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Uncertainties and choices in ice risk assessments
How to get the results you want

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Introduction

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- Ice Risk assessments since 2010
- Large turbines as well as small turbines
- Focused on ice shed (ice throw has to be avoided in Austria)
- Ongoing monitoring of ice shed

The basic idea

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- IEA recommendations give a solid framework
- Still many open points
- Results of assessments depend on several expert decisions

Parts of an assessment as described in the IEA recommendations

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- Meteorological
  - Icing frequency
  - Icing intensity
  - Wind speed
- Ballistic Model
  - Ice fragment properties
  - Distances
  - Impact energy
- Additional measures
  - Warning signs
  - De-Icing
  - Information

Meteorological: Icing events, icing frequency

- Different icing models available
- Must be suitable (validated) for the site

- Problem of data availability – time frame is often limited

Icing frequency depending on the investigation period

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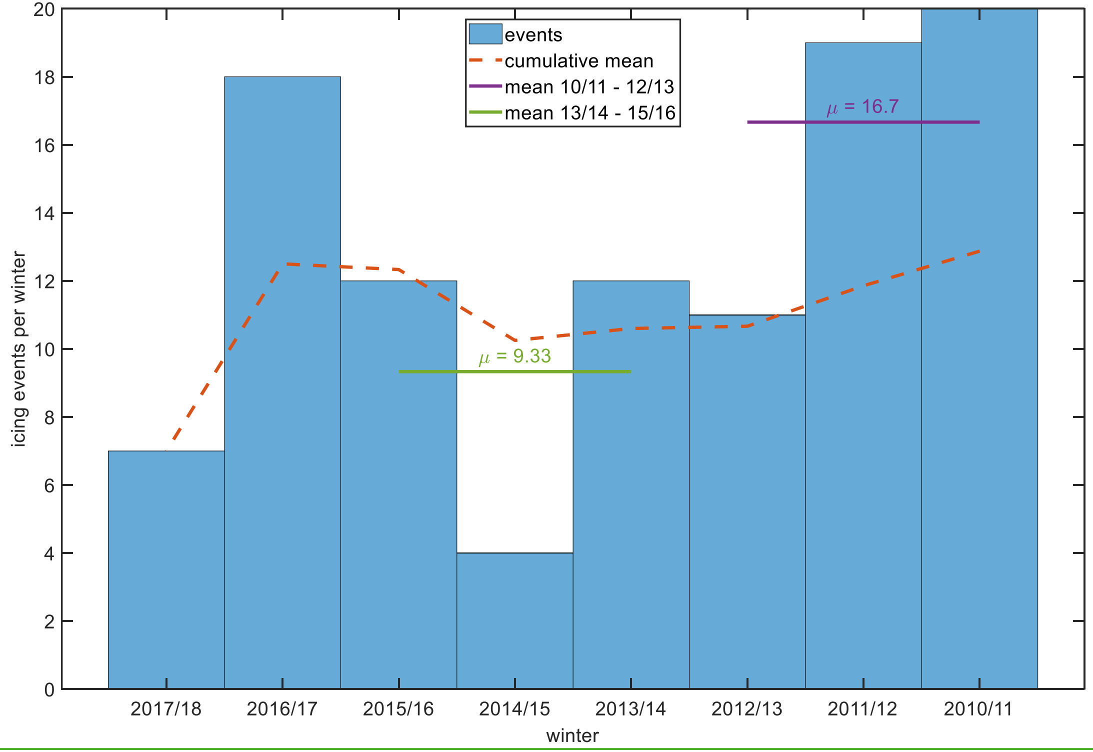

Best results for this location:
60 years in 1 day resolution

Not usable for wind data

When does the ice drop?

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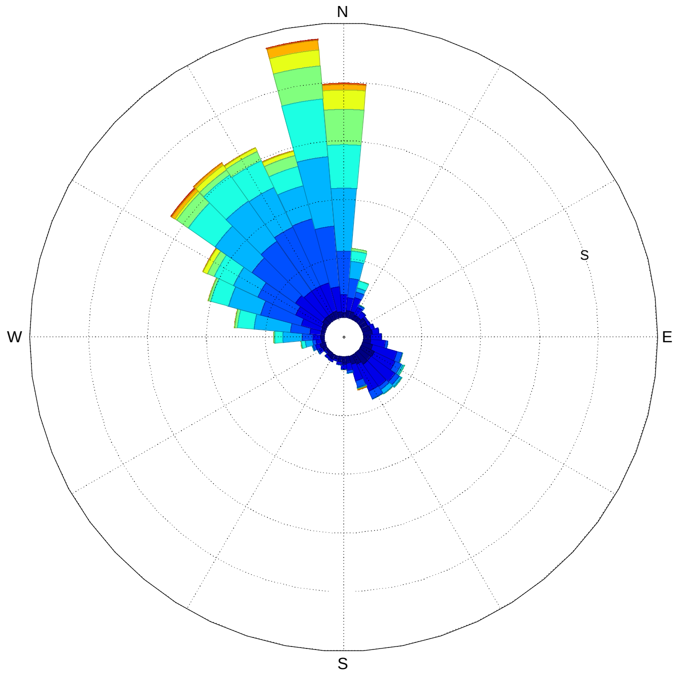
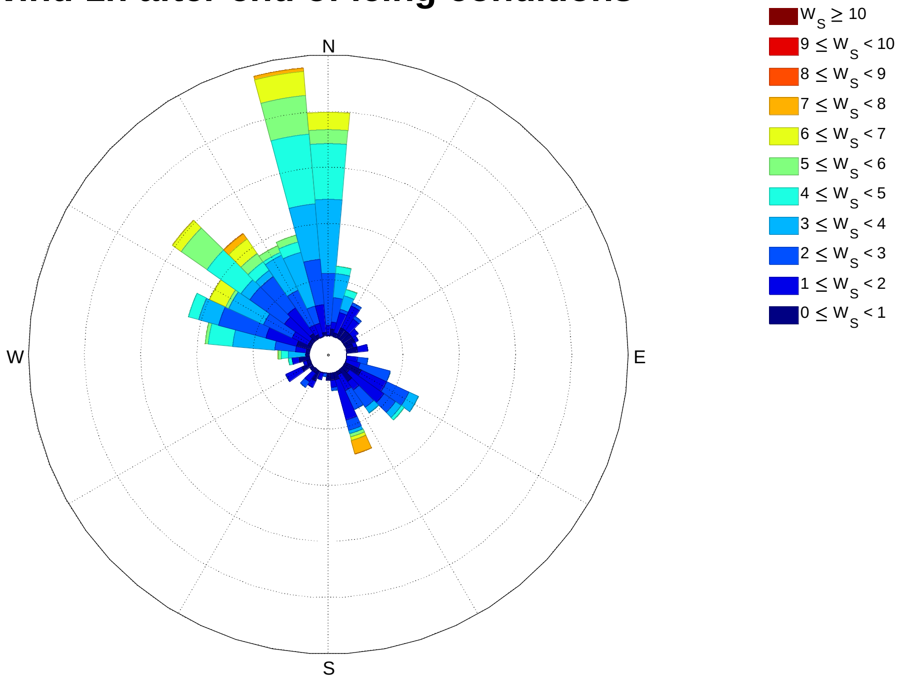
Wind during and 1h after icing conditions



Wind 1h after end of icing conditions



Effect of the time of ice shed on the risk

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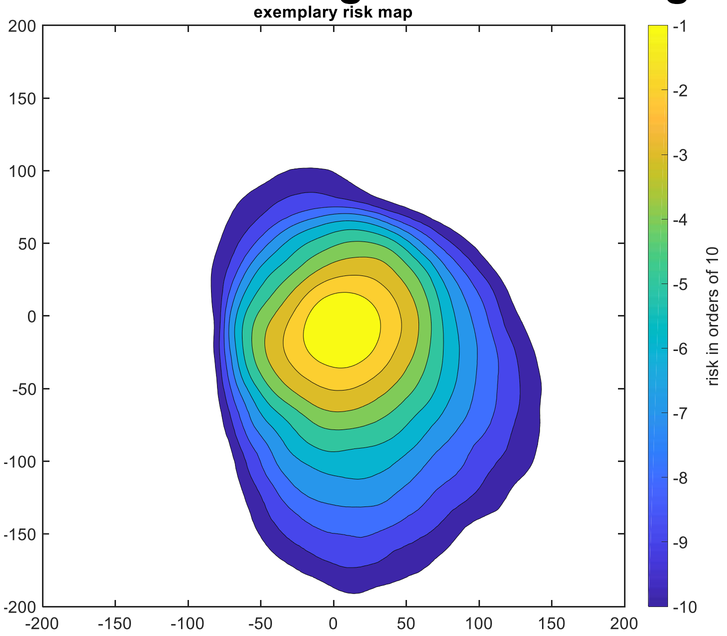
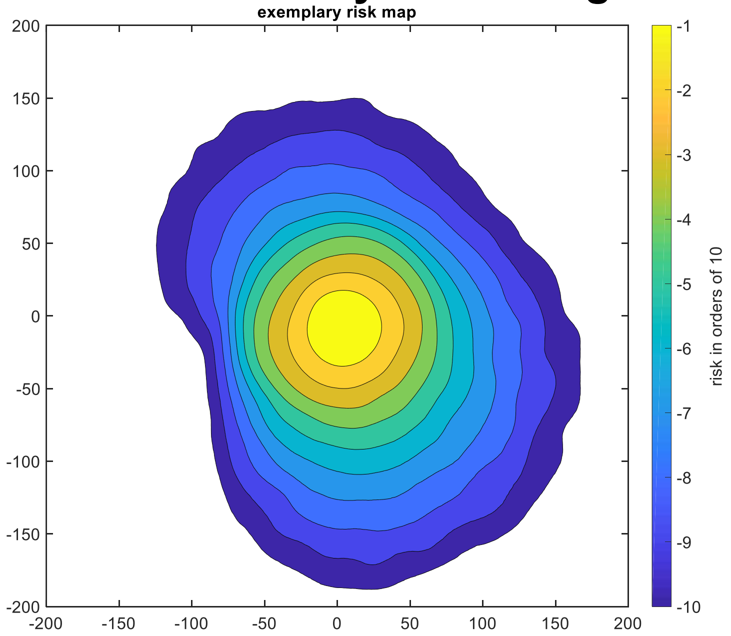
Ice shed during and after icing



Ice shed only after icing



Long icing events may consider partial throw and reaggregation

Where is the ice?
Icing intensity

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- seldom used: ISO (2017): blade cylinder model

- IEC (2017): $M = 0.125 \cdot c_{85} \cdot R$ *[kg ice per m blade]*
- Seifert (2007): $\mathrm{t_{ice}} = c(R) \cdot (0.45 \cdot e^{-0.05 \cdot R} + 0.14)$
- Seifert (2003): linear with sawtooth
- Li et al (2014): 6-16% of profile area, depending on angle of attack

Ice loads

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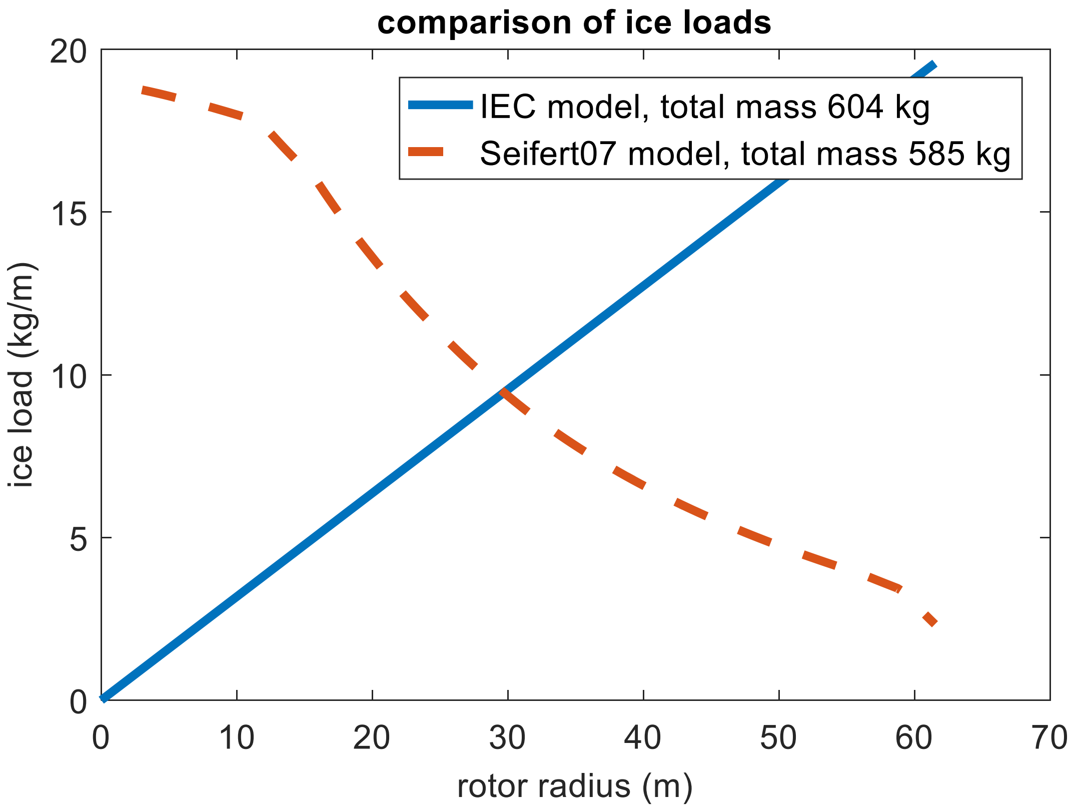

Similar total mass
Different locations

Riskmap for ice shed depending on iceload

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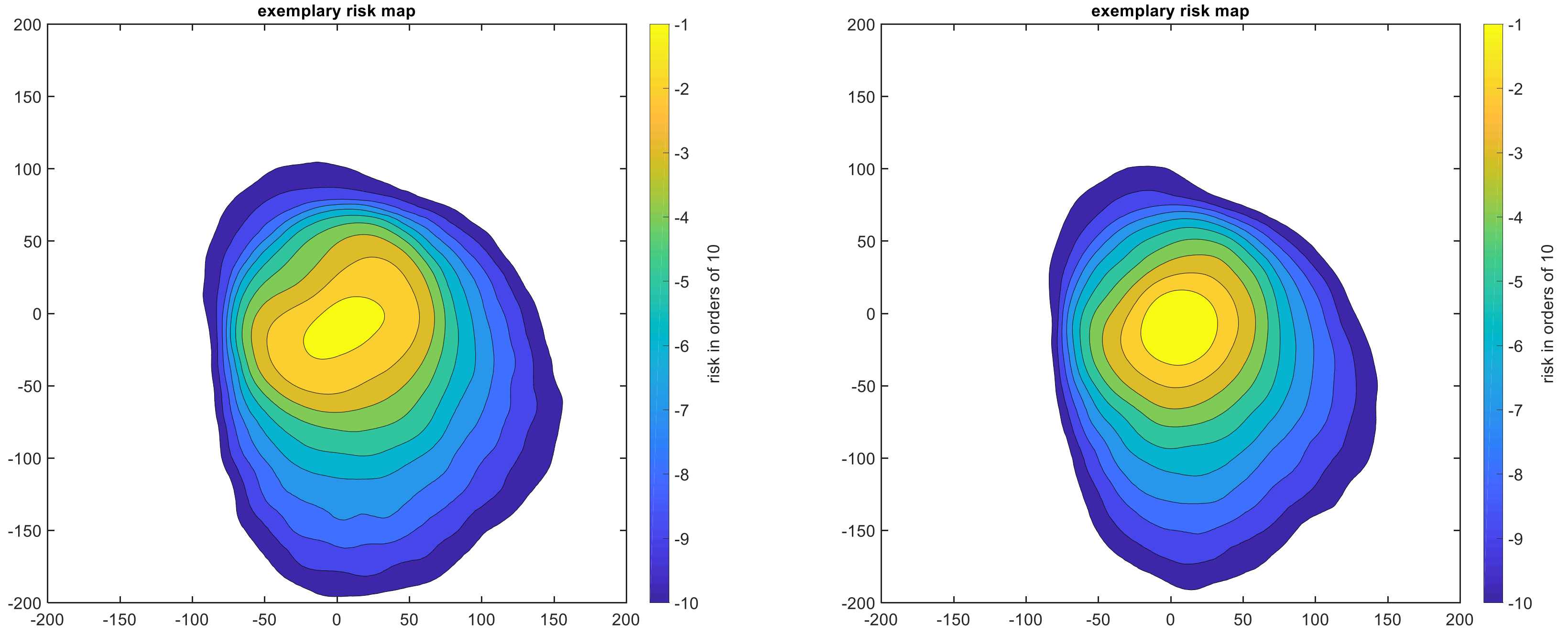
IEC

Seifert07



Riskmap for ice throw depending on iceload

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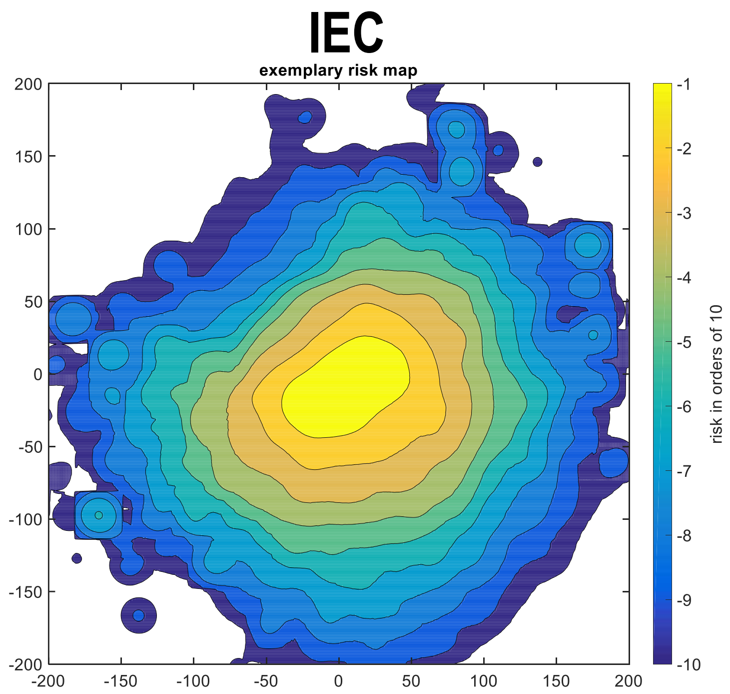
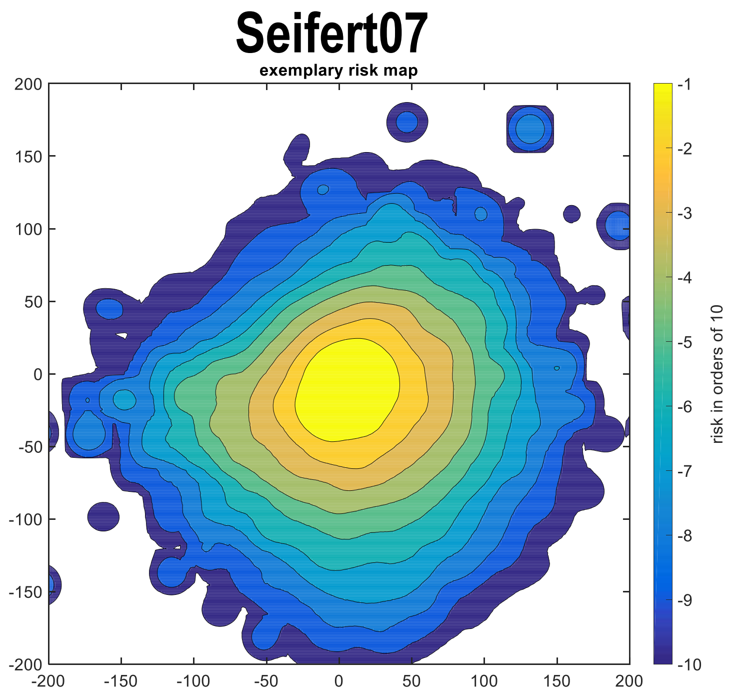


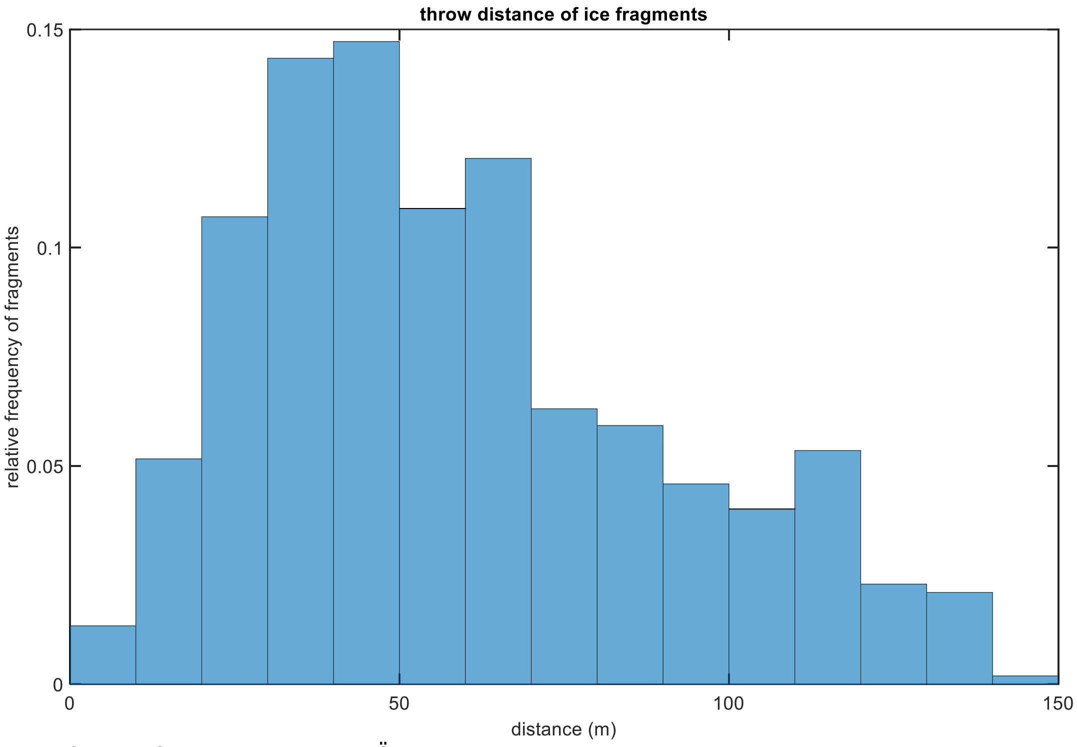


Ballistic models

- Drag-only (Morgan et al 1996 / Biswas 2012)
- One-axis rotation (Baker 2007)
- 6 Degrees of Freedom (Noda and Nagao 2010, Richards et al 2008)

Validation is necessary

ICETHROWER study



Data source: ICE THROWER database by PÖYRY

- Ice throw montoring 2013-2016
- > 500 observed fragments

ICETHROWER study

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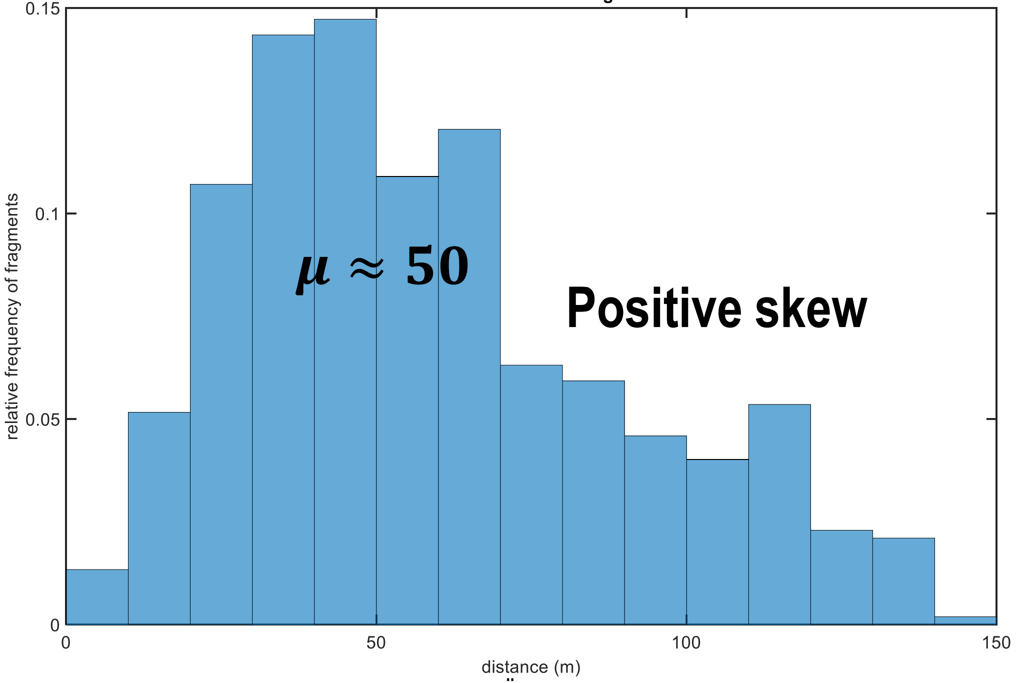
observed



Data source: ICE THROWER database by PÖYRY

modelled

$\mu \approx 100$ Negative skew

Model is conservative, but is it correct?

Problem of validation

- Best possible validation would be comparison with observed ice throwm but:
  - Too many parameters: turbine height, rotor diameter, wind speed, ice density, icing intensity, …
  - Many variables difficult to observe, e.g. wind speed during a single throw
- → Current observations are not sufficient

- Solutions:
  - Much more observations
  - Experiments

Models vs experiment

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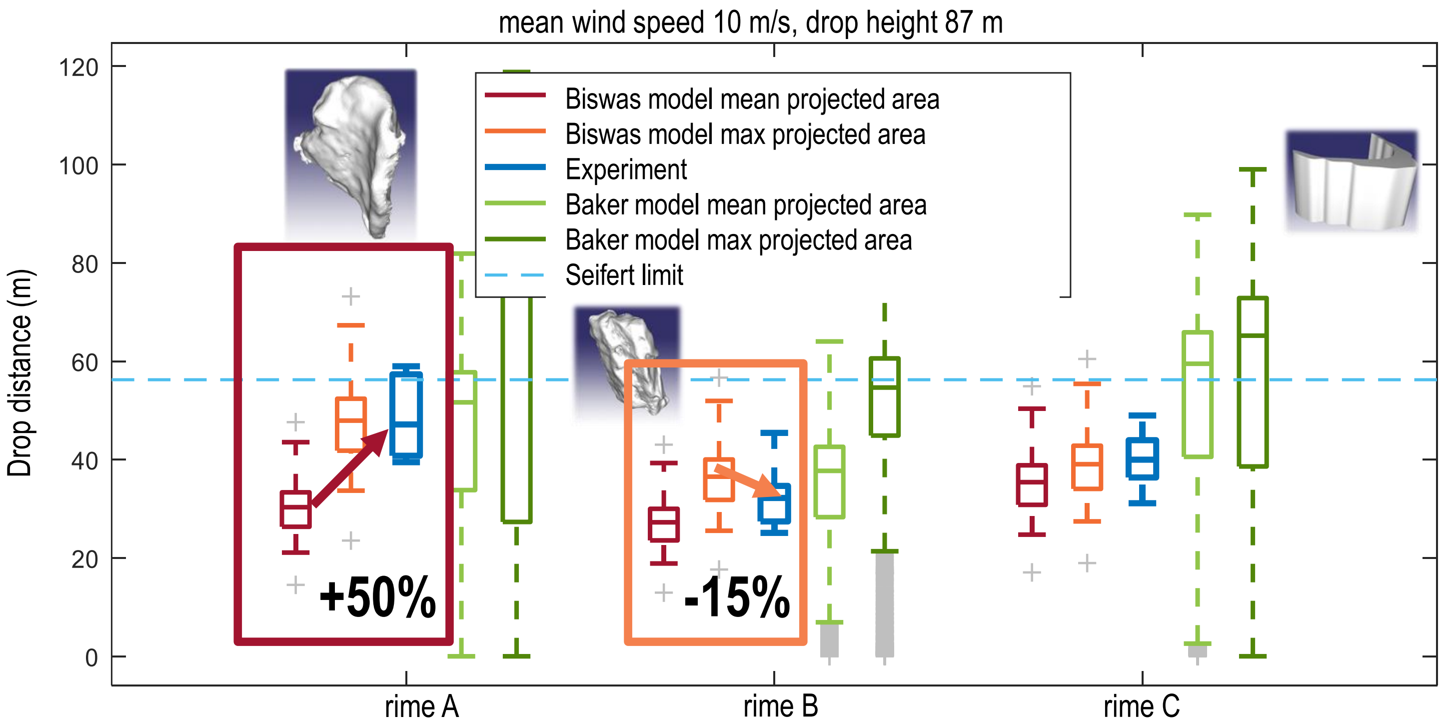
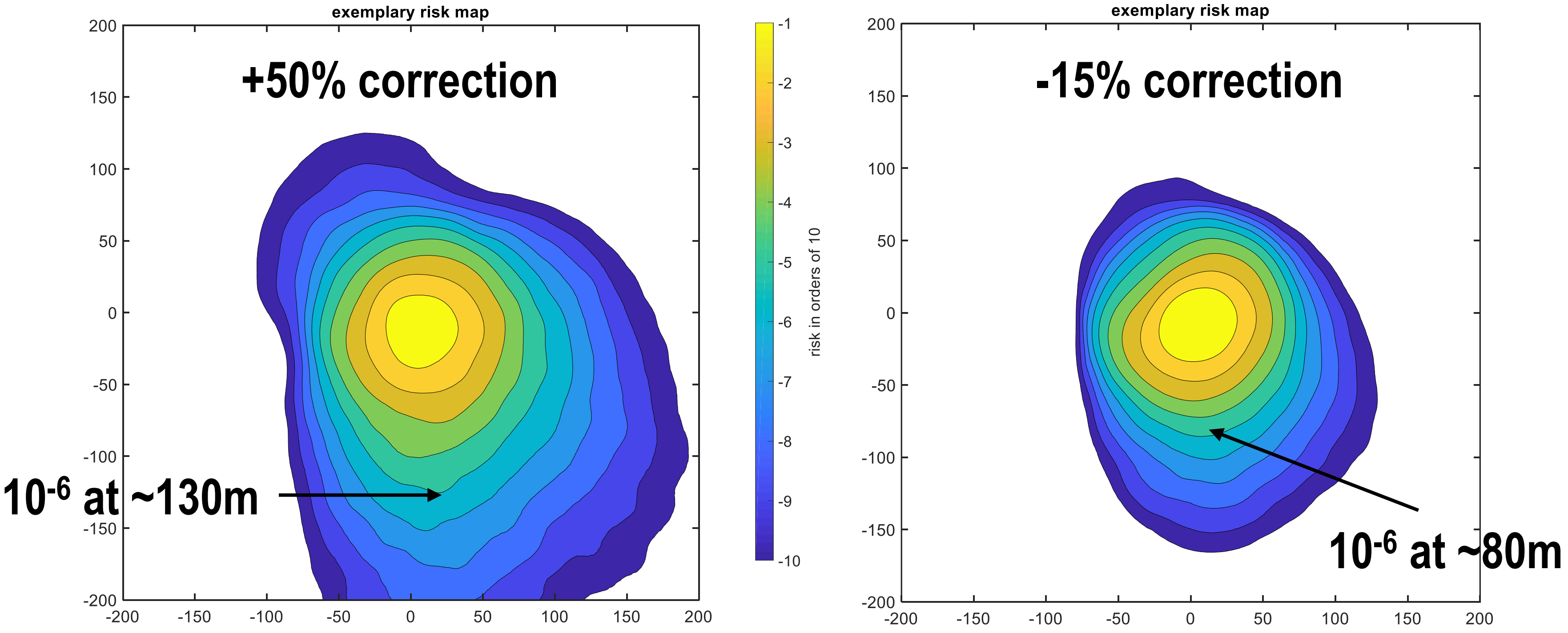


Correction factors for distances



Ballistic Models

- No accurate, validated model available
- Conservative case depends on scope – public or service personnel?
- Correction factors not applicable, vary depending on ice fragment geometry

Additional parameters

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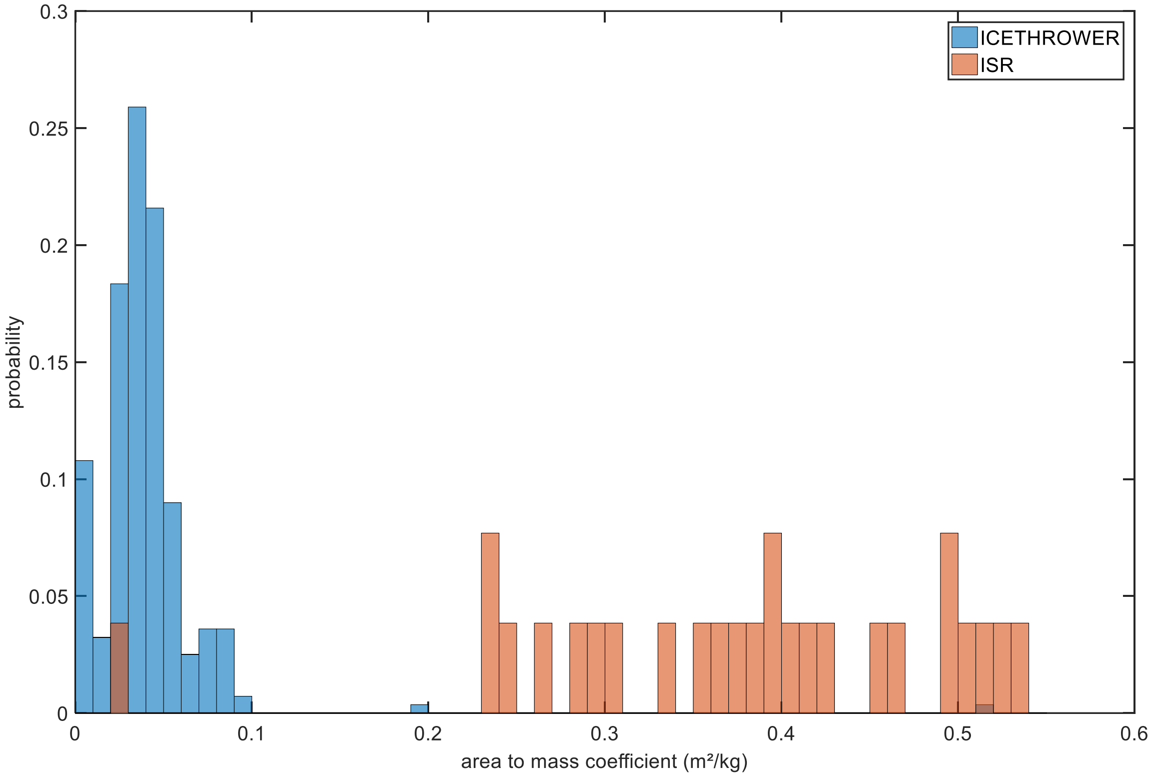
- Logarithmic wind profile
- Turbulent wind field
- Turbulences from blades
- Topographic models

Fragment parameter distributions



- In Biswas model characterised by area, mass and drag coefficient
- Different results from different campaigns
- Fragment properties probably site specific

Risk map for ice shed depending on ice fragment parameter distributions

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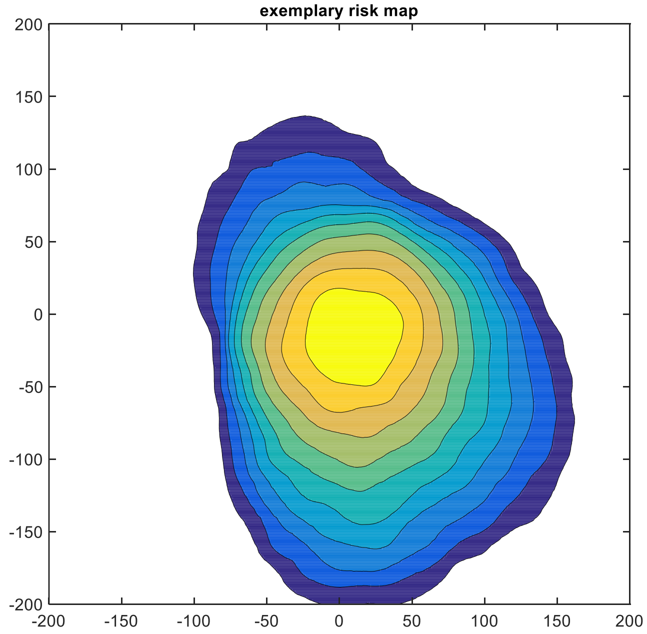

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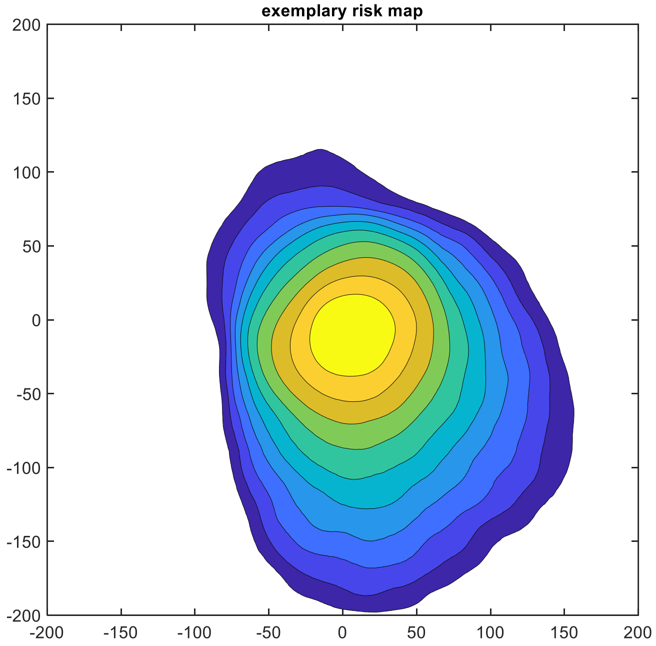
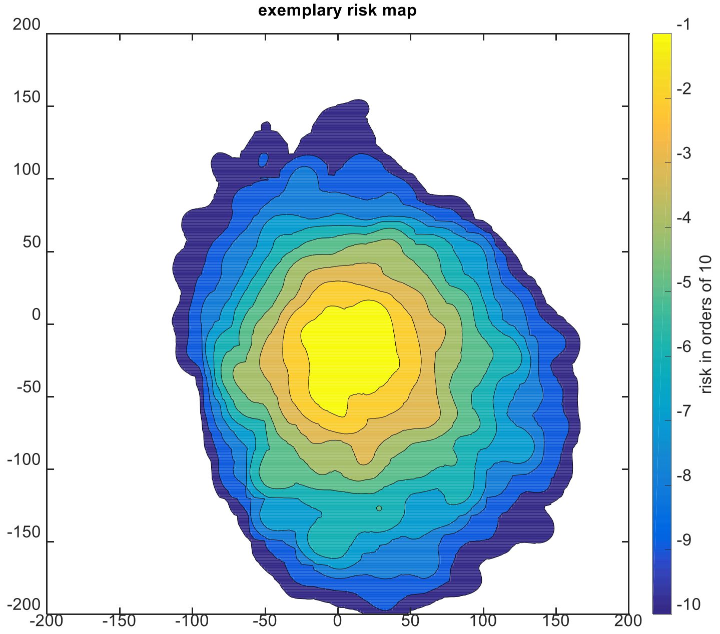


Risk map for ice throw depending on ice fragment parameter distributions

ICETHROWER



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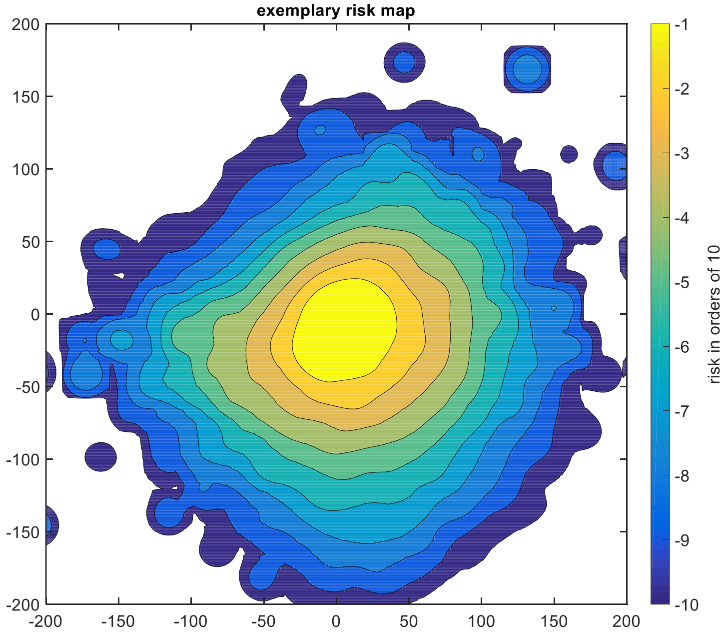

Energy limit for dangerous fragments

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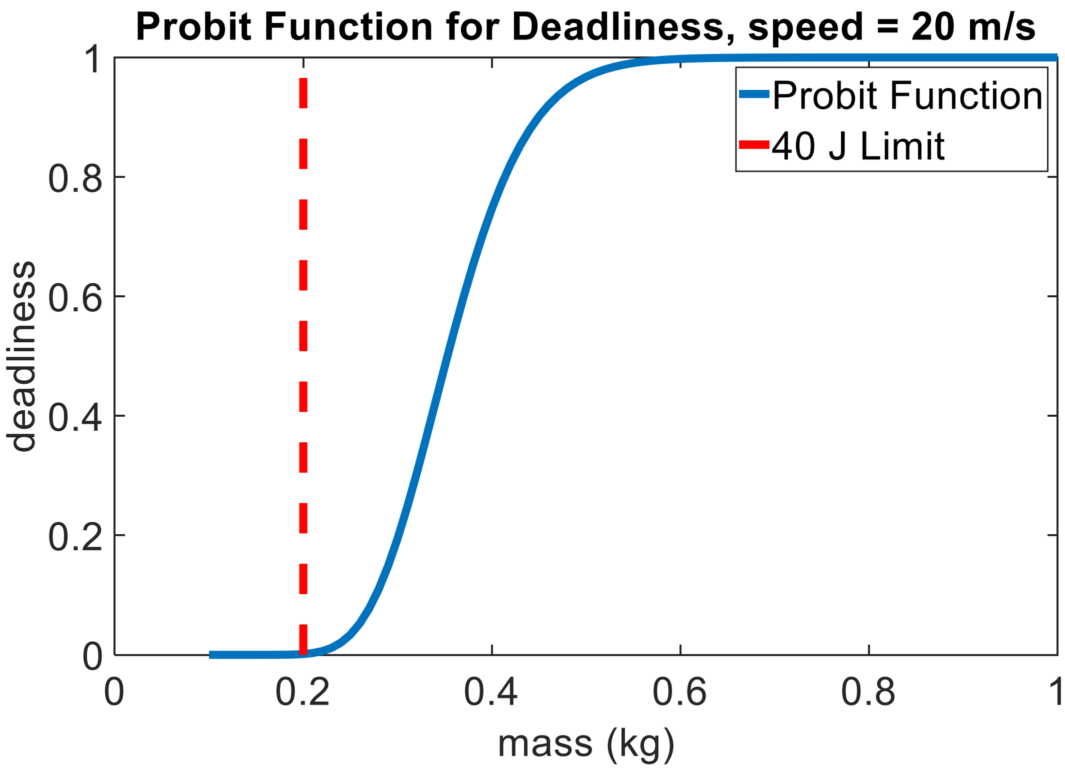

Fixed limit: 40J

Continuous: probit function

Actual danger from a single fragment difficult to assess: impact area, compressibility, affected organs

Energy limit for dangerous fragments

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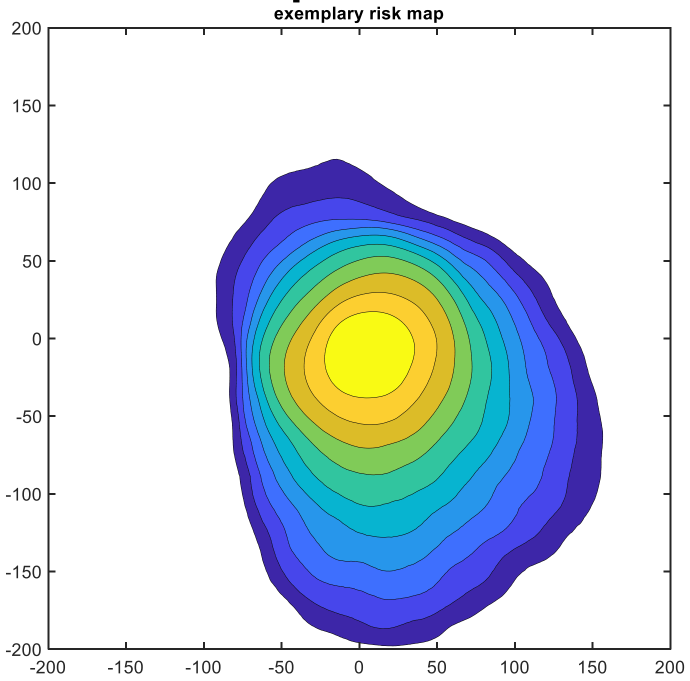
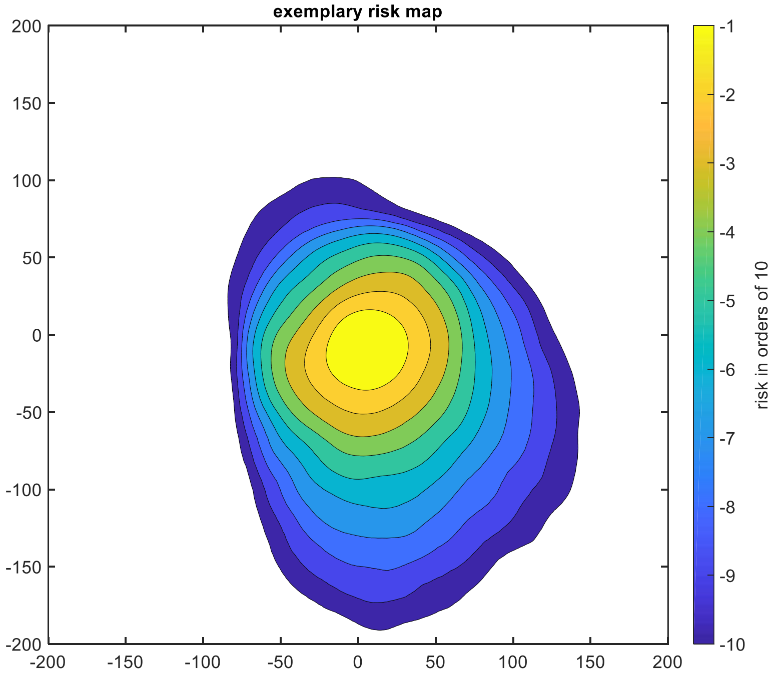
probit



>40J



Additional safety measures

- Warning signs
- Warning signs with lights
- Physical barriers
- Communication strategy
- Controlled de-icing

Risk Reduction Factors

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Category	Safety measures	Risk reduction (RRF)	Appropriate for
Reduction of likelihood of presence	Warning signs of ice fall conditions	1 to 10	Minor roads and paths
	Warning light connected to the ice detection system on the turbine in combination with warning signs	10 to 100	Minor roads and paths
	Physical barrier (official road closure) and signs	10 to 100	Roads and official frequently used hiking paths

IEA Wind TCP Task 19: International Recommendations for Ice Fall and Ice Throw Risk Assessments, October 2018

- No studies on effectiveness available
- → Almost arbitrary risk reduction factors can be applied

Conclusions

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- Changing ice risk results by at least an orders of magnitude is easy
- Sensitive (and often unknown) parameters:
  - ice mass distribution on the blade
  - Actual time of ice shed/throw (and thus wind conditions)
  - Ice fragment properties (distribution of area/mass ratio)
- Current Ballistic Models highly inaccurate

- **Use additional risk reducing measures (warning signs etc.), but do not apply Risk Reduction Factors**