Numerical Study of Atmospheric Ice Accretion on Wind Turbines

(IWAIS'15- Uppsala)

Muhammad S. Virk

Atmospheric Icing Research Team
Department of Industrial Engineering
Narvik University College, Norway

Outline

- Introduction
- Atmospheric icing physics
- CFD based numerical modelling of ice accretion

- Results
  - ✓ Parameteric senstivity analysis
  - ✓ NREL 5 MW- case study
  - ✓ Full scale - single blade study
  - ✓ Full scale - 3 blades study

- Possible future applications
- Remarks

Introduction

- Cold regions have good resources of wind energy, but atmospheric icing is one of the major hinderence in proper utilization of these useful resources.

- Wind turbine operations/performance in cold regions get effected due to accreted ice that leads to disrupted 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.

- Atmospheric icing on wind turbines mainly occurs due to collision and freezing of super cooled water droplets with the exposed surface of wind turbines. There is at present a need to develop a better understanding of atmopsheric icing physics and it's resultant effects to improve the design and safety of wind turbines operations in cold regions.

- This research work has been focused on understanding and simulating the rate and shape of atmospheric ice accretion on wind turbine blades, using computational fluid dynamics (CFD) based multiphase numerical approach.

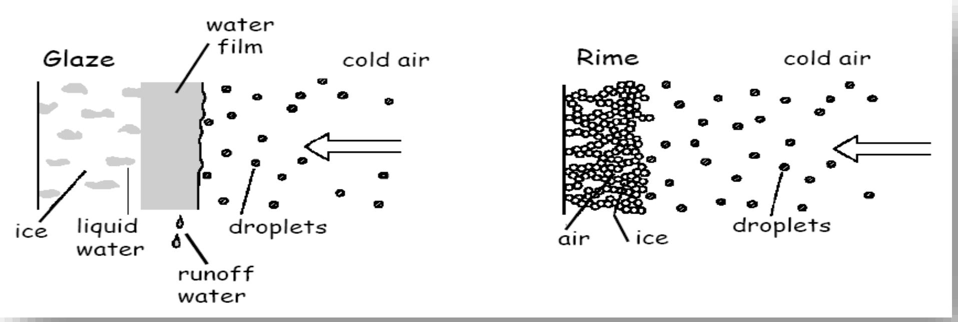
(Example cases of atmospheric ice accretion on wind turbines in cold regions)

[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.

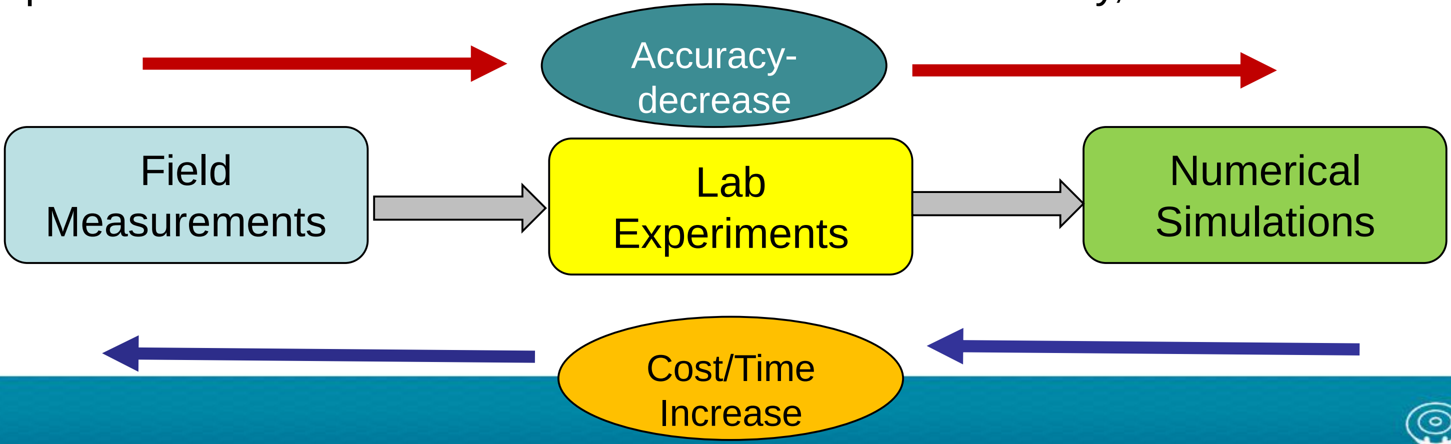
[2]- http://www.eolos.umn.edu/research.

Atmospheric Icing 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).

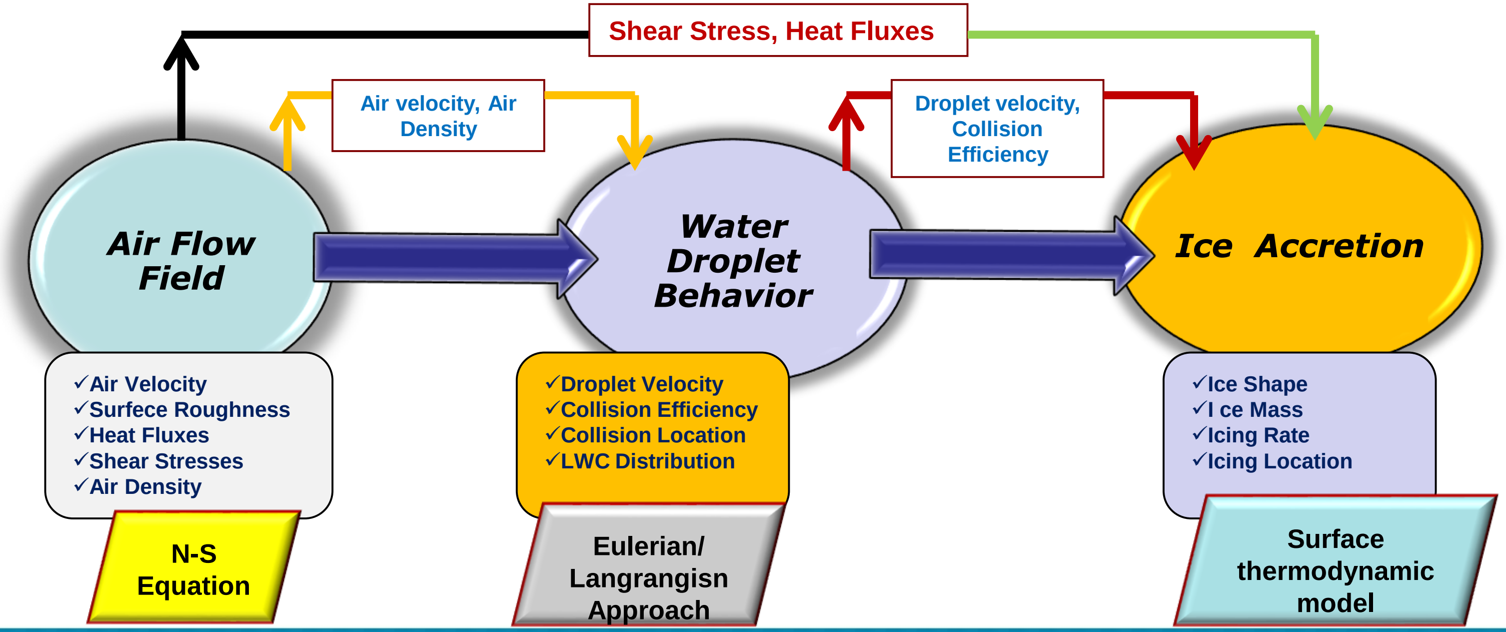


- Extant of ice accretion can be estimated either by field measurements, lab based experimentation or numerical methods with certain accuracy, because:



Numerical Modelling of Atmospheric Icing

- CFD based 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.



Parameter Senstivity Analysis

Analyses were carried out to understand the effects of :

a) Operating parameters (Temperature, Droplet size).
b) Geometric parameters (Blade chord length).

A) Operating Parameters Senstivity Analyses

- NACA 64618 blade profile was used.

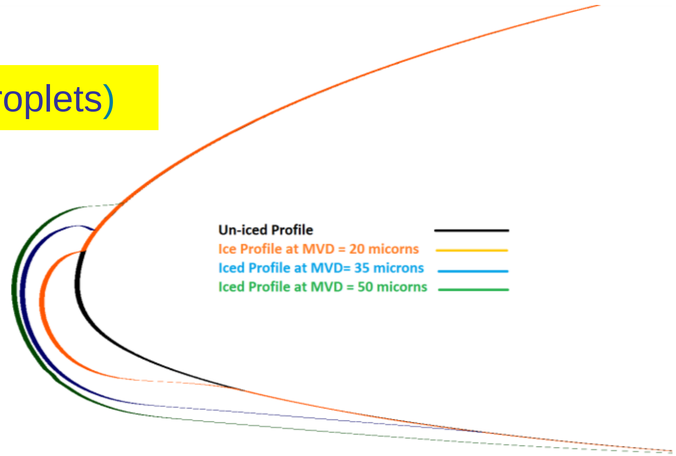
- Effect of operating temperature variation was analysed for three different values of atmospheric temperatures (-2.5 C, -10 C & -15 C) at constant droplet diameter of 20µm.

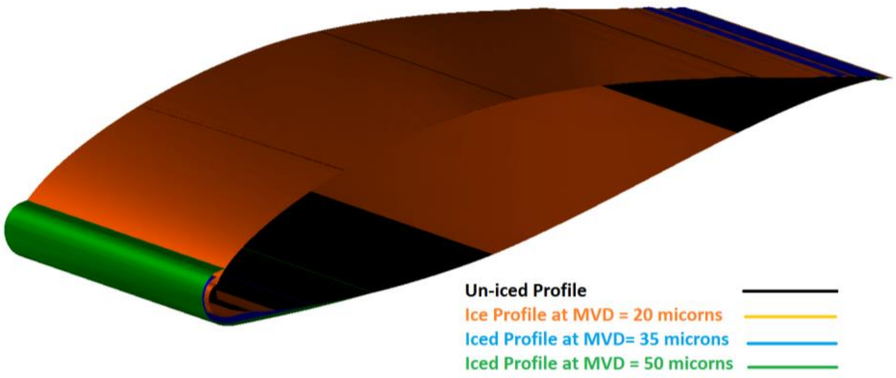
- Effect of droplet size variation was analysed for three different droplet sizes (20, 35 & 50 µm) at constant operating temperature of -10 C.

  ✓ *Analyses showed that air temperature alone can not be used to differentiate between rime and glaze ice, but that droplet size can also change the effect of an icing event.*

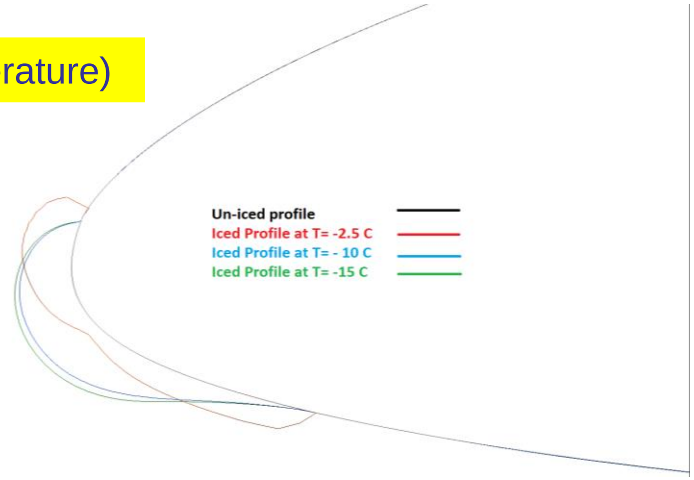
Effect of Temperature & Droplet Size

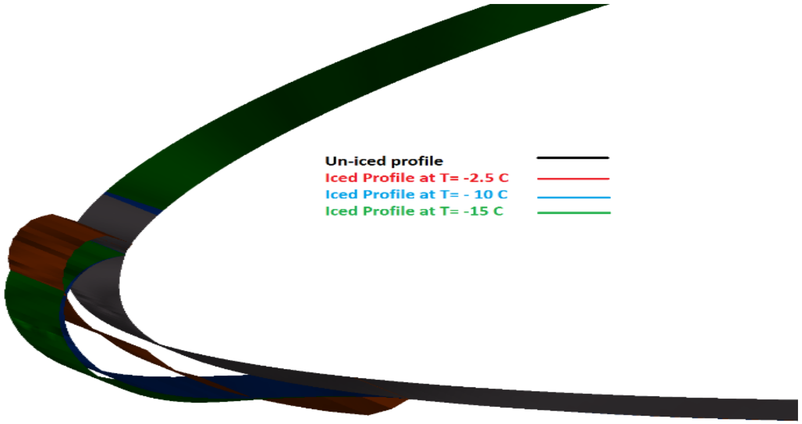
(Droplets)





(Temperature)

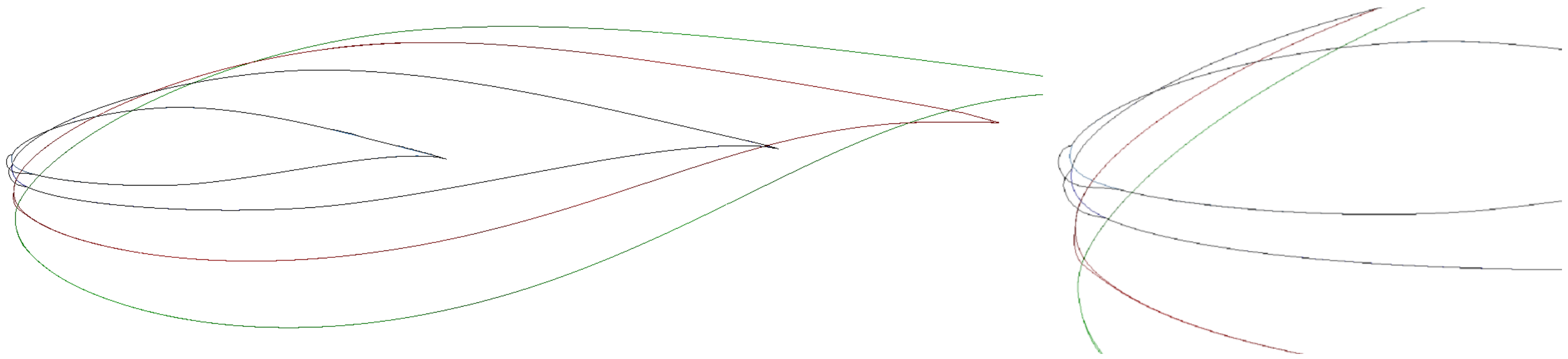




B) Geometric Parameter Senstivity Analyses

- Four different size, wind turbine blade profiles were analyzed at operating conditions, T = -10 C, MVD = 20 microns & v = 10 m/s

- 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.

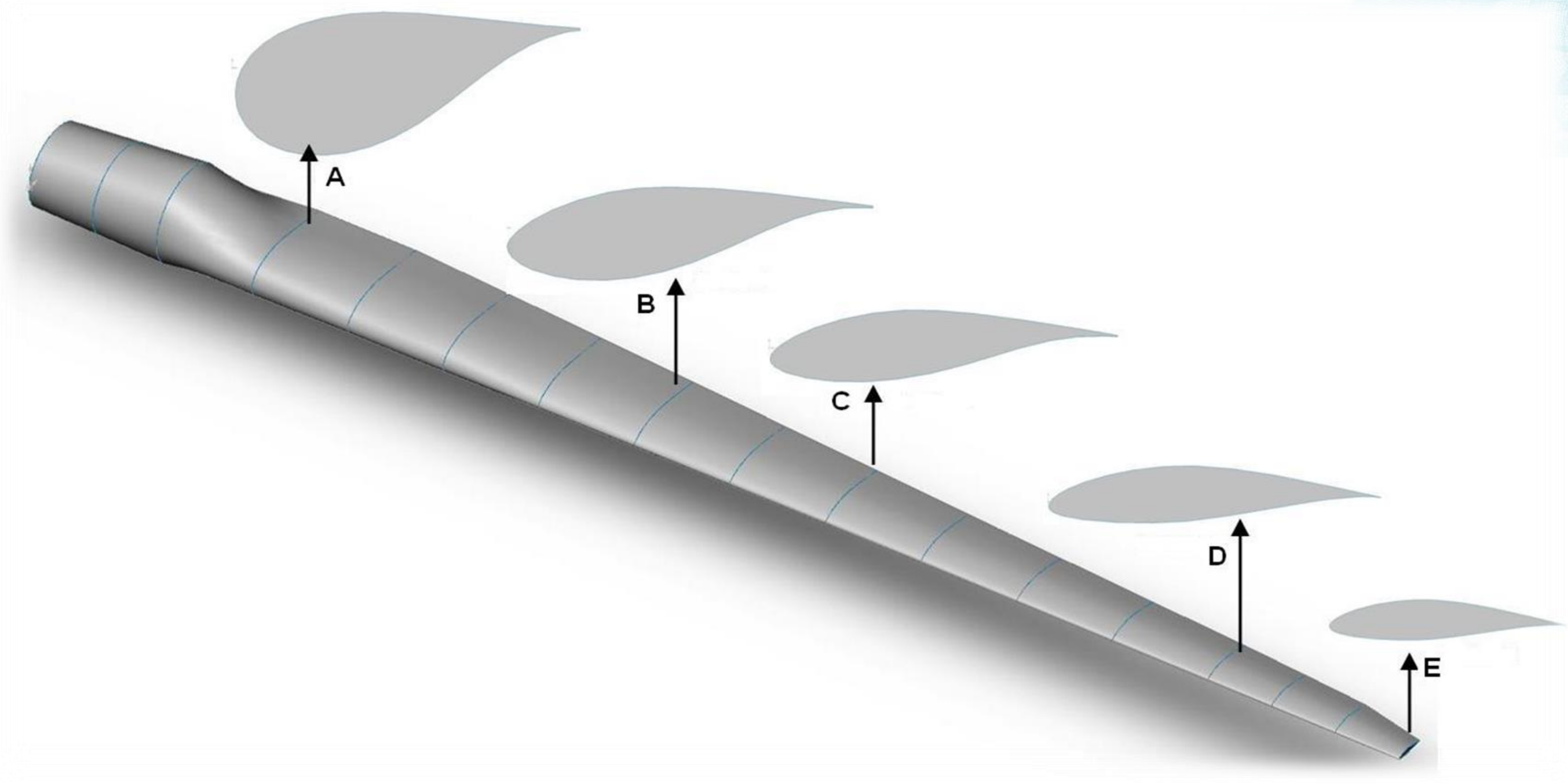


This highlights the possibility of passive anti-icing design of wind turbine blade.

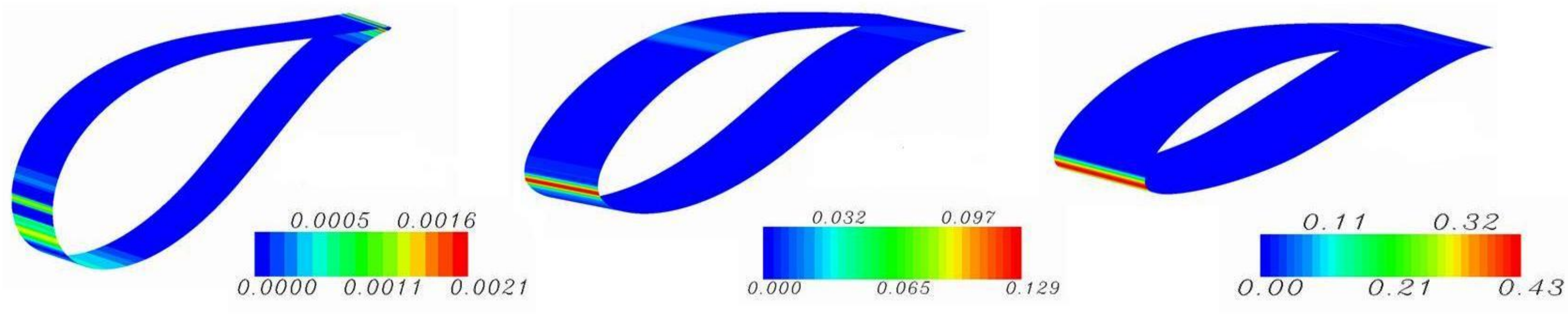
Case Study – Icing on NREL 5 MW Wind Turbine

Test Case: NREL 5 MW Wind Turbine

- Rate and shape of atmospheric ice growth at 5 different sections along NREL 5 MW wind turbine blade was numerically simulated.
- Performance losses were estimated using BEM theory.
- 5 sections (0.5m wide) were selected along the blade
- Analyses were carried out for both rime and glaze ice conditions (v= 10 m/s, T = -10C, MVD = 20 μm, t = 60 min) and the results were compared with the published data.

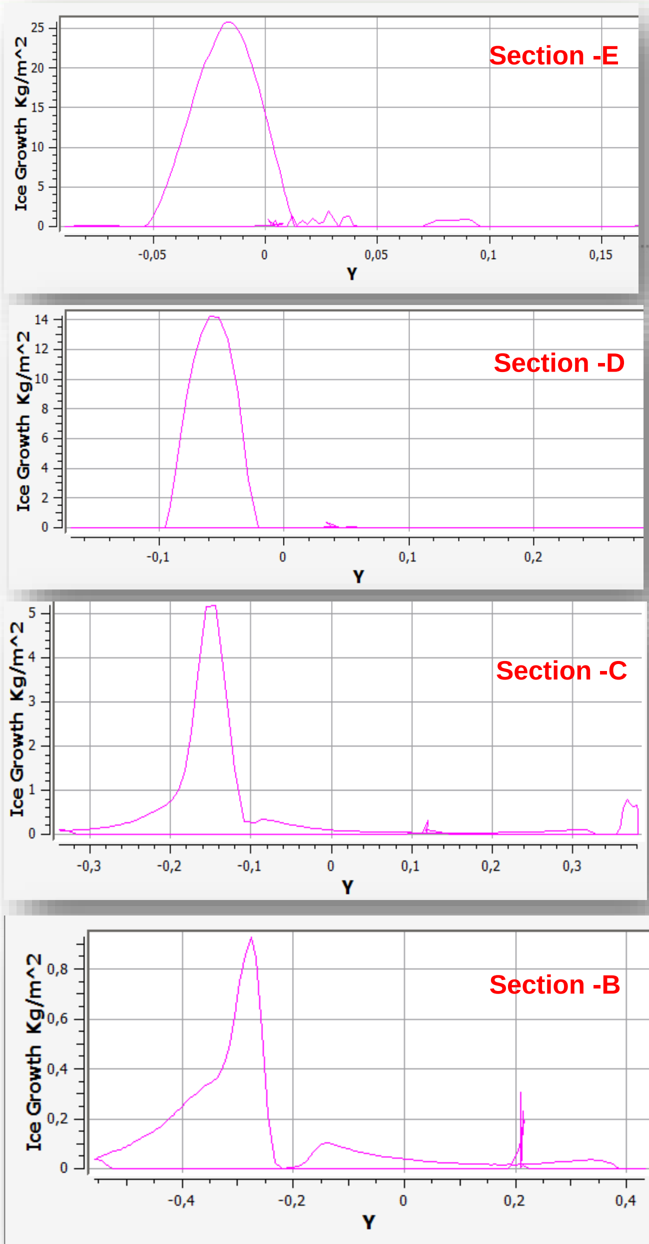


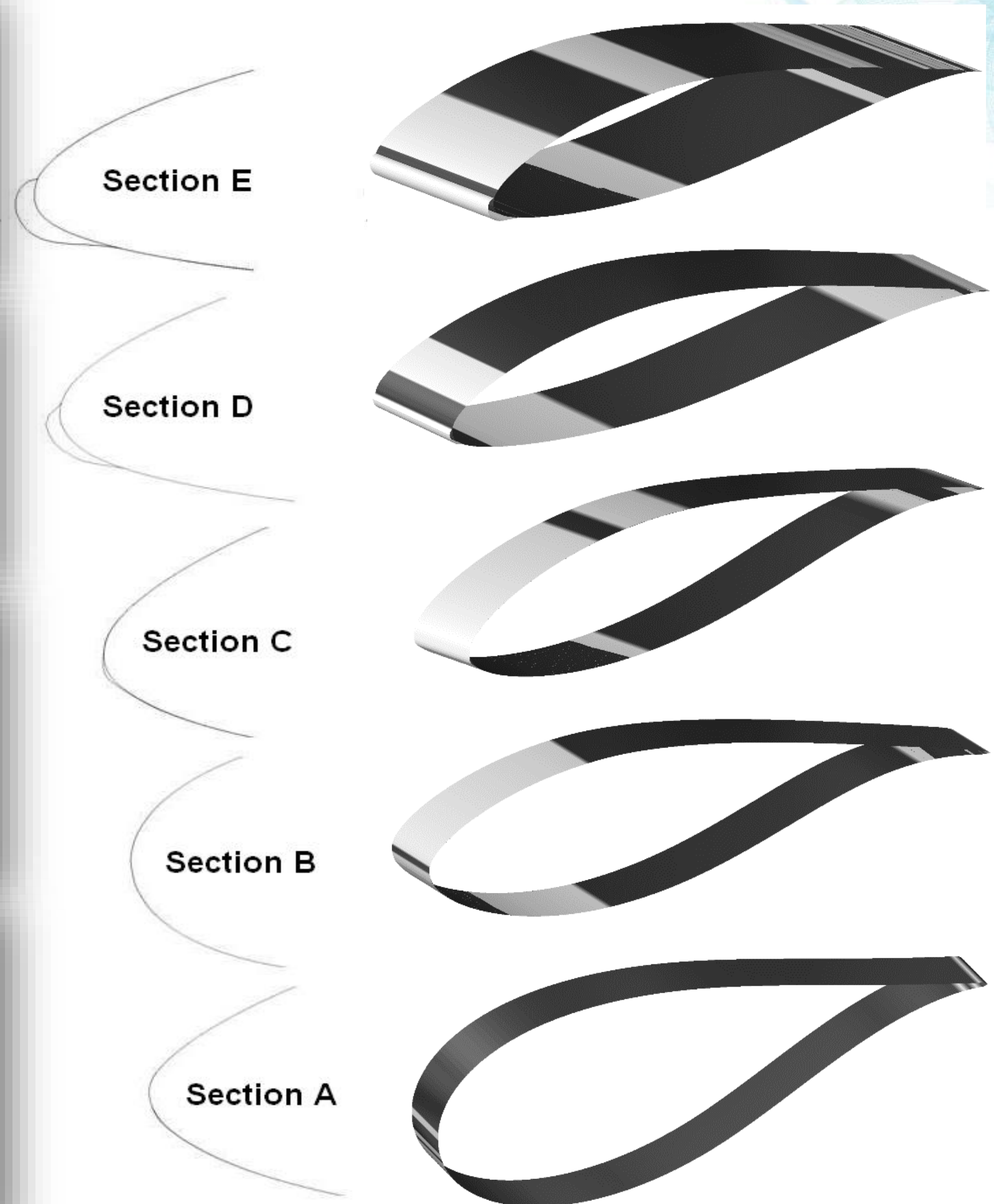
A	B	C	D	E
13.25 m	**33.75 m**	**41.95 m**	**54.25 m**	**63 m**
4.557 m	3.748 m	3.256 m	2.518 m	1.419 m



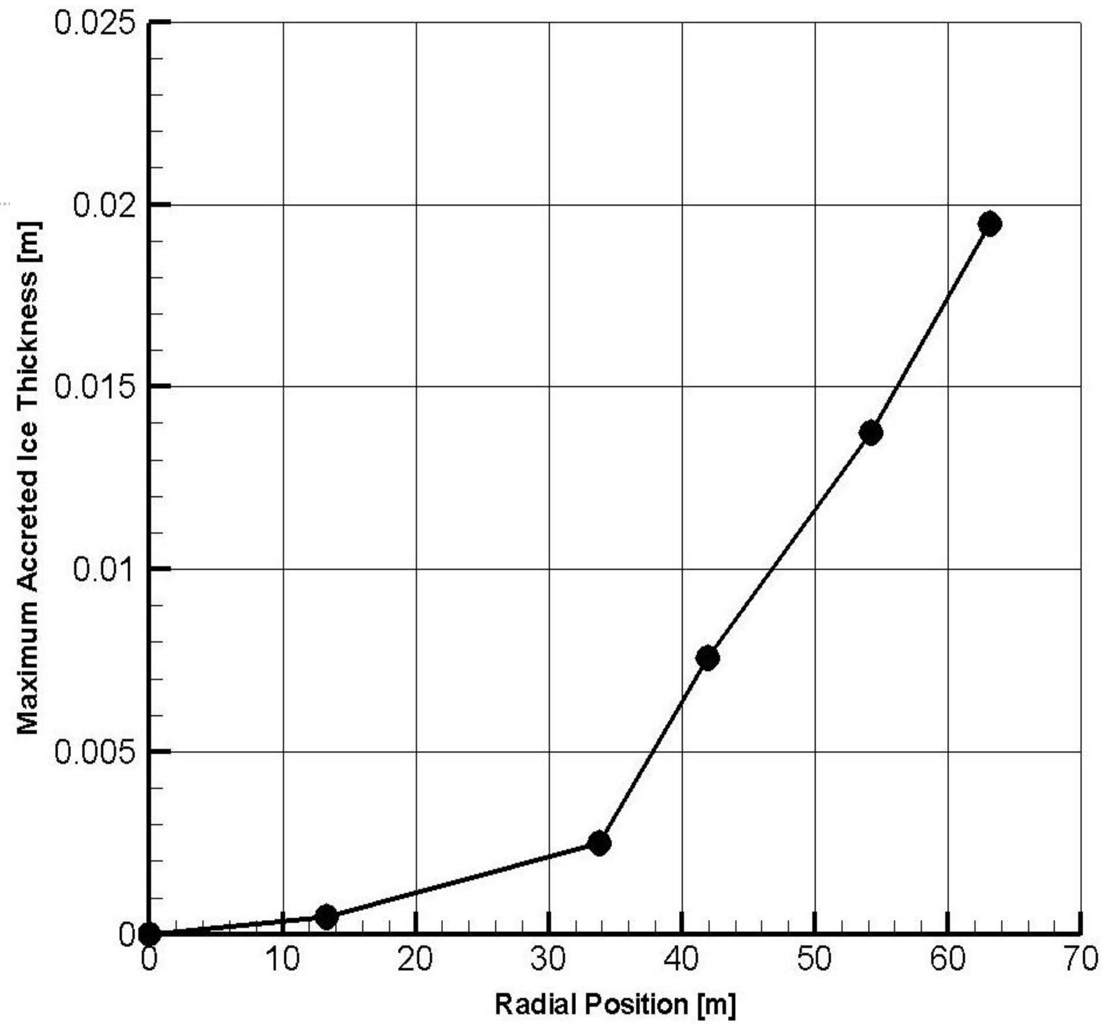
(Section A - Root) **(Section C - Centre)** **(Section E - Tip)**

(Droplet Collision Efficiency)


Section -E
Ice Growth Kg/m^2
Y
Section -D
Ice Growth Kg/m^2
Y
Section -C
Ice Growth Kg/m^2
Y
Section -B
Ice Growth Kg/m^2
Y


Section E
Section D
Section C
Section B
Section A

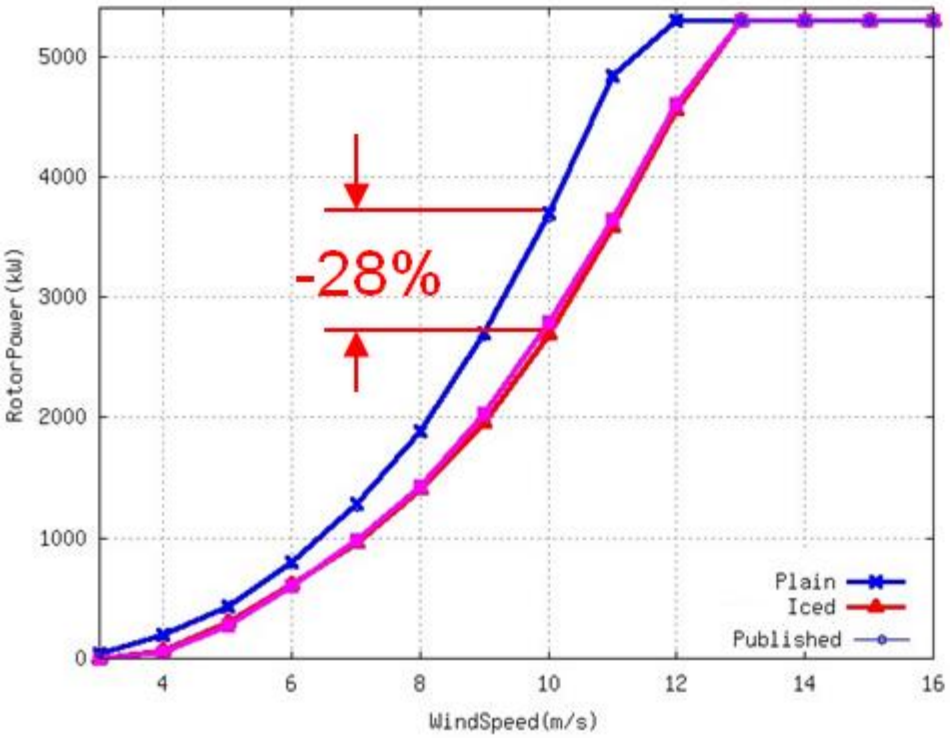
(Ice Growth)



Accreted ice thickness along the simulated NREL 5MW wind turbine blade at T = -10C, t = 60 min.

Performance Curves

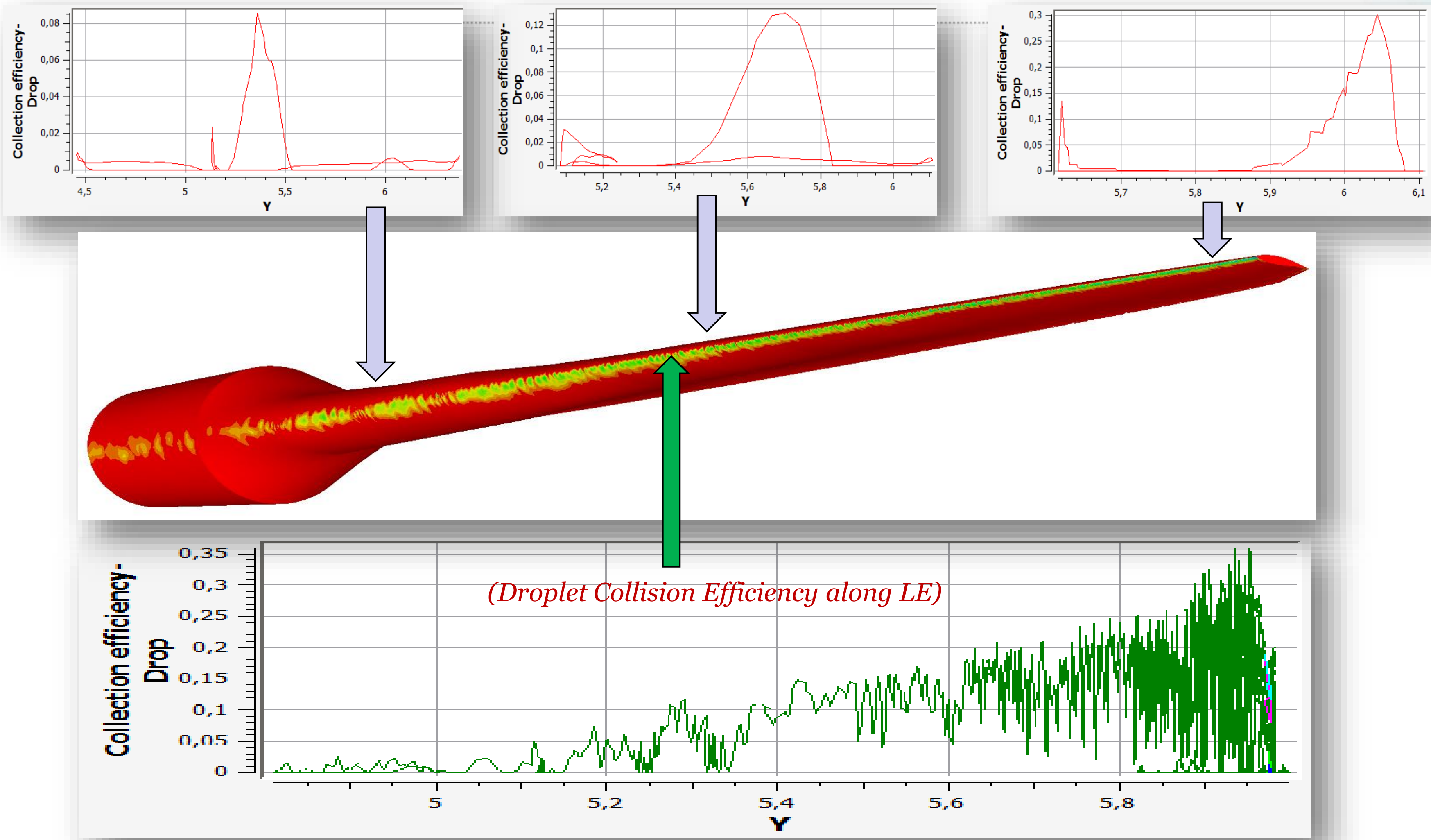
- Blade element momentum (BEM) theory based analyses of simulated NREL 5 MW blade showed a decrease in performance approximately 28 % due to icing.



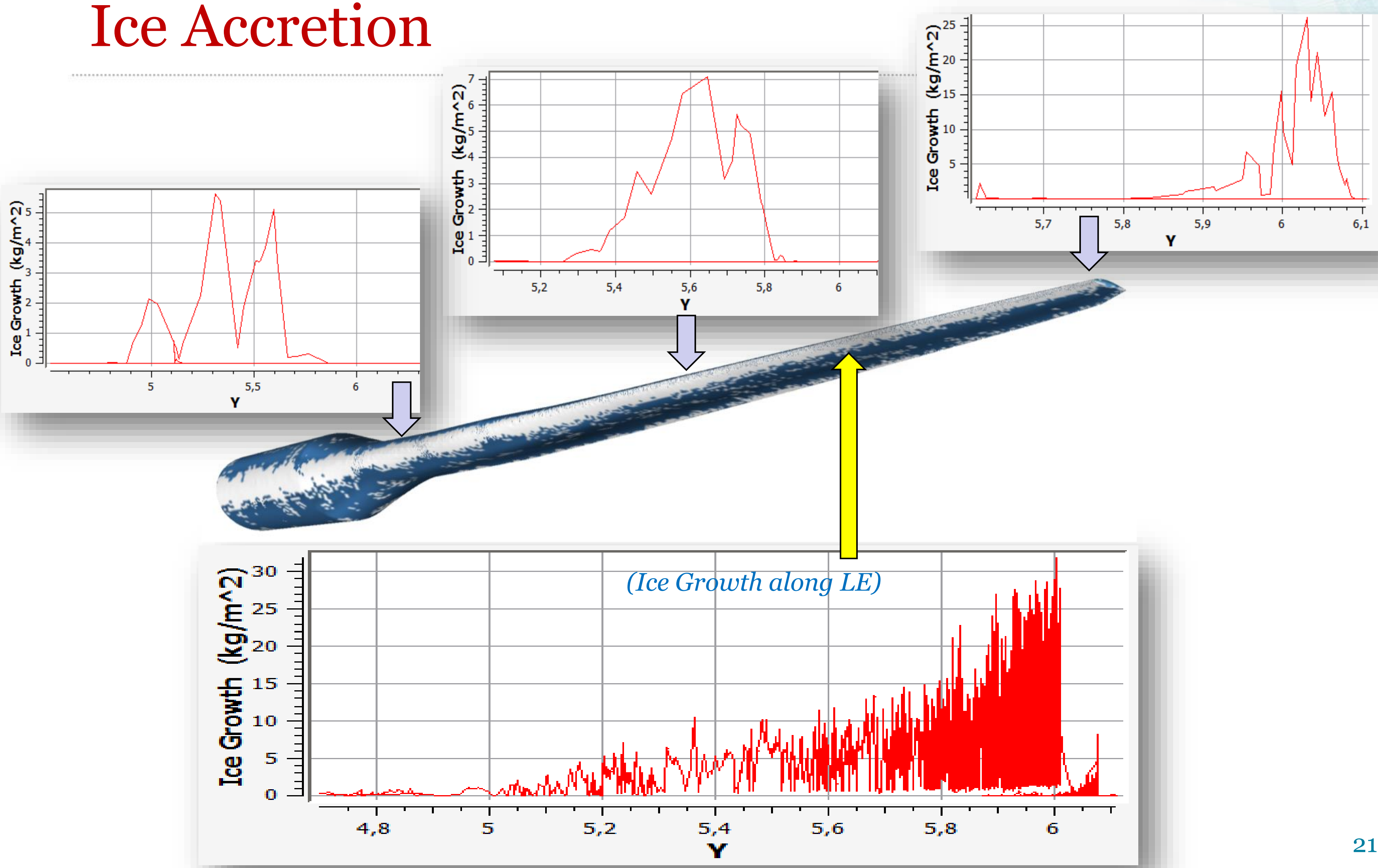
Full Scale NREL 5 MW Icing Analysis

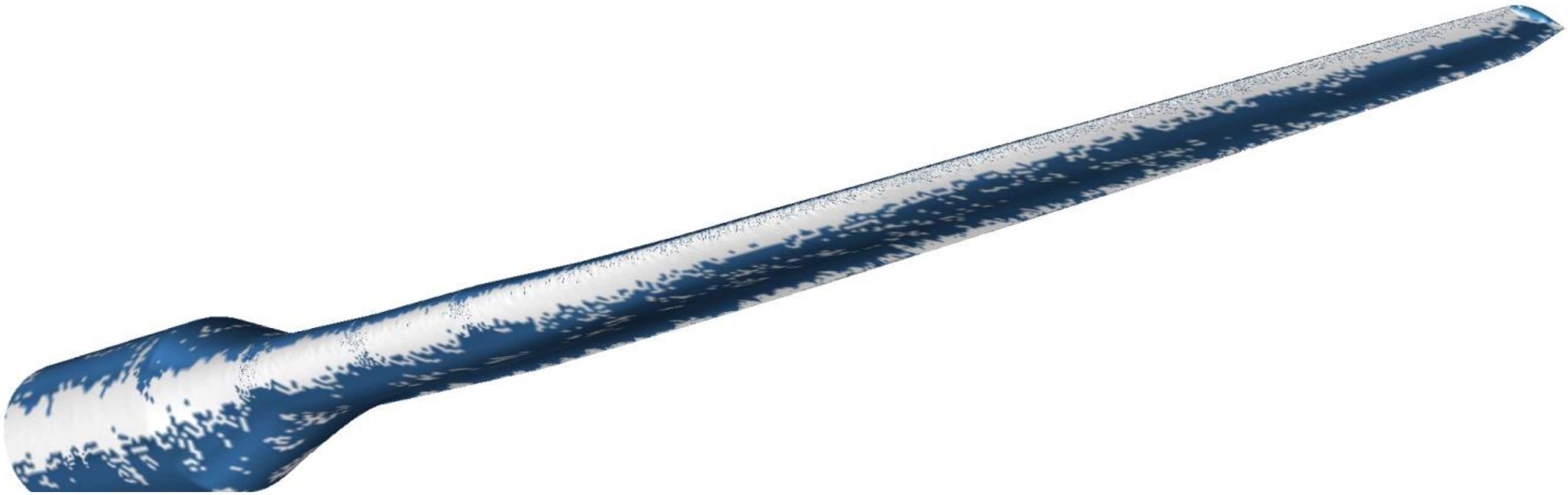
Air Flow Behavior

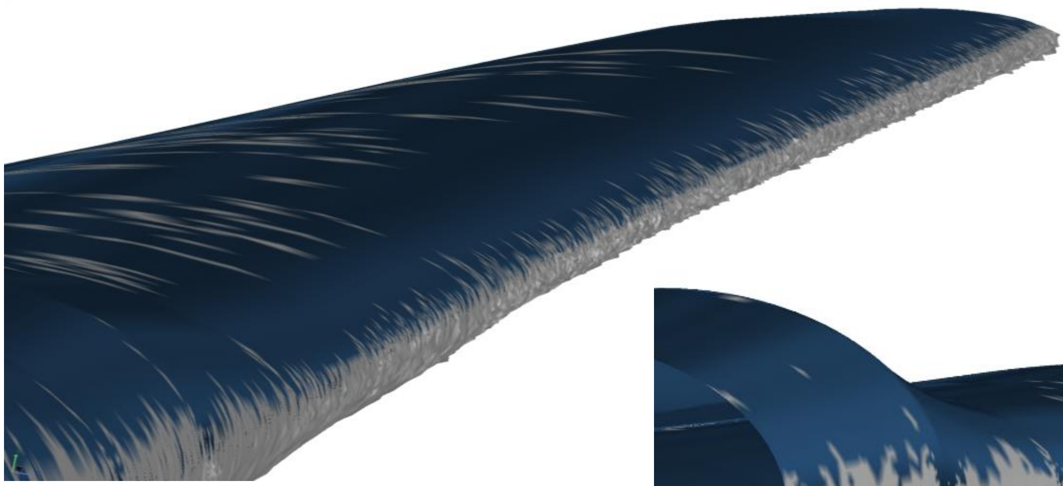
Droplet Collision Efficiency

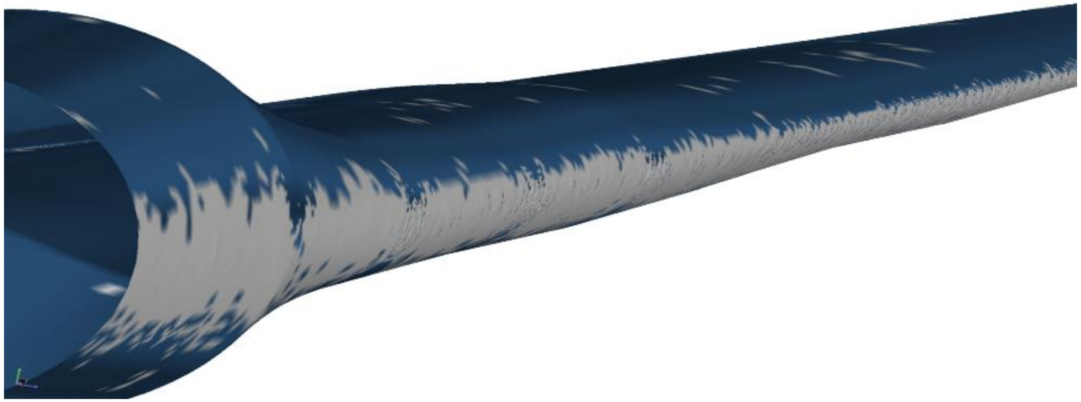


Ice Accretion

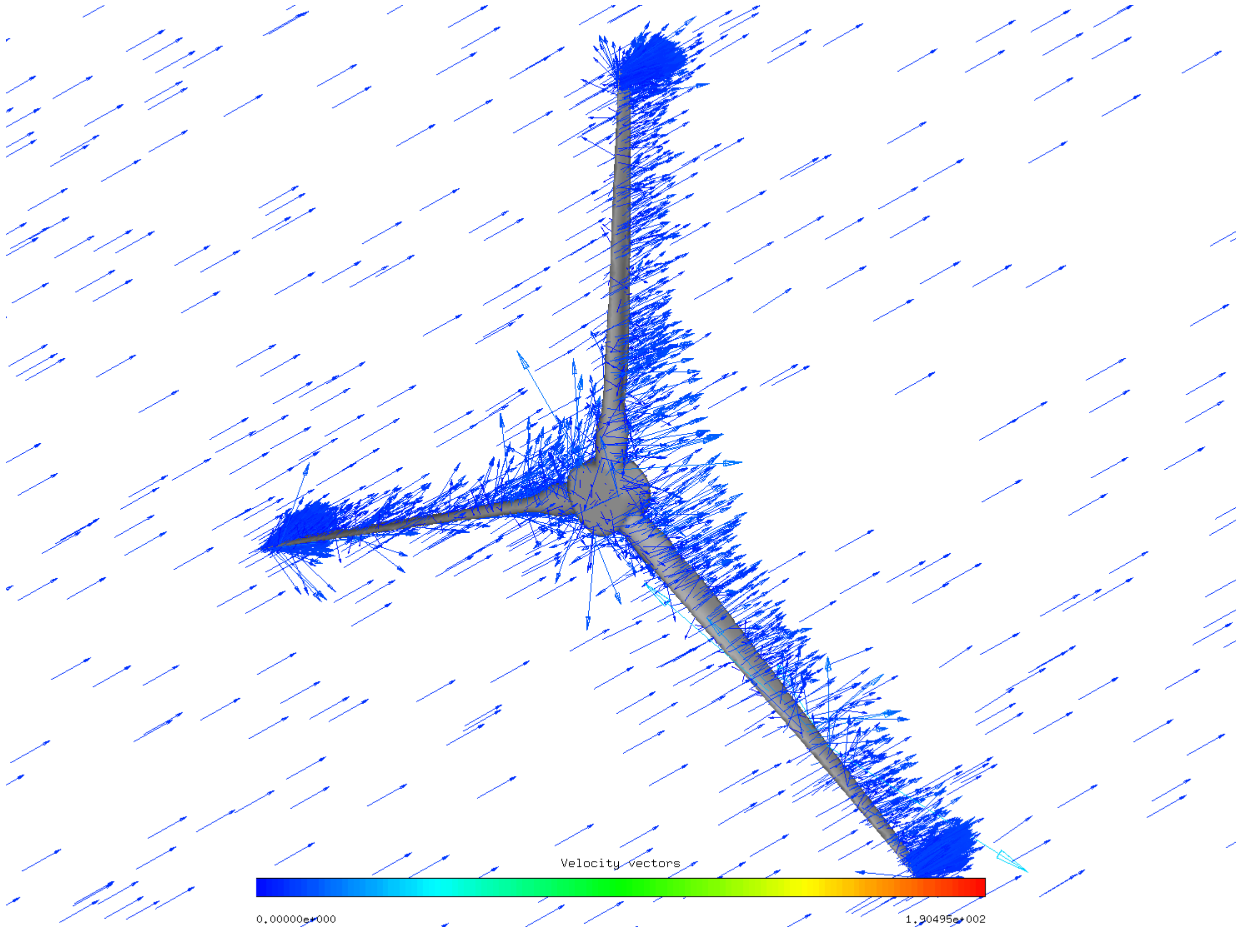




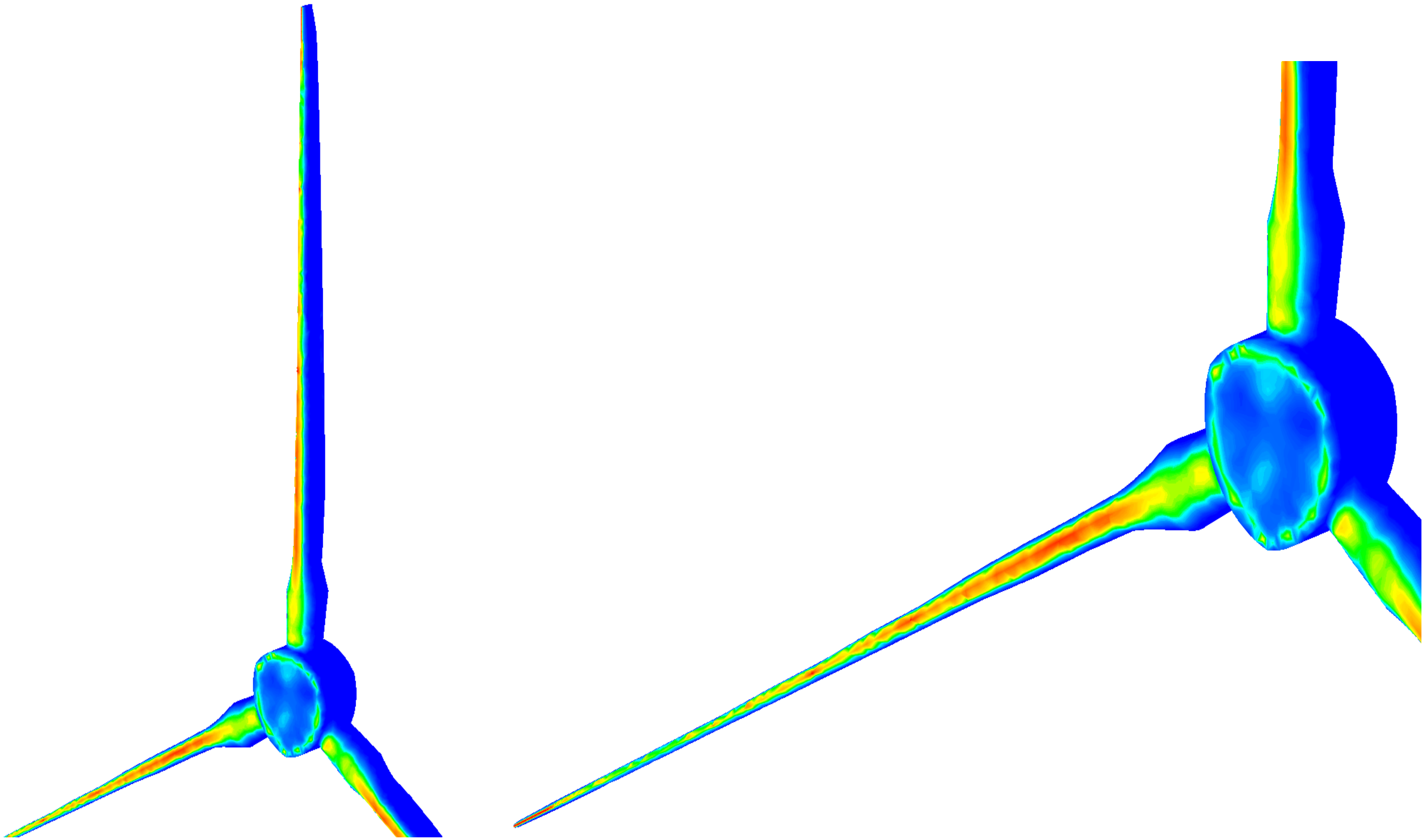




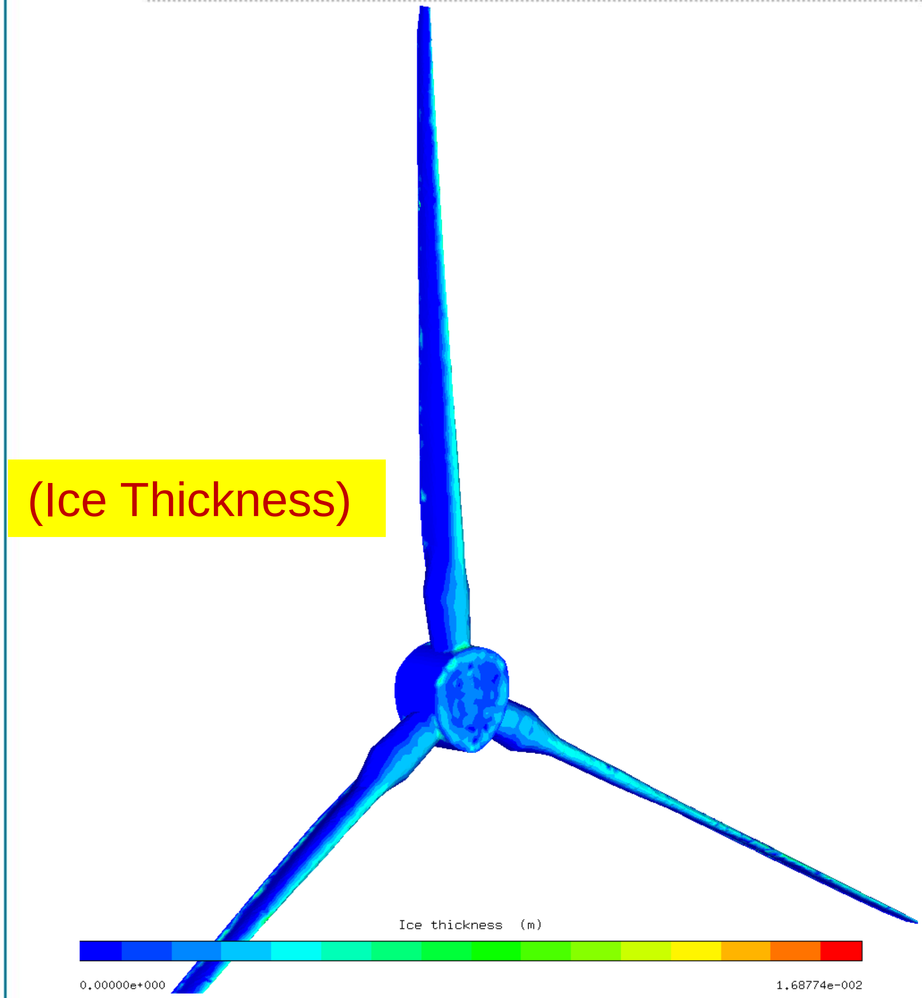
Air Flow Behavior

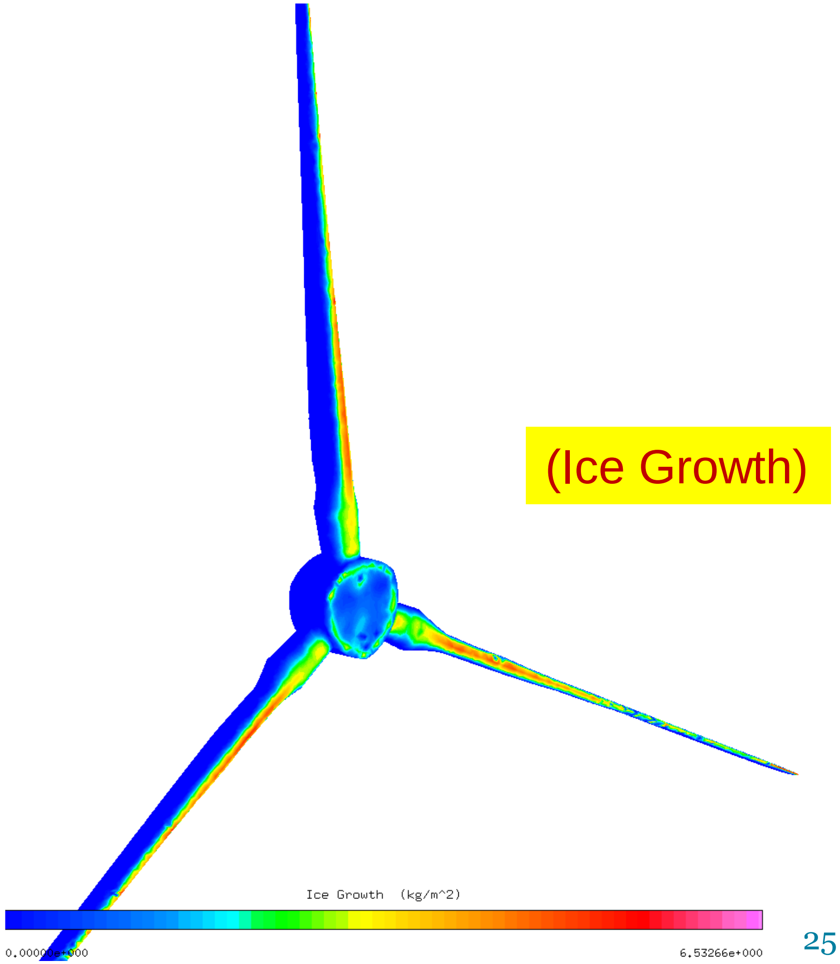


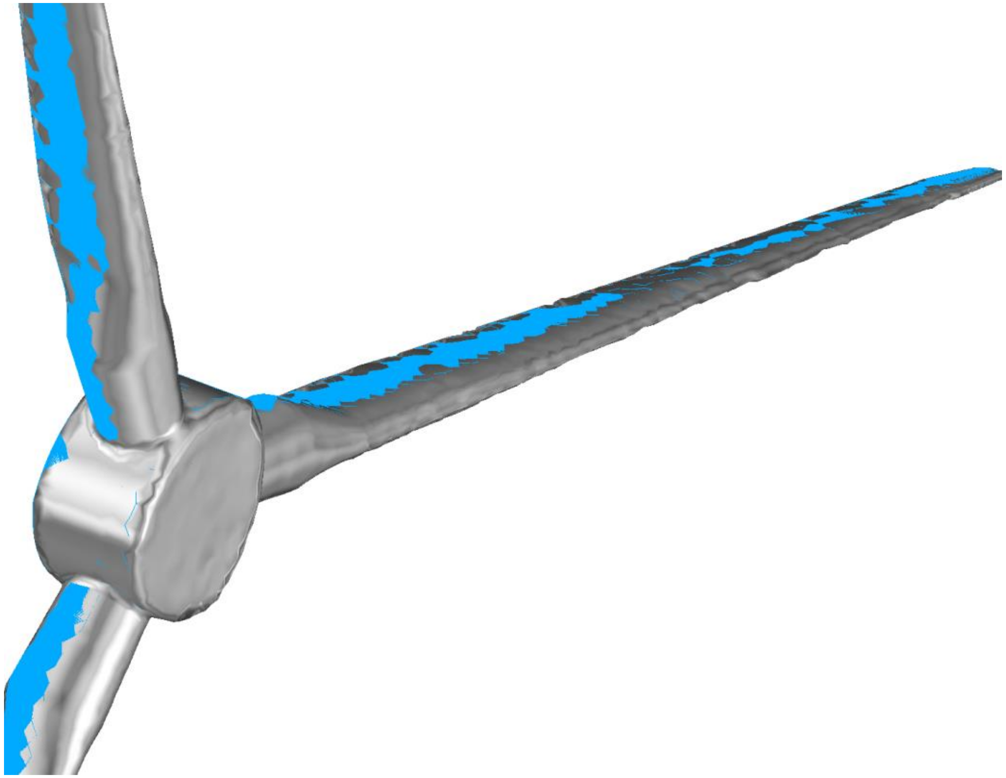
Droplet Behavior

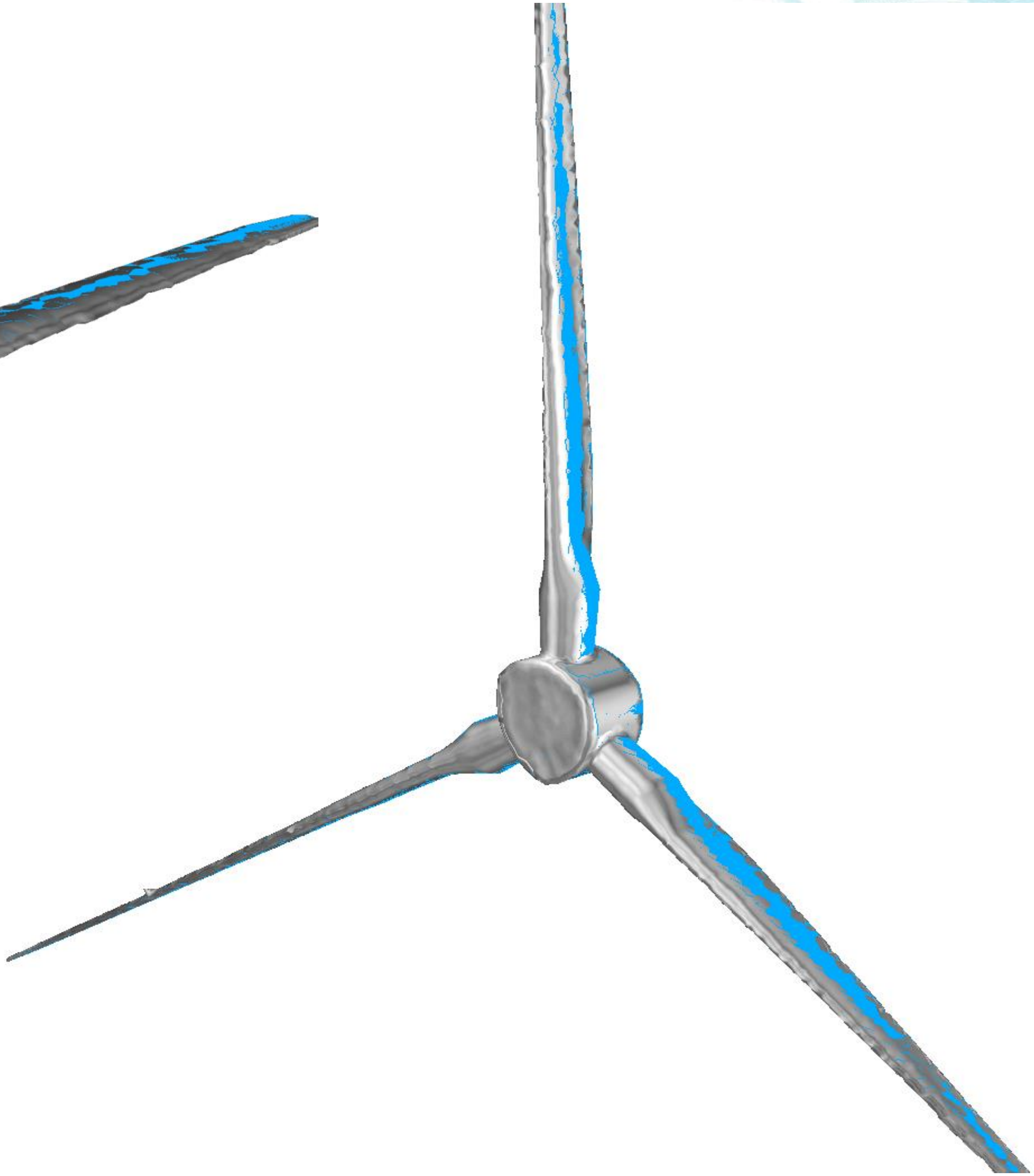


Ice Accretion



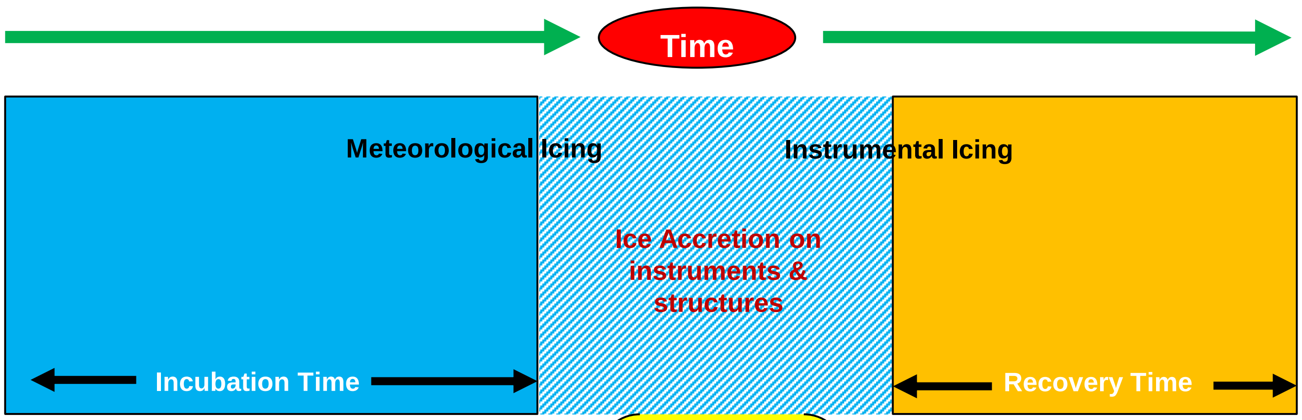






Possible Future Applications

IEA Ice Site Classification – (??)



1. *Wind Velocity*
1. *Atmospheric Temperature*
2. *LWC*
3. *MVD*
4. *Time*
5. *Surface Material*
6. *Object Shape*
7. *Object Size*

CFD Simulations:

- ✓ Circular cylinder as per ISO 12494
- ✓ Approperiate Wind turbine profiles (airfoils)

- Icing Type
- Icing Load
- Local Icing Intensity

IEA Wind ice class	Meteorological icing (% of year)	Instrumental icing (% of year)	Production loss (% of 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

- Advances in CFD based numerical techniques for simulating rate and shape of ice accretion on structures can be used as tool for estimating ice type and local ice loads on wind turbines and relaetd instruments.

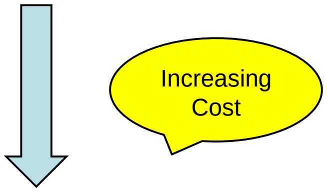
- This can also possibly help:
  - ✓ *To better estimate the AEP losses due to ice accretion.*
  - ✓ *To improve the design of wind turbines and related instruments for operations under icing conditions.*
  - ✓ *To estimate the local intensity of ice accretion.*
  - ✓ *To improve the performance of anti/deicing systems for wind turbines.*

CFD - As a Tool For Wind Turbine Design Certification (??)

- Current, national & international standards for wind turbines do not typically address icing conditions.

- Generally engineering tools used for design and certification includes:

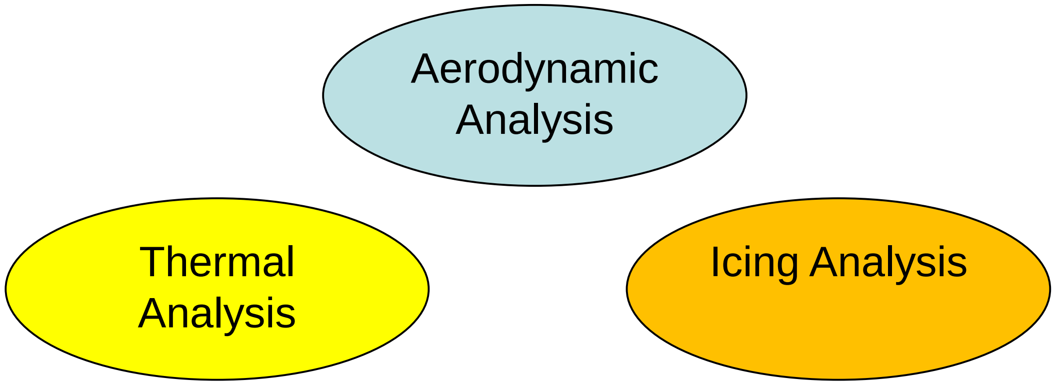
  - ✓ *Computational fluid dynamics*
  - ✓ *Lab based tunnel testing (Wind tunnel or icing tunnel)*
  - ✓ *Field testing*



- Advances in numerical models of ice accretion can possibly be used for design certification of wind turbine opeartions in icing conditions.

- The role of CFD in icing studies during design and certification may include:

  - ✓ *Predict ice shapes and their aerodynamic penalties*
  - ✓ *Design of IPS and study of design variables*
  - ✓ *Blade design optimization with ice accretion.*



Remarks

- Icing on wind turbines occur not because of single reason, but through a combination of effects that may not have been thought of during design process.

- CFD based numerical simulations can be a good way to estimate these effects during the design process of wind turbine with a reasonable degree of accuracy.

In icing ,'knowing something about behaviour of icing envelopes, even if there are errors around its fringes is better than not knowing anything'.

Still Lots More To Learn…..!!!

Thanks for your attention !!!!

This research work is partially funded by the Research Council of Norway, project no. 195153 and partially by the consortium of the ColdTech project - Sustainable Cold Climate Technology.

(Photo: Matthew Homola).