UiT

THE ARCTIC UNIVERSITY OF NORWAY

Wind Turbine Operations in Icing Conditions

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NABL Project Seminar

21 September, 2021

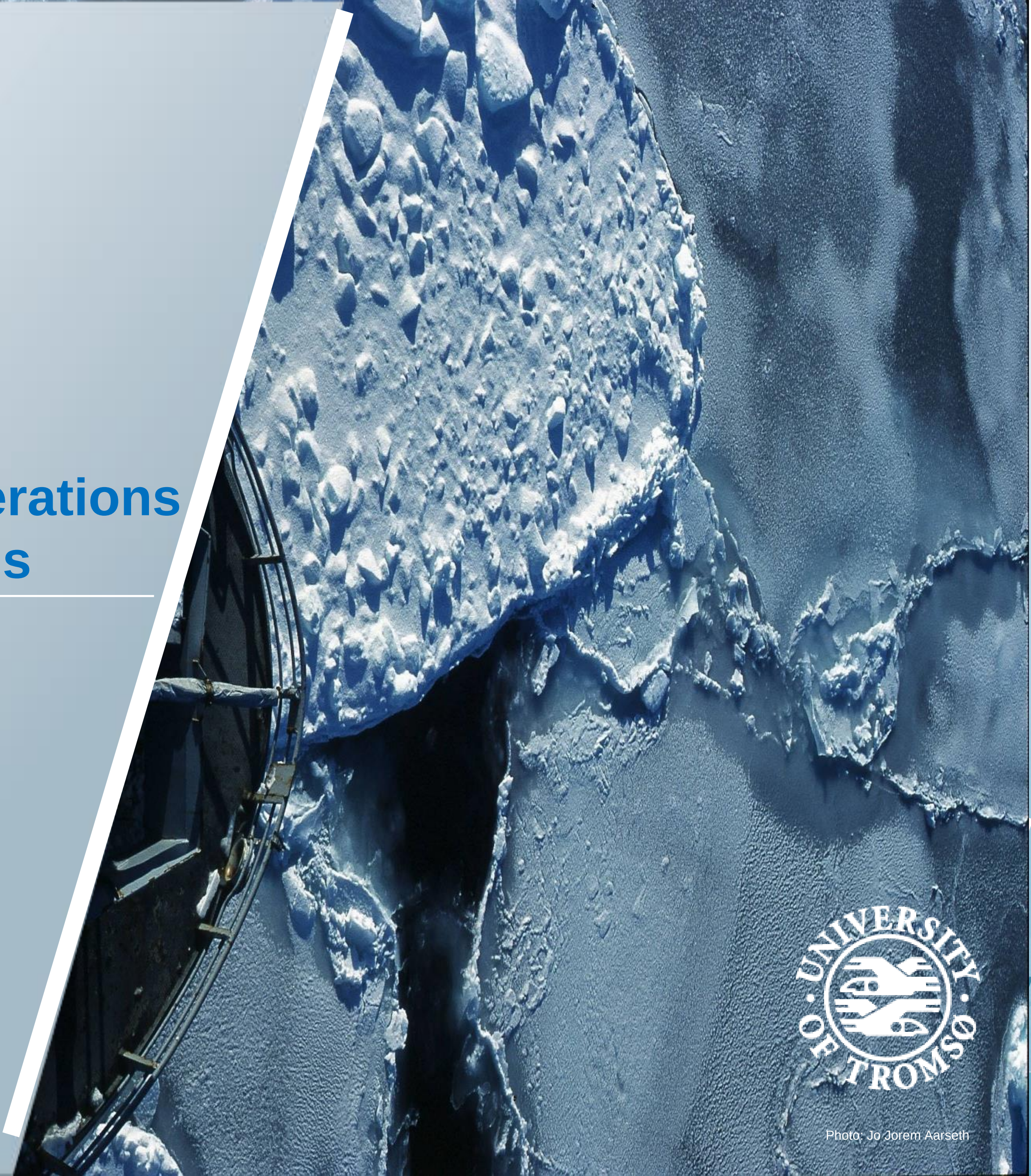


Photo: Jo Jorem Aarseth

Introduction

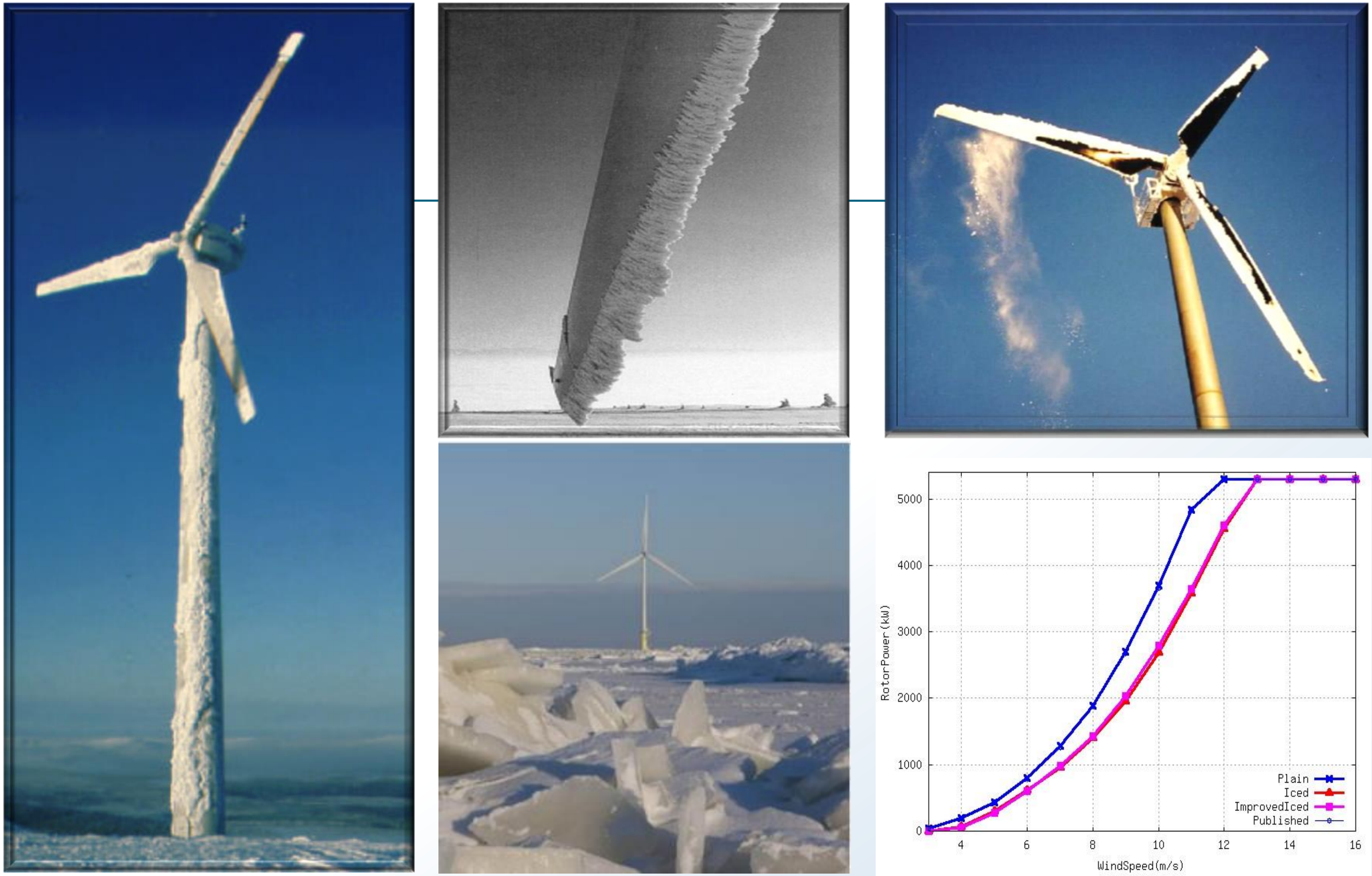
- Cold regions have good wind resources, but atmospheric icing is one of the major hinderence in proper utilization of these resources, as ice accretion on wind turbines effects its performance and resultant Annual Energy Production (AEP).

- Atmospheric icing on wind turbines mainly occurs due to collision and freezing of super cooled water droplets with the exposed surface of wind turbines.

- Wind turbine design/performance/operations in cold regions gets effected due to ice that leads to *disrupted blade aerodynamics, increased fatigue and structural failure due to mass imbalance and damage or harm caused by the possible uncontrolled shedding of ice chunks from wind turbines*.

- There is a need to develop a better understanding of atmospheric icing physics and it's resultant effects to improve the design and safety of wind turbines operations in icing conditions.

- International Energy Agency (IEA) Annex 19: *'Wind energy in cold climates'*, also calls for developing new methods to better predict the effects of ice accretion on wind turbine performance and energy production.



(Example of atmospheric ice accretion on wind turbines in cold regions)

[1]-Maissan, T.M., *The Effects of the Black Blades on Surface Temperatures for Wind Turbines* ,in W.A.T. J., Editor 2001, Université du Québec à Rimouski: Canada

[2]- http://www.eolos.umn.edu/research

Icing Effects on Wind Turbines

- Main effects of atmospheric ice accretion on wind turbine are:
  - Disrupted blade aerodynamics.
  - Increased fatigue/structural failure due to mass imbalance.
  - Human’s harm due to ice shedding.
  - Instrumental measurement errors.
  - Loss of power production.
  - Complete stop of power production.

Wind Resource & Icing Event Assesment

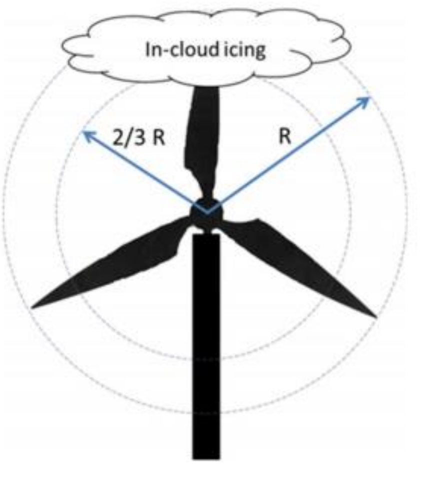
- Wind resource assessment in ice prone cold regions is important both for the operation of wind parks and also to provide more accurate wind energy production forecast. But its challenging…..!

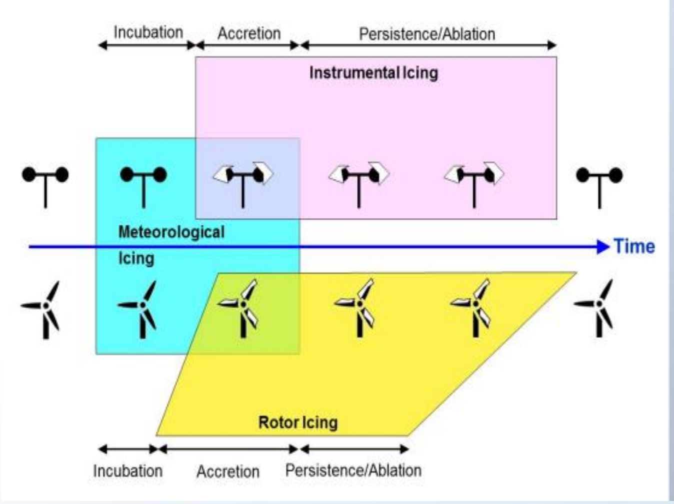
- Wind resource assesement is generally done at planning phase of the wind park, where detailed analysis are carried out using met mast and meso-scale numerical modelling tools.

- Low temperatures and icing climate set additional challenges for wind resource assessment in cold regions.

- Ice load maps are generally developed at planning/conceptual design stage to get an estimate of icing events and possible icing loads.

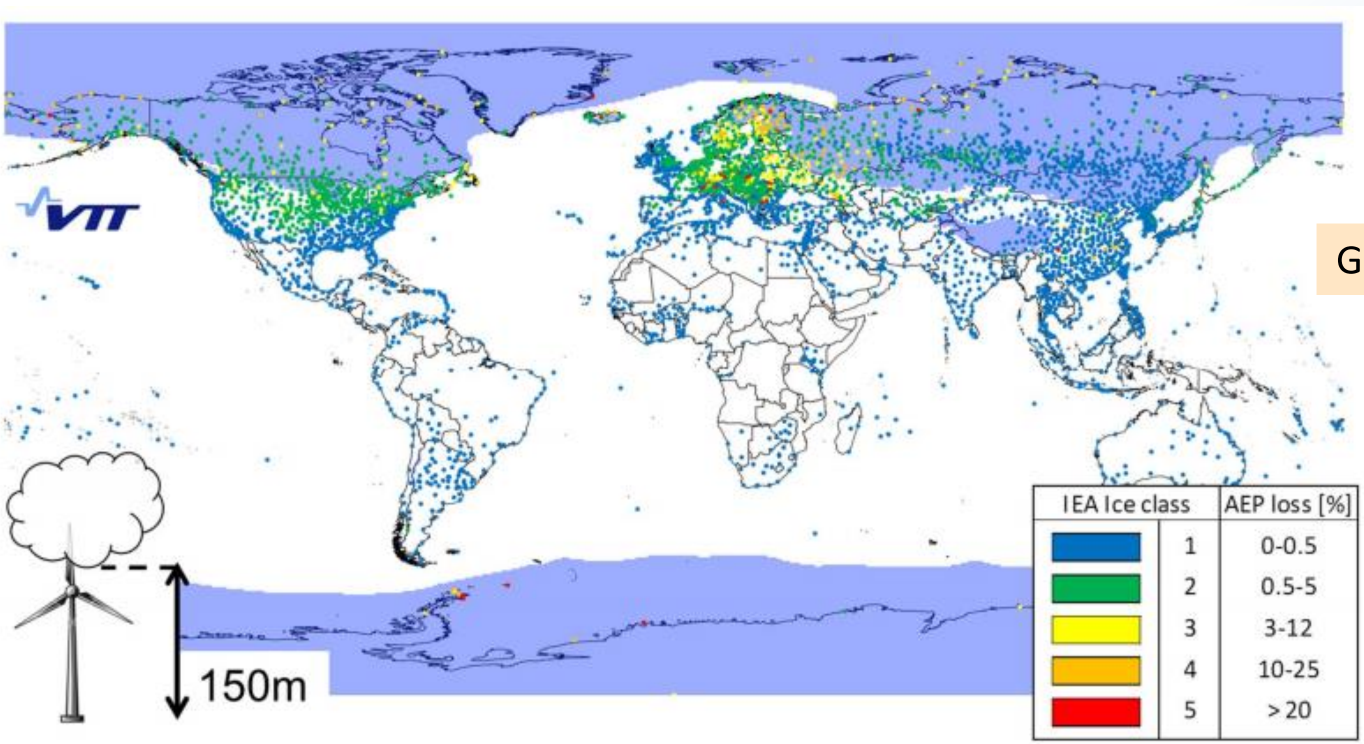
- Icing event assesments is a continuos process that we generally keep on analysing even during opeartional phase of a wind park. SCADA data analysis are carried out on regular basis during winter time to study the icing events with a particular focus of wind turbine performance optimization and enhancing the safety aspects of wind park.





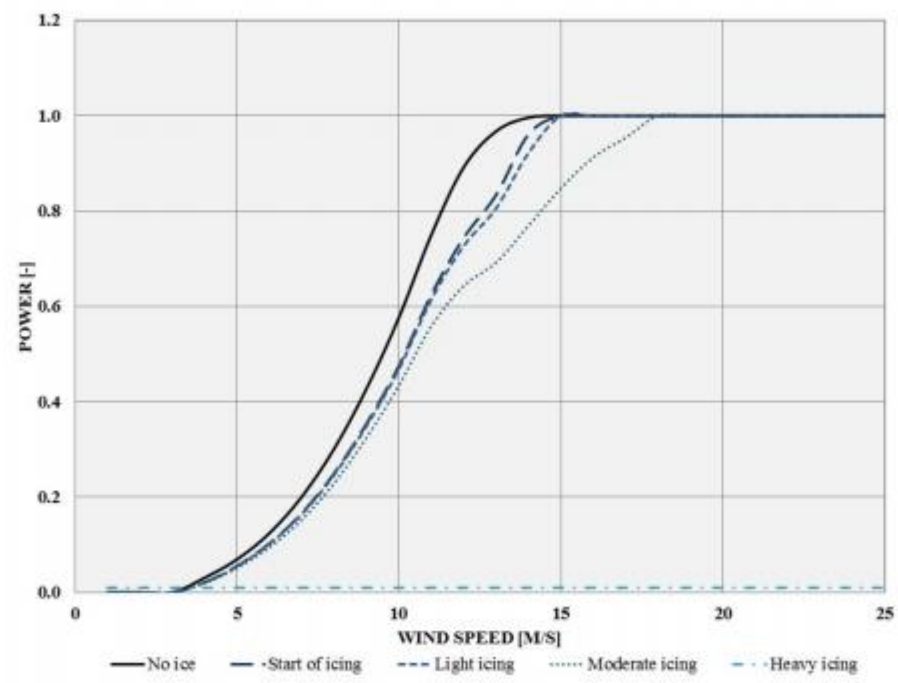
https://www.baranidesign.com/meteo-store/meteowind2-anemometer-heated
https://norwegianscitechnews.com/2017/09/controlling-problem-ice-by-cracking-it/

IEA Ice class	Meteorological icing	Instrumental icing	Icing loss
	% of year	% of year	% of gross annual production
5	>10	>20	> 20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0 - 0.5

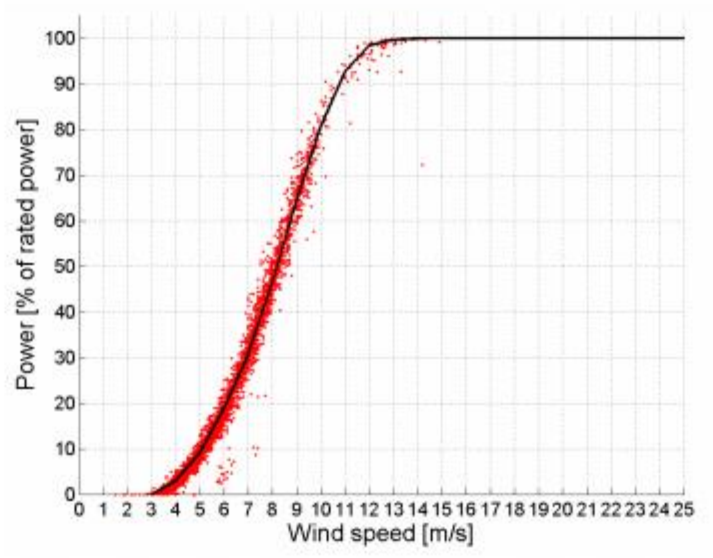


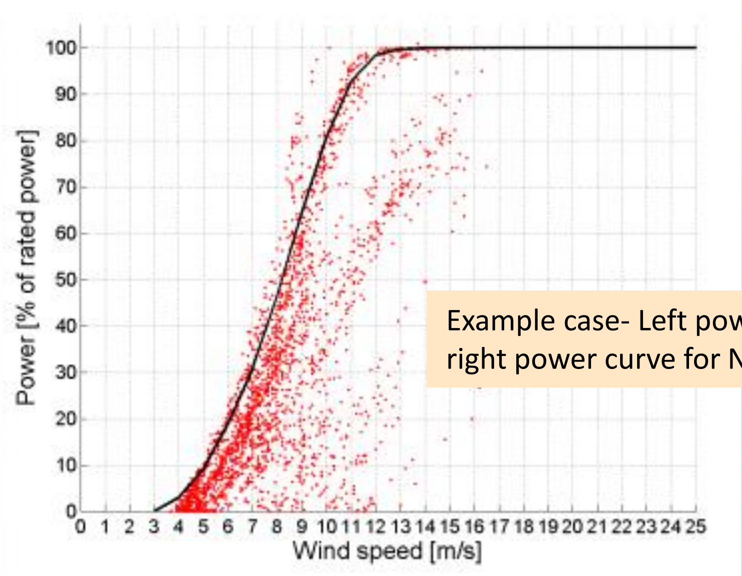
Global icing map

Ref [1]: IEA Wind TCP recommended practice 13: Wind energy in cold climates



Example case- The impact of ice on the power curves of a 3MW wind turbine – Ref [1]



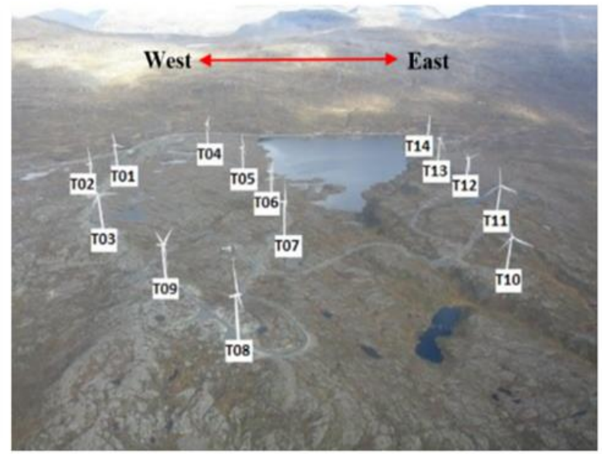


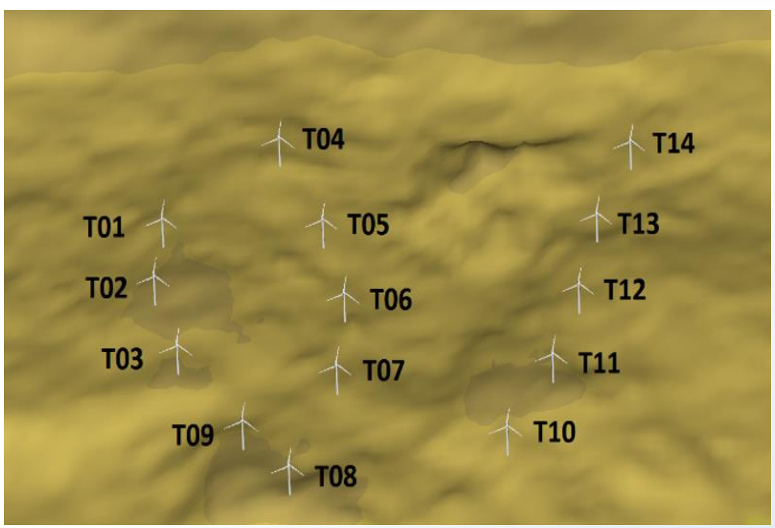
Example case- Left power curve for MAY and right power curve for November– Ref [1]

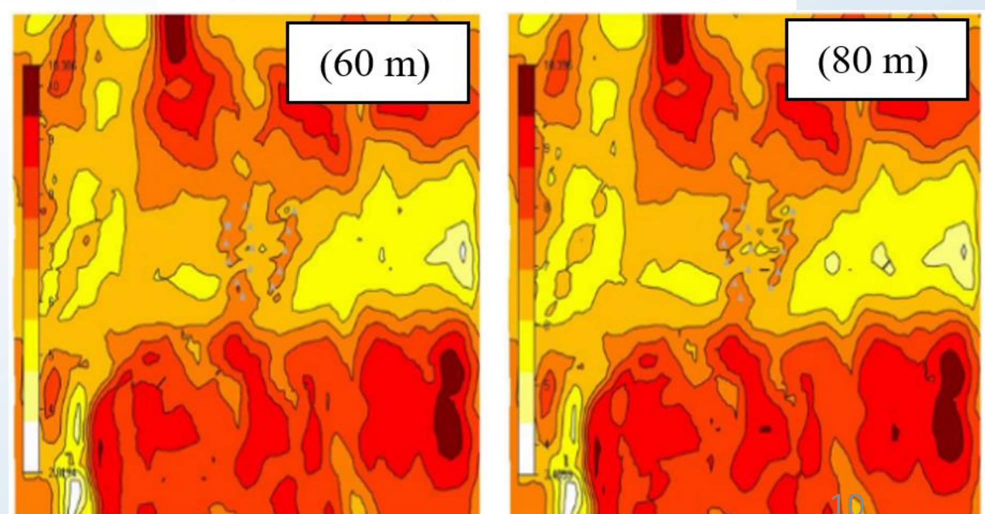
Ref [1]: IEA Wind TCP recommended practice 13: Wind energy in cold climates

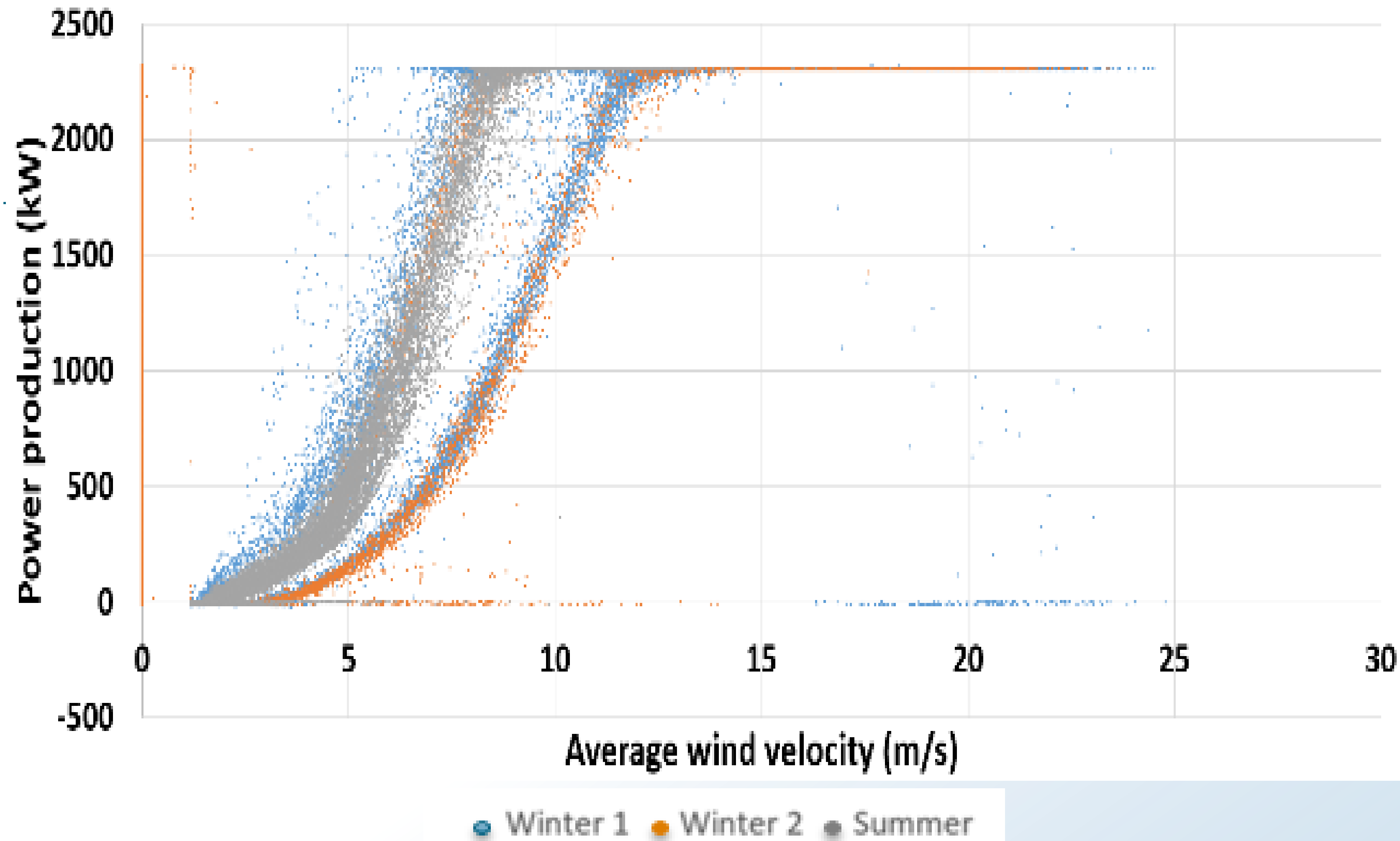
Case Study

Turbine	Siemens_23_93VS
Tower Height	80 m
Rotor Diameter	90 m

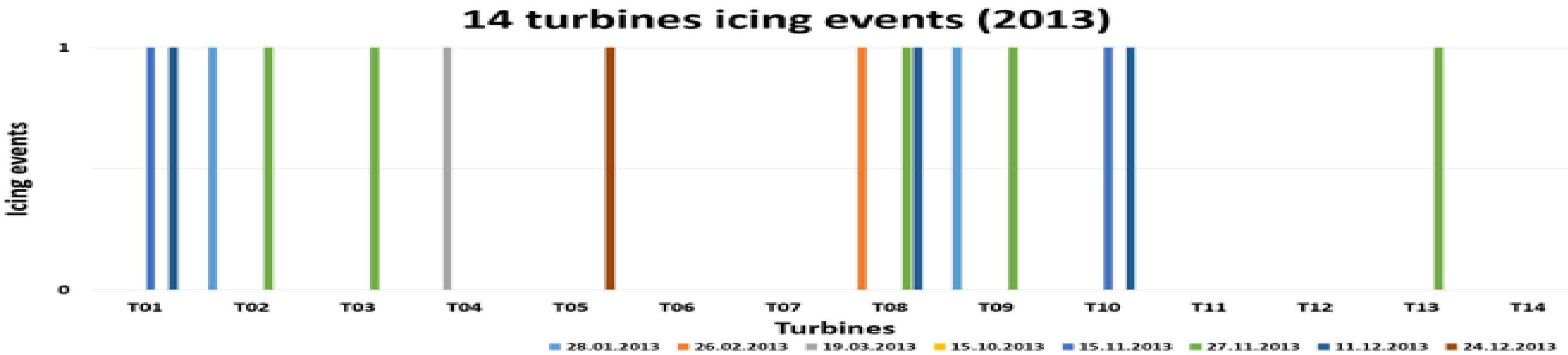


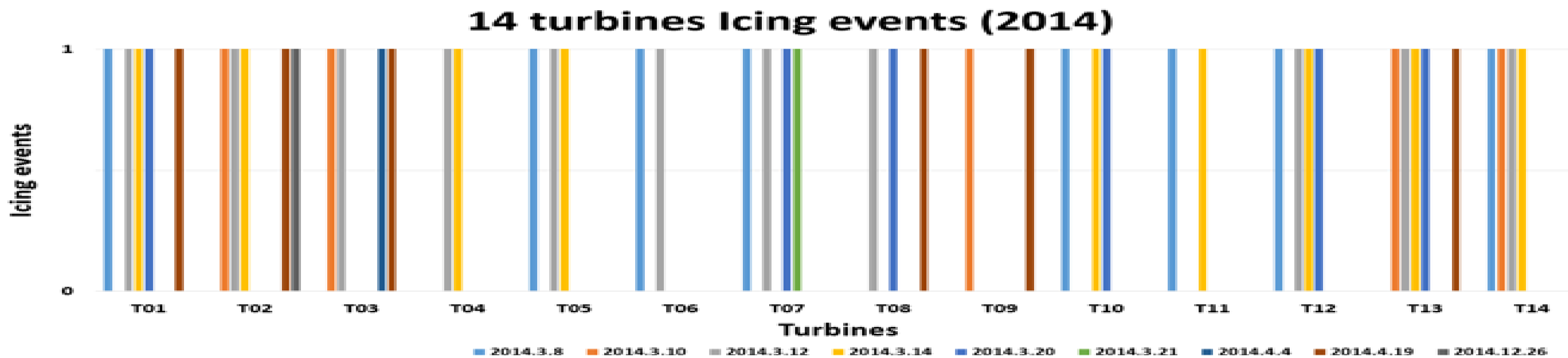






Winter 1 ***(January - April)***
Winter 2 ***(October - December)***
Summer ***(May - September)***





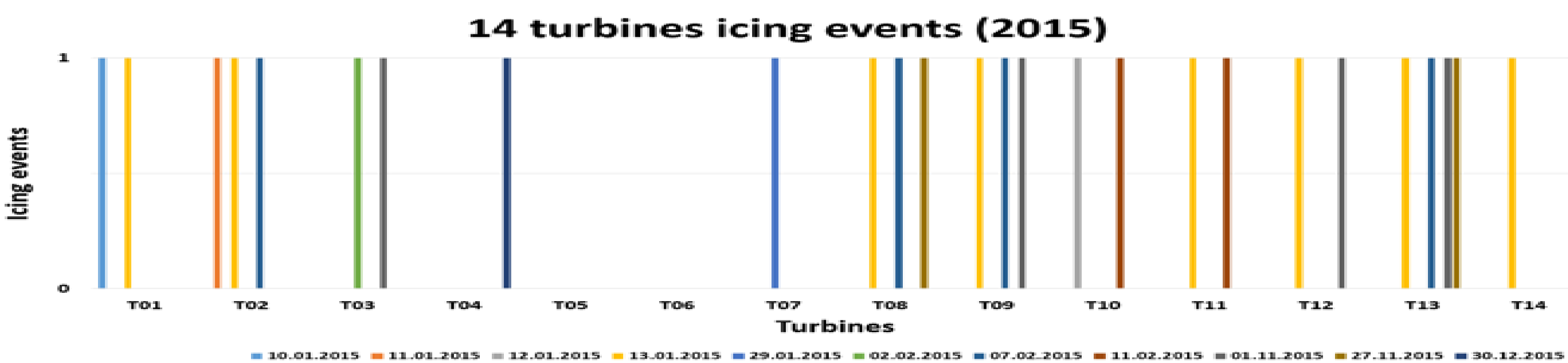
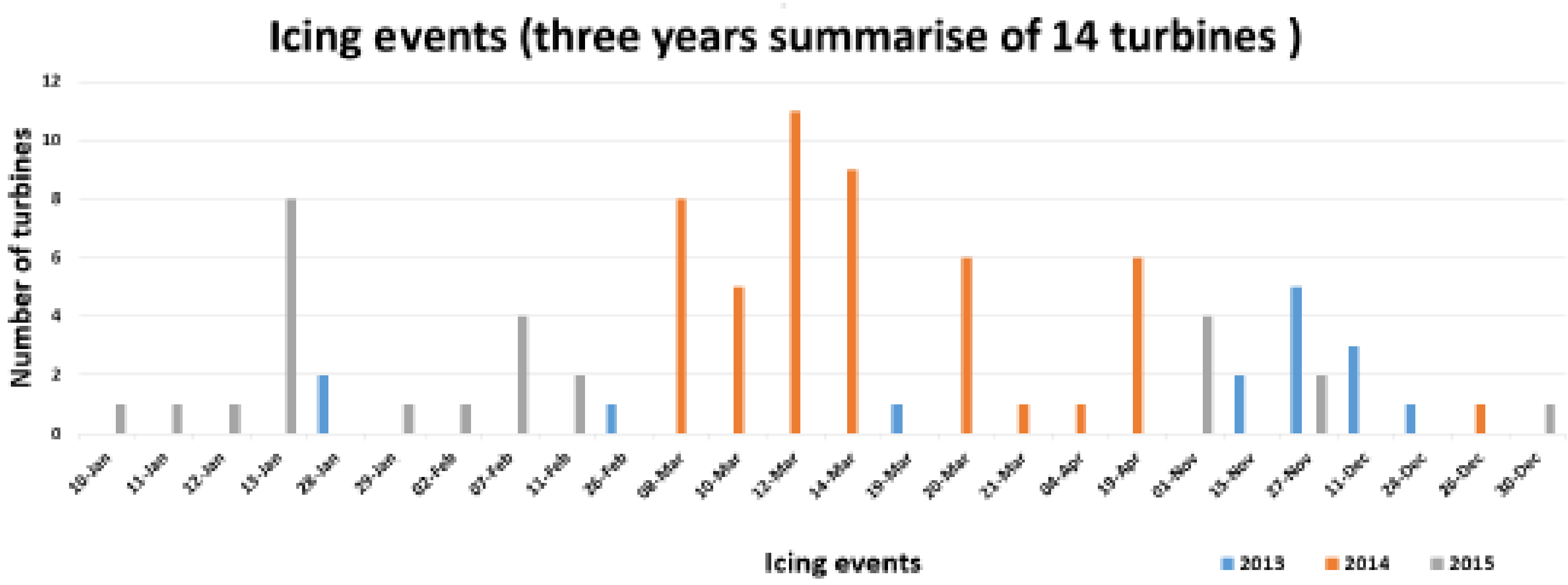
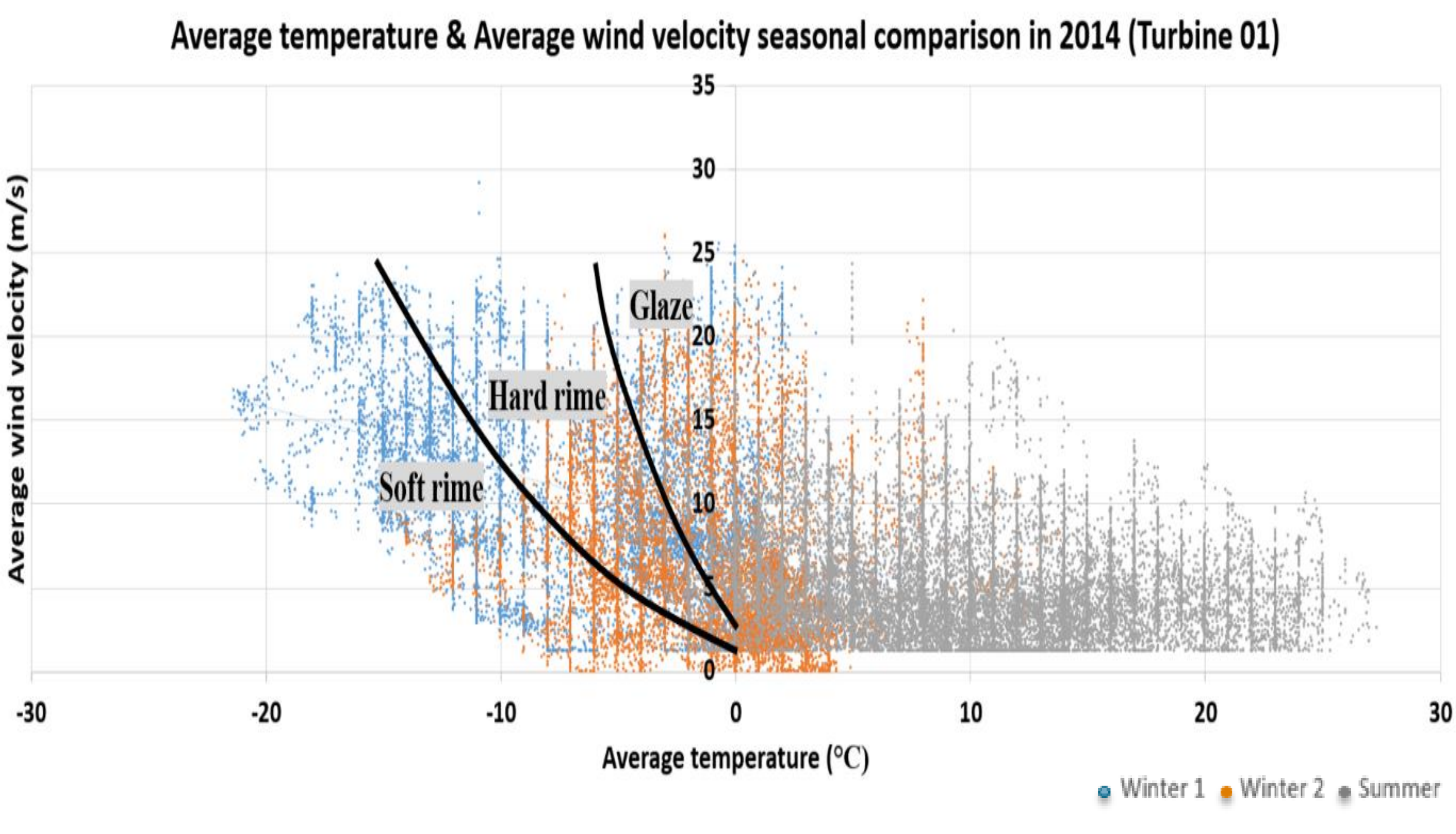


Figure shows that during three years (2013- 2015) icing events occurred 8, 9 and 11 days respectively.



Icing events (three years summarise of 14 turbines)
Number of turbines
0
2
4
6
8
10
12
10-Jan
11-Jan
12-Jan
13-Jan
28-Jan
29-Jan
02-Feb
07-Feb
11-Feb
26-Feb
08-Mar
10-Mar
12-Mar
14-Mar
19-Mar
20-Mar
21-Mar
04-Apr
19-Apr
01-Nov
15-Nov
27-Nov
11-Dec
24-Dec
26-Dec
30-Dec
Icing events
2013
2014
2015

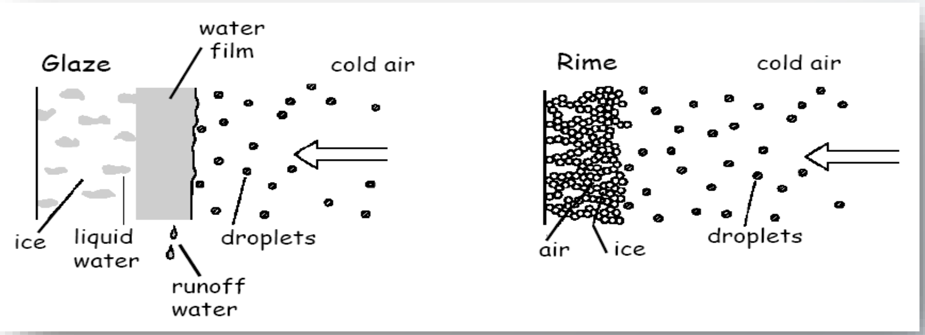
Icing Classification



Ice Accretion on Wind Turbines

Wind Turbine Ice Accretion Physics

- Rate and shape of atmospheric ice accretion on wind turbines depends upon both geometric and atmospheric parameters, such as:
  - ✓ Location.
  - ✓ Geometric dimensions.
  - ✓ Surface material.
  - ✓ Wind velocity.
  - ✓ Atmospheric temperature.
  - ✓ Droplet size (MVD).
  - ✓ Liquid Water Content (LWC).

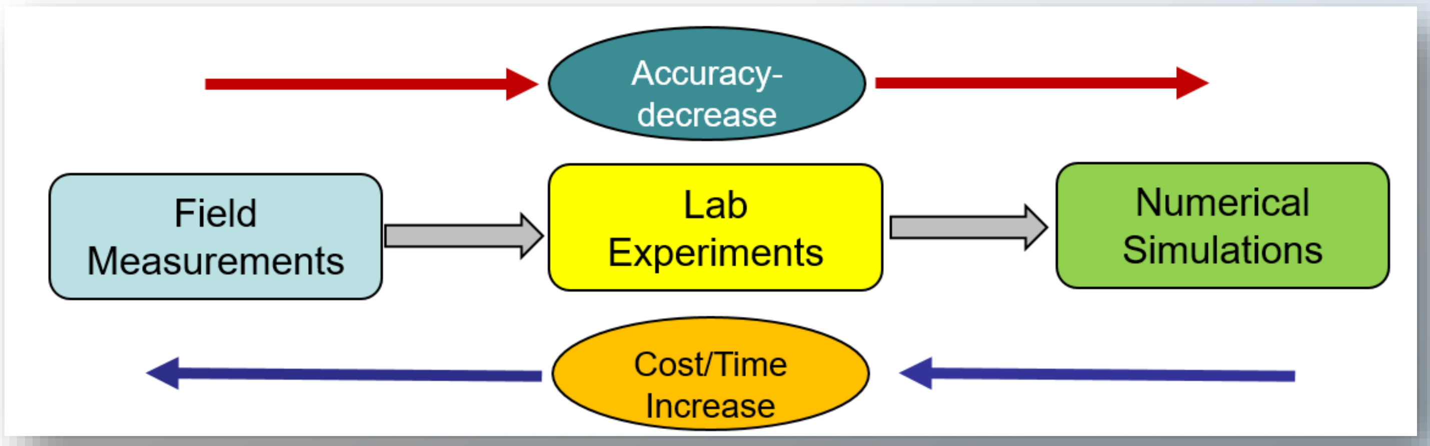


Type of ice	Density (kg/m^3)	Adhesion and cohesion	General Appearance	
			Colour	Shape
Glaze	900	Strong	transparent	Icicles
Wet Snow	300 to 600	Weak(forming) Strong(frozen)	White	Icicles
Hard rime	600 to 900	Strong	Opaque	Pointing windward
Soft rime	200 to 600	Low to medium	white	Point windward

Methodology

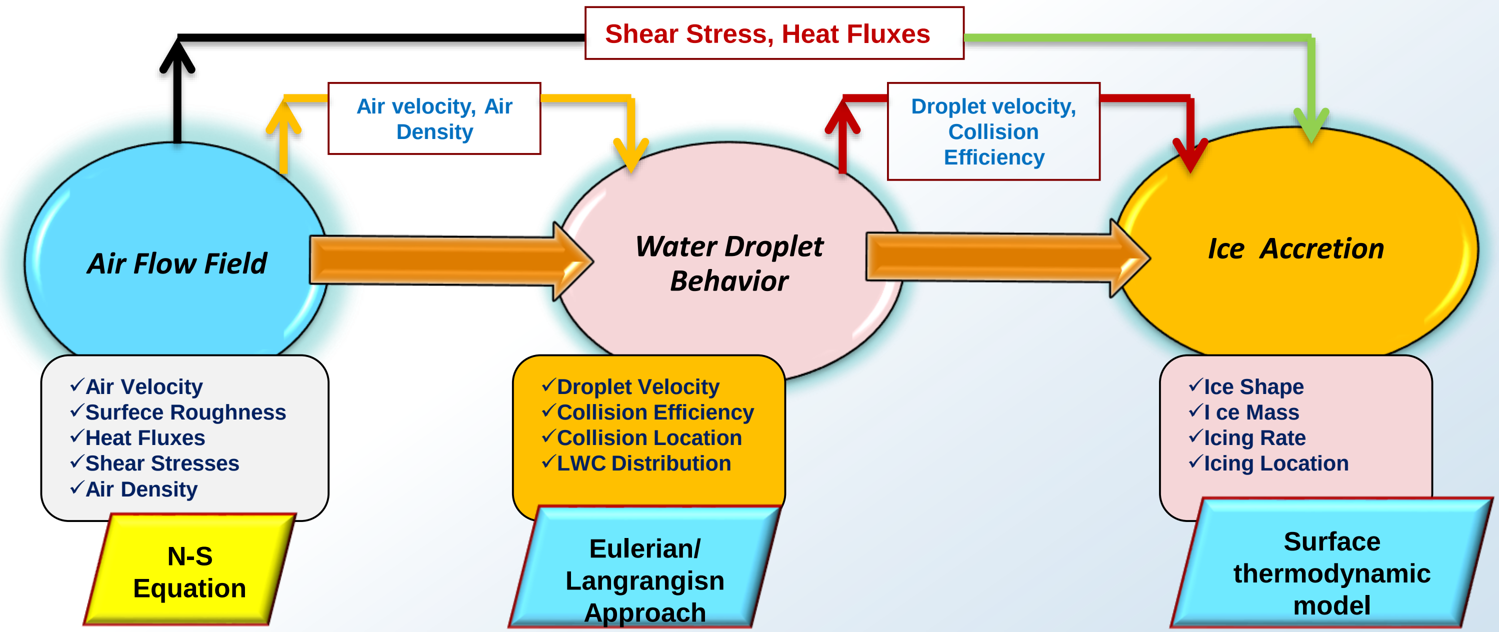
- ❑ Extant of ice accretion can be estimated either by field measurements, lab based experimentation or numerical methods with certain accuracy, because:

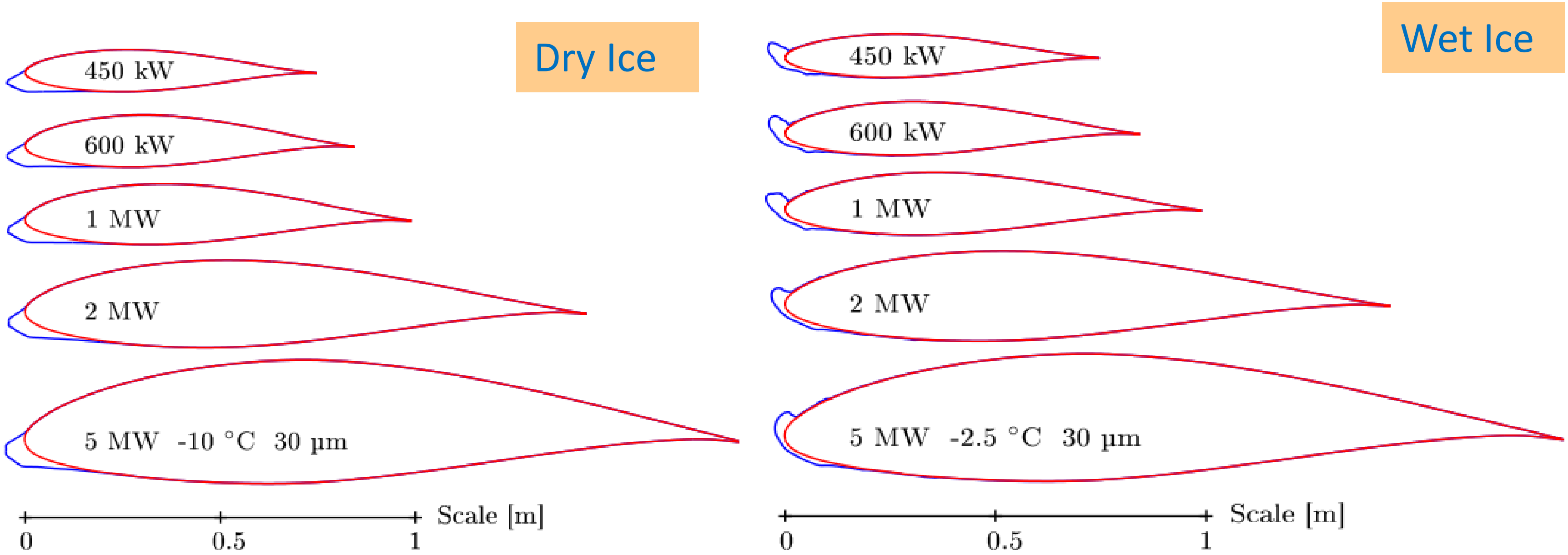
- ✓ *Numerical simulations*
- ✓ *Lab based tunnel testing (Wind tunnel or icing tunnel)*
- ✓ *Field testing*



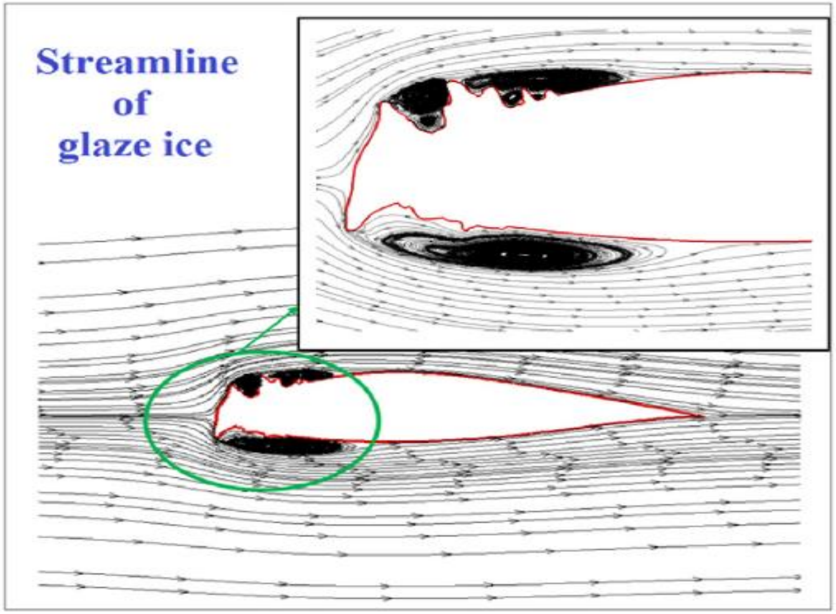
Numerical Modelling of Atmospheric Icing

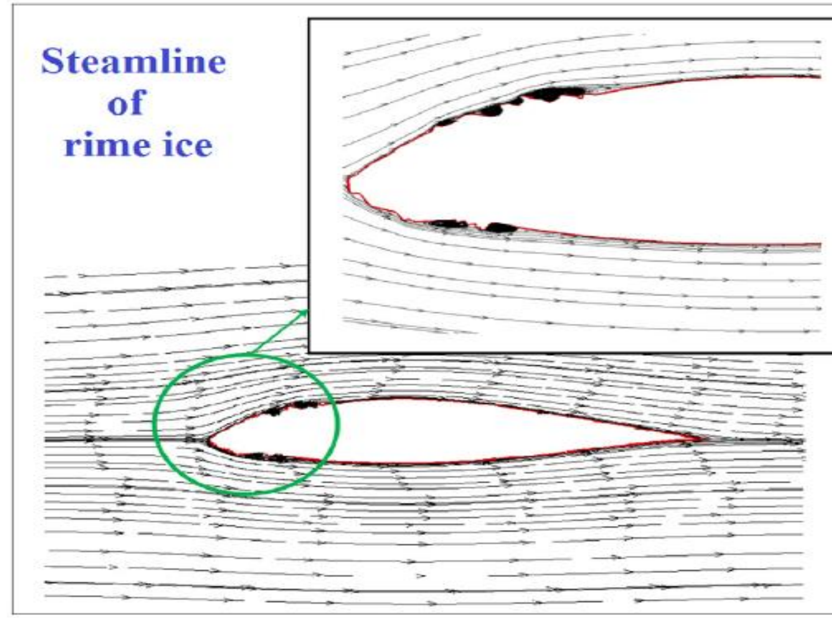
- Numerical modelling of atmospheric ice accretion on wind turbines is a complex coupled process, which mainly involves:
  - Air flow behaviour.
  - Super cooled water droplet behaviour.
  - Boundary layer characteristics.
  - Phase change involving the iced surface thermodynamics.

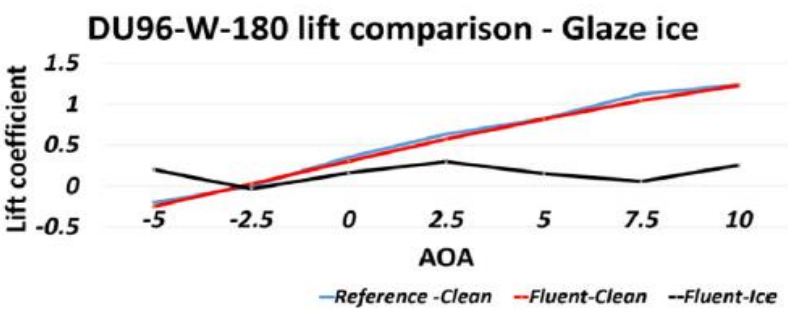


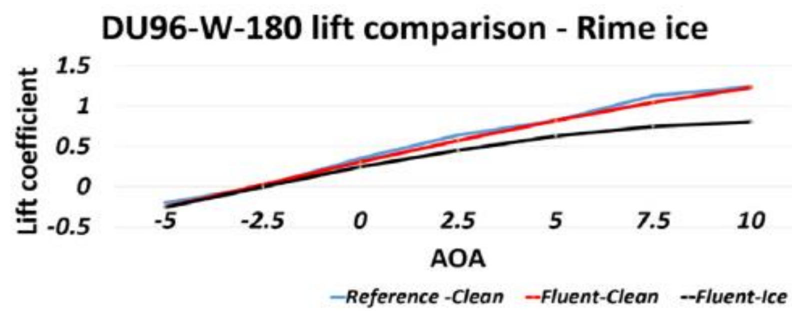


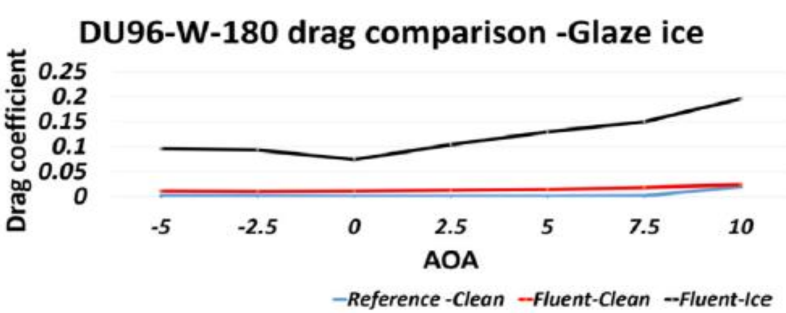
- ✓ Five different sized wind turbine blade profile were analyzed:
- ✓ Analyses were carried out at wet and dry ice conditions, T = -2 & -10 C.
- ✓ **Results indicated that icing is less severe for the larger wind turbines both in terms of local ice mass and in terms of ice thickness.**

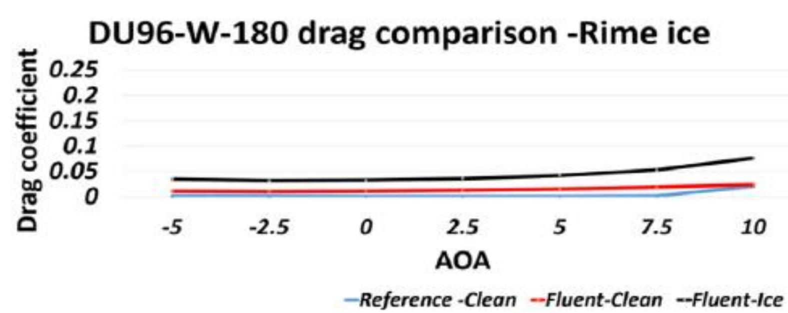

Streamline
of
glaze ice

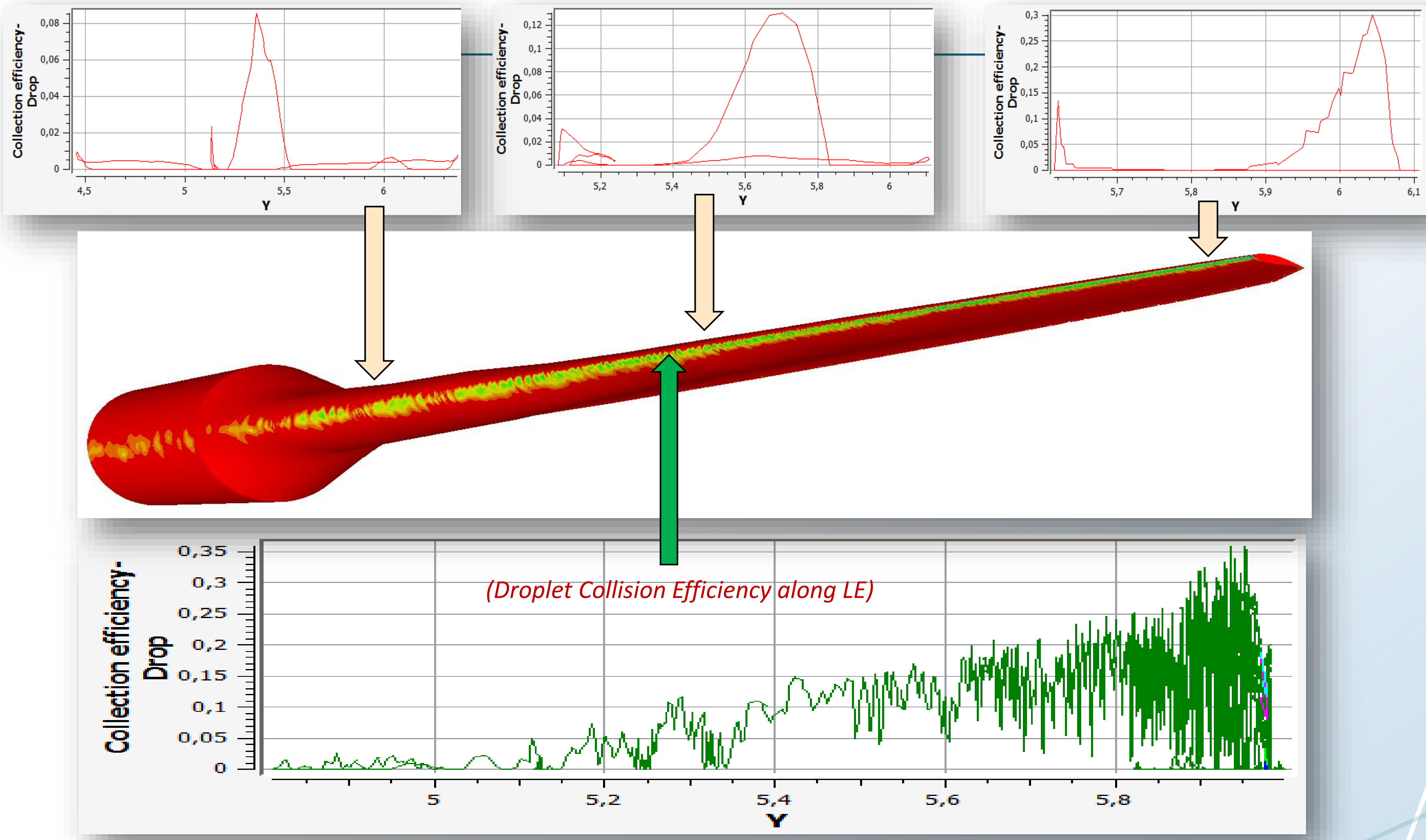

Steamline
of
rime ice

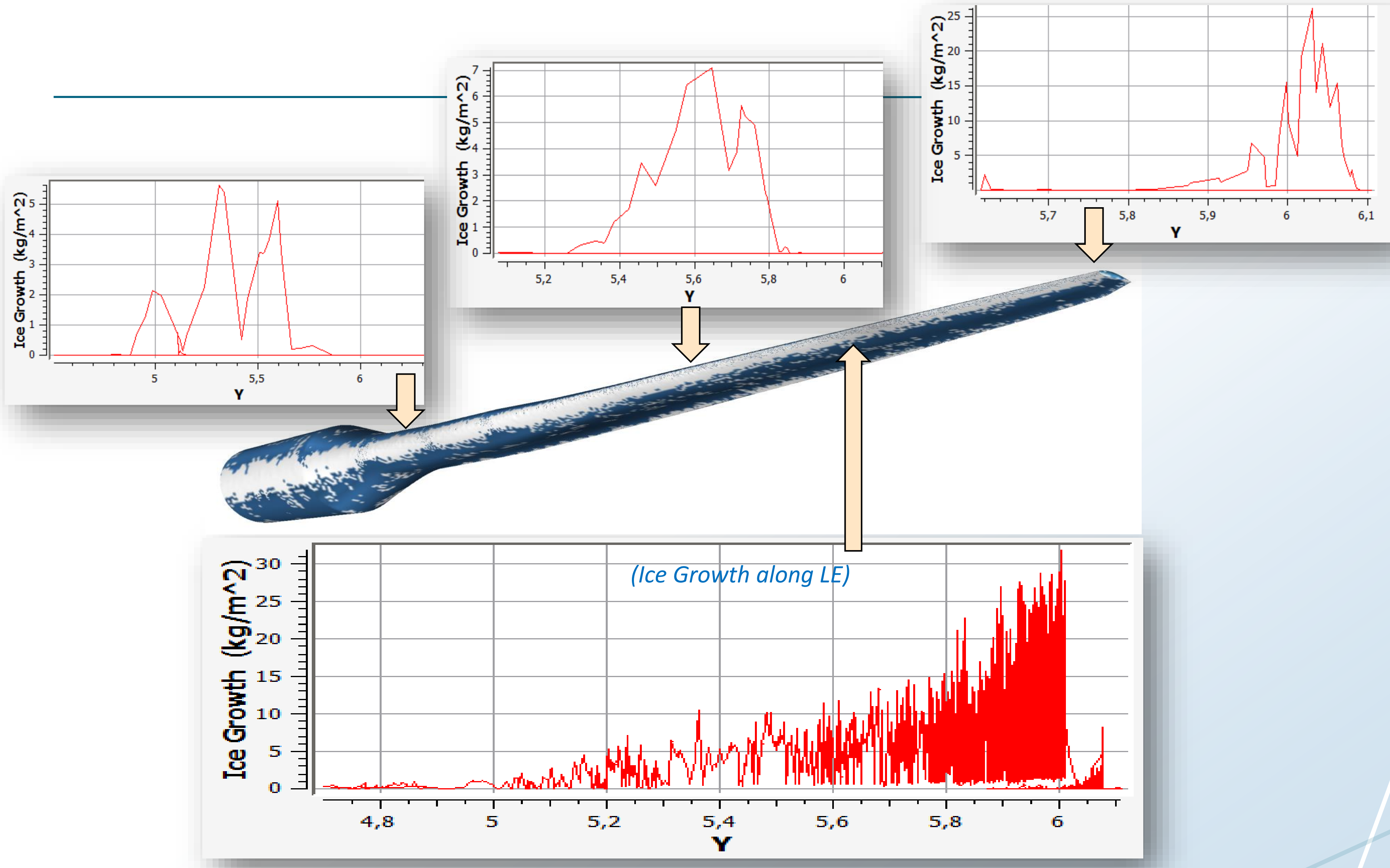

DU96-W-180 lift comparison - Glaze ice
Lift coefficient
1.5
1
0.5
0
-0.5
-5
-2.5
0
2.5
5
7.5
10
AOA
Reference -Clean
Fluent-Clean
Fluent-Ice

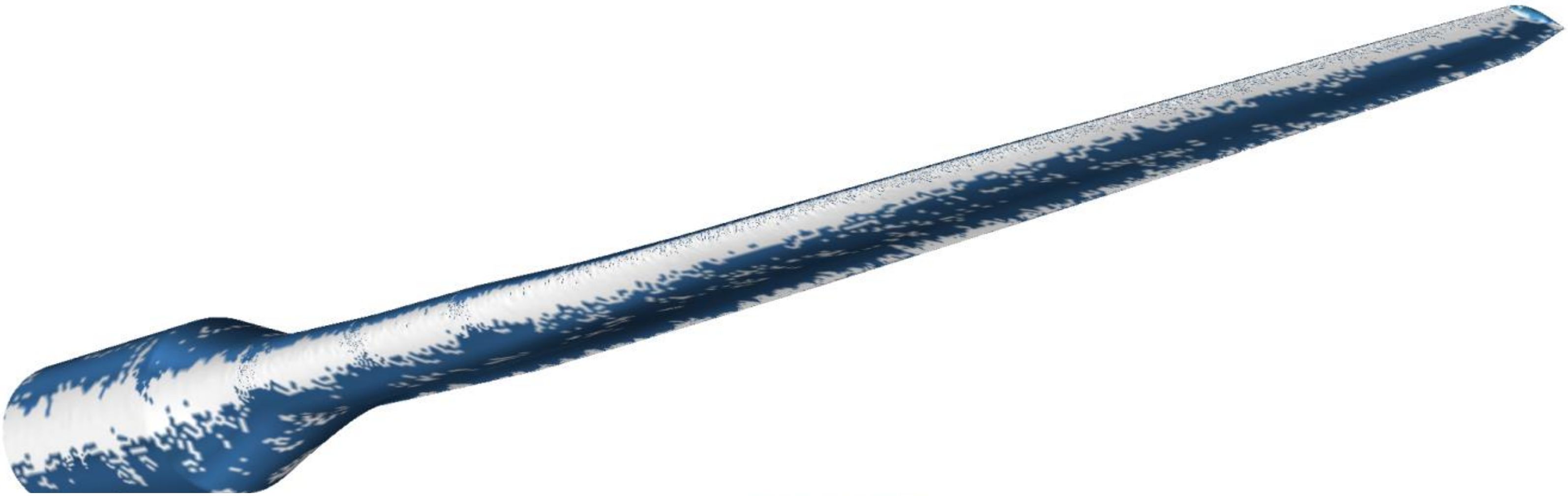

DU96-W-180 lift comparison - Rime ice
Lift coefficient
1.5
1
0.5
0
-0.5
-5
-2.5
0
2.5
5
7.5
10
AOA
Reference -Clean
Fluent-Clean
Fluent-Ice

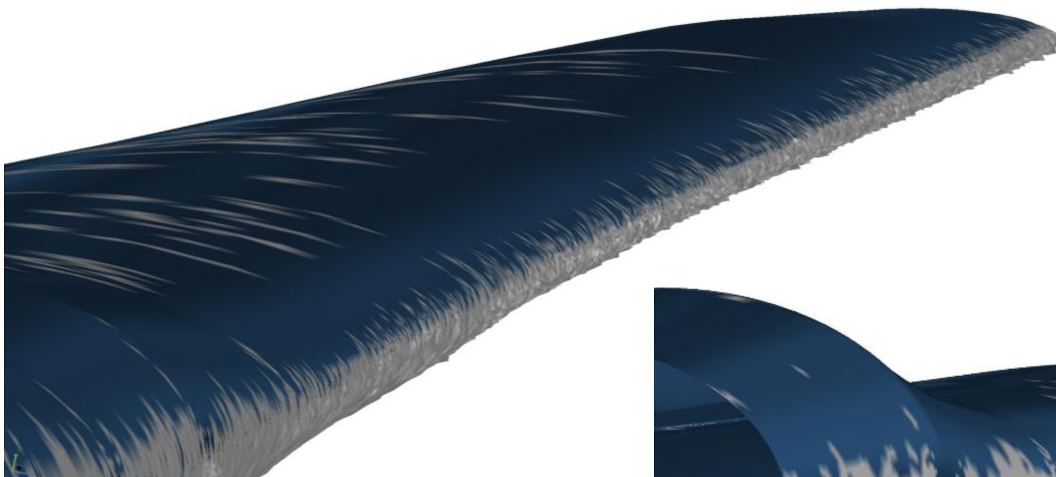

DU96-W-180 drag comparison -Glaze ice
Drag coefficient
0.25
0.2
0.15
0.1
0.05
0
-5
-2.5
0
2.5
5
7.5
10
AOA
Reference -Clean
Fluent-Clean
Fluent-Ice

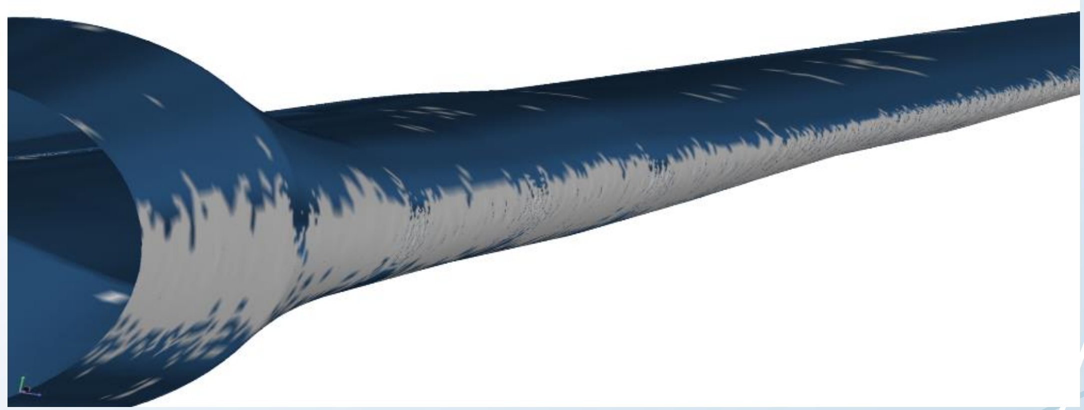

DU96-W-180 drag comparison -Rime ice
Drag coefficient
0.25
0.2
0.15
0.1
0.05
0
-5
-2.5
0
2.5
5
7.5
10
AOA
Reference -Clean
Fluent-Clean
Fluent-Ice


Collection efficiency-Drop
Y
0,08
0,06
0,04
0,02
0
4,5
5
5,5
6
0,12
0,1
5,2
5,4
5,6
5,8
0,3
0,25
0,2
0,15
0,05
5,7
5,9
6,1
(Droplet Collision Efficiency along LE)
0,35

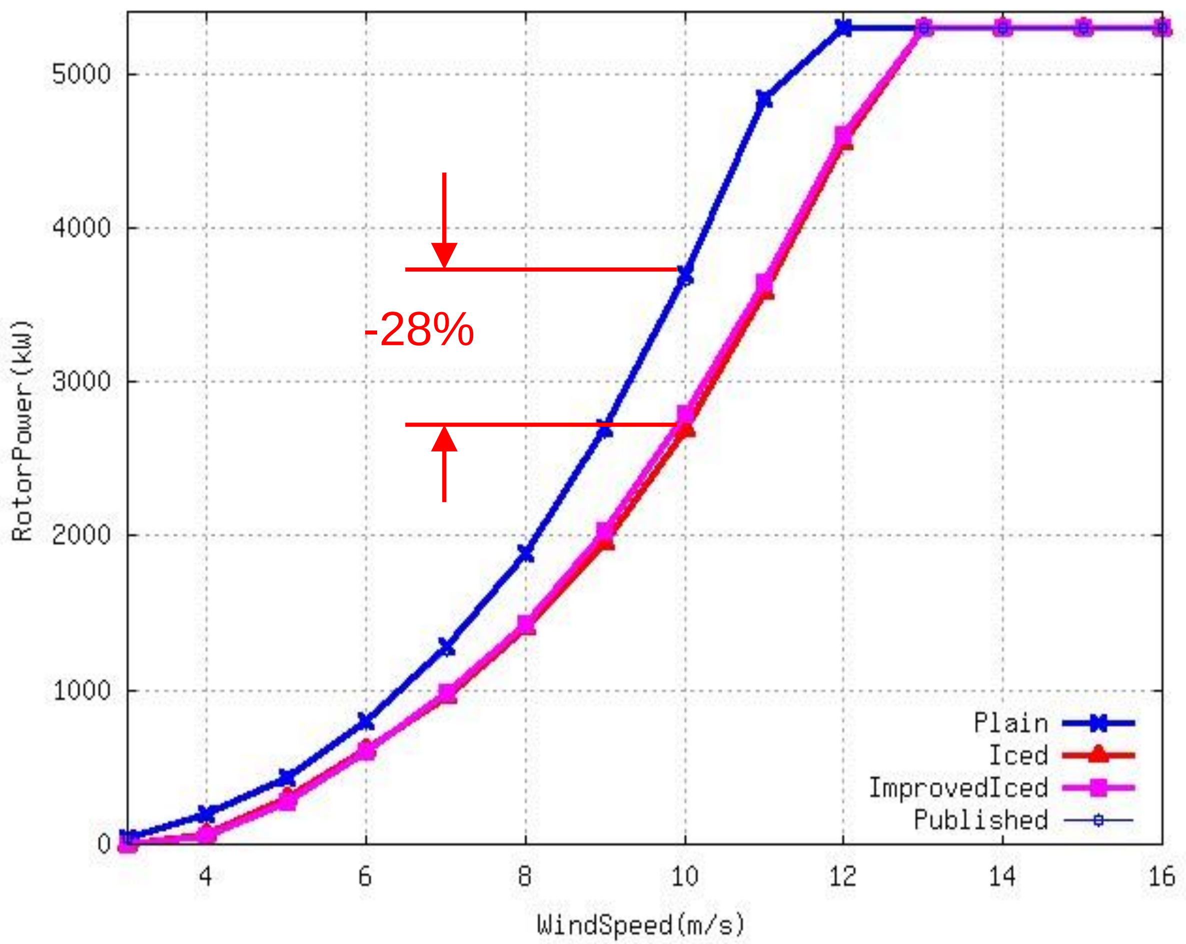

Ice Growth (kg/m^2)
Y
Ice Growth (kg/m^2)
Y
Ice Growth (kg/m^2)
Y
(Ice Growth along LE)
Ice Growth (kg/m^2)
Y



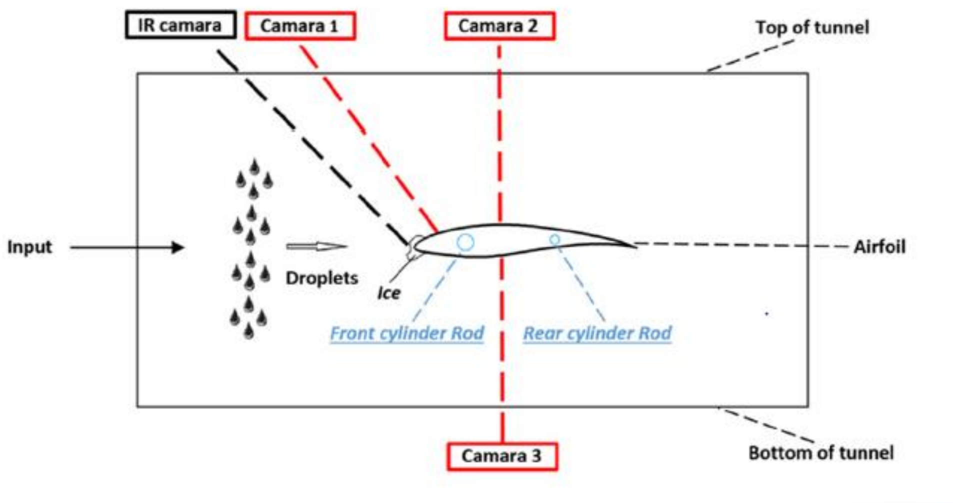


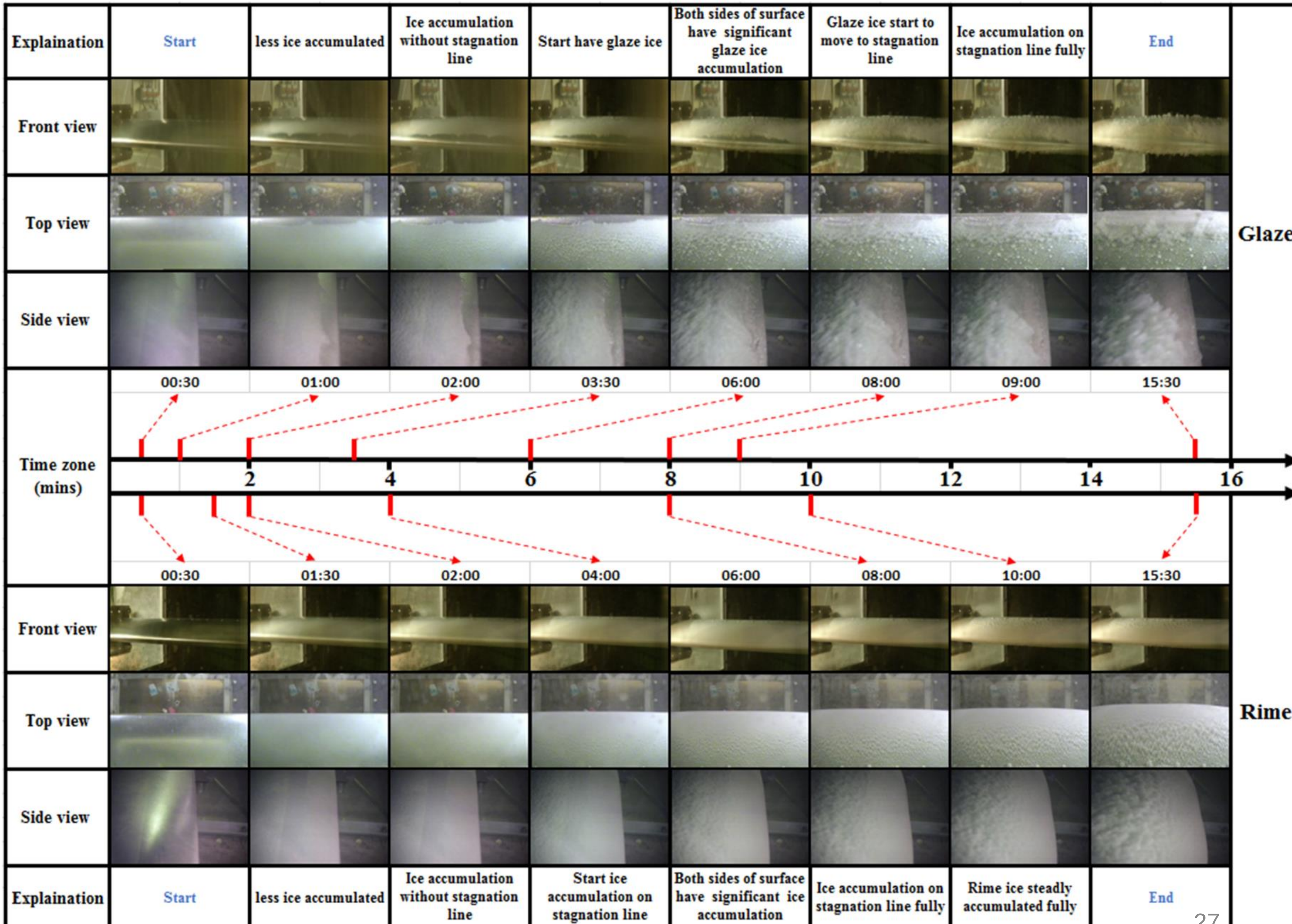


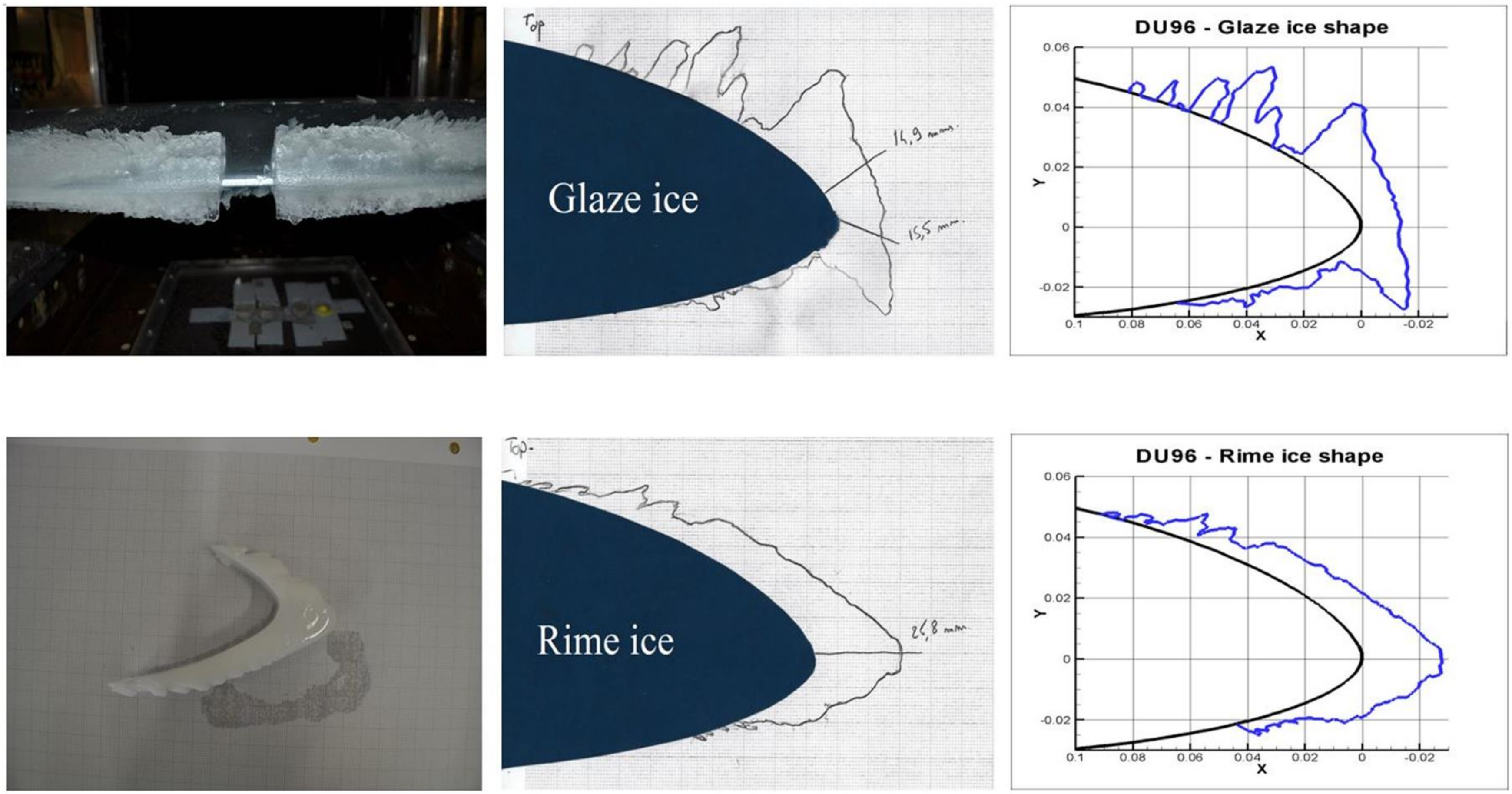
Free stream wind velocity, V_∞, [m/s]	10
Droplet size, MVD [μm]	20
Droplet size distribution	mono-disperse
Liquid water content, LWC [g/m^3]	0.22
Air temperature [°C]	-10
Modeled time [min]	60

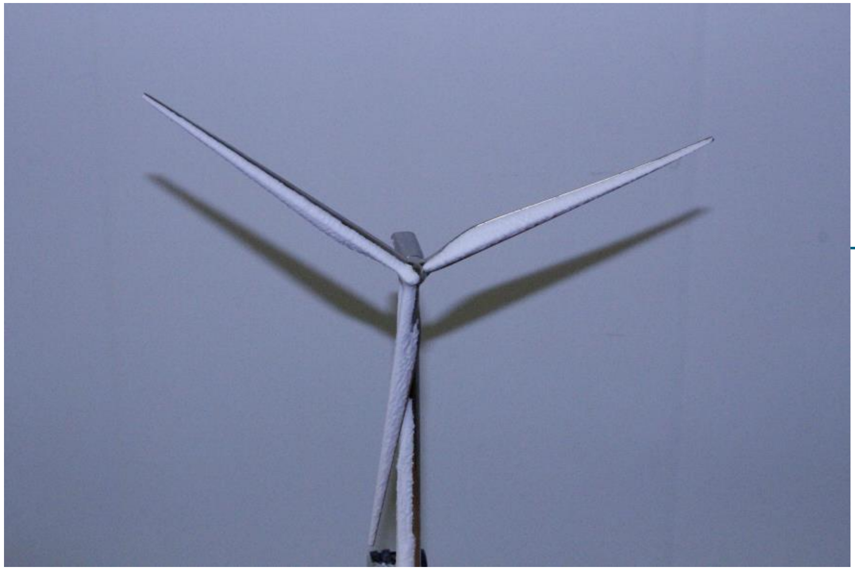


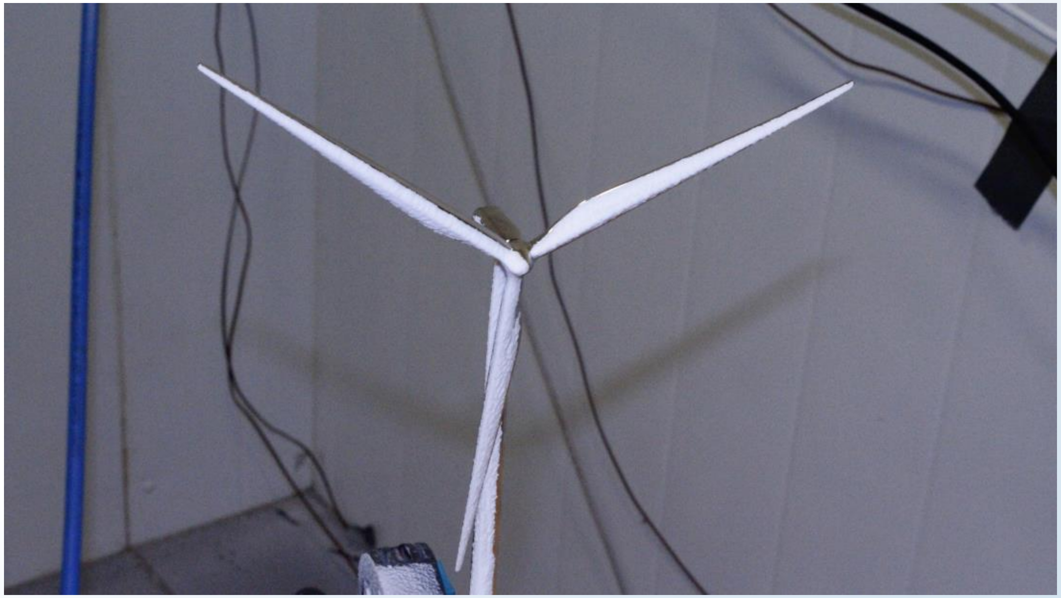
Lab Based Study of Atmospheric Icing




Explaination
Start
less ice accumulated
Ice accumulation without stagnation line
Start have glaze ice
Both sides of surface have significant glaze ice accumulation
Glaze ice start to move to stagnation line
Ice accumulation on stagnation line fully
End
Front view
Top view
Side view
Glaze
Time zone (mins)
00:30
01:00
02:00
03:30
06:00
08:00
09:00
15:30
2
4
6
8
10
12
14
16
00:30
01:30
02:00
04:00
06:00
08:00
10:00
15:30
Front view
Top view
Side view
Rime
Explaination
Start
less ice accumulated
Ice accumulation without stagnation line
Start ice accumulation on stagnation line
Both sides of surface have significant ice accumulation
Ice accumulation on stagnation line fully
Rime ice steadly accumulated fully
End


Top
Glaze ice
14,9 mm.
15,5 mm.
DU96 - Glaze ice shape
Y
X
Top
Rime ice
25,8 mm
DU96 - Rime ice shape
Y
X

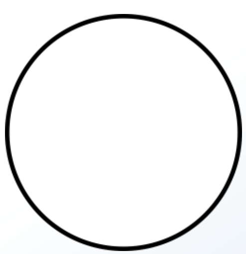


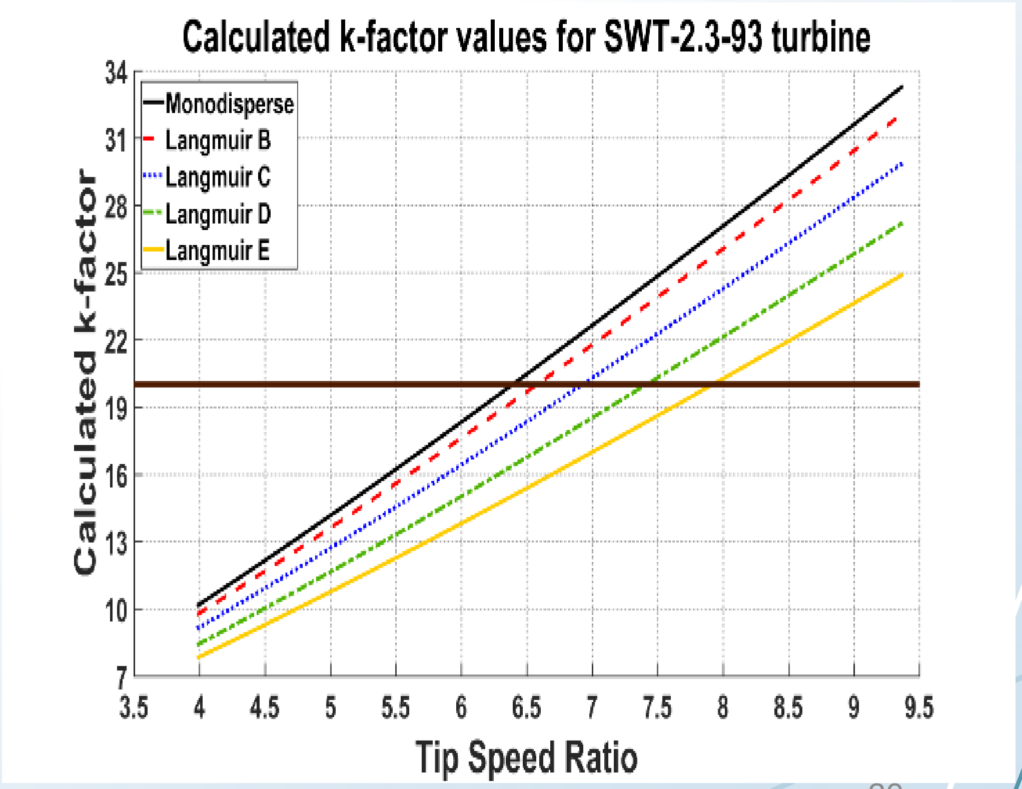


Analytical Modelling of ice accretion on Wind Turbine

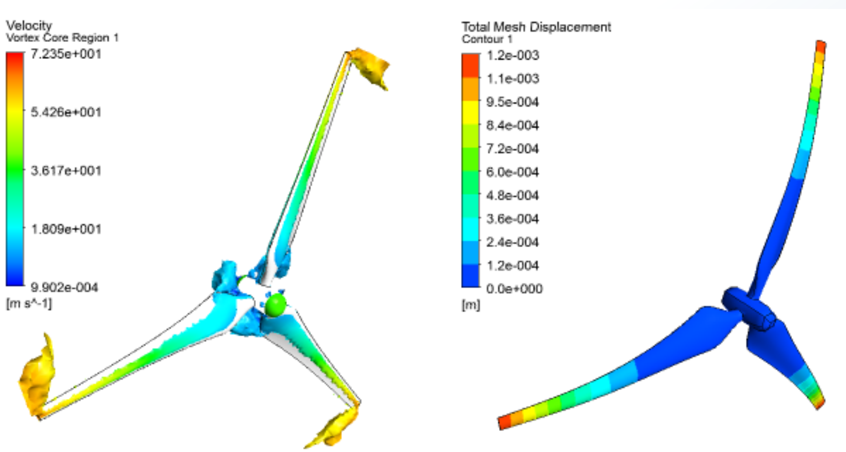
$$\frac{\mathrm{d}m}{dt} = \alpha_1 \alpha_2 \alpha_3 v A w$$

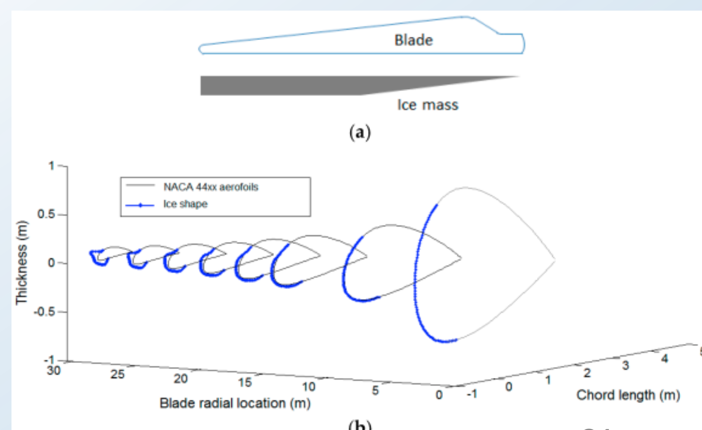
"*k*-factor" describes the ratio of accreted ice mass on a reference collector and wind turbine blade profile.



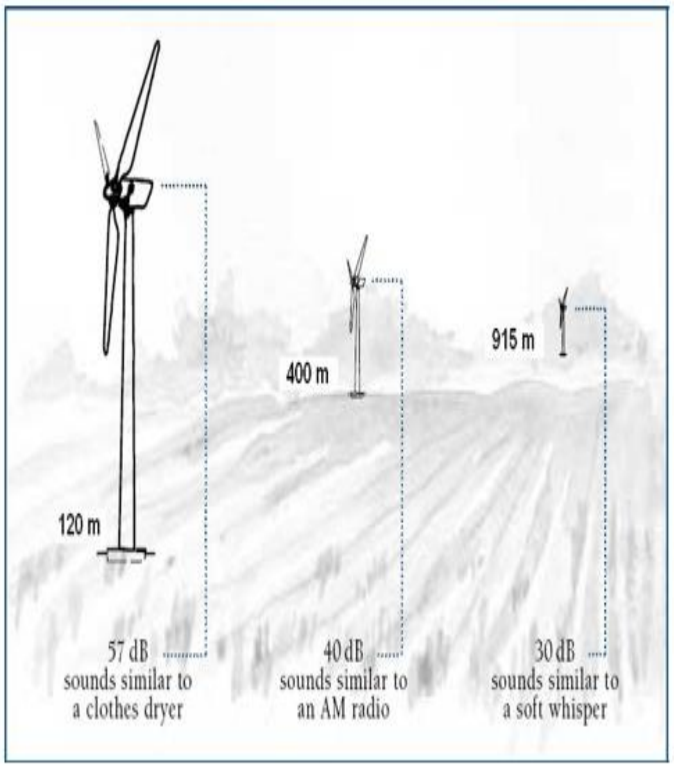


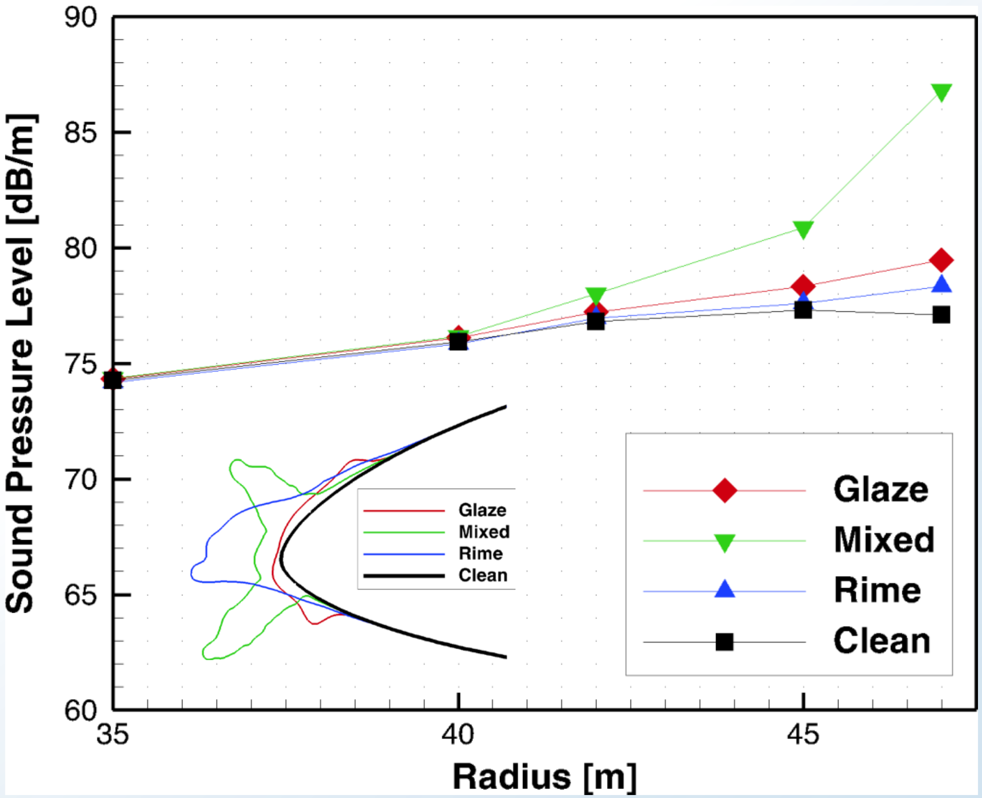
Structural Inegrity/ Ice loads





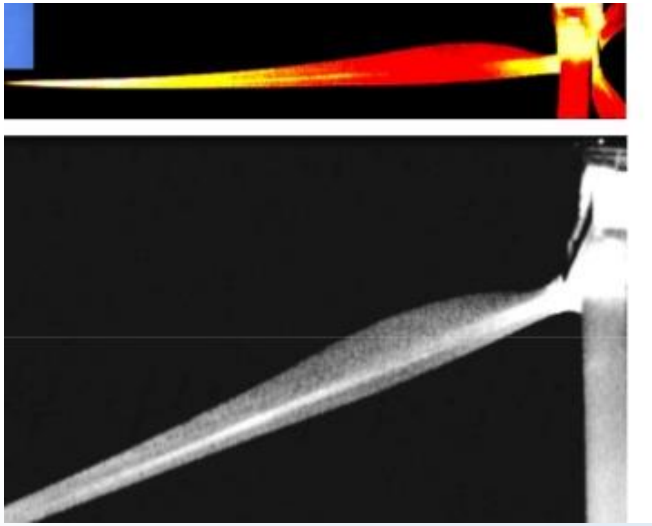
Enhanced Noise Propogation

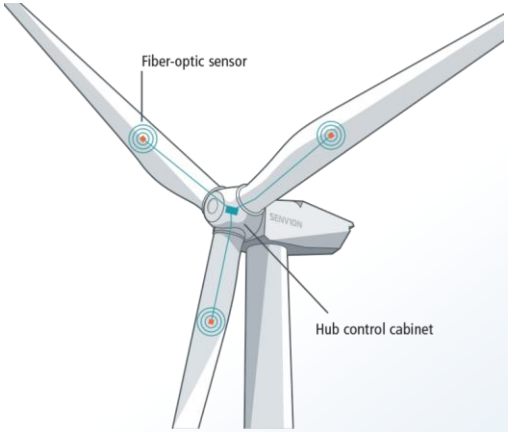




Ice Detection

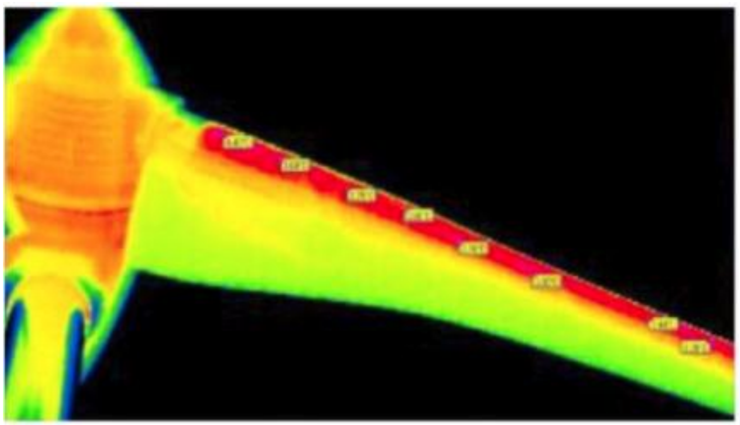
- **In-Direct Method**
  - Production Data
- **Direct Methods**
  - Sensors on the nacelle
  - Sensors on the blade

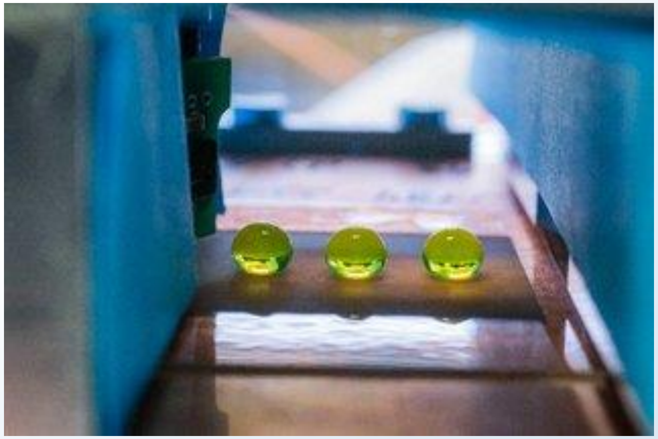


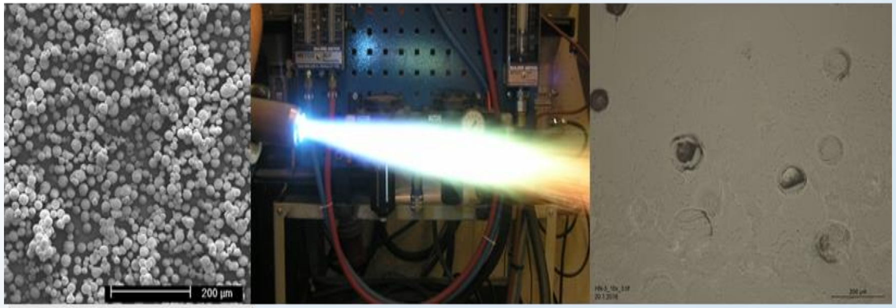


Ice Mitigation

- De-icing using thermal appraoch
- Anti icing using surface coatings







Ice Chunks

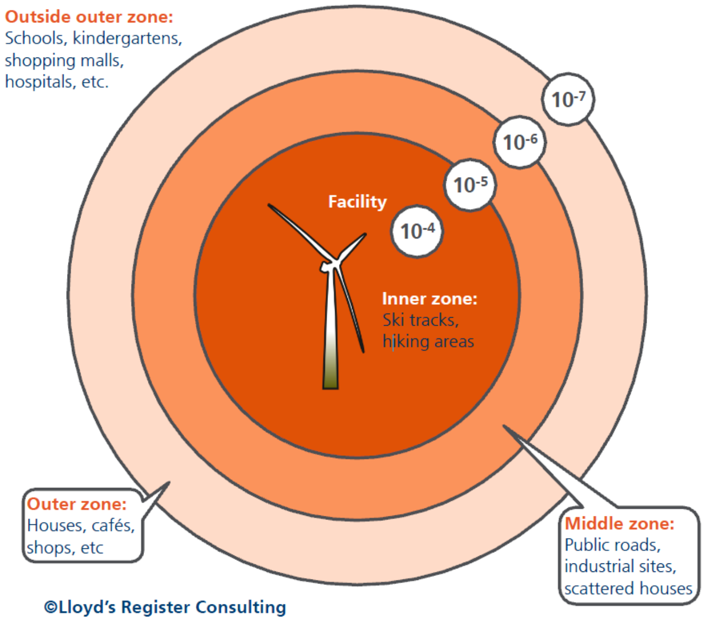
- Commonly used safety distance rule for icefall from an operational wind turbine

$$\text{Safety distance} = 1{,}5 * (H+D)$$

where

H = hub height of wind turbine

D = rotor diameter



THANKS.