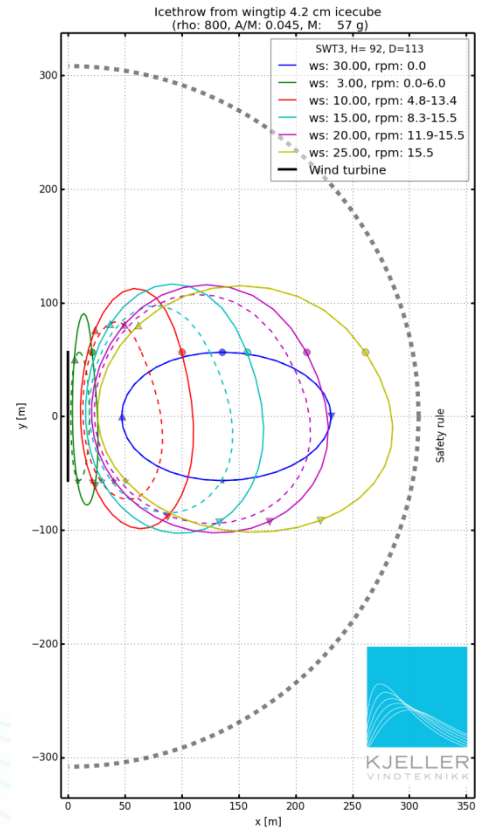
Calculation of ice throw distances

Wind



Large pieces can be thrown far to the side



Smaller pieces drift further with the wind.

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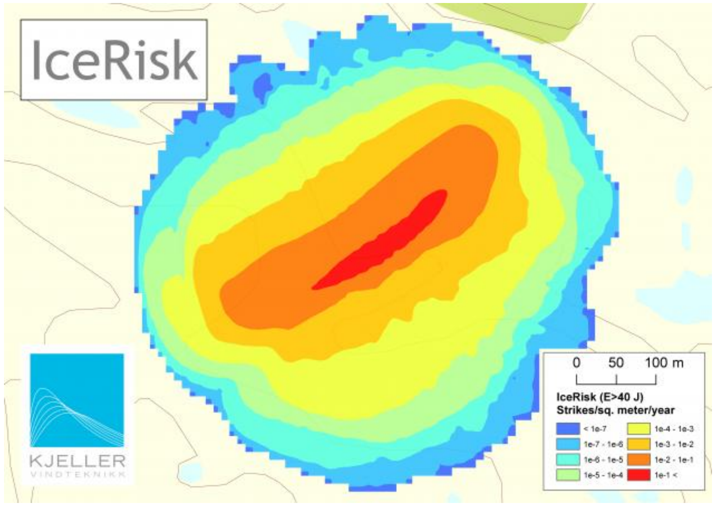
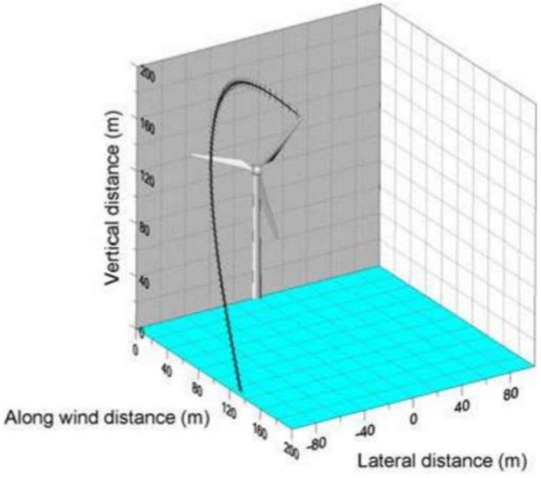
Calculation of probabilities

- Description of the climatology at the site
  - Weather models can be used
  - Measurement of icing makes the calculations more accurate
- Calculation of ice accretions for the different weather situations.
- Combined with throw distances the probabilities can be calculated for the surrounding area.





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Risk management

- The knowledge regarding the risk in your own windfarm is required
  - Professional communication.
  - Signs.
  - Routines for employees.
  - Training/Education.
  - Warning systems.


DANGER
FALLING
ICE
HAZARD
Fermeuse
Wind Power Corp.
FUTURA

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Taurern windfarm 2009

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Sign: Danger of ice fall in the wintertime

Advise against unnecessary stay

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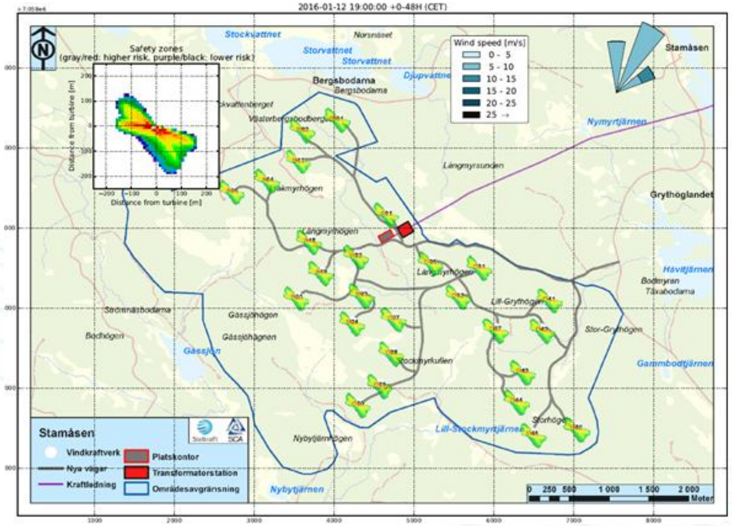
Routines for working personell

- Routines shall aid in the handling of all residual risk that is not mitigated through the design.
  - Sensors
  - Web cameras.
  - Communication procedures
  - Ice warning systems with additional information on hazardous areas.
  - Safe vehicles
  - Super structure / roof cover

Foto: Scandinavian Terrain Vehicles



Source: Statkraft

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Warning systems

- The surroundings can be warned with sounds and/or lights or other sources of information.
- Warning systems can be driven by a combination of:
  - Sensors.
  - Weather forecasts.
  - Inspection.

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IEA Wind Task 19 reports

- Recommended Practices (2011), (2017)
- Available Technologies (2016)
- International Guidelines for Ice Risk Assessment (2018)

- Other: ISO 12494 (icefall)

Approved by IEA ExCo last friday

EXPERT GROUP STUDY ON
RECOMMENDED PRACTICES

13. WIND ENERGY PROJECTS IN COLD CLIMATES

2. EDITION 2017

Submitted to the Executive Committee
of the International Energy Agency Programme
for
Research, Development and Deployment on
Wind Energy Conversion Systems

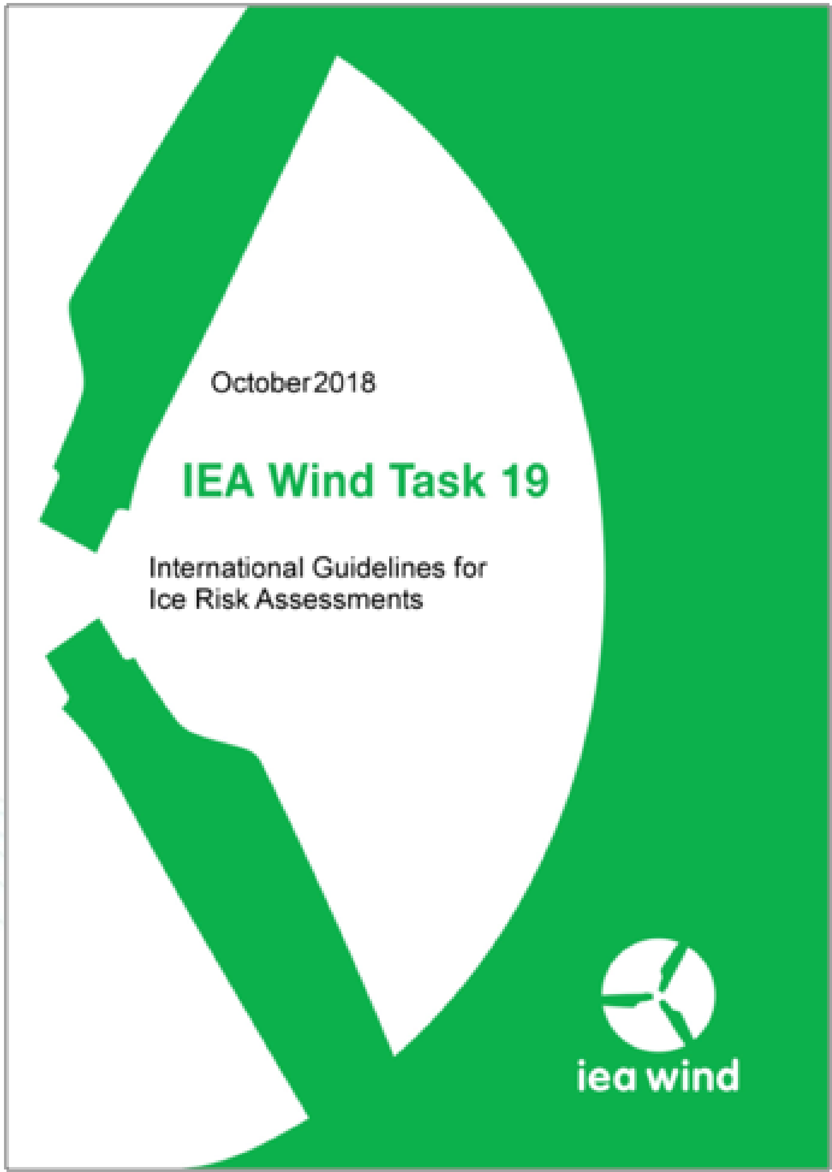
January, 2017

Subtask: Ice-throw challenge

- **Current situation and project objective:** In an increasing number of countries the authorities are asking for ice-throw / ice-fall risk assessments during approval procedure of new wind parks. However up to now, no international recommendations, guidelines or standards are available as to the elaboration of those assessments. As a matter of consequence, the quality requirements of public authorities as well as the used methodologies and results of individual consultants vary to a large extent.
- The experts of IEA Wind Task 19 (http://ieawind.org/task_19.html) have identified this lack of regulation as highly relevant for the current 5th term and decided to setup a subtask, which aims at enhancing standardization of ice throw risk assessments.

International Guidelines for Ice Risk Assessments (2018)

- As a result of this project, an official recommendation of Task 19 will be published, selecting and defining the essential methodology and input parameters for ice-throw / ice-fall risk assessments.
- https://www.ieawind.org/task_19/task_19_riskAssessment.html
- International working group: Enercon, Meteotest, TÜV Süd, F2E, RES, Kjeller Vindteknikk and Energiewerkstatt.
- http://www.energiewerkstatt.org/wp/wp-content/uploads/2016/10/IEA-TASK-19_Presentation.pdf



R. E. Bredesen, H. Farid, M. Pedersen, D. Haaheim, S. Rissanen, G. Gruben and A. Sandve, “IceRisk: Assessment of risks associated with ice throw from wind turbine blades (PO.339). https://windeurope.org/summit2016/conference/allposters/PO339.pdf,” in *WindEurope Summit*, Hamburg, 2016.

International ”harmonization” of existing methodologies

- Mathematical model
  - Desciption on how to use and setup the trajectory models
- Relevant data set
  - Databases on collected ice pieces etc.
- Risk assessment
  - Risk metrics, methods and risk acceptance criteria for different exposures

Non-objectives

- Aspects related to O&M shall not be covered within this project
- Whereas the most important mitigation measures (e.g. warning signs…) will be addressed, a comprehensive discussion about other means of mitigation measures (e.g. shut down of WT with iced up blades) cannot be included.

Planning for H&S by assessing the risk of ice throw (2011)

iea wind

EXPERT GROUP STUDY ON
RECOMMENDED PRACTICES

13. WIND ENERGY PROJECTS IN COLD CLIMATES

1. EDITION 2011

Submitted to the Executive Committee
of the International Energy Agency Programme
for
Research, Development and Deployment on
Wind Energy Conversion Systems

May 22, 2012

A risk analysis of ice throw can be presented as iso-IR (individual risk) lines. IR is defined as the risk per m^2 and year to be hit by an object of significant size. The IR should be calculated for the winter season only. Iso-IR lines are to be drawn for 10^{-4}, 10^{-5} and 10^{-6} and must take into account the actual wind direction and wind speed frequency distributions during icing situations as well as the prevailing wind directions when the temperature tend to rise towards zero degrees. Currently there is no commercial planning tool available for the risk assessments of ice throw or ice fall.

Planning for H&S by assessing the risk of ice throw and ice fall (2. Edition 2017)

1) Carry out site specific ice assessment to determine if icing will occur at your sit
2) Screening turbine surroundings for ice throw with Seifert Formula,
3) Perform ice throw simulations providing strikes/year/m^2,
4) Determine acceptable risk levels and
5) Apply risk mitigation strategies.

Figure 8.1 describes the recommended ice throw analysis process.

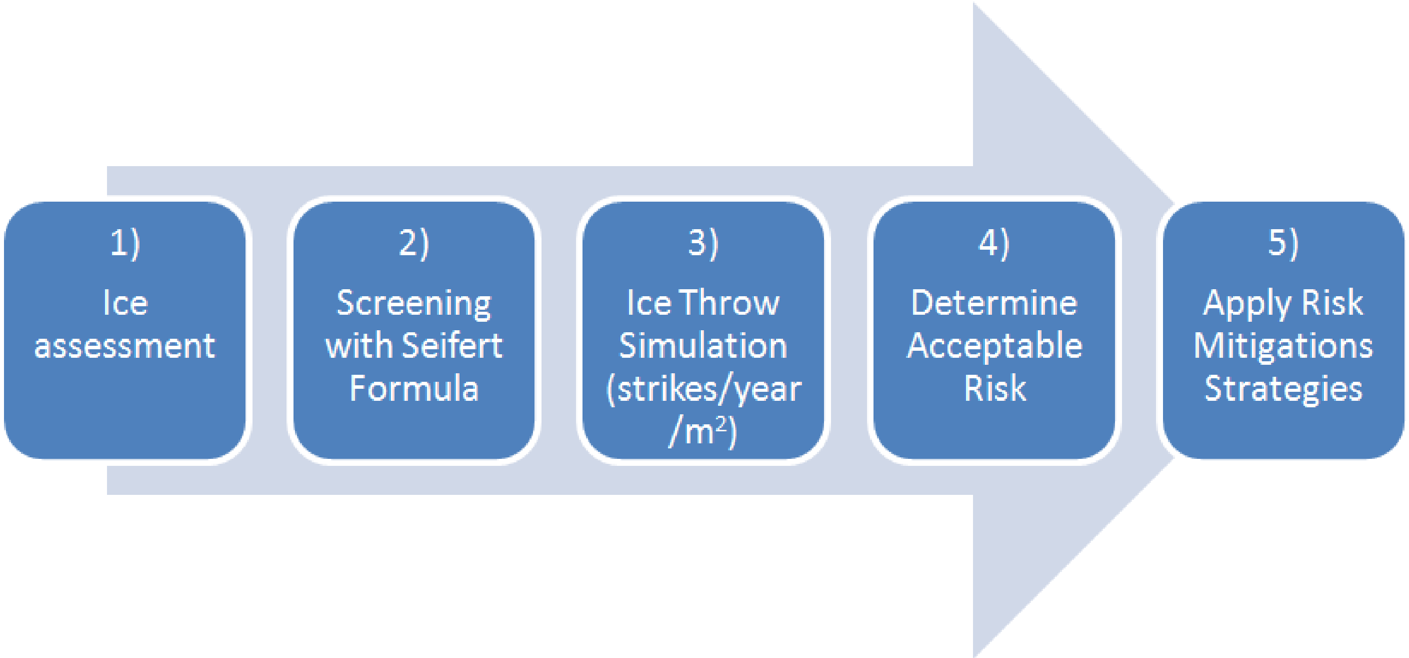
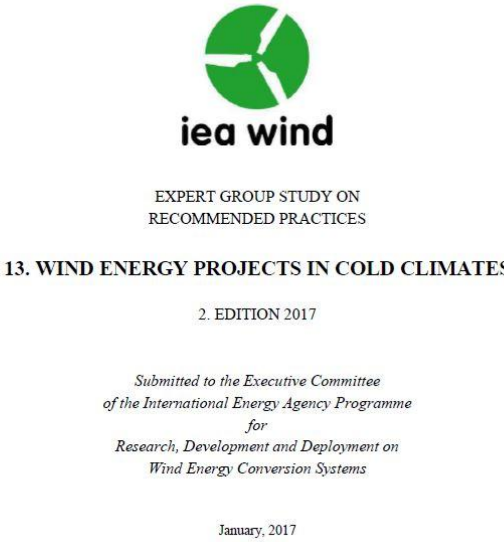


Figure 8.1: A flowchart for managing the risk of ice throw during the project development stage (incl. ice fall).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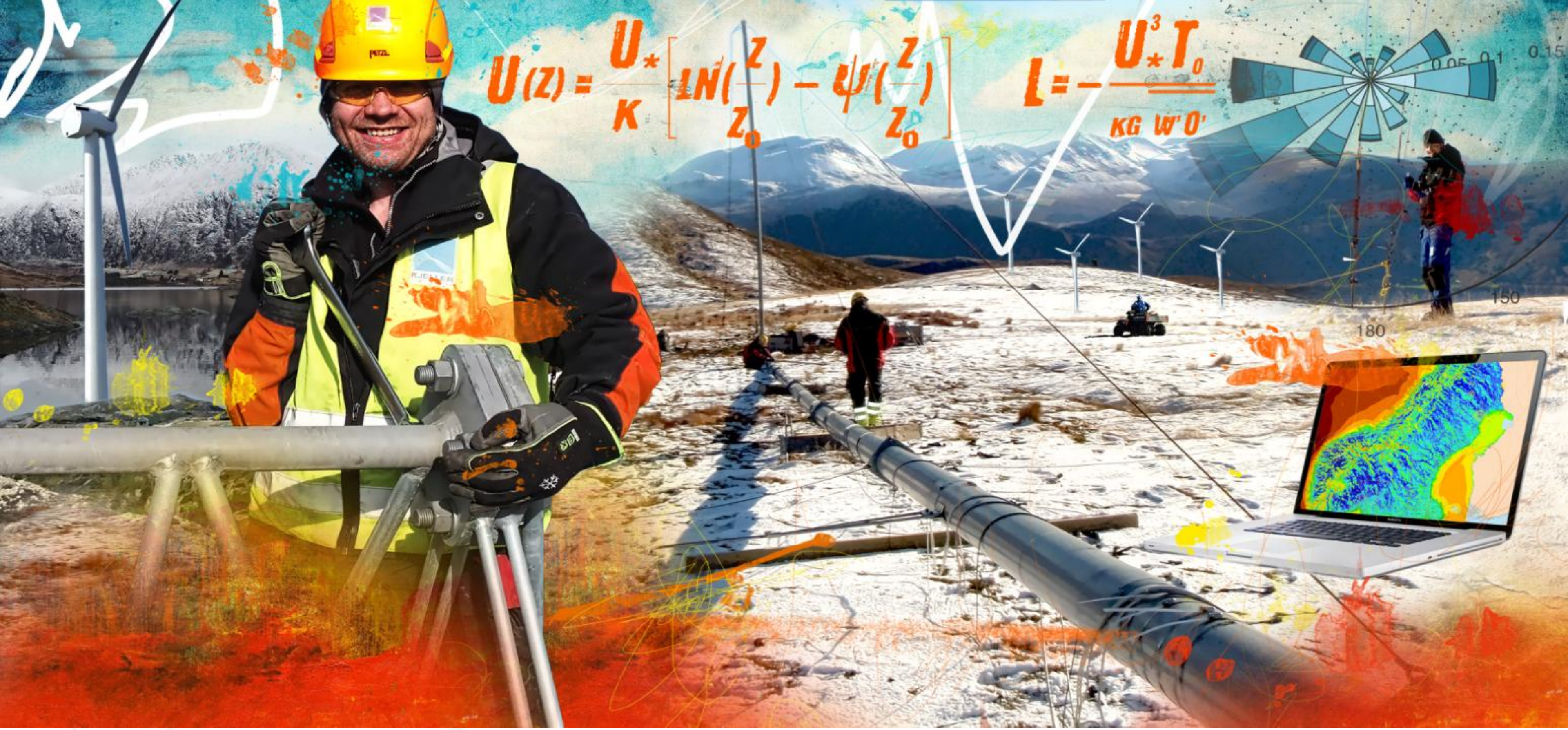
RECOMMENDED PRACTICES

13. WIND ENERGY PROJECTS IN COLD CLIMATES

2. EDITION 2017

Submitted to the Executive Committee of the International Energy Agency Programme for Research, Development and Deployment on Wind Energy Conversion Systems

January, 2017



Thank you for listening

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Bonus

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Requirements from Norwegian ministry regarding Icing and ice throw (loose translation):

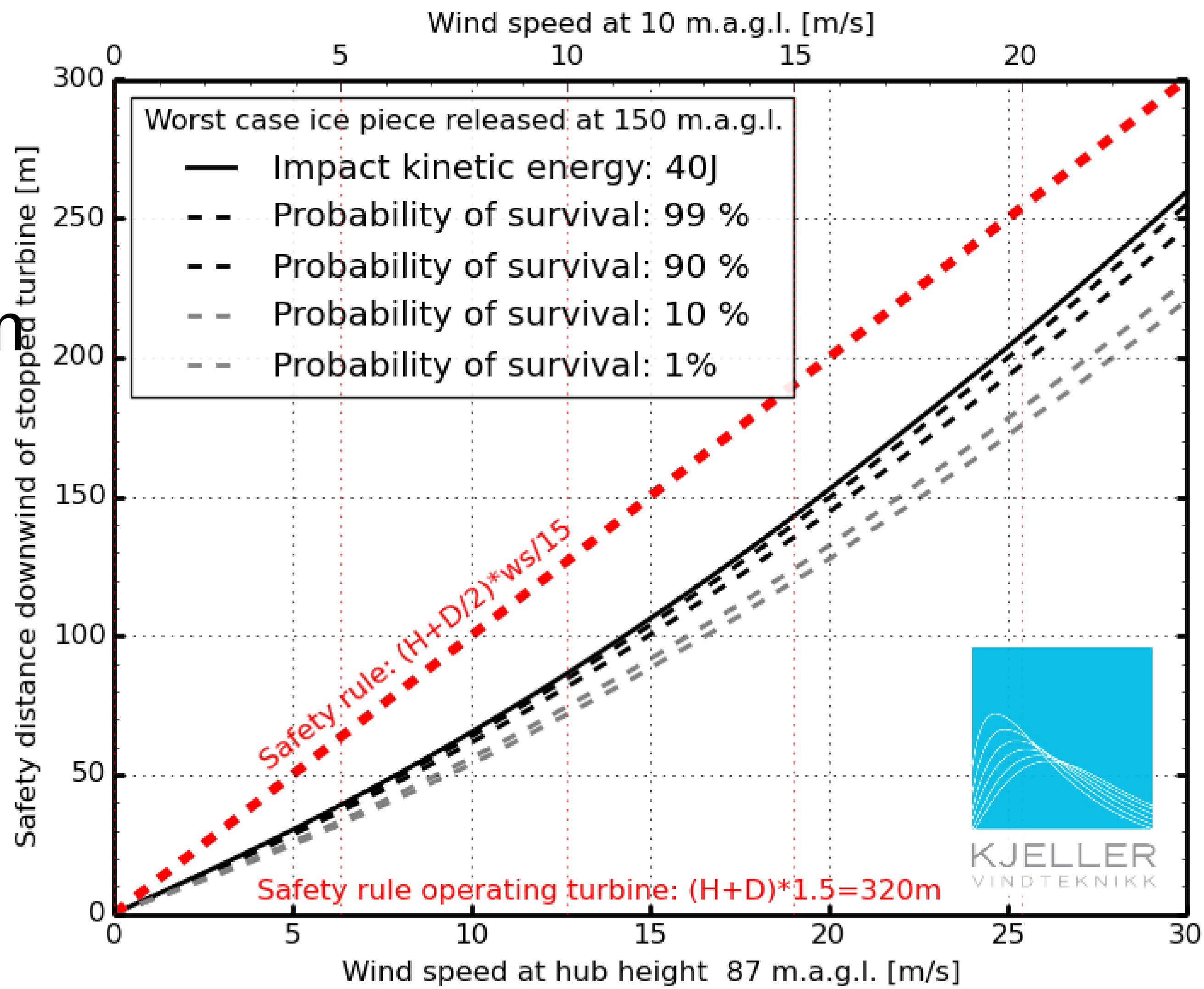
- Risk assessment for ice throw
- Establish routines in order to warn when there is a danger of ice throw

Strict German/Austrian regulations

- Seifert screening formula of danger zone:
  (Hubheiht+rotordiameter)*1.5
- In Germany/Austria it is required to have ice detection systems if there are roads or buildings within this distance.
- **Restriction on production**: turbine must stop when there is icing.
- If detection systems are realiable and sensitive, then the potential hazard is most likely associated with ice fall and not throw of smaller ice pieces.

Safety rule stopped turbine: distance = (H+D/2)*ws/15

- Windshear Alpha = 0.11
- Hub = 87 m
- RotorD = 126 m



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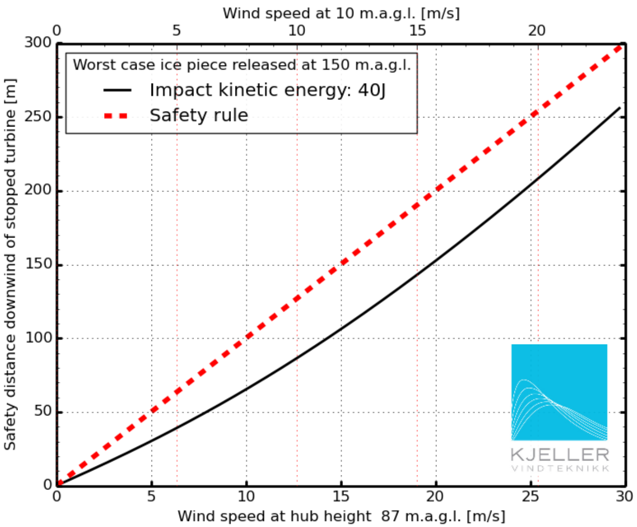
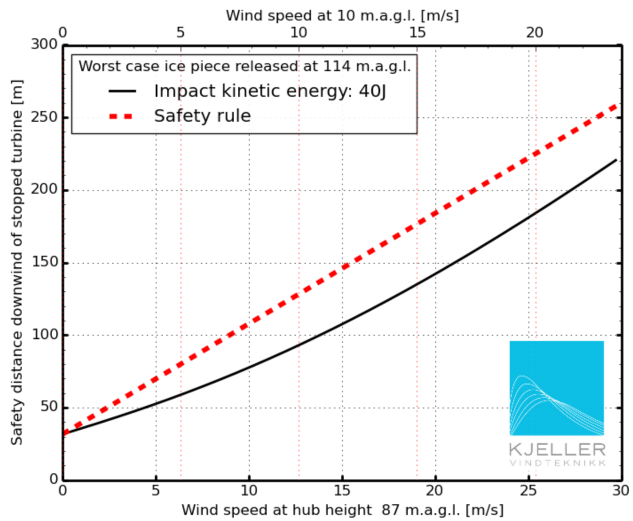
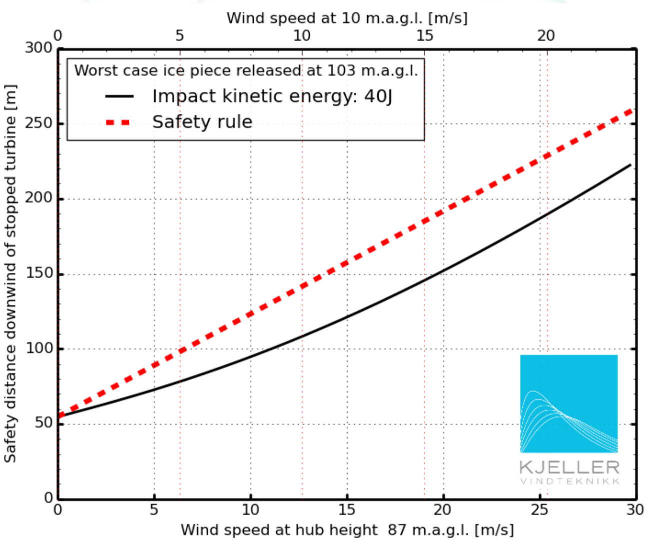
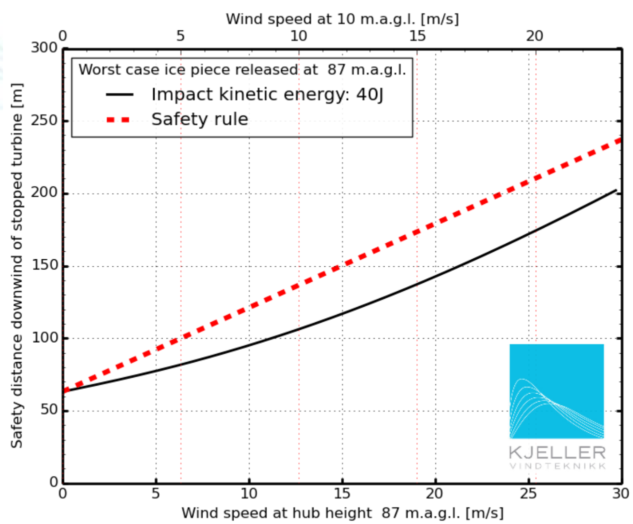
What if the turbine is not yawing against the wind or the blade is not pointing upwards?

0,30 ,60 90 degree roll of blade downwind -> 0, 31, 54,126/2 m horizontal offsets of release position. Crossing point at roughly 150 m (15 m/s hub wind)









87 m hub (11-15 m/s)

Release at nacelle:
Less than 100 m (150 m) drift for safety rule

Less than 50 m (120 m) from 40 J limit.

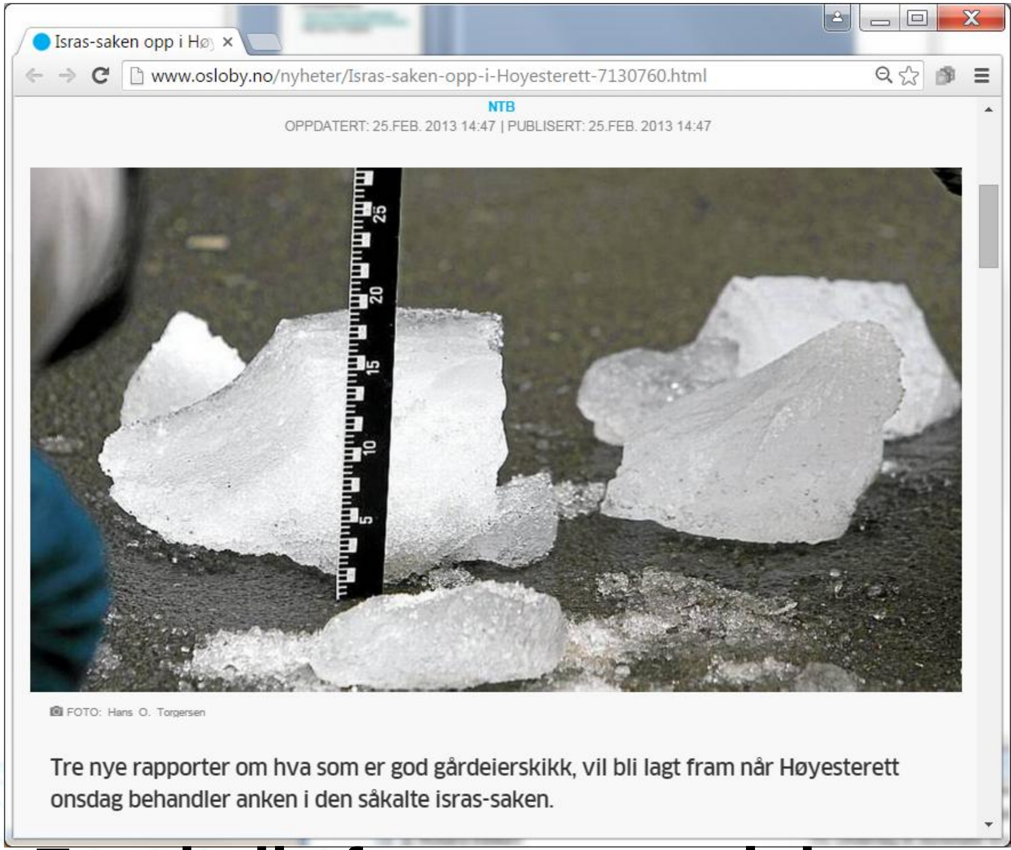
Norwegian supreme court case regarding rooftop avalanche in Oslo (15 cm block of ice)

A third person was severely injured

Land lords are now fined 5000,- NOK in Oslo when roofs tops are not sufficiently sequred against avalanches.

Settlement: 1.5 million Euros in compensation, restitution, and vindication.

The land owner, but not the manager, was **aquitted** by supreme court **after showing best practices** on the charge of grieveous bodily harm.



Facsimile from www.osloby.no showing debris from 15 cm thick icesheet from a rooftop avalanche.

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http://www.osloby.no/nyheter/Robin-fikk-isblokk-i-hodet_-gardeieren-frikjent-7145533.html

Fatal roof avalanche Stockholm

- An iceblock of dimensions 60 x 50 x 25 centimeter falls from 5 floor building on Monday 7 Jan 2002.
- https://www.svd.se/isblock-dodade-14-aring
- http://www.dn.se/sthlm/istappsdom-har-gjort-stockholm-farligare/

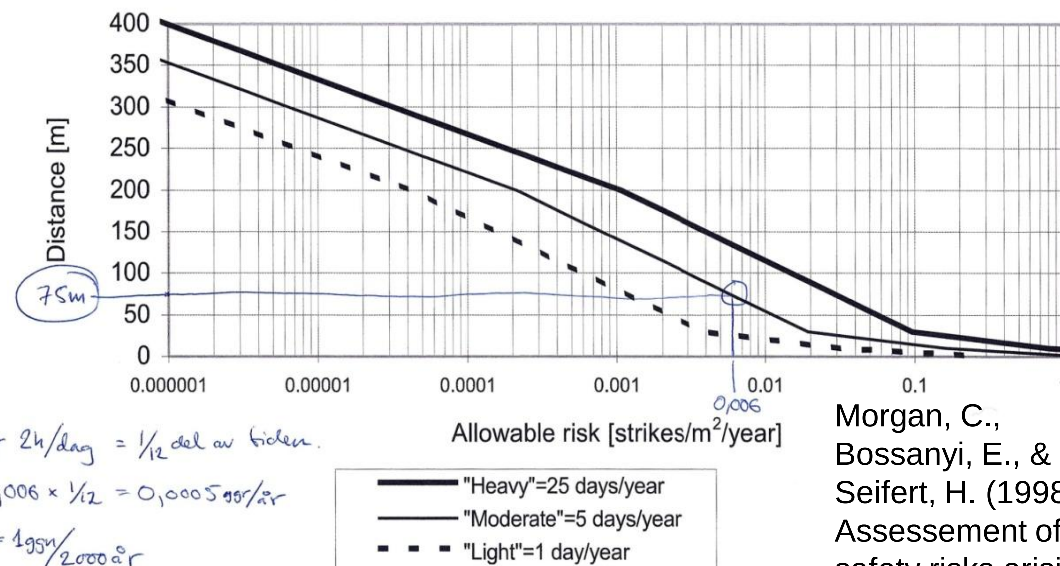
Scaling of strike probabilities given days with meteorological icing

- Figure 3 is based on a rate of ice accretion averaging 75 kg/day during icing conditions, a figure which has been estimated for a 3-bladed turbine of 50m diameter. The allowable risk should be scaled pro rata under different assumptions.

Grafen baseras på verk med D=50m, h=40m
Antagande: Verk med D=100m kastar 2×(D=50m)
Vi studerar kast från ett verk med D=100m, h=100m ⇒ Max kast = 300m ⇒ Medelkast = 150m

$\bar{x}_{D100m} = 150m \Rightarrow \bar{x}_{D50m} = 75m$

- **Doesn't differentiate on hazard and nuiscance**
- **What is the proper pro rata scaling for modern large turbines?**



Antar 2h/dag = 1/12 del av tiden.
∴ 0,006 × 1/12 = 0,0005 ggr/år
= 1ggn/2000år

Figure 3 Safety distance for different icing levels (50m rotor)
(Morgan, C. et al. 1998)

Morgan, C., Bossanyi, E., & Seifert, H. (1998). Assessement of safety risks arising from wind turbine icing. *Boreas IV* (ss. 113-121). Hetta: VTT. (WECO)

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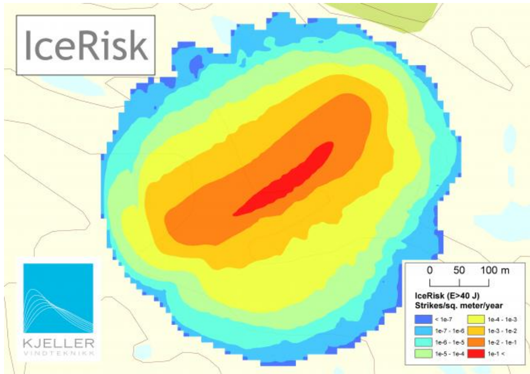
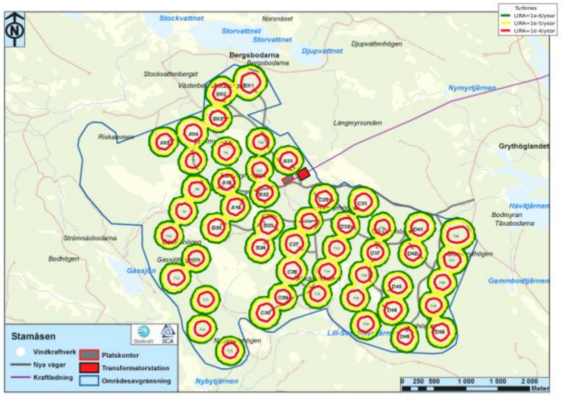
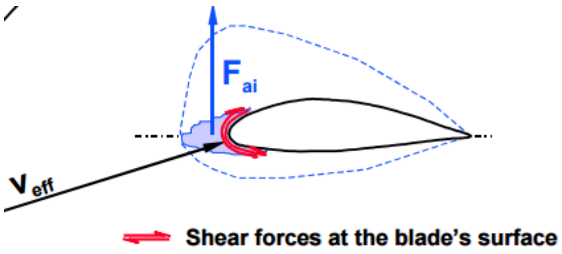




Current knowledge

In-cloud icing of

wind turbine blades



Measurements of icing
Calculation of icing
Extent of icing
Forecasts
Hazard zones
Ice throw
Damage potential
Criteria for Risk acceptance
Communication
Suitable measures
International guidelines

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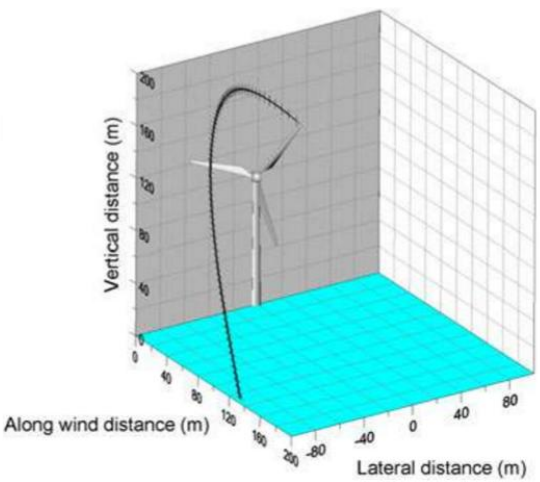
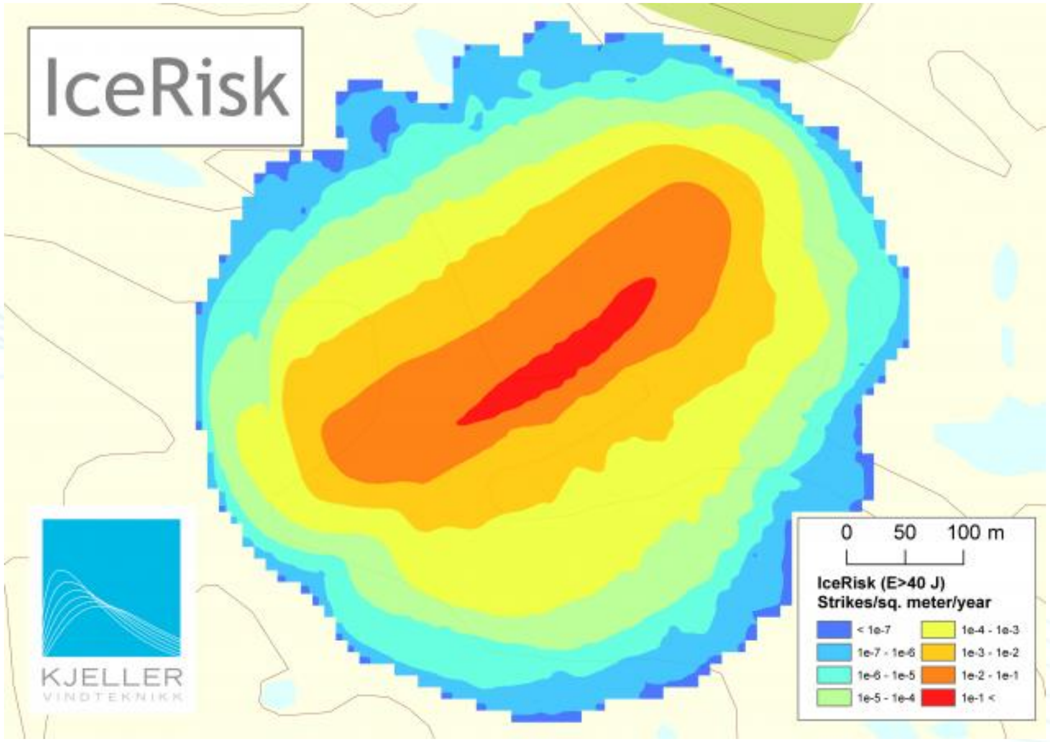


IEA Wind Task 19. Open workshop for the exchange of experience and practices regarding ice throw and ice fall for the upcoming guidelines. Winterwind, February 15, 2017,

IceRisk – methodology:

spatial distributions and safety distances

- Meteorological modelling of the ice and wind condition at the site
- Aggregation of ice in the construction
- Statistics on wind/turbine conditions when ice is released from blade
- Classification of ice throw/fall size distribution
- Calculation of trajectories and impact kinetic energy for each ice piece
- Validation and verification
- Risk assessment



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Key questions for ongoing and future work:

- What is the largest ice accretion expected in the wind farm and what is the maximum throw distance associated with this ice accretion?
- At which ice load is the turbine influenced in the form of a penalty on the performance and rotational speed. What is the reduced rate of further ice accretions on the blade?
- What is the long-term size and density distribution of ice accretion on a blade for a site specific turbine?
- How much energy is absorbed on impact for snow/ice debris of varying density?
- How effective are detection, deicing and anti-icing systems with respect to the prevention of buildup of dangerous ice amounts?
- How effective are de-icing systems with respect to not attempting start-ups when dangerous ice amounts are still present after a failed deicing cycle?

IceRisk work, increased understanding of physics

- Realistic ice accretion shapes, densities
- Adhesive and cohesive ice strength
- Shedding
- Ice crush mechanics
- Validation of ice throw probabilities
- Risk communication

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Zones: Ice shed and throw distances

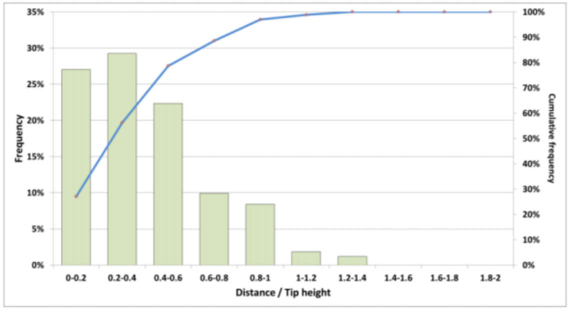


Fig. 8: Frequency distribution of the ice particles collected (Gütsch, St. Brais, Mont Crosin) depending on the distance, normalised with the tip height of each turbine.

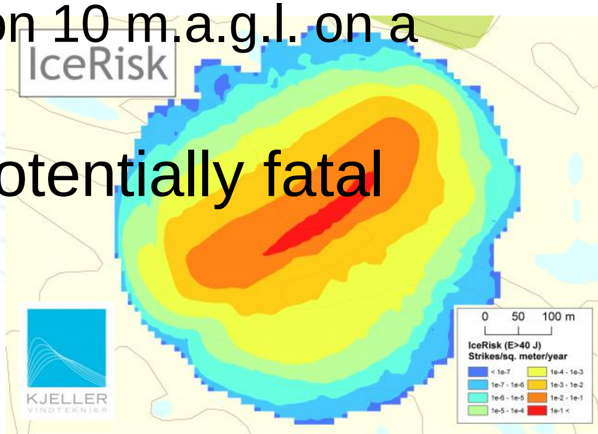
- Seifert danger zone: (hubheight+rotordiameter)*1.5
- Icethrow/fall within totalheight

  + 40 % (Cattin, 2016)

  3 % above total height

  IceThrower: totalheight (150m)
- ISO 12494 – Ice shed from constructions:

  2/3 H, H, og 3/2H, where H is the total height depending on 50 year return period maxium ice accretion 10 m.a.g.l. on a reference object.
- IceRisk – probability of impact for a potentially fatal ice throw.



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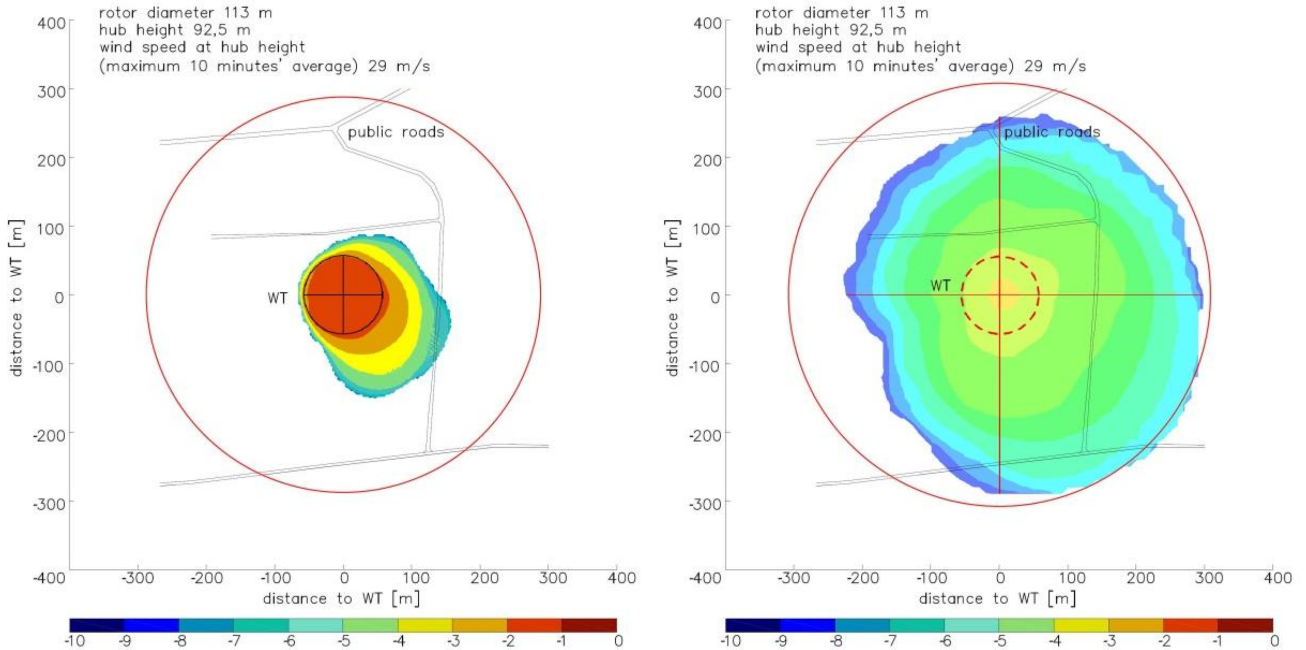
Safety distances – Danger zone

- **Ice Shed (left):** what is the drift distance of the smallest still dangerous ice piece that can drift the furthest with the wind.
- **Ice Throw (right)** what is the largest expected ice accretion seen in connection with the turbines performance.

Figure: On the left hand side, the results are presented for 'Ice Fall', on the right hand side for 'Ice Throw' for the same amount of ice fragments. (Source: Andreas Krenn. IEA Task 19, Available Technologies ,2016)



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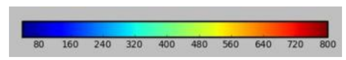
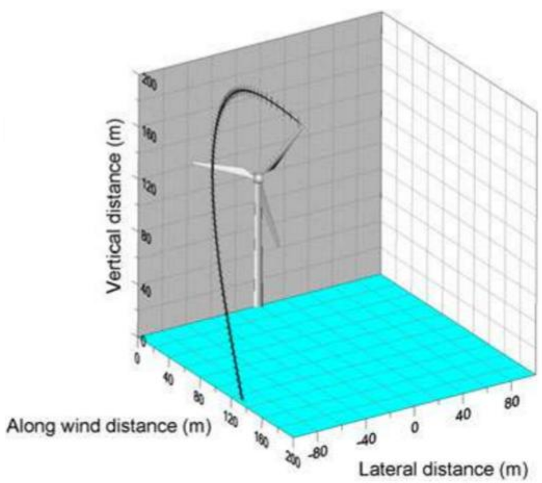
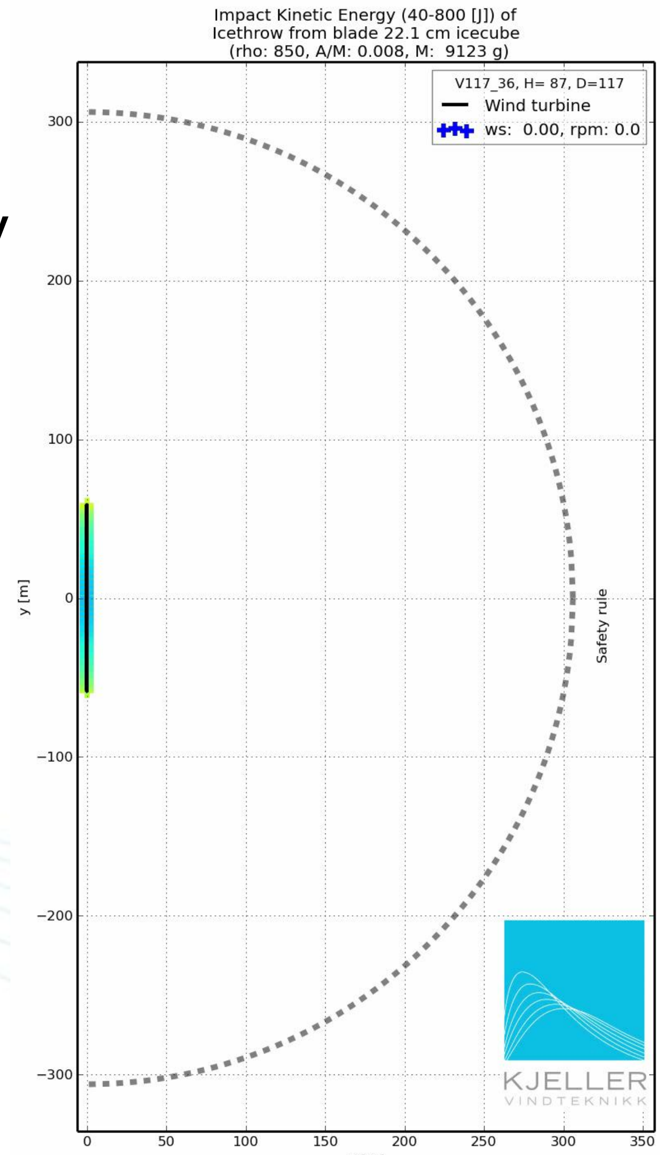
Ice throw distance for 9 kg ice piece

- Vestas V117 3.6 MW
- Colored by impact kinetic energy (40-800J)







February 15, 2017

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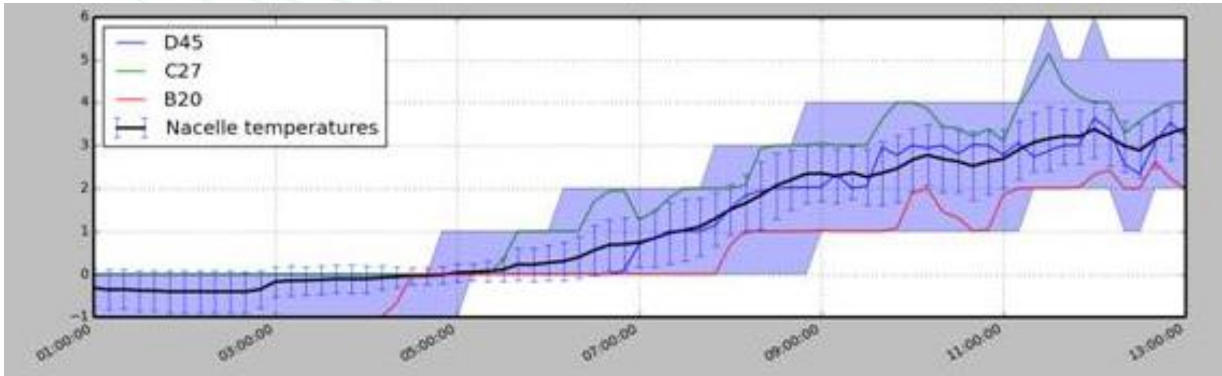
Collection of larger pieces is difficult

- Large ice pieces are very likely to crush due to the high energy on impact.
- The furhest throws are expected to be unlikely and therefore hard to document
- Stamåsen 2016.04.07 Turbines operating again after an icing episode: safe working conditions for ice piece collection



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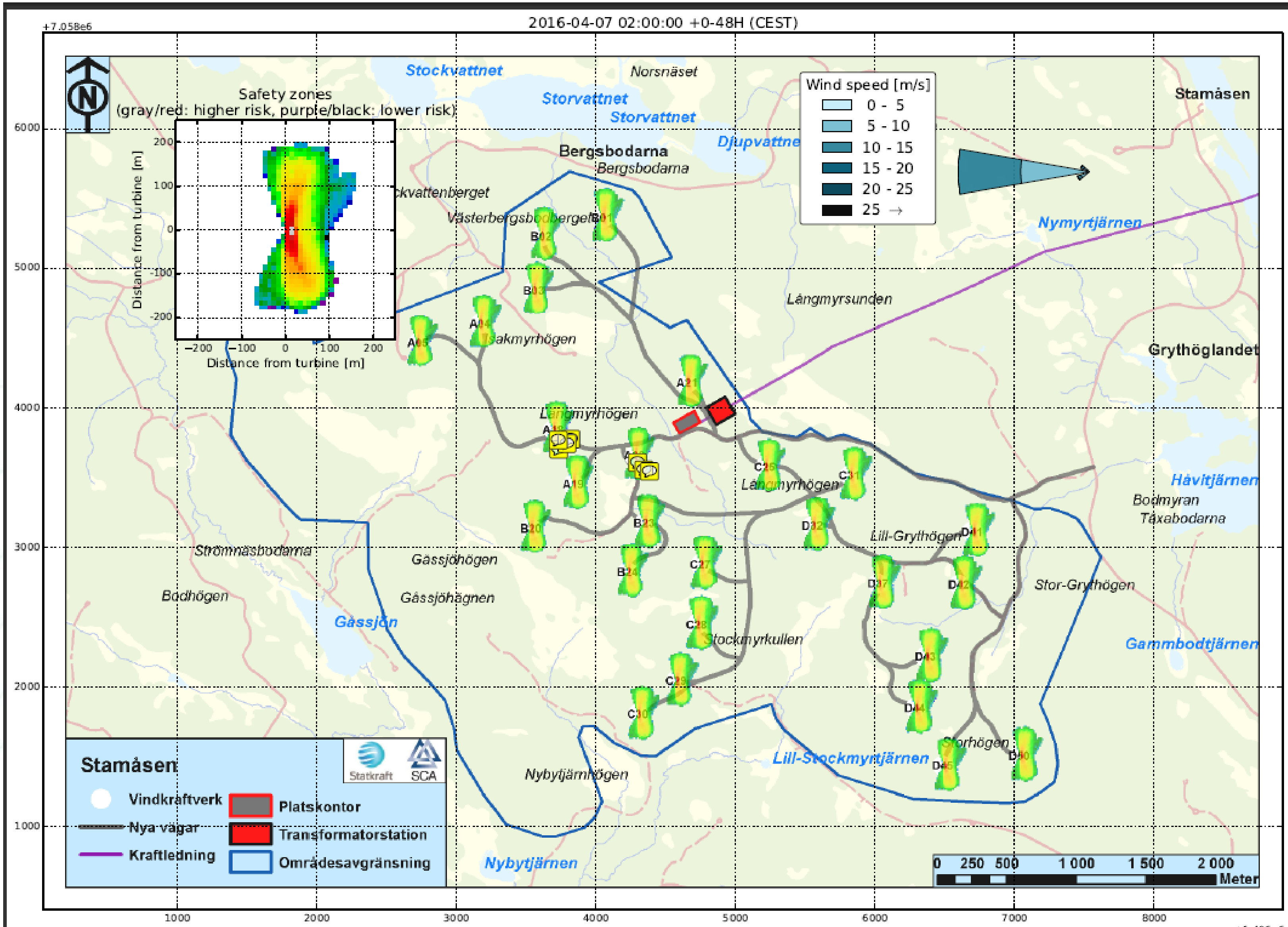
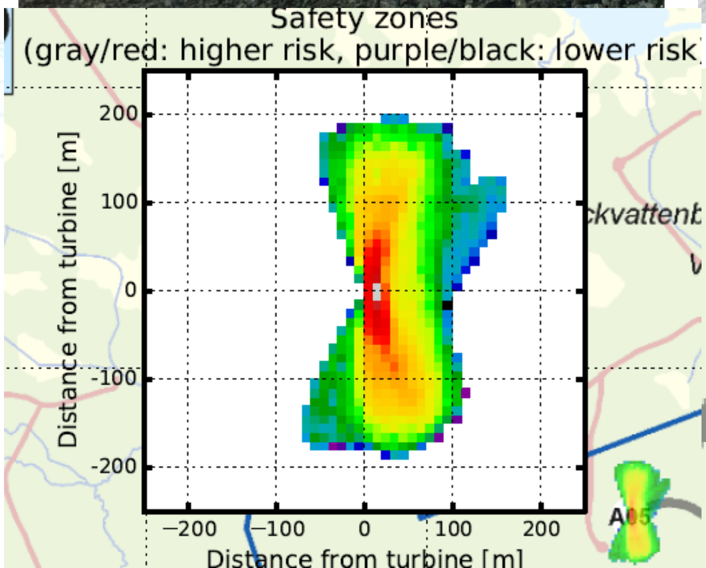
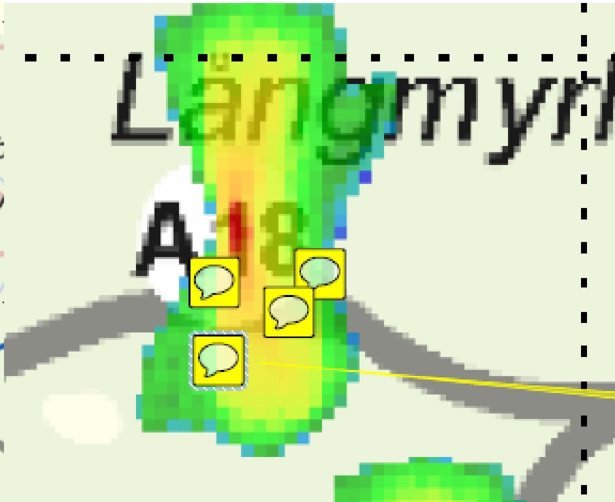
Inspection of hazard zones performed 8/4-2016 10:00

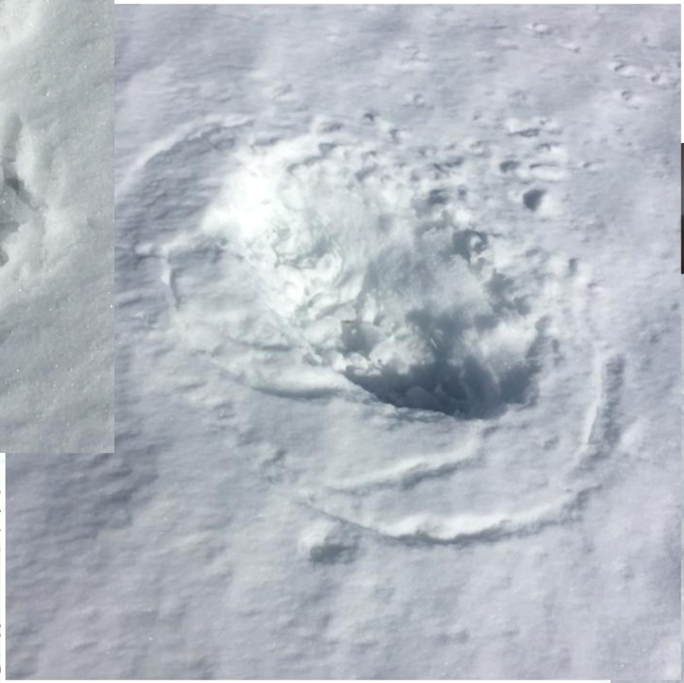


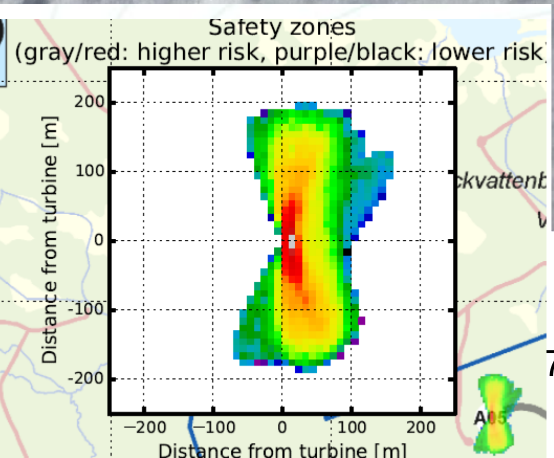
Largest observed crater 70x30 cm at 70 m distance from turbine





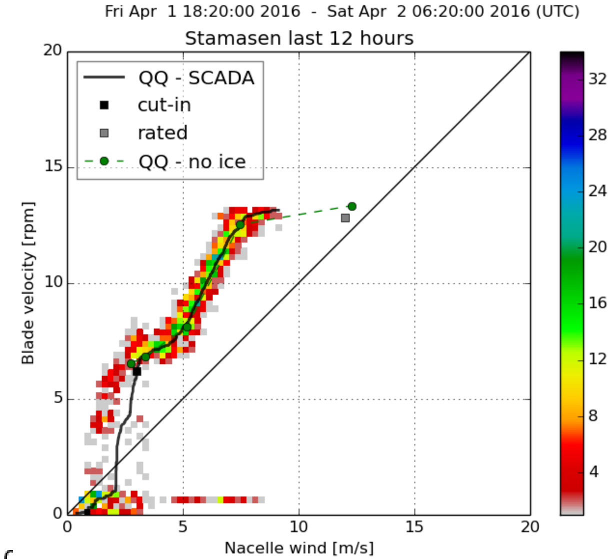
Only crushed ice

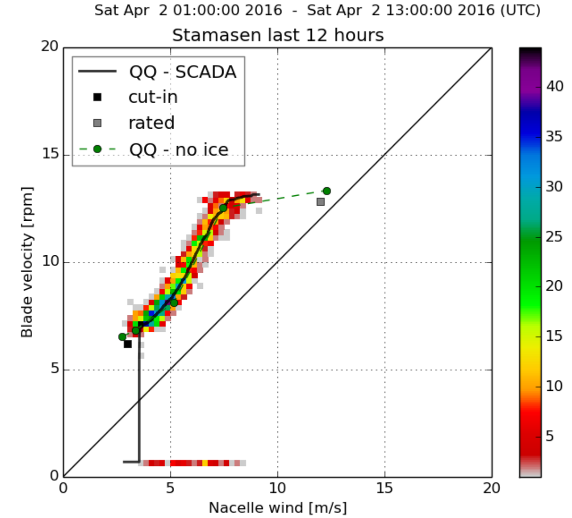


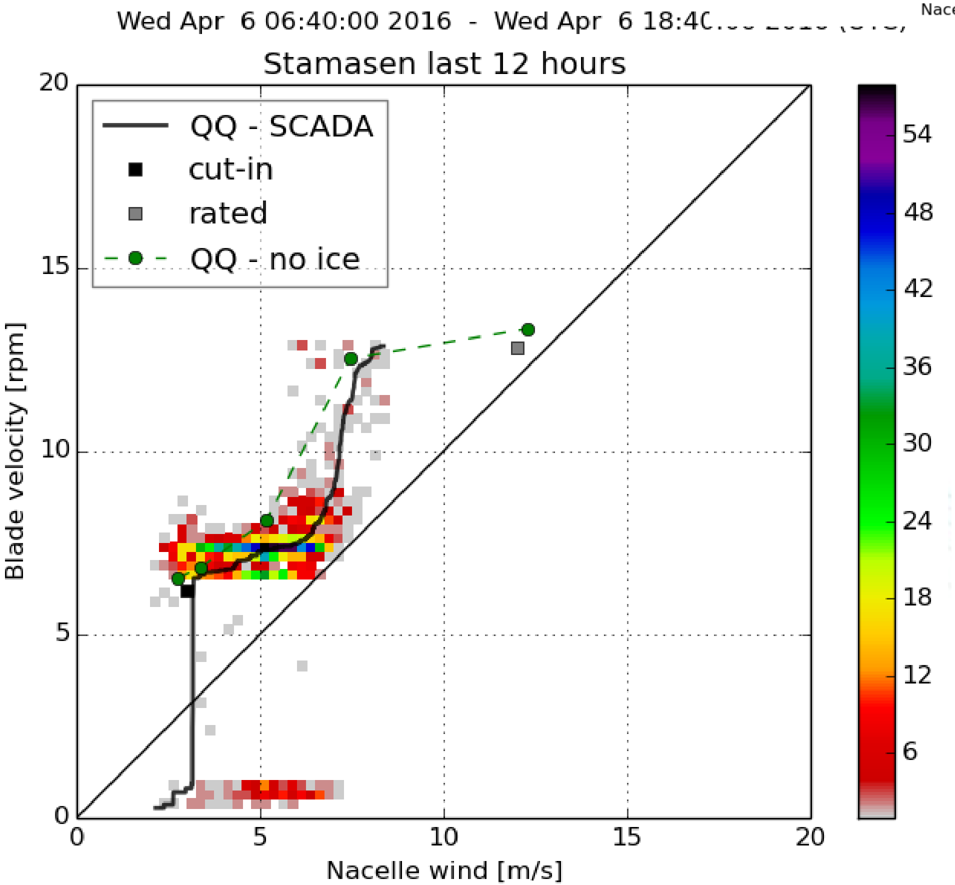


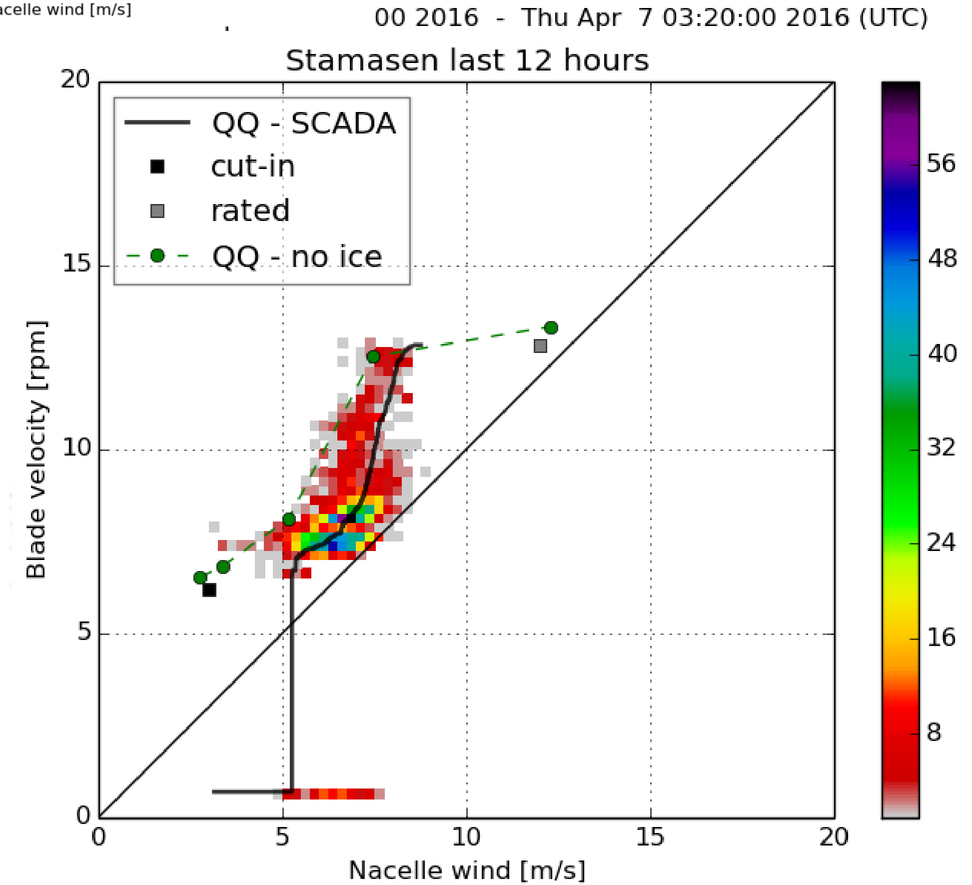
7

Some reduction in rotational velocity [rpm] during the episode









Ice collection Oslo, mast: 500-700 m.a.s.l.

Icing from one night on guy (Oslo)

- 8 cm mask width

Swiss Icethrow database: 1000 icepieces collected, suggesting that the probability of finding ice debris beyond 1.4 x tip height is fairly low.

- Met icing: max wind speed 12 m/s at hub

Site	Winters	Inst icing	Met icing	Turbine	1.4 * tipheight
Gütch	2009-2010	7.7 %	1.5 %	Enercon E-40, hub height 50 m	98 m
St Brais	2009-2015	11.8 %	3.1 %	Enercon E-82, hub height 78 m	167 m
Mont Crosin	2014-2015	15.9 %	1.4 %	Vestas V90, hub height 95 m	195 m

Icethrow/fall distances bounded by 1.4 * tipheight

Cattin, R. 2016. Icing at St. Brais and Mont Crosin, Consequences of icing for the operation and power production of wind turbines in the Jura Mountains - Executive Summary. Meteotest. 2016.04.06

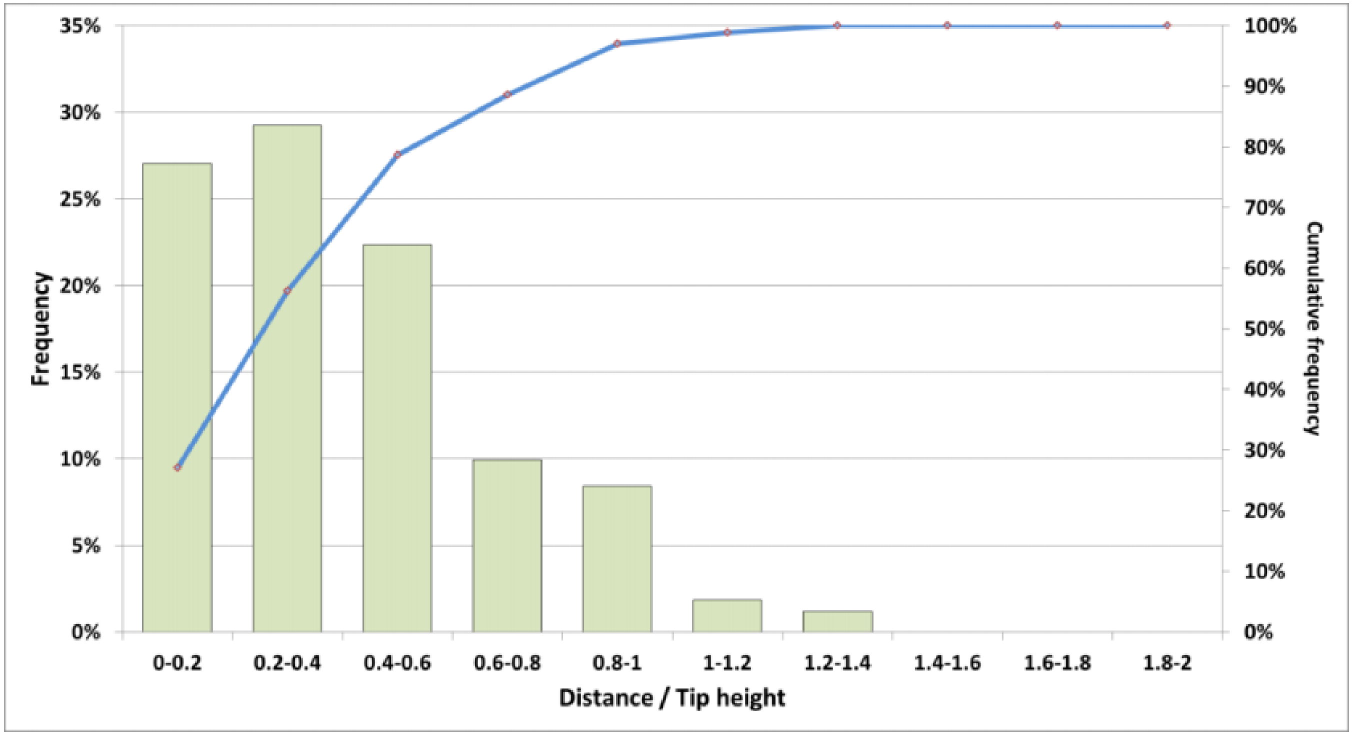
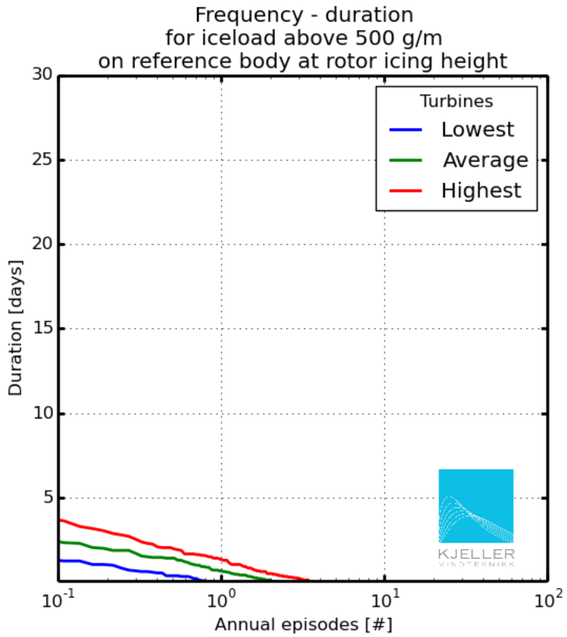
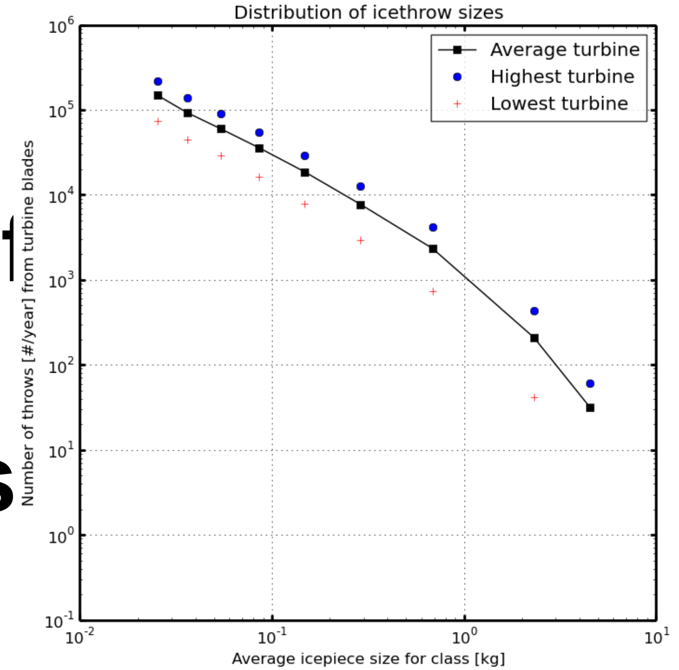
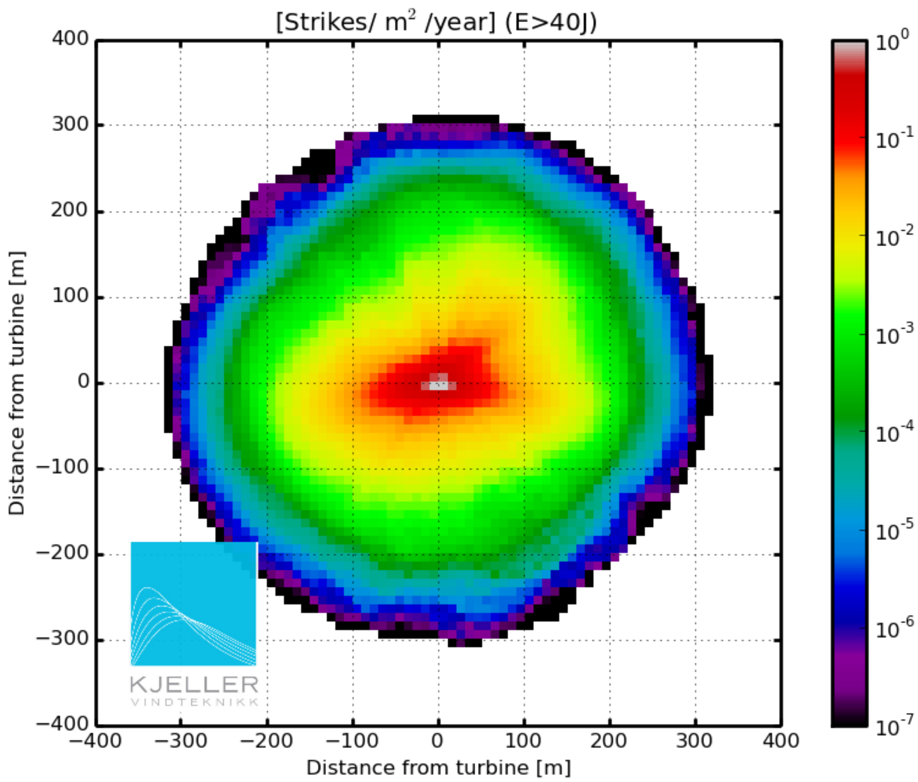


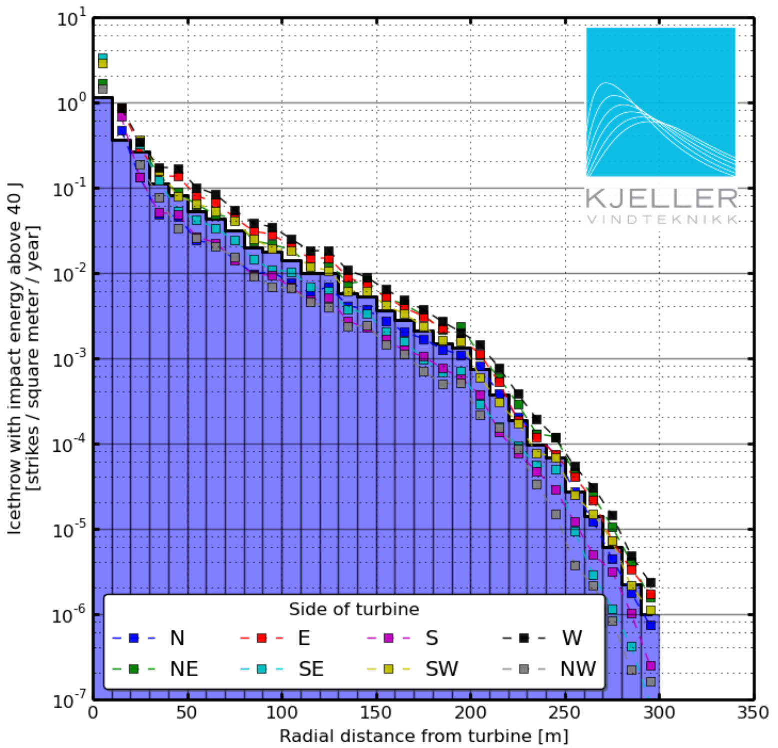
Fig. 8: Frequency distribution of the ice particles collected (Gütsch, St. Brais, Mont Crosin) depending on the distance, normalised with the tip height of each turbine.

Sensitivity of size distributions



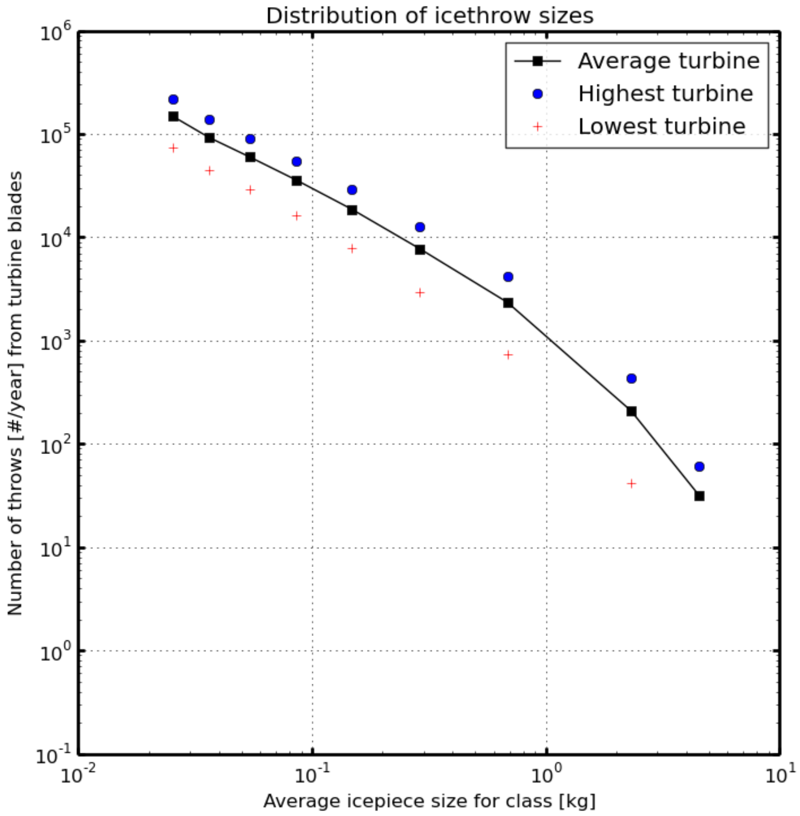


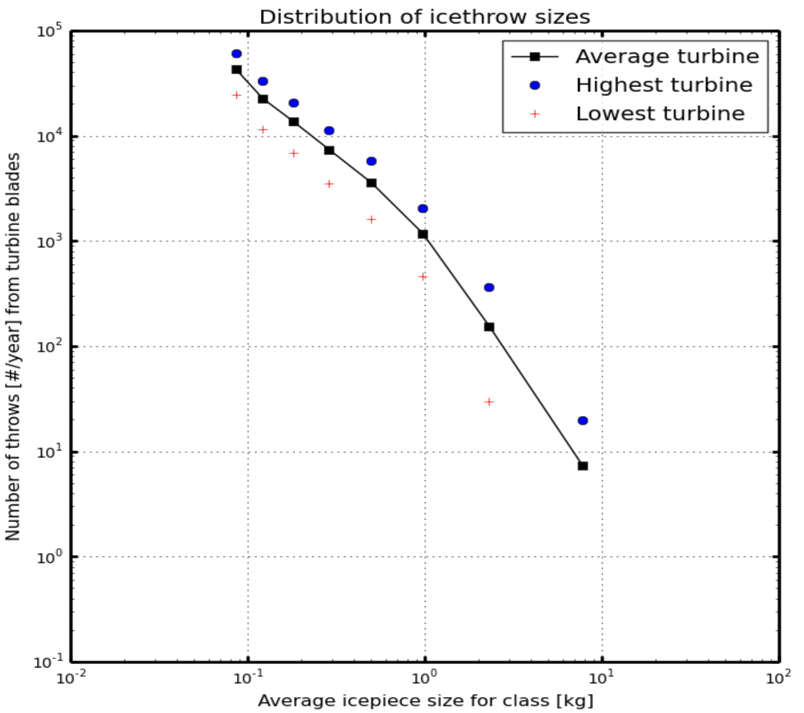




Sensitivity test on size distribution

- With a given amount of ice, what happens with fewer but larger ice pieces
- Calculated sizes for fixed Cd*A/M cactor with and without the assumption of freely rotating ice cubes (corresponds to 50 % increase in formfactor)





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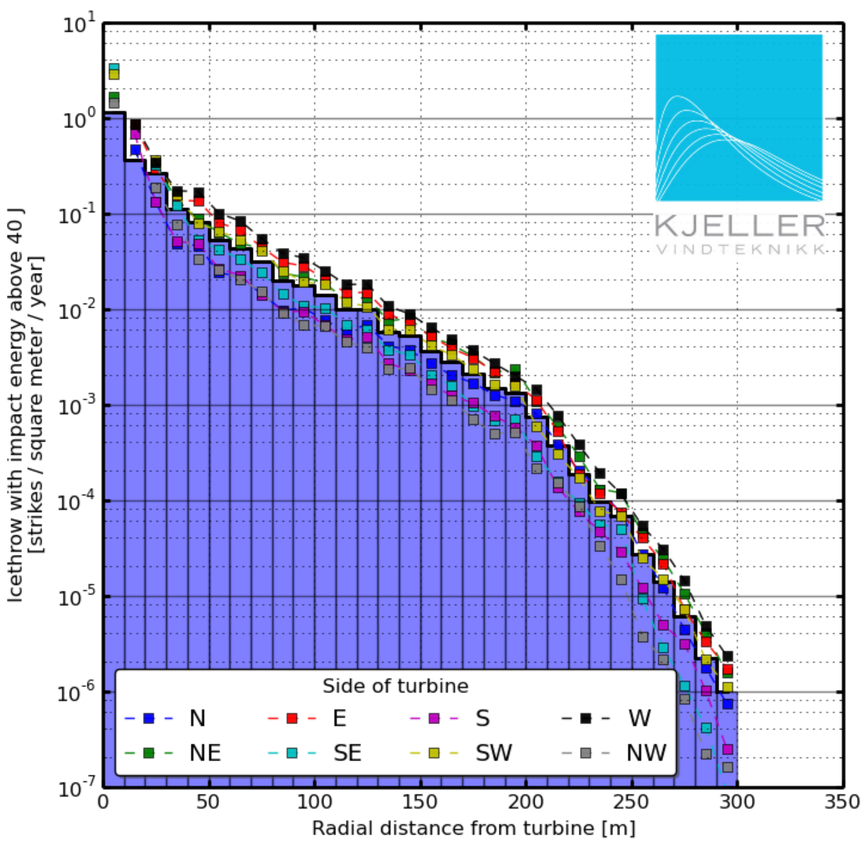
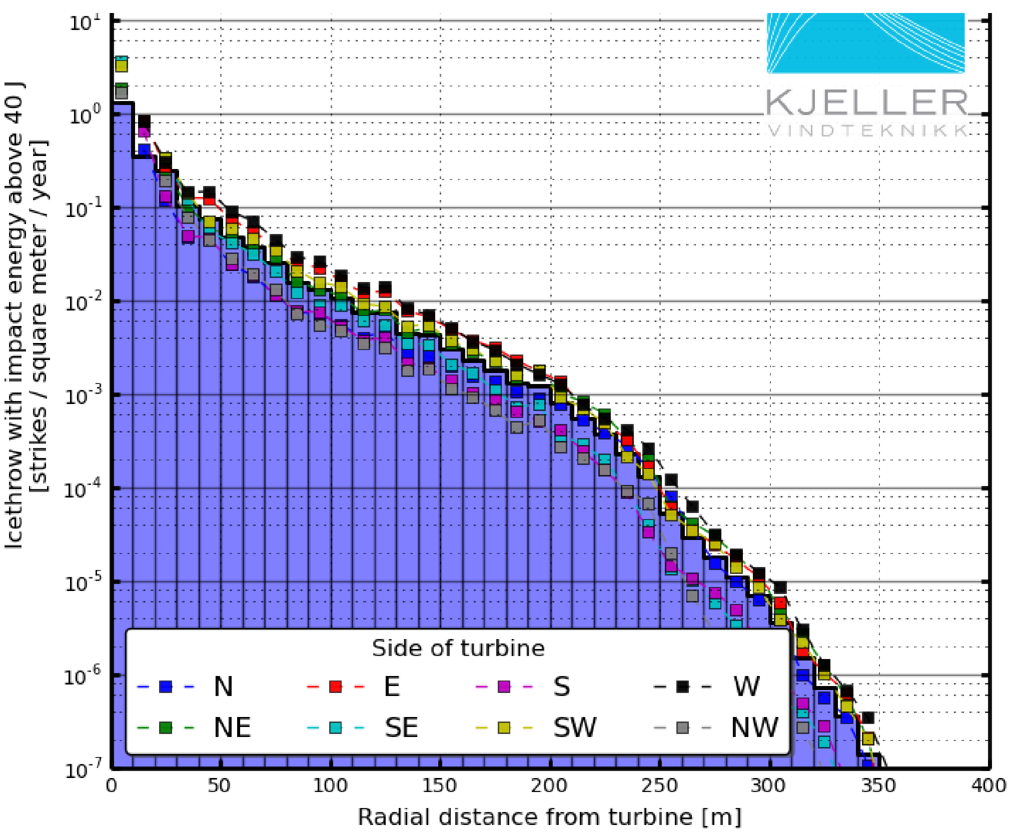
Sensitivity test on size distribution yields similiar strike probabilities out to 200 m

- With more large ice pieces in the distribution the risk reduces slower with distance and the ”danger zone” is 50 m longer.
- Outside 200 m the risk is reduced by a power of ten every 33 m or 37.5 for the two scenarios.





Other databases

- Storrodliden (Vattenfall)
- TechnoCentre Éolien (Matthew) Forrest 100 m away
- IceThrower project (Poyri) 150 m ?
- Statkraft, 2 examples:
  - Craters, spring 2016
  - 9 kg ice piece, October 2014
- Kjøllefjord, 1 kg icepiece 25 m away from turbine ++
- Tryvann 209 m telecommast, ice shed