Making Ice Fall and Ice Throw Predictions More Reliable

Winterwind Åre, February 6th, 2018

Sten Barup

Co-Authors: Monelle Comeau, Wojciech Martko, Héctor Rodríguez, Nina Weber, Uta Zwölfer-Dorau

ENERCON
ENERGY FOR THE WORLD

AGENDA

1 The Challenge

Past and current practices I Future solutions

2 Ice Throw and Ice Fall Research at ENERCON

Measurements I Database I Model development I Validation

3 Next steps

For the field I For ENERCON

1 I THE CHALLENGE

Skogberget, Sweden

- Young field
- No standards or guidelines
- Models based on large number of assumptions

Quantified risks instead of subjective feelings and fear

PAST

- Empirical formulas
  - ice throw $d = 1.5(D + H)$
    (WECO, 1998)
  - ice fall $d = \frac{\left(\frac{D}{2}+H\right)*v}{15}$
    (Seifert, 2003)
- Measurement campaigns
- Trajectory models
- Hypothesis on icing properties

CURRENT DEVELOPMENT

- Automated measurement systems
- Build larger database
- Validate underlying theories
- Regulations
- IEA task 19 Guideline

More elaborate and uniform risk assessments

AGENDA

1 The Challenge

Past and current practices I Future solutions

2 Ice Throw and Ice Fall Research at ENERCON

Measurements I Database I Model development I Validation

3 Next steps

For the field I For ENERCON

2.1 I ICE PIECE MEASUREMENT CAMPAIGN

- Collaboration with Meteotest
- 4x E-82
- Different operating modes
- 3 years
- Site with frequent icing

  (IEA ice class 4)
- Over 25 000 pieces

2.1 I ICE PIECE DATABASE

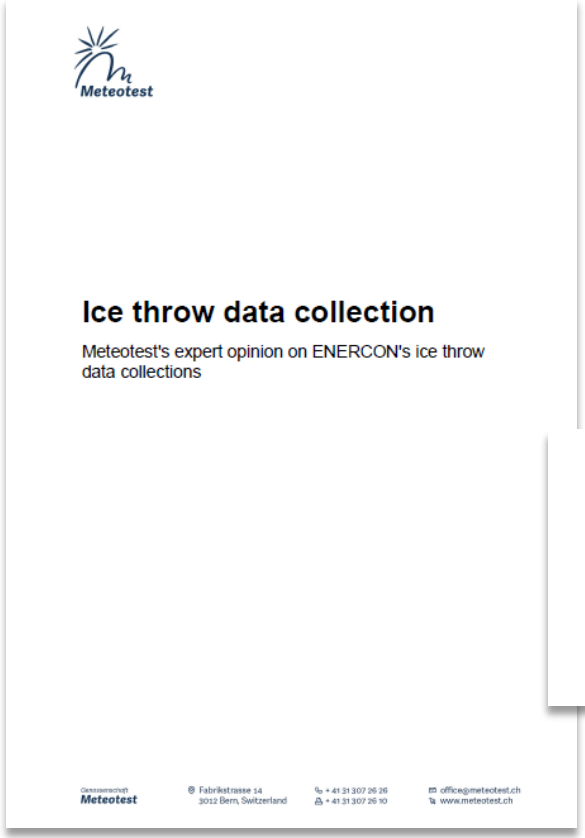
SIGNIFICANT DATABASE

- Amount of Data
- Several operating/heating modes
- Inter-annual variability captured
- Quality controlled

RECORDED DATA

- Date and time
- Turbine
- Number of pieces/fragments
- Position of pieces
- Weight & dimensions
- Type of icing
- Photo filename
- Comments

2.1 I DATABASE APPROVED BY EXTERNALS


Meteotest

Ice throw data collection

Meteotest's expert opinion on ENERCON's ice throw data collections

Gesellschaft Meteotest

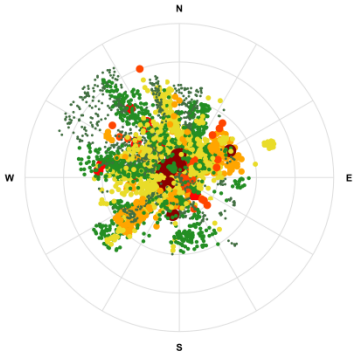
Fabrikstrasse 14
3012 Bern, Switzerland

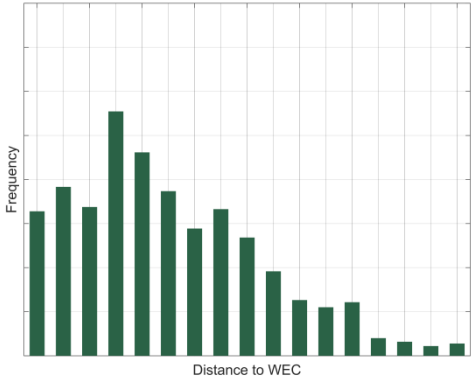
+ 41 31 307 26 26
+ 41 31 307 26 10

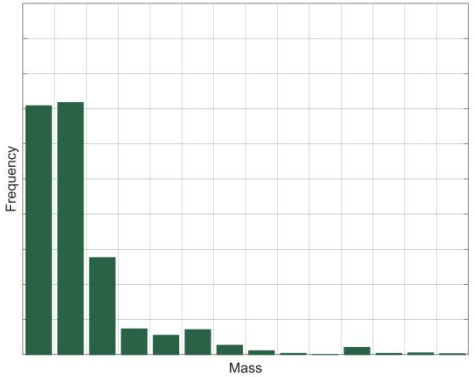
office@meteotest.ch
www.meteotest.ch

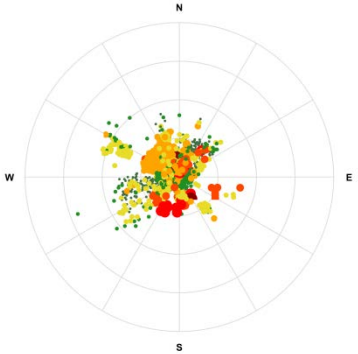
We can therefore conclude that the ice throw data collection has been conducted in the best possible way. In addition, the amount of data collected is a significant increase of a very sparse data base of ice throw data worldwide. ENERCON's database of ice pieces is most likely the largest data base of ice throw field collection in the world. This large collection provides relevant information about ice piece distributions regarding mass and distances.

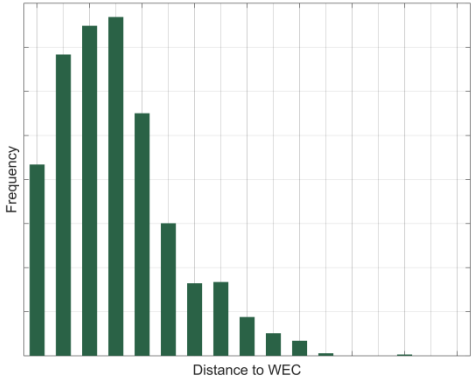
2.1 I RESULTS FOR DIFFERENT OPERATION MODES

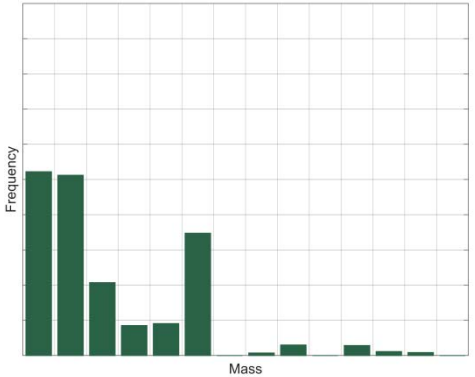










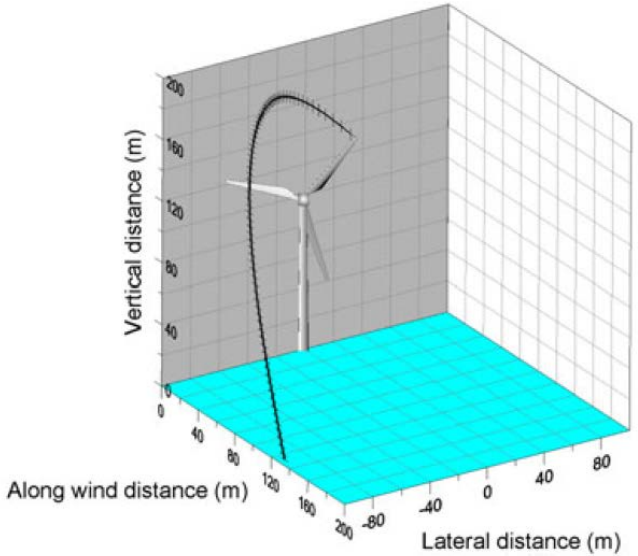


MODEL

- Safety distance method
- Trajectory model

SPECIAL ATTENTION

- Conservative assumptions
- Accurately represent ENERCON product line



S. Biswas et al., 2011
A Model of Ice Throw Trajectories from Wind Turbines.

MODEL APROACH

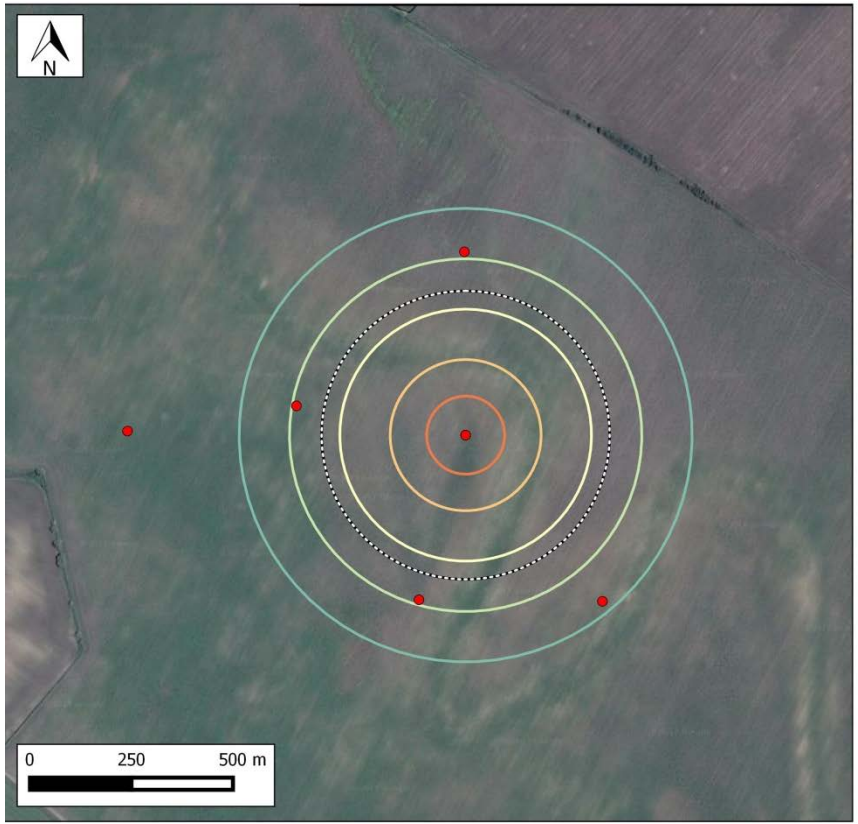
- Industry best practice
- Ice fall and throw distance equations

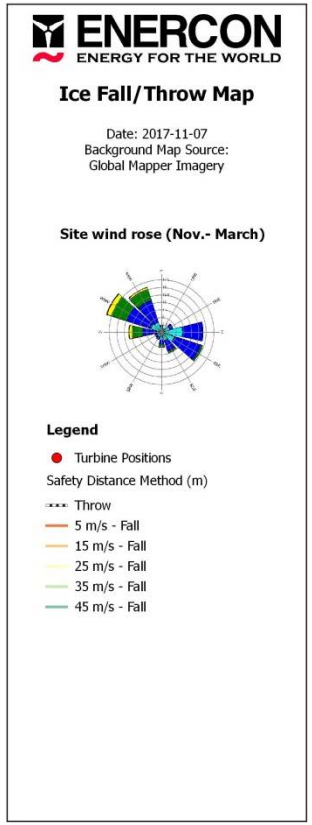
INPUT

- Layout

OUTPUT

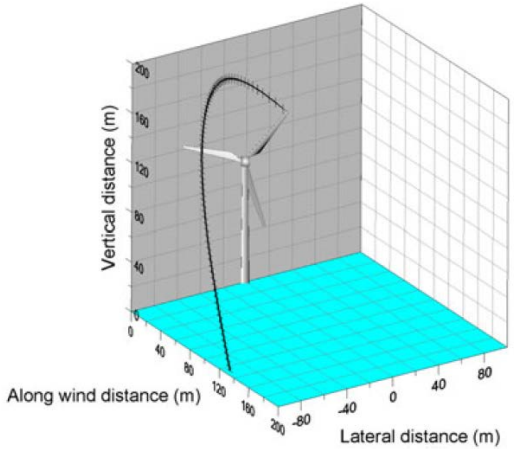
- Safety distances for ice throw and fall





2.2 I TRAJECTORY MODEL – MODEL APPROACH

- Monte Carlo Simulation
- Underlying distribution and parameters
  - Measured probability distribution Area/Mass
  - Ice distribution on blade
  - Drag coefficient
  - Probability distribution rotor position
  - Sector wise wind conditions
  - Rotational speed curves
- Ice fragments released per year
  - Probability of icing at the site
  - Rotor size
  - Heating and operational mode



S. Biswas et al., 2011
A Model of Ice Throw Trajectories from Wind Turbines.

Probability of impact

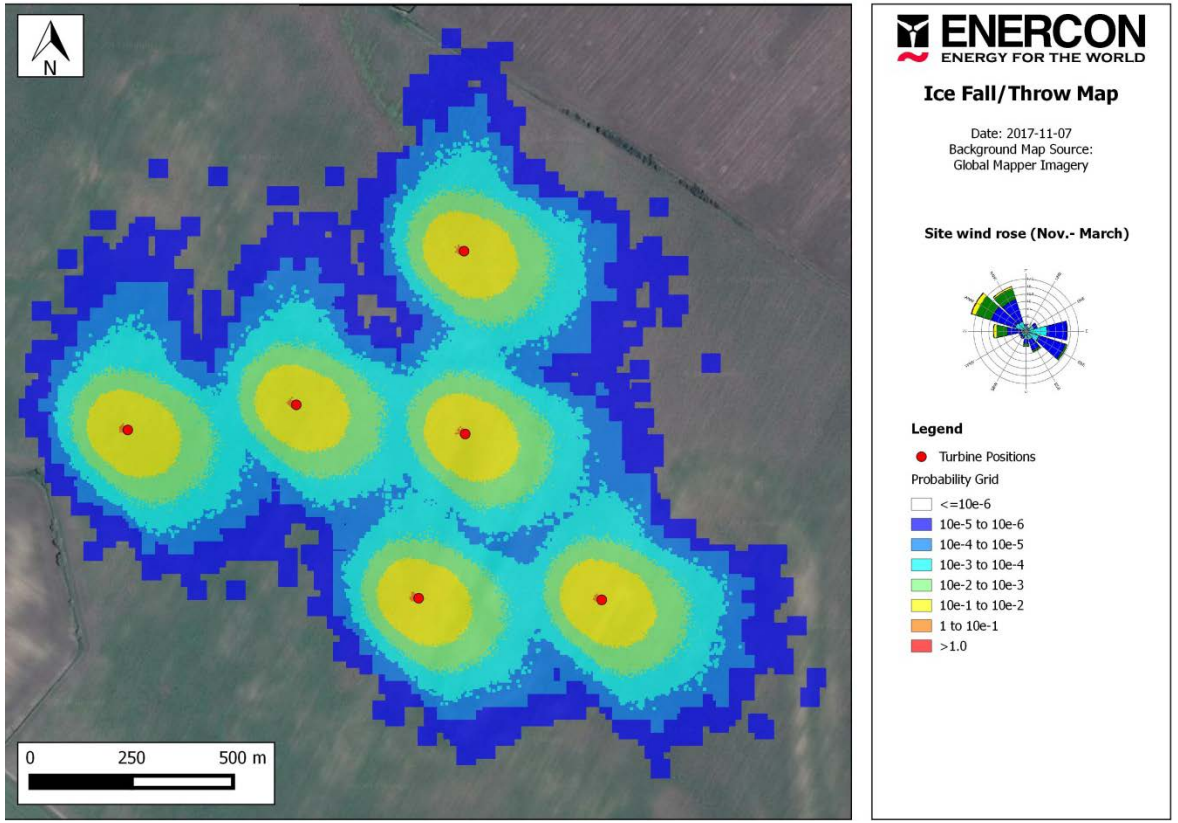
2.2 I TRAJECTORY MODEL – TURBINE IN OPERATION

INPUT

- Layout
- Wind conditions
- IEA Icing class
- Operational mode

OUTPUT

- Probability map for ice fall and ice throw



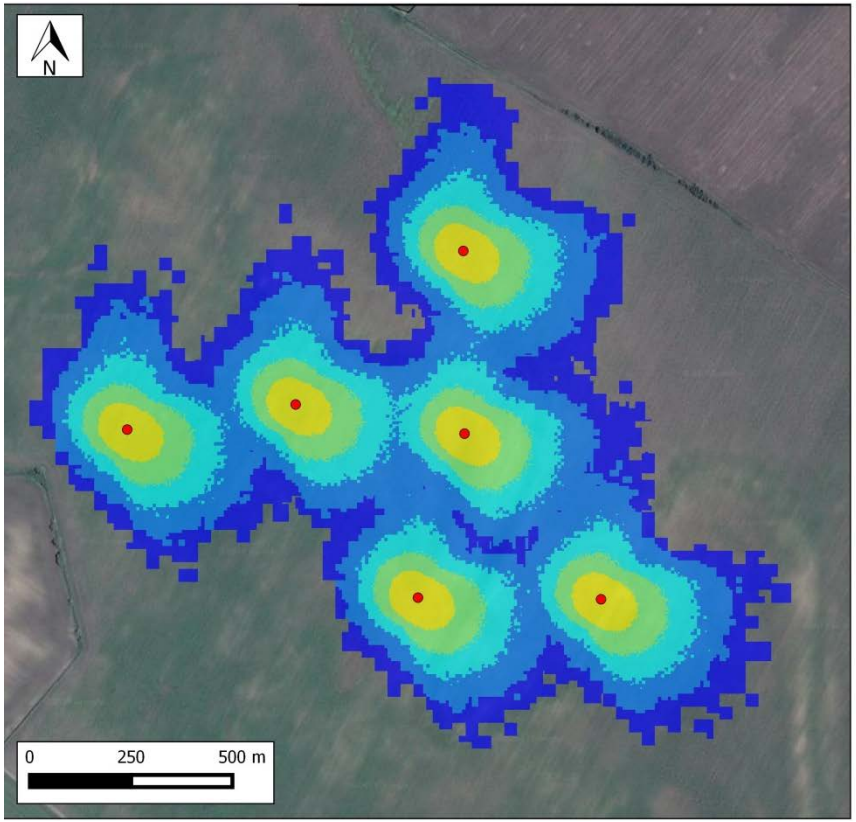
2.2 I TRAJECTORY MODEL – TURBINE IN STANDSTILL

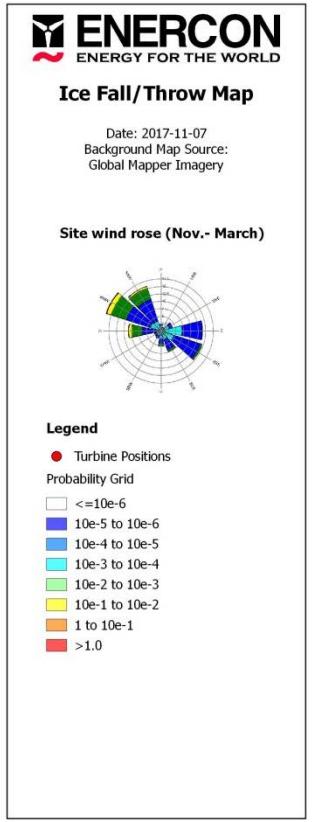
INPUT

- Layout
- Wind conditions
- IEA Icing class
- Operational mode

OUTPUT

- Probability map for ice fall and ice throw





CONCEPTUAL MODEL VALIDATION

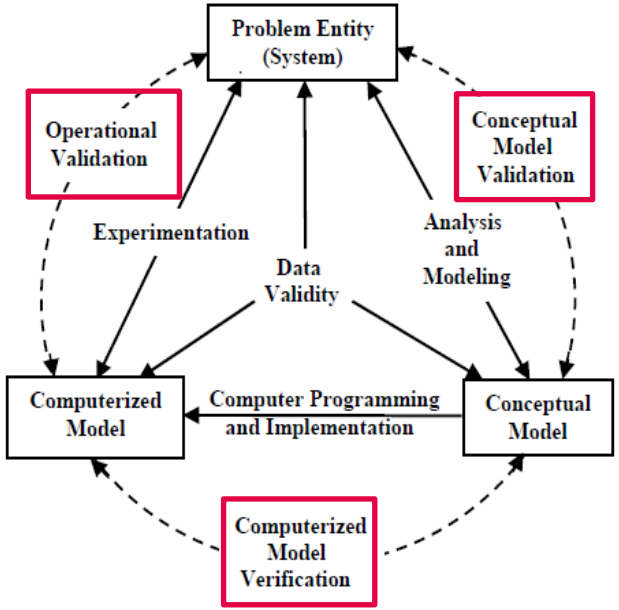
- Measurements
- Literature and industry best practice
- ENERCON internal R&D

COMPUTERIZED MODEL VERIFICATION

- Automated tests integrated into code
- Comparison to literature results
- Convergence of results and stability of model

OPERATIONAL VALIDATION

- Validation of model and procedure
- Validation of model for different operating modes



R. G. Sargent, 2011
Verification and Validation of Simulation Models.

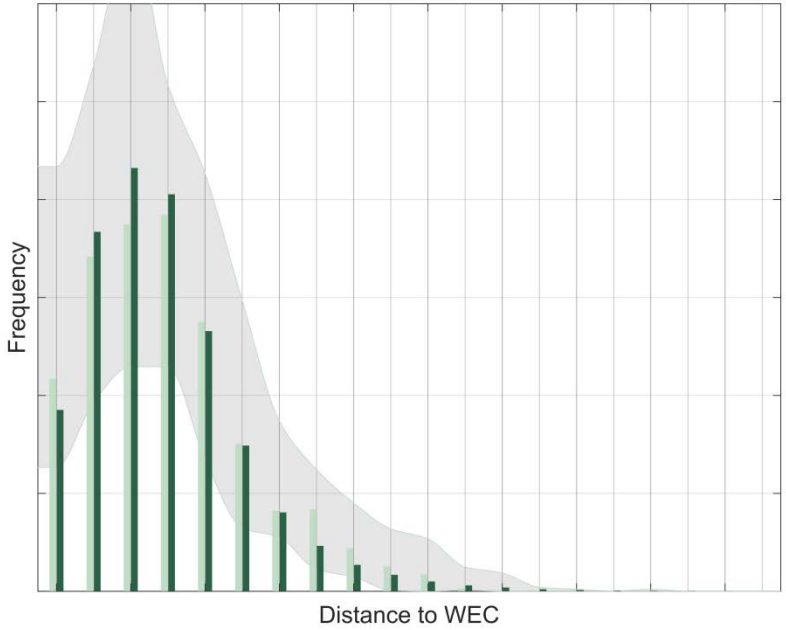
SAFETY DISTANCE METHOD

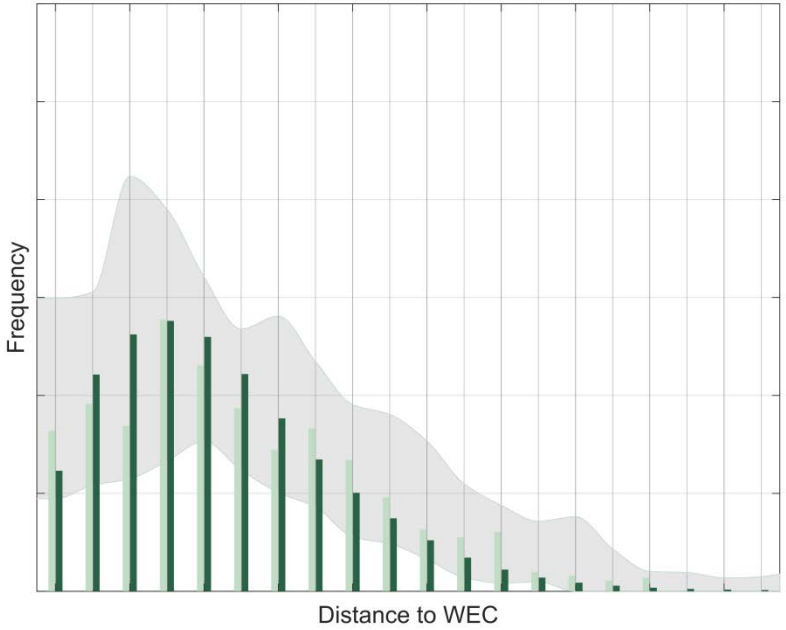
Rotor diameter [m]	Ice throw distance [m]	Ice fall distance 23m/s [m]	Maximum measured distance [m]	
			Measured	Uncertainty corrected
82	240	183	140	167
	240	183	170	203
	240	183	145	173
	240	183	140	167

- 4 turbines
- 3 winter seasons
- Different operation modes

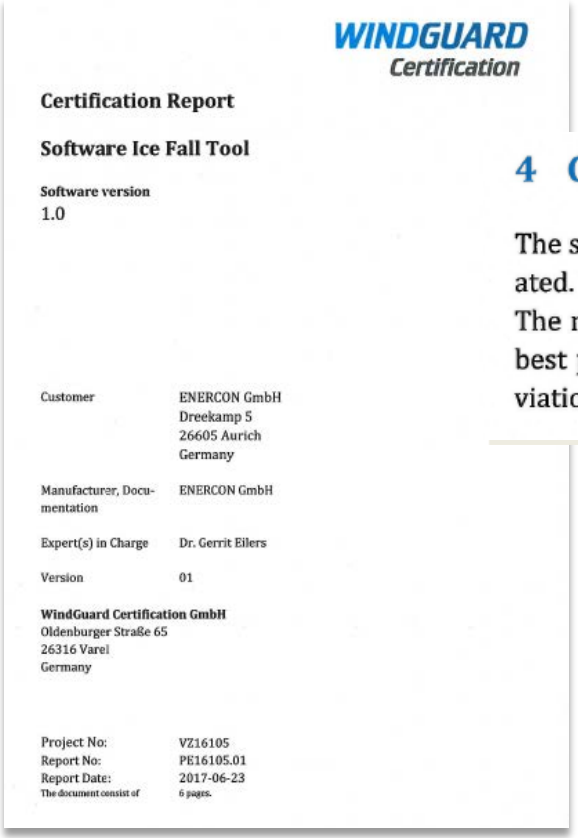
Distance measured < Distance calculated

TRAJECTORY METHOD





2.4 I MODEL CERTIFICATION



WINDGUARD
Certification

Certification Report

Software Ice Fall Tool

Software version
1.0

Customer	ENERCON GmbH Dreekamp 5 26605 Aurich Germany
Manufacturer, Documentation	ENERCON GmbH
Expert(s) in Charge	Dr. Gerrit Eilers
Version	01

WindGuard Certification GmbH
Oldenburger Straße 65
26316 Varel
Germany

Project No:	VZ16105
Report No:	PE16105.01
Report Date:	2017-06-23
The document consist of	6 pages.

4 Conclusion

The software Ice Fall Tool for calculating site specific ice fall or ice throw risk was evaluated. The documentation of the procedure and results has been assessed to be adequate. The methods and assumptions are in compliance with relevant standards and industry best practice. Deviations from the requirements were assessed to be negligible and deviations found in compared values are within technical limits.

WINDGUARD
Certification
Oldenburger Straße 65 · 26316 Varel
Tel. +49 (0)4451 - 9515 - 213
Fax +49-(0)4451-9515-218
Email: info@windguard-certification.de

AGENDA

1 The Challenge

Past and current practices I Future solutions

2 Ice Throw and Ice Fall Research at ENERCON

Measurements I Database I Model development I Validation

3 Next steps

For the field I For ENERCON

STANDARDS

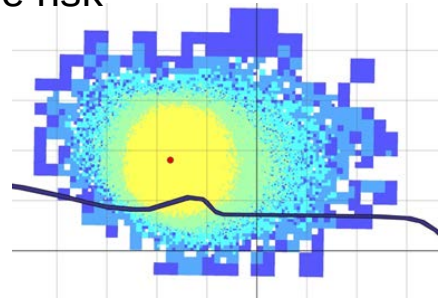
- Guidelines for ice fall and ice throw risk assessments

RESEARCH

- Refine measurement techniques
- Increase database

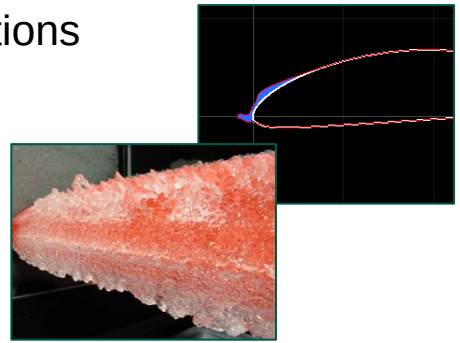
ENERCON MODEL

- Curtailment to decrease risk
- Detailed risk analysis



ENERCON R&D

- Ice accretion simulations and measurements



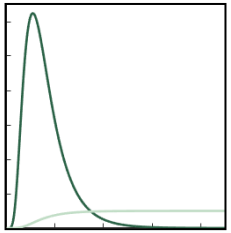
Making ice fall and ice throw predictions more reliable

OUR MODEL IS

- Created with an ***adequate level of conservatism***
- Built on the ***latest research***
- Based on the ***best ice measurement campaign to date***
- Carefully crafted to represent the ***specific parameters of the*** **ENERCON** ***fleet***
- ***Validated and certified***

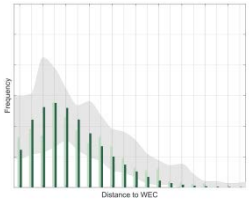
MEASURE

EVALUATE



REPRESENT

VALIDATE



THANK YOU FOR YOUR ATTENTION

ENERCON
ENERGY FOR THE WORLD

ENERCON GmbH
Dreekamp 5 | D-26605 Aurich
Telephone: +49 4941 927-0 | Fax: +49 4941 927-109

LEGAL NOTICE

Publisher

ENERCON GmbH ▪ Dreekamp 5 ▪ 26605 Aurich ▪ Germany
Telephone: +49 4941 927-0 ▪ Fax: +49 4941 927-109 ▪ e-mail: info@enercon.de ▪ Internet: http://www.enercon.de
Managing Directors: Hans-Dieter Kettwig, Simon-Hermann Wobben
Court of jurisdiction: Aurich ▪ Commercial register number: HRB 411 ▪ VAT ID No.: DE 181 977 360

Document details

Dokument-ID	03_1_07_Barup_Making_ice_fall_and_throw_predictions_for_wind_turbines_more_reliable_Pub_v1
Note	

Date	**Language**	**DCC**	**Plant / Department**
2018-02-02	en		Wind Farm Engineering

Revisions

Rev.	**Date**	**Change**
0	2018-02-02	Document created