

Case Study of Ice Sensor using CFD, Measurements and Pictures - Surface Boundary Displacement

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- Wind turbines and icing
- Introduction to the project
 - Production loss assessment
- CFD model
 - Surface boundary displacement
- Results
- Conclusion and future work



[Vattenfall internal, Stor-Rotliden wind farm Oct. 2014]

- Wind power in cold climate
- Icing related issues:

1. Safety
2. Blade fatigue
3. Production losses

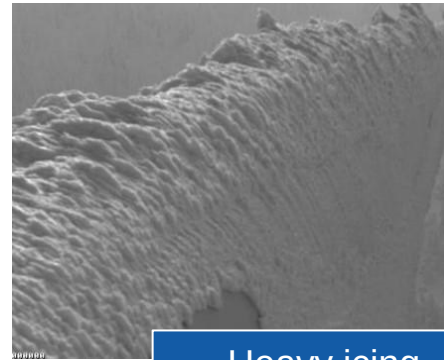
Vattenfall is building(projecting)
~1000 MW in cold climate
over the coming 5 years



[Vattenfall internal]

Production losses at Stor-Rotliden wind farm

- At Stor-Rotliden wind farm,
we see production losses of magnitude
 $5\% < P_{loss} < 15\%$
(of total annual production)



Heavy icing



[Vattenfall internal]

- Example

Production during icing event, March 5th to 6th → 67% !

March 5 at 9am



March 6 at 10am



March 7 at 9am



[Vattenfall internal]

- Current methodology

**Numerical weather
prediction model** ↓

Wind speed, LWC, T_{air} , RH

Droplet concentration/size

Ice model

Makkonen's model
(cylinder based)

Ice load

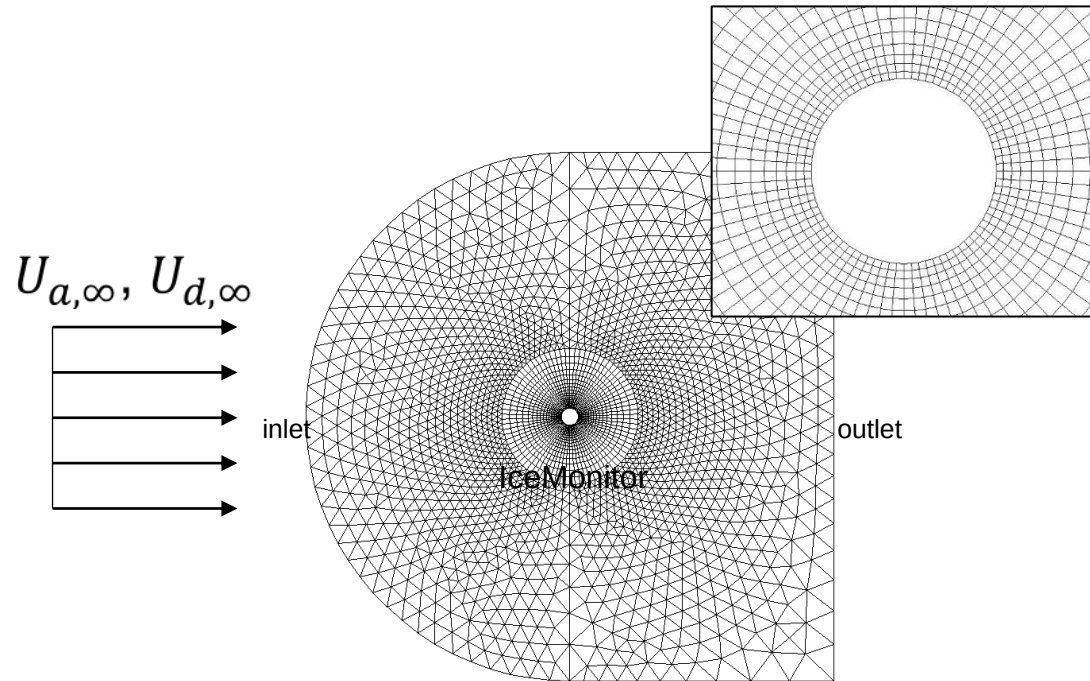
**Production loss
assessment**

**Computational
Fluid Dynamics
model**

- In-cloud icing in CFD
 - Ice model
 - Boundary displacement
- Validation
 - Measurements
 - Pictures

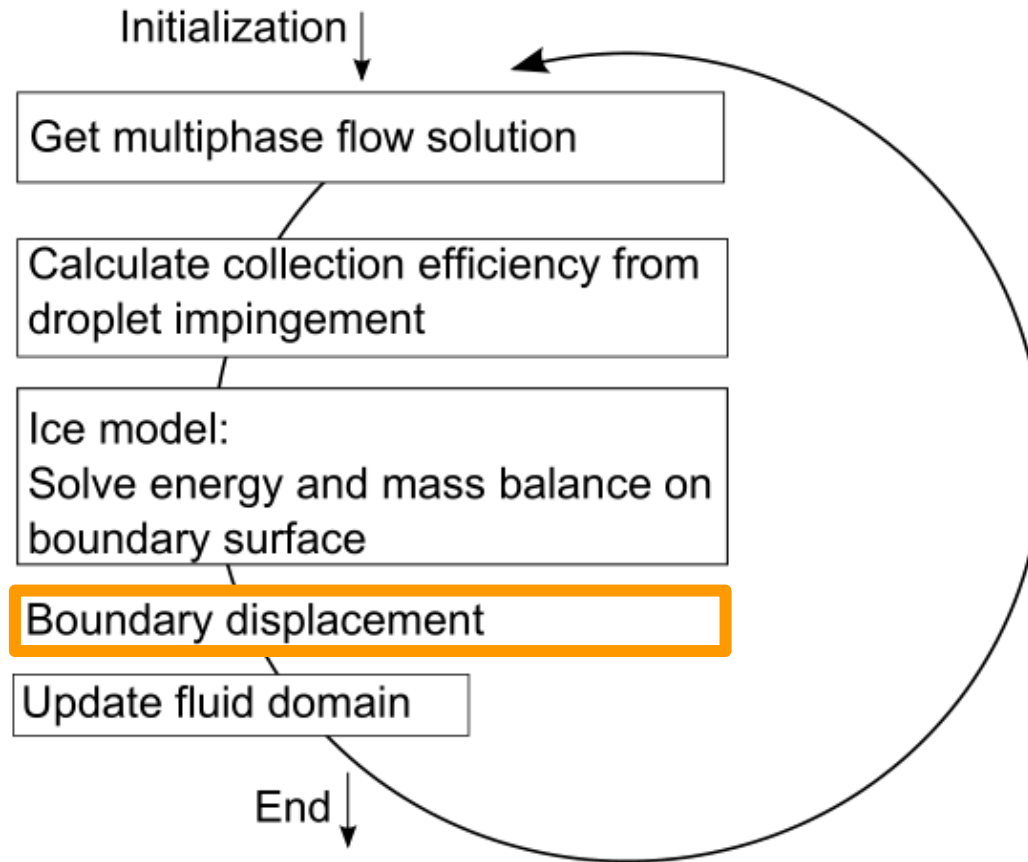
Case study of ice study

- The ice monitor

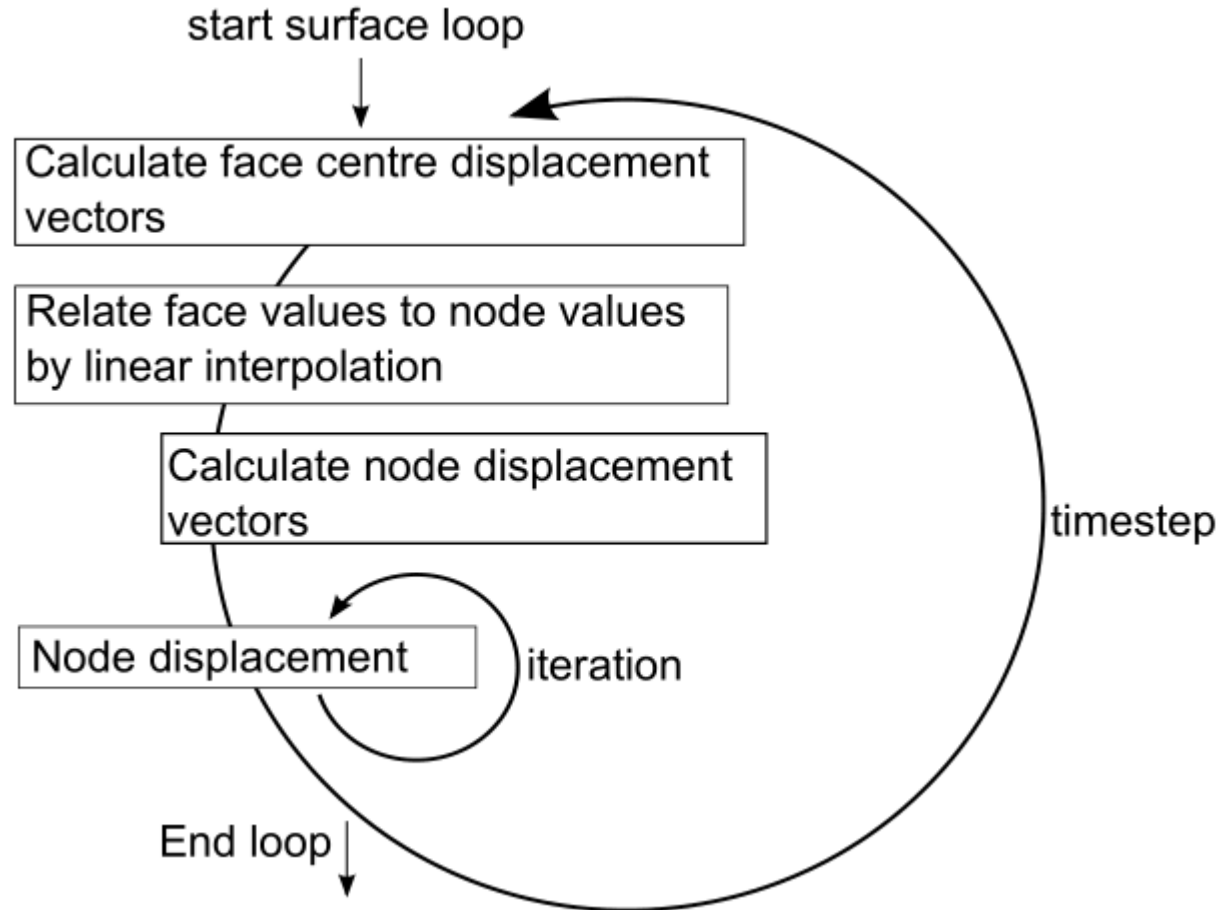


Goal

- Icing model applicable for any geometry
- Study aerodynamics
- Ice shapes
- More accuracy.. !?



Surface boundary displacement



Development of surface boundary displacement method

1. Face centre displacement vector at every boundary face cell centre

$$v_{f,i} = \frac{\dot{m}_{ice,f,i}}{\rho_{ice}} \mathbf{n}$$

2. Relating face displacement to node displacement by linear interpolation

3. Node displacement per time step Δt

$$p_{n,i}^{t+\Delta t} = p_{n,i}^t + v_{n,i}^t \Delta t$$

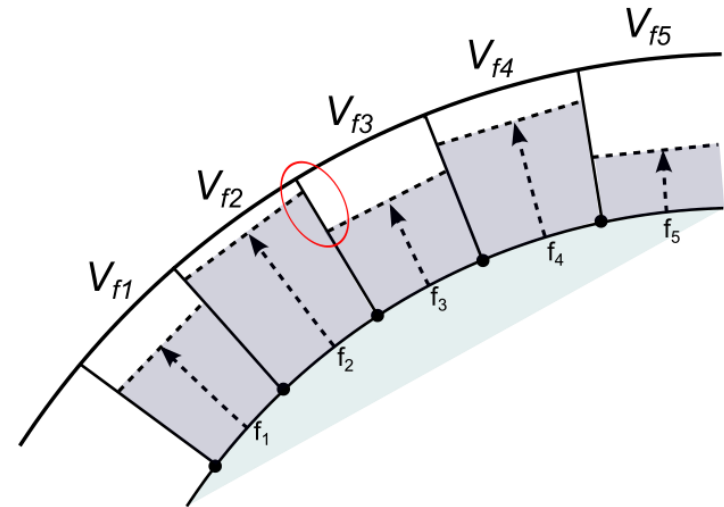


Figure 1

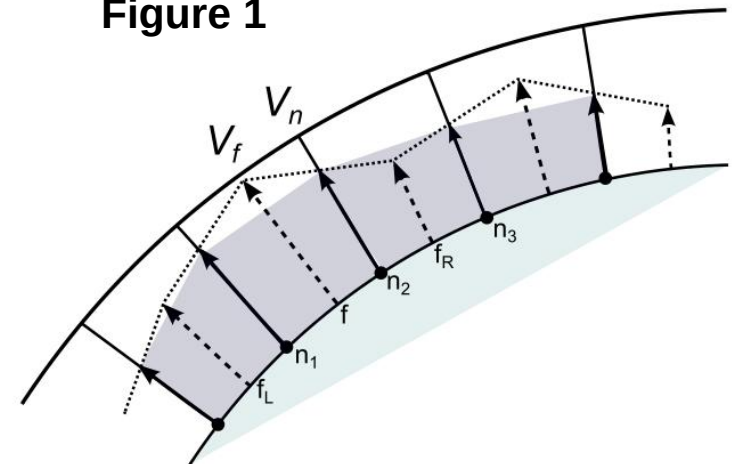


Figure 2

- Test case

Parameter:

Total no. cells	5013	mixed cells
BC cells	82	no. cells
Time step size	0.01	(s)
Simulation time	15	(min)
aoa	0, 16	°
U_∞	20	$\frac{m}{s}$
T_∞	-10	$^\circ C$
$\alpha_{d,\infty}$	$3.33 \cdot 10^{-7}$	—
LWC	0.3	$\frac{g}{m^3}$
MVD	10	μm

LWC = liquid water content

MVD = median volumetric diameter

aoa = angle of attack

T_∞ = freestream temperature

$\alpha_{d,\infty}$ = freestream droplet volume fraction

U_∞ = freestream velocity

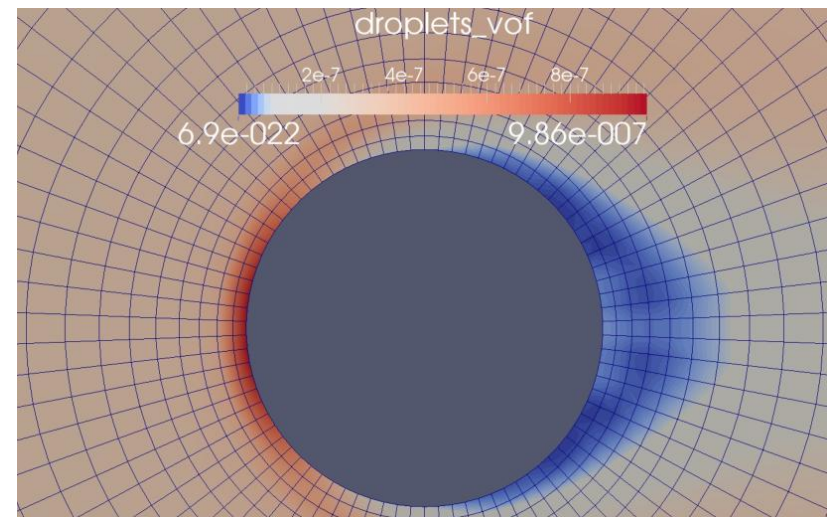
- Simplified ice model (rime ice)

- Impingement:

$$\beta = \frac{\alpha_n (\mathbf{u} \cdot \mathbf{n})}{U_\infty}$$

$$\dot{m}_{imp,f,i} = \beta (LWC) U_\infty$$

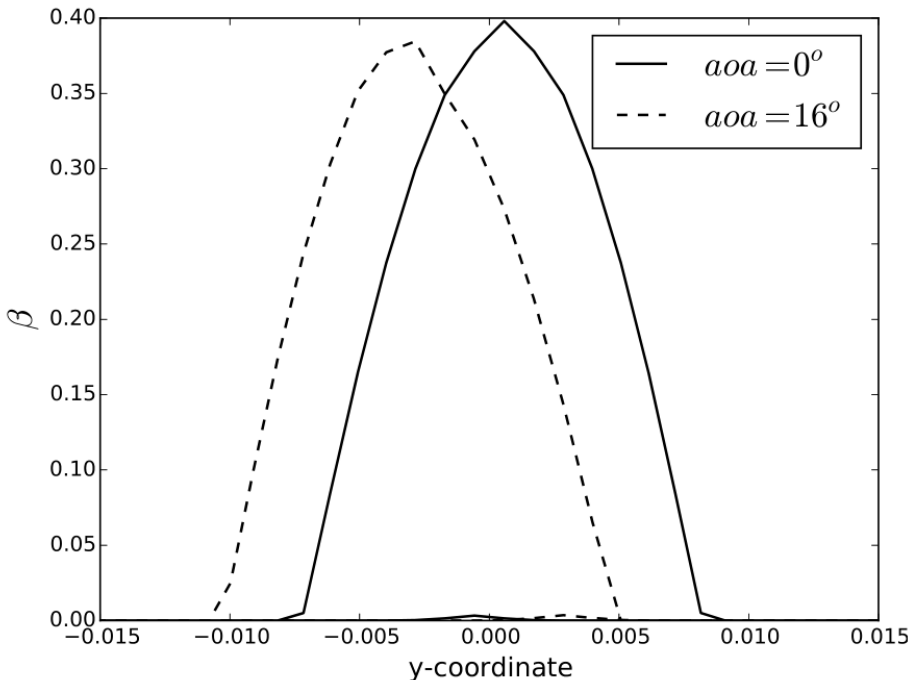
$$\dot{m}_{imp,f,i} \approx \dot{m}_{ice,f,i}$$



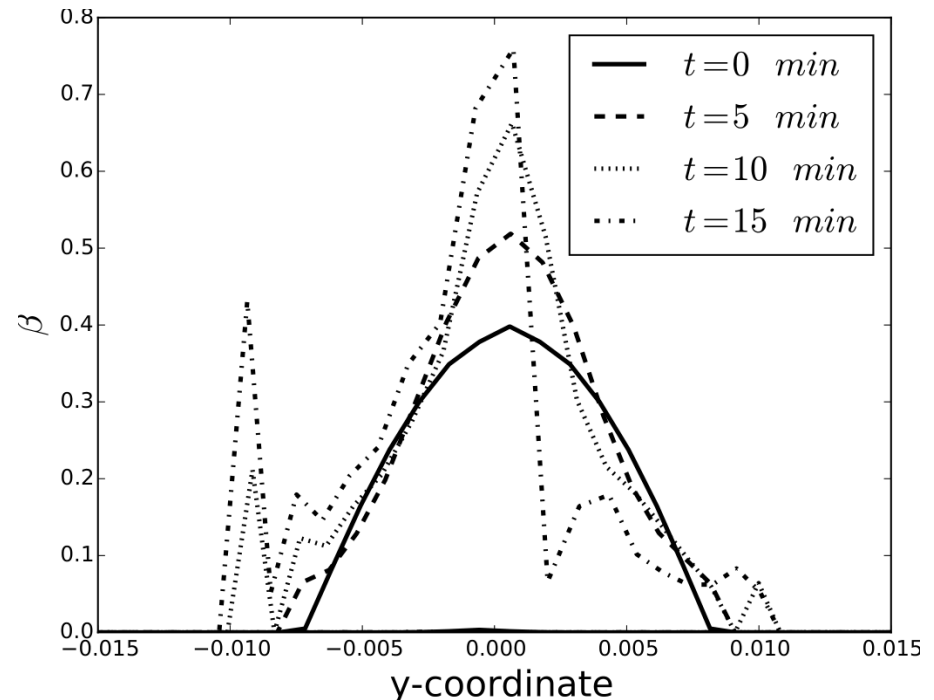
Contour plot, droplets volume fraction

Results – collection efficiency

- Collection efficiency
 - $t = 0$ minutes – no ice accretion

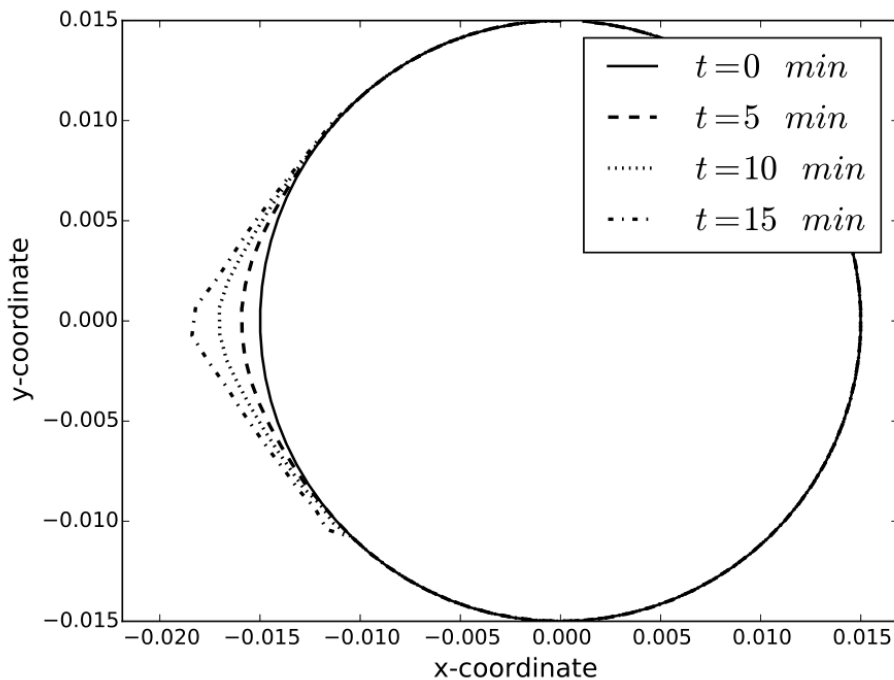


- Collection efficiency
 - $t = 5, 10, 15$ minutes of ice accretion

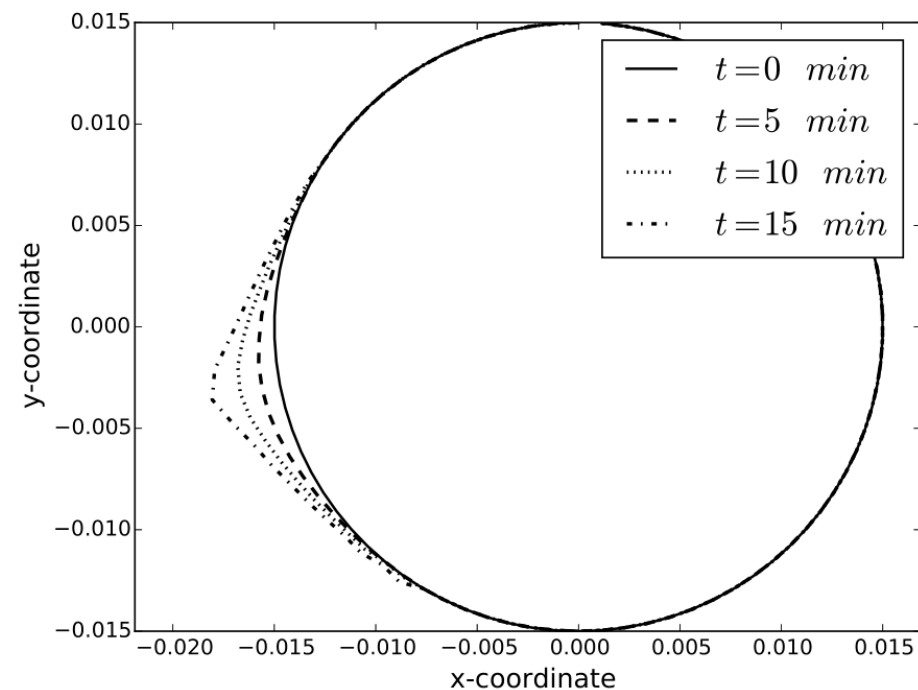


- 15 minutes of ice accretion including surface boundary displace every timestep

- Angle of attack = 0 degrees

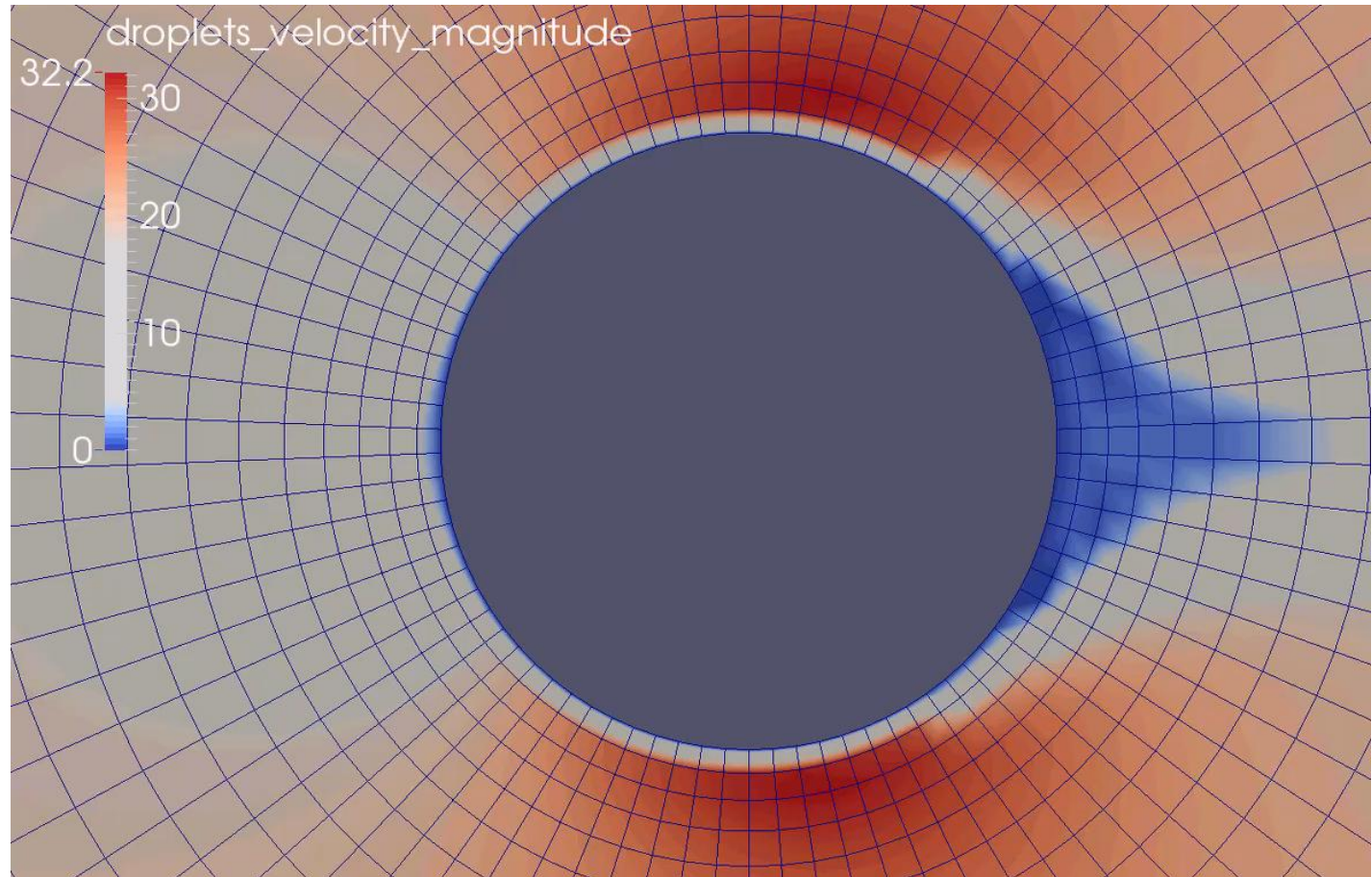


- Angle of attack = 16 degrees



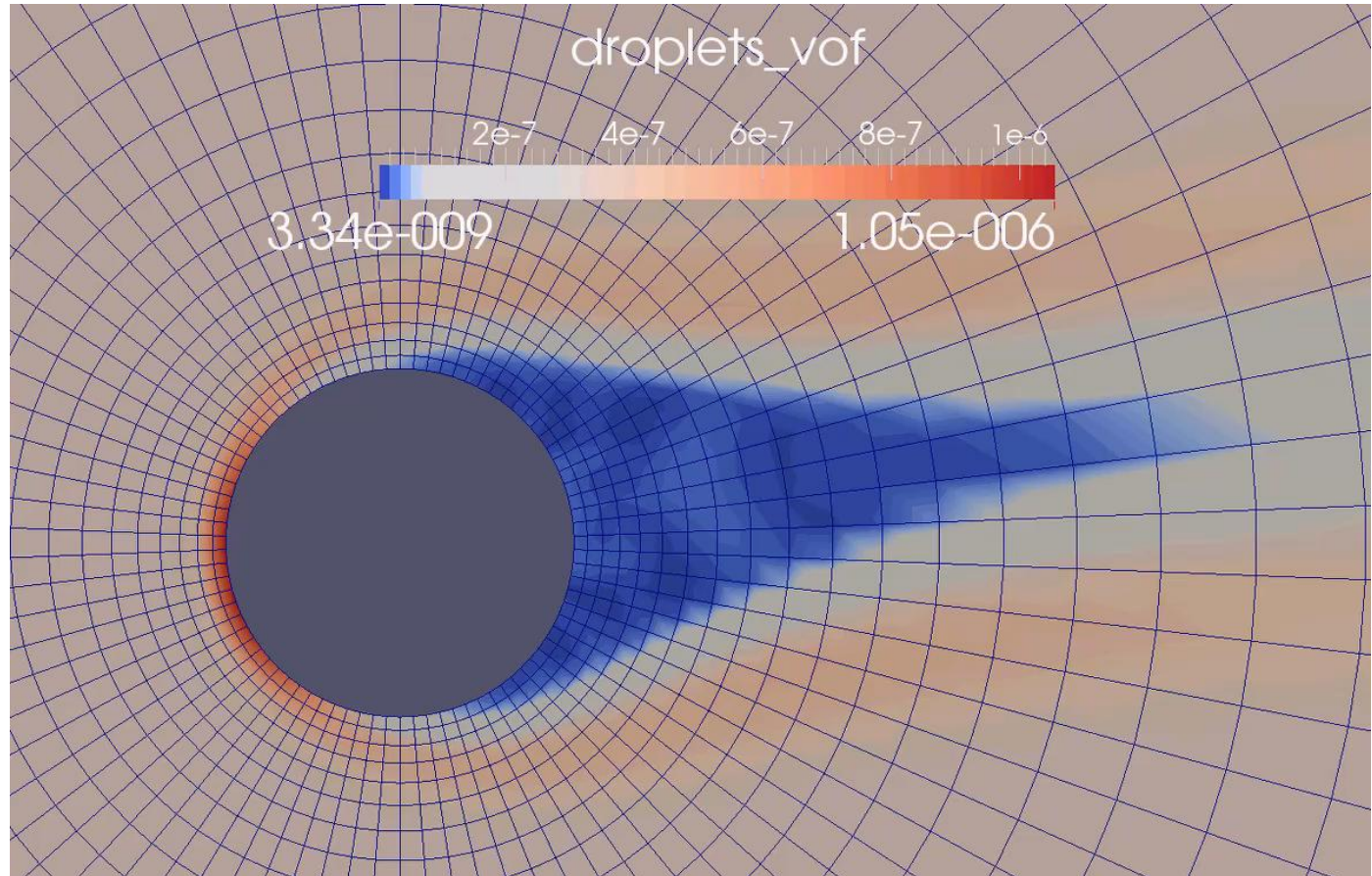
Results – angle of attack 0 deg

- Animation of 15 minutes of ice accretion
- Compressed to 10 seconds



Results – angle of attack 16 deg

- Animation of 15 minutes of ice accretion
- Compressed to 10 seconds



- Summary

- Surface boundary displacement was possible by the developed node displacement algorithm
- The approach shows promising results
- Mesh smoothening might be needed

- Future work

- Include thermodynamic model to account for wet conditions like glaze ice
- Improve on discretization scheme for surface boundary displacement
- Validation by measurements and pictures
- Simulate longer icing events

Thank You for the attention

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Mesh update - 8

- Idea 2 – mesh smoothing
 - Example

