# ICETHROWER

## Mapping and tool for risk analysis

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# WHAT IS THE PROBLEM AND IS THERE A SOLUTION?

1. Wind turbines drop ice pieces occasionally

2a. The emotional conclusion is
"often" and "long distance" (km!)
2b. The pragmatic approach is
"now and then" and "within 1D"

- Level of confidence is often poorly known but can be increased by more observations
- Empirical formula:

distance = 1.5 x (hub height + rotor diameter)


Photo: B. Göransson

# THE ICETHROWER PROJECT

Joint research project within Energimyndigheten's research program "Wind power in cold climate"

The project is divided into three parts:

- Field study to collect ice data from 3 wind farms in Sweden and create a database for common use
- Verify and integrate the existing tool KASTIS into a common tool box
- Develop a usable simulation tool for risk evaluation based on collected data

# THE ICETHROWER PROJECT

**Pöyry Sweden**
Project leader
Data analysis / development of statistical ice throw model

**ProgramoGrafik**
Validation KASTIS model

**Dala Vind**
Field study
1 turbine in mid-Sweden
forest
without blade heating

**Skellefteå Kraft**
Field study
2 turbines in northern Sweden
mountain terrain
with blade heating

**Vattenfall Vindkraft**
Field study
1 turbine in northern Sweden
forest
without blade heating

# THE FIELD STUDY - METHOD

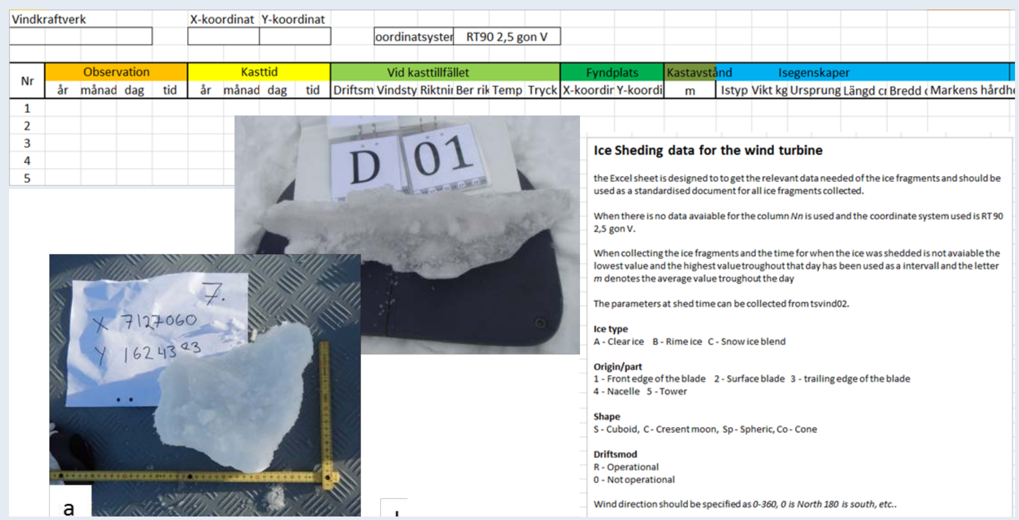
Systematic approach in the search for ice lumps

- Ice lump measurement and classification
- Location of ground impact and throwing distance
- Photographs

**Challenges in field work:**

- Severe winters -> increased risk
- Mild winters -> less data

Data collection during
winter 2013 - 2016



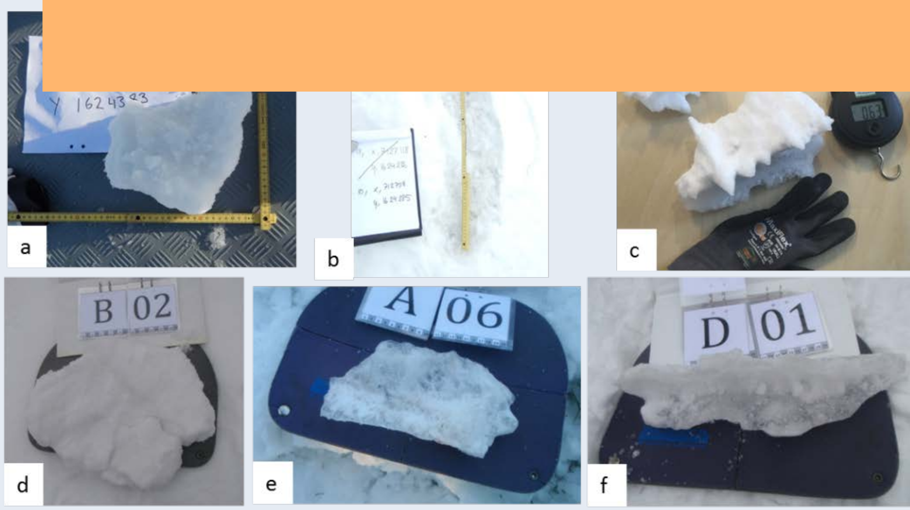
# THE FIELD STUDY - METHOD

**Three wind farms in Sweden**

Collect information:

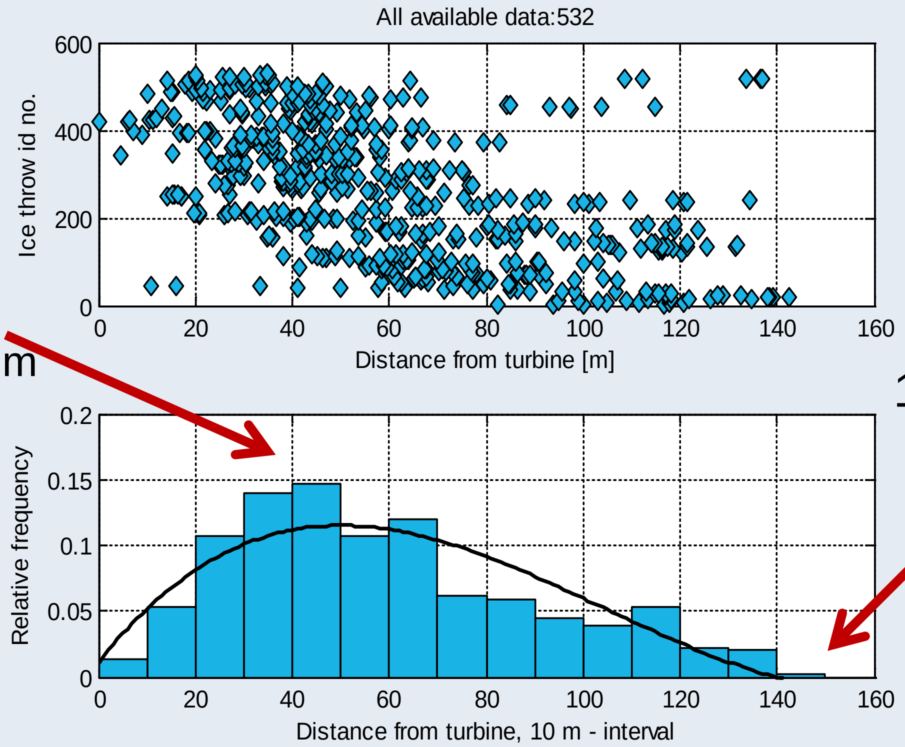
- Physical properties of ice lumps
- Throwing distance

**Over all data from 530 ice lumps was collected!**




# THE FIELD STUDY – RESULTS (ALL DATA)

75% of ice lumps between 20 – 90 m



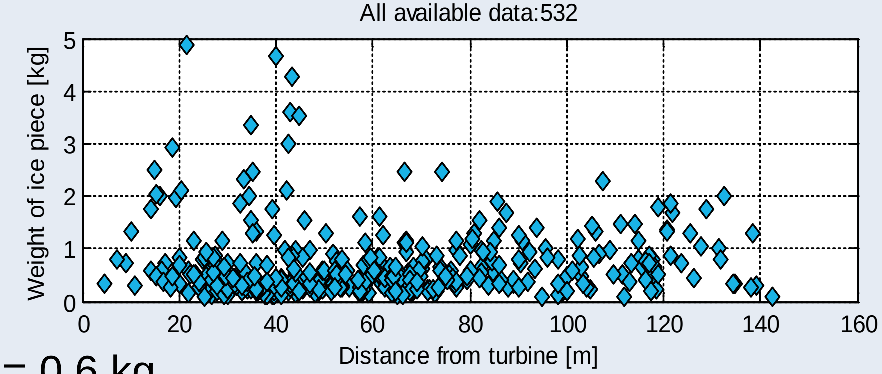

140 m = 1.55 RD

Empirical formula : distance = 1.5 x (hub height + rotor diameter)

distance = 277 m

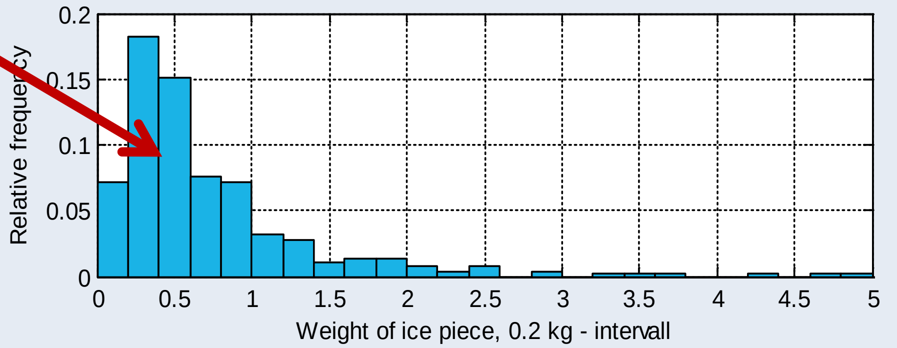
Turbines in the field study had 90 m rotor and 95 m tower (no de-icing system)

# THE FIELD STUDY – RESULTS (ALL DATA)




No trend between distance and ice mass

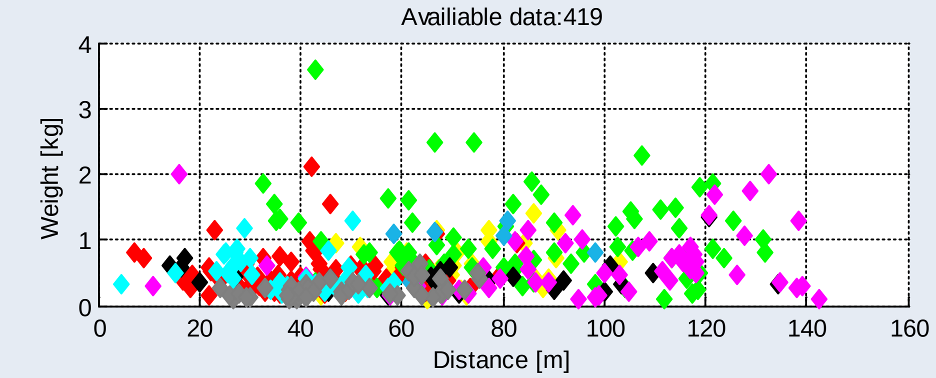
Average ice mass = 0.6 kg




Turbines in the field study had 90 m rotor and 95 m tower (no de-icing system)

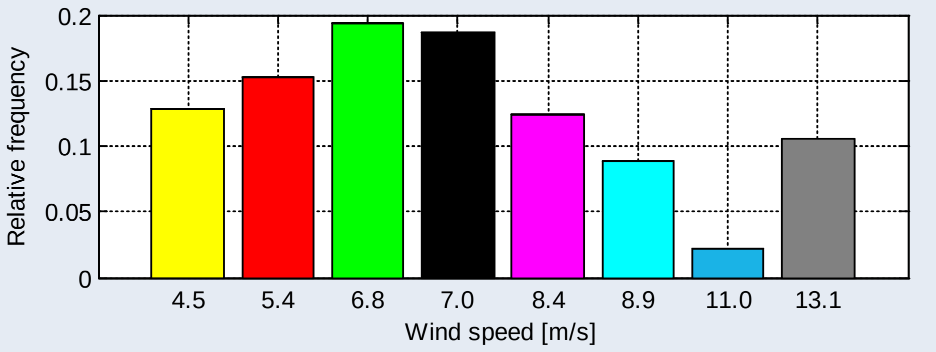
# THE FIELD STUDY – RESULTS (CASE STUDY)

No trend between
- distance and wind speed
- distance and ice mass




2013: 2 ice days
2014: 2 ice days
2015: 1 ice day
2016: 3 ice days

10 – 80 ice lumps / ice event

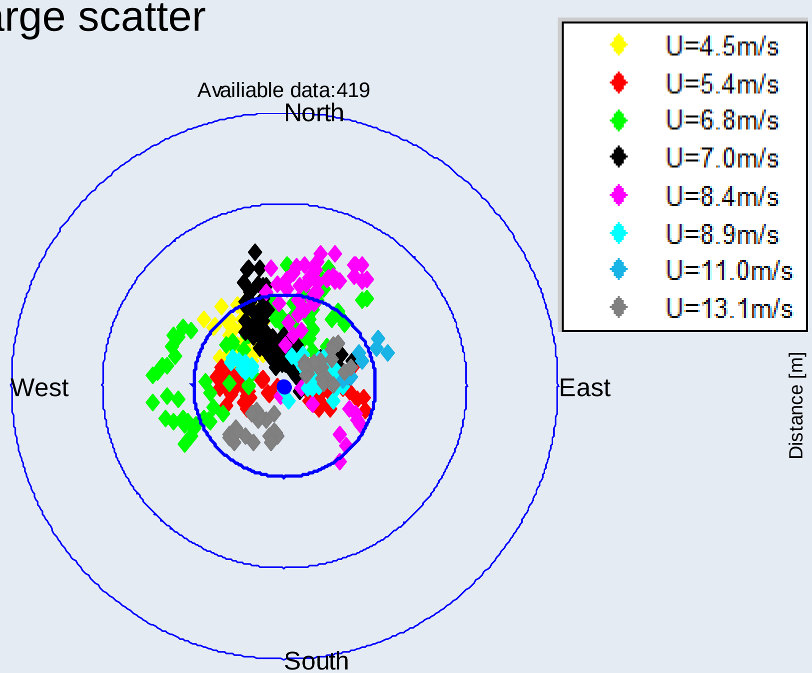


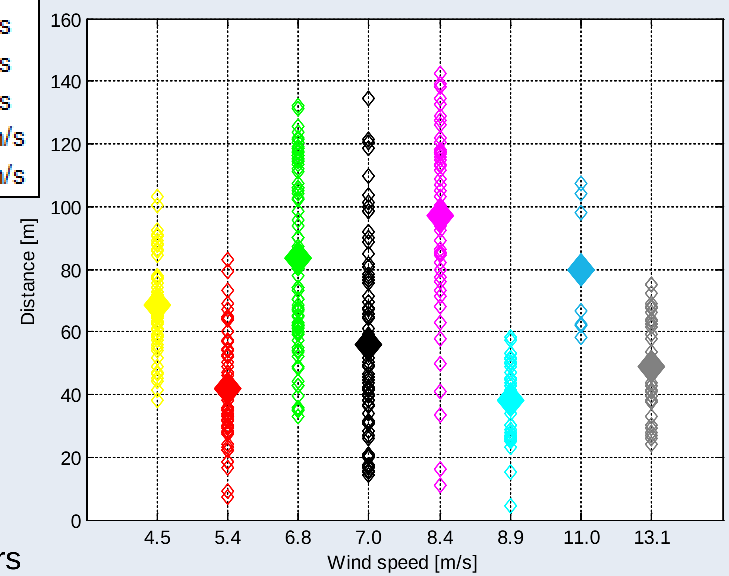

Turbine in the case study had 90 m rotor and 95 m tower (no de-icing system)

# THE FIELD STUDY - RESULTS (CASE STUDY)

Ice lumps fall in the wind ward direction.
All ice lumps were found within 2 RD
Large scatter

Wind speed between 4.5 – 13 m/s
at the time of ice release




The blue circles show one, two respective three rotor diameters (e.g. 90, 180 and 270 m)

Turbine in the case study had 90 m rotor and 95 m tower (no de-icing system)

# THE KASTIS MODEL – SELECTED OUTCOME

Purpose: calibrate and tune the previously developed model KASTIS.

- A developed version of KASTIS was derived in the project, called iceThrow
- The program calculates trajectories for ice lumps released from wind turbine blades during operation using very detailed information of the ice lump

Result:

- The iceThrow model showed that most of the ice lumps in the range 0.1 – 0.4 kg hit the ground with a speed, converted to energy, in the potential lethal region i.e. in excess of 40 J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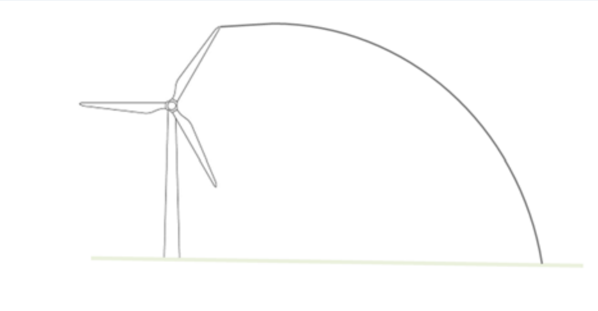
# THE ICE THROW MODEL - METHOD

A statistical ice throw model was developed using the equations of motion in combination with Monte Carlo simulations.



$$M\frac{d^2x}{dt^2} = -\frac{1}{2}\rho C_D A\left(\frac{dx}{dt} - U\right)|V|\ Eq.3$$

$$M\frac{d^2y}{dt^2} = -\frac{1}{2}\rho C_D A\left(\frac{dy}{dt}\right)|V|\ Eq.4$$

$$M\frac{d^2z}{dt^2} = -Mg - \frac{1}{2}\rho C_D A\left(\frac{dz}{dt}\right)|V|\ Eq.5$$

The relative wind speed is given by,

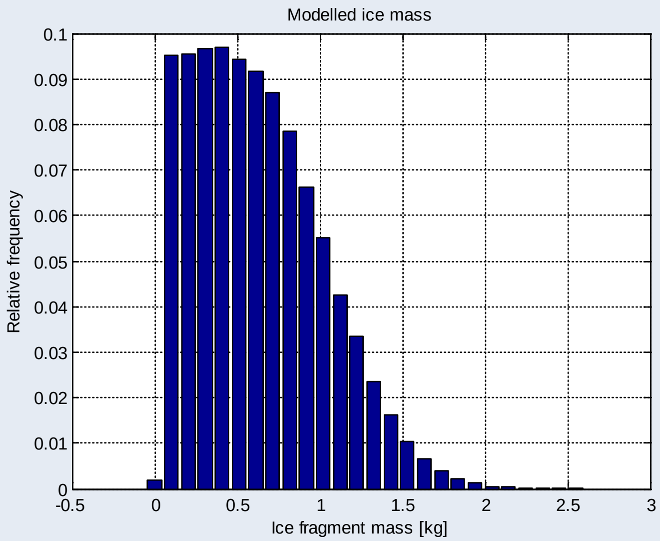
$$|V| = \sqrt{\left[\left(\frac{dx}{dt} - U\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2\right]}\ Eq.\ 6$$

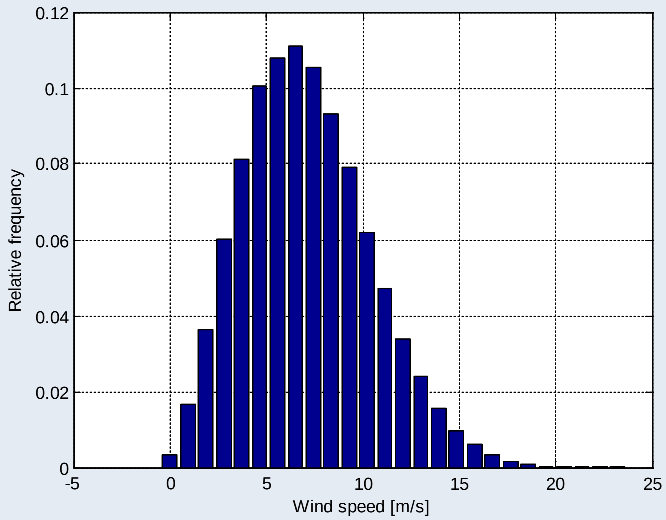
Where *M* is the mass of the ice fragment, $C_D$ is the drag coefficient, ρ is air density, *U(z)* is the wind speed with x-axis parallel to the wind and *g* is the gravity.

# THE ICE THROW MODEL - ASSUMPTIONS

Assumptions used in the ice throw simulations

- Random normal distribution of mass
- Random Weibull distribution based on wind speed and direction
- Turbine specifics (rotor radius, hub height, rotor revolution)

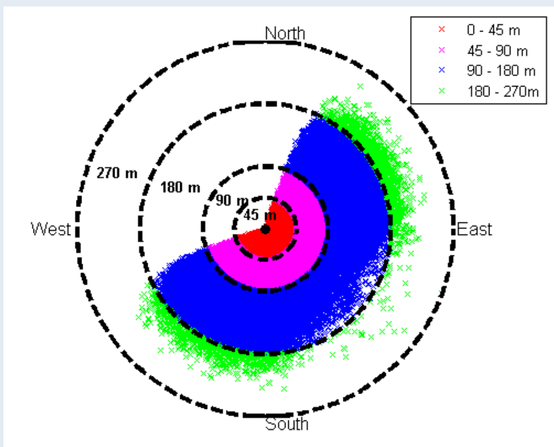


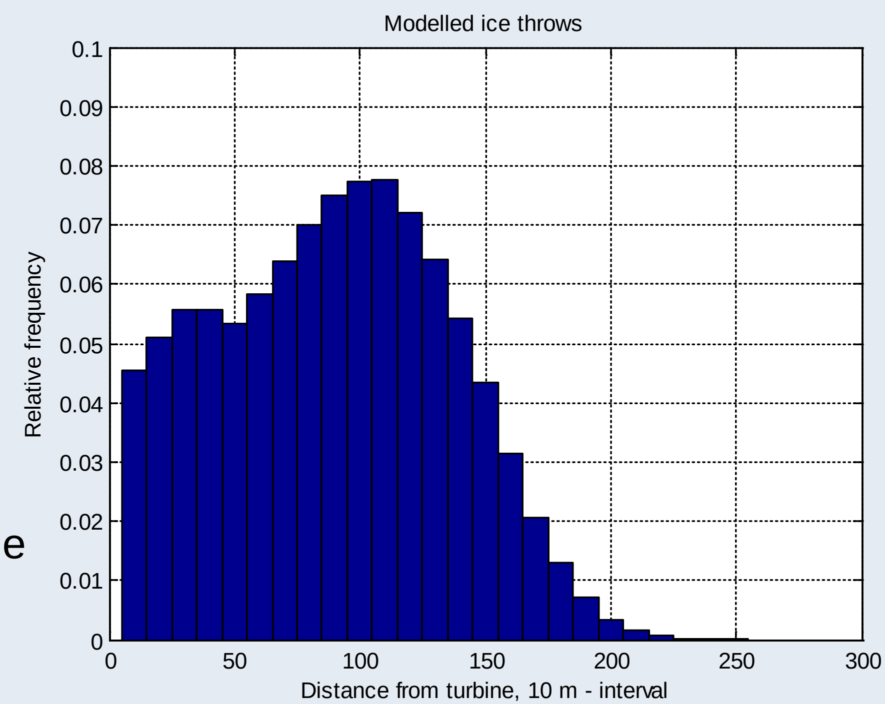

Turbine used in the simulation had 90 m rotor and 95 m tower

# THE ICE THROW MODEL - RESULTS

Example:
Turbine with 90 m rotor diameter and 95 m hub height
Only using wind from the prevailing wind direction (WNW & NNW)

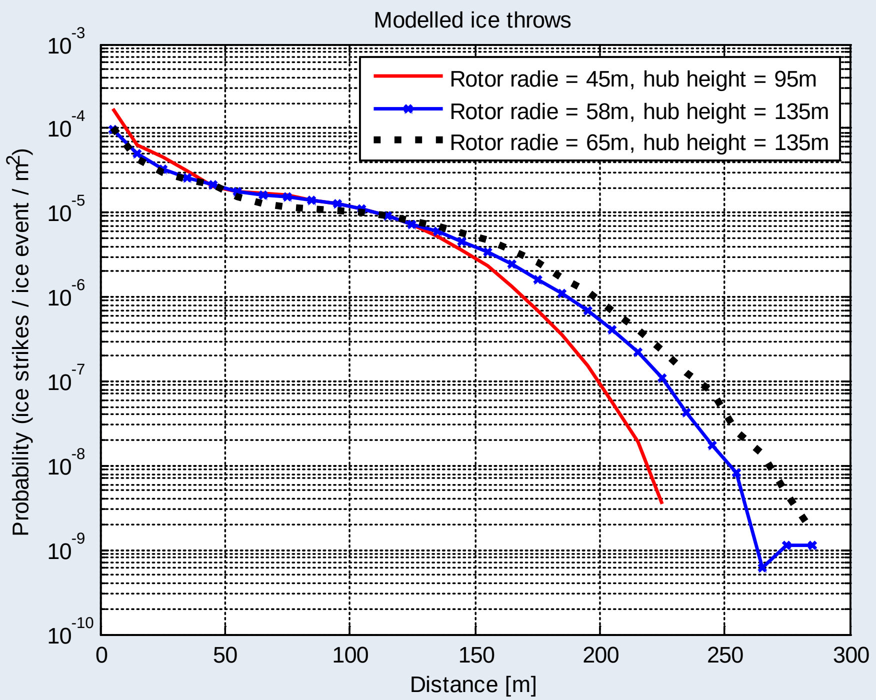



Ice lumps land on the wind ward side




The furthest modelled throwing distance: 250 m

# THE ICE THROW MODEL - RESULTS




Larger wind turbine -> longer throwing distance
However the probability rapidly decreases with distance

Based on 100 000 simulated ice throws, all wind directions included

# EXAMPLE OF RISK ESTIMATE

Two service personnel visit wind farm after indication of icing on the turbines.

- Park the car 10 m from entrance
- Get tools, walk to the turbine (5 min)
- Work for 1 hour inside the turbine
- Walk back to the car, load tools (5 min)

During a working day they visit 5 turbines.

The estimated total risk is then

- 0.009 for the car or 1 in 115 year
- $1.5 \cdot 10^{-4}$ for 2 service personnel on one working day or 1 in 6 900 years.

Photo: Vattenfall

Assumptions: car = 10m$^2$, one person = 0.5 m$^2$
70 ice lumps released per icing day and turbine.
Probability from the red curve on previous slide.

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# EXAMPLE OF RISK ESTIMATE CONT.

## High or low risk?

In the example the total risk (one working day)

- $1.5*10^{-4}$ for 2 service personnel

  or 1 in 6 900 years.
- In comparison the risk of car accident is $5*10^{-5}$

The estimated risk is considerable high and not acceptable without certain safety provisions.

For the public the risk is lower since they do not know if the turbine are affected by ice.

*(e.g. the number of  ice day / the winter season)*

It is important to have warnings signs at the wind farm entrance to alert the public of the potential hazard.

Photo: Vattenfall

# Thank you!

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Engineering balanced sustainability™

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