Influence of ice accretion on the noise generated by an airfoil section

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WINTERWIND 2015

Wind Turbine Icing Research

- Where?
  - Icing maps
- Ice prevention
  - passive
  - active
- Detection and measurement

- How does the ice accrete?
  - Measurements
  - Computations

Modeling Ice Accretion

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

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

- α_i – collision/sticking/accretion efficiency

- Strategies

Ice shape → Flow

Flow → Ice shape

LEWICE, TURBICE

Flow & Ice shape

FENSAP-ICE

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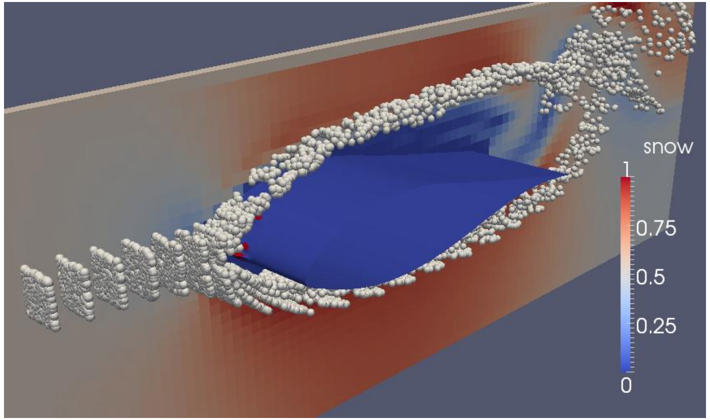
Goals



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

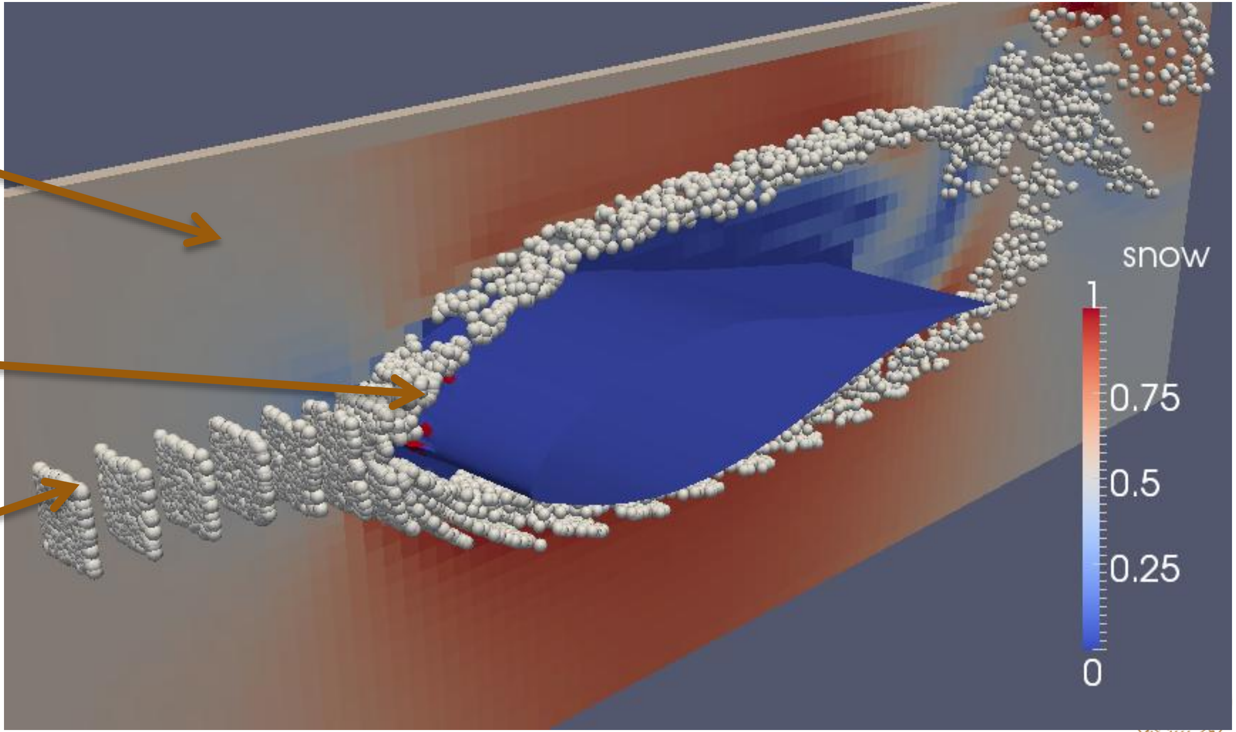
- Develop tool to model simultaneously flow and ice accretion
  - Efficient (relative)
  - Flexible
    - » Avoid/fewer model coefficients
    - » Complex/moving geometries
  - Combine with other modules
    - » Performance
    - » Noise

Method

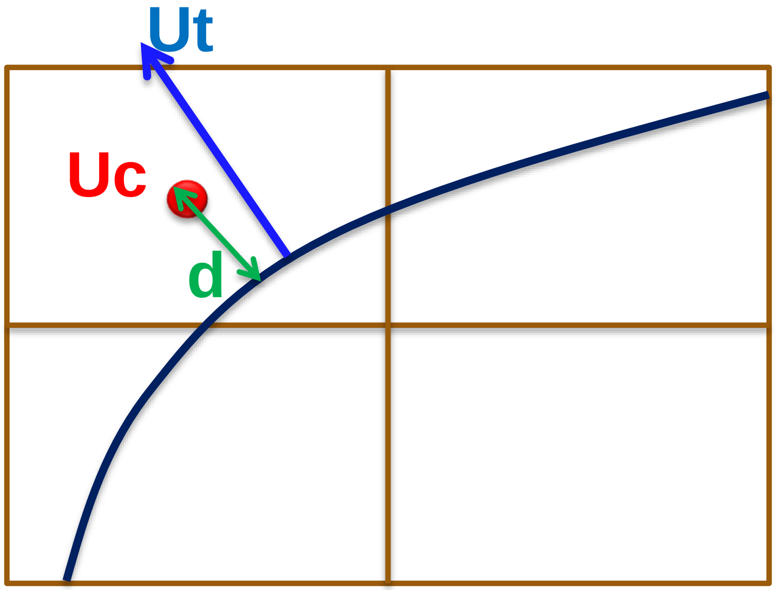
Flow: LES + Im.Bound.

Accretion: Impacting droplets freeze instantaneously

Droplets: LPT

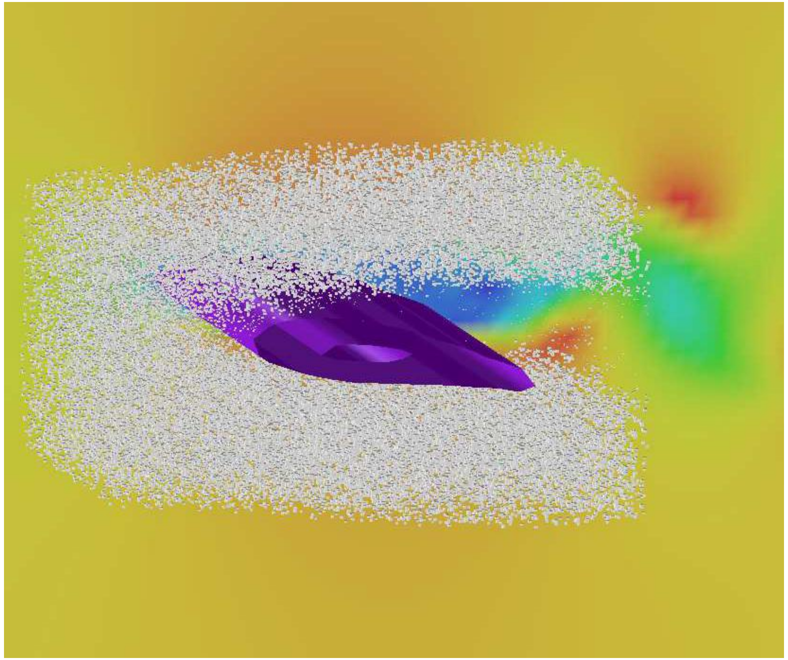


Flow



- Incompressible Navier Stokes
- Finite Differences (3rd, 4th)
- LES (implicit)
- Equidistant Cartesian grid
- Immersed Boundary

Droplet transport



- Lagrangian Particle Tracking
- Typically low LWC
  - Only drag force
  - No collision
  - No break-up
- Release: rectangular area, random distribution
- Removal: accretion or max streamwise position
- Impact parameters logged

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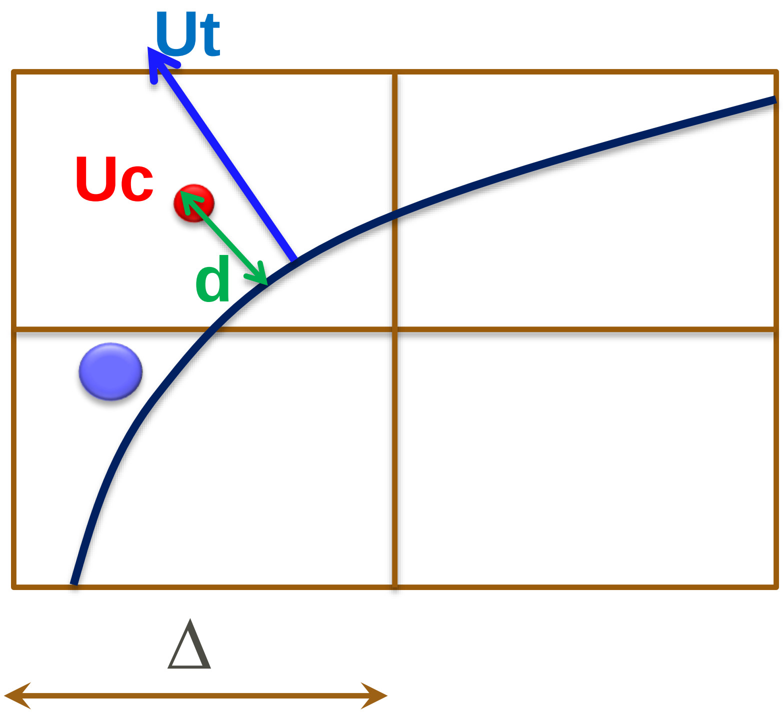
Ice Accretion



- All droplets impacting on the surface freeze instantaneously
  - Rime-ice conditions
  - For other conditions heat transfer must be included
- Distance from distance function used for IBM
  - Efficient but slightly lower accuracy
- Critical distance
  - $d_{cr}=f\Delta$

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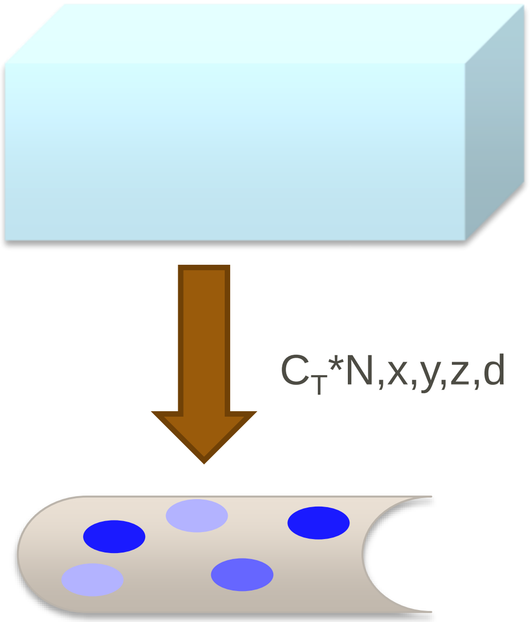
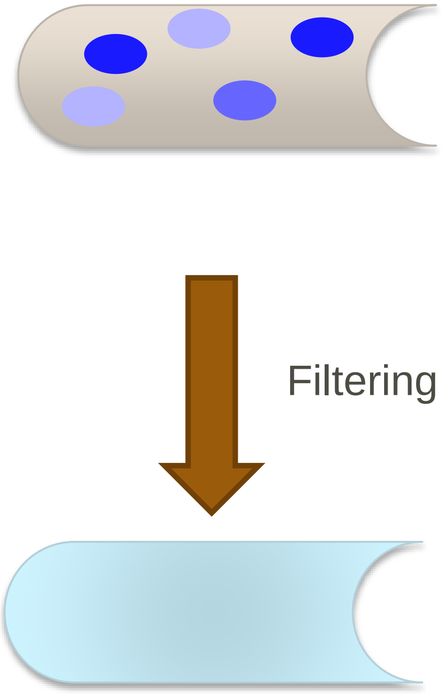
Changing the surface shape



- CFD: N,x,y,z,d,m
- every N[th] timestep
  - Can be extrapolated in time: $m_{ice}=m_{ice}*C_{time}$

Changing the surface shape



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  - Trapped air can be accounted for here
- Filtering

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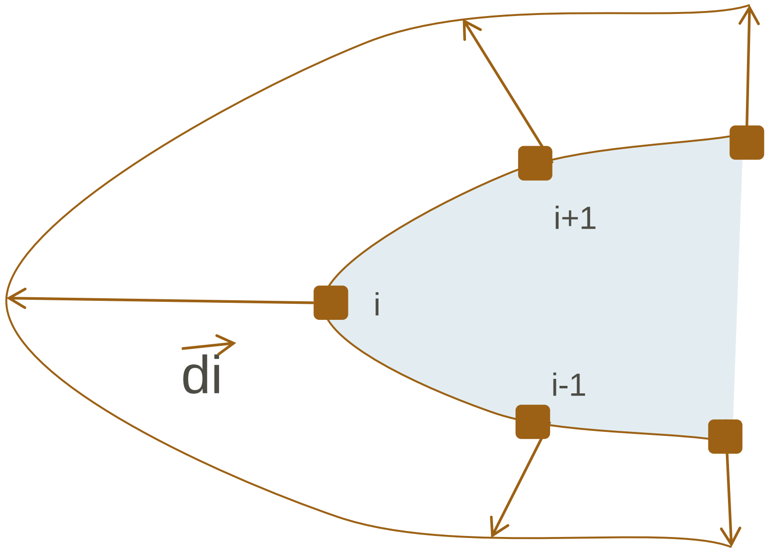


$\vec{Di} \approx V_{ice\_i} / A_{dualcell}$

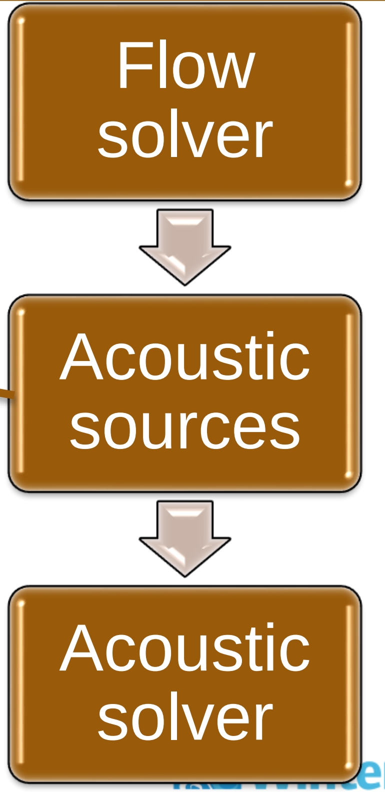
- CFD: N,x,y,z,d,m
- every Nth timestep
  - Can be extrapolated in time: $V_{ice}=V_{ice}*C_{time}$
  - Trapped air can be accounted for here
- Filtering
- Iterative algorithm
  - Towards outer normal
  - Assure added V_{ice}
  - Only a few iterations needed

Noise computations

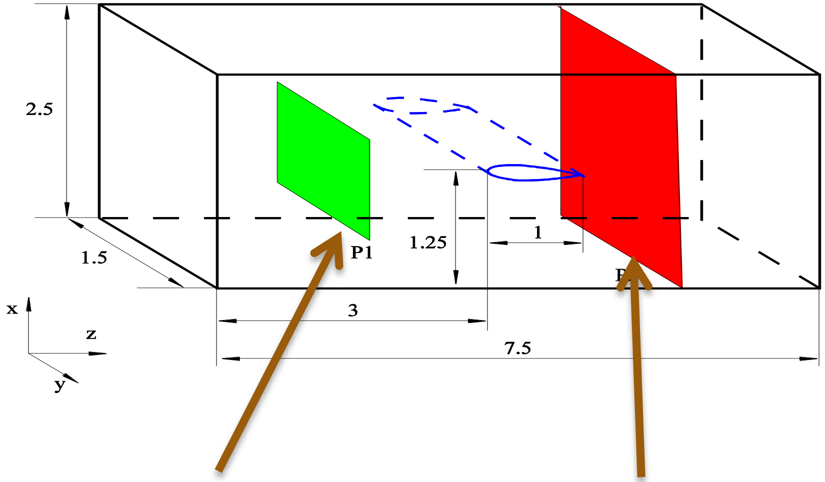
- Hybrid-method (Lighthill)

$$\frac{1}{c^2}\frac{\partial p'^2}{\partial t^2} - \nabla^2 p' = \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j}$$

- Advantages
  - Dedicated solvers for flow & acoustics
  - Acoustic sources can be iterated
  - Possibility of different
    - » Mesh
    - » Computed physical time



Case set-up



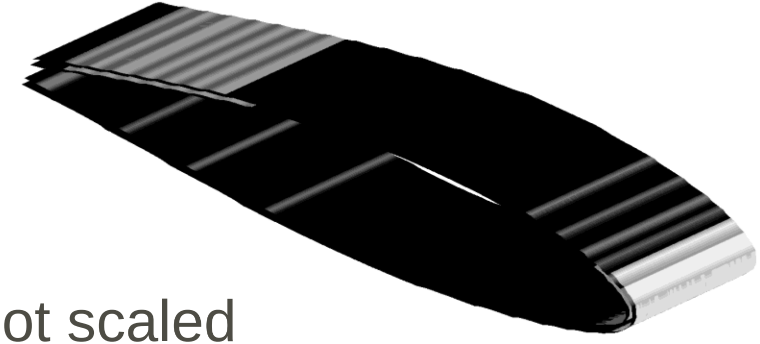
Droplets released here

Droplets removed here

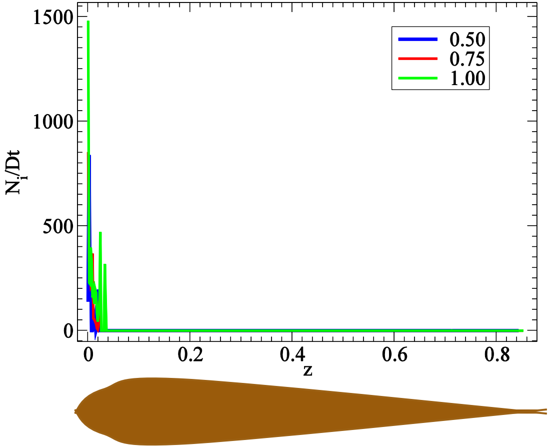
- ’In-fog icing event 2’ [Hochart2008]

Parameter	Value
Profile	NACA 63415
Angle of attack	3°
LWC	$0.37 g/m^3$
MVD	27.6 μm
Vrel	18.7 m/s
Re	2.49e5
Time	10.6 min
Mass of accreted ice	24±1.75 g

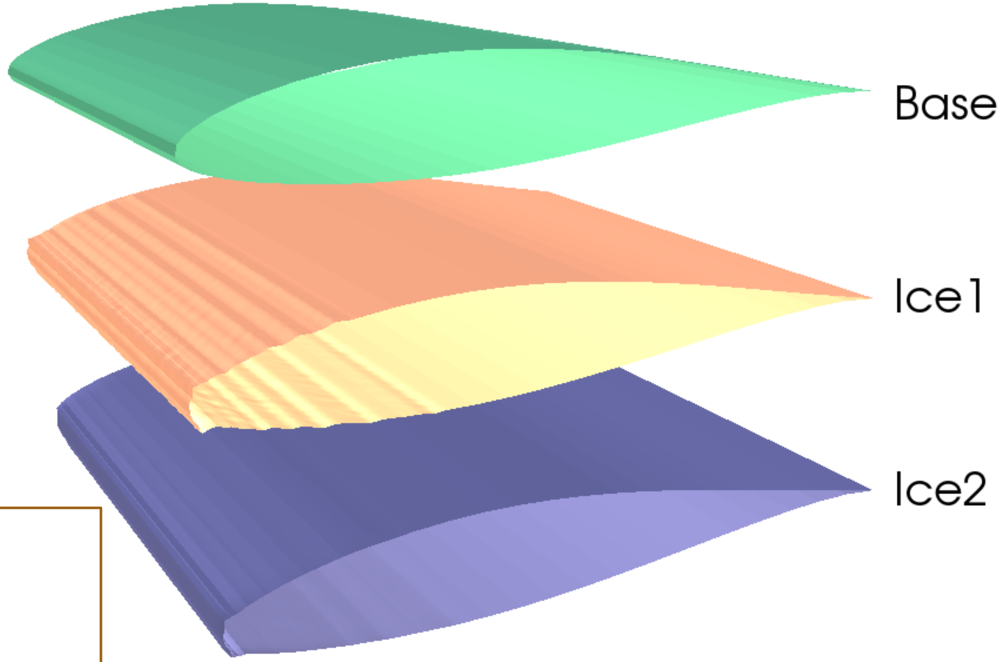
Ice distribution

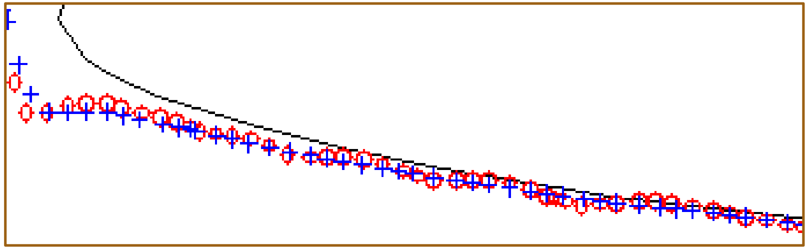


Not scaled



Ice distribution





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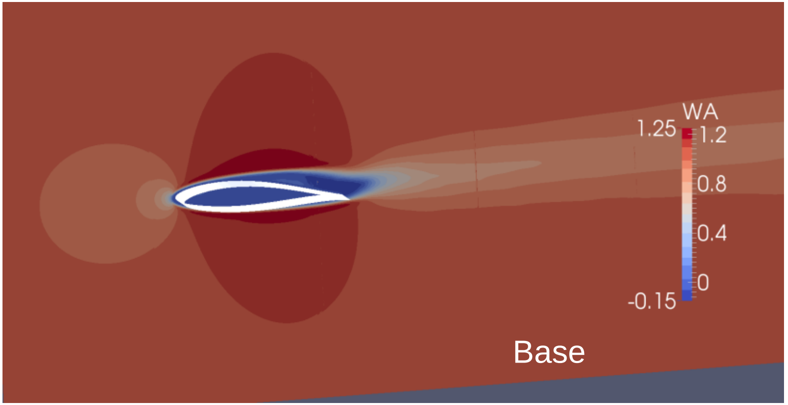
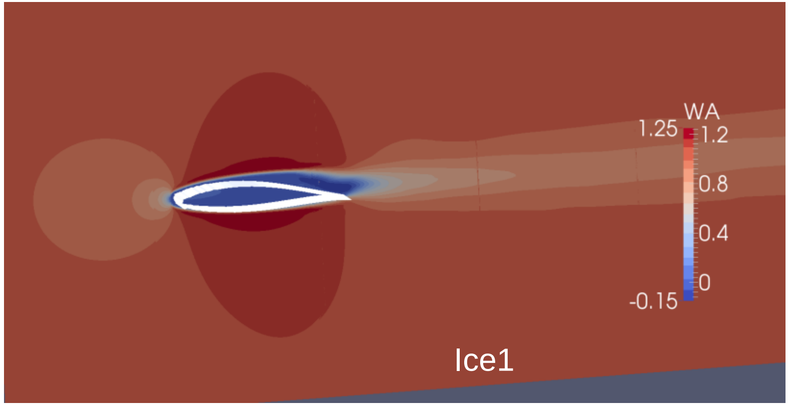
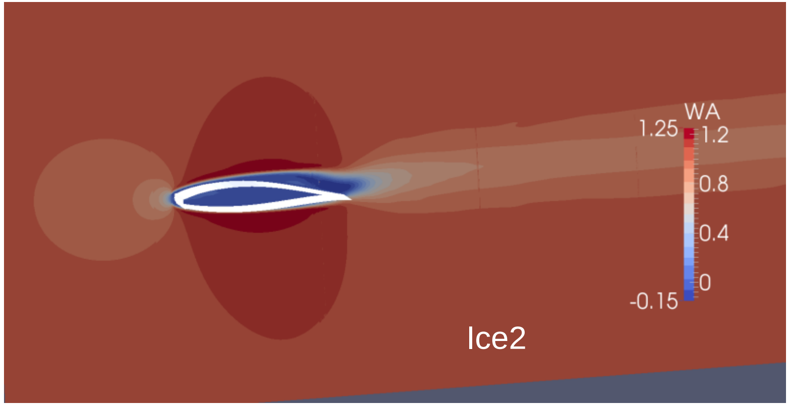
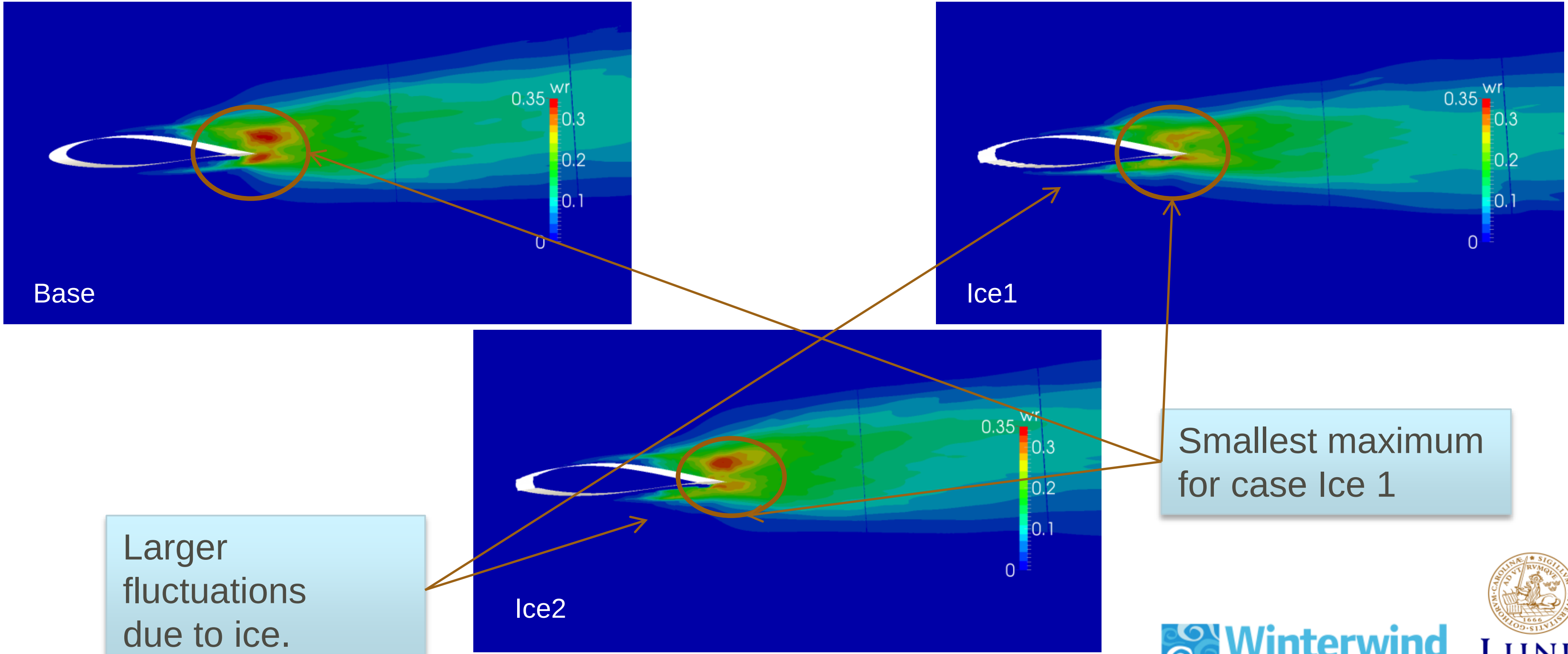
Average velocity







RMS velocity



Smallest maximum for case Ice 1

Larger fluctuations due to ice.

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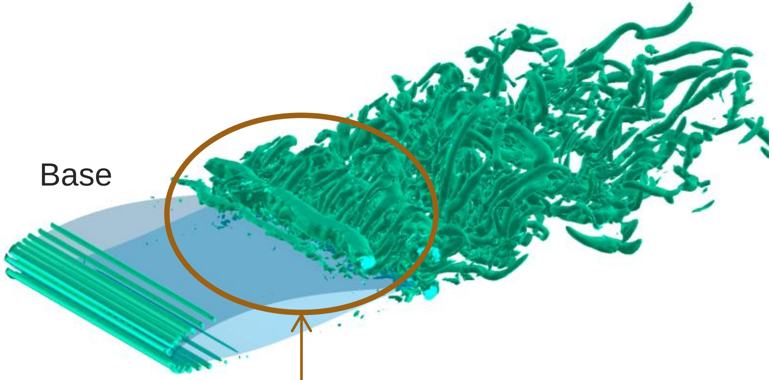
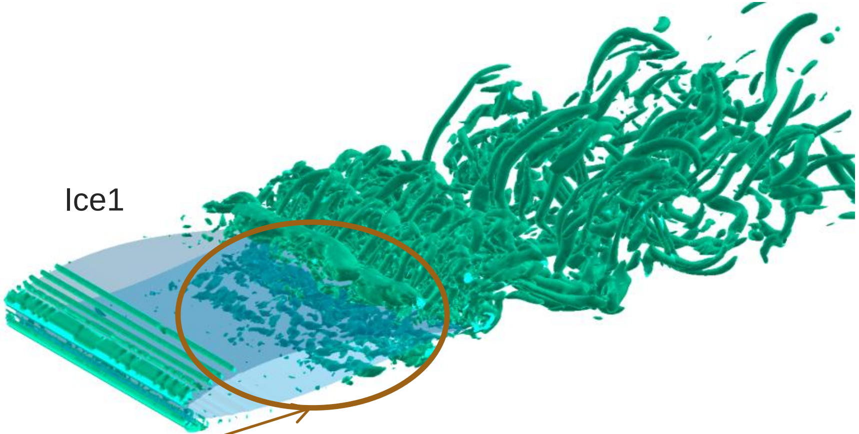
Vortical structures (λ2)

Base



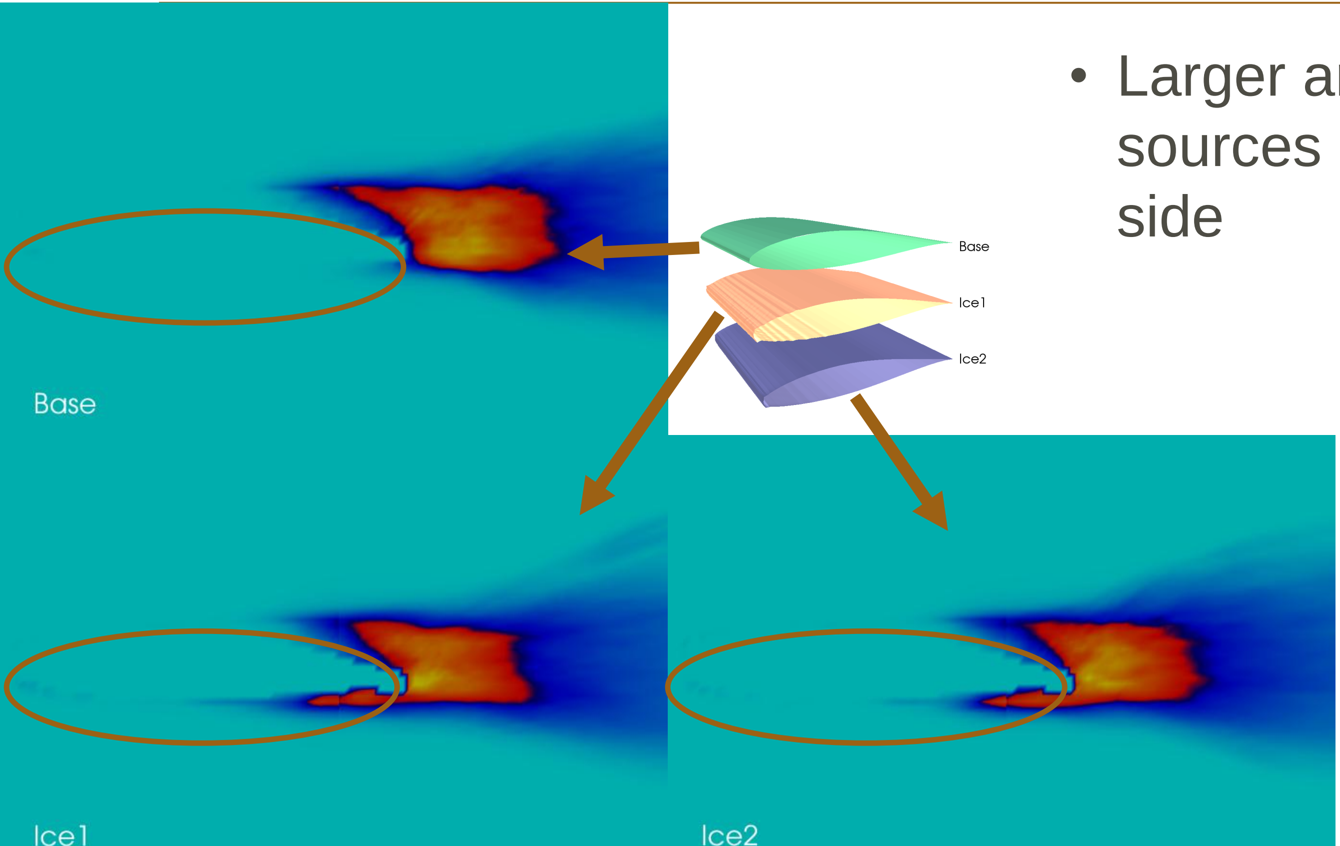
Ice1



Long structure

Small vortices

RMS Lighthill source



- Larger amplitude sources on pressure side

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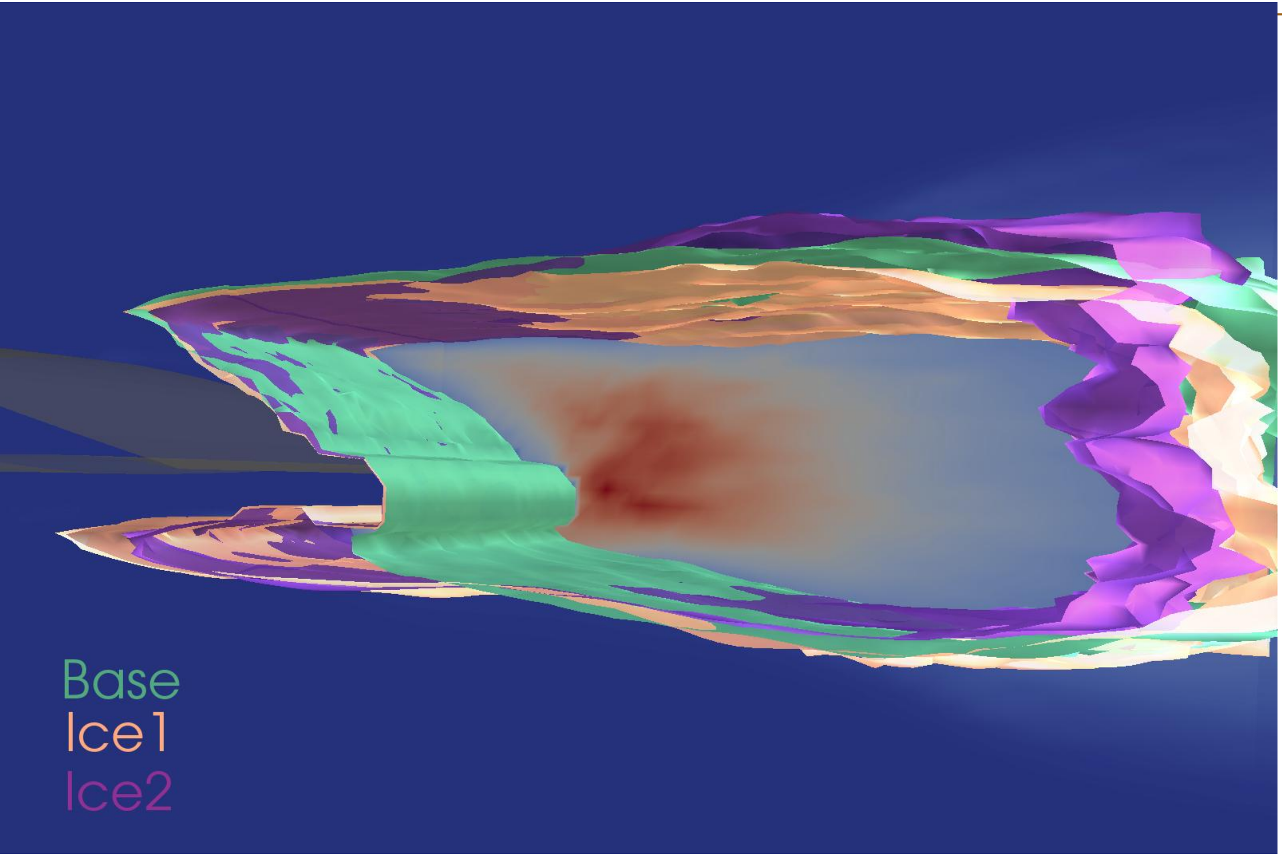
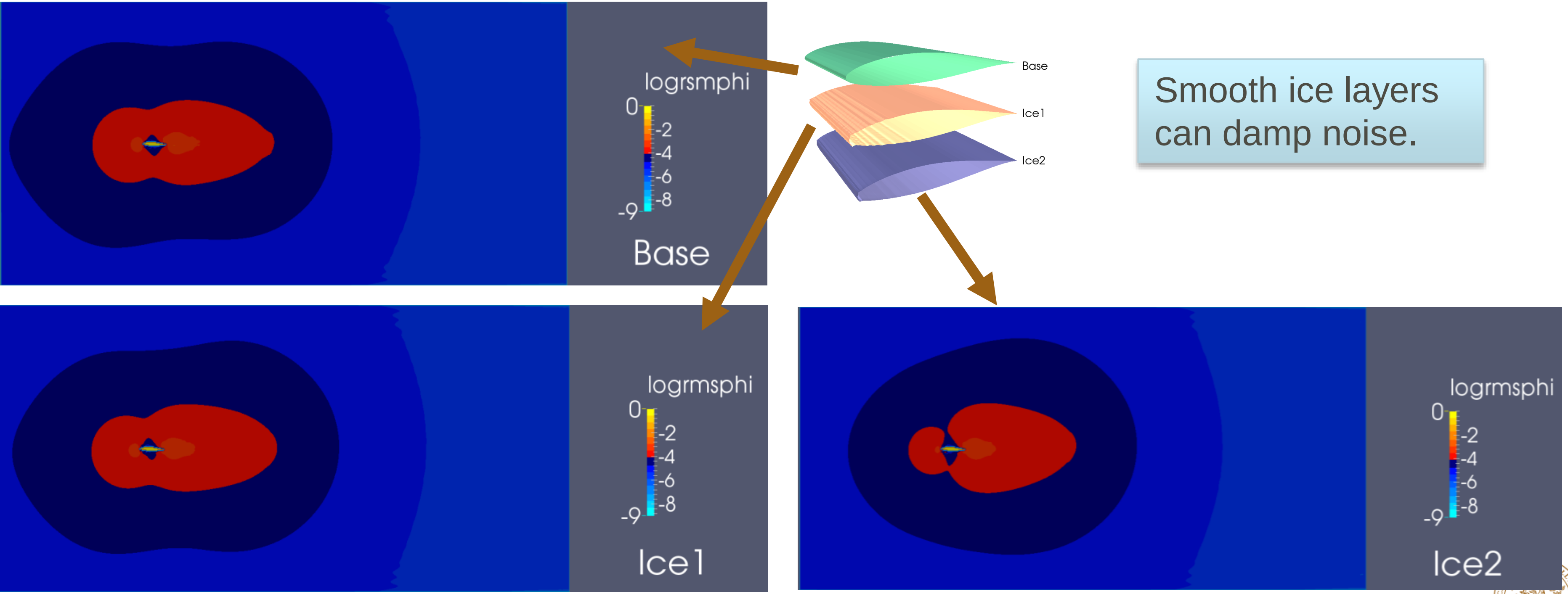
Acoustic sources



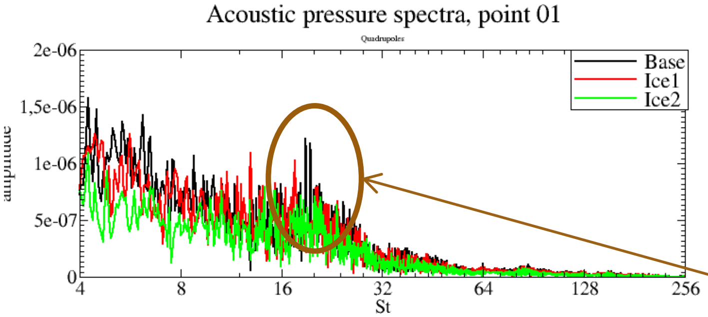
- Isosurfaces of ca 25% max rms
- No significant effect on downstream extent

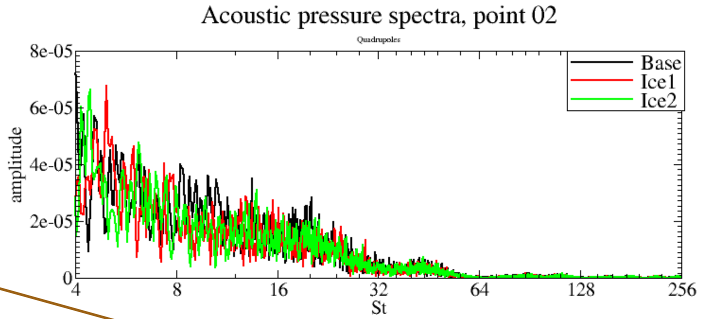
Log10 RMS Acoustic Density Fluctuation

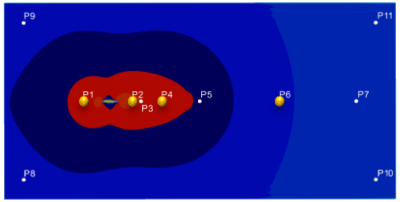


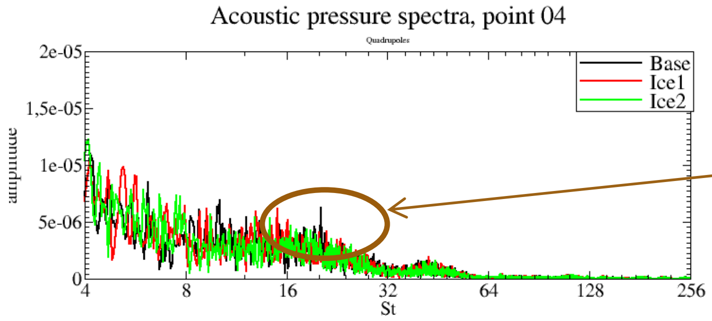
Smooth ice layers can damp noise.

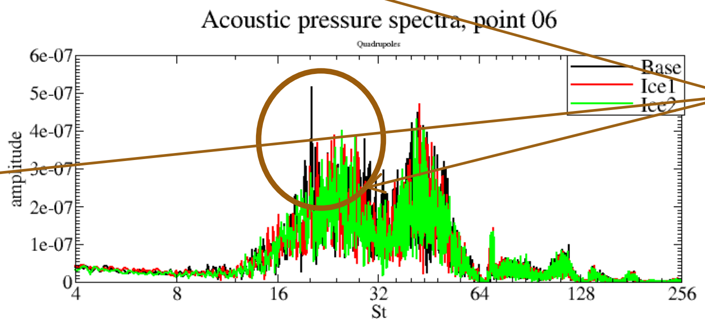
Acoustic presssure spectra





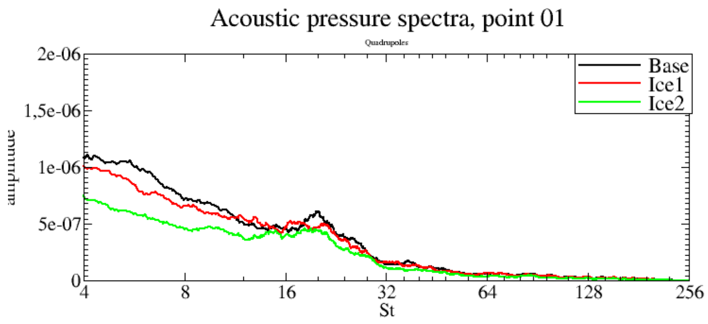


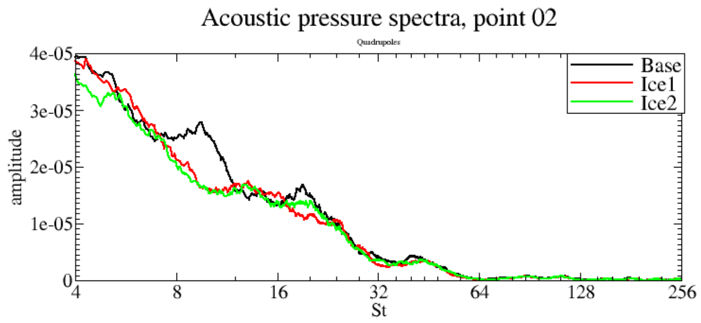


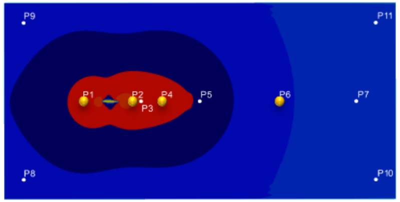


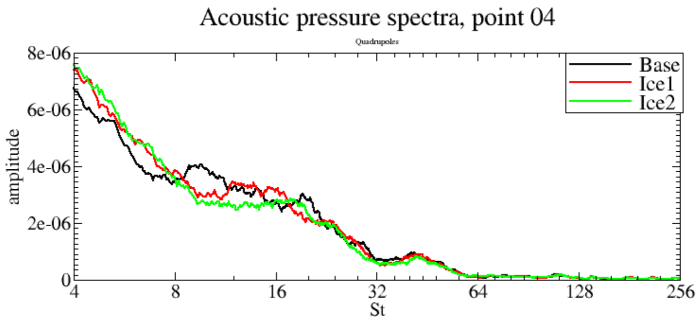
Some tones damped by ice

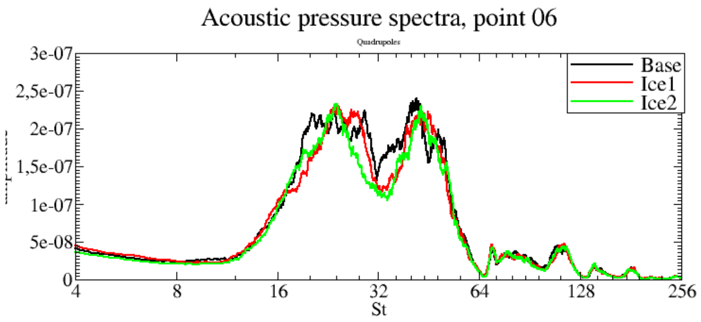
Filtered acoustic presssure spectra











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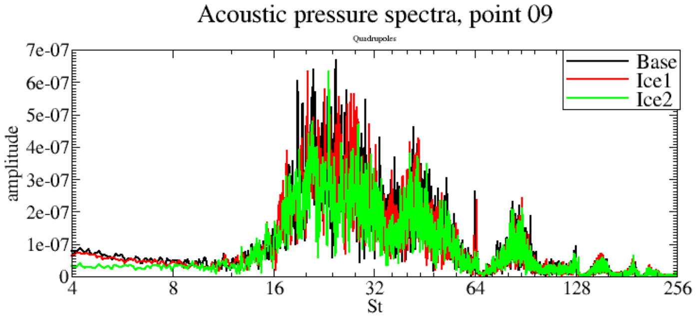

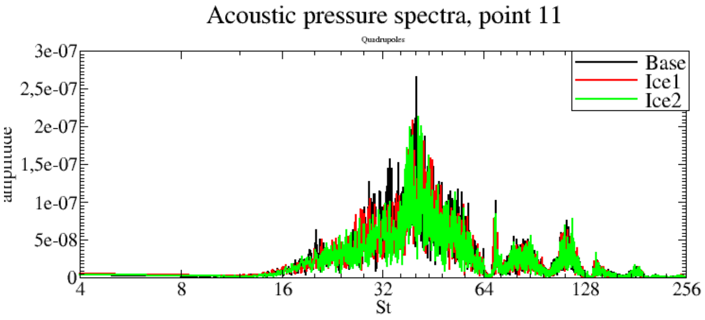

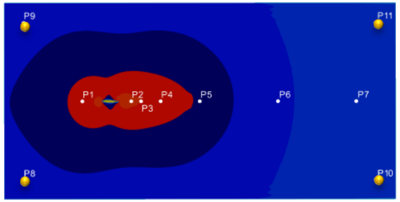

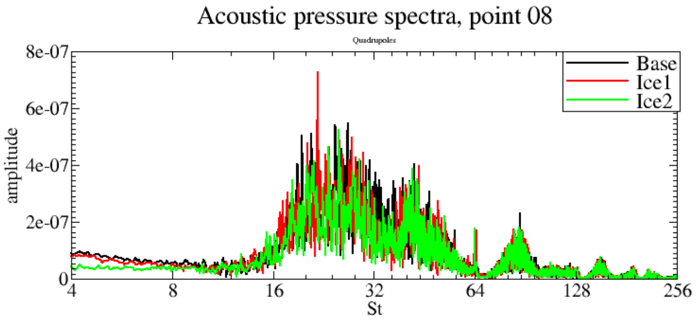

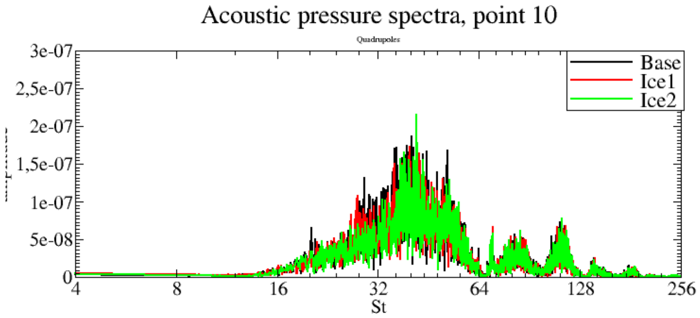

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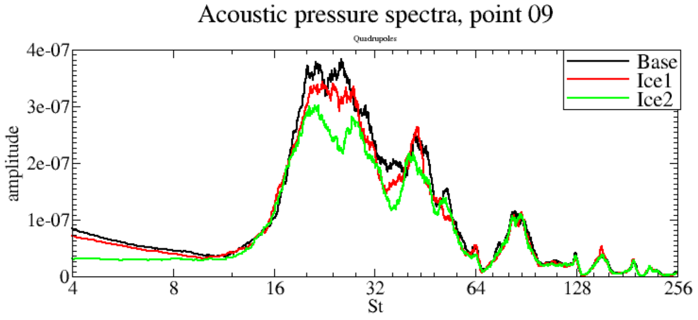
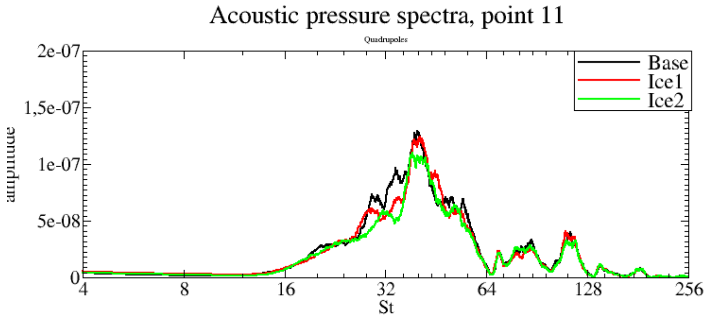
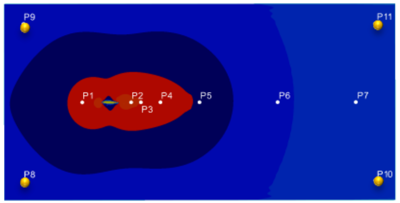
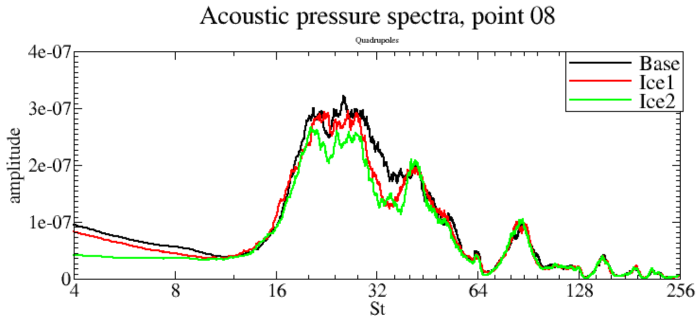
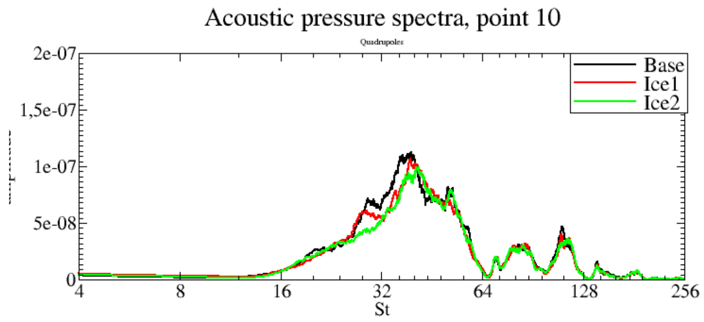
Filtered acoustic presssure spectra











Future work

- Other icing conditions
  - Add heat transfer
- Acoustics
  - Account for monopoles and dipoles as well
- Improve efficiency
  - Oct-tree mesh
  - Implement method in OpenFOAM
- Landscape/ground effects
- Realistic geometry

Acknowledgements

- Financing: STEM Kallt klimat: *Wind Turbines in Cold Climate: Fluid Mechanics, Ice Accretion and Terrain Effects*
- Computing resources: SNIC/Lunarc (Lund Univ.)

Thank you!