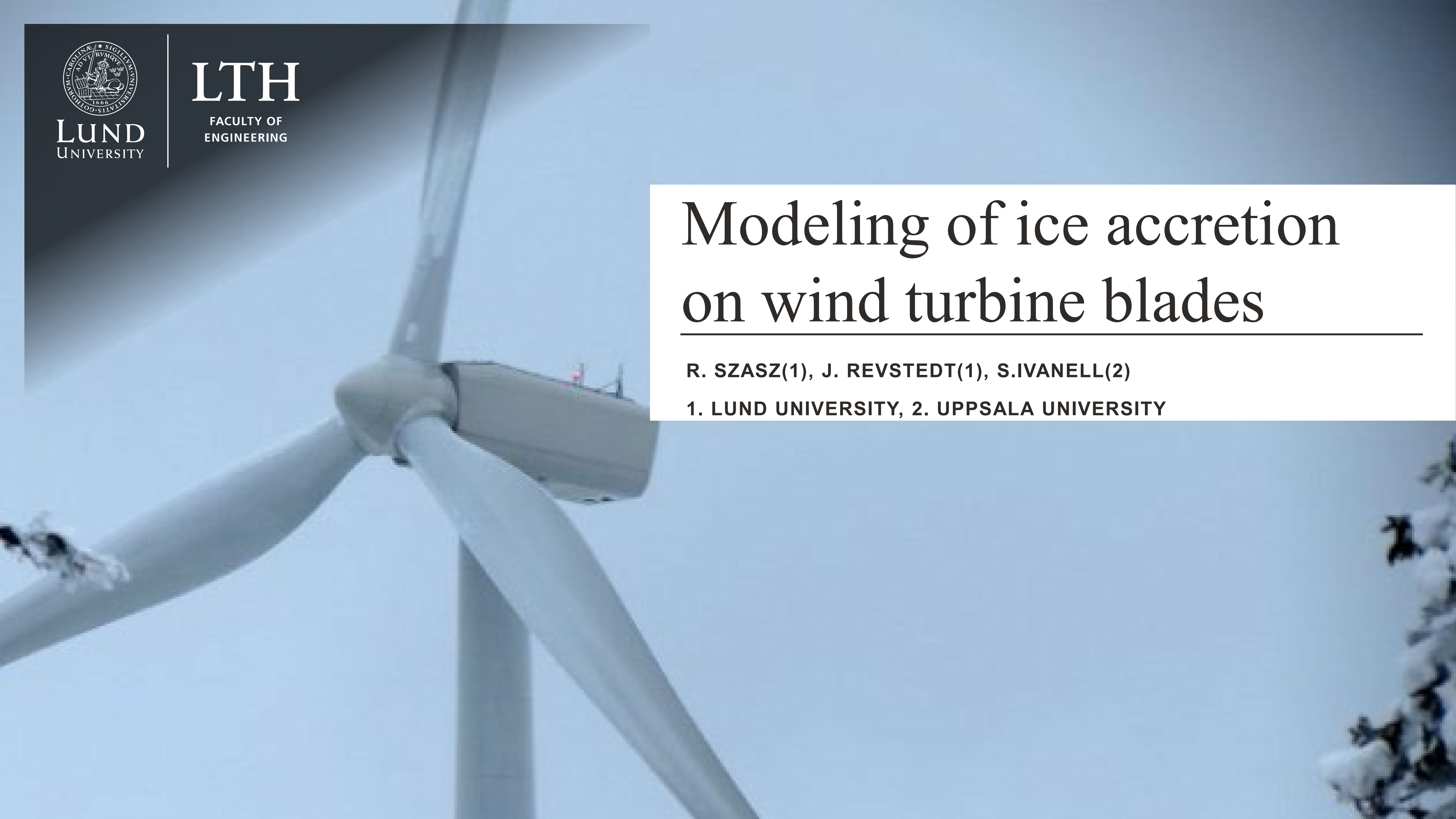

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Modeling of ice accretion on wind turbine blades

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Why?

- Ice accretion may lead to several issues:
  - Mechanical (extra load, imbalance)
  - Aerodynamic (reduced efficiency)
  - Danger (ice shed/throw)
- Understanding ice formation would help:
  - Design anti- and de-icing devices
  - Optimize airfoils
  - Predict losses
- Experiments
  - On site observations
  - Climatic wind tunnels
- Modeling
  - Varying degrees of complexity and accuracy
  - Easier to vary parameters
  - Need to be validated

Modeling

- Icing types
  - Rime
  - Glaze
- Makkonen [Makkonen1985]

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \phi u A$$

- α_i – collision/sticking/accretion efficiency
- LEWICE, TURBICE, FENSAP-ICE, …

Flow → Ice shape

Flow & Ice shape

[CC https://commons.wikimedia.org/wiki/File:Rime_Ice.jpg]

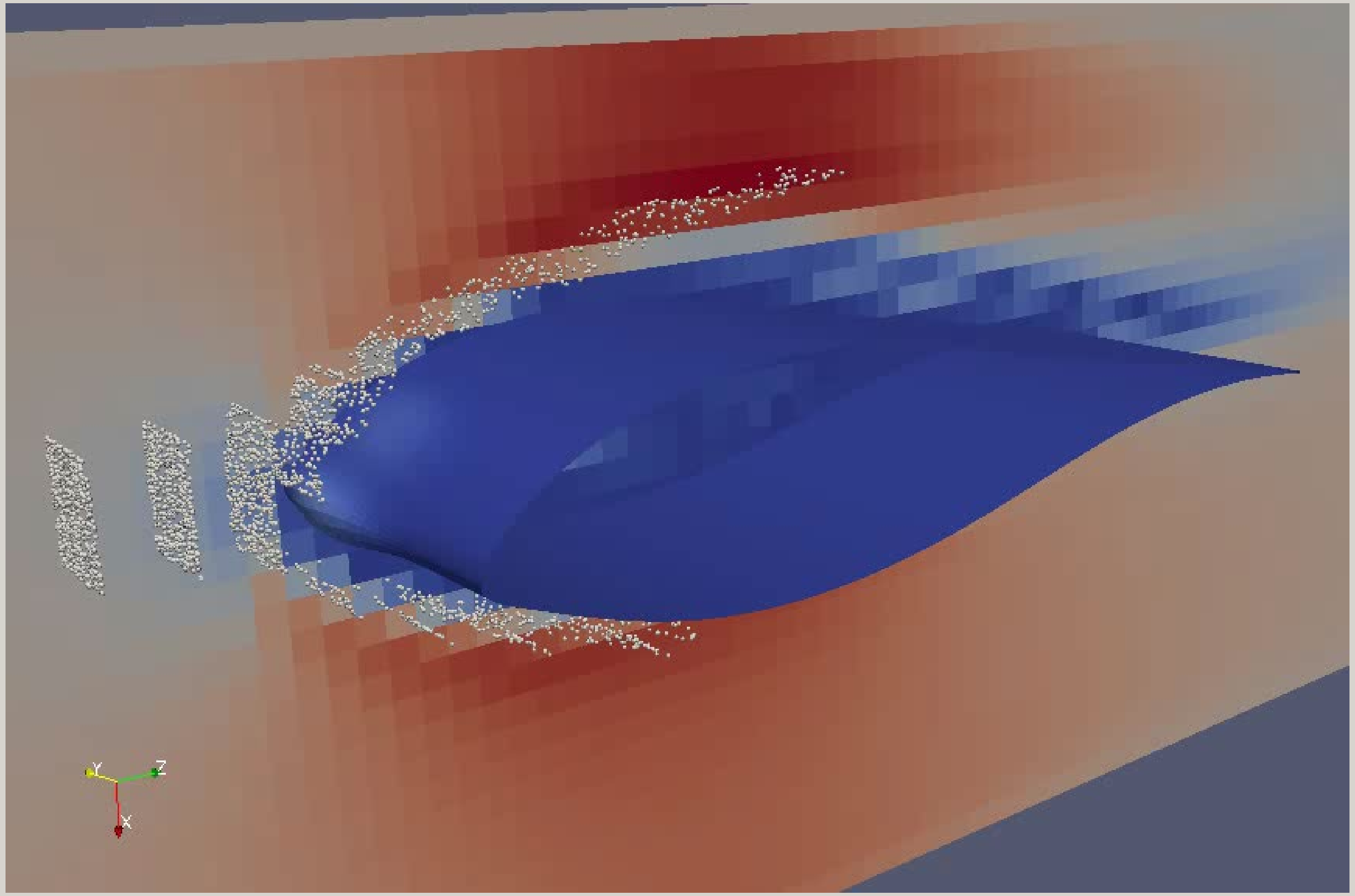
[CC https://commons.wikimedia.org/wiki/File:
Freezing_Rain_on_Tree_Branch.jpg]

Goals of the model

- Ability to model simultaneously flow and ice accretion
- Efficient (relatively…)
- Flexible
  - Avoid/fewer model coefficients
  - Complex/moving geometries
  - Taylor to available resources
- Combine with other modules
  - Performance
  - Noise

Ice accretion modeling

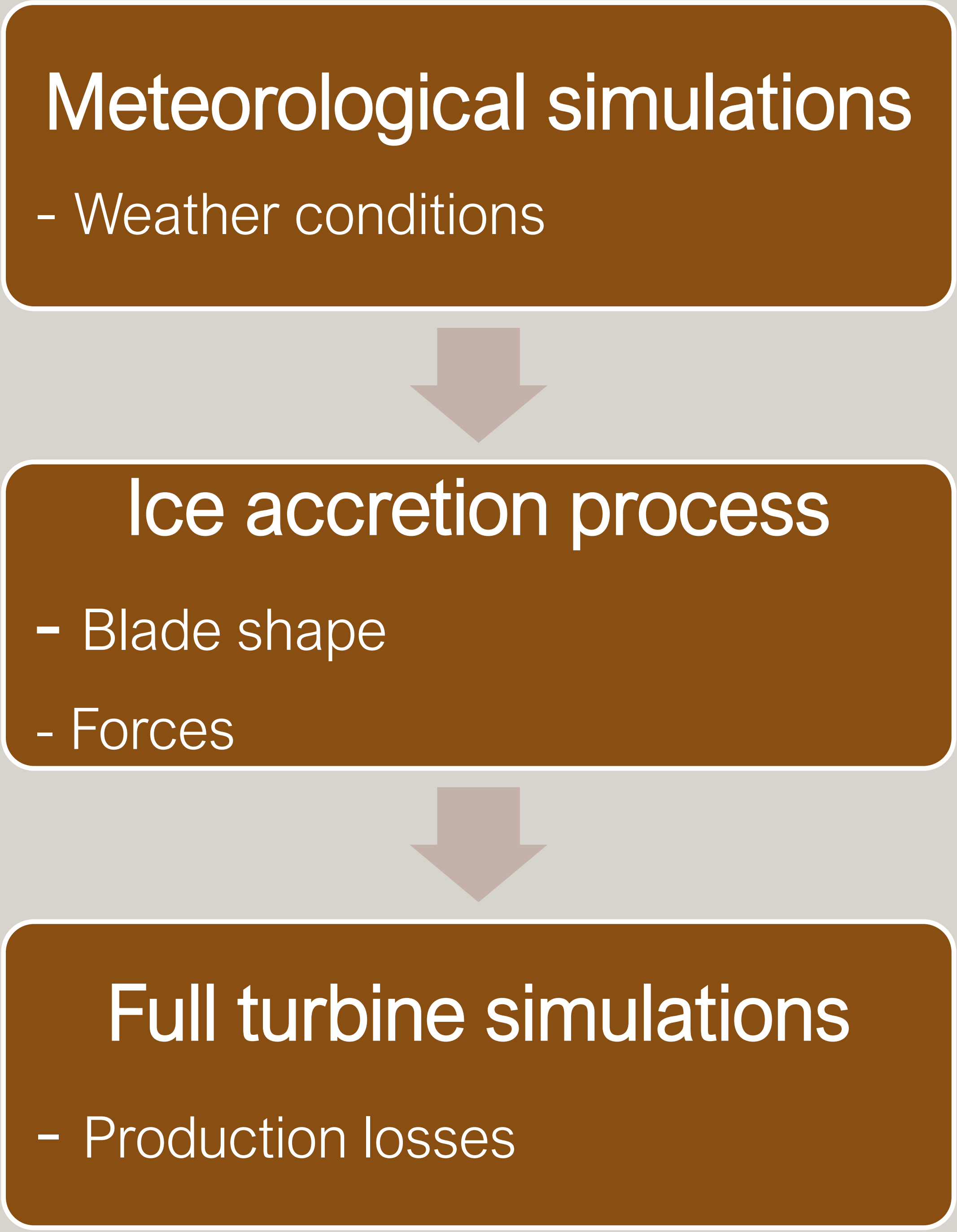
- Initially in-house, now OpenFOAM
- Flow: incompressible Navier-Stokes equations
- Droplets: Lagrangian Particle Tracking (LPT)
- Ice accretion
  - Rime: Freeze instantaneously
  - Glaze: water displaced along surface



Recent results

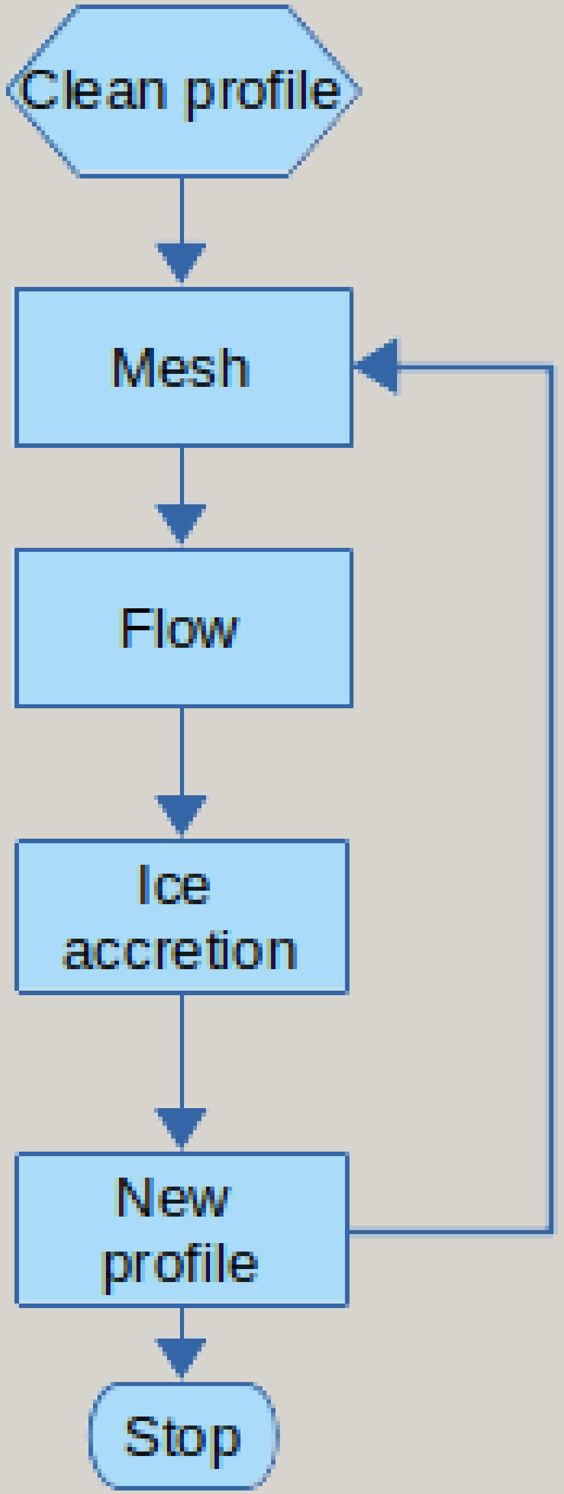
Background

- Developing a model chain to predict production losses
  - Swedish Energy Agency, Proj.Nr. 47053-1
  - SMHI, Lund University, Uppsala University
- Lund University
  - Ice accretion process
  - Large number of simulations for different weather conditions, angles of attack, relative velocity…
  - Fast models needed

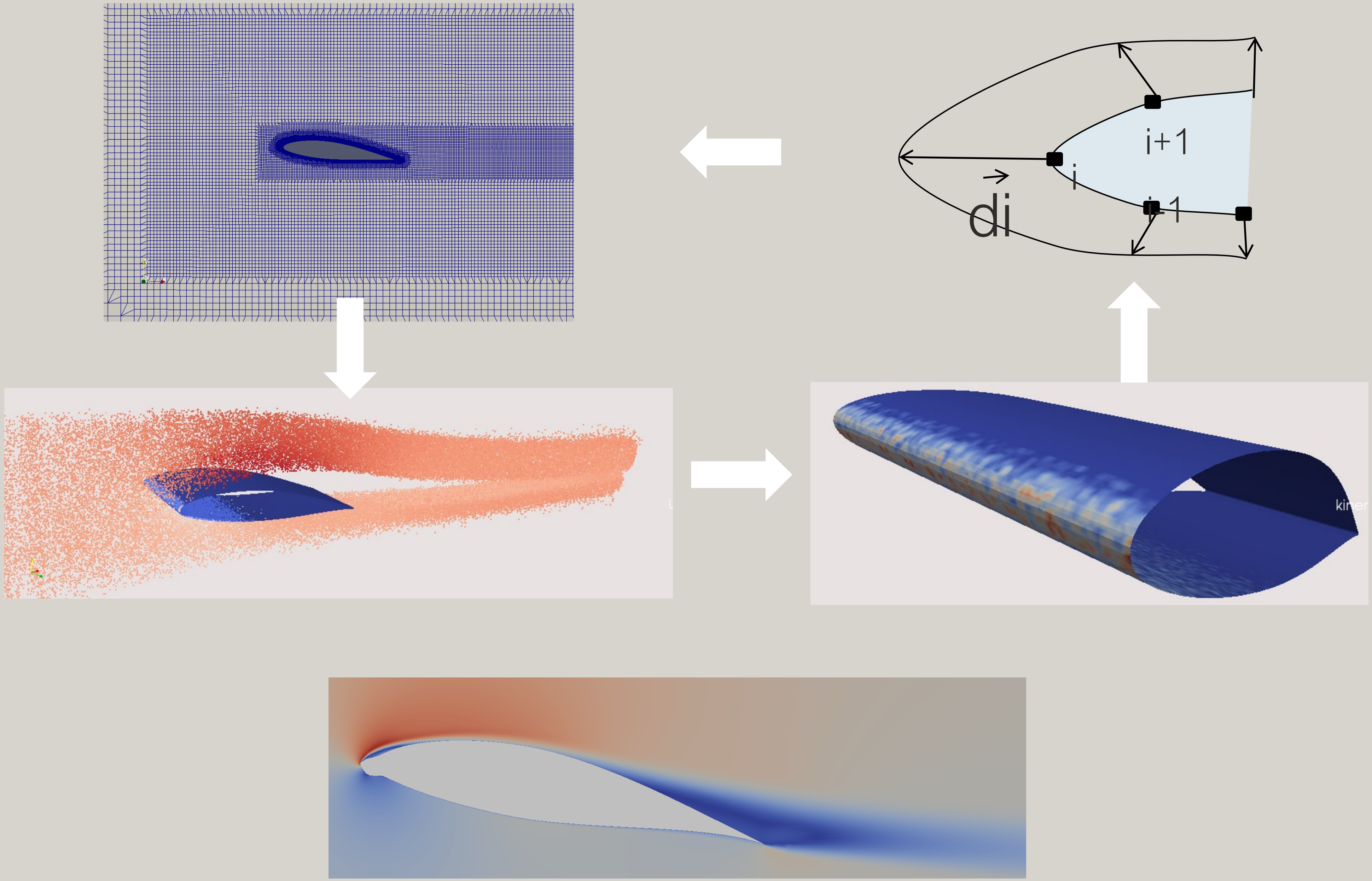


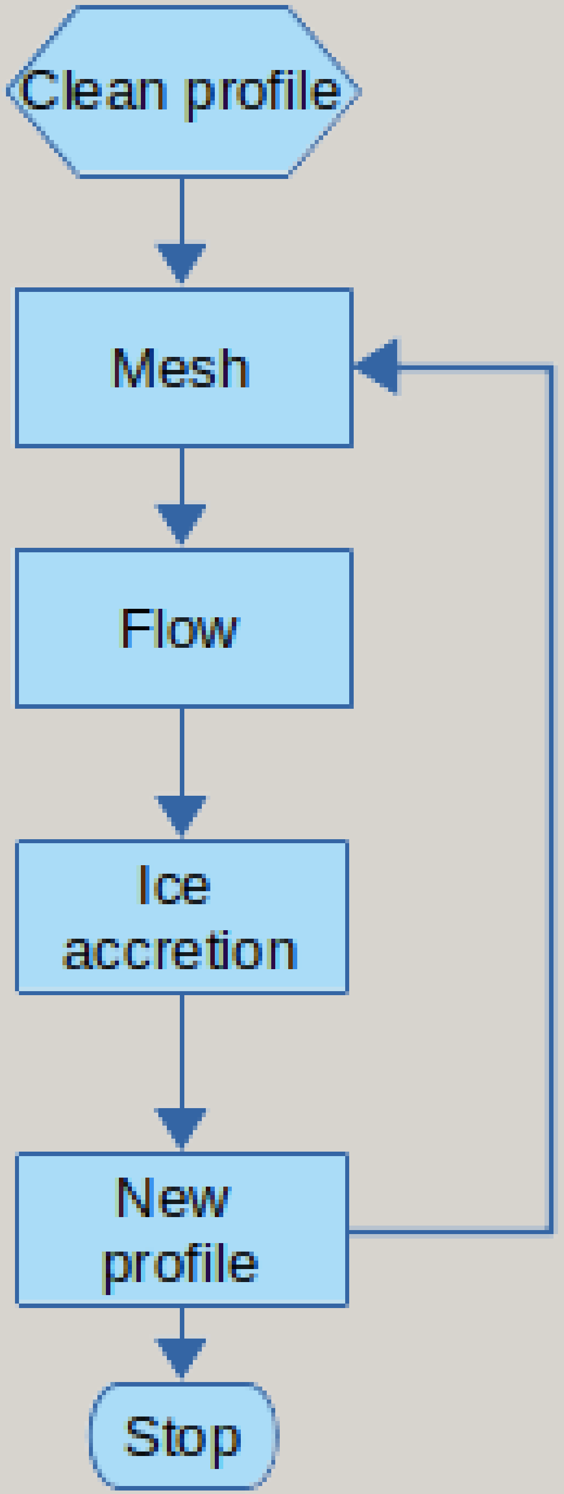
Ice accretion modeling

- Ice accretion and flow time scales significantly different -> possibility to speed up computations:
- Ice accretion process divided in sub-intervals
- Assuming constant shape in each sub-interval
- Flow and ice accretion computed separately
- Extrapolating the amount of ice accreted in a sub-interval in time

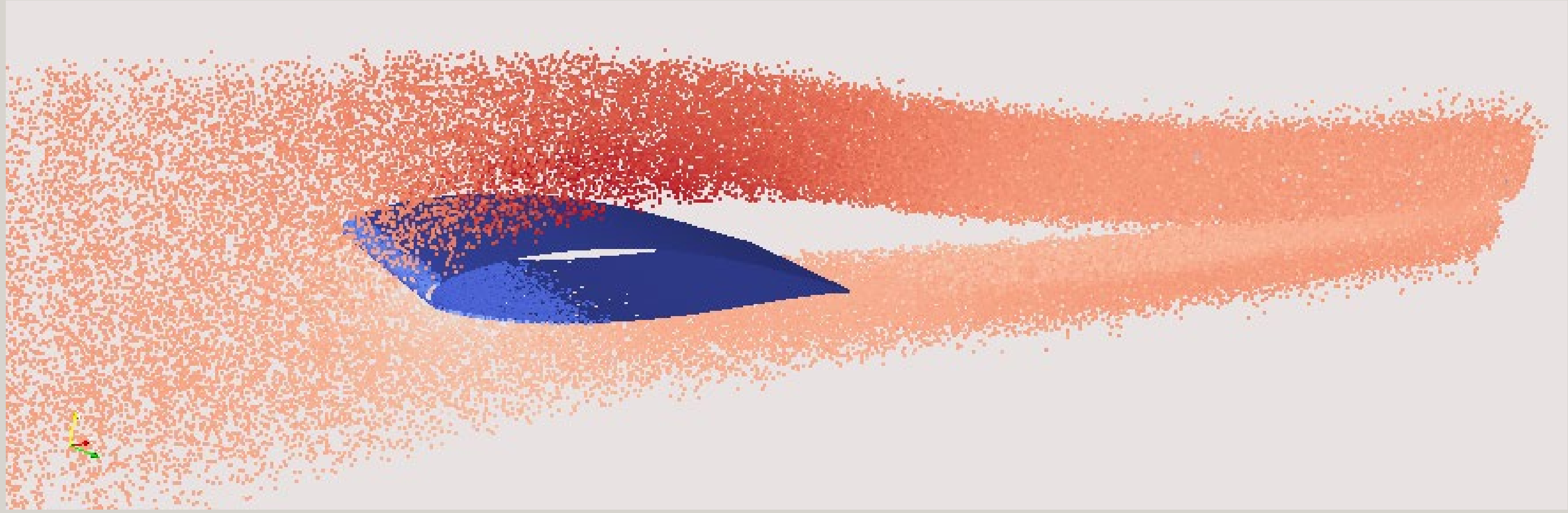


Ice accretion modeling



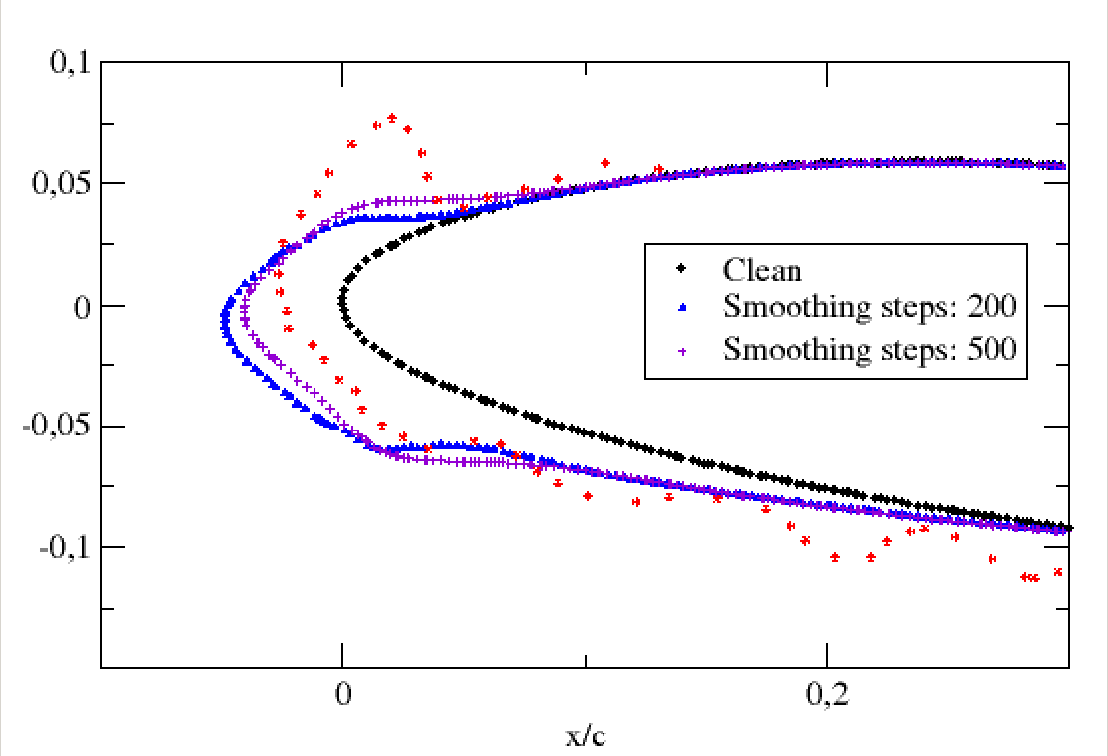


Severe rime ice case



Experiments [Hochart et al (2008)]: NACA 63 415

LWC	0.48 g/m^3
MVD	27.6 µm
T	-5.7 ^{o}C
u_{rel}	55 m/s
t_{ice}	19.6 min
AoA	9 deg
m_{ice}	0.182 kg/m



Smoothing steps	Accreted mass	Differerence comp. to exp.[1]
200	0.190 kg/m	4.4 %
500	0.198 kg/m	8.8 %

Hochart, C., Fortin, G., Perron, J., Wind turbine performance under icing conditions, Wind Energy, 11:319-333, 2008

Instantaneous speed

NACA 63415
U=36m/s

Clean | With ice

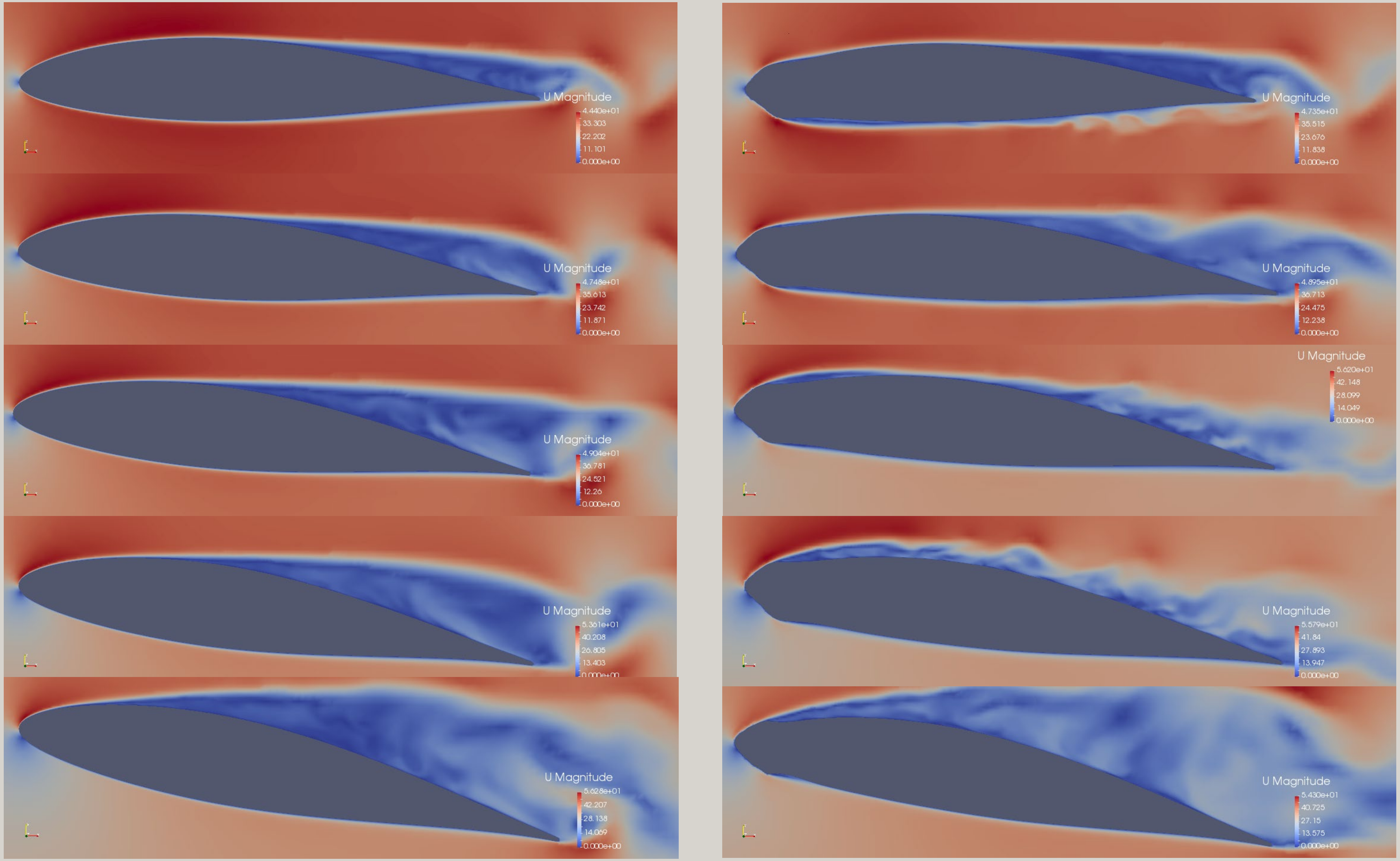
$\alpha=2^o$

$\alpha=5^o$

$\alpha=7^o$

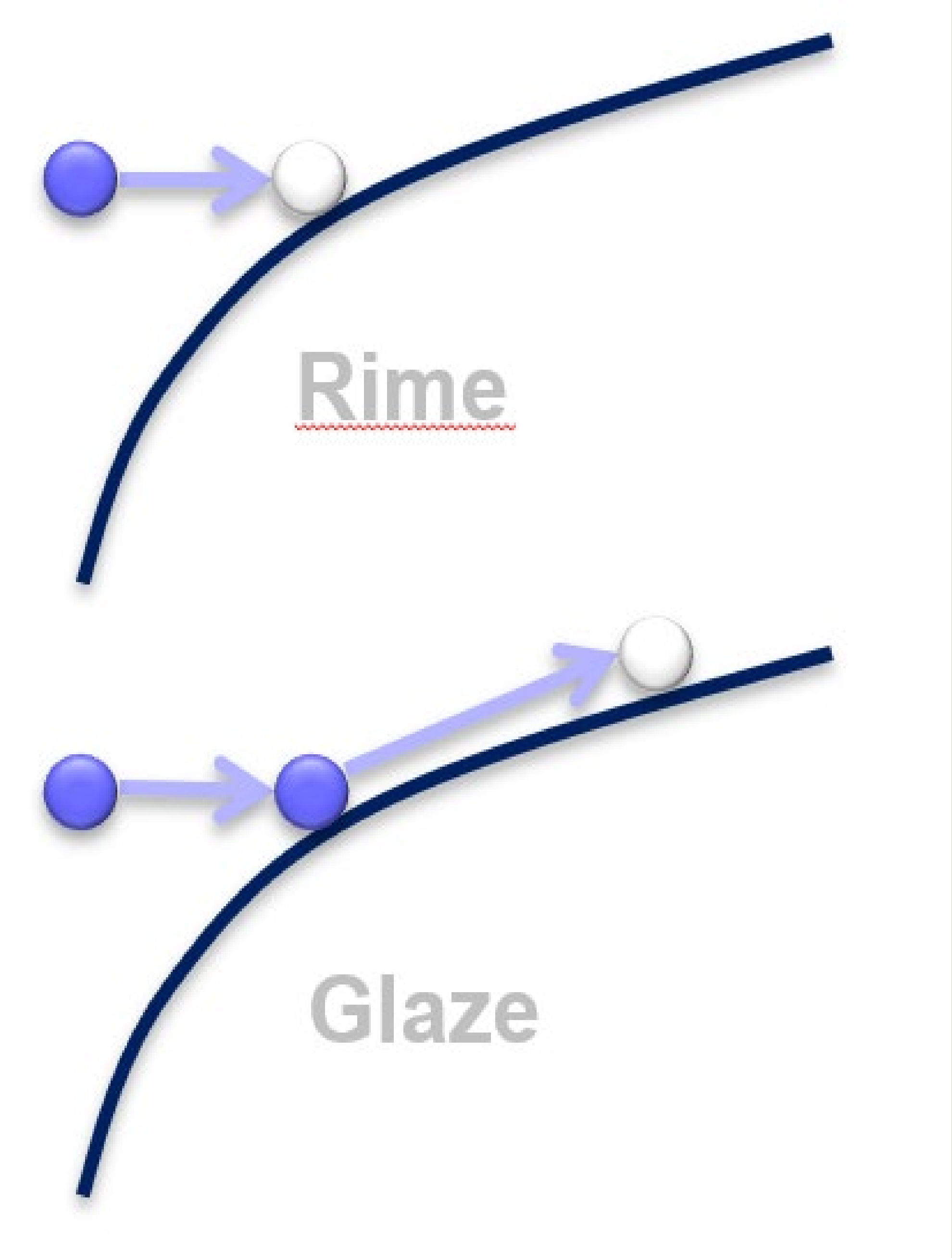
$\alpha=9^o$

$\alpha=12^o$



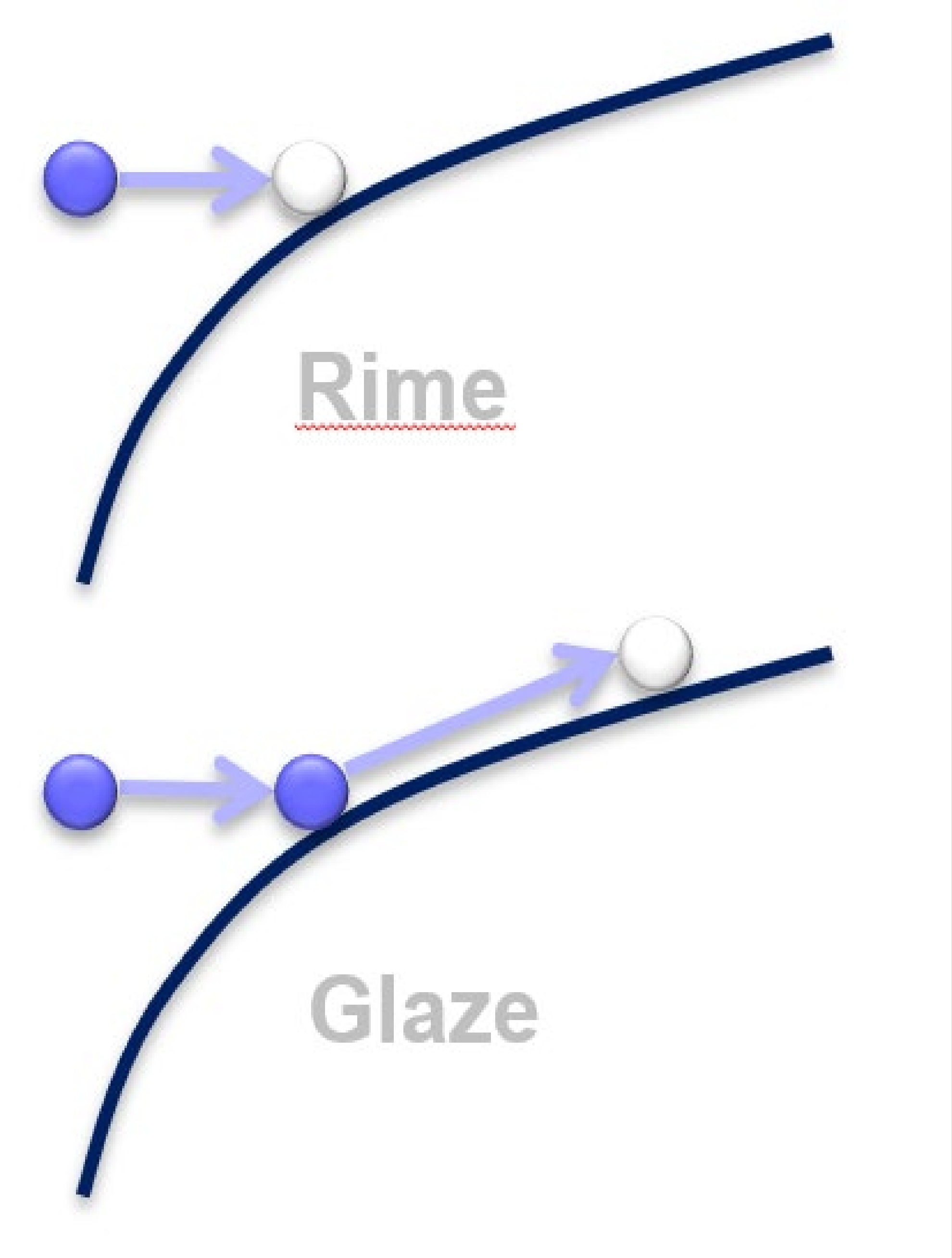
Glaze ice conditions

- Complex physics
  - Heat transfer
  - Wall film
  - …
- Goal
  - Mimic glaze conditions qualitatively
  - Advantages:
    - Faster & more robust model
    - Fewer parameters
  - Disadvantages:
    - Not universal
    - Validation needed



Idea

- Allow LPT droplet to move along the surface, for a certain time, t_f
  - Rime ice conditions become special case with $t_f=0$
  - Freezing time can be specified
    - Constant
    - First order approximation, f(d,T)
  - Additional model constant, e
    - $u_N=e\ u_T$



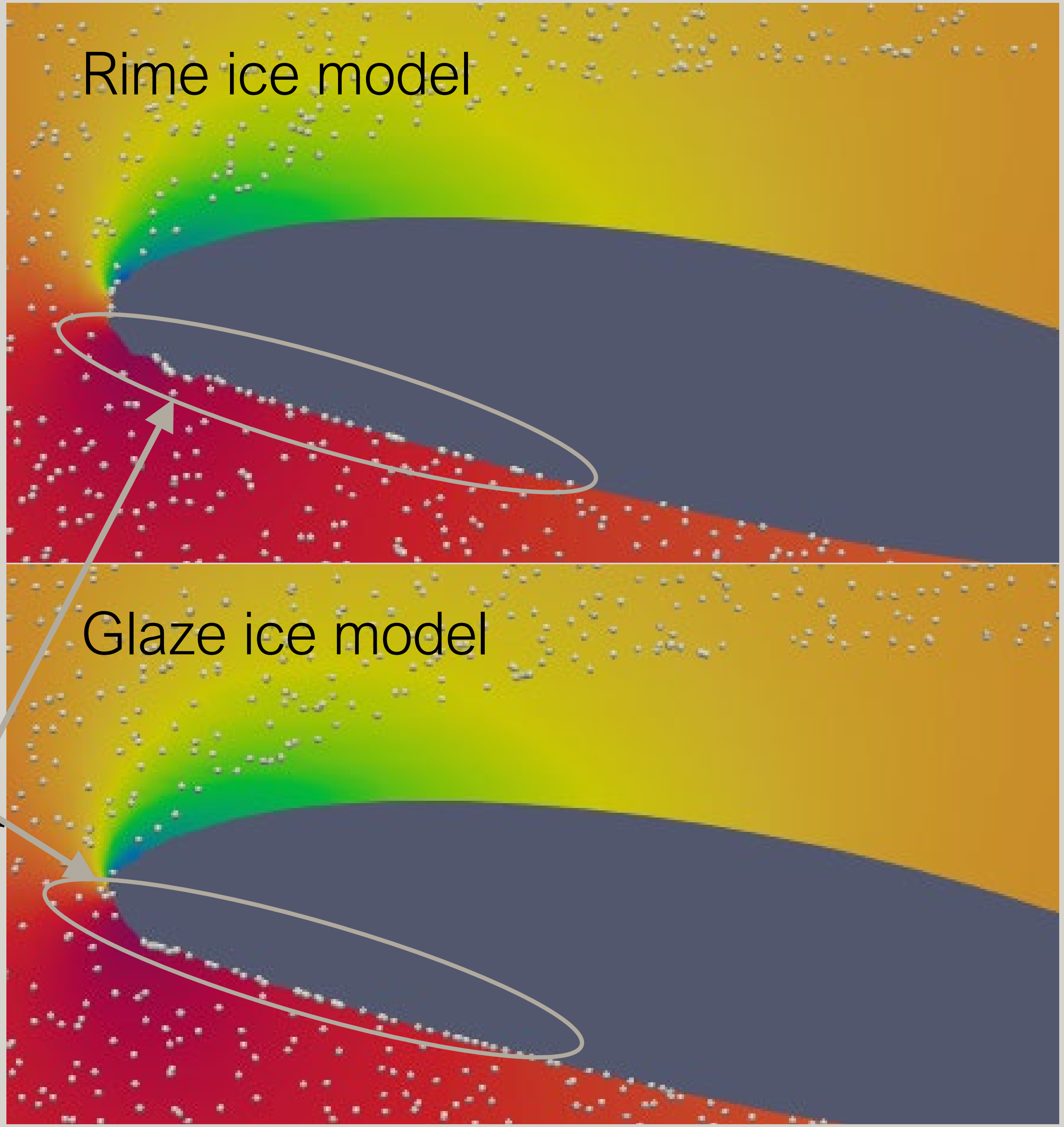
Validation case 1

- Mild glaze ice conditions [1]
- Qualitatively good
- Quantitatively overpredicts ca. 24%

LWC	0.37 g/m^3
MVD	27.6 μm
T	-1.4 ^{o}C
u_{rel}	19.9 m/s
t_{ice}	14.8 min
AoA	6 deg
m_{ice}	48 g
$m_{computed}$	59.4 g

1. Hochart et al. Wind Energ. Vol. 11 (4) pp. 319-333

- Smoother ice surface
- Droplets freeze further downstream



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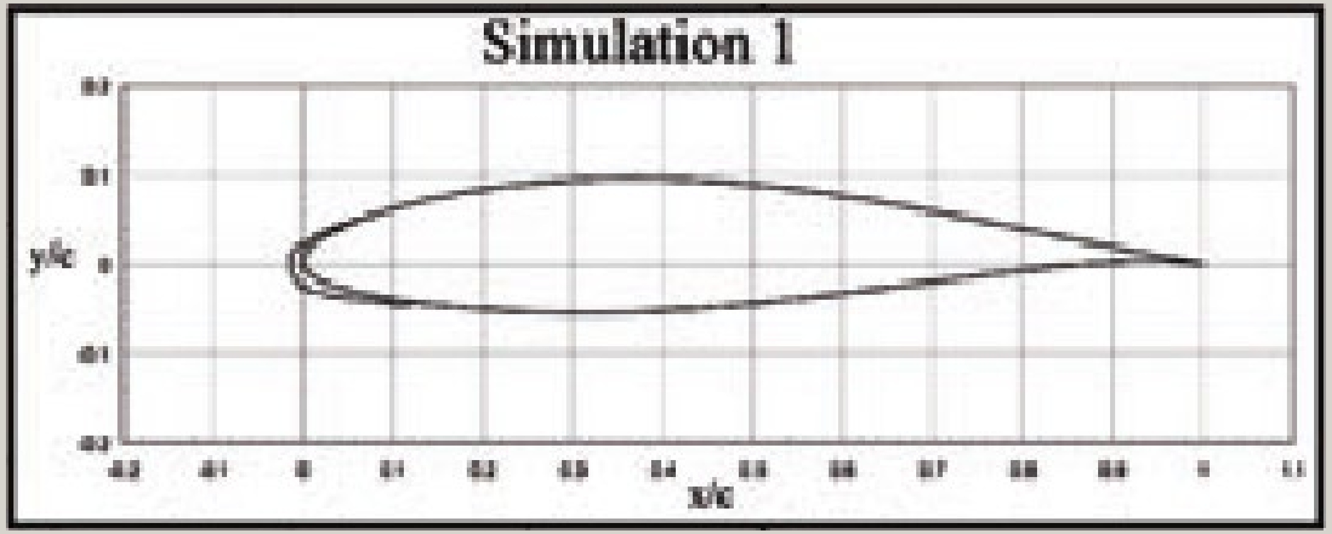

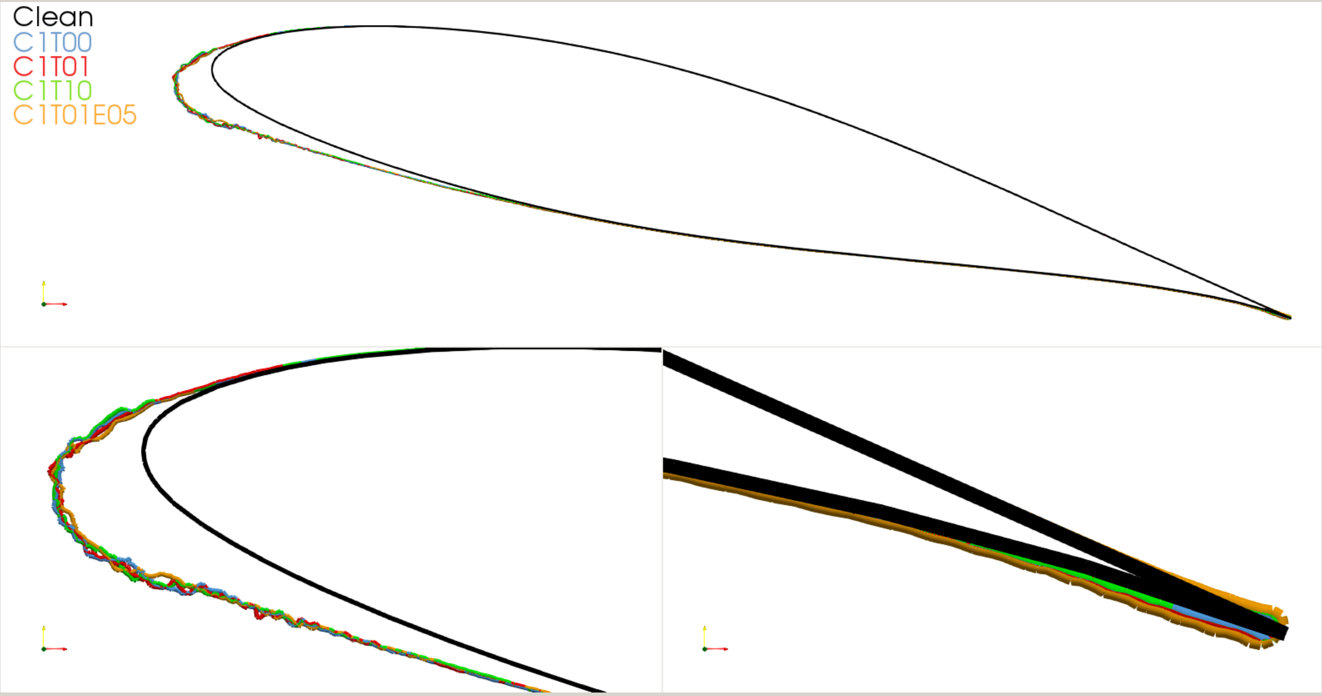

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AoA	6 deg
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1. Hochart et al. Wind Energ. Vol. 11 (4) pp. 319-333

- Smoother ice surface
- Droplets freeze further downstream

Validation case 2

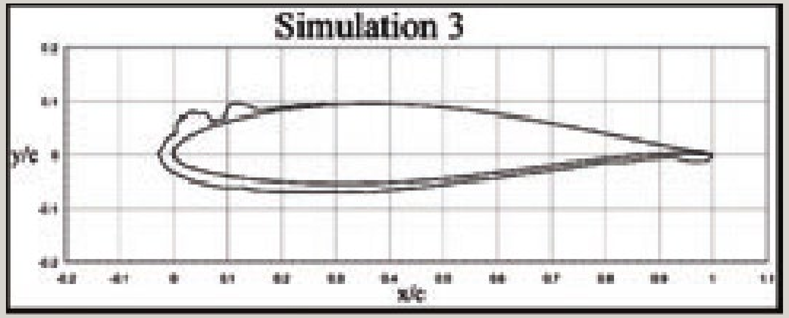
- Severe glaze ice conditions [1]
- Better than rime ice model, but improvements needed
- Significant overprediction, ca. 59%

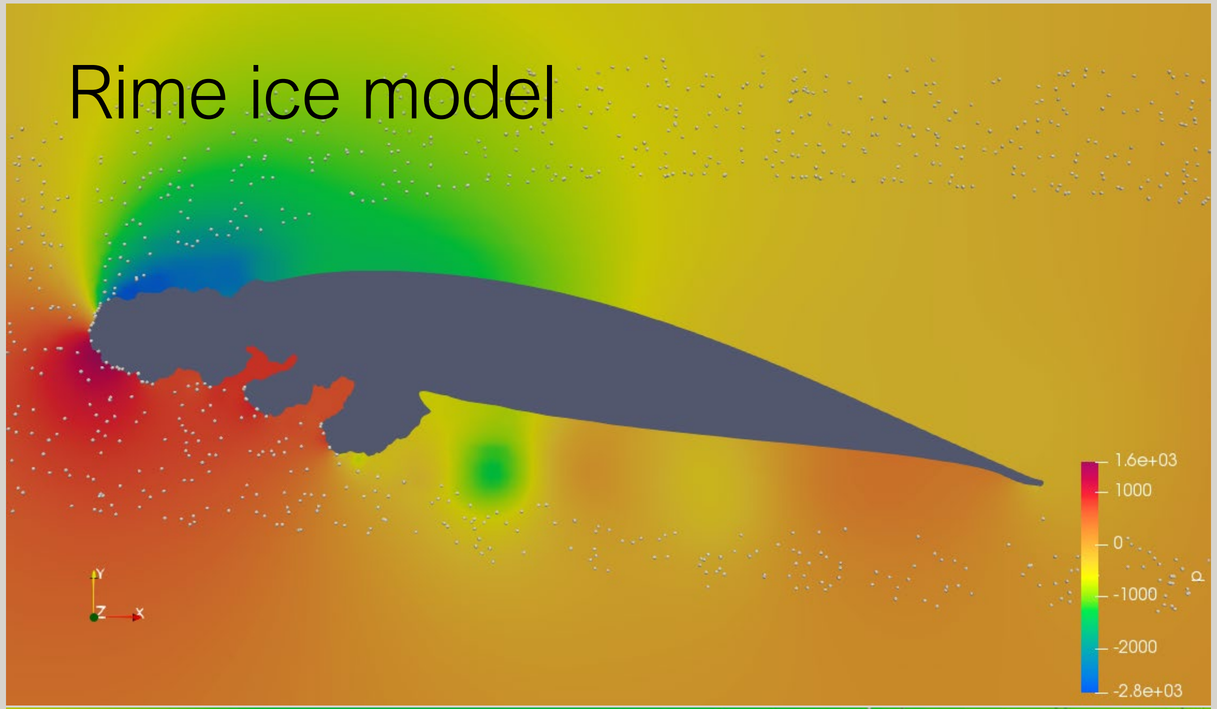
LWC	0.48 g/m^3
MVD	27.6 µm
T	-1.4 ^{o}C
u_{rel}	56 m/s
t_{ice}	24.8 min
AoA	6 deg
m_{ice}	354 g
$m_{computed}$	563 g

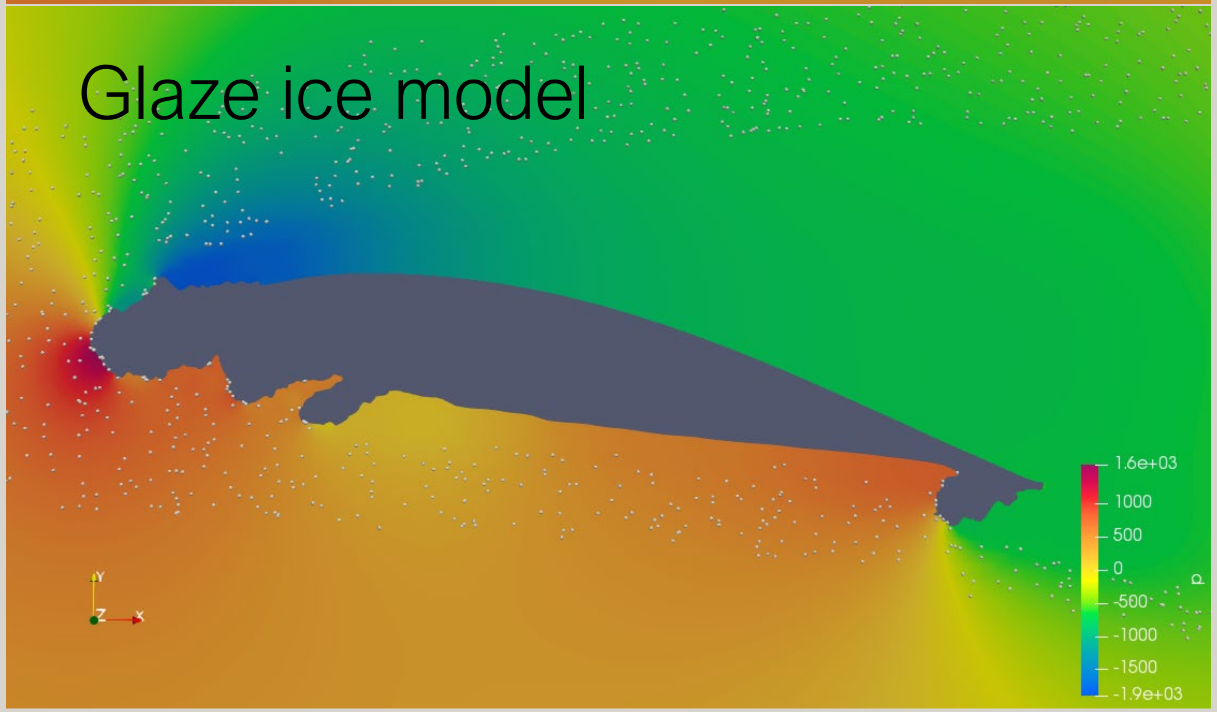
1. Hochart et al. Wind Energ. Vol. 11 (4) pp. 319-333

- 2D/3D, RANS effects?
- Lack of ice loss model?

1. Hochart et al. Wind Energ. Vol. 11 (4) pp. 319-333







Conclusions

- A felxible ice accretion model is implemented
- Good performance for rime ice conditions
- Glaze ice
  - Qualitatively good for mild conditions,
  - For severe conditions unrealistic ice structures
  - Quantitatively overpredicting the amount of ice
- Improvements needed
  - Improved glaze ice modeling
  - Ice loss model planned

Acknowledgements

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- LUNARC

Thank you!

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