Which parameters govern the strength of entrainment?

Wiebke Frey, Silvio Schmalfuß, Frank Stratmann, Dennis Niedermeier

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Motivation

- entrainment (and detrainment) key small scale process, yet physically not well understood
- parameterisations in models partly disagree on physical basis
- treatment of mixing processes in numerical models found responsible for much of large spread in climate sensitivity estimates

➢ understand which underlying physical parameters govern entrainment

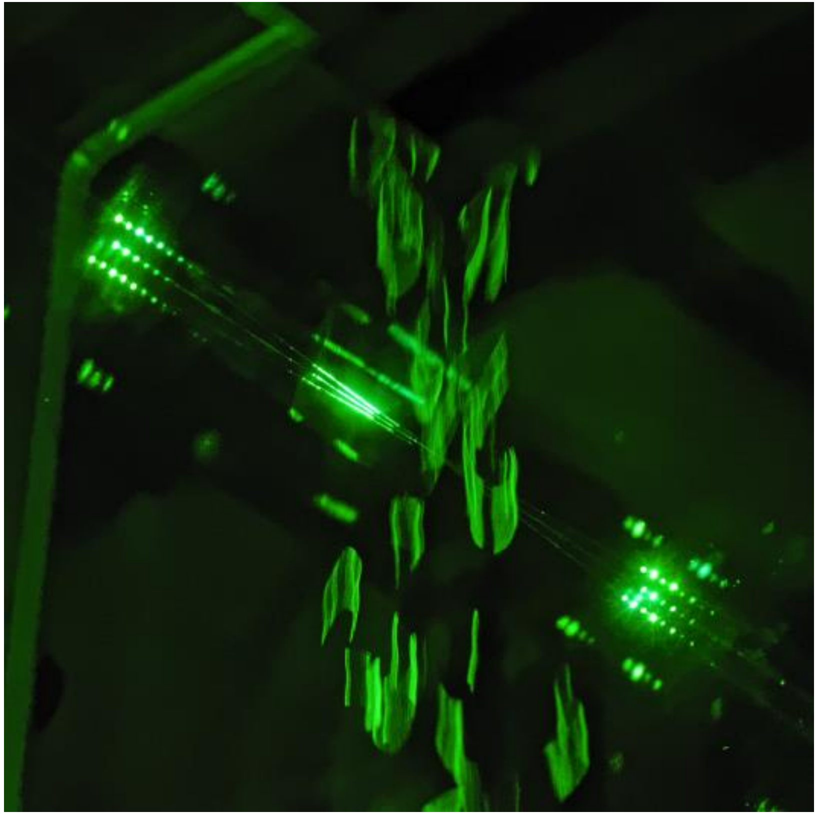

Photo: Tilo Arnhold (TROPOS)

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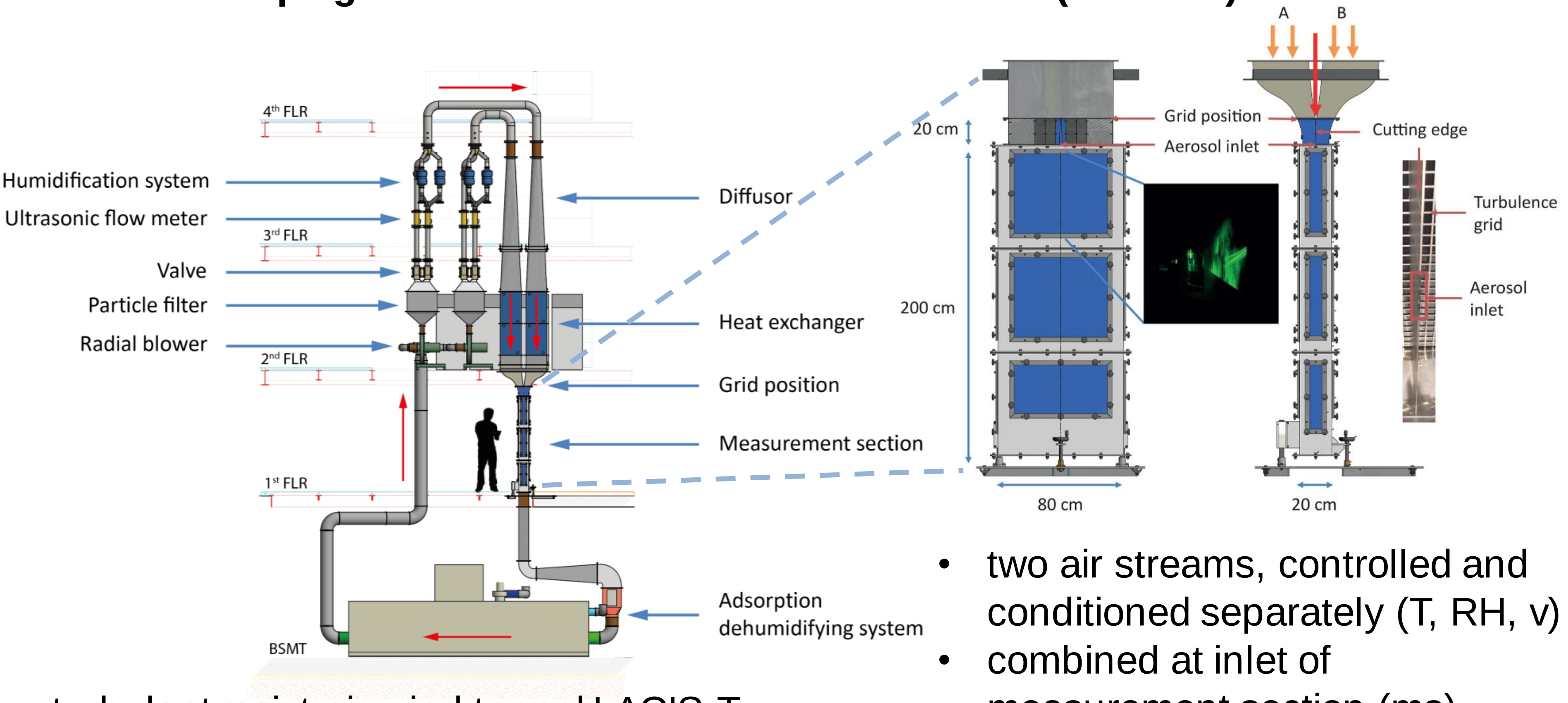
turbulent Leipzig Aerosol Cloud Interaction Simulator (LACIS-T)



turbulent moist-air wind tunnel LACIS-T

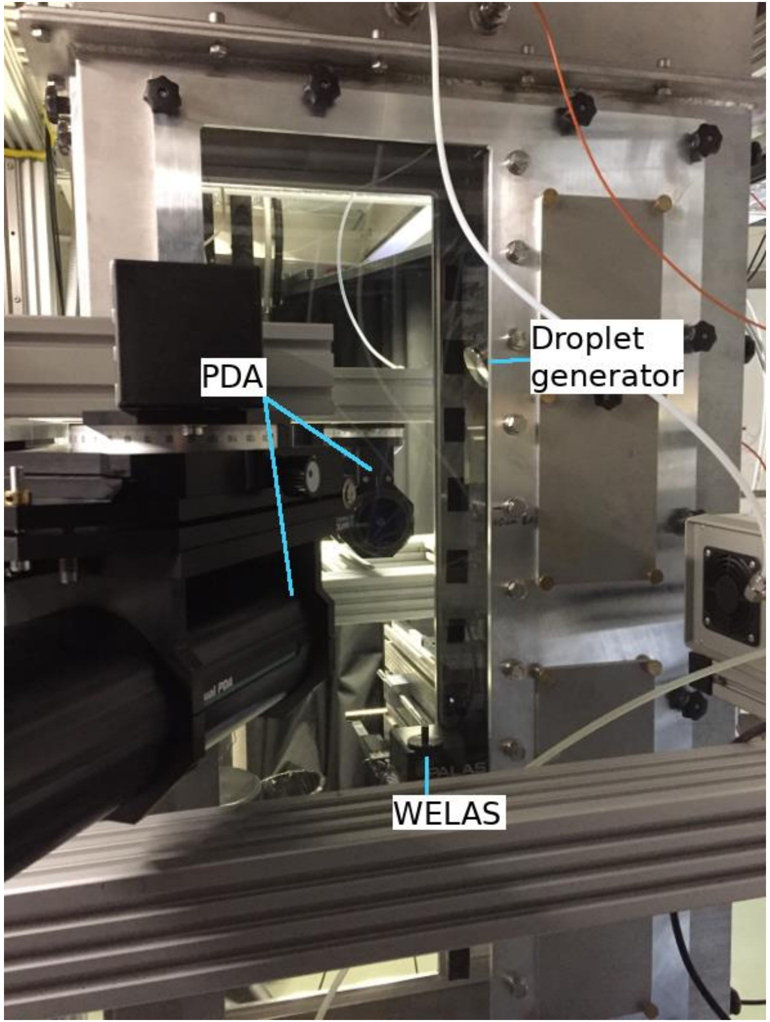
- two air streams, controlled and conditioned separately (T, RH, v)
- combined at inlet of measurement section (ms)
- turbulence induced upstream ms

Niedermeier et al., 2020, *Atmos. Meas. Tech.*, 13, 2015–2033, https://doi.org/10.5194/amt-13-2015-2020

Experimental design

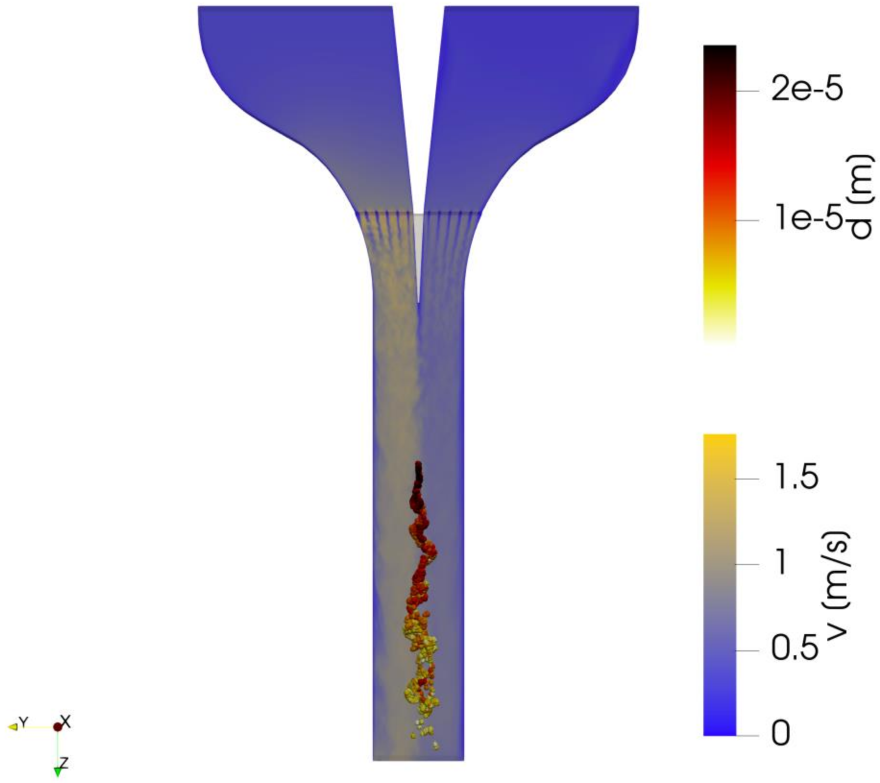
- one stream kept at constant conditions
- second stream varies one parameter (i.e. T, RH, flow speed)
- droplets generated with droplet generator fed into mixing zone – bimodal size distribution to mimic real cloud
- observations of doplets with PDA system at two positions

Droplet generator (MSP Corporation)	17-93µm
Phase Doppler Anemometer (Dantec)	2-73µm
White Light Aerosol Spectrometer (Palas)	0.2-100µm



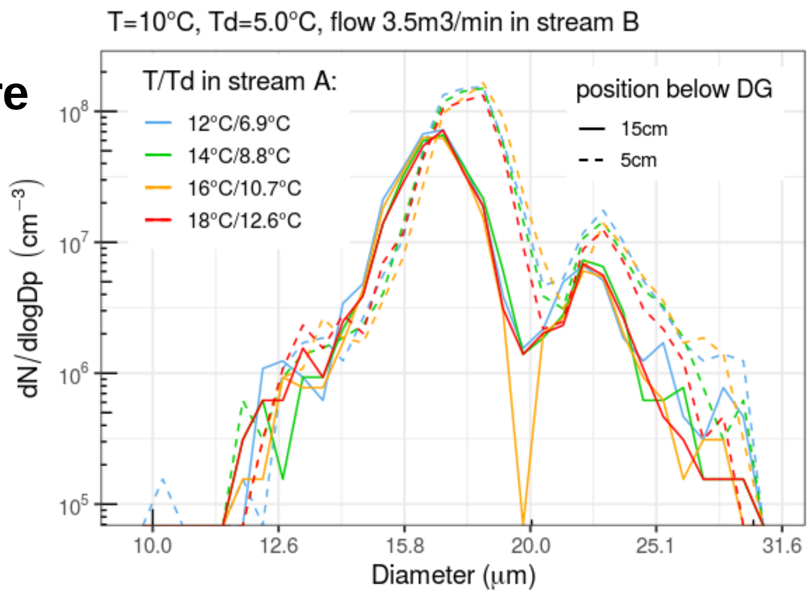
Computational Fluid Dynamics (CFD) simulations

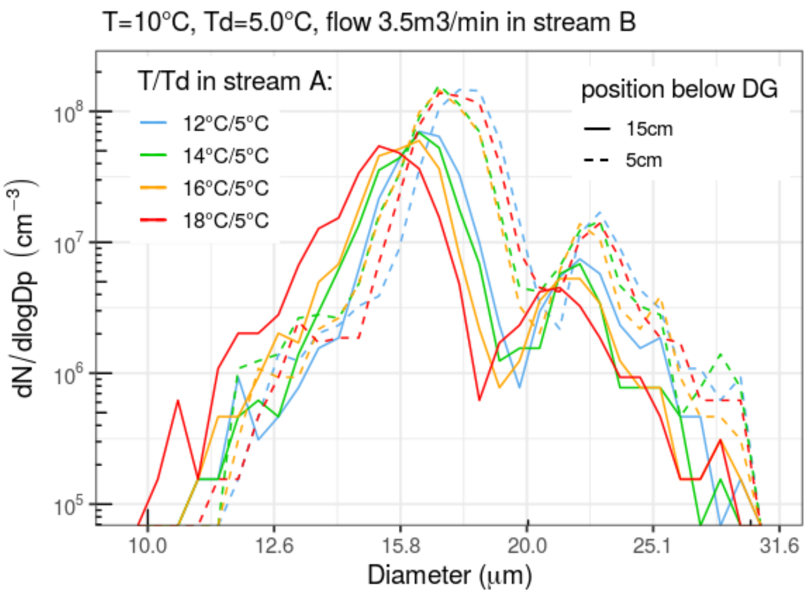
- OpenFOAM
- solving transient, incompressible Navier-Stokes-Equations
- hexahedral dominated mesh grid with approx. 1mm resolution (~7 million cells)
- lagrangian particles/droplet trajectories are calculated during model run time
  - two-way coupling for particles
- delivers full 3D fields (cf. point measurements)



Results

Variable temperature





- left: temperature increase @ RH ~ 70% → consistency in particle sizes
- difference in upper/lower measurement position due to residence time of particles in subsaturated environment

➢ change in temperature by itself has no impact, as expected

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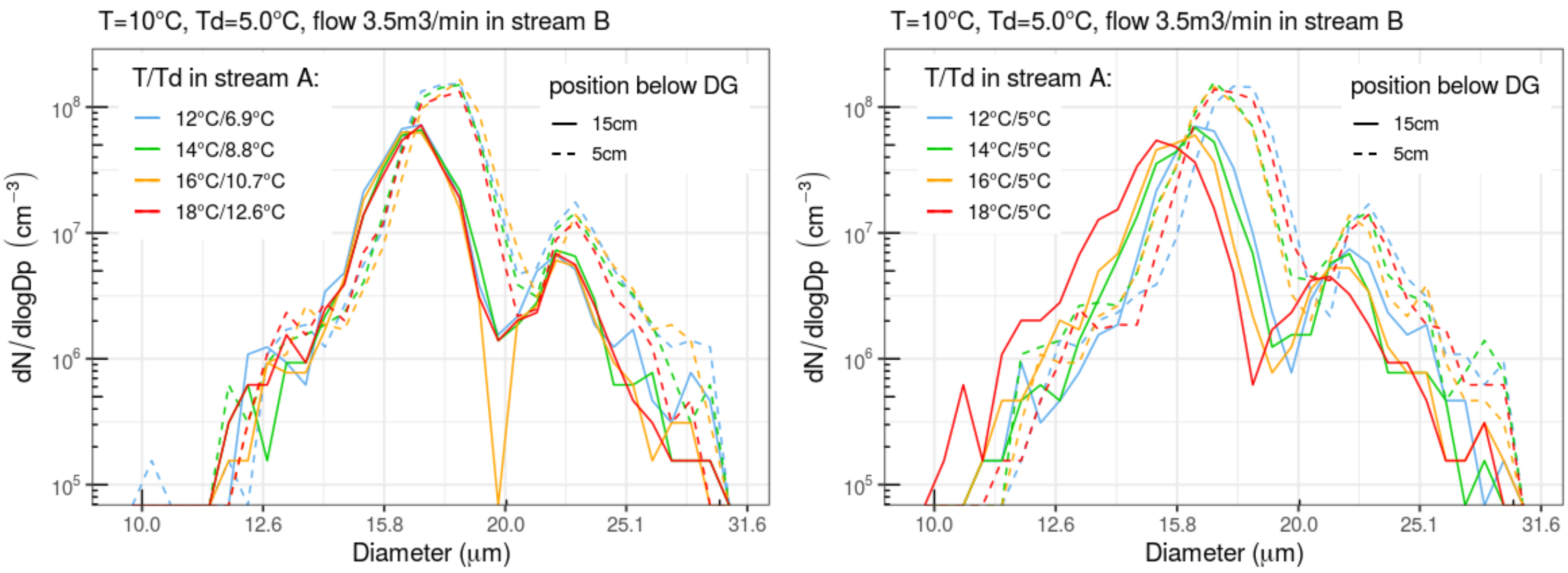
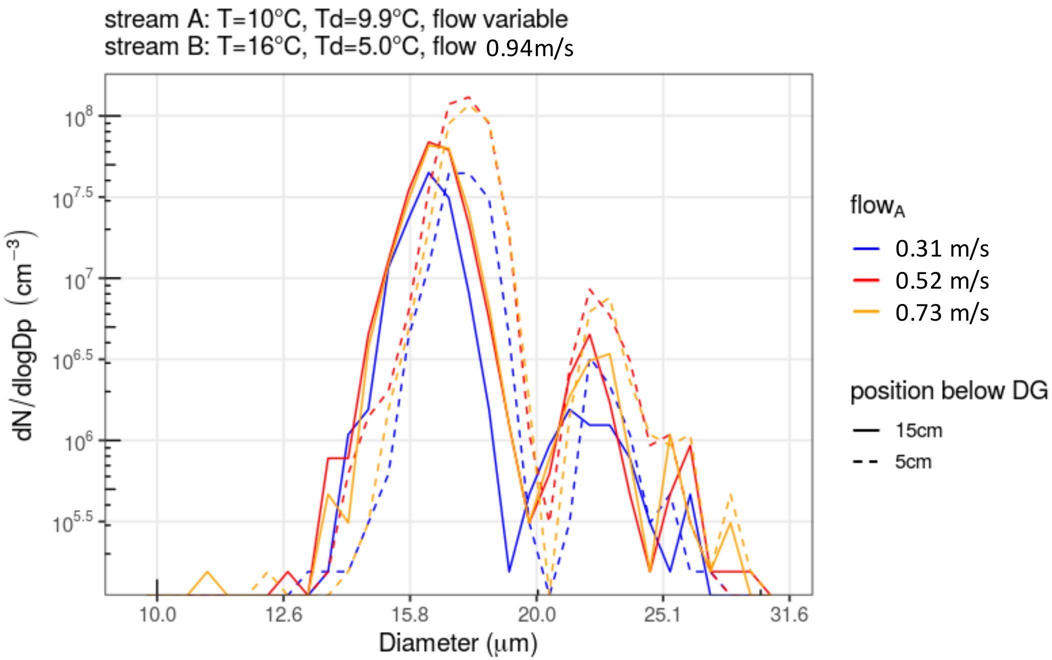
Variable RH



- right: RH drops from 71.1% to 42.3% (@18°C) when temperature increases

➢ slight shrinking of particles, as expected

Variable shear flow



- size distributions comparable

➢ no change visible though expected in different shear environments

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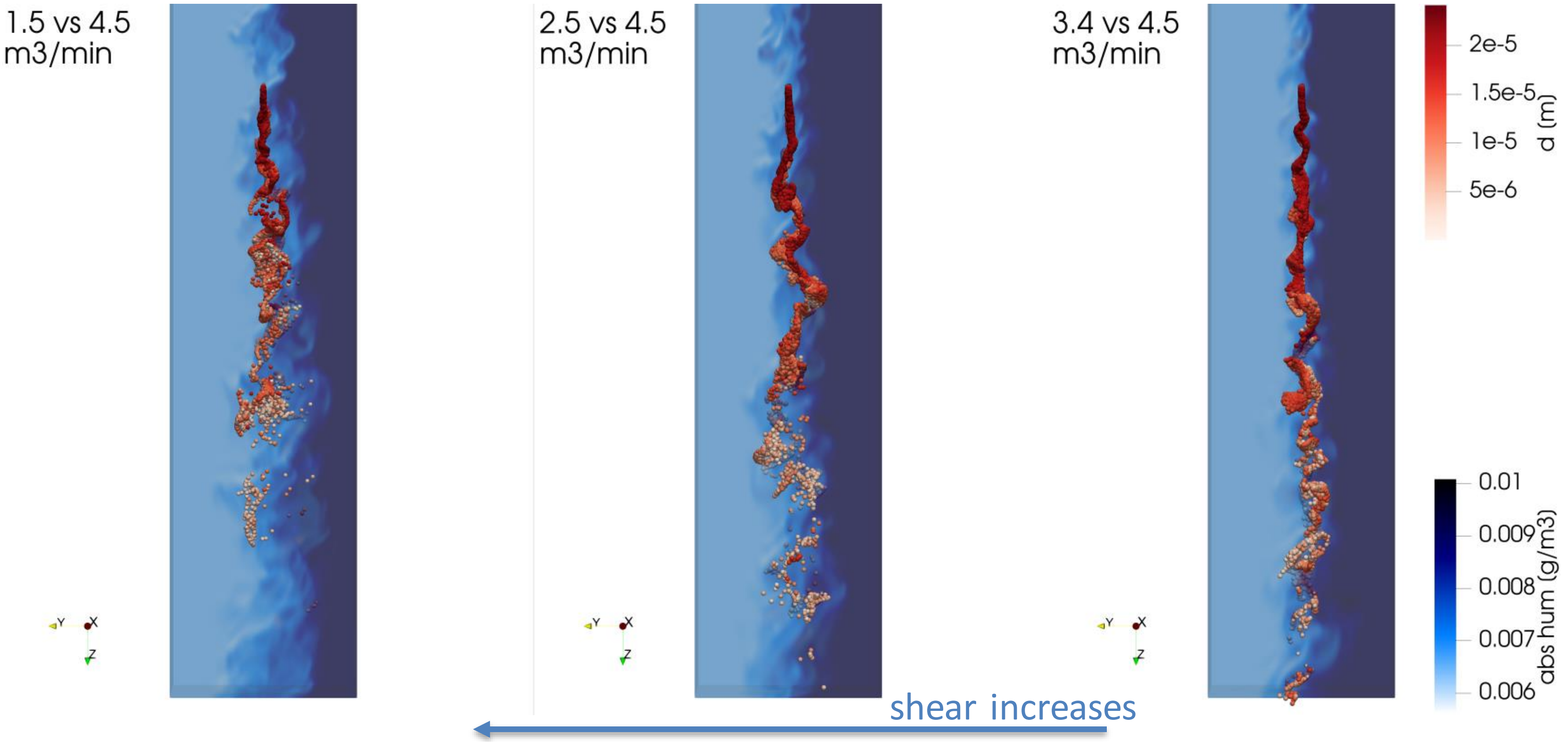
Simulation with variable shear flow



broadening and even breaking up of droplet stream with increased shear => 'patchyness'

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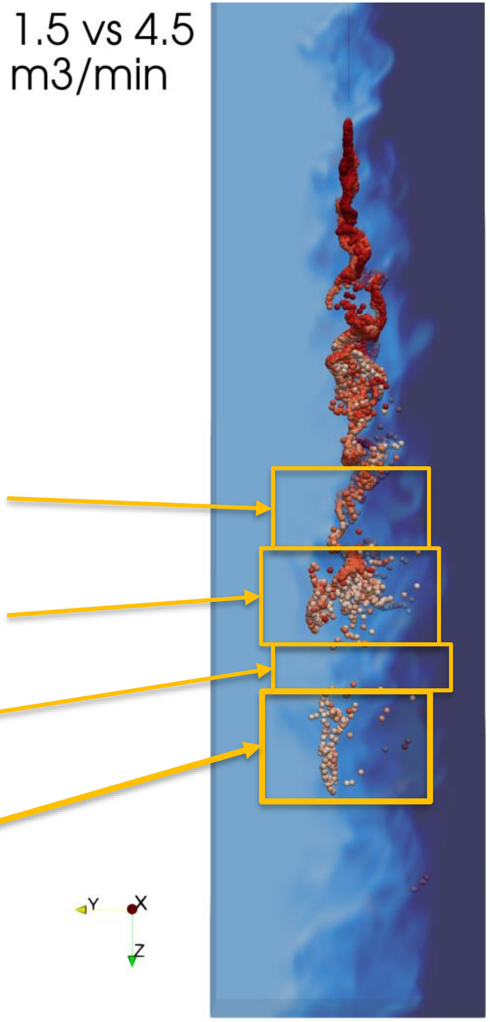
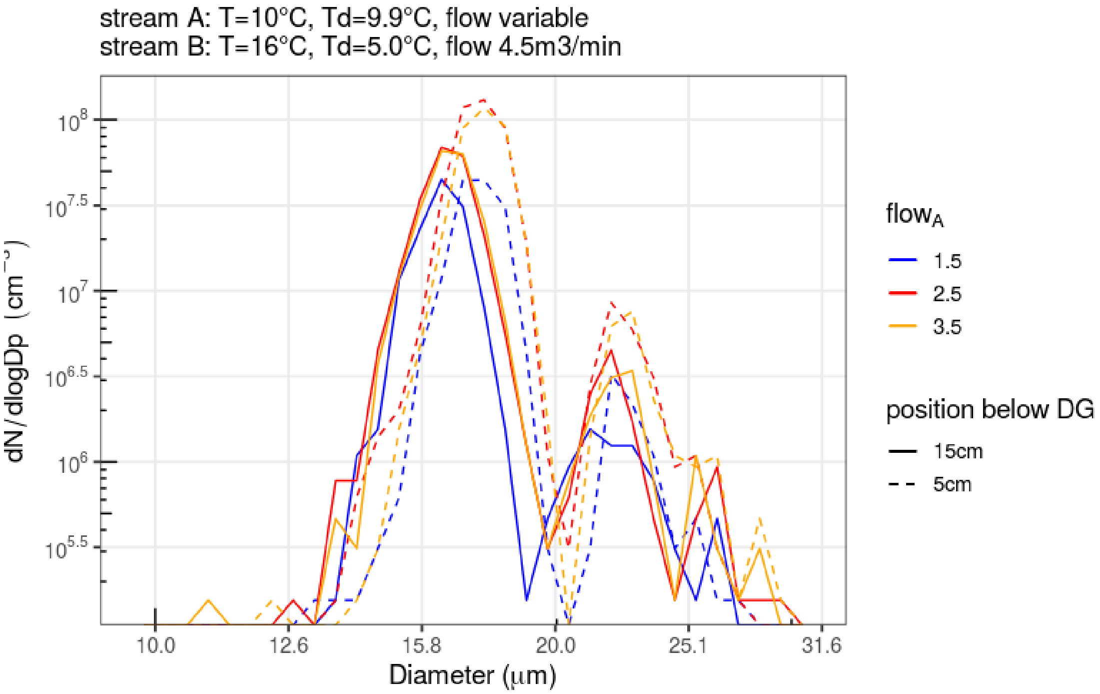
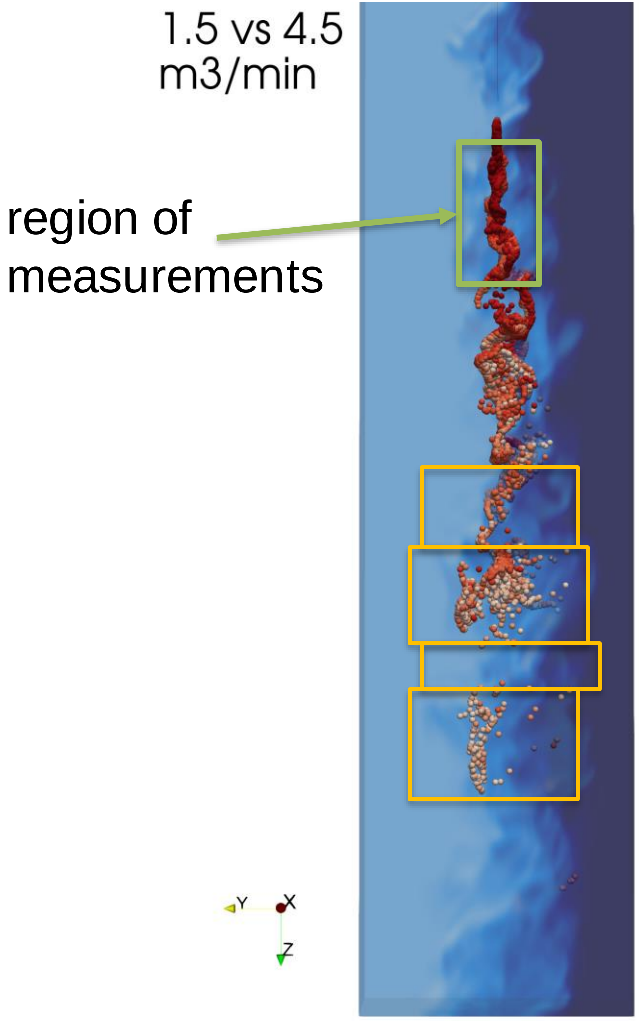
Variable shear flow - simulation



- some particles
- more particles
- no particles
- few particles

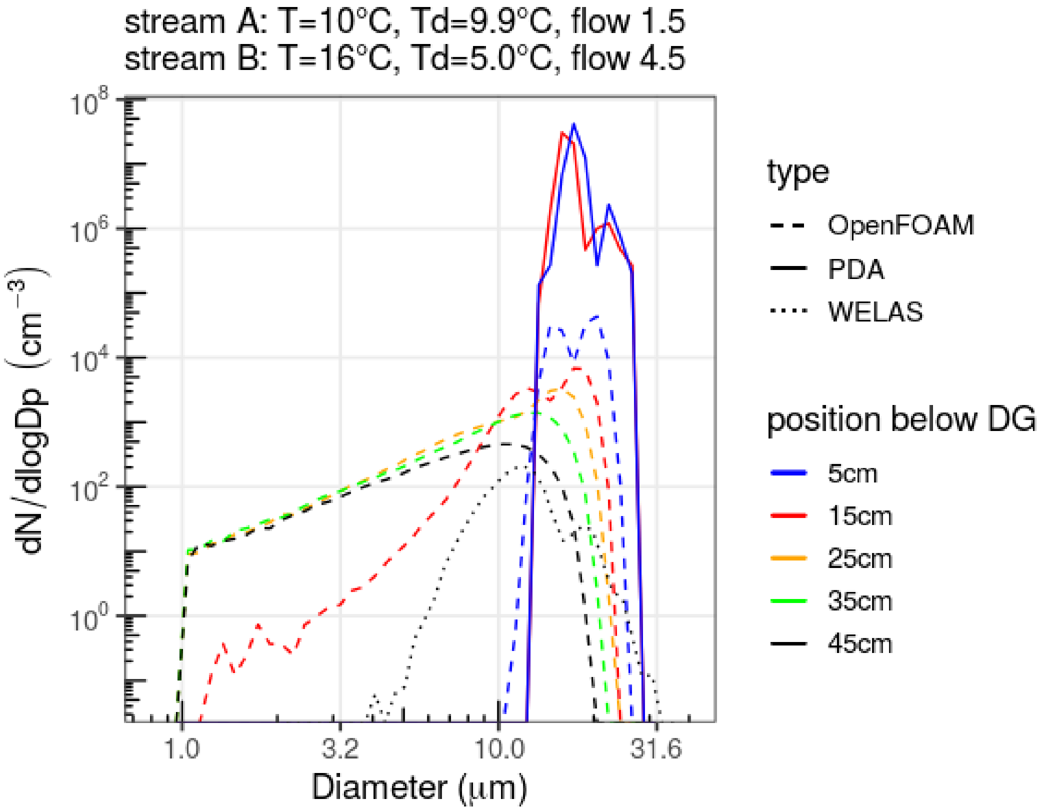
Variable shear flow





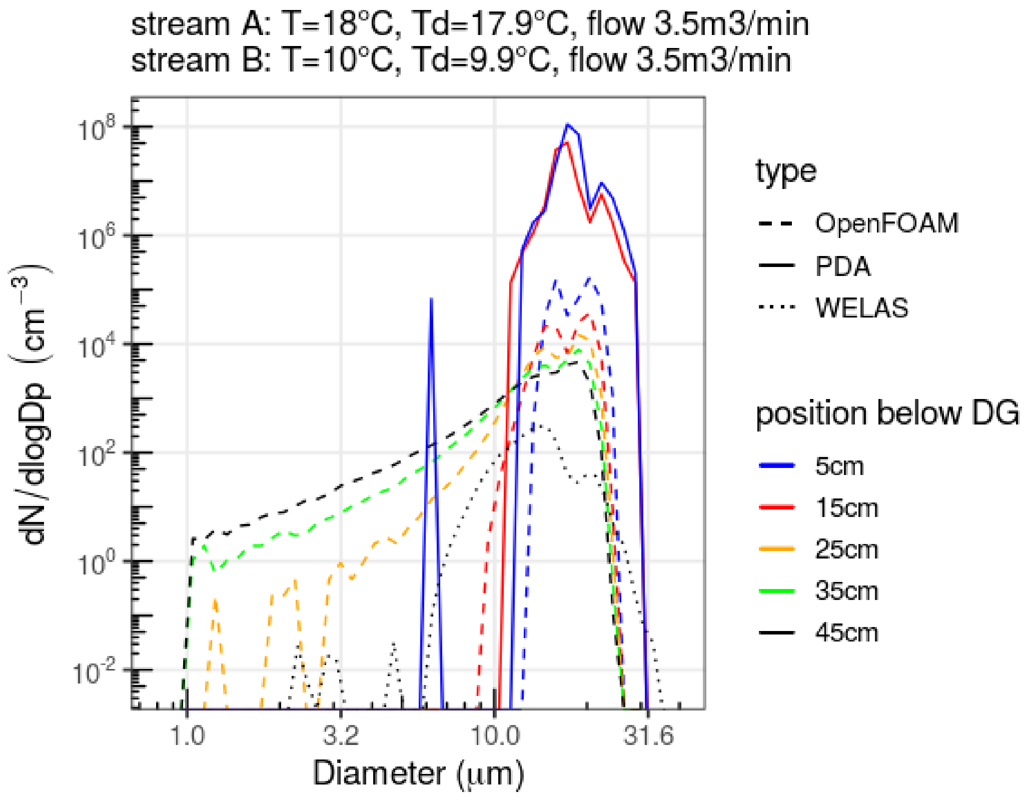
- measurements only in upper part of stream
- ➢ observations further down droplet stream needed

Comparison measurements/model – variable shear flow



- simulated peak sizes decrease more than measured

Comparison measurements/model – variable temperature



- simulated peak sizes decrease more than measured
  - not apparent in variable T cases

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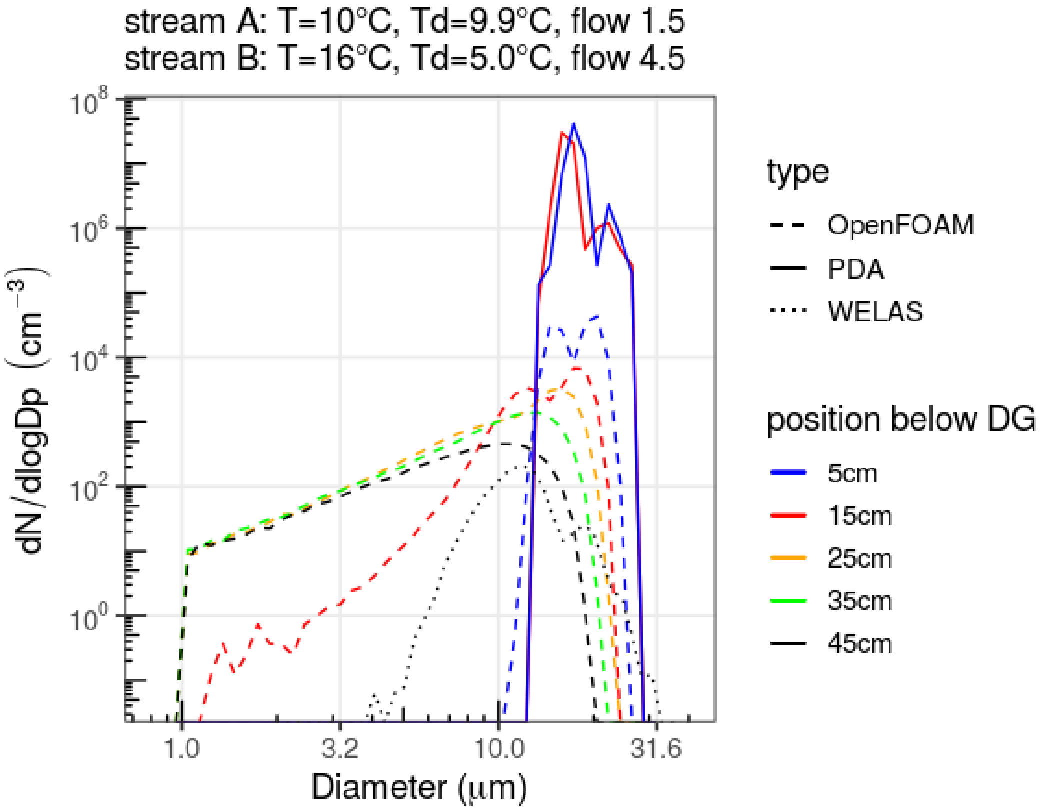
Comparison measurements/model – shear flow



- simulated peak sizes decrease more than measured
  - not apparent in variable T cases
- stronger broadening of size distributions in model

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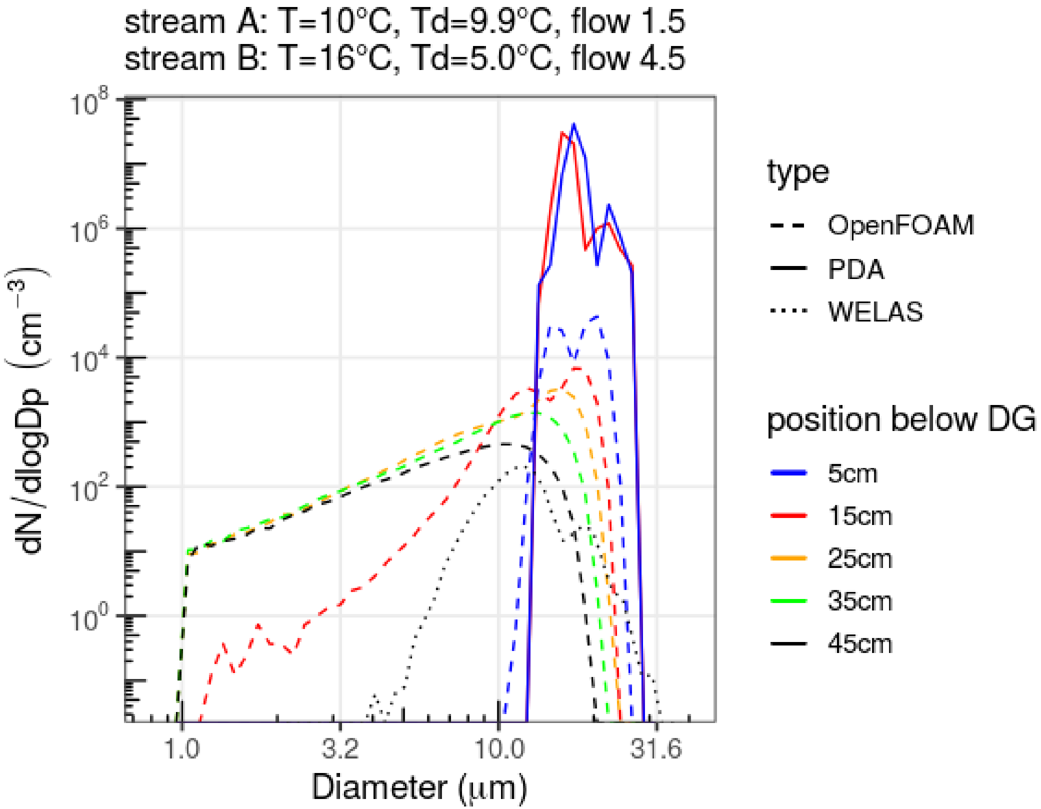
Comparison measurements/model - conclusions



- simulated peak sizes decrease more than measured in variable flow case
- stronger broadening of size distributions in model
- simulated particle mass decreases faster:
  - too small particles in model input
  - velocities in model too small – too long residence time?
  - too low particle numbers in model?

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Summary and Outlook

- first measurements in LACIS-T to study entrainment
    - changing T and RH expected behaviour
    - shear: leads to 'patchyness', more measurements needed

- droplet stream with too high number concentrations

- model helpful tool for identifying ideal measurement setup
- differences model/measurements – under investigation

Future:
- droplet spray system and active turbulence grid
    - possible to fill one stream with droplets
    - variable turbulence
- PDA and WELAS movable through full lengths of measurement section

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Thank you!

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OpenFOAM simulations have been performed using computing time at the ZIH Dresden.

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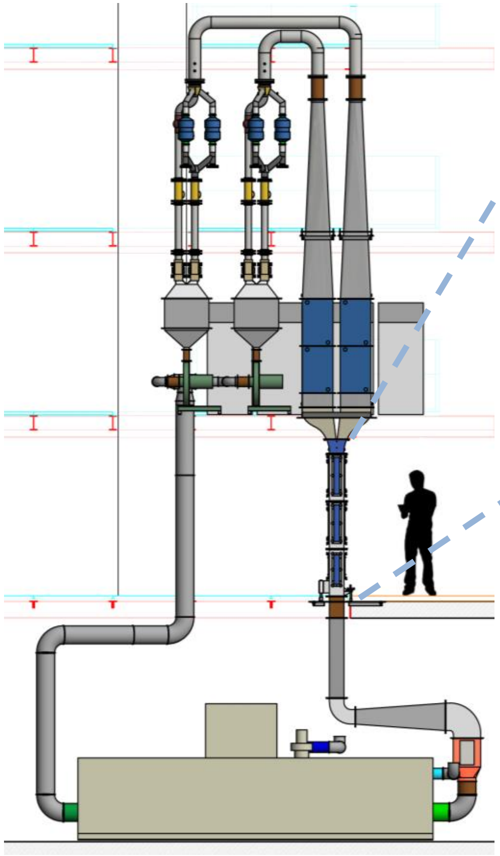
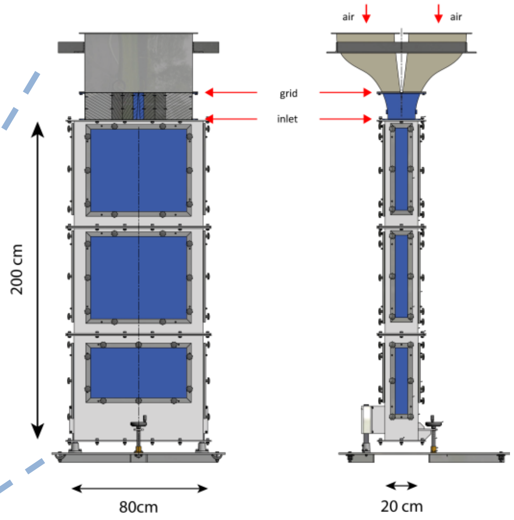
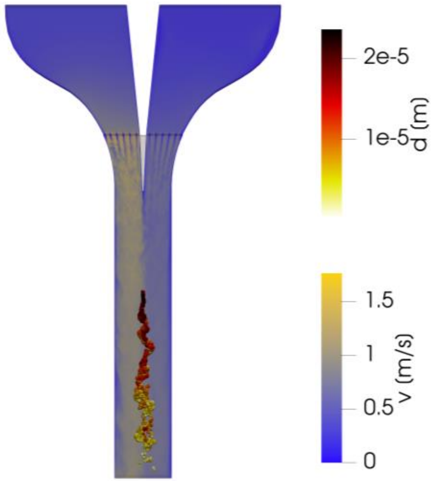
Motivation / experimental design

- entrainment (and detrainment) key small scale process, yet physically not well understood

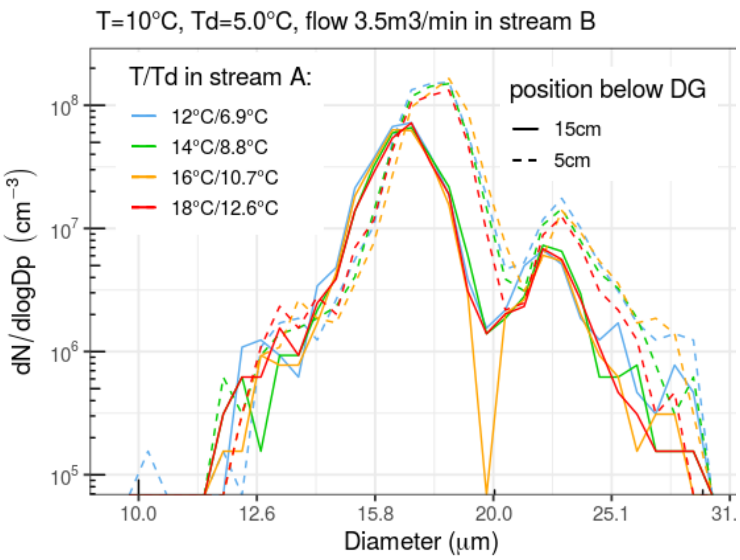
➢ understand which underlying physical parameters govern entrainment, using:
  – measurements in turbulent wind tunnel LACIS-T
  – CFD simulations with OpenFOAM

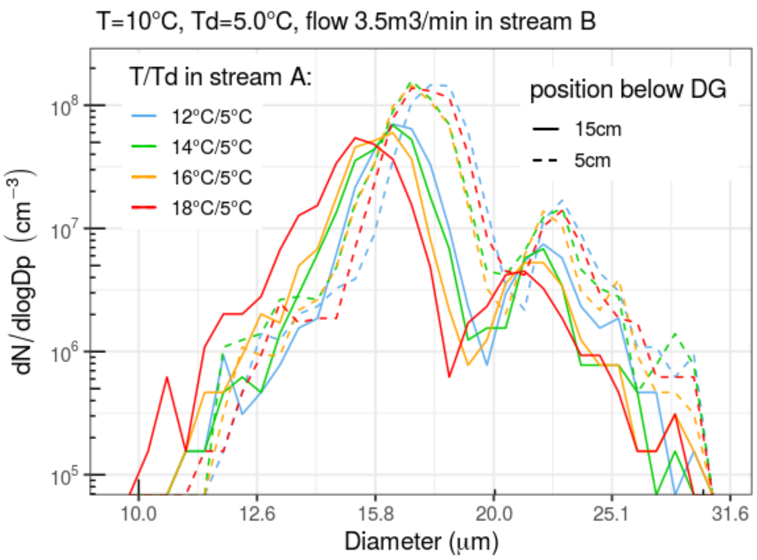






Measurements with variable T and RH





- bimodal size distributions injected by droplet generator
- system behaves as expected for changes in T and RH
  - consistency of sizes in increasing temperature @ same RH
  - decrease of sizes with decreased RH

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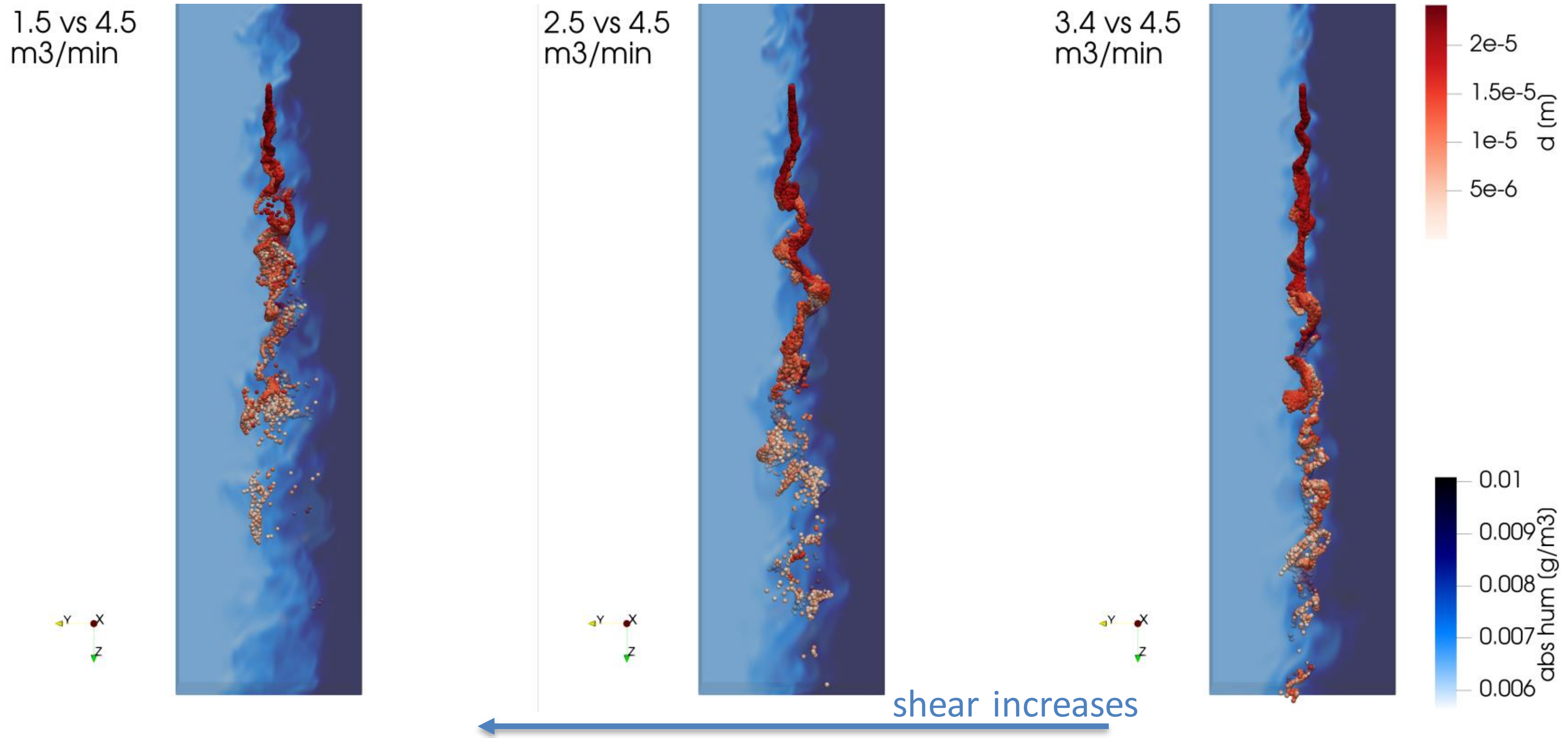
Simulation with variable shear flow



broadening and even breaking up of droplet stream with increased shear => 'patchyness'

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Significance/Impact

- combination of measurements and model helpful tool for gaining better physical understanding of entrainment process

→ improvement of model parameterisations

→ improved forecasts/predictions of clouds

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