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Competitive activation of mixed aerosol systems: cloud chamber experiments and modelling studies

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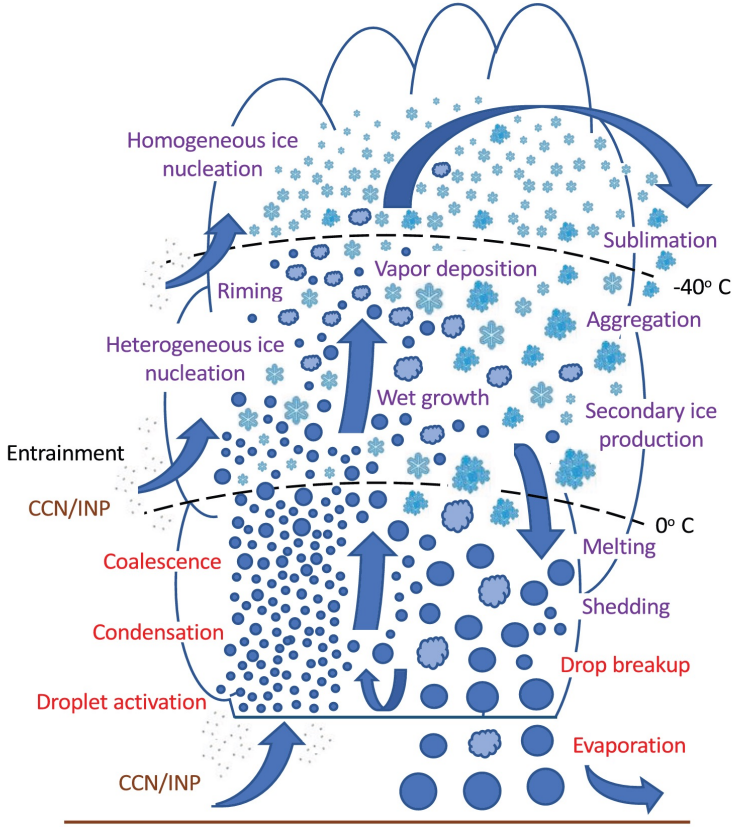
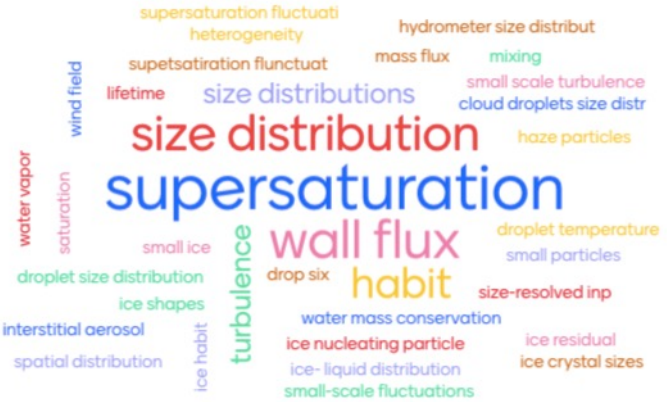
11th ICMW 2024, Yonsei University, Seoul, South Korea

10:30 – 10:45, 11.07.2024

Why cloud process modelling + laboratory is important!



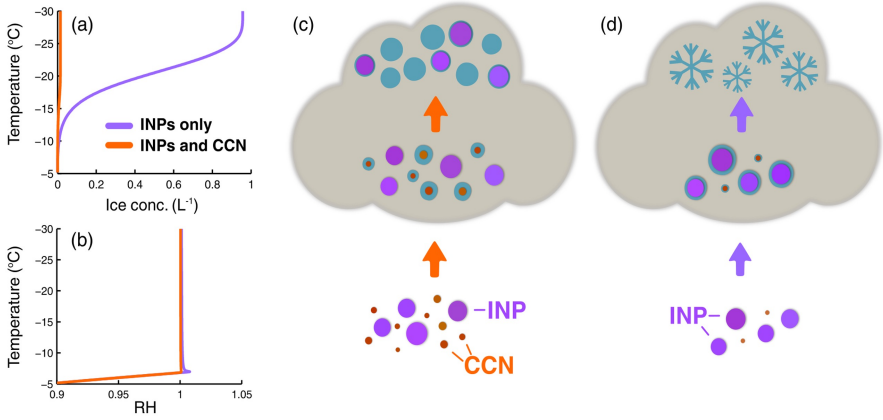
Morrison et al., 2020

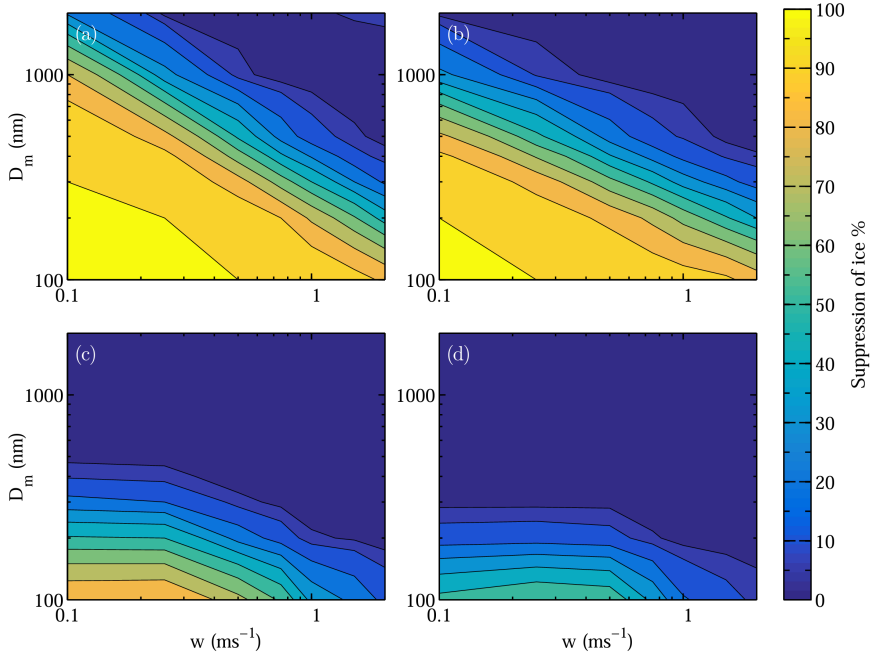


11th ICMW 2024, Korea

- Complex processes in the atmosphere
- Difficulty in varying all the parameters in laboratory experiments
- Our understanding is still limited —and the uncertainly is still high (IPCC, 2021)

The key research question to address…





- Competition in aerosols →droplets activation
- Suppression of ice due to competition effect!?
- What happens with external mixtures of aerosol particles?

Simpson et al. 2018, ACP

The birth of ‘iSKYLAB’ project

- **i**mproved **S**cientific **K**nowledge of Clouds, Ice Cr**Y**stals, and Aerosols through **LAB**oratory Access of the New Dynamic Cloud Chamber (**iSKYLAB**)
- Combination of **Laboratory Experiments** & **Modelling**
- **17** Scientists
- **8** Institutions | **4** Continents
- **Paul Connolly**, University of Manchester, UK [**PI**]
- **Funding:** EU Transnational Access (TNA) + Helmholtz Association via KIT

ATMO ACCESS
Access to Atmospheric Research Facilities

HELMHOLTZ ASSOCIATION

Scientific objectives of the 'iSKYLAB' project

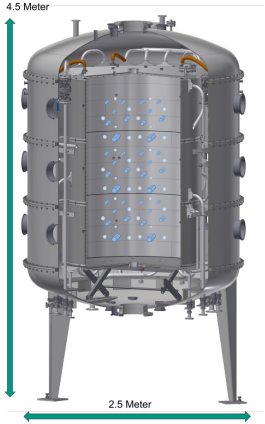
iSKYLAB is designed to perform quantitative experiments to understand the competition effects in cloud activation by particles.

Specific Objectives

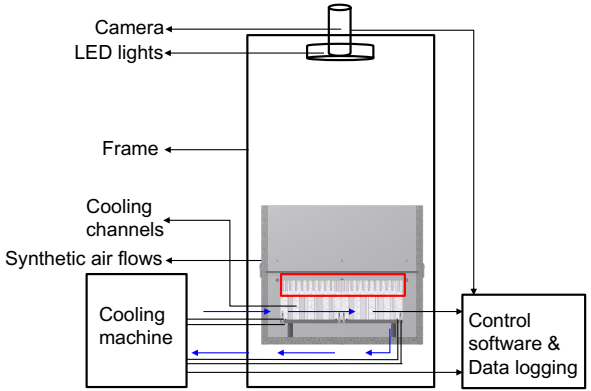
- To perform experiments into the activation of droplets on **single component** aerosol and **external aerosol mixtures** with the new AIDAd chamber.
- To investigate the **activation of both INPs and CCN** in order to understand whether the **competition effects** proposed by Simpson et al. *(2018) holds.*
- To test results from #1 & #2 **quantitatively** against the **ACPIM model**, the **Lagrangian-particle-based DNS model**, and the **PartMC model** whether they are able to capture competition effects due to 'size effects'.

Simpson et al. 2018, ACP

iSKYLAB study tools – Laboratory & Modelling



AIDAd



INSEKT

Laboratory

ACPIM Model

University of Manchester

PartMC Model

University of Illinois

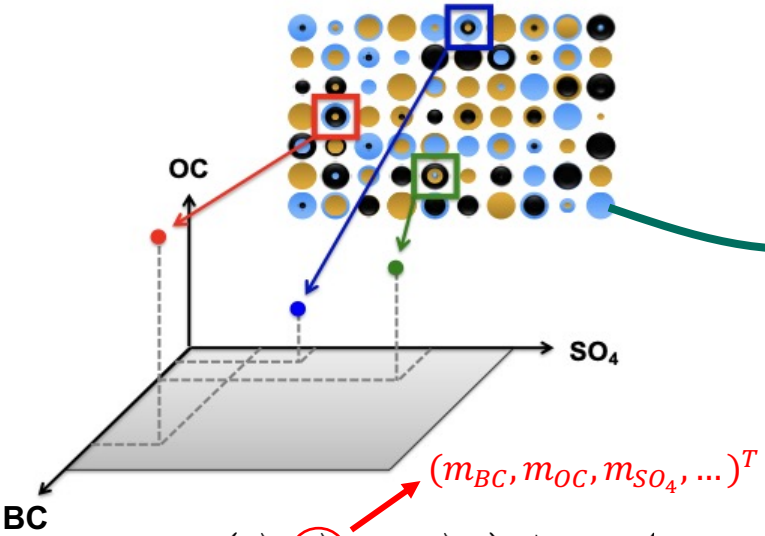
Lagrangian-particle-based DNS Model

NCAR

Modelling

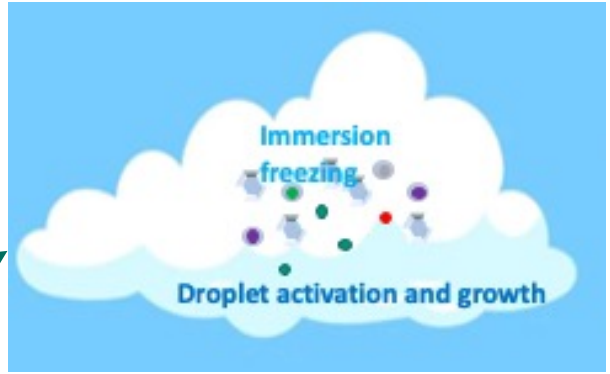
Particle-resolved Monte Carlo model (PartMC)

(Riemer et al., 2009; DeVille et al., 2011; Ching et al., 2012; Curtis et al., 2016; DeVille et al., 2019; Yao et al., 2022, Curtis et al., 2024)



$$(m_{BC}, m_{OC}, m_{SO_4}, \ldots)^T$$

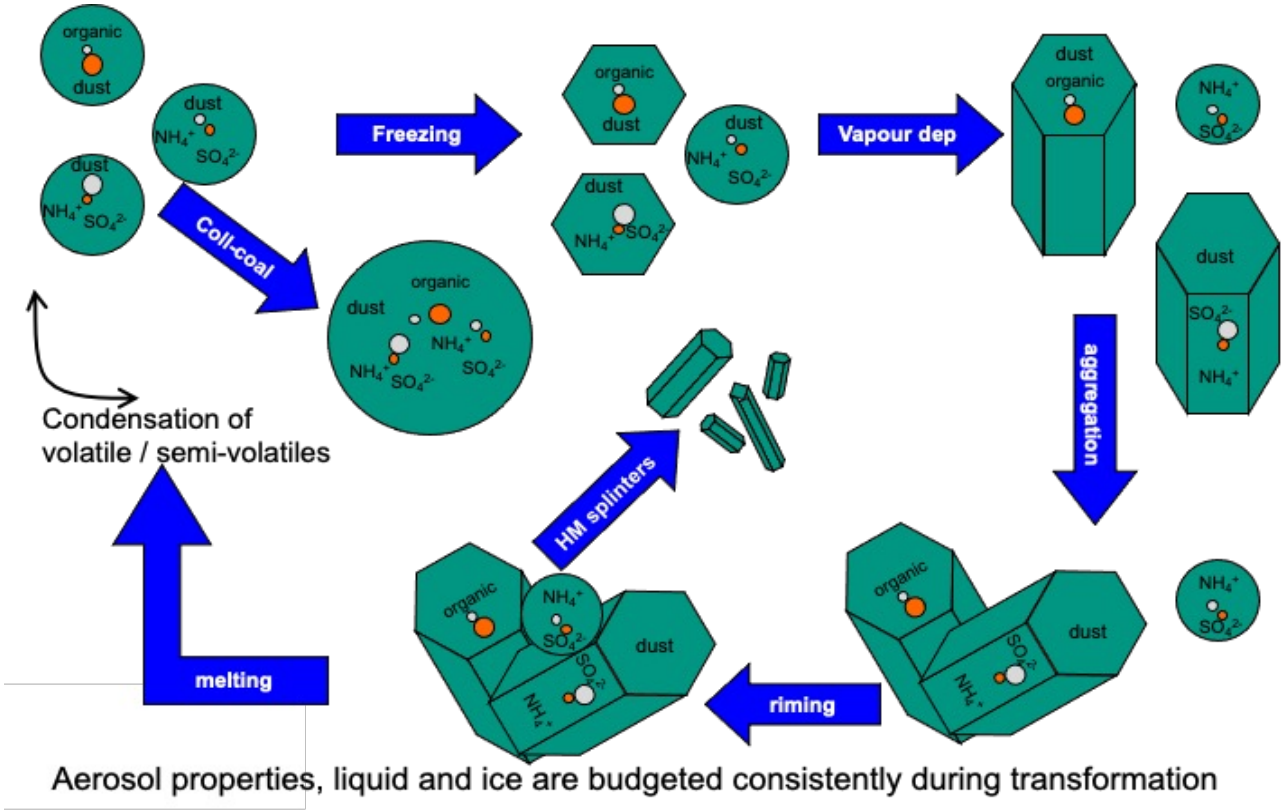
$$\Pi = \left(\vec{v}_1, \vec{v}_2, \ldots, \vec{v}_{N_p}\right) \vec{v}_i \in \mathbb{R}^A$$



- Discrete computational particles to represent aerosol particles, cloud droplets, and ice crystals.
- Coupled to chemistry code MOSAIC (Zaveri et al., 2008).
- Detailed representation of aerosol mixing state evolution and its impacts on clouds.

PartMC

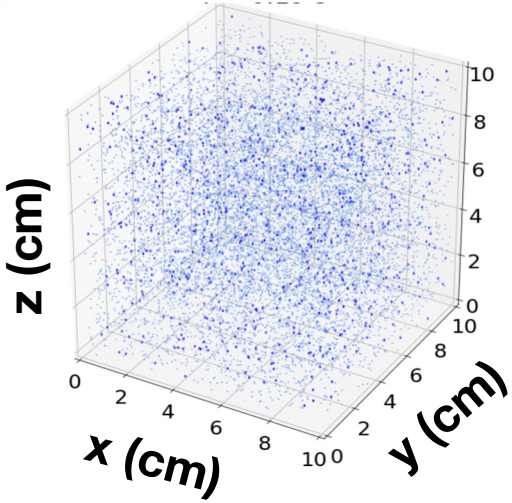
Bin Microphysics Model (ACPIM Model)

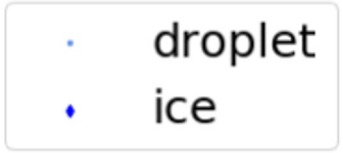


The modelling will be driven by the **temperature** and **pressure** measurements and compared with chamber to understand the competition effects.

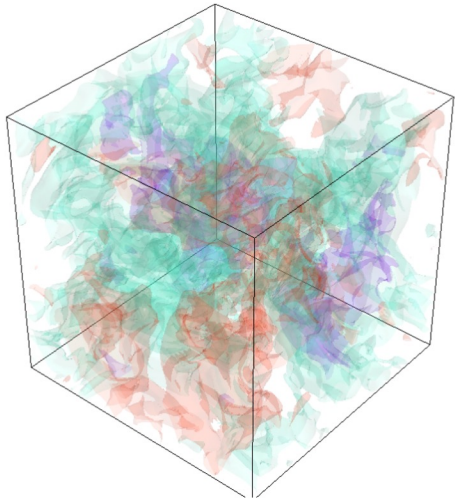
Conolly et al., 2009; Topping et al., 2013; Simpson et al., 2018; Fowler et al., 2020; James et al., 2023

Lagrangian-particle-based (Mixed-Phase) DNS Model





Interactions of microphysics, thermodynamics, and dynamics



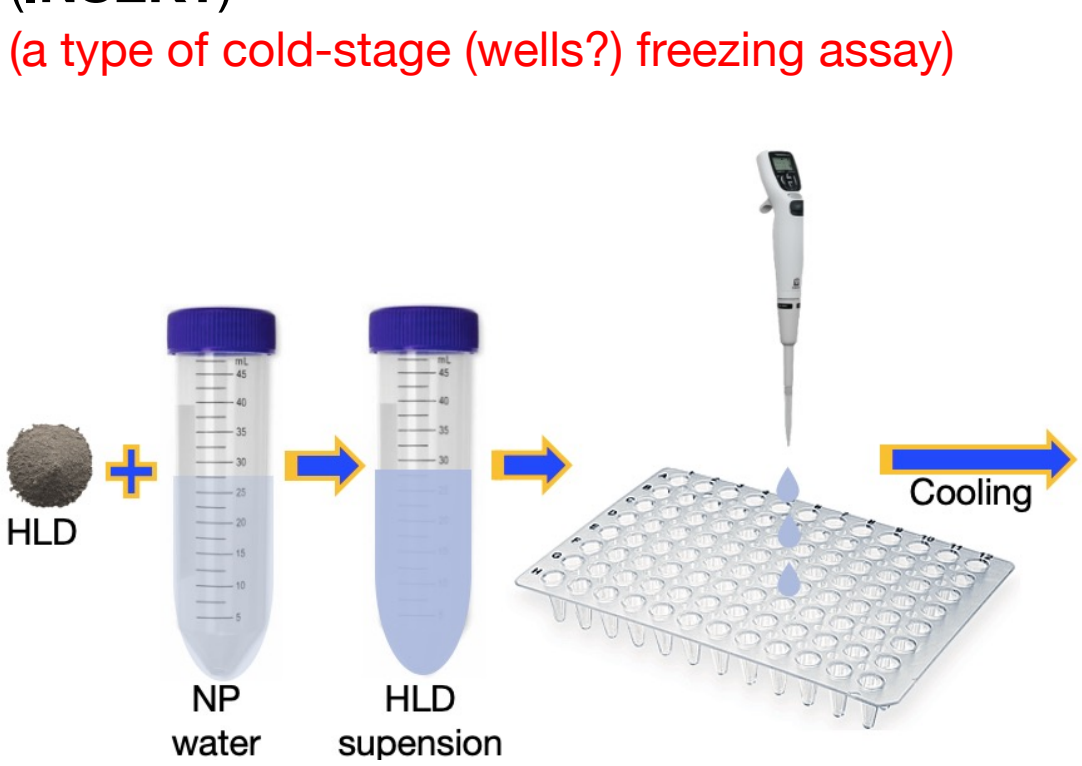
- Lagrangian particles
- Warm & Mixed-phase cloud microphysics
  - Aerosol activation
  - Droplets and ice crystal growth
  - Particle-flow interaction

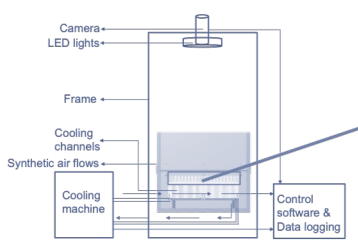
Turbulent mixing of the dynamics (velocity) and thermodynamics (temperature and water vapor)

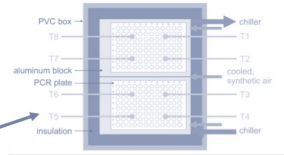
Experimental set-up of INSEKT

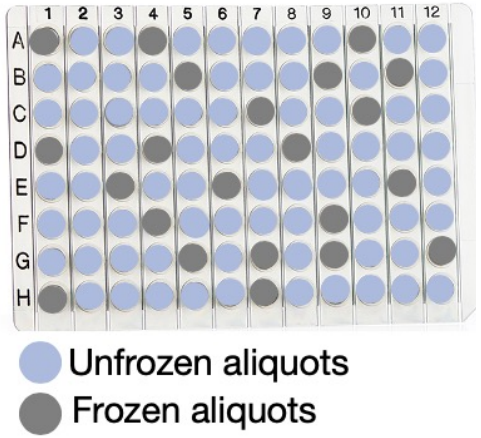
Ice **N**ucleation **S**p**E**ctrometer of the **K**arlsruhe Institute of **T**echnology (**INSEKT**)

(a type of cold-stage (wells?) freezing assay)

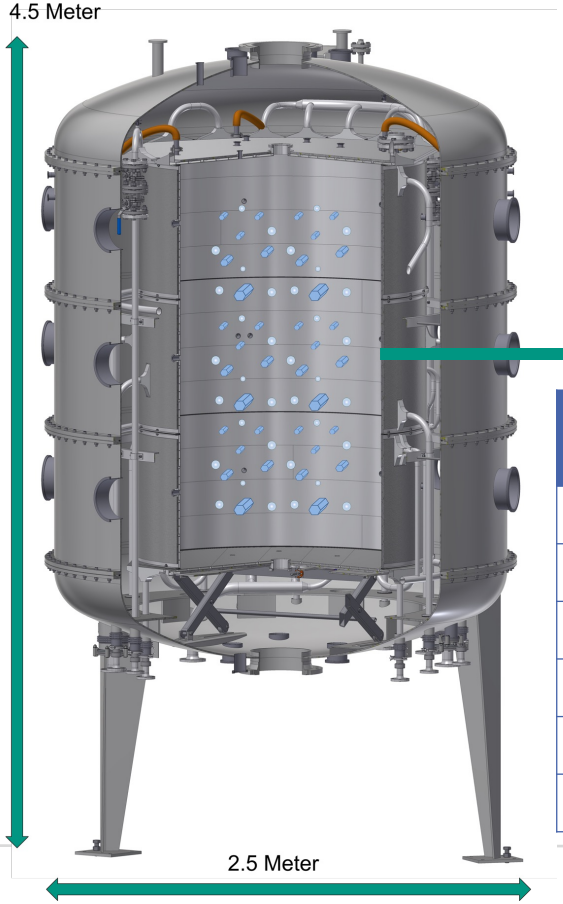








The AIDAd aerosol & cloud simulation chamber



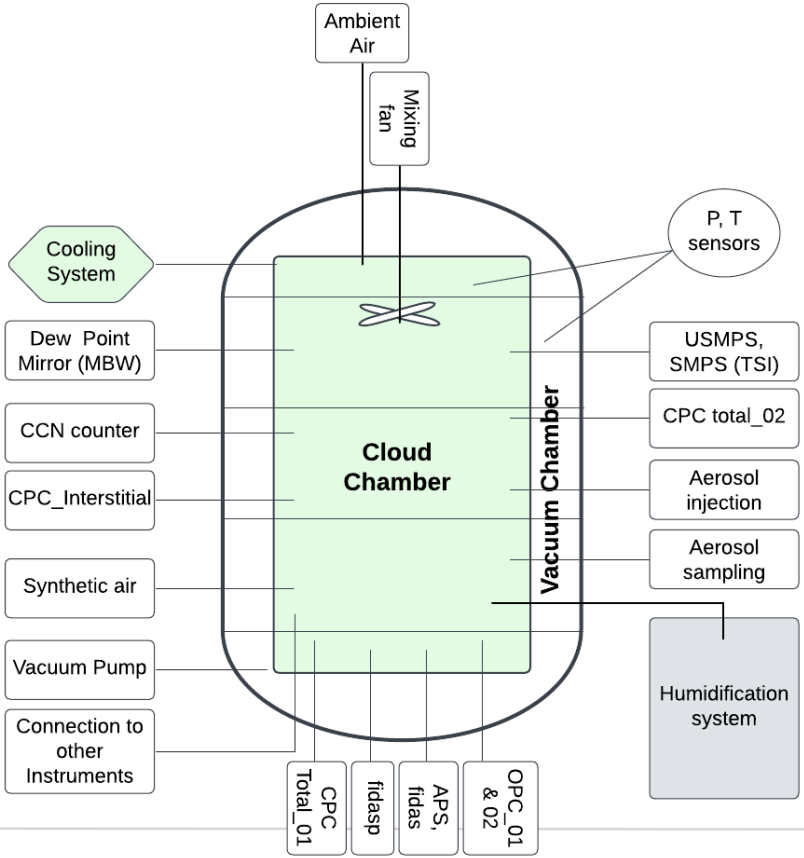
Basic Parameters	Cloud Chamber	Vacuum Chamber
Height	2.15 m	3.50 m
Diameter	1.50 m	2.50 m
Volume	3.8 m^3	15.8 m^3
Temperature range	+30°C to -55°C	
Cooling medium	Syltherm xlt	
Minimum pressure	< 1 hPa	

The AIDAd aerosol & cloud simulation chamber

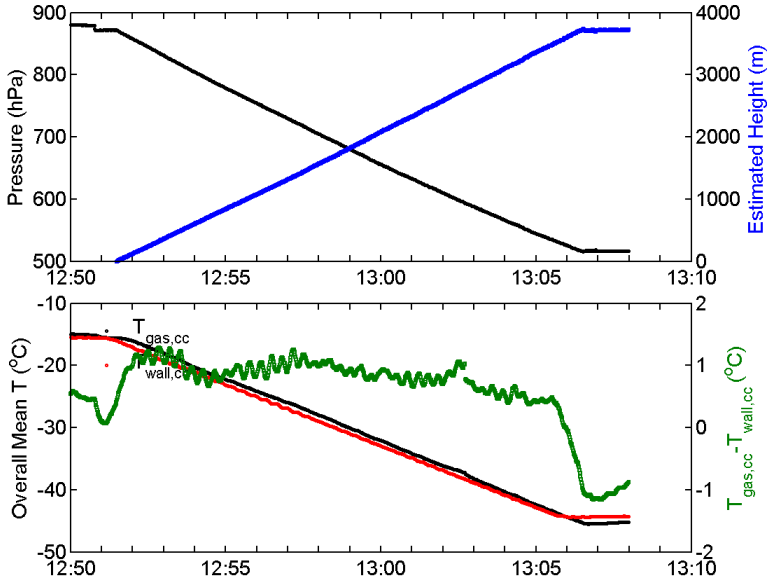
AIDAd = Atmospheric **I**nteractions and **D**ynamics in the **A**tmosphere (**d***ynamic*).

- It is a unique facility for cloud process studies It can simulate convective clouds with updrafts up to 15 m s^{-1}.
- Control of the dew/frost point and condensation temp: +20 to -30 °C.
- It has an innovative engineering design with wall cooling during cloud expansion experiments (+30 °C to -55 °C).
  → isothermal conditions minimise internal heat fluxes and maximise cloud life-time.
- It has 5 segments with independent temperature control.
- Each segment can be set to any temperature difference between 0 and ±10 K.
- It can be operated at constant cooling rates up to 10 K/min with isothermal conditions.

The AIDAd instrument & instrumentation

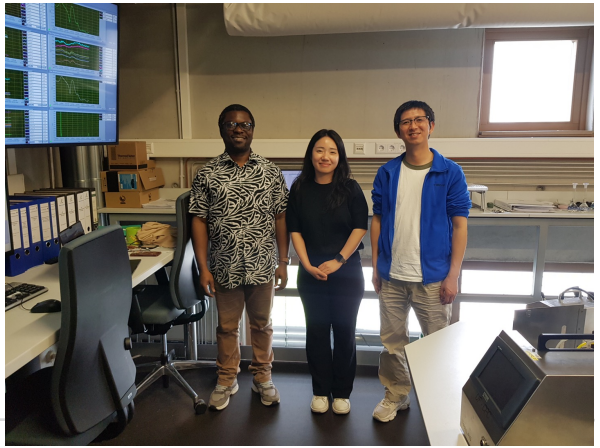


- Because of the active wall-cooling of the **AIDAd** chamber, a quasi-adiabatic expansion can be achieved.



The AIDAd instruments & instrumentation

Instrumentation at the AIDAd facility



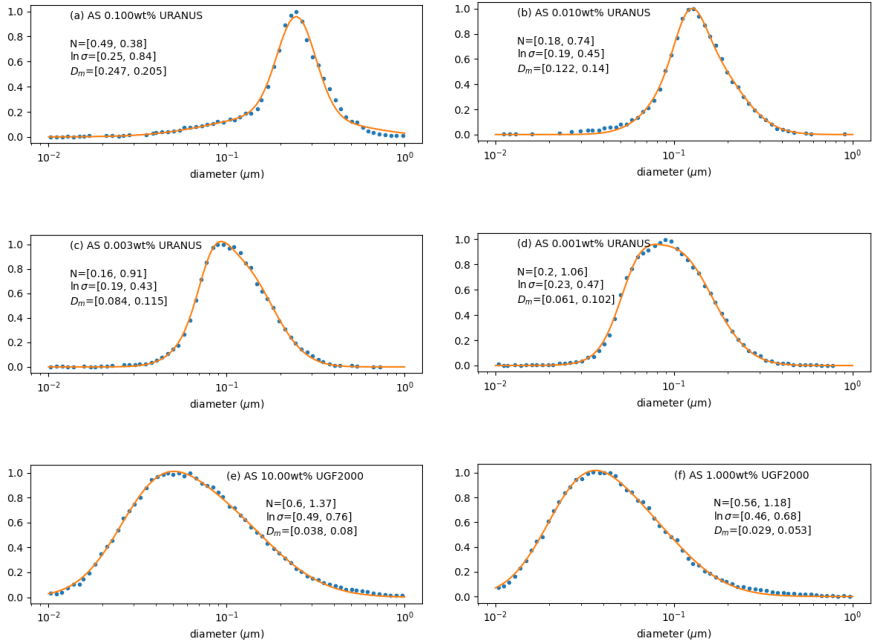
IMK-AAF

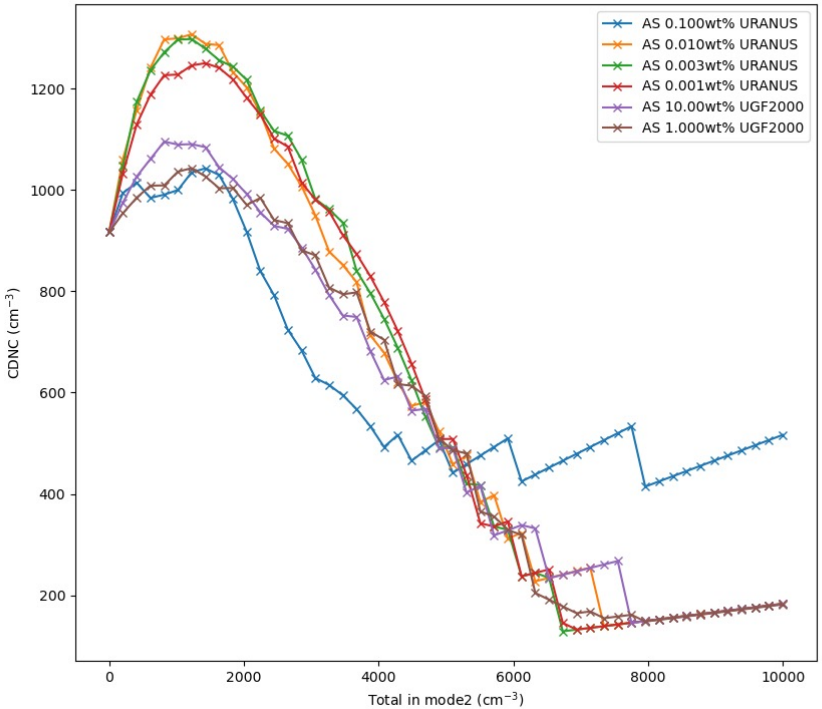
Aerosol systems and experimental plans

- ***Aerosol systems:*** *$(NH_4)_2SO_4$, NaCl, Fulvic acid, SDSA, and ATD*
- ***Aerosol generators/injection:*** *RBG, UGF 2000, & Ultrasonic nebuliser*
- ***Cooling rates:*** *0.5, 1, 2, and 4 K/min*
- ***27*** *experiments in* ***15*** *days*

Exp. No.	Aerosol Type	Target Conc. (#/cm^3)	Cooling Rate (K/min)
1	Background	0	4.0
2	AS	500	0.5
3	AS	5000	0.5
4	AS	5000	0.5
5	AS	3000	0.5
6	AS+NaCl	3000+600	0.5
7	AS+NaCl	3000+2000	0.5
8	AS+NaCl	3000+2000	0.5
9	AS+NaCl	3000+4000	0.5
10	AS+NaCl	3000+4000	0.5
11	AS	5000	0.5
12	NaCl	2000	0.5
13	NaCl	600	0.5
14	NaCl	2000	0.5
15	FA	3000	0.5
16	AS	3000	0.5
17	AS	3000	4.0
18	FA+NaCl	3000+600	0.5
19	FA+NaCl	3000+2000	0.5
20	SDSA01	3000	0.5
21	SDSA01	1000	0.5
22	SDSA01+NaCl	3000+2000	0.5
23	SDSA01+NaCl	3000+2000	0.5
24	SDTP02	1000	2.0
25	ATD03	1000	0.5
26	ATD03+NaCl	1000+4000	0.5
27	ATD03+NaCl	1000+10000	0.5

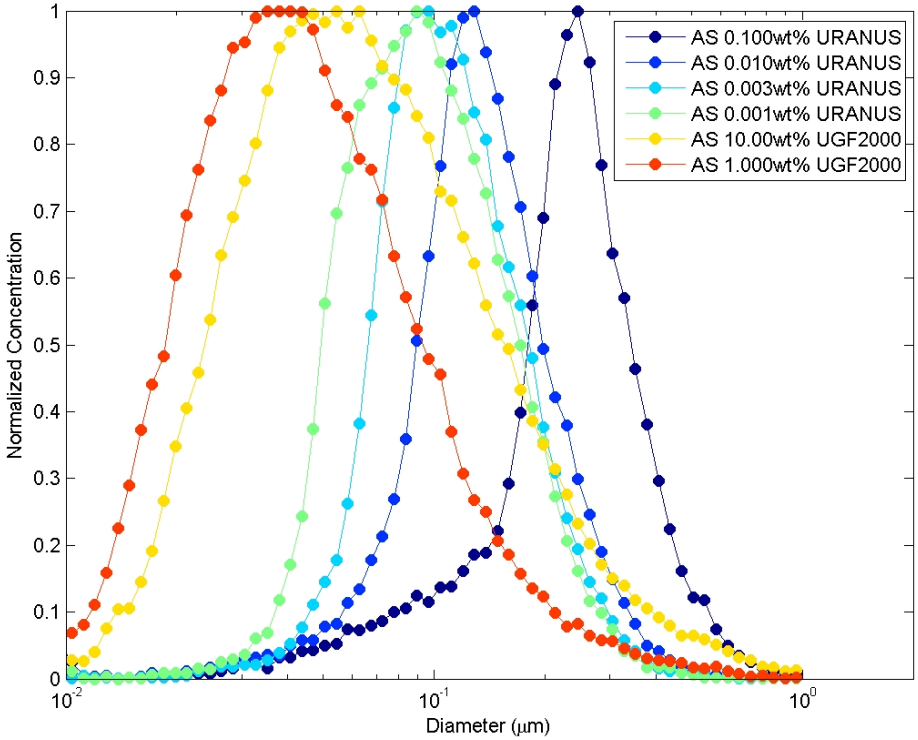
Model predictions for the experiments…

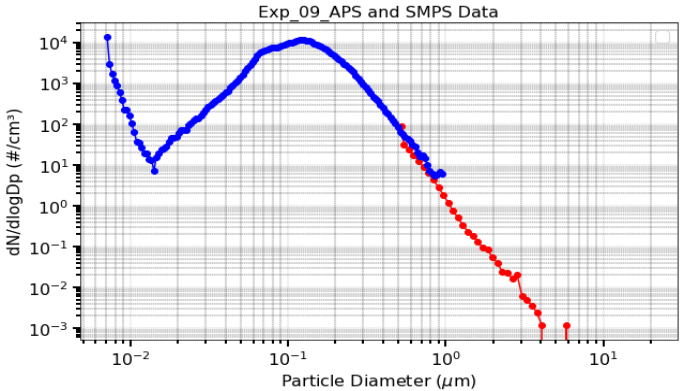


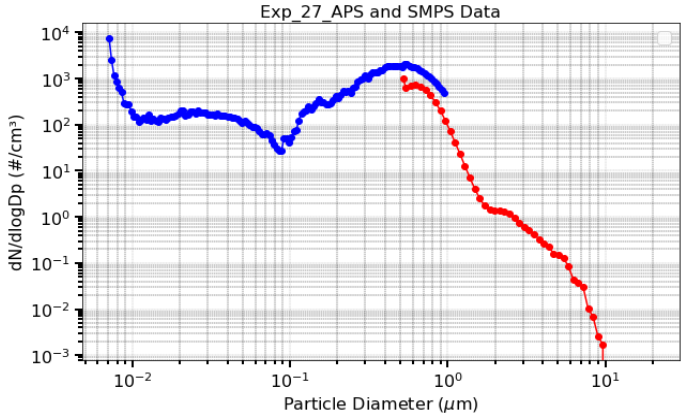


- Simulation of the particle sizes to be generated
- Comparative activation of cloud droplets wrt the number concentrations

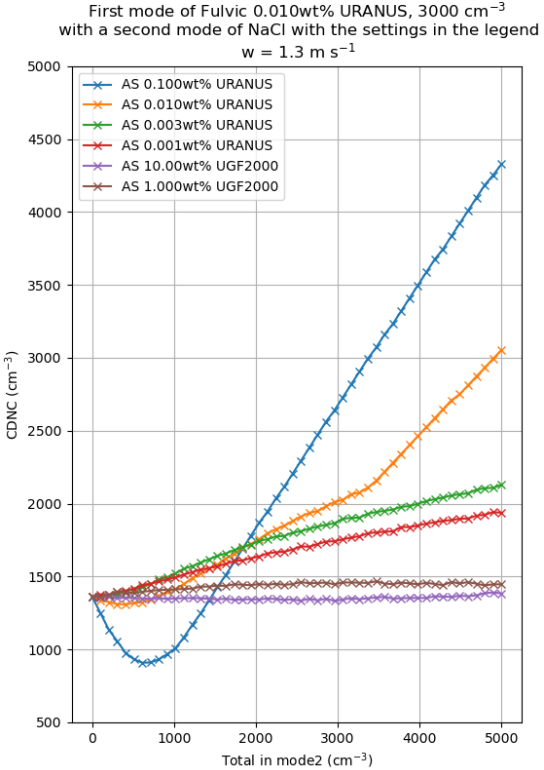
Particle size distribution of AS+NaCl & ATD+NaCl

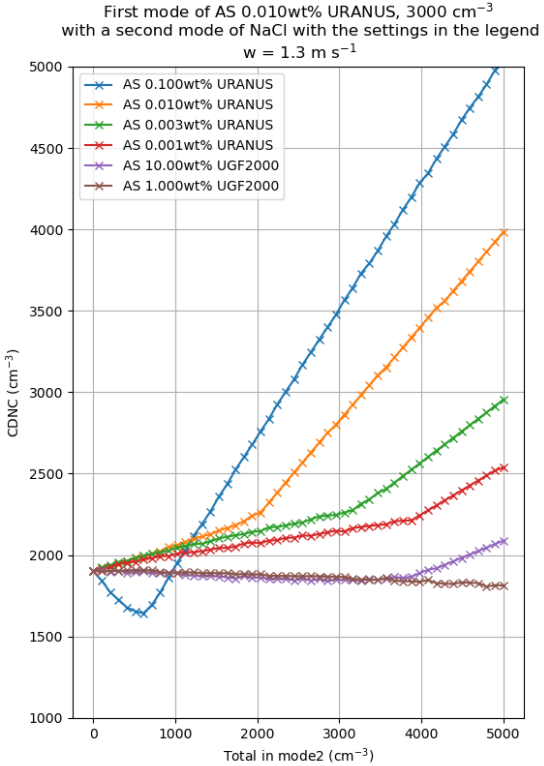


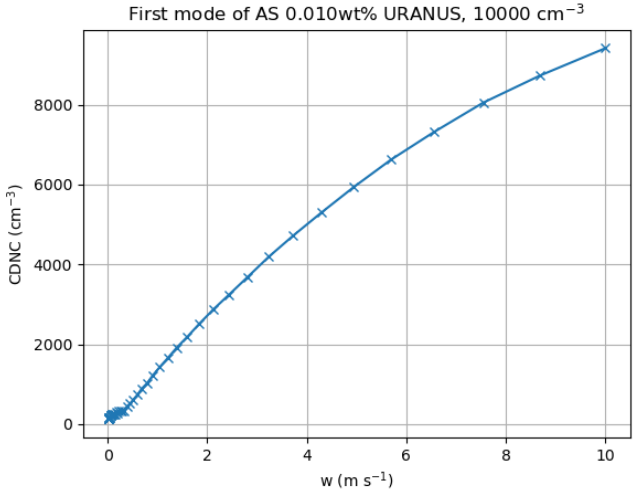




Model predictions for the experiments…







- External mixtures – AS + NaCl
- Expected activation matches what we observed in some experiments

AIDAd overview plots – AS | AS + NaCl

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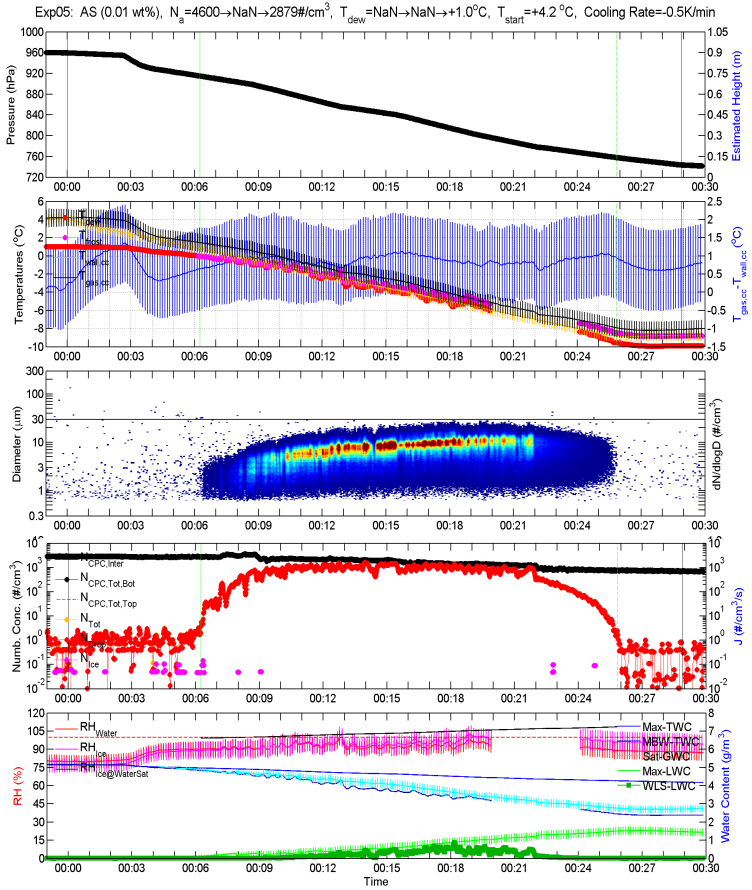
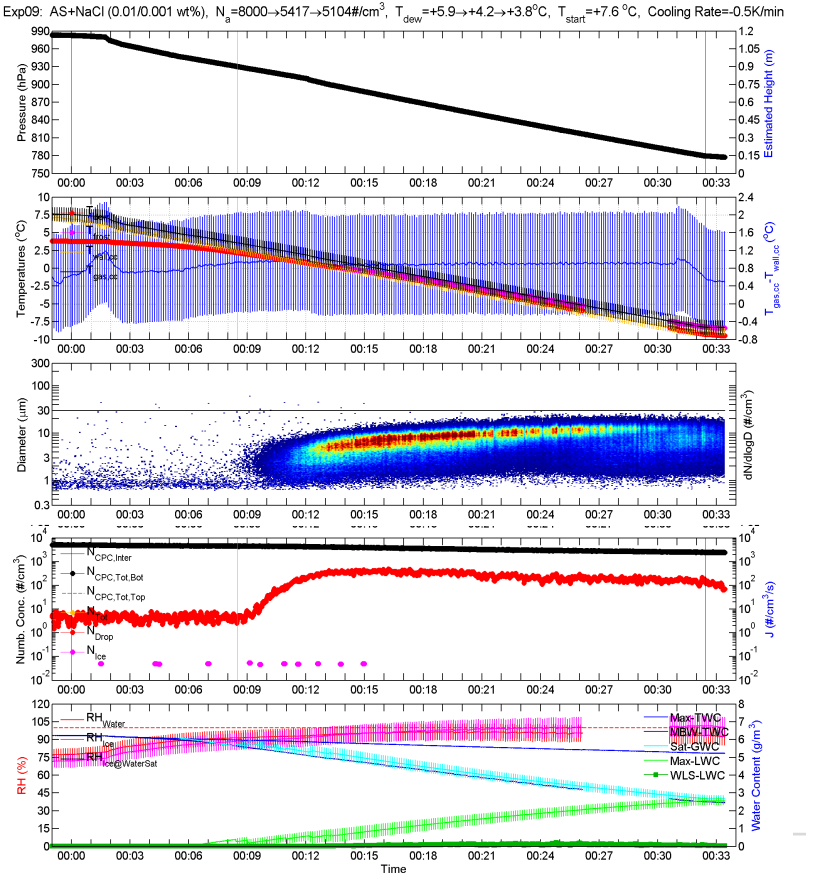


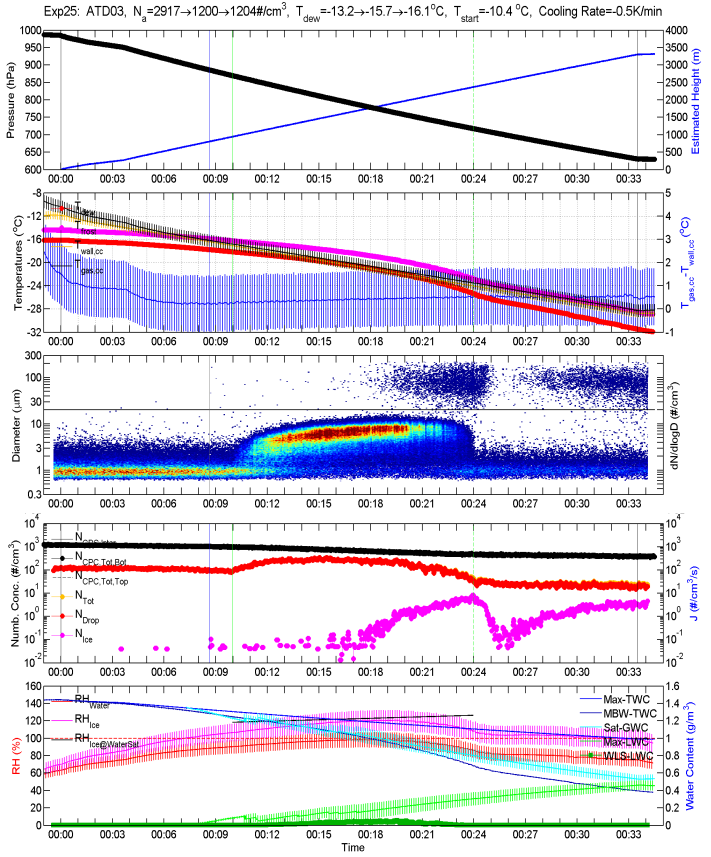
N_{aer}= ~2900

N_{aer}= ~5100

- CR=0.5K/min
- Clear droplet activation
- Number concentration : aerosol, droplets and ice



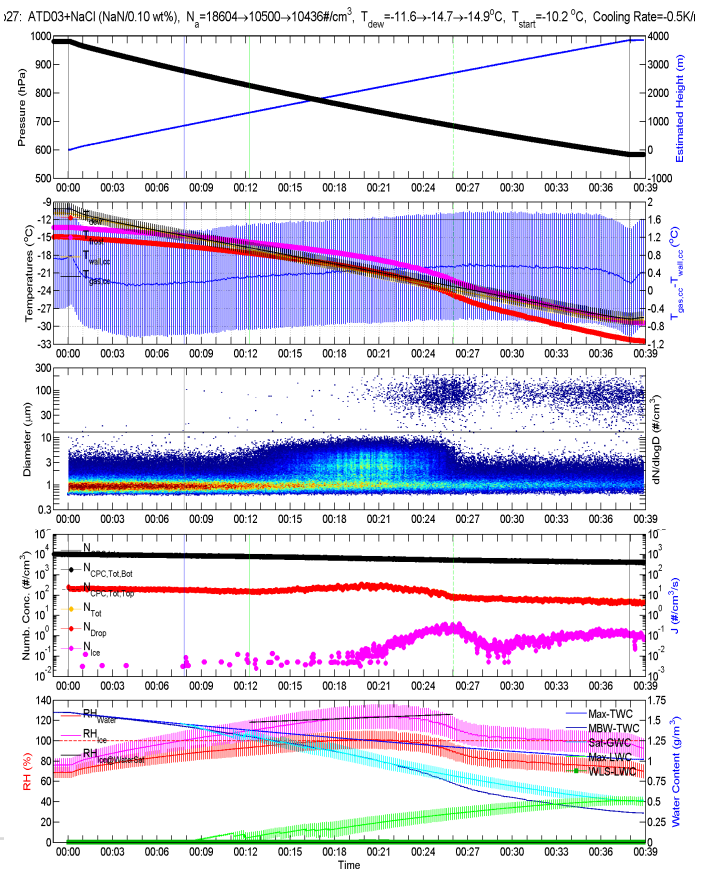
AIDAd overview plots – ATD | ATD + NaCl



N_{aer}= ~1200

N_{aer}= ~10400

- CR=0.5K/min
- Cloud activation before ice formation
- Number concentration: aerosol, droplets and ice



Summary + Outlook

- Competition effects were observed for the various experiments performed in the chamber.
- CCN: we measured size-resolved CCN activation [data analyses ongoing]
- Other data processing…INAS densities, explicit size dsn of the droplets, growth by diffusion, settling losses in the chamber, etc.
- More aerosol systems need to be tested with varying conditions.
- There is need to combine laboratory & modelling activities. **iSKYLAB** is another good ‘case’ for this collaboration.

- What can we or cannot measure? Technical limitations?
- What are the most important and least important parameters to consider?
- To what extent do the models need improvement?
- More collaboration cannot be overemphasized!