IceRisk: Assessment of risks associated with ice throw from wind turbine blades

PO.339

Rolv Erlend Bredesen, Kjeller Vindteknikk, Norway
Hicham Farid, Université du Québec à Chicoutimi, Québec, Canada
Michael Pedersen, Dag Haaheim, Niklas Sondell, Statkraft, Norway
Simo Rissanen, Ville Lehtomäki, VTT, Finland
Gaute Gruben, SINTEF Materials and Chemistry, Norway
Arve Sandve, Lloyds Register Consulting, Norway

Abstract

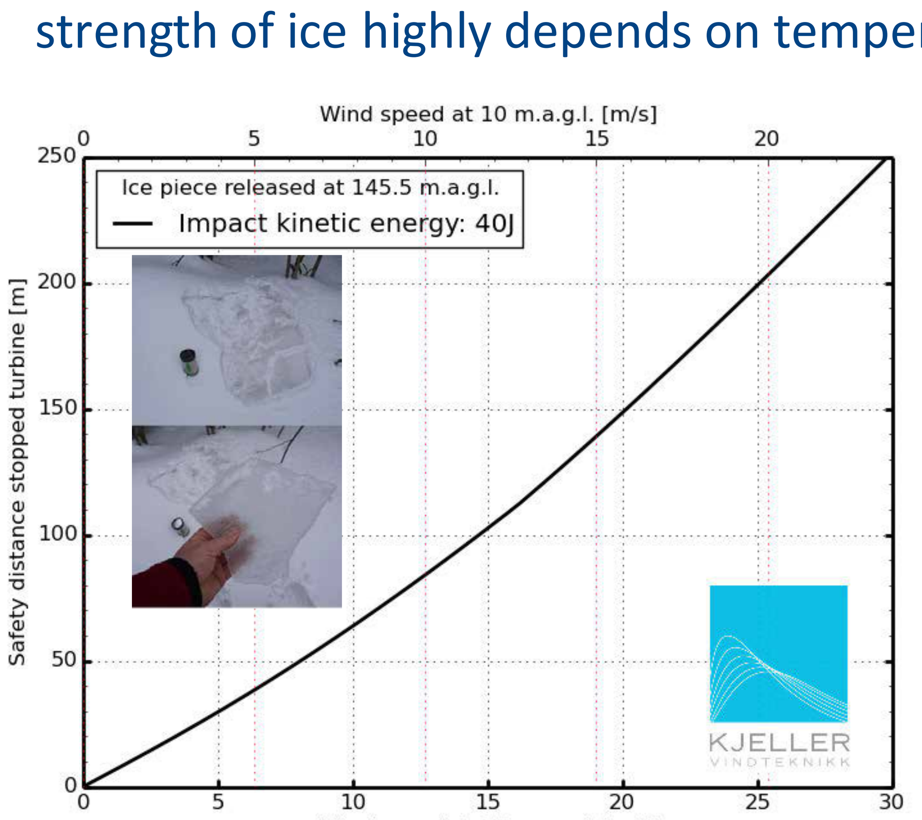
Uncertainties are large and empirical data is scarce when considering the risk assessment associated with ice throw from the blades of operational wind turbines. In order to assure a realistic risk assessment and to avoid an overly conservative risk picture, one should strive to make realistic assumptions at each sub-step in the risk assessment process. A general methodology to assess risks related to ice throw from turbines and falling ice debris in general was presented in [1] and applied on wind farms and turbines, tall masts, and fjord crossing power lines in Norway. Operational forecasts of risk zones relevant for maintenance purposes for the wind farm Stamåsen in Sweden has also been presented [2]. Here, a review is also given on ongoing and suggested improvements to the methodology of correctly assessing the risk associated with ice throw.

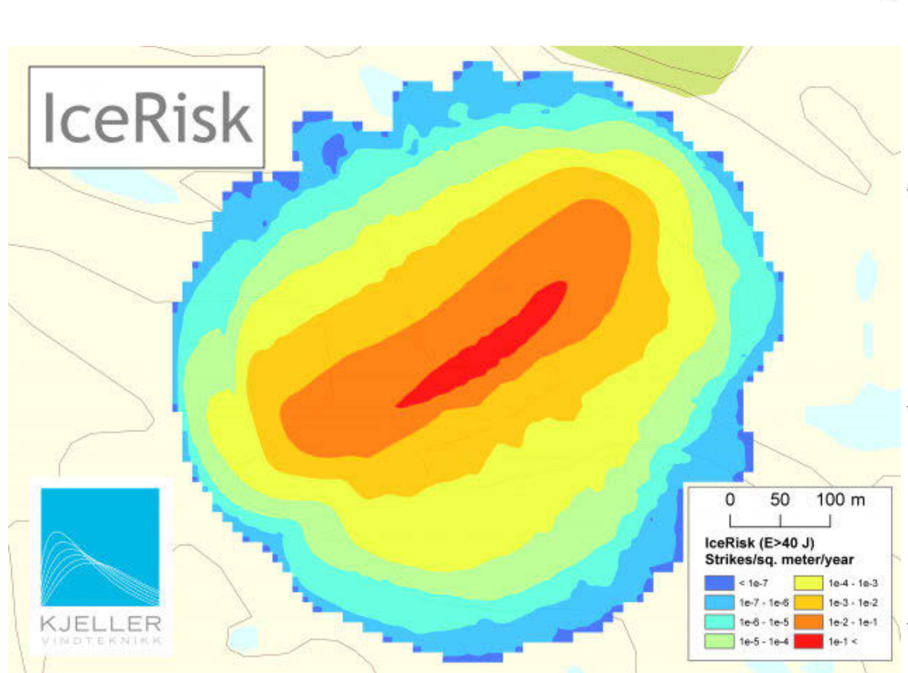
Approach

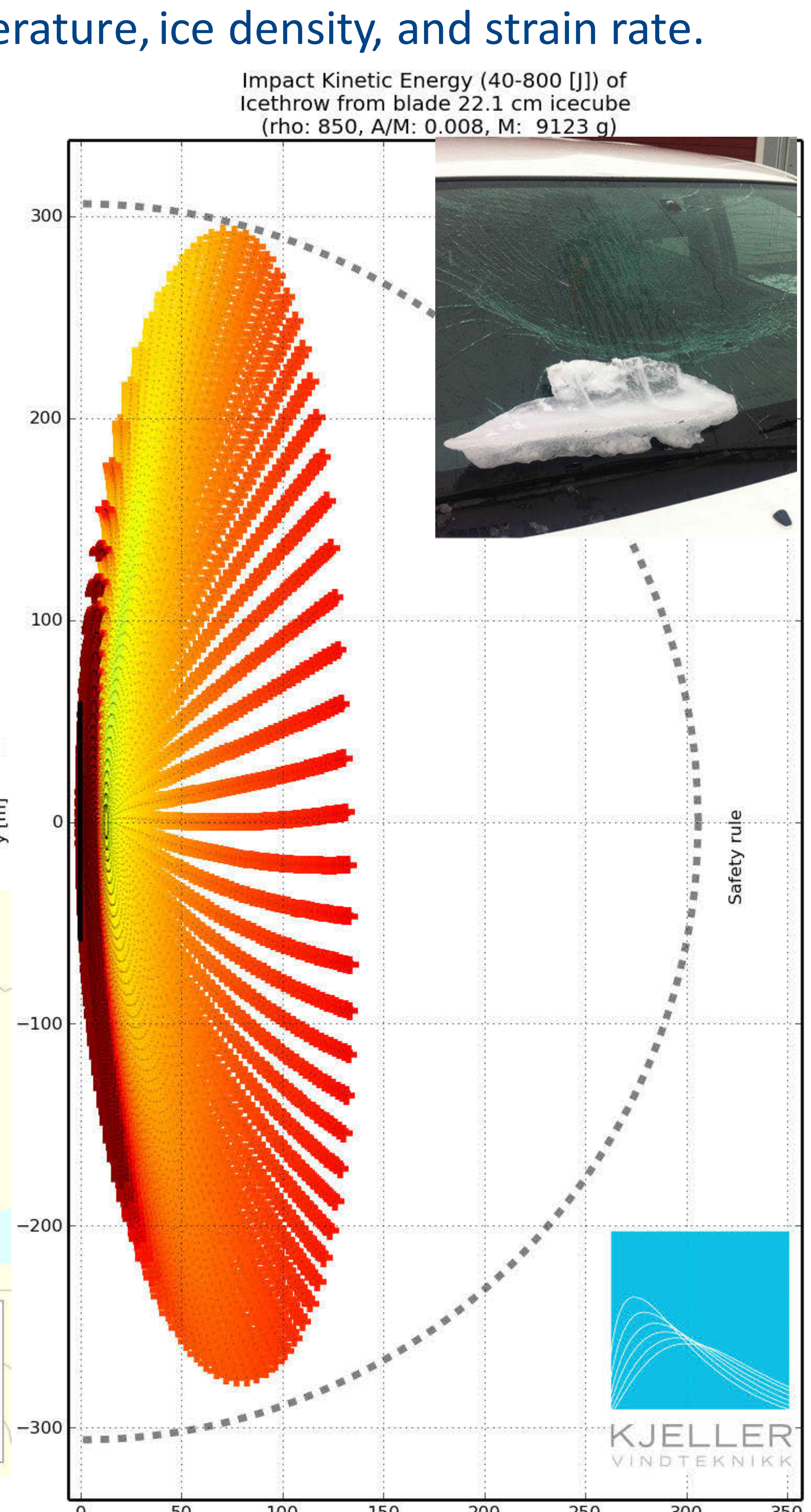
A ballistic trajectory model is used together with the energy limit of 40 J to differentiate dangerous ice throw or fall from other ice debris. Safety zones based on calculated risks was previously suggested [1] based on similar criteria for other industries. For the icefall a generic shape of freely 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 was employed and compared favorably with observations. For ice throw, the safety zones have been calculated using a typical density of 800 kg/m3 since denser ice pieces can be thrown further than lighter ones. 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 accurate.

Methods

Examples on calculated ice throw and ice fall (shed) distances are given below. Note that the results presented here, which are based on energy limit of 40 J, does not incorporate the crushing characteristics of ice as the strength of ice highly depends on temperature, ice density, and strain rate.



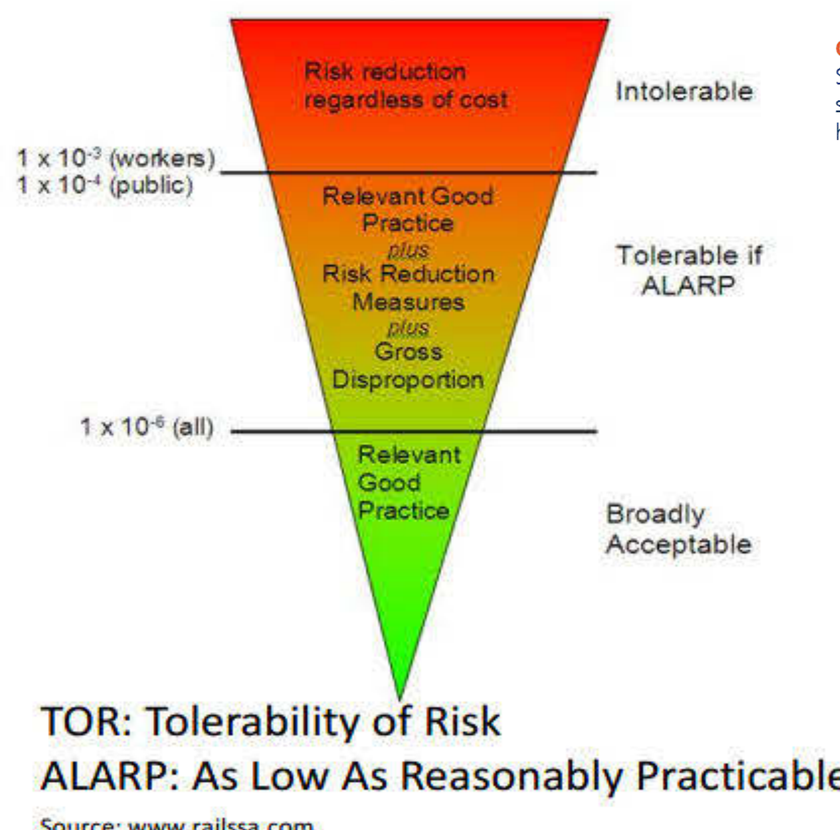


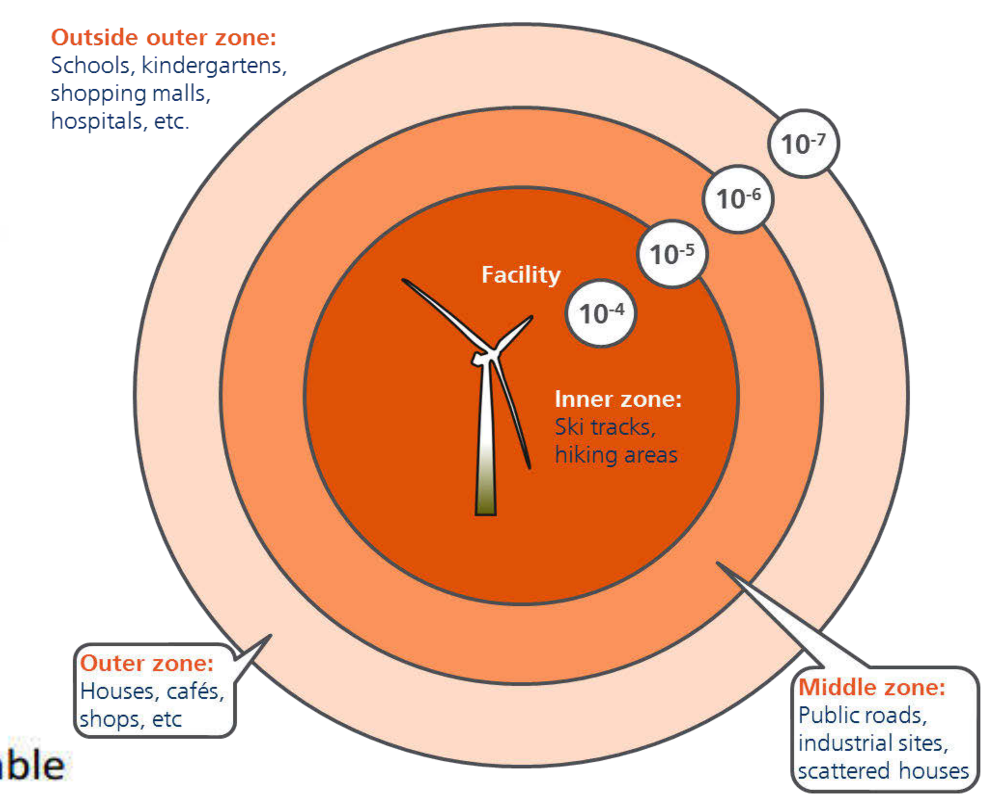


Upper left: The 40 Joule safety distance for ice-shed from the tip of a stopped wind turbine blade (smallest possibly fatal ice piece). Right: Birdsview of the span of impact positions for ice throw from a wind turbine operating with a blade velocity of 14 rpm and hub wind speed for 15 m/s (coloured by impact kinetic energy). Lower left: Example map on calculated probability of ice throw from a turbine with dominant wind from NW and SE during iced conditions.

Results

Standardized method of risk acceptance and communication: The inner safety zone for third persons (LIRA <=10^-4/year corresponding to the millennium ice piece hitting a square meter with impact kinetic energy above 40 J), where ski tracks and hiking areas are accepted has for 9 wind farms in Norway and Sweden been calculated in the range from 70 m for a site with little icing, 150 m for sites with moderate icing, and up to 240 m for a site with severe icing as all-sector averages.





Left: Risk reduction according to the ALARP principle as presented by IEA Task 19 suggestion [7]. Right: Lloyd's Register Consulting's suggested safety zones around installation that may cause risk of ice throw or ice fall. The numbers indicate the iso-risk contours for localised individual risk (LIRA), the probability that an average unprotected person, permanently present at a specified location, is killed during one year due to ice fall or throw from the facility. [1][7]

Conclusions

The furthest ice throw distances suggested by ballistic models have not yet been confirmed, however with increasing empirical evidence we expect the safety distances to be addressed with a higher level of certainty. Uncertainties and simplifications still exist in the presented IceRisk methodology, though with incremental improvements and increasing empirical evidence the precision in such analyses will increase. The advantages of using the presented assumptions are evident: 1) the method enables comparison of the risk related to falling and thrown ice, between sites and different installations and 2) the method could be applied by others in the community to compare with their own models and experience, especially regarding the size of and risk level associated with the ice throw risk zones around turbines. Such a scrutiny is welcome and wanted as the community improves the awareness and knowledge with respect to the safety issue. Ongoing improvements are listed below:

- Improvements are made to the ice debris size distribution by utilizing e.g. the TurbIce model [6] for detailed blade ice accretion calculation.
- Review of material properties of ice at different densities and temperatures relevant for i) impact studies, and ii) modeling of shedding [3], [4].
- Review of damage criteria for blunt impacts against the human body [8].
- Improvements for impact analysis beyond using the 40 J limit for possibly fatal ice debris as the assumption becomes conservative with decreasing ice densities [8].

References

[1] R. E. Bredesen and H. Refsum, "Methods for evaluating risk caused by ice throw and ice fall from wind turbines and other tall structures," in IWAIS 2015. 16th International workshop on atmospheric icing of structures. ISBN 978-91-637-8552-8.

[2] R. E. Bredesen, "Ice risk forecast system for operational wind farms," in WinterWind, 2016.

[3] H. Farid, M. Farzaneh, A. Saeidi, and F. Erchiqui, "A contribution to the study of the compressive behavior of atmospheric ice," Cold Reg. Sci. Technol., vol. 121, pp. 60–65, Jan. 2016.

[4] H. Farid, "Experiments on atmospheric ice under different conditions," 2016.

[5] ISO/TC98/SC3/WG6: Atmospheric icing of structures, International Standard, ISO 12494, 2000

[6] Makkonen, L., Laakso, T., Marjaniemi, M., and Finstad, K. J. Modelling and prevention of ice accretion on wind turbines. Wind Engineering, 25:3-21, 2001.

[7] Wadham-Gagnon et al., 2015. IEA Task 19 - Ice Throw Guidelines. Winterwind 2015.

[8] Bredesen, R.E., 2015. IceRisk - Damage Criteria. Literature study on the damage potential for falling ice debris. KVT Memorandum. KVT/REB/2015/N071.