

Making Ice Fall and Ice Throw Predictions More Reliable

Winterwind Åre, February 6th, 2018

Sten Barup

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1 The Challenge

Past and current practices | Future solutions

2 Ice Throw and Ice Fall Research at ENERCON

Measurements | Database | Model development | Validation


3 Next steps

For the field | For ENERCON



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 $d = 1.5(D + H)$
(WECCO, 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**

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2.1 | 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



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



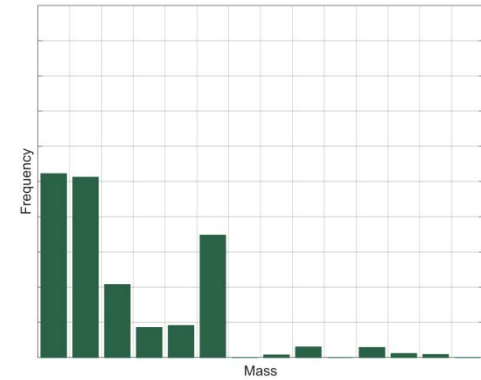
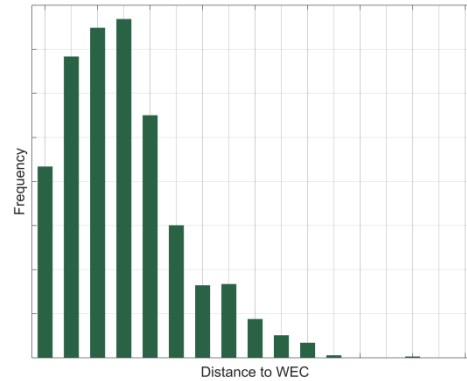
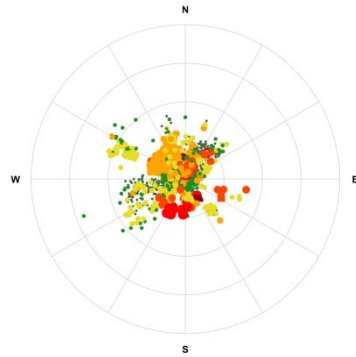
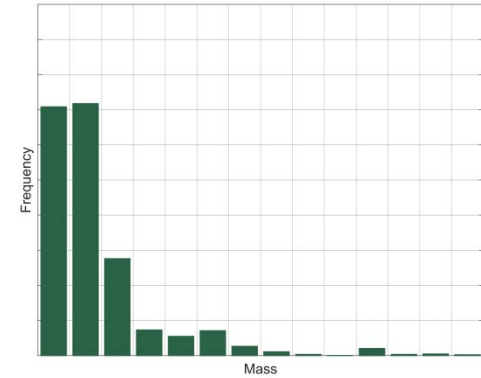
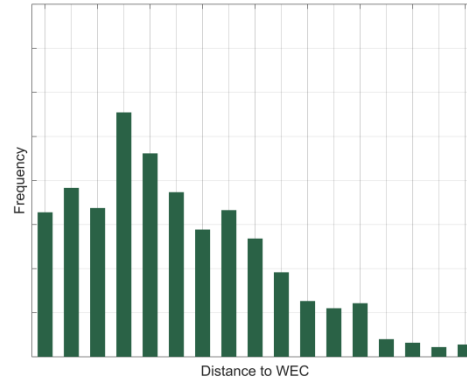
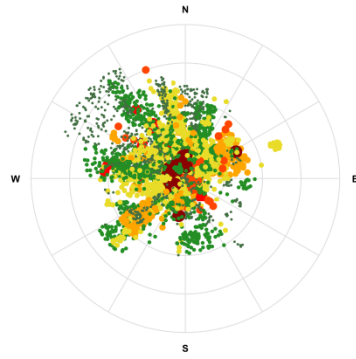


Ice throw data collection

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

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 | RESULTS FOR DIFFERENT OPERATION MODES

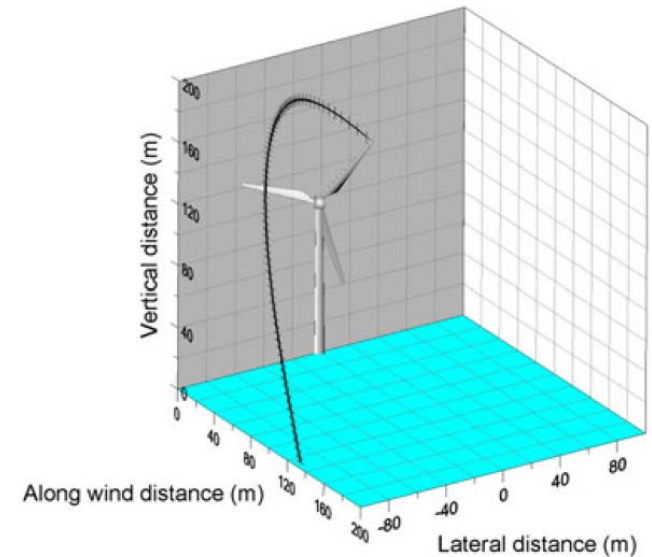


MODEL

- ~ 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 APPROACH

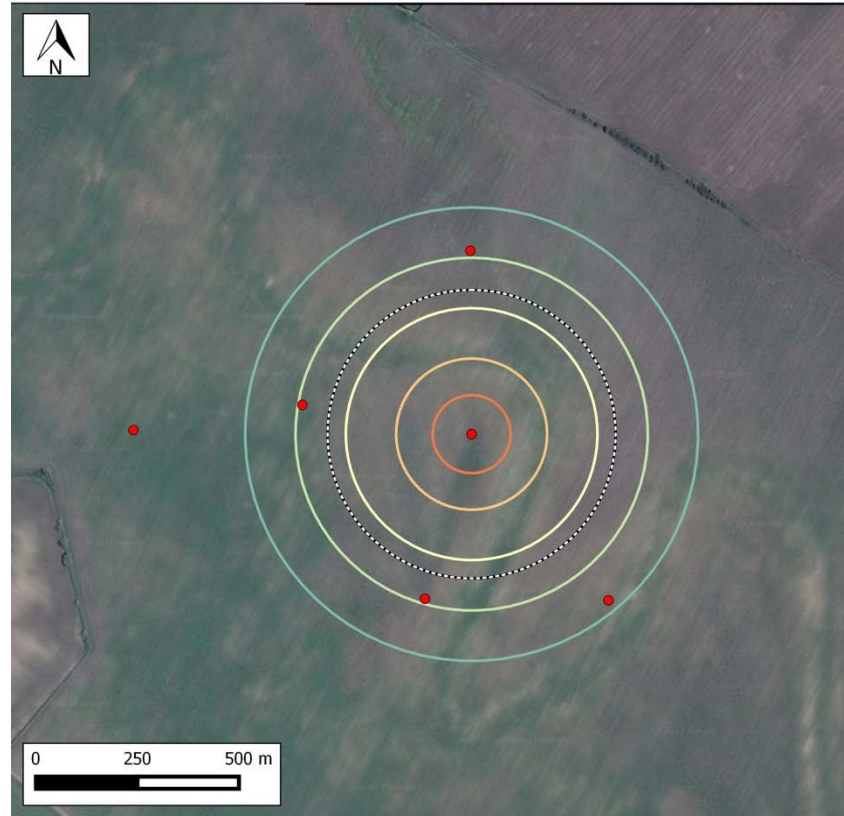
- ~ Industry best practice
- ~ Ice fall and throw distance equations

INPUT

- ~ Layout

OUTPUT

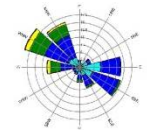
- ~ Safety distances for ice throw and fall



Ice Fall/Throw Map

Date: 2017-11-07
Background Map Source:
Global Mapper Imagery

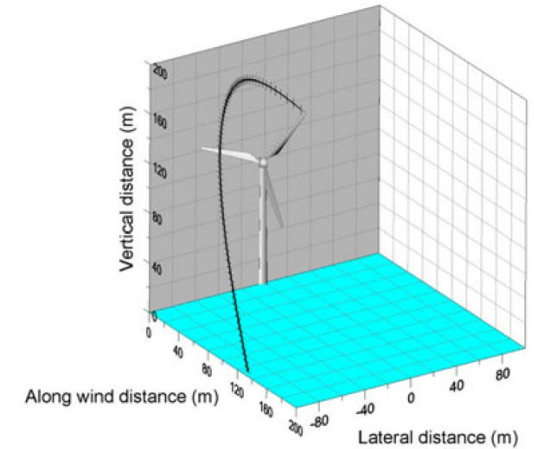
Site wind rose (Nov.- March)



Legend

- Turbine Positions
- Safety Distance Method (m)
 - Throw
 - 5 m/s - Fall
 - 15 m/s - Fall
 - 25 m/s - Fall
 - 35 m/s - Fall
 - 45 m/s - Fall

- ~ 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

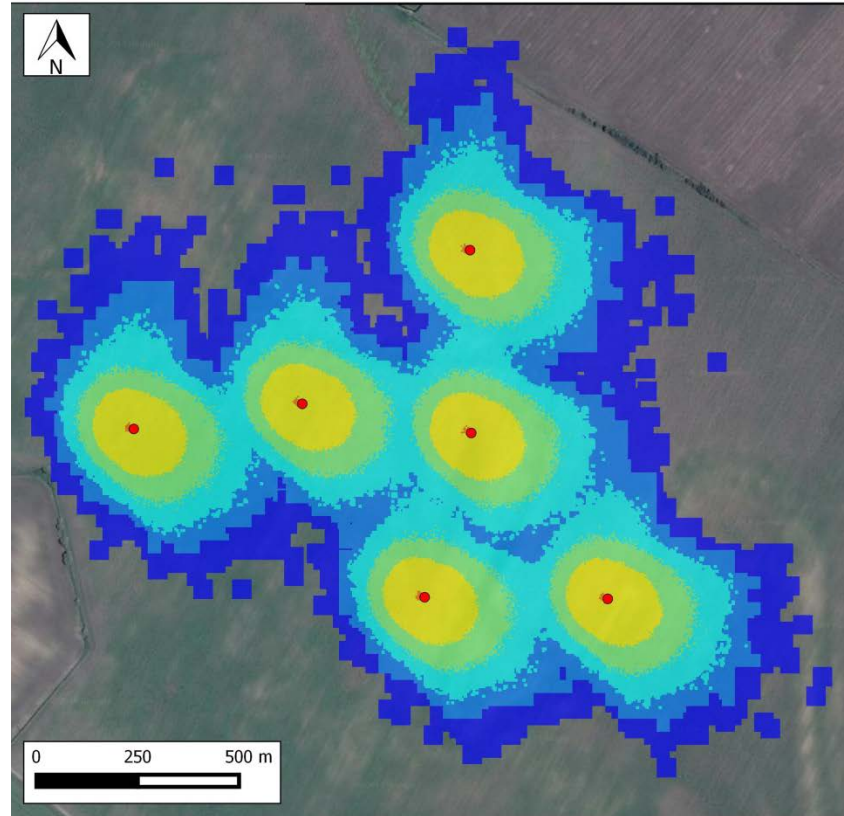
2.2 | TRAJECTORY MODEL – TURBINE IN OPERATION

INPUT

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

OUTPUT

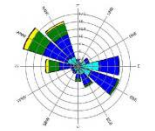
- ~ Probability map for ice fall and ice throw



Ice Fall/Throw Map

Date: 2017-11-07
Background Map Source:
Global Mapper Imagery

Site wind rose (Nov.- March)



Legend

- Turbine Positions
- Probability Grid
 - $\leq 10^{-6}$
 - 10^{-5} to 10^{-6}
 - 10^{-4} to 10^{-5}
 - 10^{-3} to 10^{-4}
 - 10^{-2} to 10^{-3}
 - 10^{-1} to 10^{-2}
 - 1 to 10^{-1}
 - > 1.0

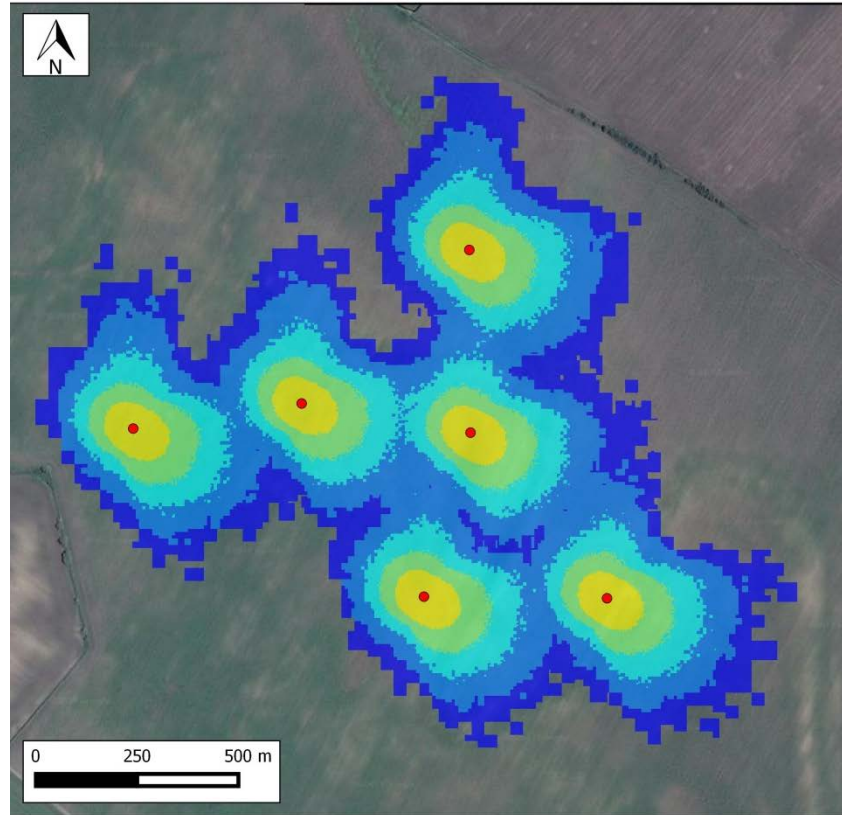
2.2 | TRAJECTORY MODEL – TURBINE IN STANDSTILL

INPUT

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

OUTPUT

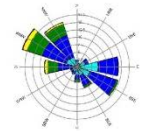
- ~ Probability map for ice fall and ice throw



Ice Fall/Throw Map

Date: 2017-11-07
Background Map Source:
Global Mapper Imagery

Site wind rose (Nov.- March)



Legend

- Turbine Positions
- Probability Grid
 - $\leq 10e-6$
 - $10e-5$ to $10e-6$
 - $10e-4$ to $10e-5$
 - $10e-3$ to $10e-4$
 - $10e-2$ to $10e-3$
 - $10e-1$ to $10e-2$
 - 1 to $10e-1$
 - >1.0

CONCEPTUAL MODEL VALIDATION

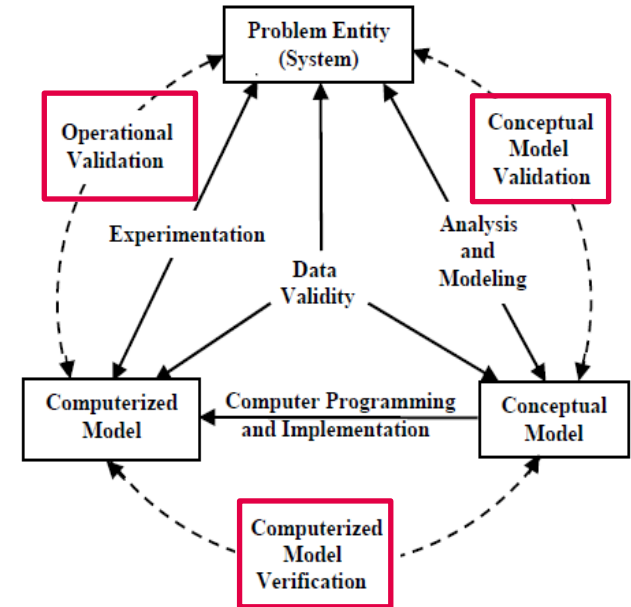
- ~ Measurements
- ~ Literature and industry best practice
- ~ ENERCON internal R&D

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

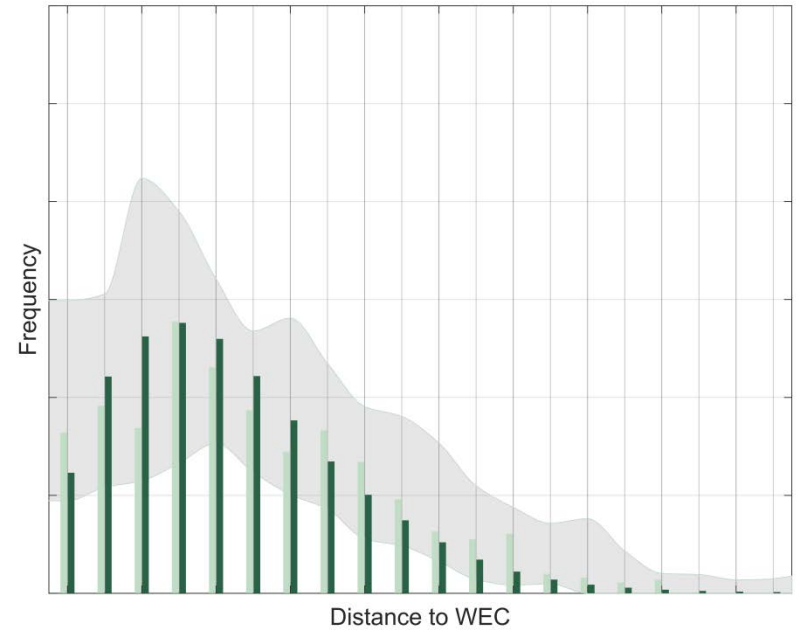
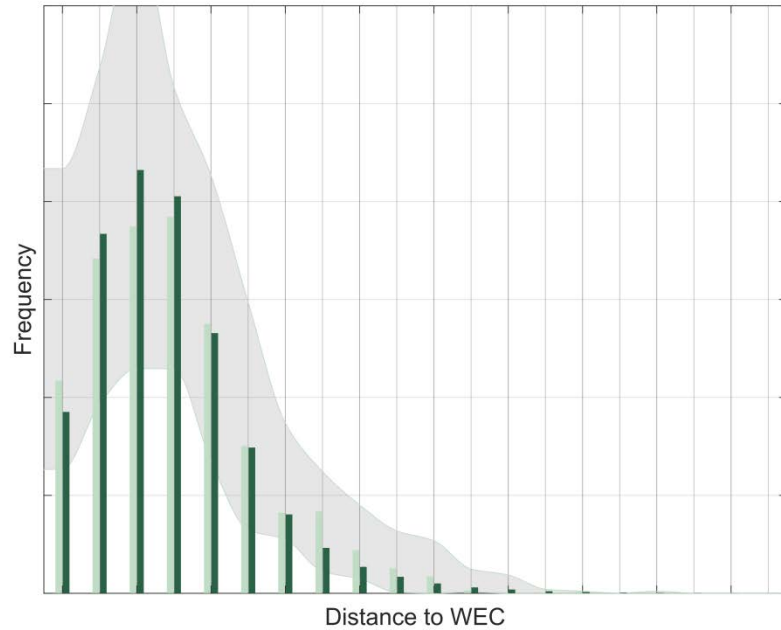
~ 3 winter seasons

~ Different operation modes



Distance measured < Distance calculated

TRAJECTORY METHOD



WINDGUARD Certification

Certification Report

Software Ice Fall Tool

Software version
1.0

Customer ENERCON GmbH
Dreerkamp 5
26605 Aurich
Germany

Manufacturer, Docu- ENERCON GmbH
mentation

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

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1 The Challenge

Past and current practices | Future solutions

2 Ice Throw and Ice Fall Research at ENERCON

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3 Next steps

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STANDARDS

- ~ Guidelines for ice fall and ice throw risk assessments

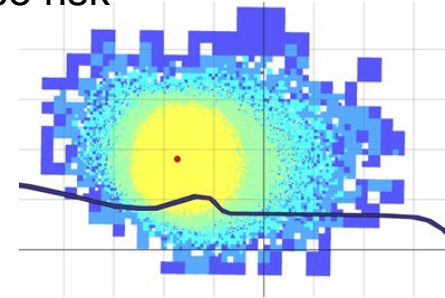


RESEARCH

- ~ Refine measurement techniques
- ~ Increase database

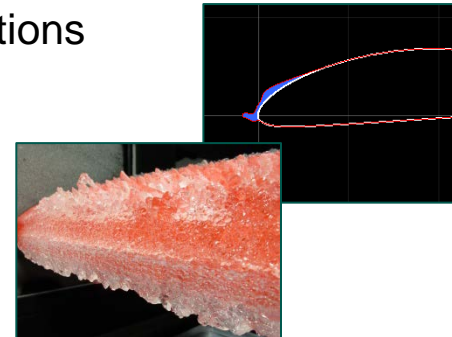
ENERCON MODEL

- ~ Curtailment to decrease risk
- ~ Detailed risk analysis



ENERCON R&D

- ~ Ice accretion simulations and measurements



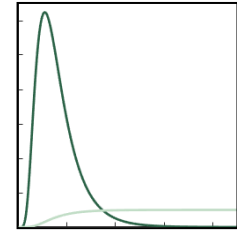
OUR MODEL IS

- ~ 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



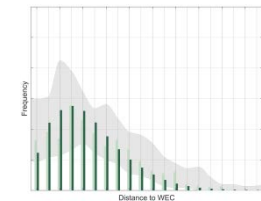
EVALUATE



REPRESENT



VALIDATE



THANK YOU FOR YOUR ATTENTION



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