Atmospheric Icing of Transmission Line Conductor Bundles

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Incidences

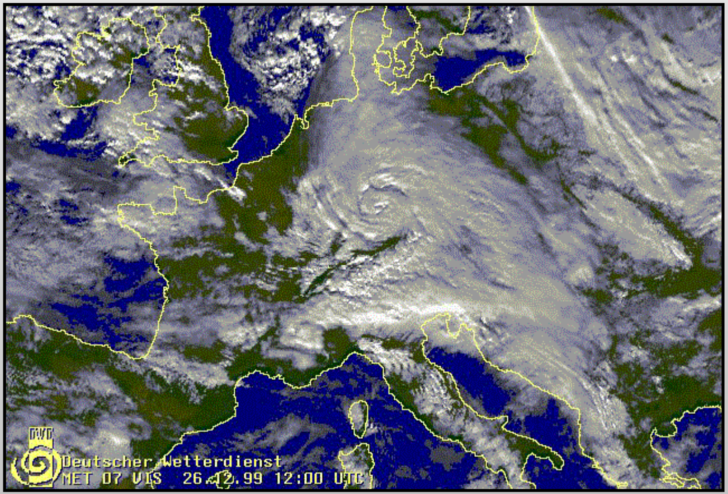
Winter Storms

Germany November 2005

Germany November 2005
- in Münsterland
- ca. 250.000 people without electricity for up to a week
- monetary damage of over 100 million euro

Northern America January 1998
- just in Canada (Québec and Ontario)
- ca. 1300 high voltage power line towers failed
- over 2 million people without electricity for weeks
- 25 people died
- monetary damage of several billion dollars

Federal Office of Civil Protection and Disaster Assistance (BBK)



Strom Lother December 1999

Disaster Simulation (LÜKEX 2004)

Blackout in Baden-Württemberg due to winter storm in the magnitude of Lother (1999) in combination with heavy snowfall

- Telecommunication
- Livestock farming
- Logistics in general and especially food supply
- money transaction and supply

Motivation

Increasing vulnerability to blackouts of modern societies with growing energy demand

Increasing application of bundled conductors to coup the energy demand

Leading to increased ice loads on transmission lines

How can we asses the risk of transmission line failures?

- Static ice loads on iced transmission lines
- Aerodynamic coefficients of the iced conductors

Simulation of Ice Accretion

- Flow field around conductor bundles
- Significant types of precipitation
- Dry and wet ice growth

Hazard Scenarios

- Identifying weather scenarios
- Combining wind and ice loads

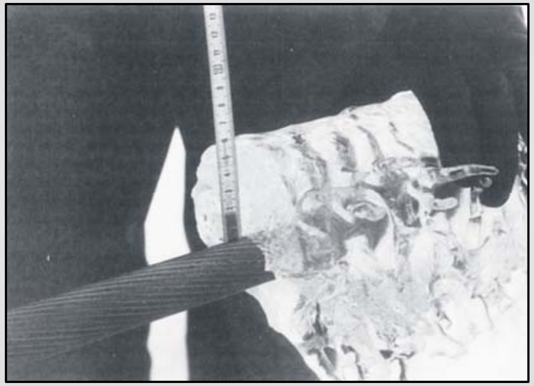
Ice Evolution

Rime

Density of 100-600 kg/m³

At temperatures below 0°C

Can occur as in-cloud and as precipitation icing



Glaze

Density up to 917 kg/m³

At temperatures around 0°C

Occurs commonly in freezing rain

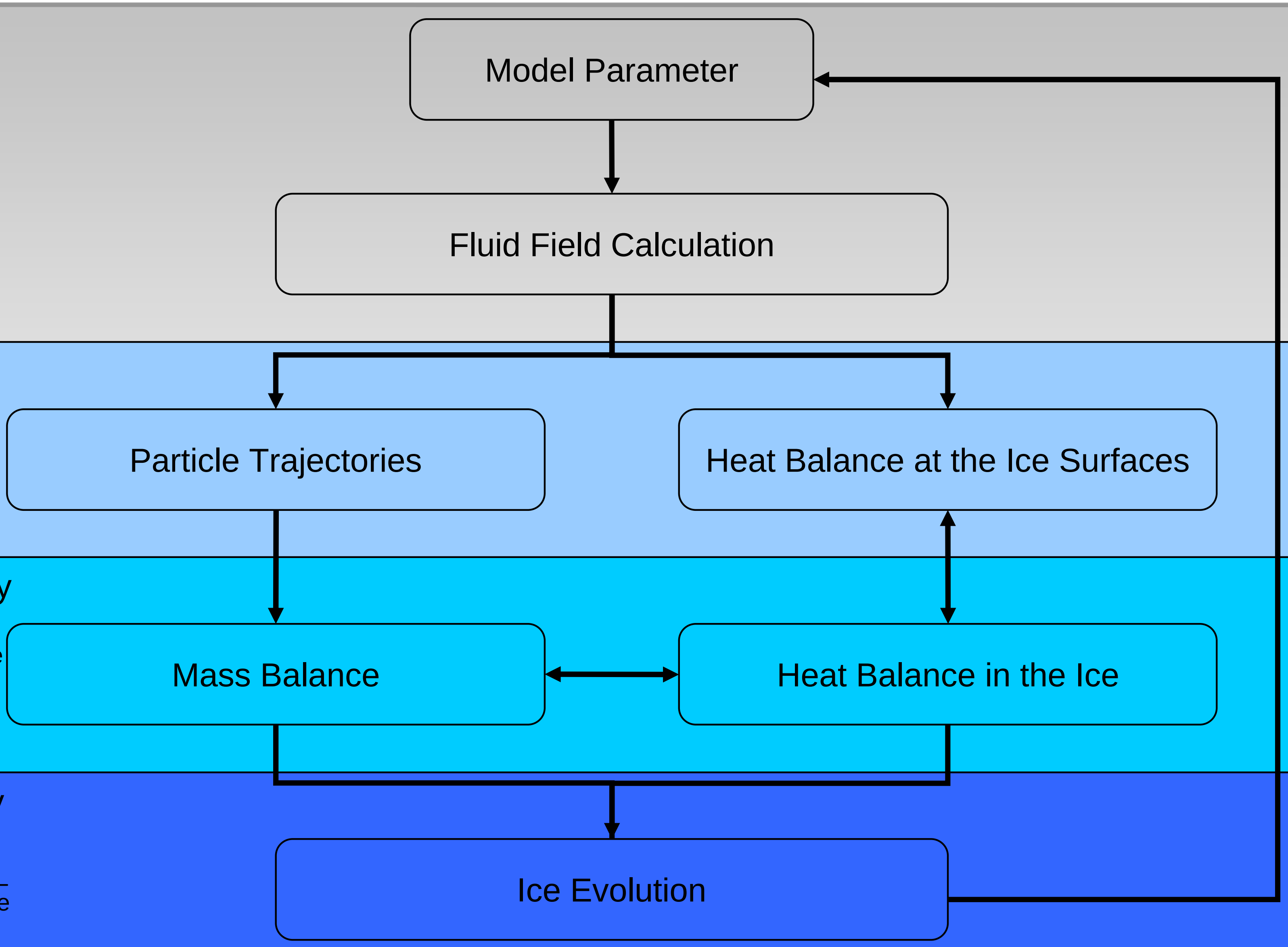
Wet Snow

Density of 200-990 kg/m³

At temperatures just above 0°C

Caused by wet snow precipitation

Simulation Scheme



Model Parameter

Fluid Field Calculation

Particle Trajectories

Heat Balance at the Ice Surfaces

Mass Balance

Heat Balance in the Ice

Ice Evolution

Collision Efficiency

$$\frac{\text{particles hitting the cable}}{\text{total mass flow}}$$

Collection Efficiency

$$\frac{\text{particles sticking to the cable}}{\text{particles hitting the cable}}$$

Accretion Efficiency

$$\frac{\text{particles being iced}}{\text{particles sticking to the cable}}$$

Fluid Flow Calculation

Incompressible and Isothermal Navier-Stocks Equation

Conservation of Mass

$$\nabla \cdot \mathbf{u} = 0$$

Conservation of Momentum

$$\rho \frac{\partial \mathbf{u}}{\partial t} + (\rho \mathbf{u} \cdot \nabla)\mathbf{u} = -\nabla p + \nabla \cdot \tau + \mathbf{F}$$

Viscous Stress

$$\tau = \eta(\nabla \mathbf{u} + (\nabla \mathbf{u})^{\mathrm{T}})$$

Numerical Model

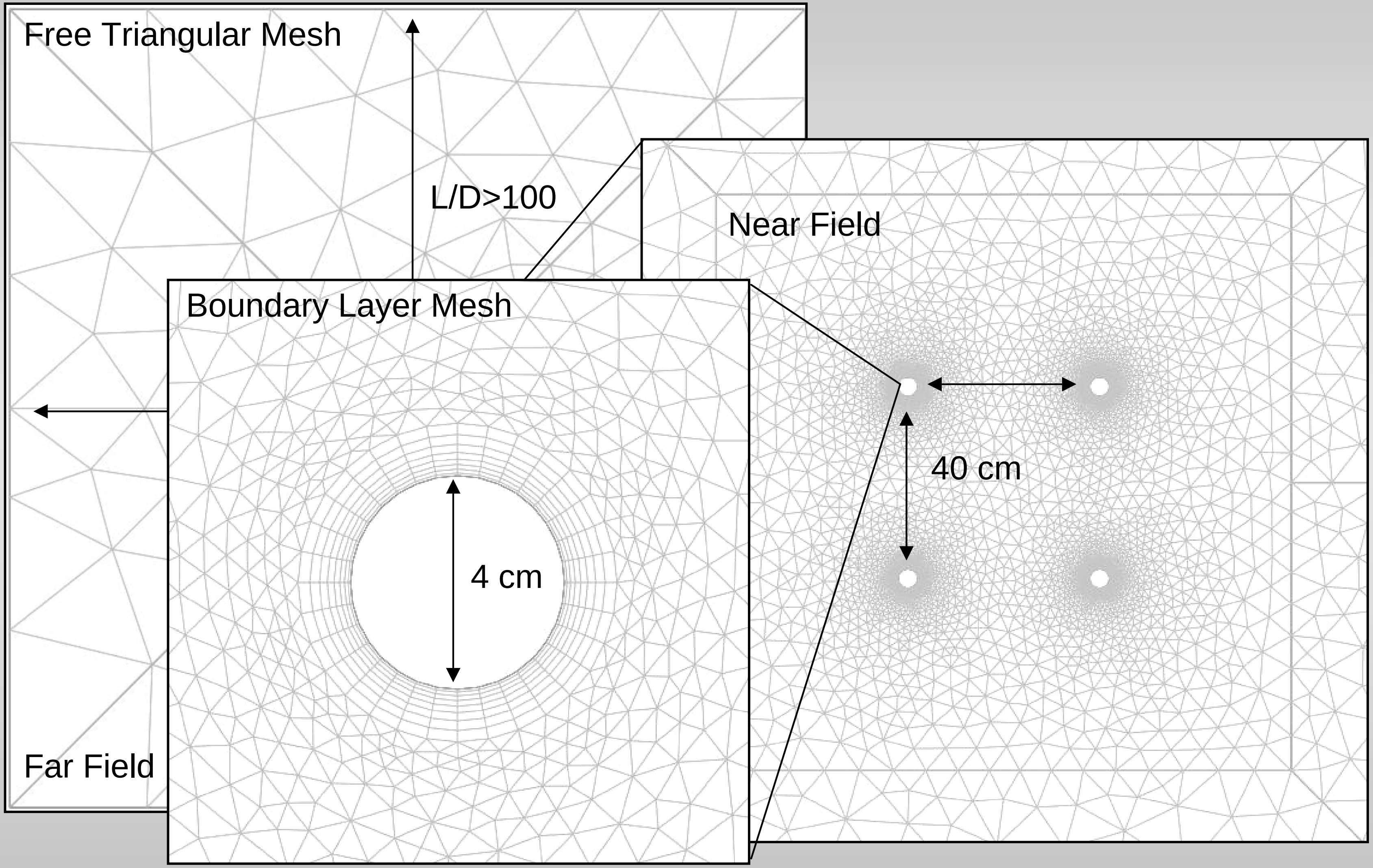
- Reynolds-Average-Navier-Stocks (RANS) equation
- k-ε Turbulence Model
- Numerical stabilisation with Galerkin Least Squares

Solver

- Stationary Segregated Solver
- Pardiso as linear system solver
- Absolute Tolerance of 0.001

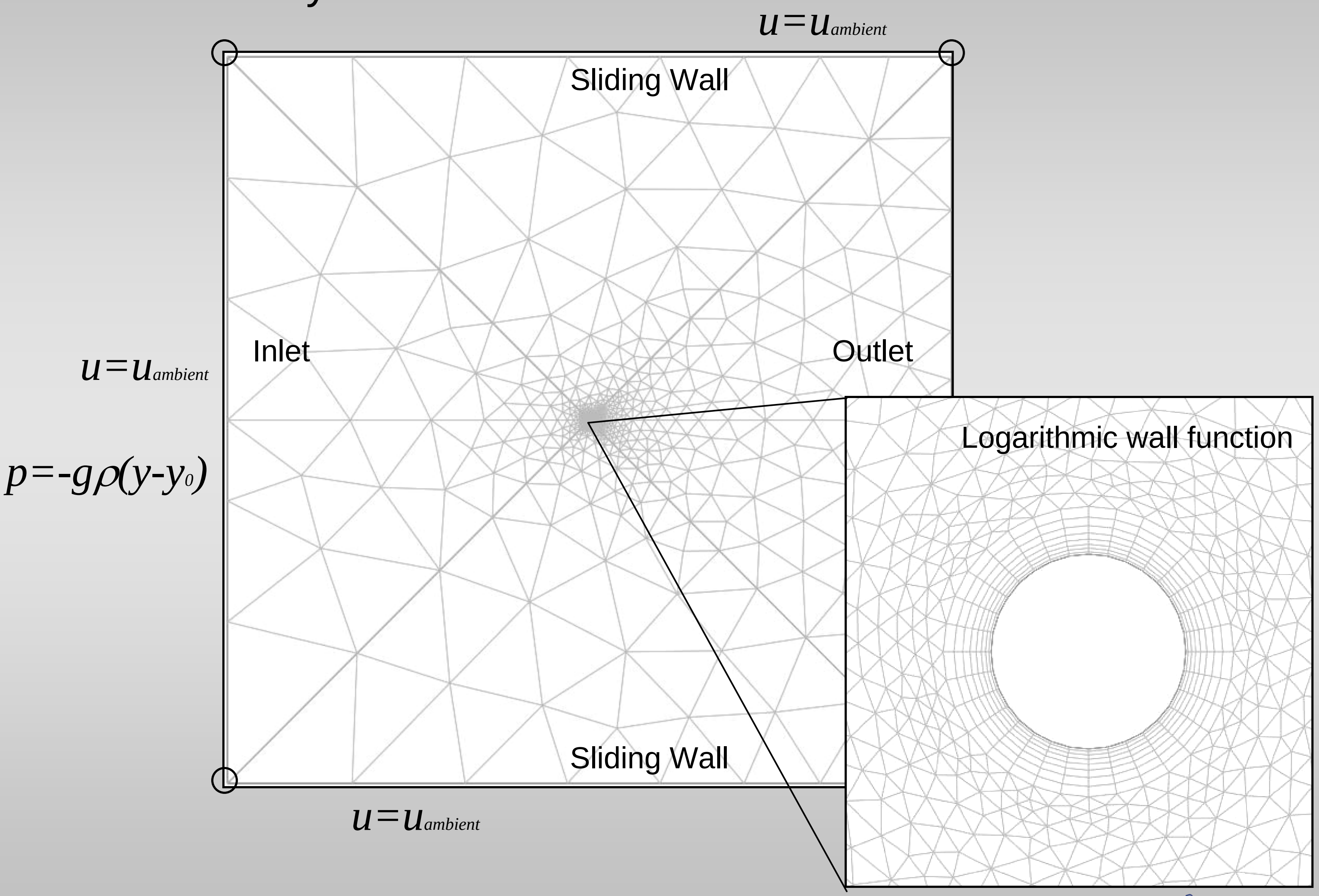
Fluid Flow Calculation

Mesh



Fluid Flow Calculation

Boundary Conditions



$u=u_{ambient}$

Sliding Wall

Inlet

Outlet

$u=u_{ambient}$

$p=-g\rho(y-y_0)$

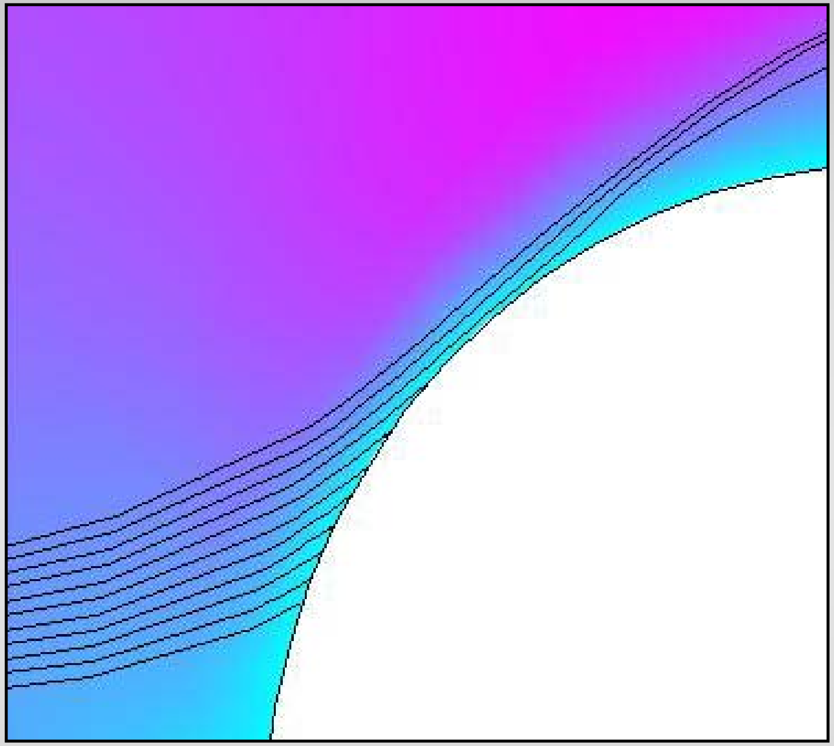
Logarithmic wall function

Sliding Wall

$u=u_{ambient}$

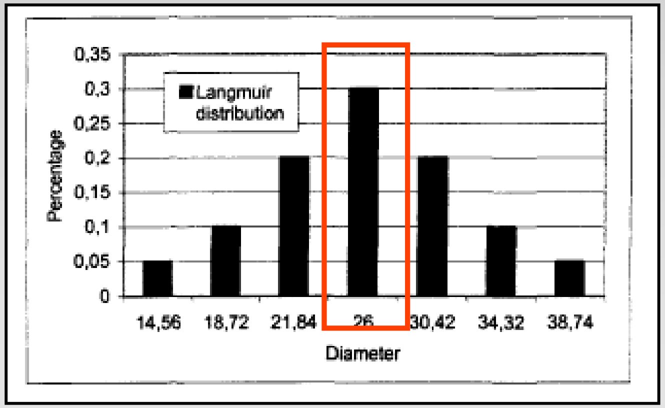
Particle Trajectories

$$\text{Collision Efficiency} = \frac{\text{particles hitting the cable}}{\text{total mass flow}}$$



Particle Tracing

Droplet Spectra



Particle Trajectories of a droplet with

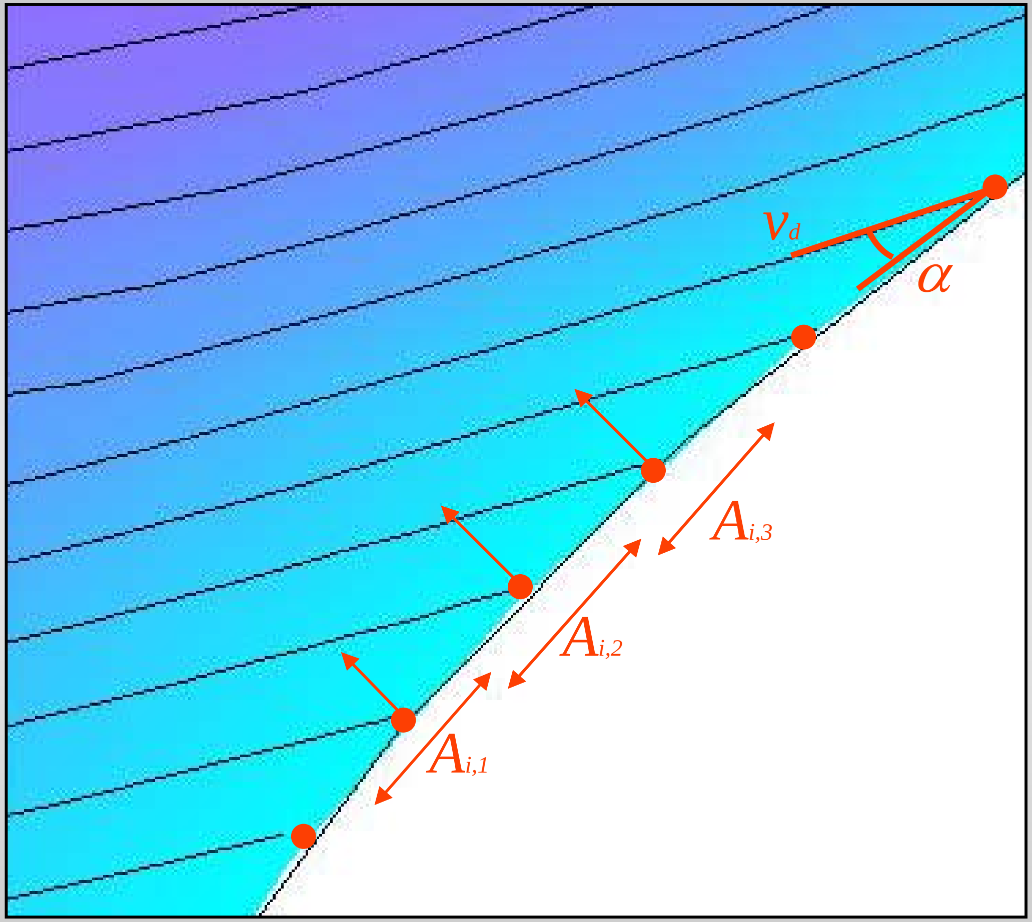
- medium volume diameter (MVD)
- initial trajectory spacing of (A_0)
- liquid water content (LWC)

$$F = \pi r_p^2 \rho (\bar{u} - \bar{u}_p)^2 (1.84(\mathrm{Re}_p)^{-0.31} + 0.293(\mathrm{Re}_p)^{0.06})^{3.45}$$

$$\mathrm{Re}_p = (|\bar{u} - \bar{u}_p| 2 r_p \rho)/\eta\,.$$

Mass Balance

$$\text{Collection Efficiency} = \frac{\text{particles sticking to the cable}}{\text{particles hitting the cable}}$$

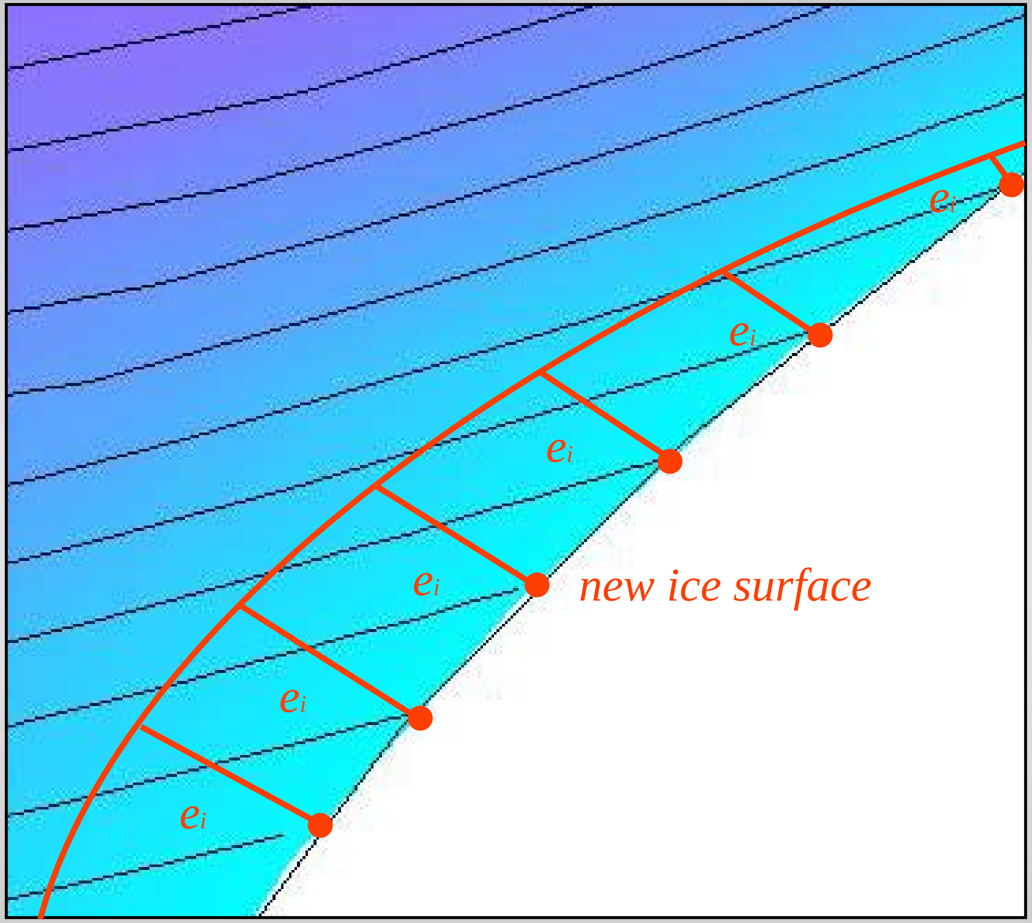


Collection Efficiency

$$\boxed{\beta = \frac{A_0 \cos(\alpha)}{A_i}}$$

Ice Evolution

$$\text{Accretion Efficiency} = \frac{\text{particles being iced}}{\text{particles sticking to the cable}}$$



Macklin’s Parameter

$$R = \frac{MDV \cdot v_d}{2 \cdot T_s}$$

Ice Density

$$\rho_i = 110 \cdot R^{0.76} \qquad R \le 10$$

$$\rho_i = \frac{R}{R+5.61} \cdot 10^3 \qquad 10 \le R \le 60$$

$$\rho_i = 917 \qquad R > 60$$

Accretion Density Ratio

$$\chi = \frac{LCW}{\rho_i}$$

Ice Evolution

$$e_i = u_0 \chi \cdot \beta \cdot t_{\text{int}}$$

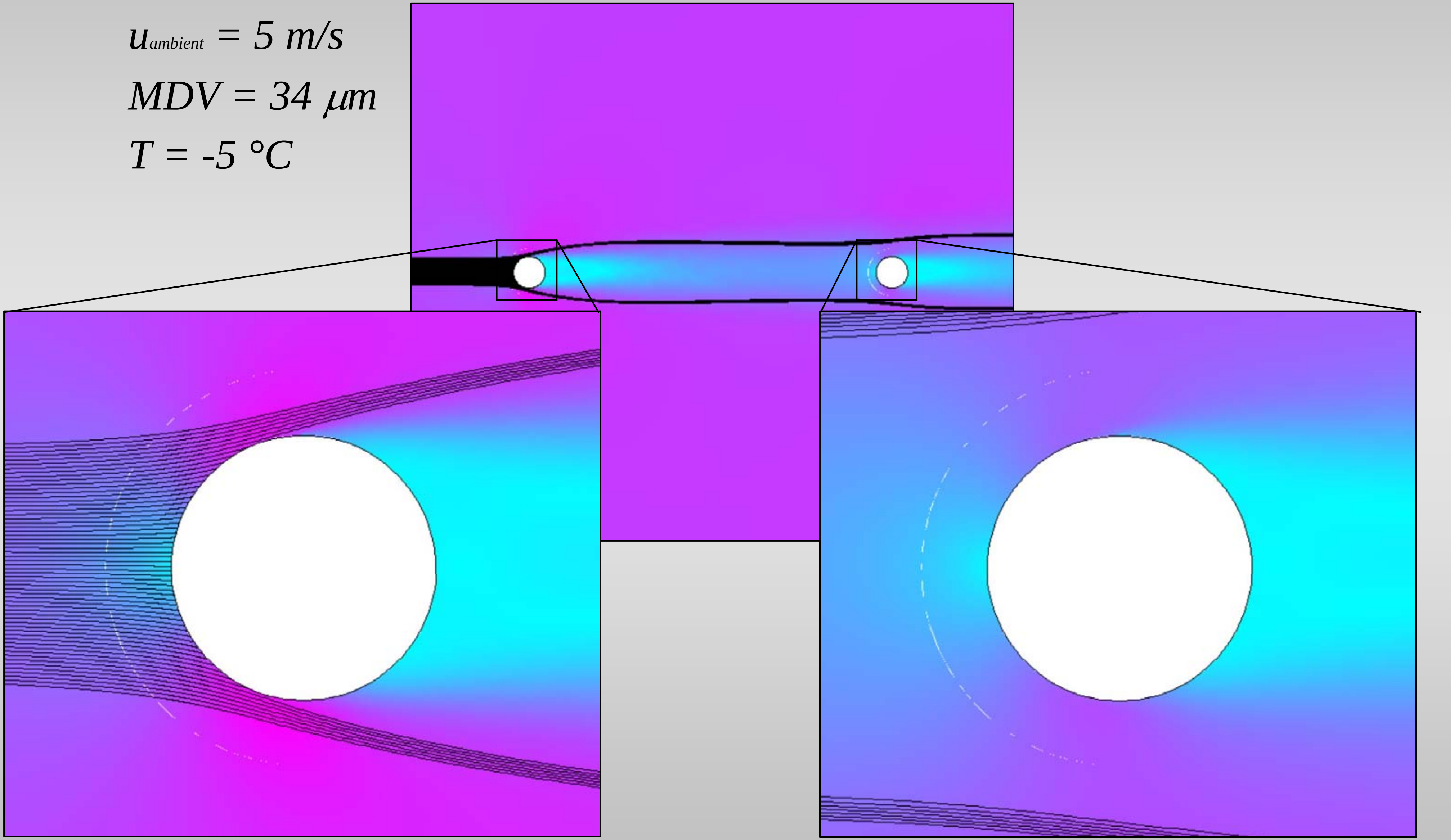
Shielding Effect

In-cloud Icing

$u_{ambient} = 5\ m/s$

$MDV = 34\ \mu m$

$T = -5\ °C$



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