IceRisk

Methods for evaluating risk caused by ice throw and ice fall from wind turbines and other tall structures

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IWAIS, Uppsala
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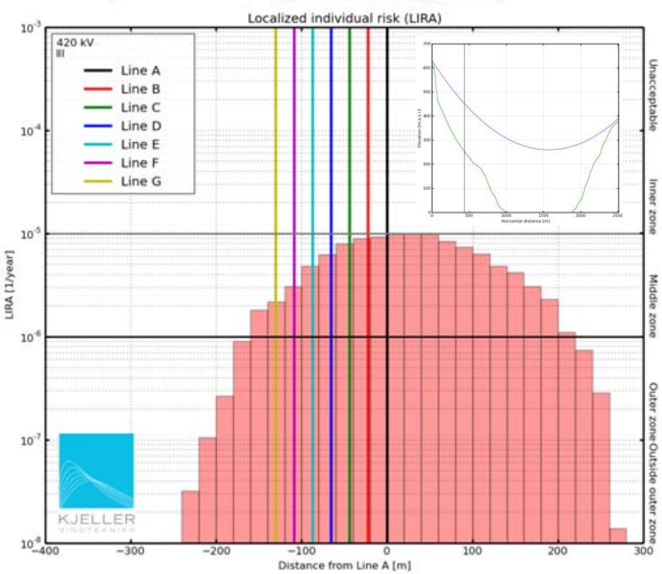
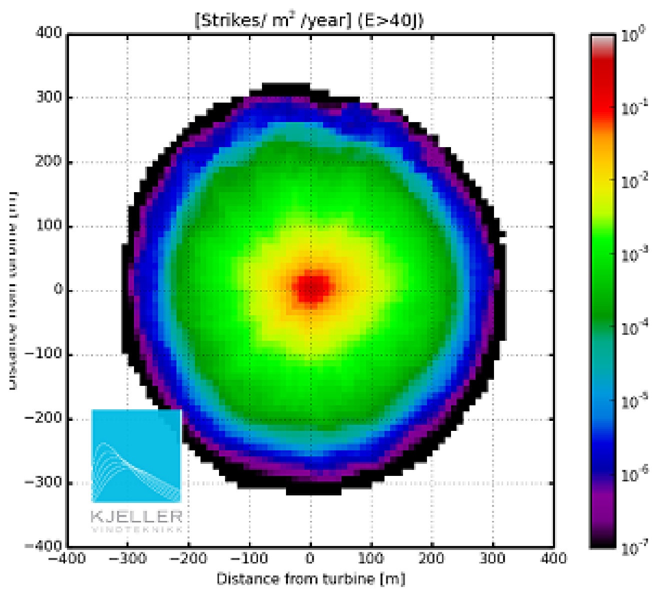
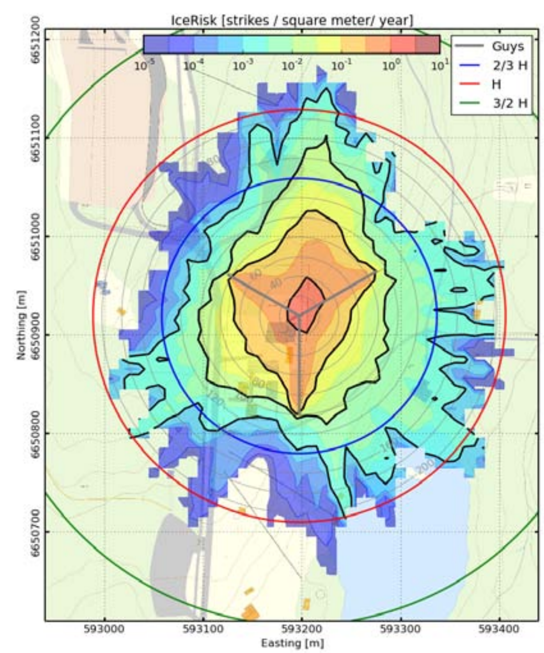
Methods for evaluating risk caused by ice throw and ice fall from wind turbines and other tall structures

- Mast and towers, windturbines, powerlines, bridges, etc.
- Analyses for possibly fatal ice debris. Smaller ice debris are not considered.
- Suggested risk acceptance critera for different exposures (safety zones)



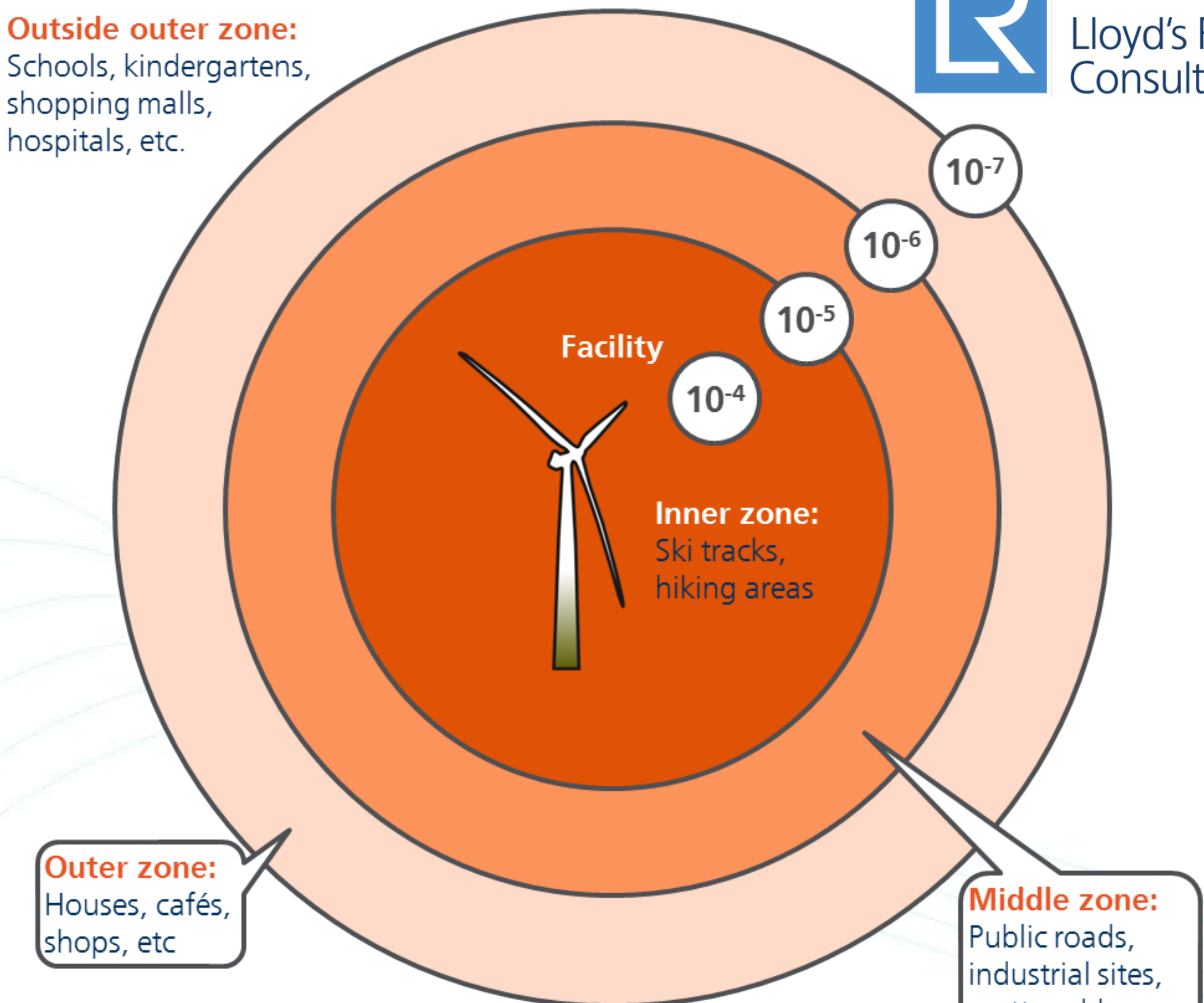




Localized Individual Risk (LIRA)

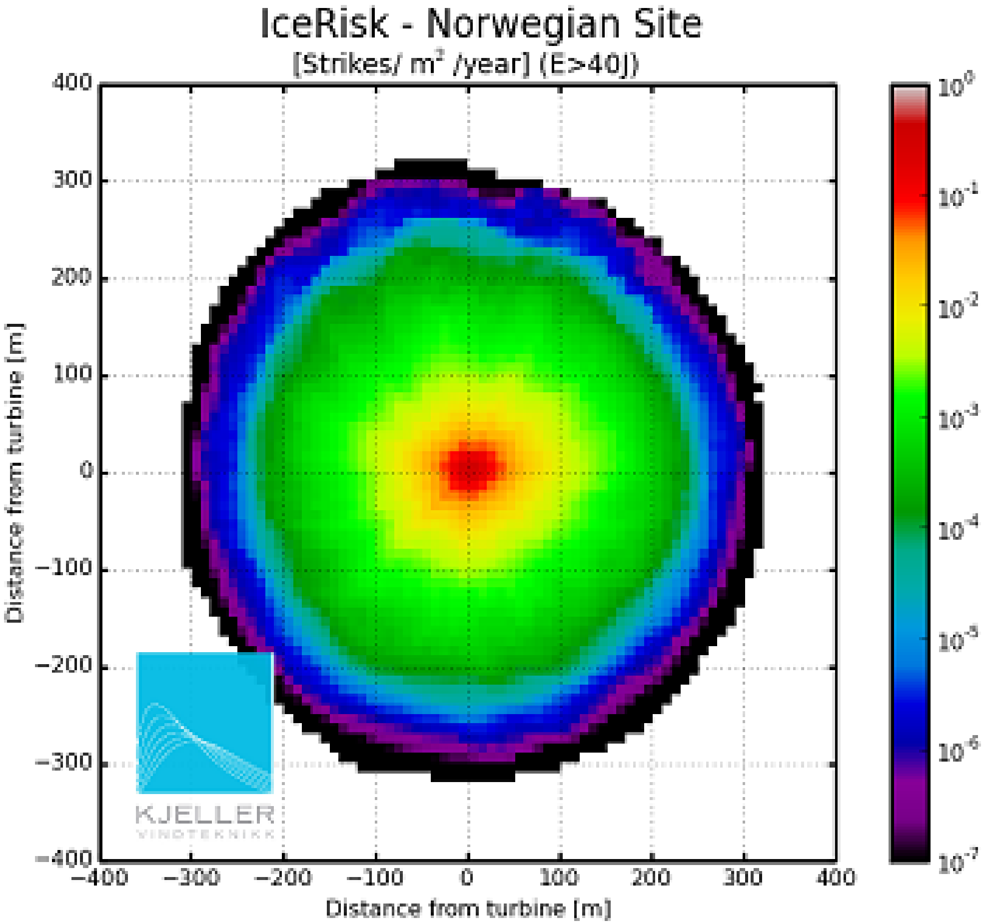
- LIRA is the probability that an average unprotected person, permanently present at a specified location, is killed in a period of one year due to an accident at a hazardous installation
- Ice debris with impact kinetic energy above 40 J is assumed fatal (head)
- Projected size of person typically 0.1 m2

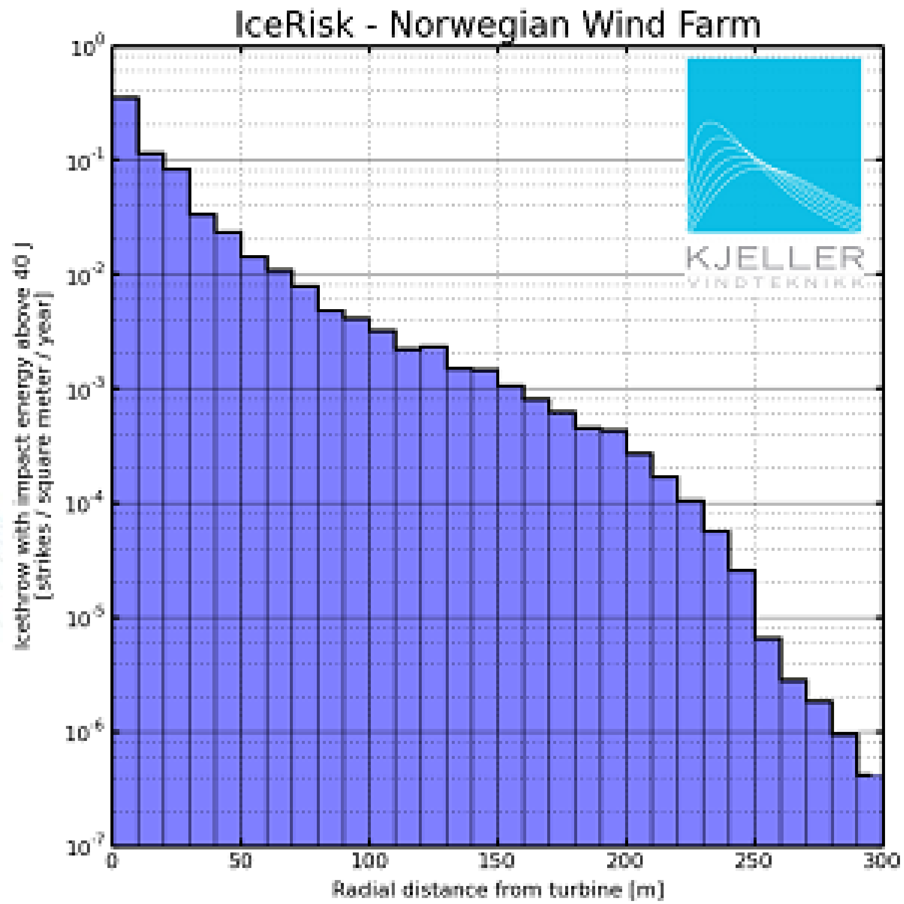
Suggested acceptance criteria for third person



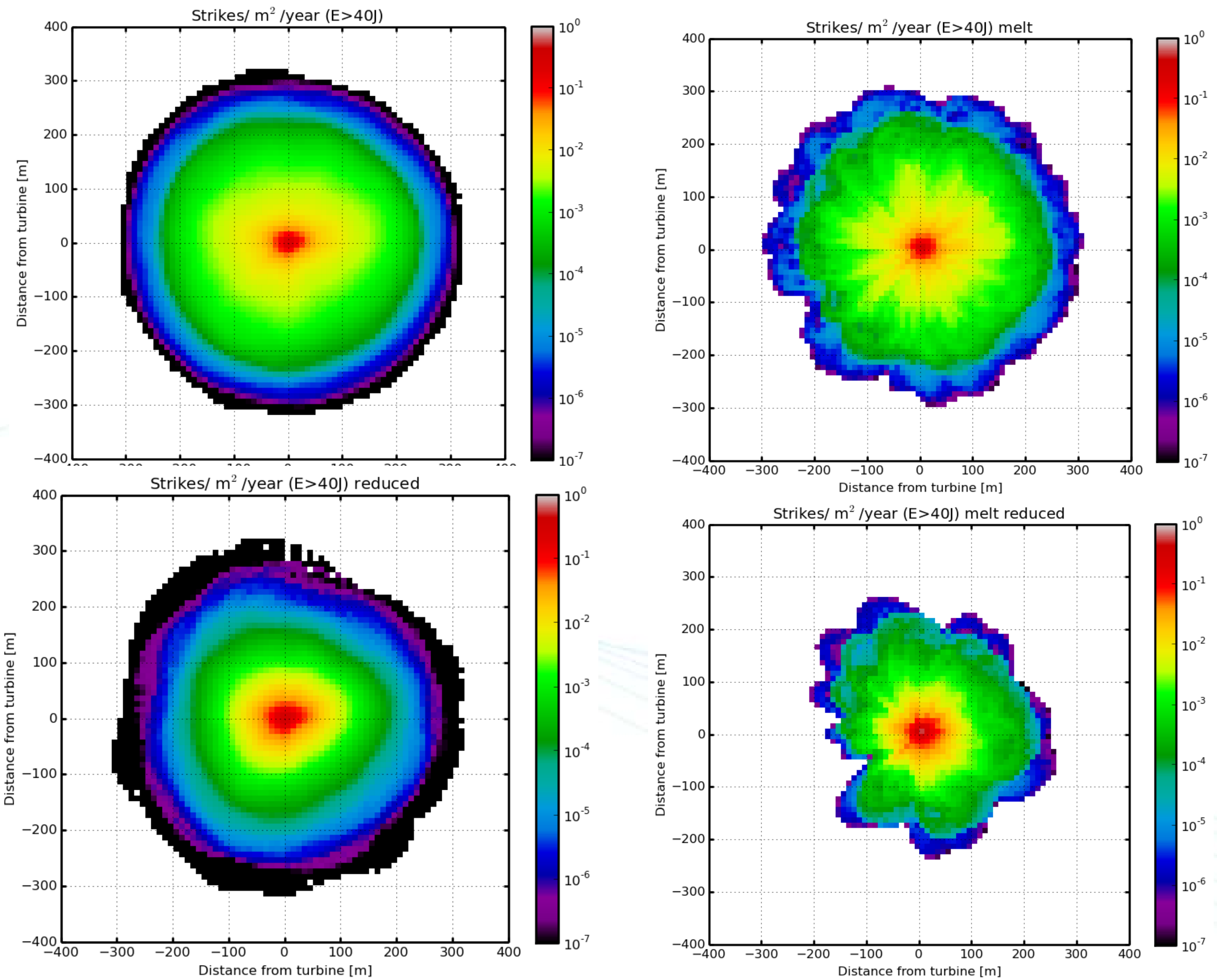
Icethrow from a Norwegian windturbine

return period of 10 y at 25 m, 100 y at 75 m, 1000 y at 150 m, 2 500 000 y at 300 m





Lower row: reduced turbine performance due to icing. Right column: shedding



Icethrow: Safety distances will depend on turbine characteristics, wind speed, wind shear ,terrain, and icepiece weight and shape.

- Wind from left
- landing position is given by **colored zones for different wind speeds**,
- dashed lines indicate reduced performance of turbine due to icing,
- **grey line show safety rule (H+D)*1.5**
- Markers for blade oriented along 2-axes:
  - +z: **v** topside moving south
  - -z: **^** bottomside moving north
  - +y: **o** northside moving up
  - -y: * southside moving down

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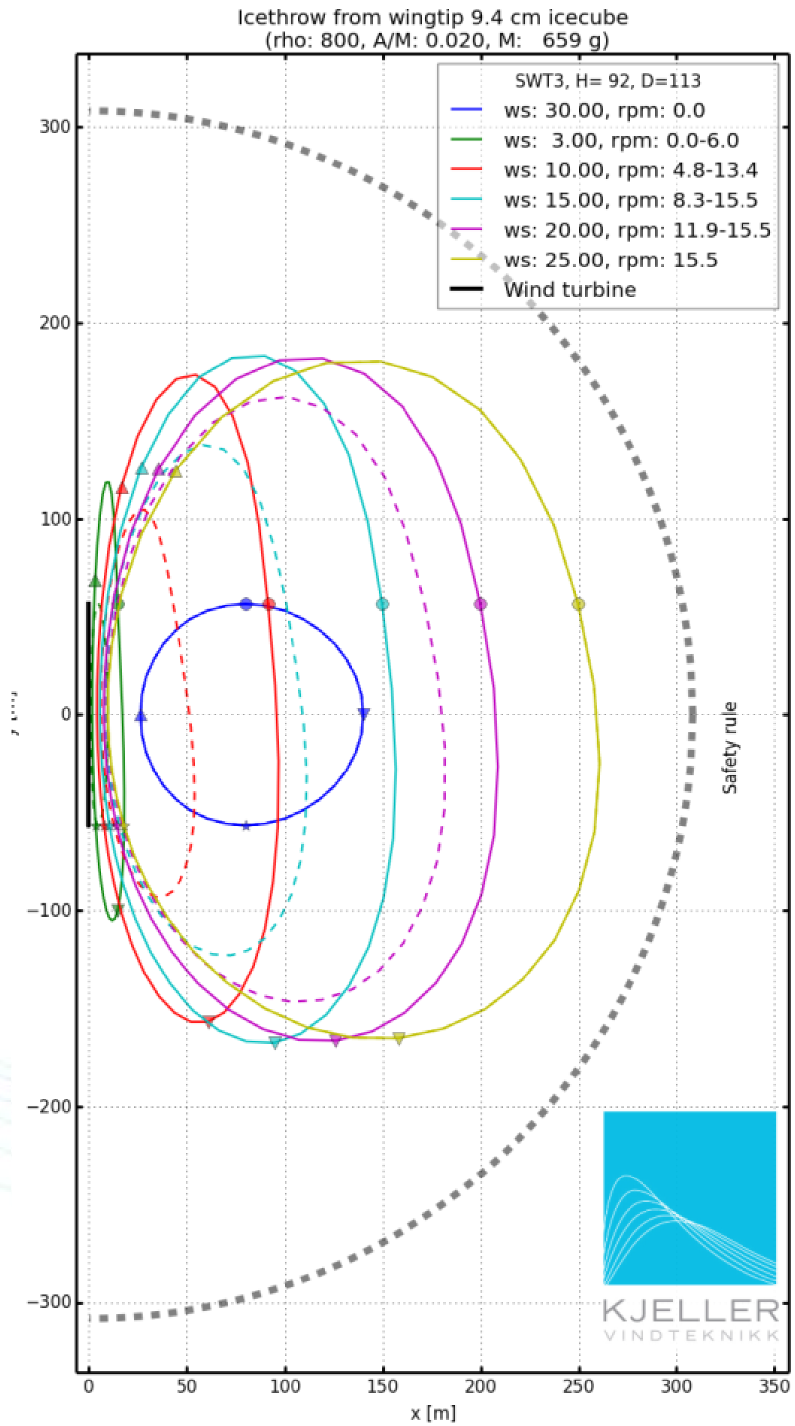
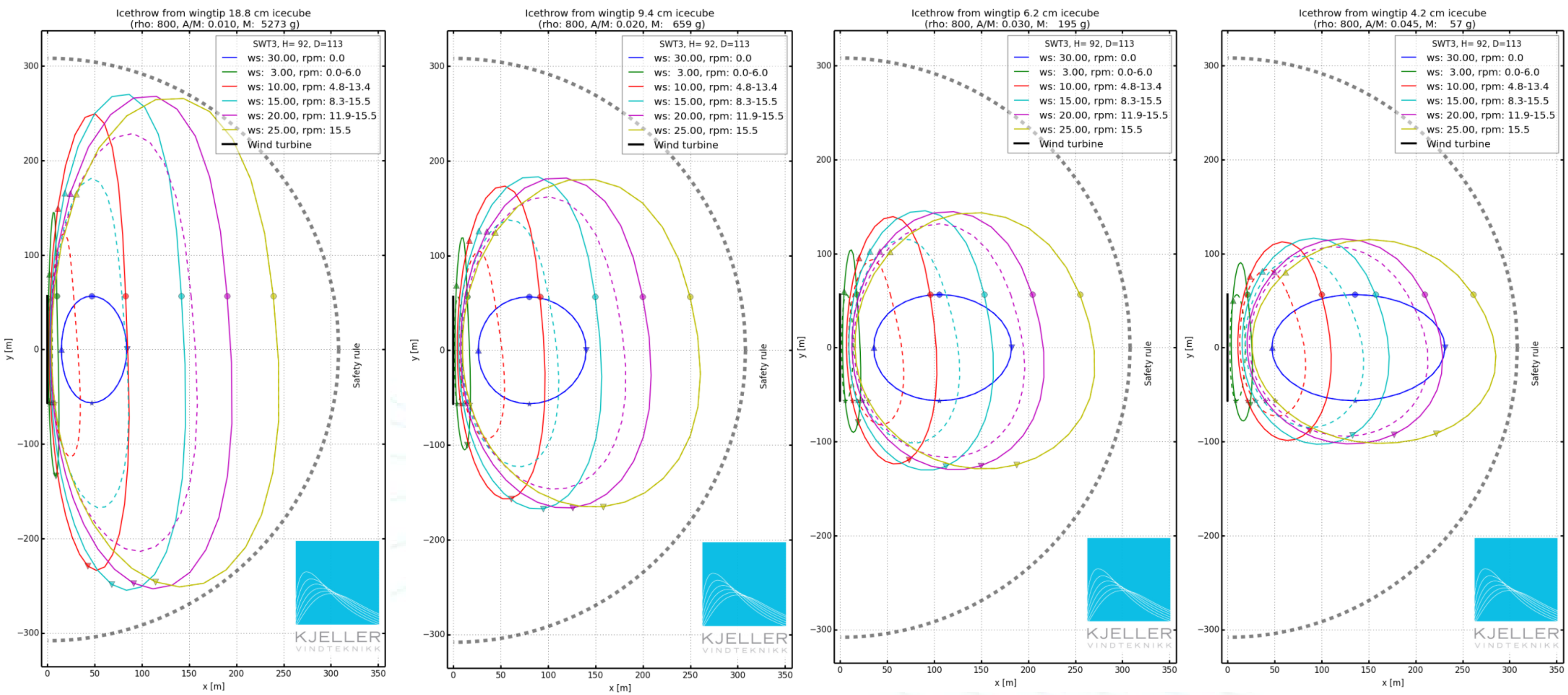


Sensitivity analysis for icethrow using a given turbine and local icing conditions

Wind from left, landing position is given by **colored zones for different wind speeds**, dashed lines indicate reduced performance of turbine due to icing, **grey line show safety rule (H+D)*1.5**



Large and heavy

Small and light

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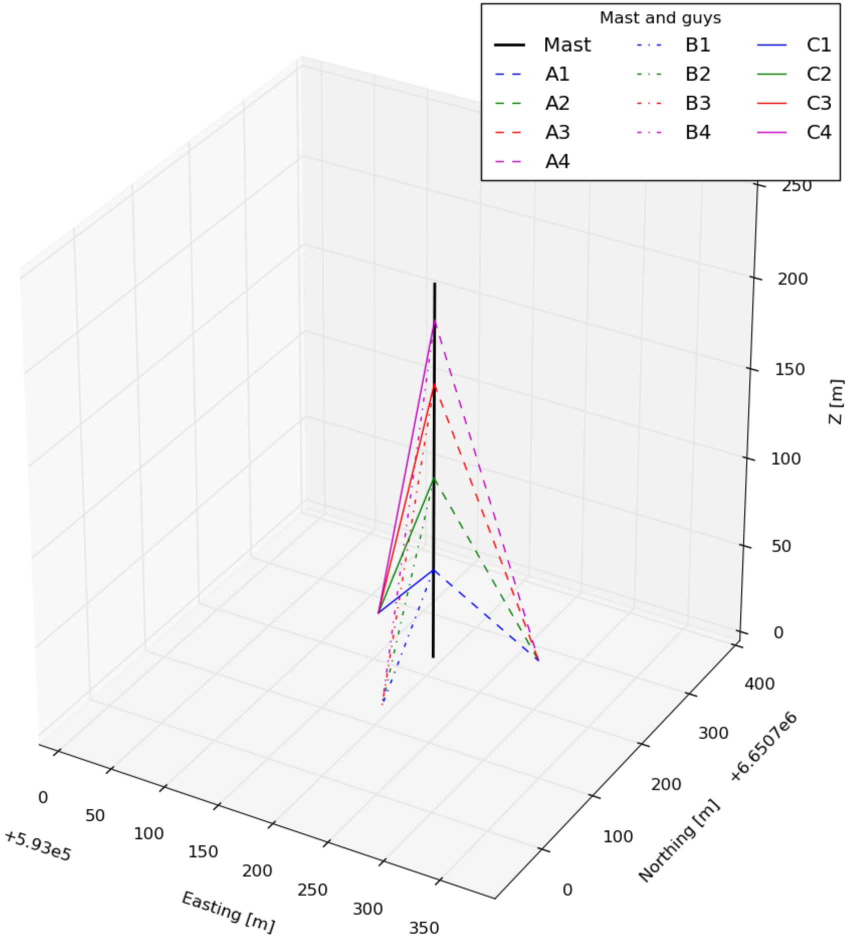
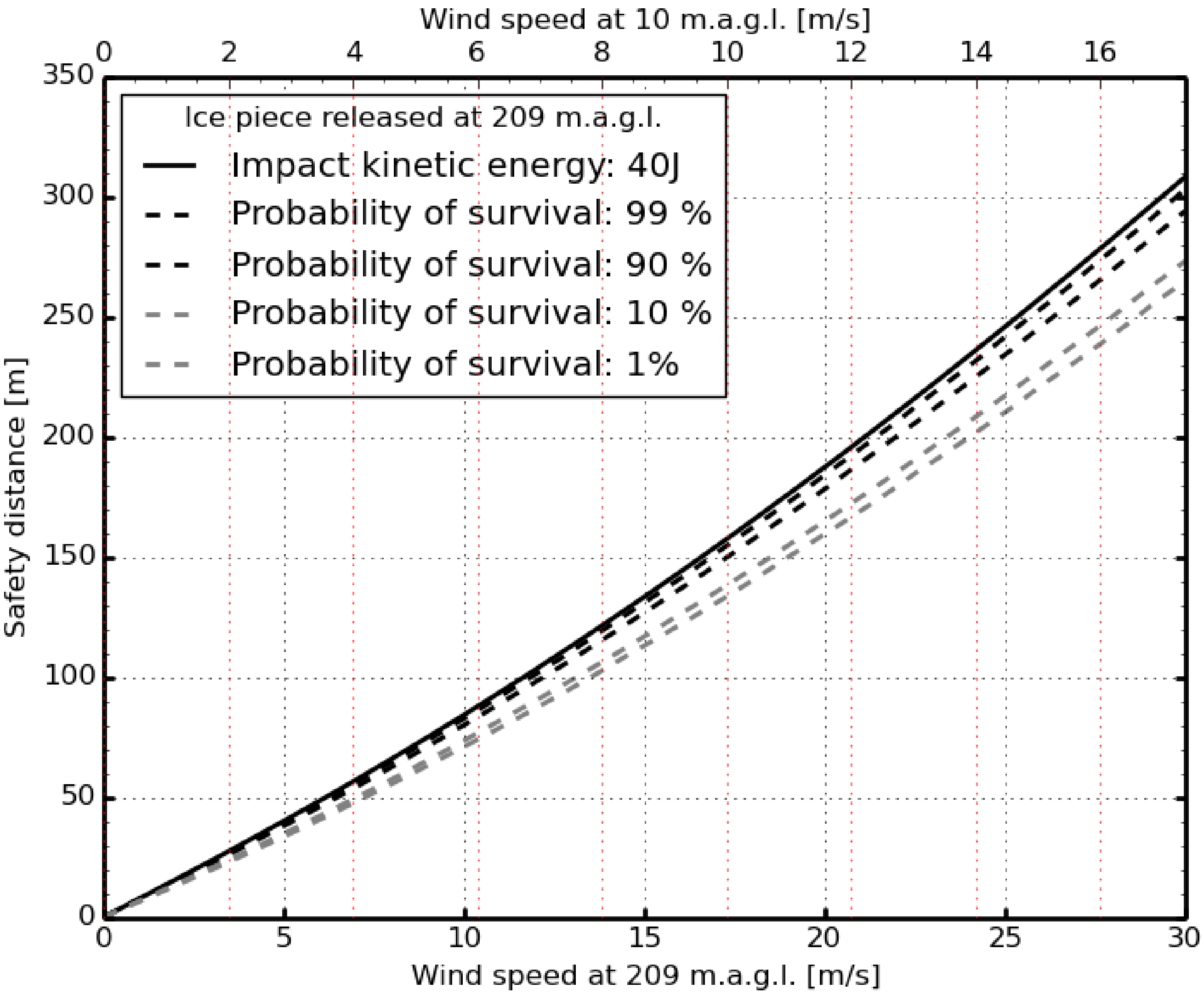
Guyed 209 m telecom mast at Tryvann, Oslo



Safety distance function for ice debris:

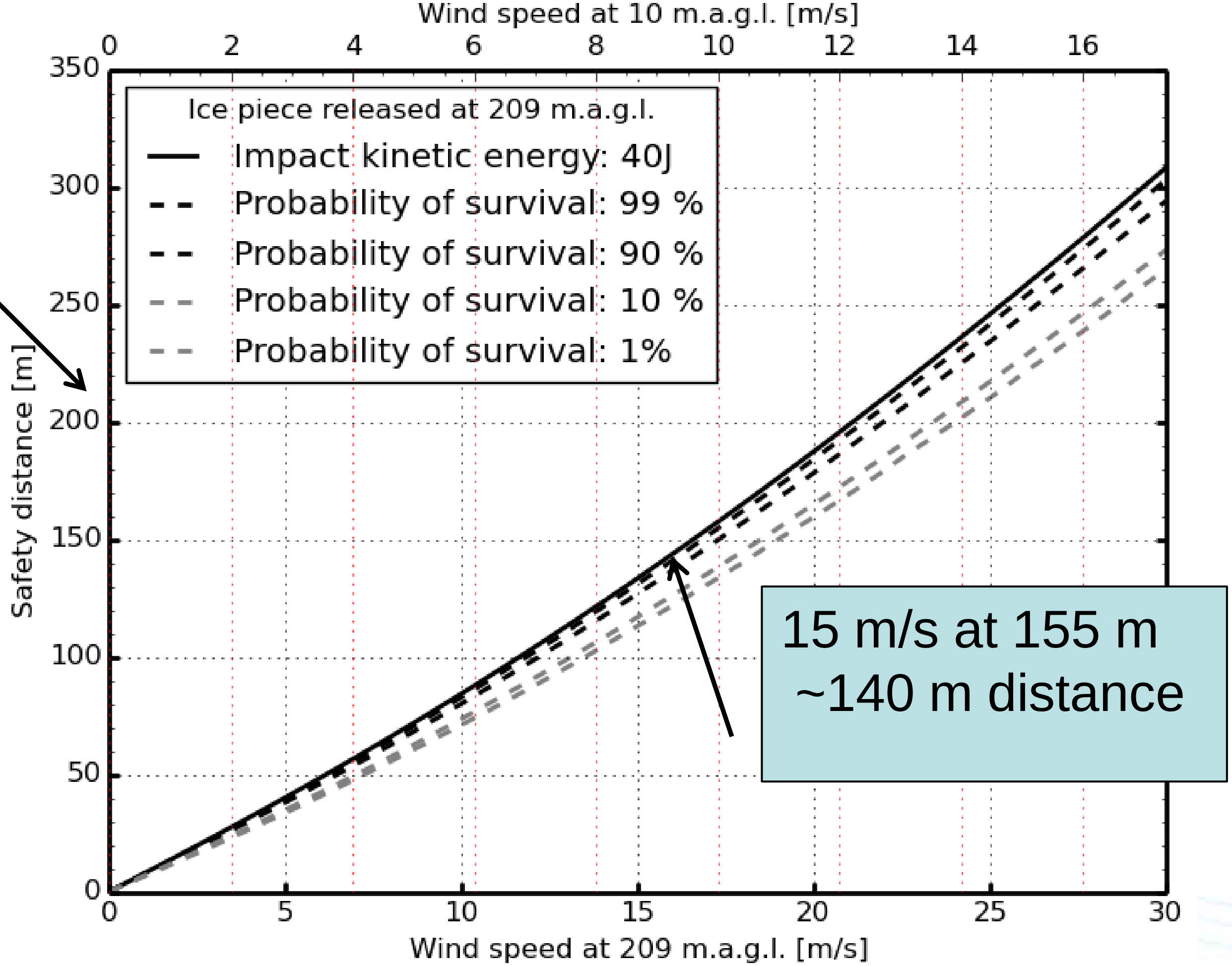


Conservative safety distance rule for stopped wind-turbine

d=H*V/15

d: Safety distance,
H: Total height stopped turbine
V: Vind speed at hub height)

Narrow zone between very dangerous and safer zones



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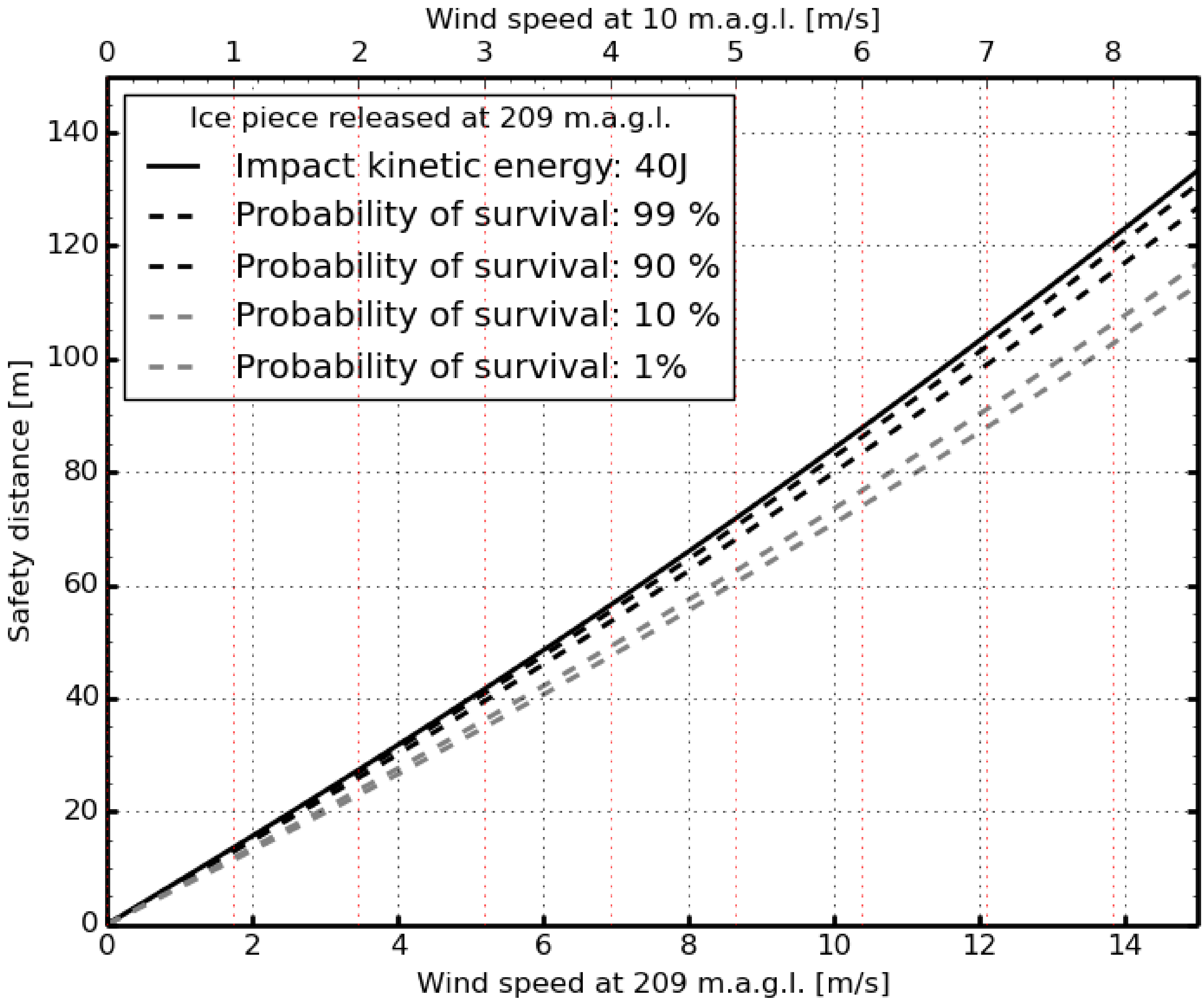
Zoom:



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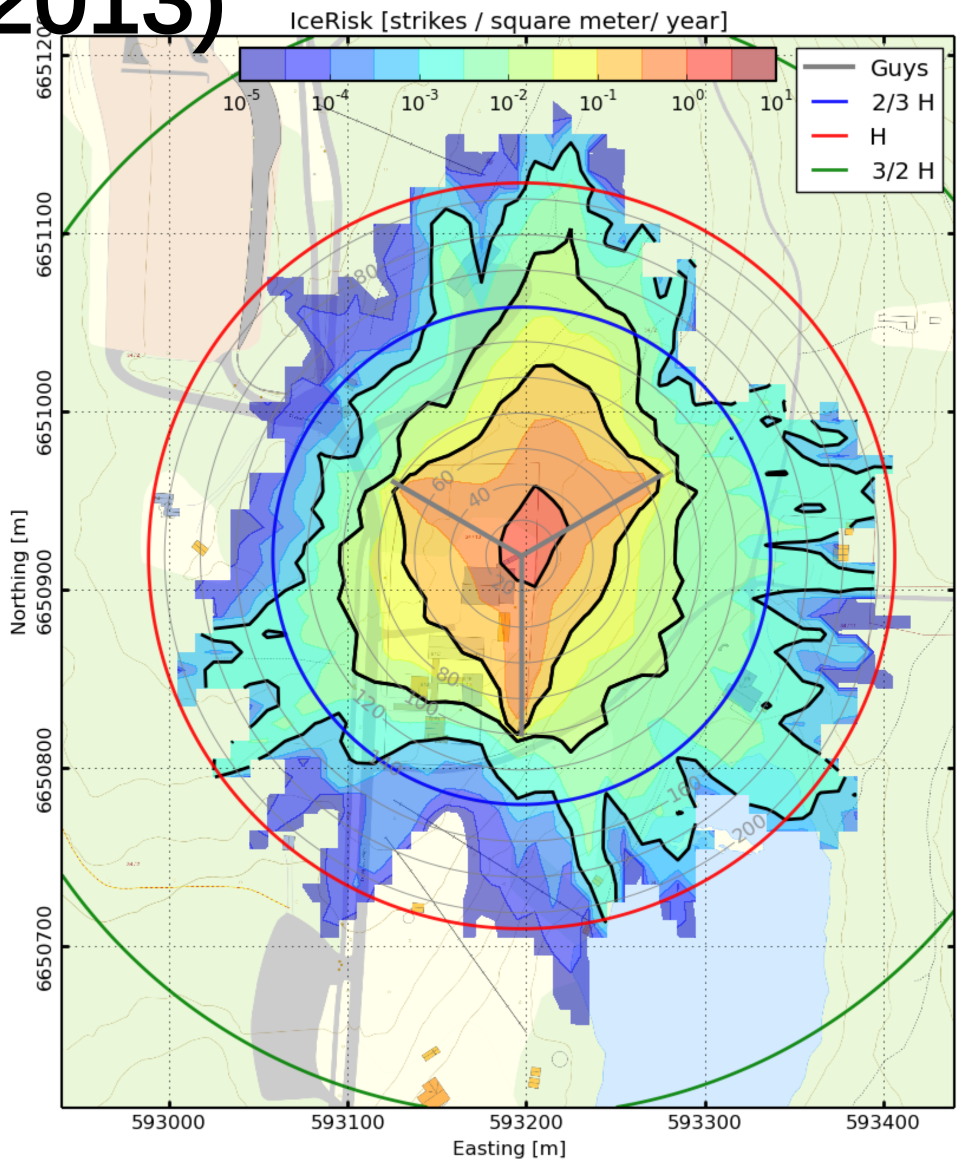
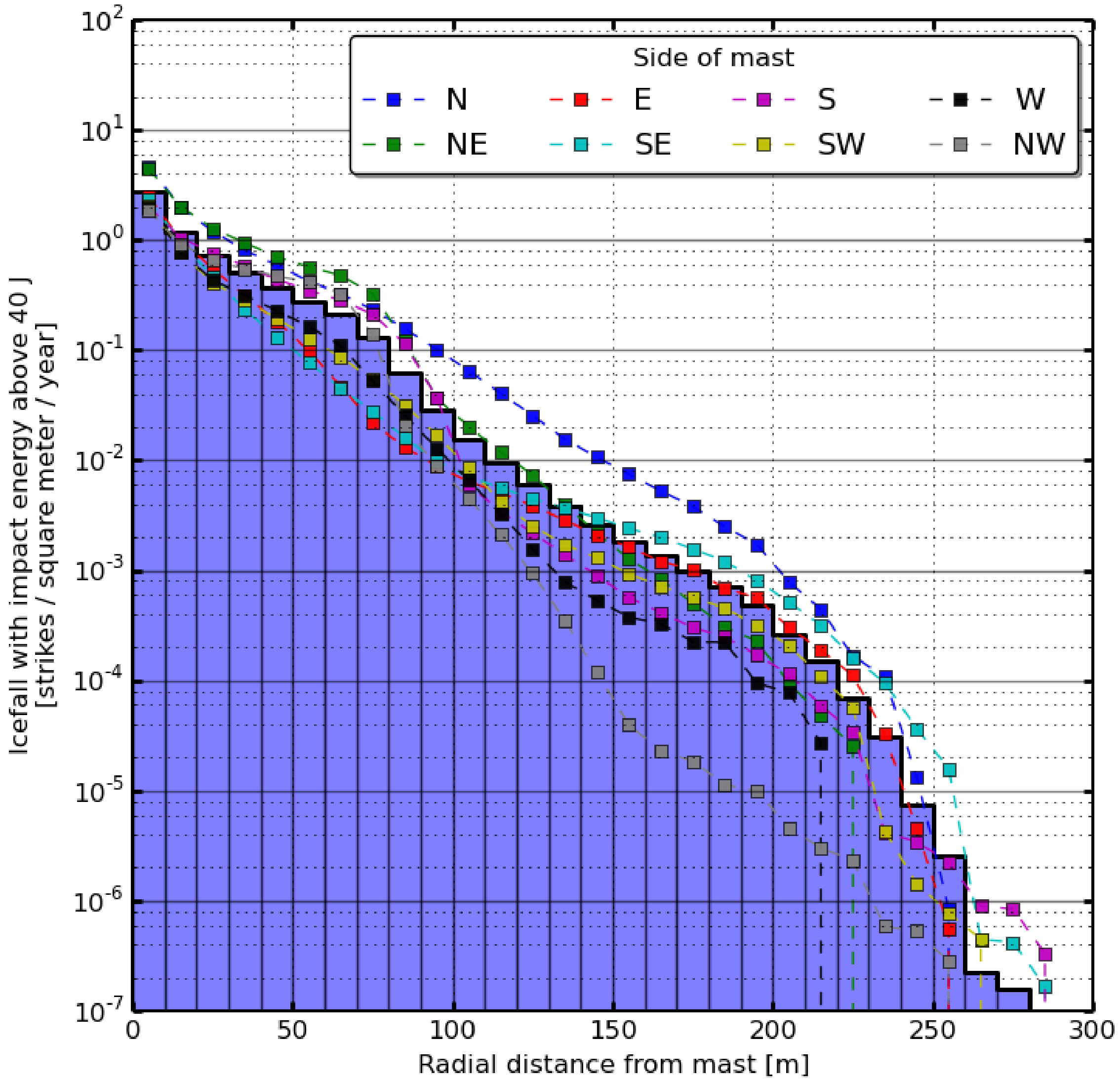
Dangerous icefall within the height of the construction (red) (1979-2013)



Directional distribution of dangerous ice fall



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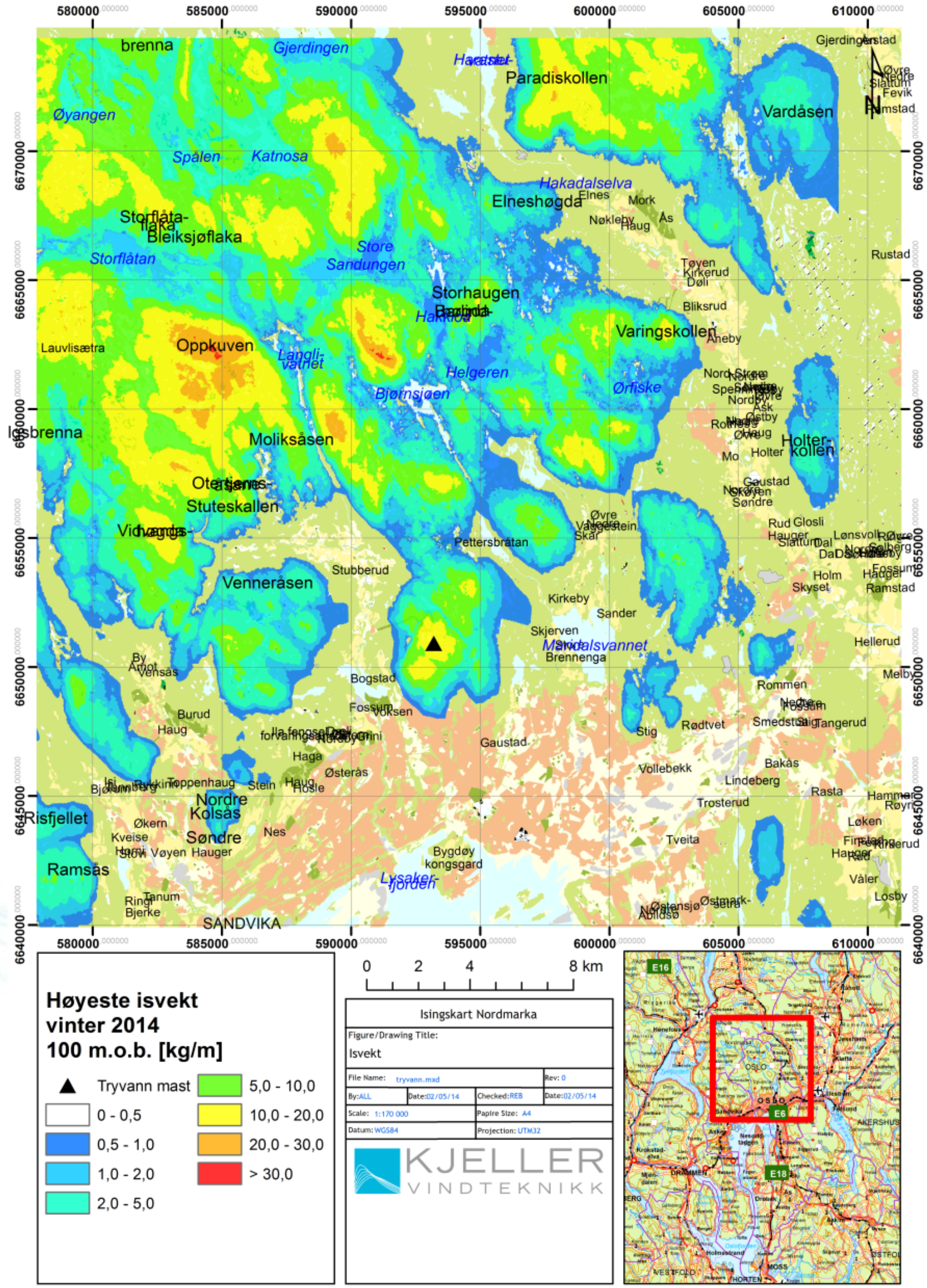
2014: Extreme icing in southern Norway

- Power lines collapsed
- Long periods with sustained fog and icing
- Map shows maximum 100 m.a.g.l. iceloads near Oslo



Inspection of ice in mast (~100 m.a.g.l.)









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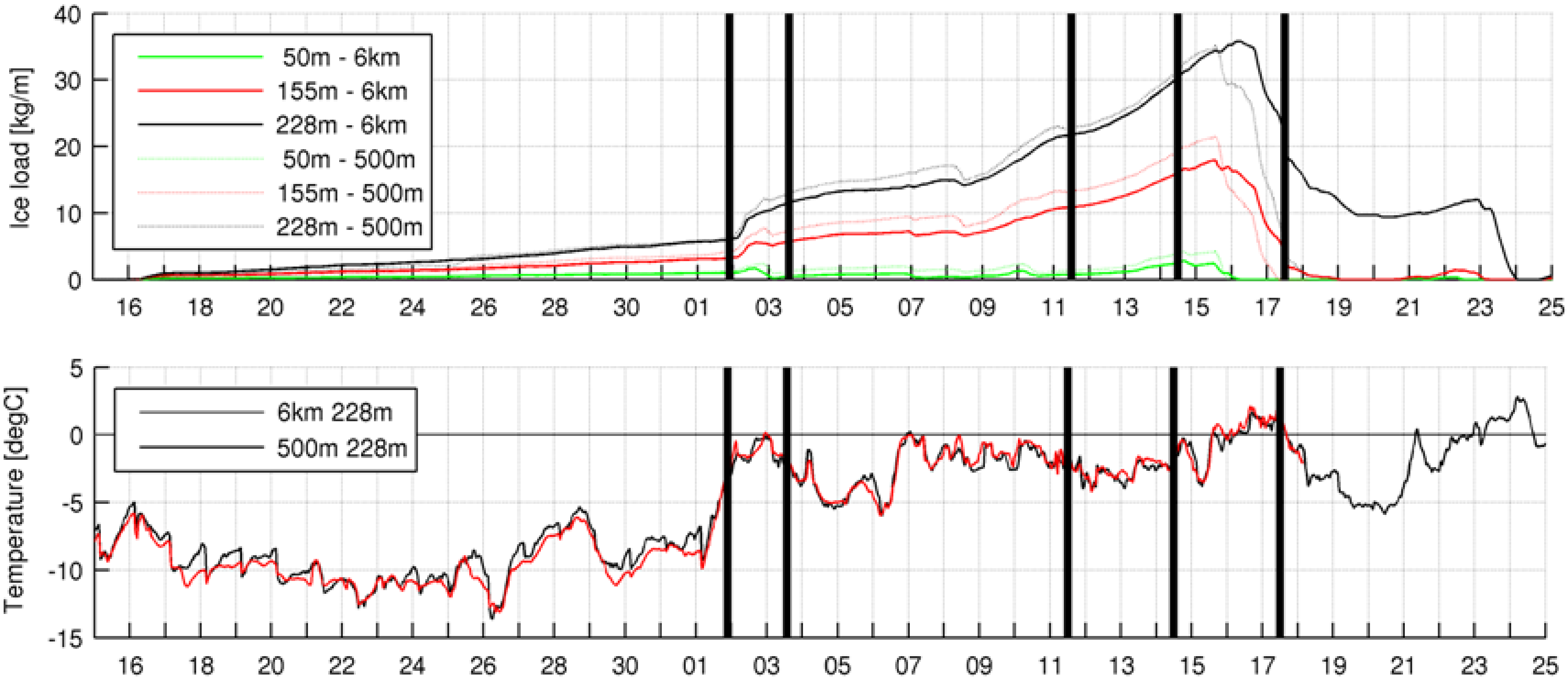
Excellent conditions for on-site inspection of icefall

- Inspections (black bars) in the period from 15th of January until 25th of February 2014



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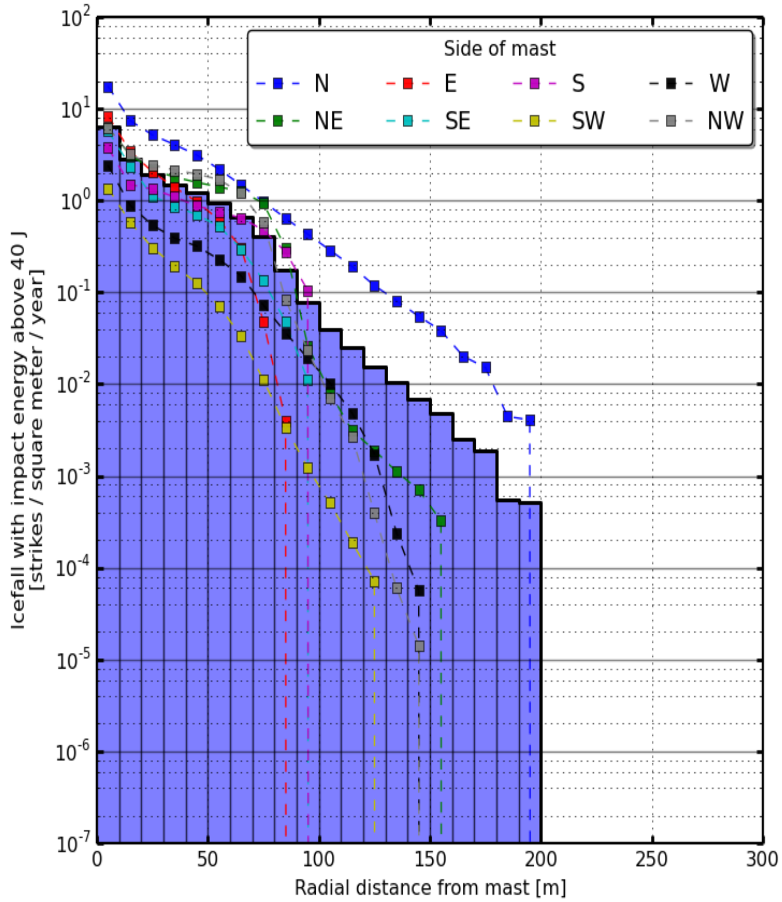
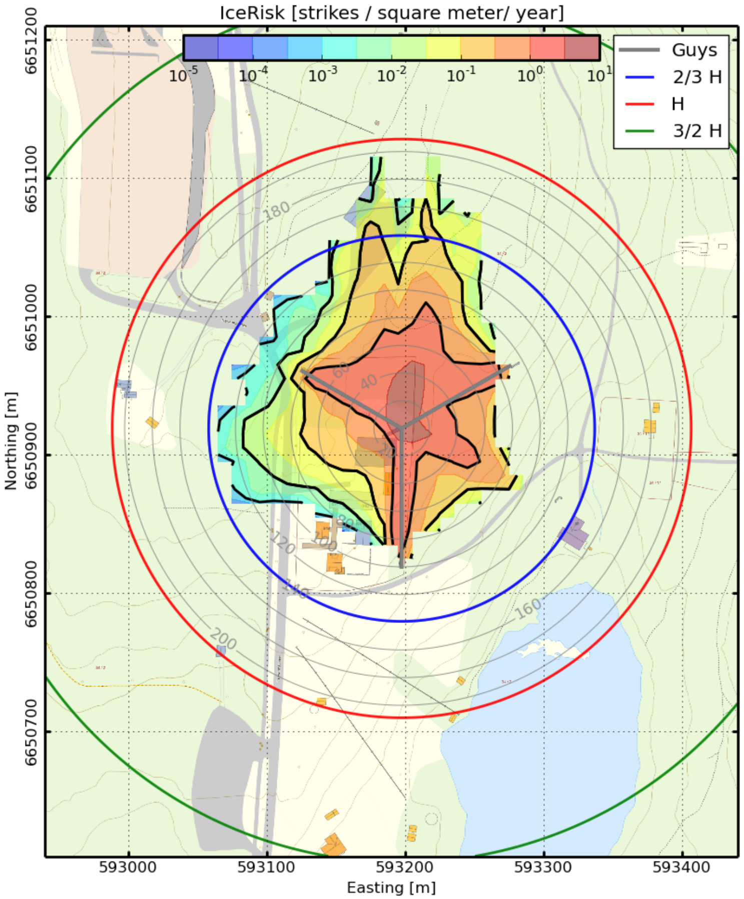
Separate probability map using wind and icing conditions for Winter 2014





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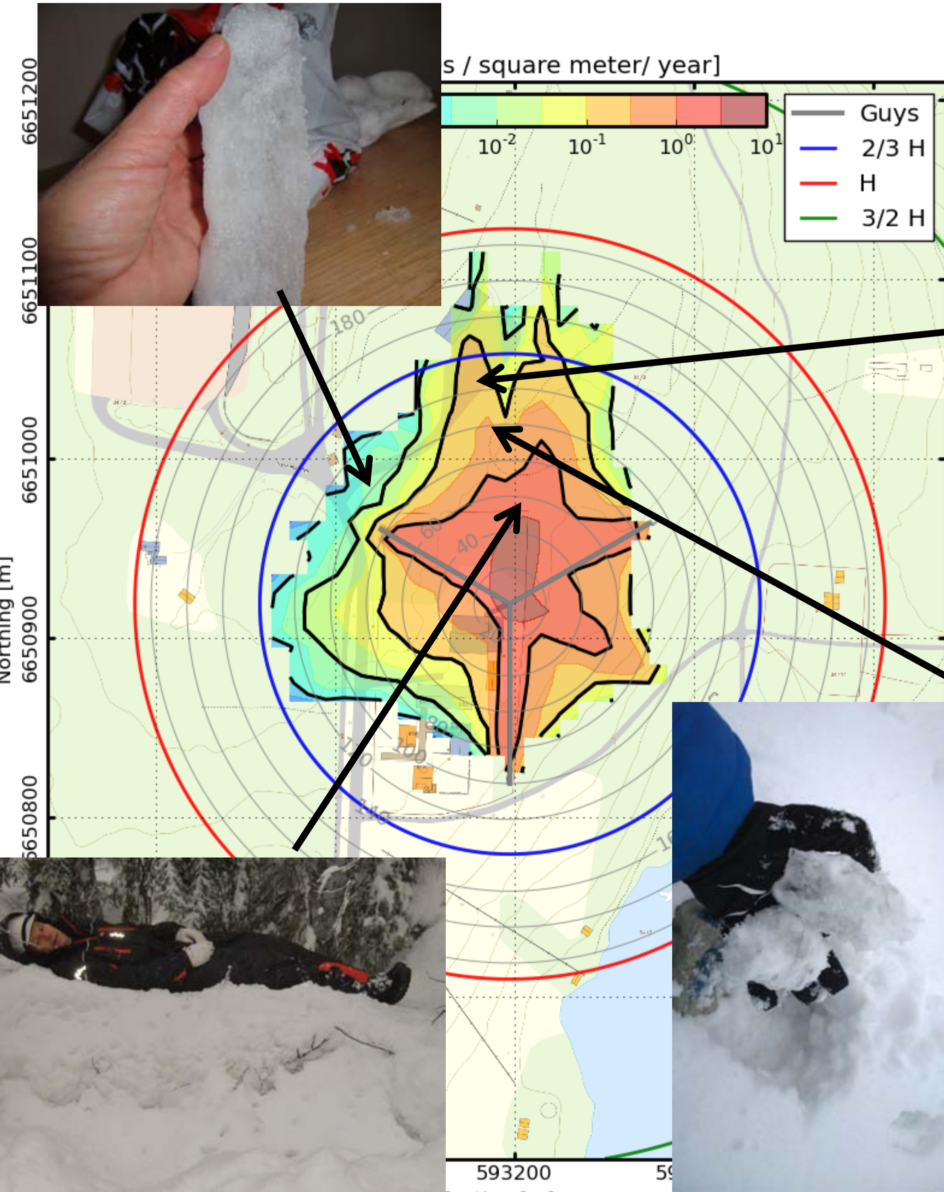
Inspection of area surrounding mast



30 cm craters

50 cm craters

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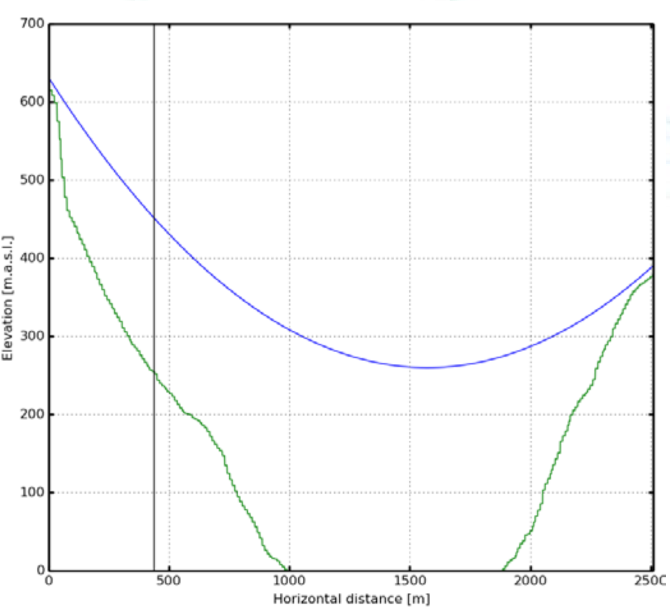
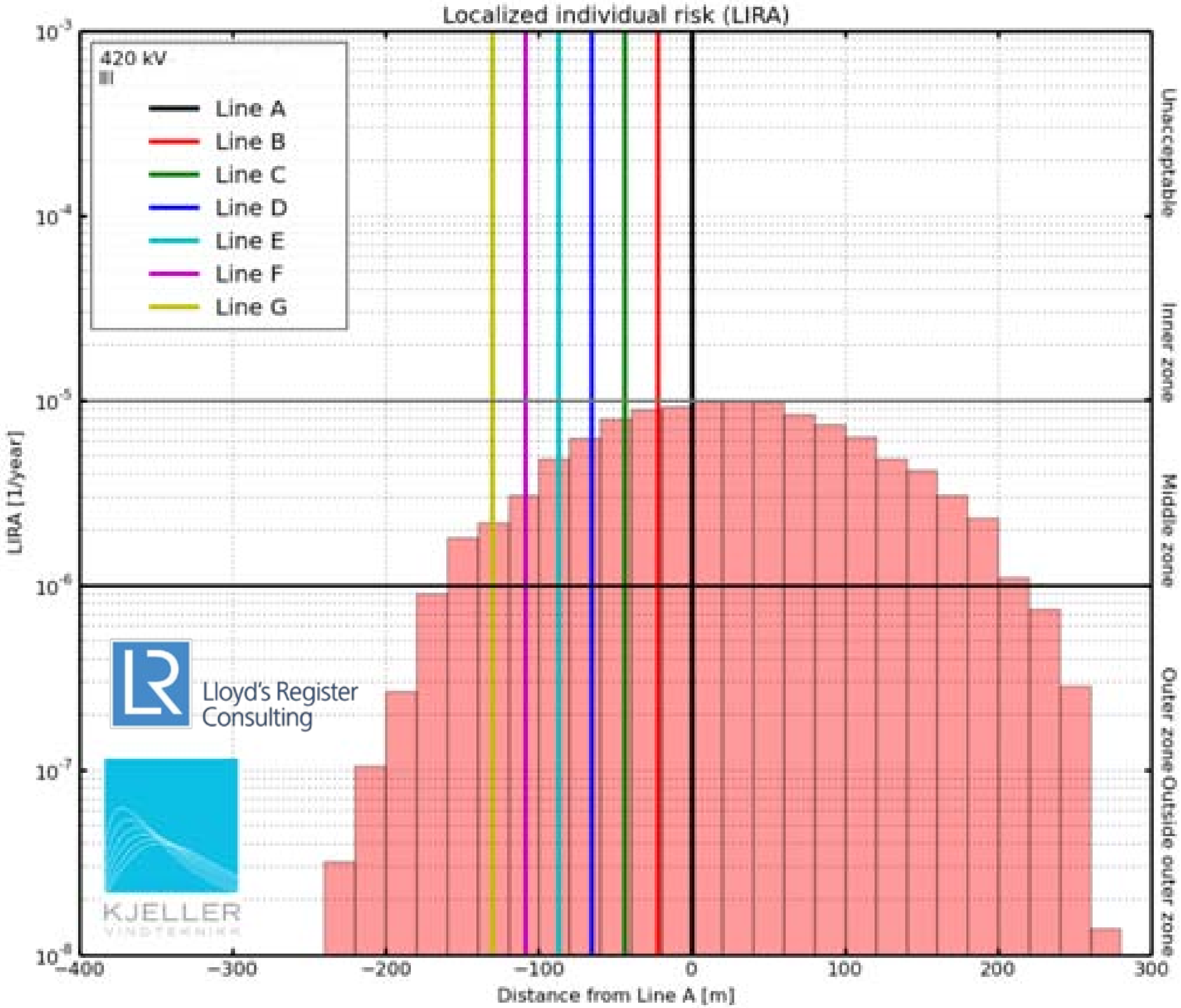
Norwegian fjord crossing span: Acceptable risk for scattered houses, but no error margin with current assumptions.

3 kg/m as 50 year ice load
6 cm conductor
2.5 cm radial ice thickness
Freely rotating ice cubes
Density 500 kg/m3
Assumed conservative

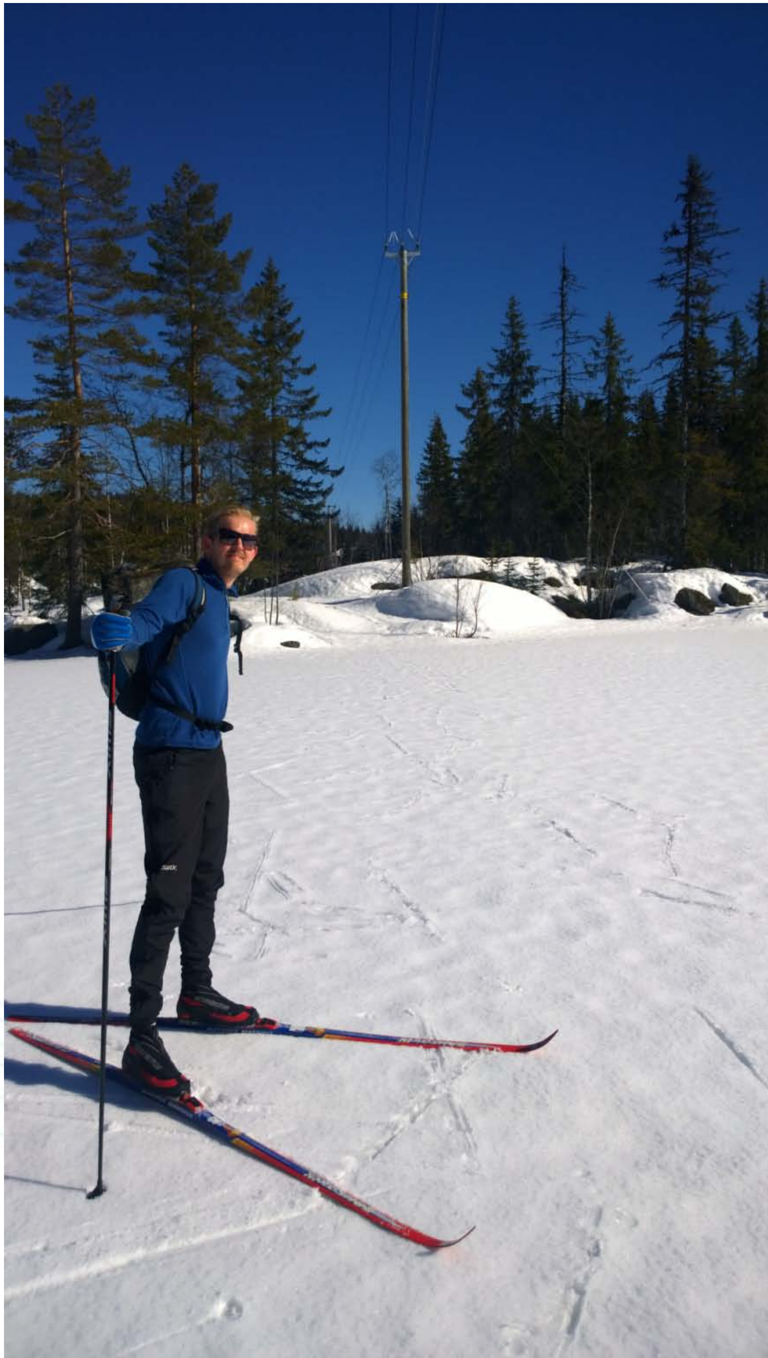




IceRisk analyses for the considered powerlines are especially sensitive (wet snow)

- For a line with diameter 56.7 cm, a 3 kg/m modeled wet snow iceload corresponds to a radial thickness of 2.5 cm (rho =500 kg/m3) around the conductor.
- Ice cube size distribution better suited for sites where the acreted iceloads are high
- Frozen wet snow is brittle, but rods can be shedded as longer sections.
- **Observations of ice debris sizes and drift distances (when and where)?**
- On the lower threshhold iceload enabling a dangerous ice piece?
- How often does the wet snow sleeve have time to freeze before shedding
- No lab experiments found in litterature for neither frozen sleeves nor thin sleeves
- Inflight erosion?

2014-03-25 Gjerdingen, Nordmarka, Oslo



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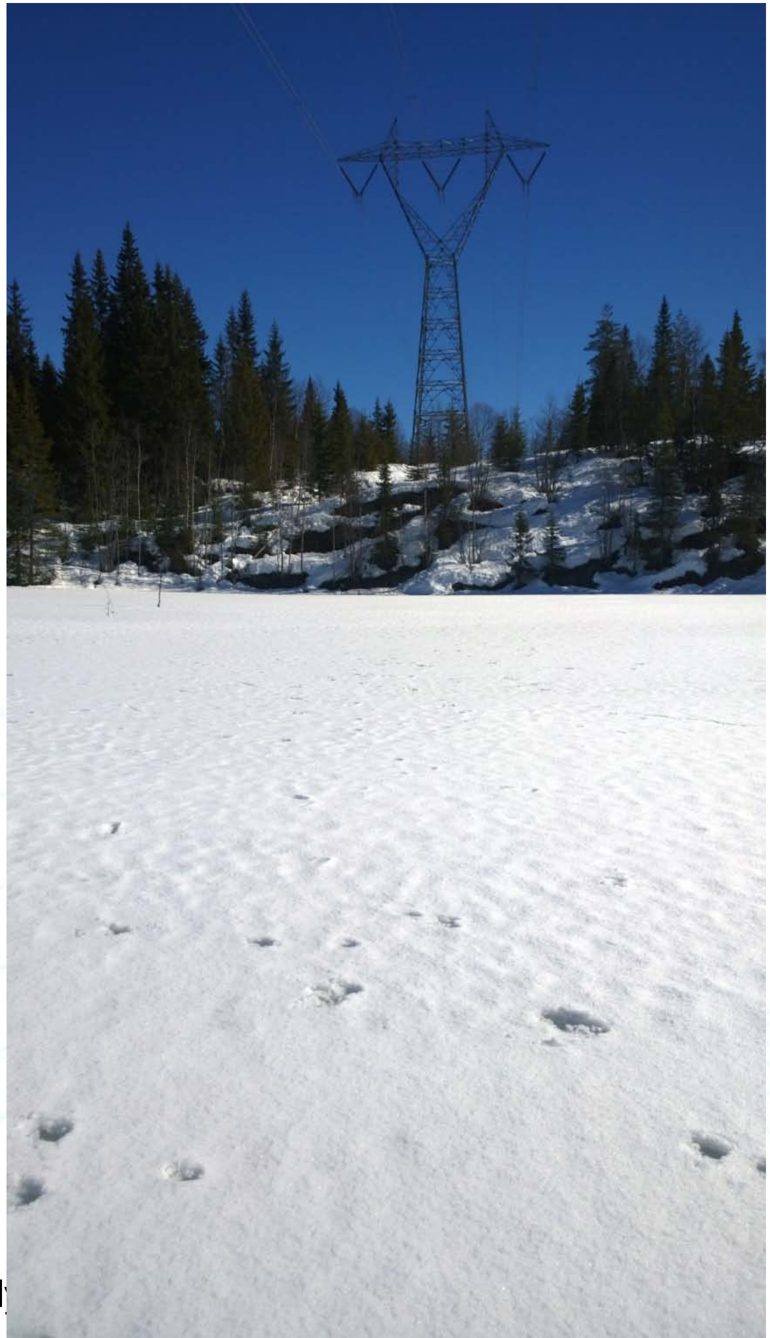

Jul

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Acknowledgement

- Work by colleges at KVT and LRC.
- Norkring, owner of telecom mast at Tryvann (Oslo)
- Statnett as sponsor
- Article was written with partial funding from the FRonTLINES project.

Risk Evaluation

- Acceptance criteria for ice risk not clearly defined in regulations, but owner is responsible for reducing risk to a minimum
- Suggested acceptance criteria for third person
- Risk evaluation for site
- Possible risk reducing measures for personnel permanent at site
- Possible risk reducing measures for third person

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Lloyd's Register
Consulting

Summary IWAIS article

- A trajectory model is used together with the energy limit of 40 J to differentiate dangerous ice throw or fall from other ice debris. Safety zones based on calculated risks are suggested based on similar criteria for other industries. For the icefall from the Tryvann communication mast we assumed freely rotating ice cubes of density 500 kg/m3 where the length of the ice piece (l) in each class is dimensioned after the accreted ice load (L) and density (rho), l = *(L/rho)^0.5*
- Based on current observations of differently shaped ice pieces with varying densities the safety distances calculated for the freely rotating ice cube holds and we consider the calculated ice fall risk zones as highly accurate.
- For ice throw, the safety zones have been calculated using a density of 800 kg/m3 since denser ice pieces can be thrown further than lighter ones and ice gets denser when accreted at high speeds which is the case for a moving turbine blade.