The moist-air wind tunnel LACIS-T: A laboratory facility to study aerosol–cloud–turbulence interactions

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Leibniz Association

Workshop on laboratory facilities for cloud research
2021/09/22 – 09/25

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Introduction

- Aerosol particles interact with clouds by affecting their formation and glaciation, thereby influencing cloud microphysical and radiative properties.
- The particles’ effects depend on their physical and chemical properties as well as thermodynamics and heat/mass transfer kinetics.
- Furthermore, clouds are turbulent, and therefore thermodynamic and compositional variables, such as water vapor or trace gas concentration fluctuate in space and time.
- Indeed, the coupling between turbulence and cloud-microphysical processes is recognized as one of the major research challenges in cloud physics.

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Introduction

- Aerosol particles interact with clouds by affecting their formation and glaciation, thereby influencing cloud microphysical and radiative properties.

In order to study interactions between turbulence and cloud microphysical processes, such as droplet and ice crystal formation, we developed the turbulent moist-air wind tunnel LACIS-T (Turbulent Leipzig Aerosol Cloud Interaction Simulator).

- Indeed, the coupling between turbulence and cloud-microphysical processes is recognized as one of the major research challenges in cloud physics.

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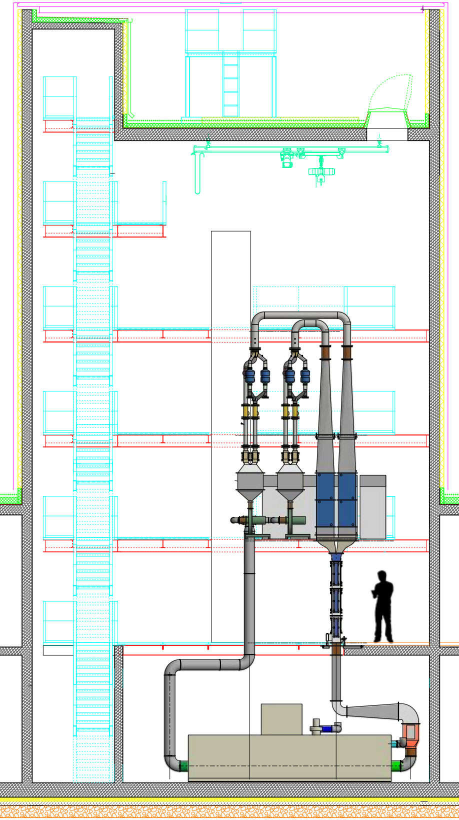
Turbulent Leipzig Aerosol Cloud Interaction Simulator (LACIS-T)



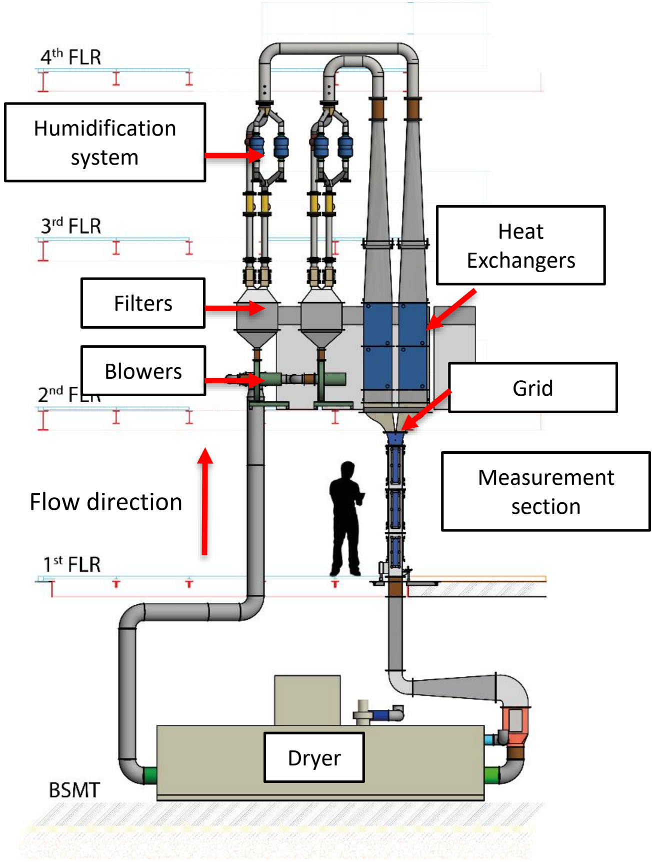
Humidification system

Blower, filter, Heat exchanger

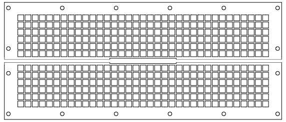
Measurement section

Niedermeier et al. [2020]

Turbulent Leipzig Aerosol Cloud Interaction Simulator (LACIS-T)



- Closed-loop moist-air wind tunnel
- Focus on aerosol-cloud-turbulence interaction
- Two particle-free air-flows, each with up to 6000 L/min
  → Velocity: up to 2.0 m/s
  → Temperature and dew-point: -40°C … 25°C
- Passive grids for defined turbulence



- Supersaturation through isobaric mixing
- Injection of well defined, size selected particles into the mixing zone
- Focus on short time (few seconds) and small spatial scales
- Large Eddy Simulations for experimental design and to interpret the results

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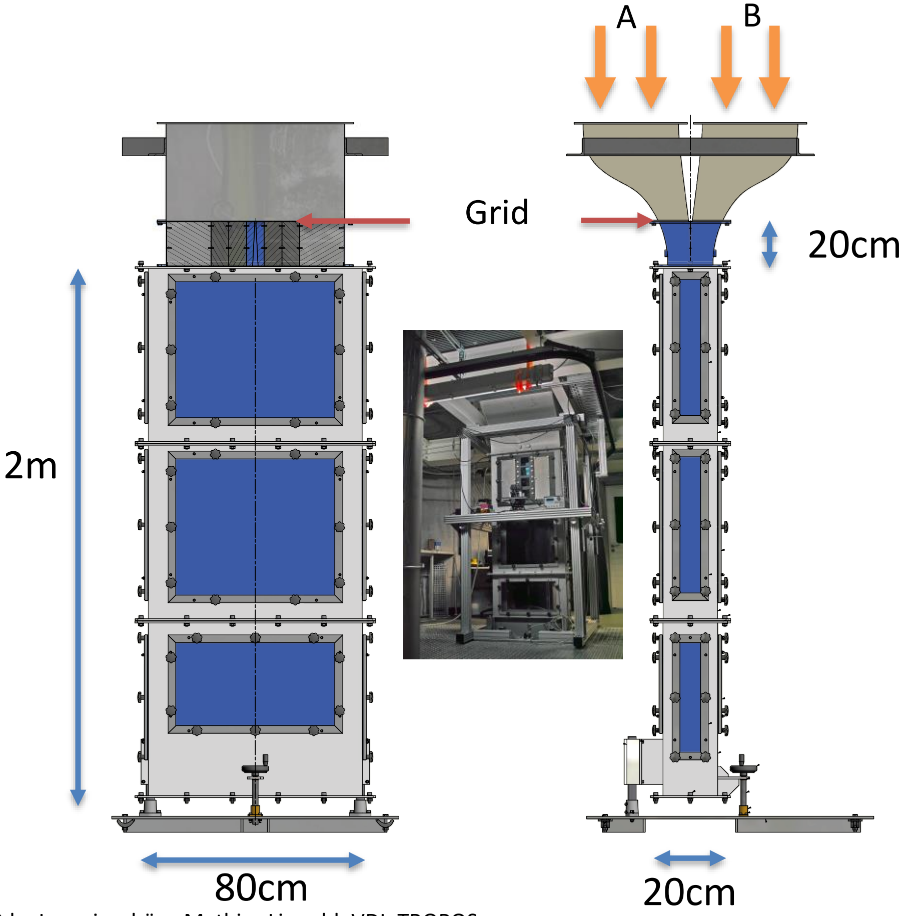
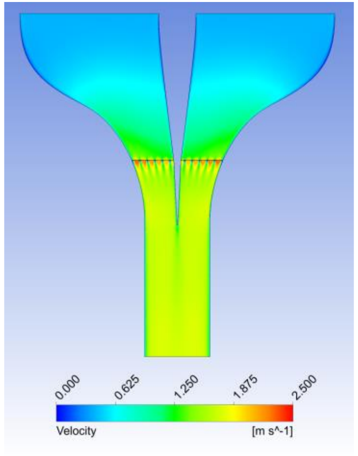
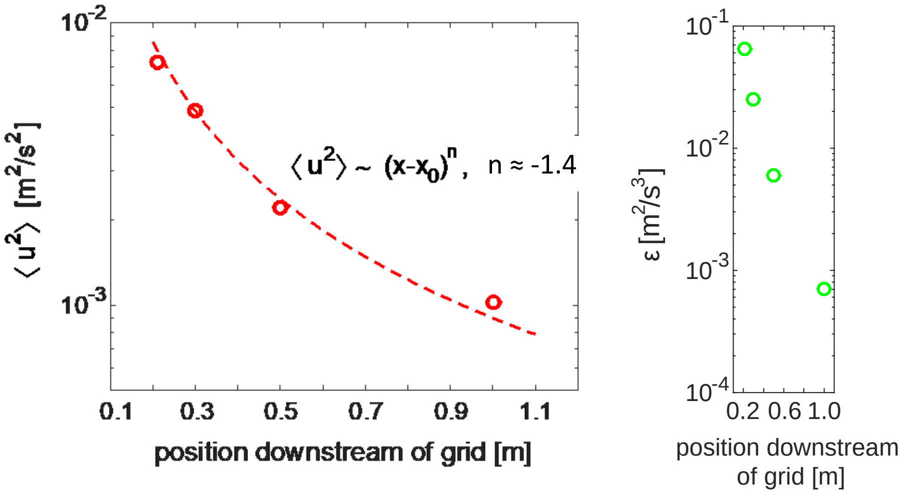
Inlet and measurement section of LACIS-T







Niedermeier et al. [2020]

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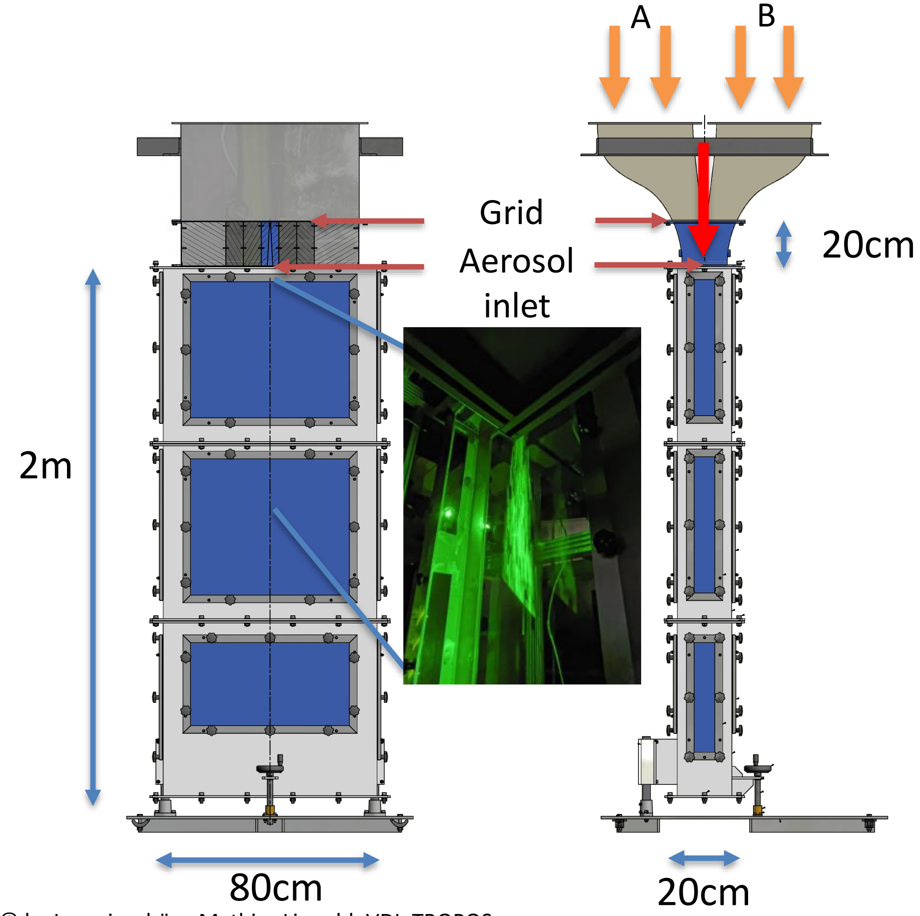

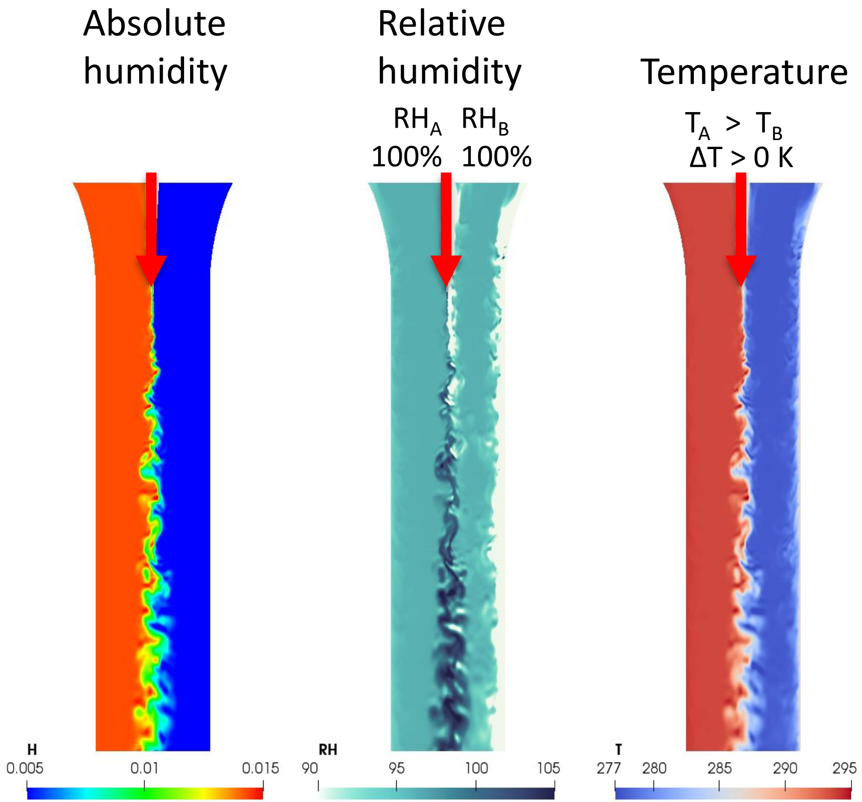

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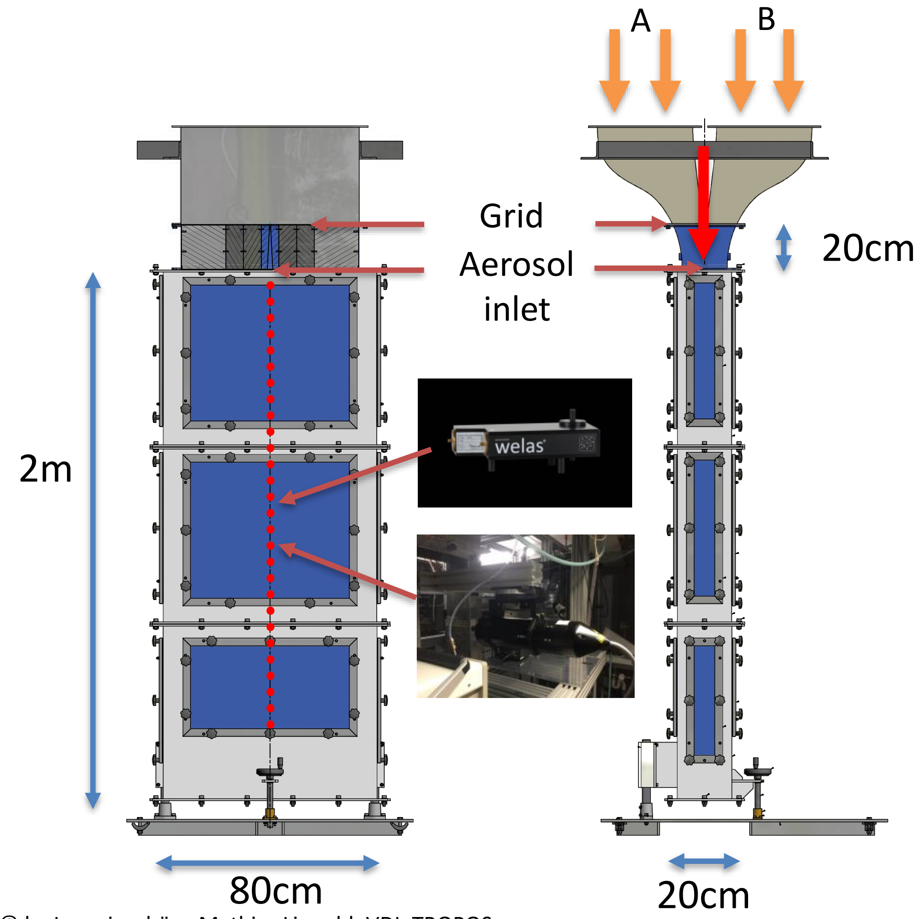


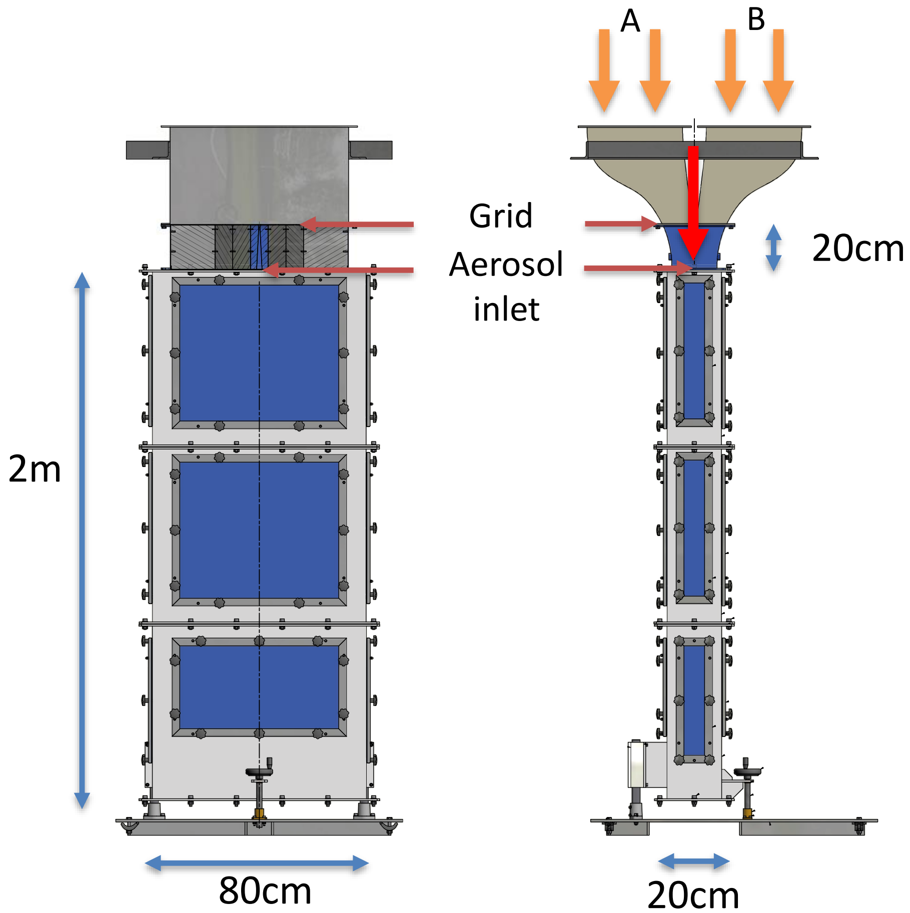
Aerosol particles:

- Size-selected, quasi-monodisperse particles
- Different particle materials (e.g., salts, mineral dusts, biological)
- Variable number concentration

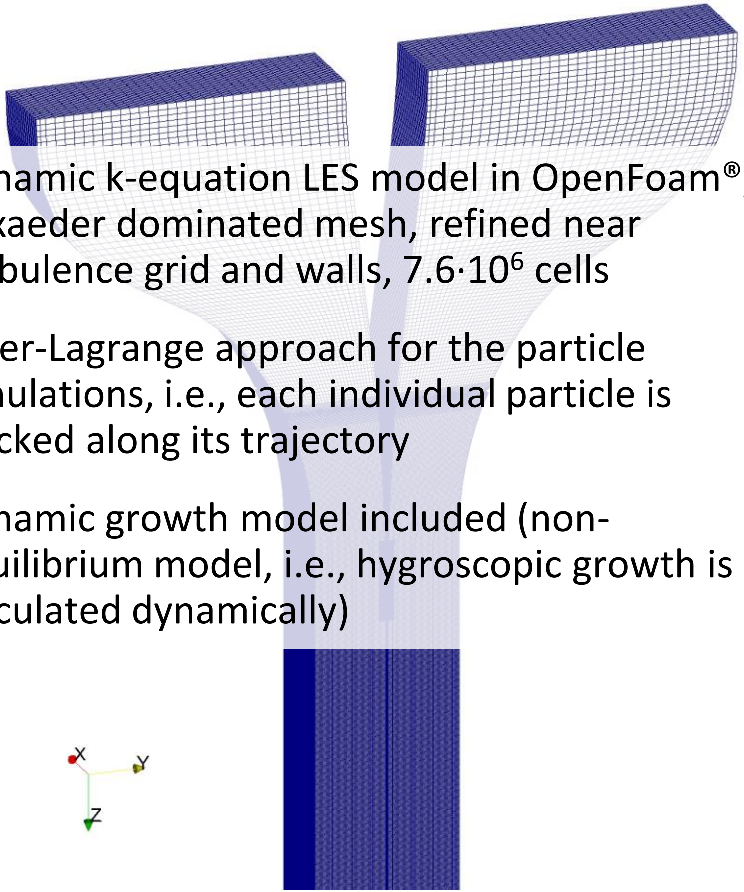
Measurements:

- Measurements of u_{mean}, u', T_{mean}, T' and RH_{mean} - currently no measurement of RH'
- Droplet size distribution measured at different locations with welas 2300 (PALAS GmbH) and Phase Doppler Anemometer (Dantec Dynamics)

Large Eddy Simulations

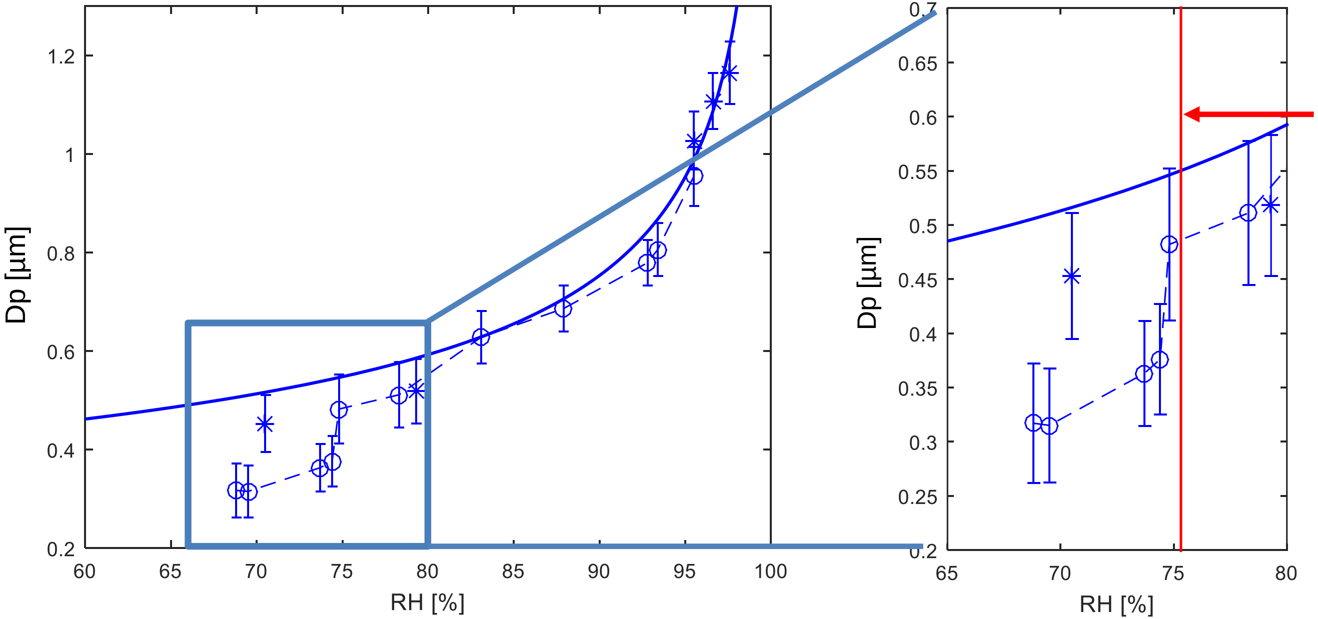


- Dynamic k-equation LES model in OpenFoam®, hexaeder dominated mesh, refined near turbulence grid and walls, $7.6 \cdot 10^6$ cells
- Euler-Lagrange approach for the particle simulations, i.e., each individual particle is tracked along its trajectory
- Dynamic growth model included (non-equilibrium model, i.e., hygroscopic growth is calculated dynamically)



Deliquescence and hygroscopic growth: Measurement results - NaCl particles, Dp_{dry} = 320nm

- Measurements on deliquescence (o) and efflorescence branch (∗)
  - ➢ Deliquescence is observed over a range of RH



Deliquescence relative humidity (DRH) for NaCl about 75.5%

Niedermeier et al. [2020]

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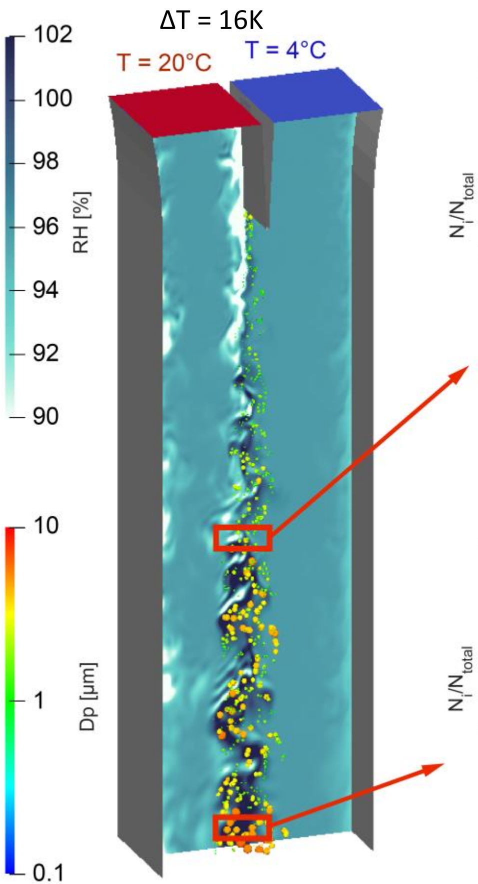
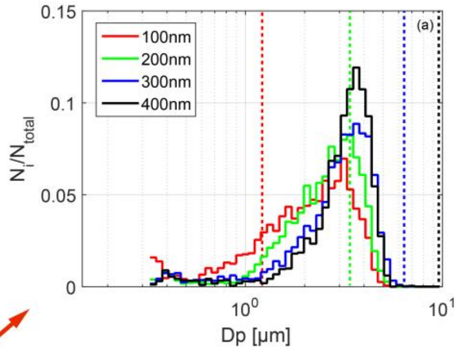
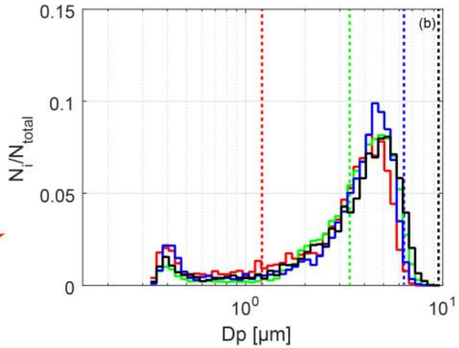
Droplet formation and growth: Measurement and simulation results - NaCl particles





RH_{mean} = 101.5%
σ_{RH} = 4%



- Droplet formation and growth on monodisperse NaCl particles (Dp_{dry} = 100 nm – 400 nm) for ΔT = 16K measured at two different positions below the aerosol inlet.
- For each Dp_{dry}, the mean droplet diameter and σ_{Dp} increase with distance (time).
  → At 80cm, all DSDs look very similar.
- Note that Dp_{crit} (100nm, 200nm, 300nm, 400nm) = 1.2µm, 3.4µm, 6.3µm, 9.7µm.

➢ Droplet growth is kinetically limited.

Niedermeier et al. [2020]

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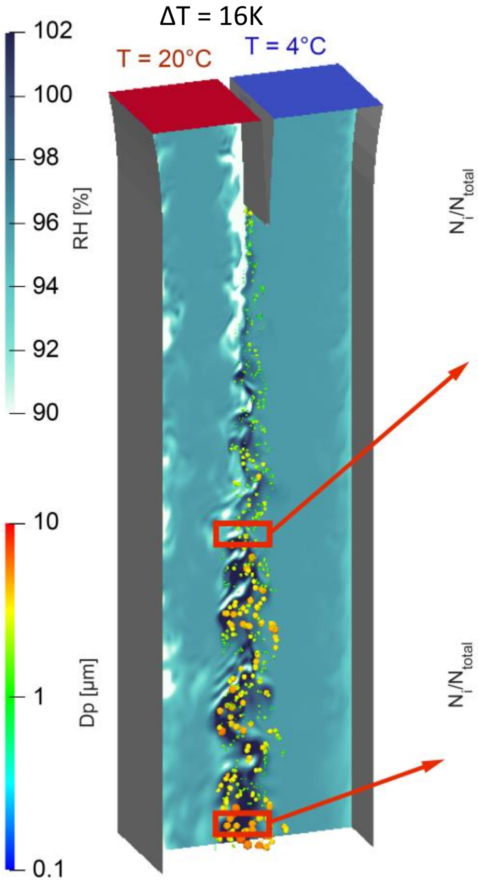
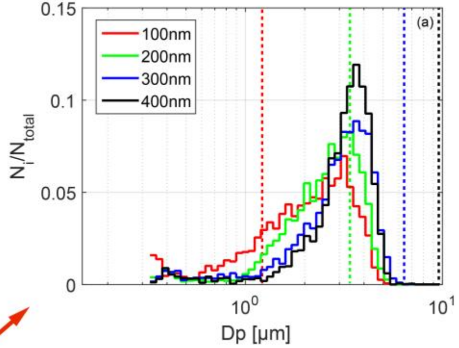
Droplet formation and growth: Measurement and simulation results - NaCl particles





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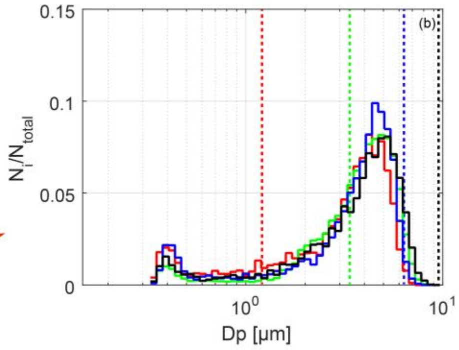

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- For each Dp_{dry}, the mean droplet diameter and σ_{Dp} increase with distance (time).
  → At 80cm, all DSDs look very similar.
- Small particles detected ?
- Negatively skewed DSDs ?

Niedermeier et al. [2020]

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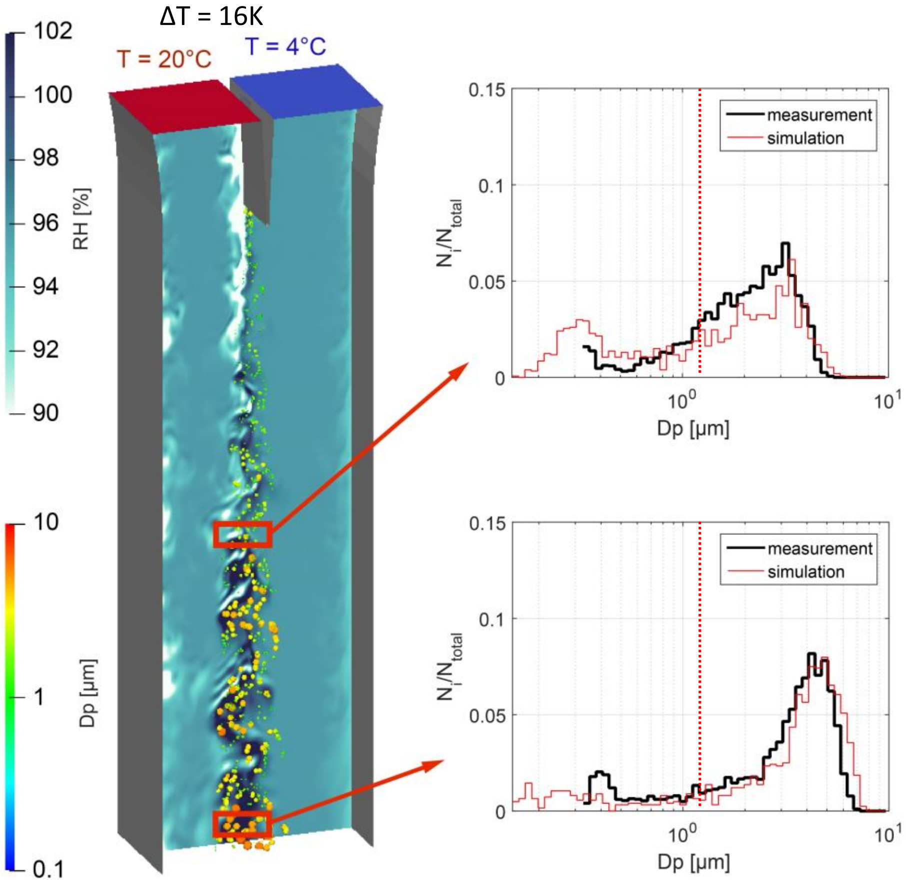
Droplet formation and growth: Measurement and simulation results - NaCl particles



Measurement + simulation of droplet formation and growth on monodisperse NaCl particles (Dp_{dry} = 100 nm)

- Small particles detected:
  - Hygroscopically grown particles

- Negatively skewed DSDs:
  - Saturation fluctuations broaden DSD to smaller Dp (evaporating droplets or less grown droplets in left tail of the DSD).

Niedermeier et al. [2020]

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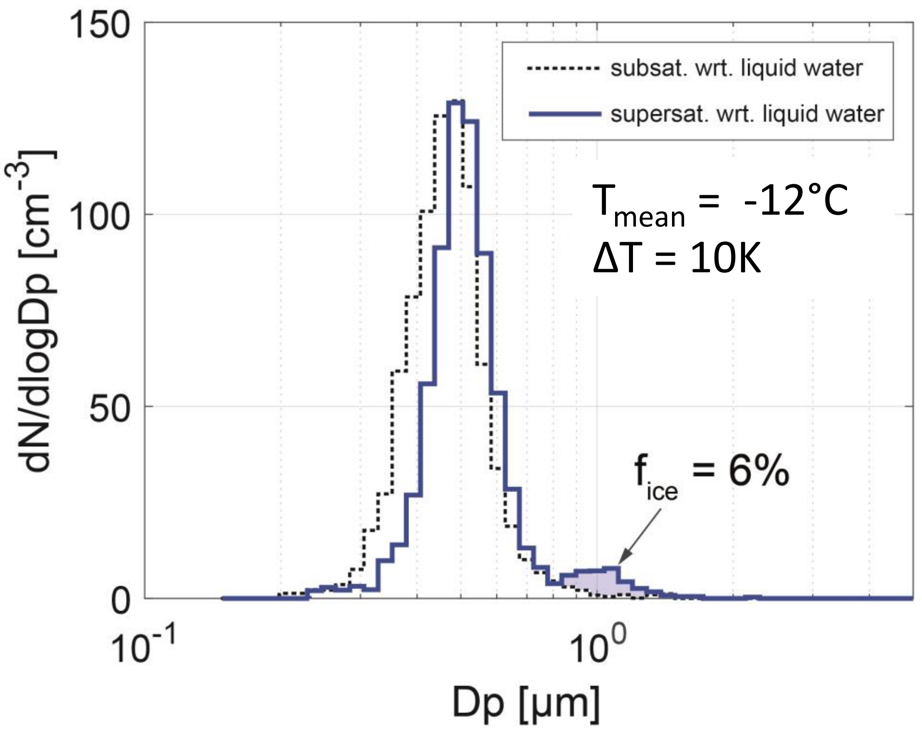
Heterogeneous droplet freezing: Proof-of-principle experiment – Snomax particles

- Immersion freezing experiment utilizing Snomax® particles with Dp_{dry} = 500nm.
- T_A = -7°C and T_B = -17°C, leading to a temperature difference ΔT = 10K and T_{mean} = -12°C.
- Size distributions were determined for sub-saturated (1) and supersaturated (2) conditions wrt. liquid water.
- A bimodal shape in case (2) is observed which is indicative for formed ice crystals.
- The determined f_{ice} = 6% is in line with observations by e.g. Hartmann et al. [2013].



➢ LACIS-T can be used for investigating immersion freezing processes.

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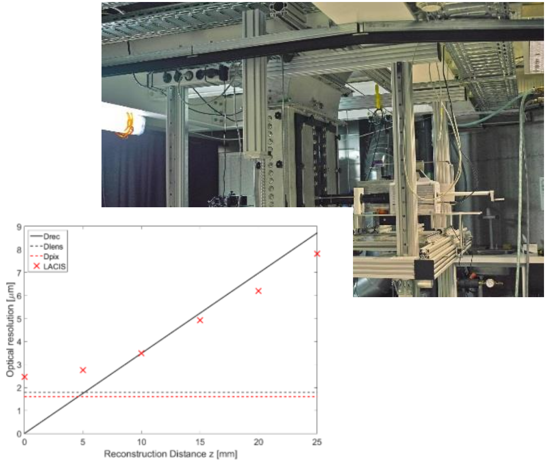
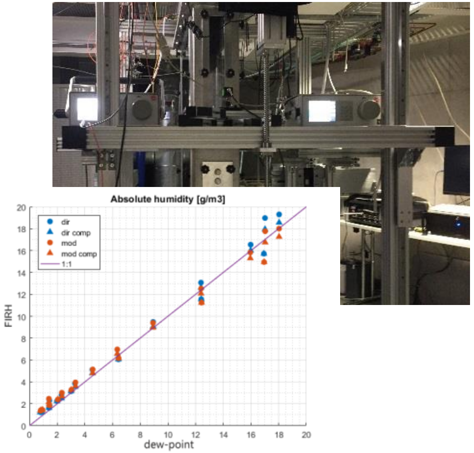
Collaborations and Transnational Access (TNA) to LACIS-T

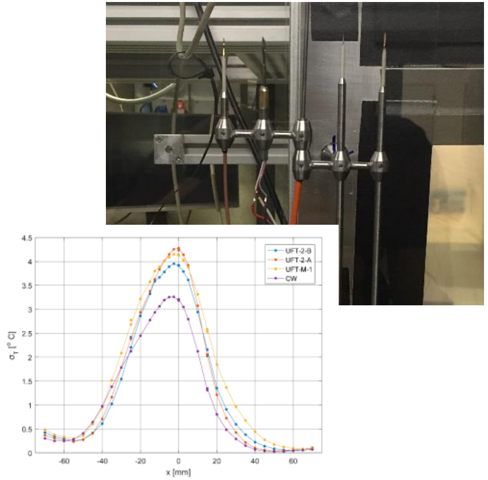
- Exploring the limits of the Michigan Tech University (MTU) holographic droplet detection system HoloPi
  N. Desai, R. A. Shaw – Michigan Tech (2017, 2018)



- Exploring performance of the Fast Infrared Hygrometer across the range of environmental conditions
  R. Grosz, T. Stacewicz – University of Warsaw (2019)



- Performance of the UltraFast Thermometer 2.0 under turbulent cloudy conditions
  J. Nowak, S. Malinowski – University of Warsaw (2019)



Summary

- LACIS-T is suitable for studying the influences of turbulent temperature and water vapor fluctuations on cloud microphysical processes.

- We observe an influence of turbulence on particle deliquescence.

- Droplet formation and growth - we found that:
  - Turbulent saturation fluctuations lead to a broadening of the droplet size distribution,
  - Kinetic effects and/or limitations may inhibit droplet activation in turbulent environments.

- First proof-of-principle experiments show that LACIS-T can be used for investigating immersion freezing processes which will be an important research focus for the near future.

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Acknowledgement and access to LACIS-T

EUROCHAMP 2020

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ATMO ACCESS
Access to Atmospheric Research Facilities

LACIS-T is part of ATMO-ACCESS, an European Union's Horizon 2020 research and innovation programme (www.atmo-access.eu). **Within ATMO-ACCESS, LACIS-T will offer TNA to researchers. The call for TNA will open in October 2021 and will be open for 10 - 12 weeks.**

Please contact me (dennis.niedermeier@tropos.de) for details

ACTRiS
Exploring the Atmosphere

LACIS-T is listed as National Facility within ACTRIS - the Aerosol, Clouds and Trace Gases Research Infrastructure - offering access to LACIS-T for researches from the academia as well as from the private sector.

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