Training event “Atmospheric standardized observations: Methods and maintenance in observatories – In-Situ.” Cloud sampling, CCN & INP

Marco Zanatta, Franziska Vogel

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
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Ministero dell'Università e della Ricerca
Italiadomani

INTRO – Who we are

Franziska Vogel
PhD in Meteorology
Researcher at CNR-ISAC

Ice nucleating particle measurements

Marco Zanatta
PhD in Atmospheric science
Researcher at CNR-ISAC

Liquid clouds measurements

OUTLINE

An introduction to clouds

- Cloud droplet formation & impact on cloud properties
- Ice crystal formation & impact on cloud properties

The ACTRIS Center for Cloud In-situ Measurement

- Mission
- Units

Cloud condensation nuclei measurements

Ice nucleating particle measurement

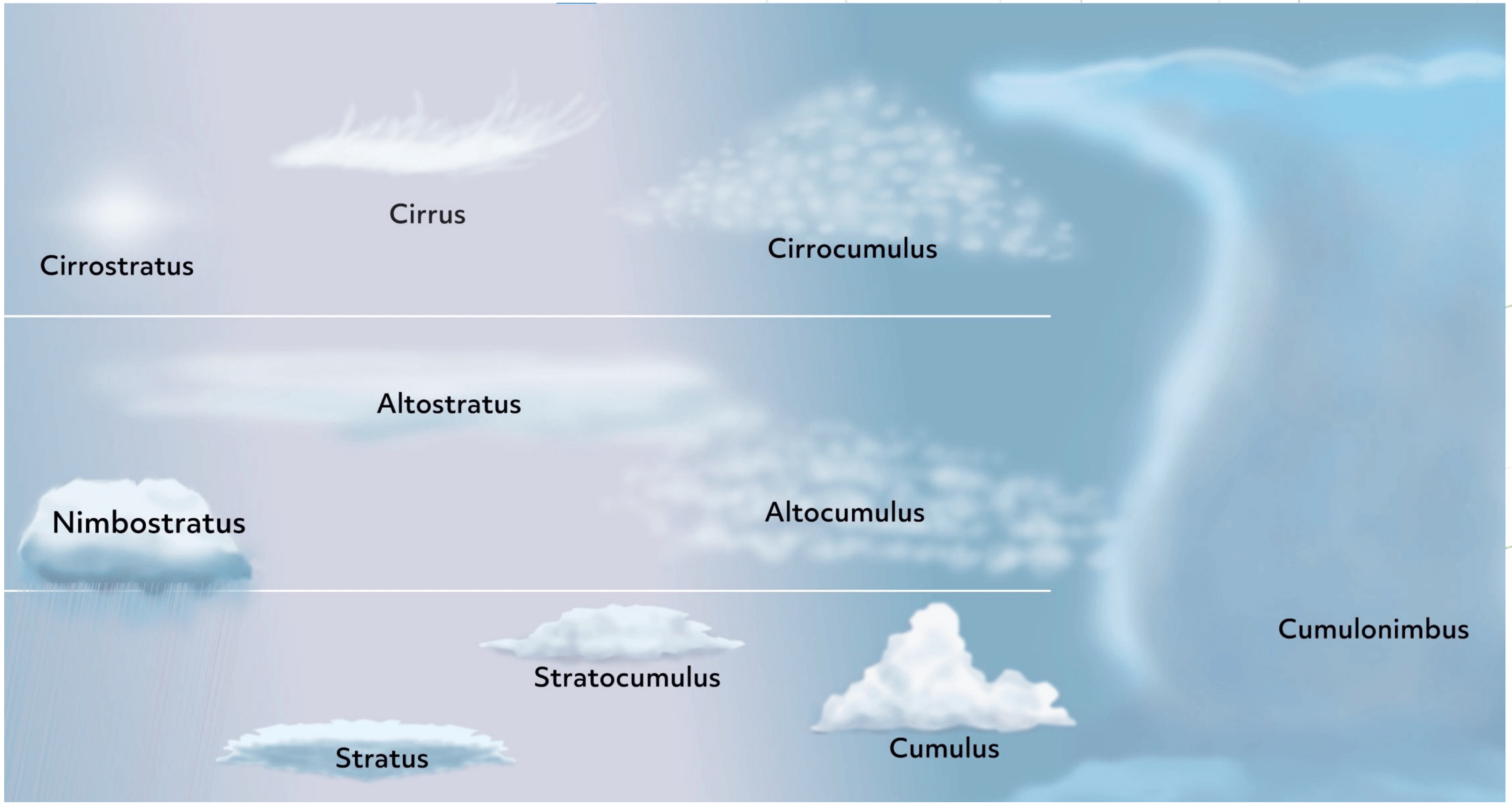
Liquid water content measurements

INTRO – Types and phases of clouds

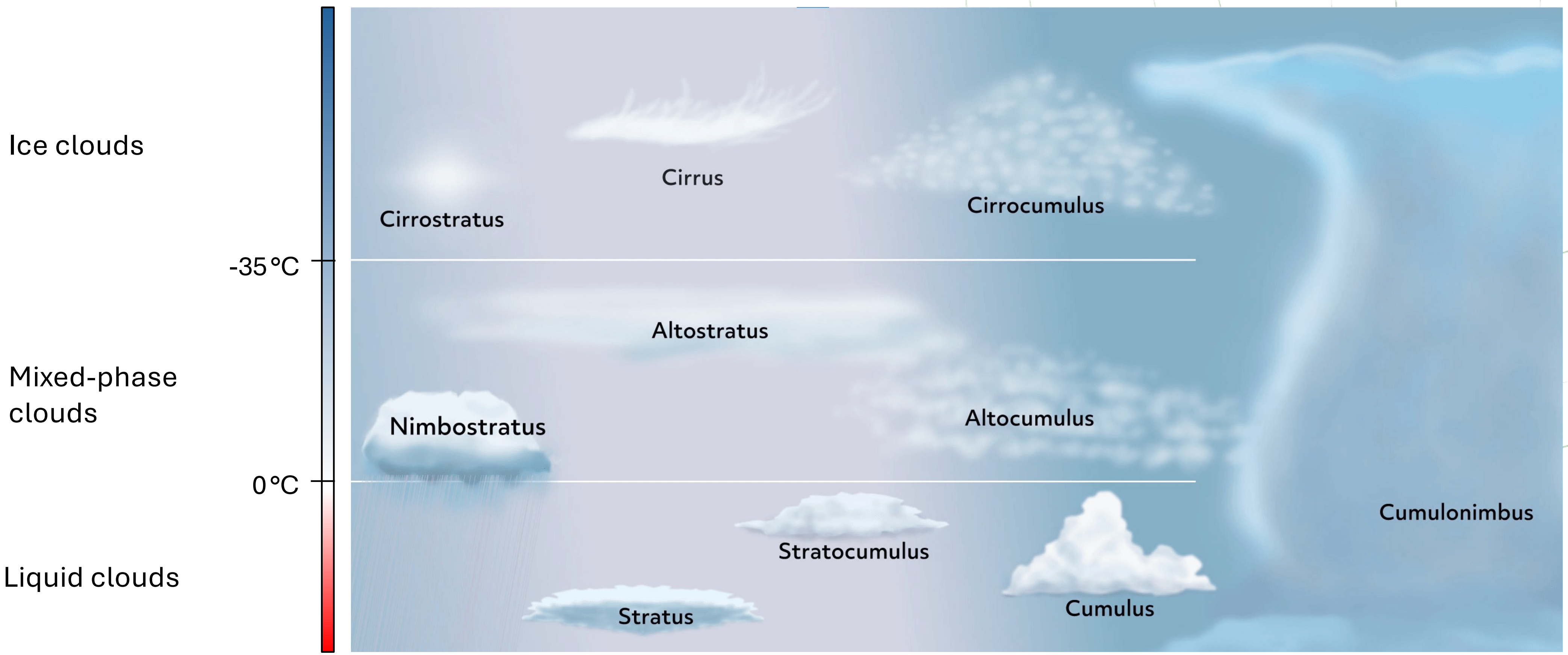
High-level clouds
>7 km

Mid-level clouds
2 – 7 km

Low-level clouds
0 – 2 km



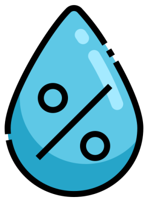
INTRO – Types and phases of clouds

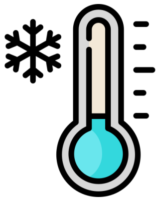


INTRO – Types and phases of clouds

Vocabulary

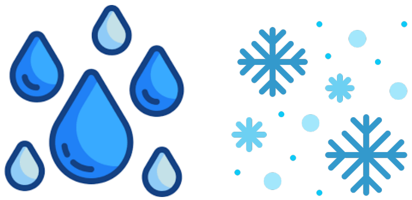
Moisture **Cooling**





Super saturation (SS)

Water and ice
RH > 100%



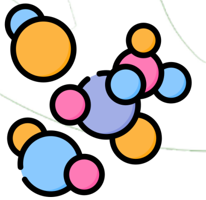
Cloud

Liquid droplets

Supercooled liquid droplets

Ice crystals

Particles



Aerosol

Cloud condensation nuclei (CCN)

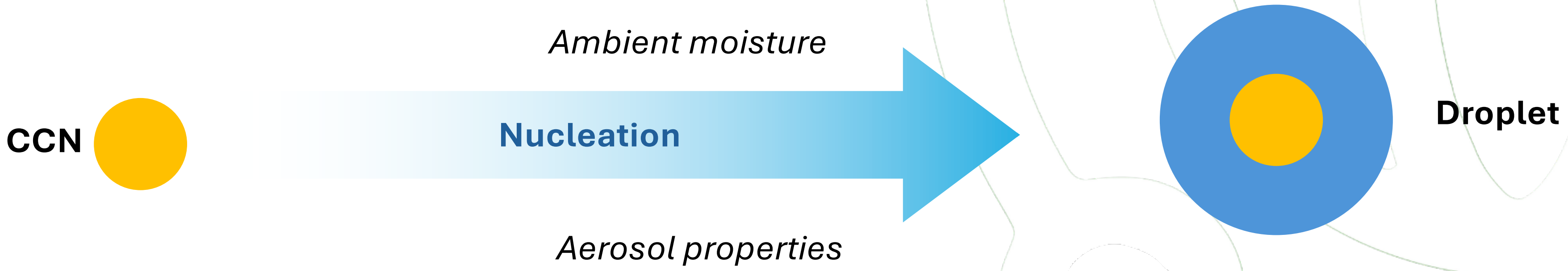
Ice nucleating particles (INP)

Questions

Are you working with clouds in your project?

INTRO – Cloud condensation nuclei (CCN)

CCN provides a support on which droplets can form



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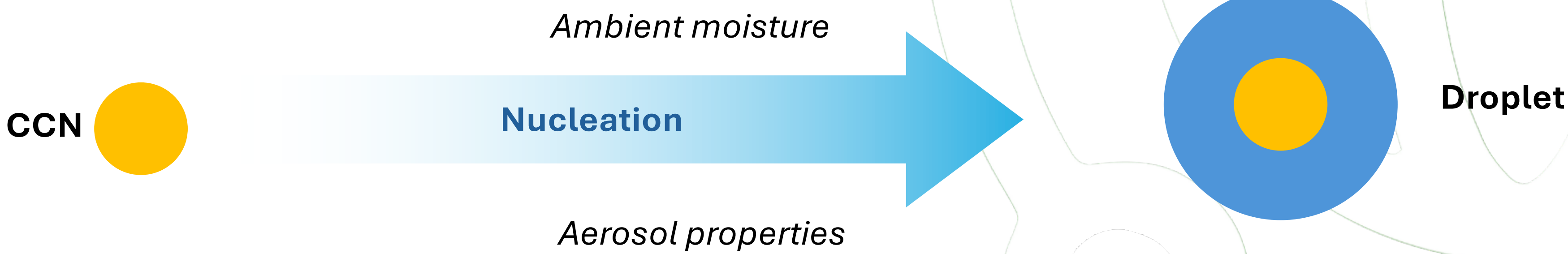
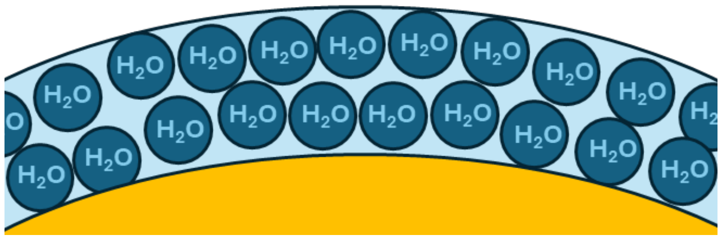


Curvature effect

Curvature increases water pressure needed for equilibrium



A large particle offers
a “flat” surface

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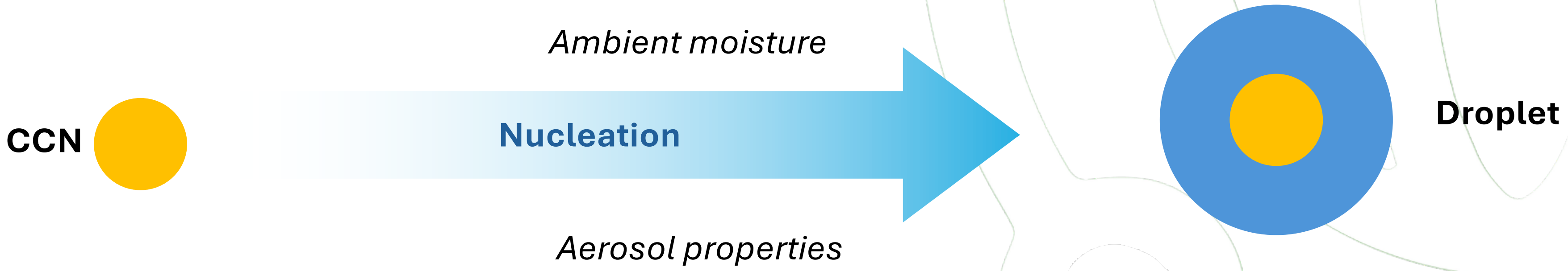

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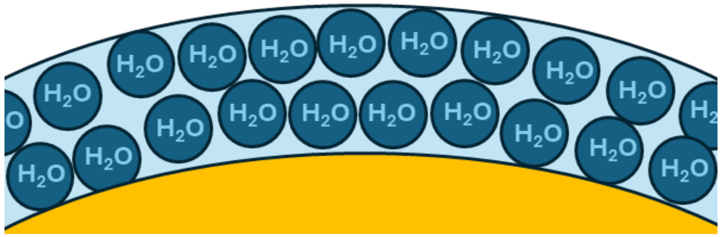
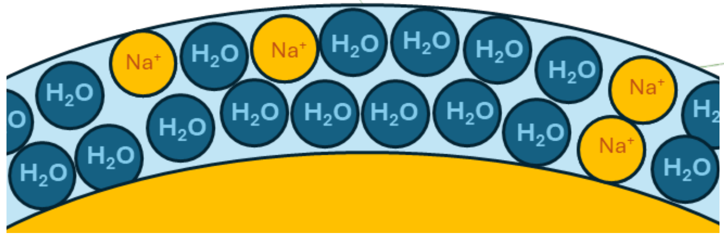


A large particle offers
a “flat” surface

Solute effect

Solute lowers water pressure needed for equilibrium



A soluble particle offers
plenty of solute

INTRO – CCN Hygroscopicity

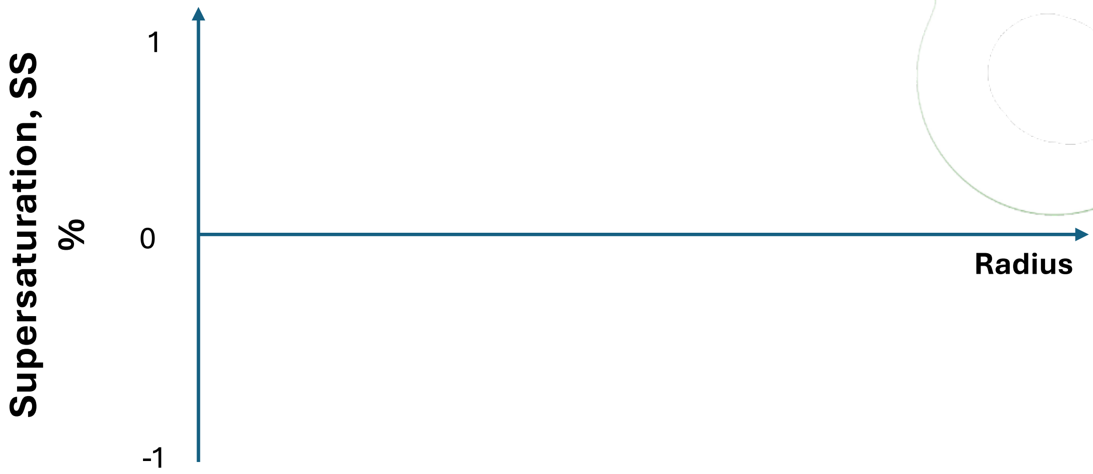
Curvature effect

Solute effect

Koehler Theory

Parametrizes the **hygroscopicity**

Critical SS and radius to support a droplet



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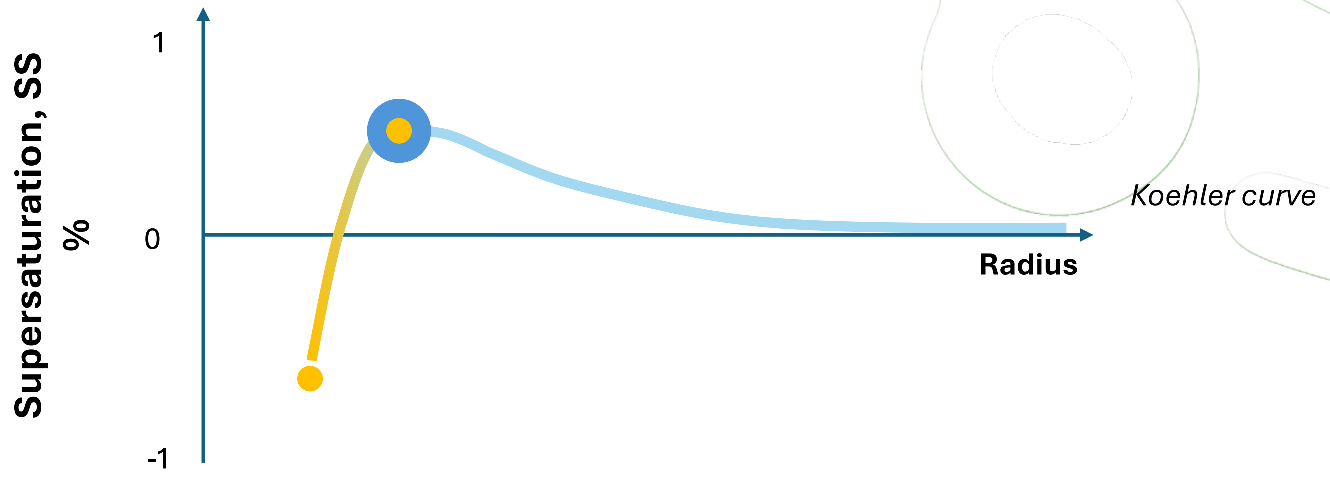

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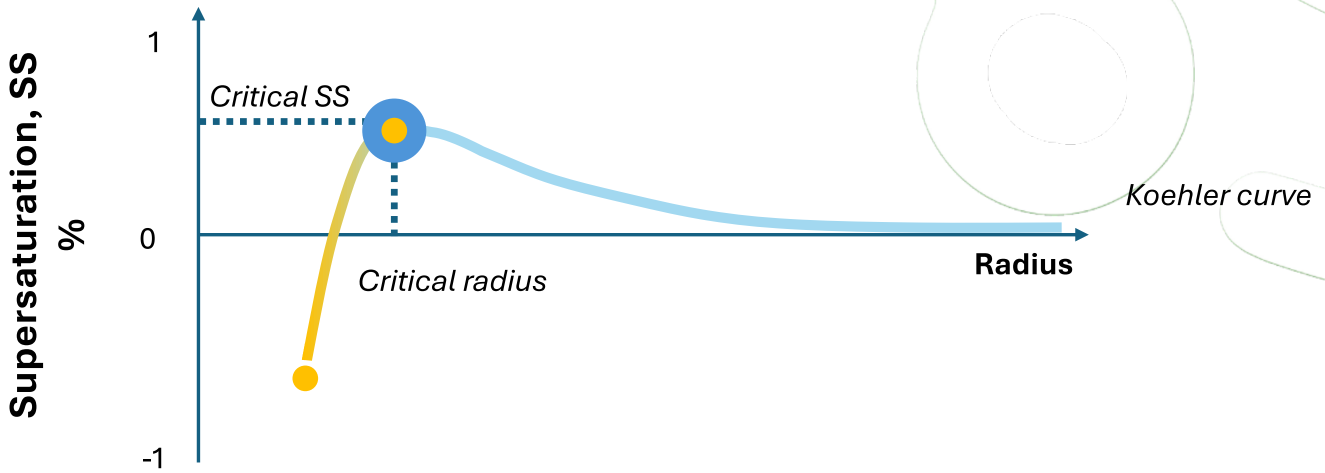

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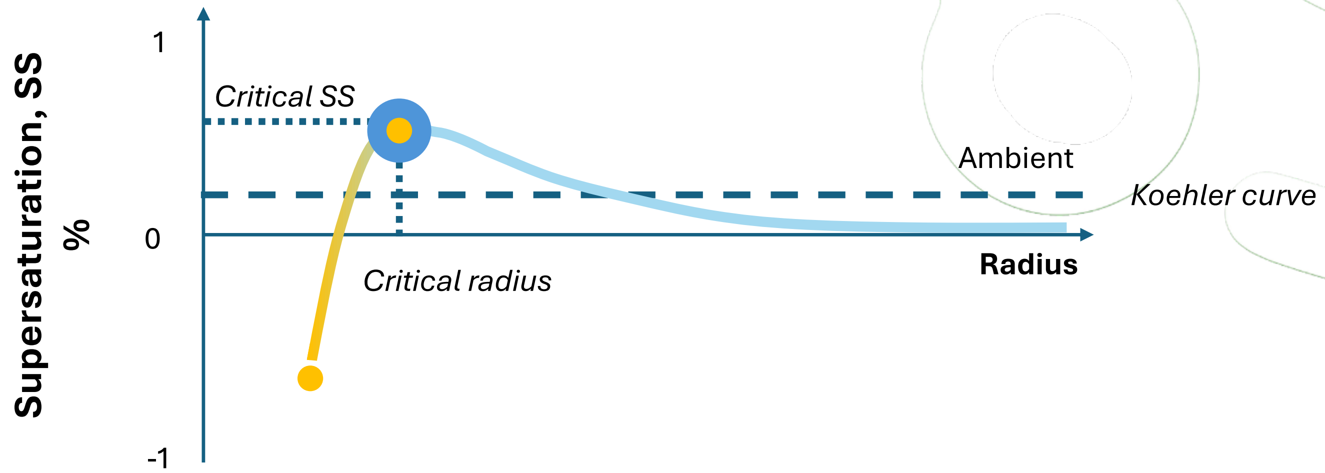

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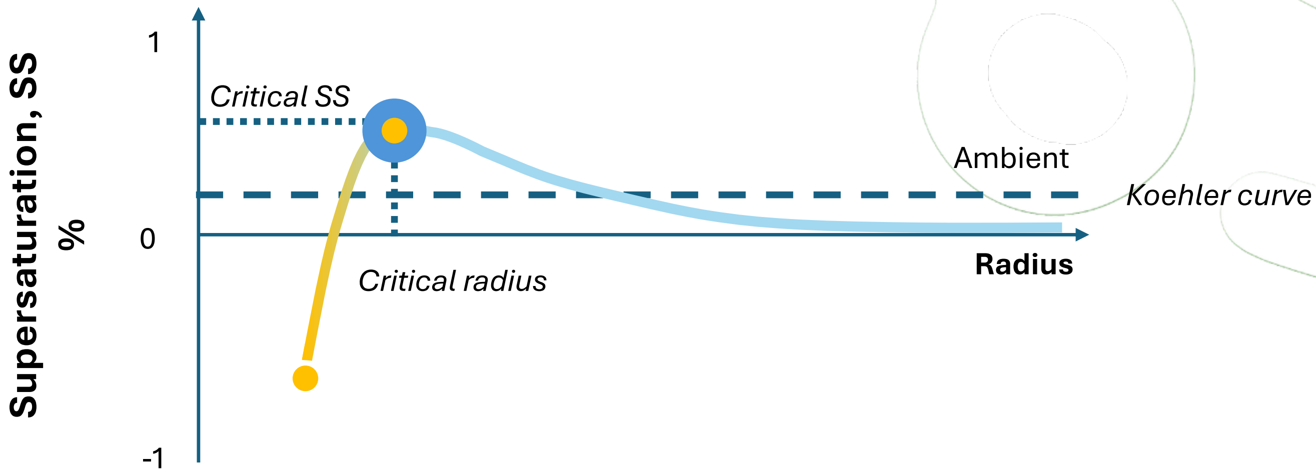

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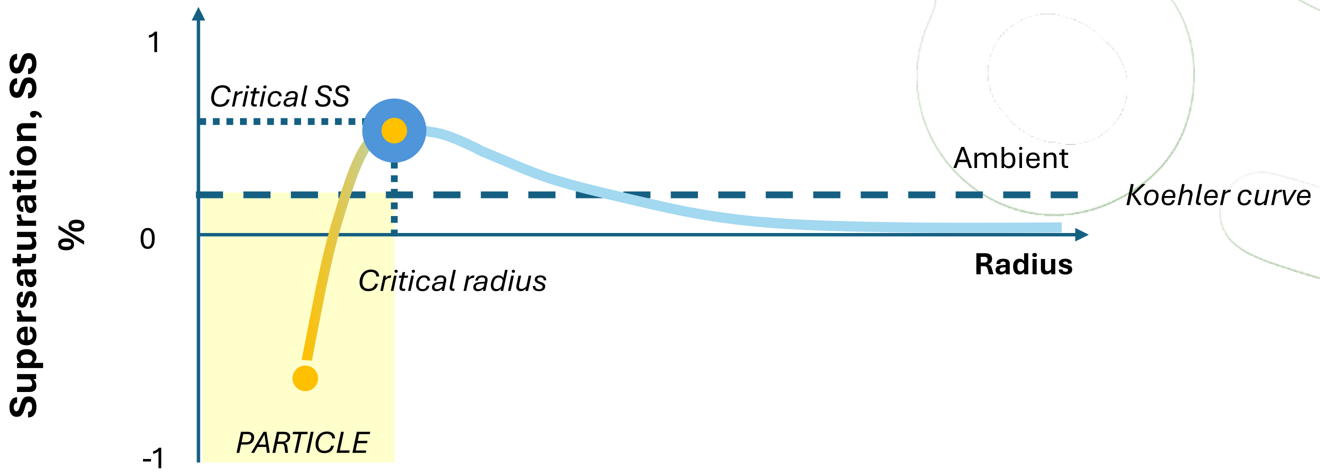

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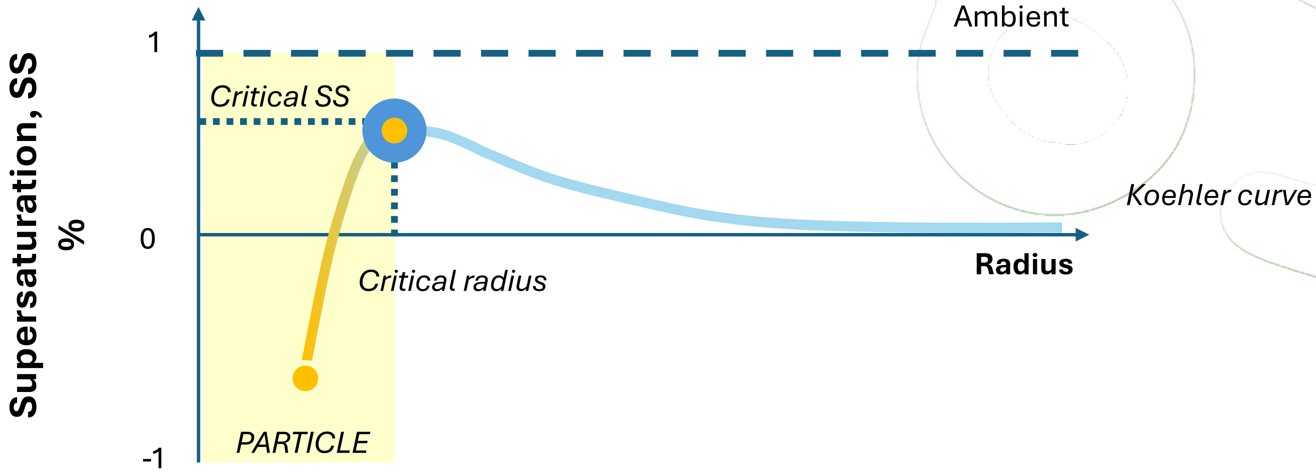

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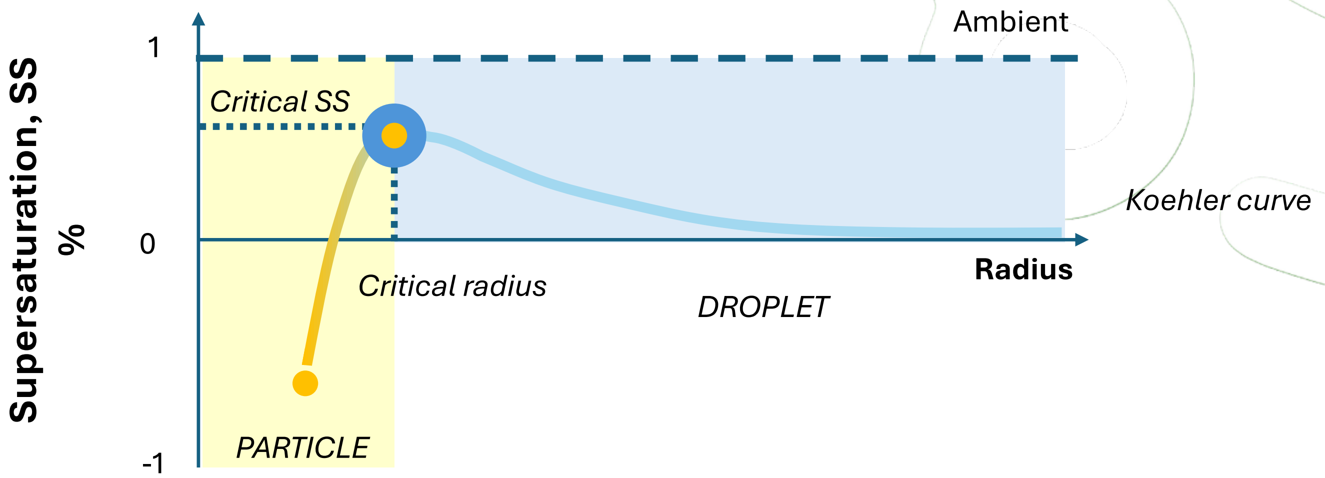


INTRO – CCN Impact on droplets properties

The Twomey effect or First indirect aerosol effect

Impact of CCN concentration on droplets properties

CCN population
Critical SS = 0.5 %
Ambient SS = 0.1%

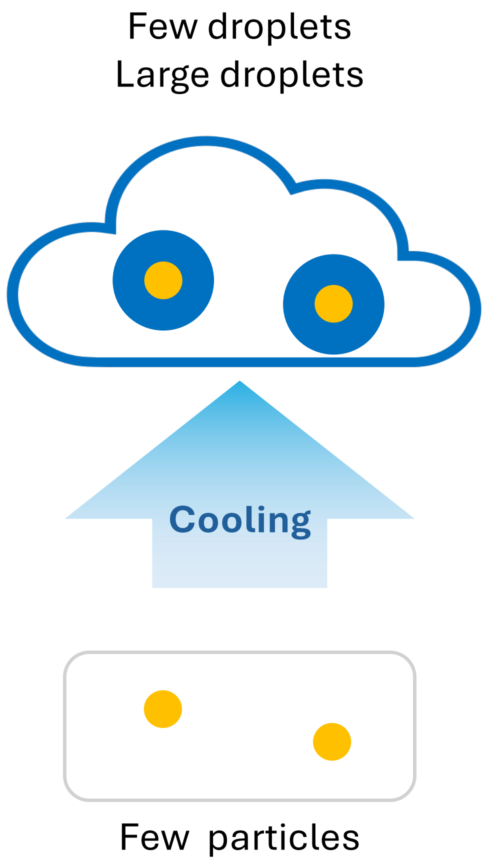
Few particles

INTRO – CCN Impact on droplets properties

The Twomey effect or First indirect aerosol effect

Impact of CCN concentration on droplets properties

CCN population
Critical SS = 0.5 %
Ambient SS = 0.7 %



CCN population
Critical SS = 0.5 %
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INTRO – CCN Impact on droplets properties

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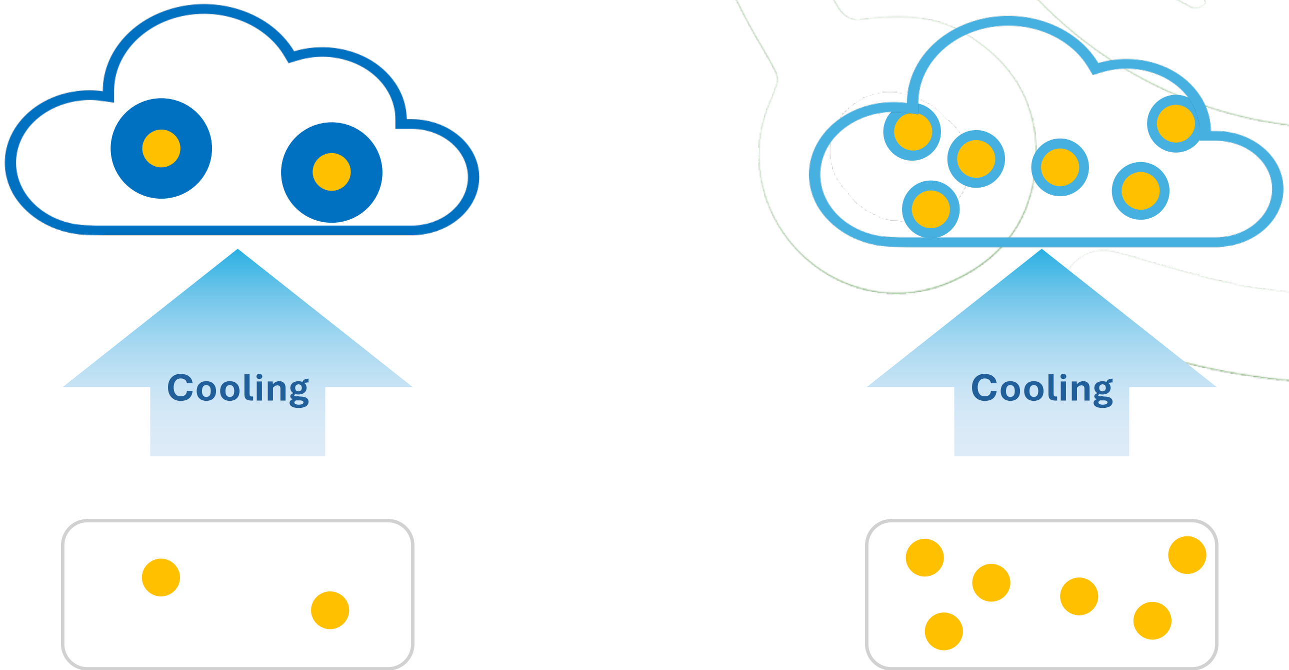
Impact of CCN concentration on droplets properties

Few droplets
Large droplets

Many droplets
Small droplets

CCN population
Critical SS = 0.5 %
Ambient SS = 0.7 %



CCN population
Critical SS = 0.5 %
Ambient SS = 0.1%

Few particles

Many particles

INTRO – CCN Impact on cloud properties

The Twomey effect or First indirect aerosol effect

Impact of CCN concentration on droplets properties

CCN population
Critical SS = 0.5 %
Ambient SS = 0.7 %

Few droplets
Large droplets

Less surface → less albedo

Large droplets → More precipitation

Precipitation → Short cloud lifetime

Many droplets
Small droplets

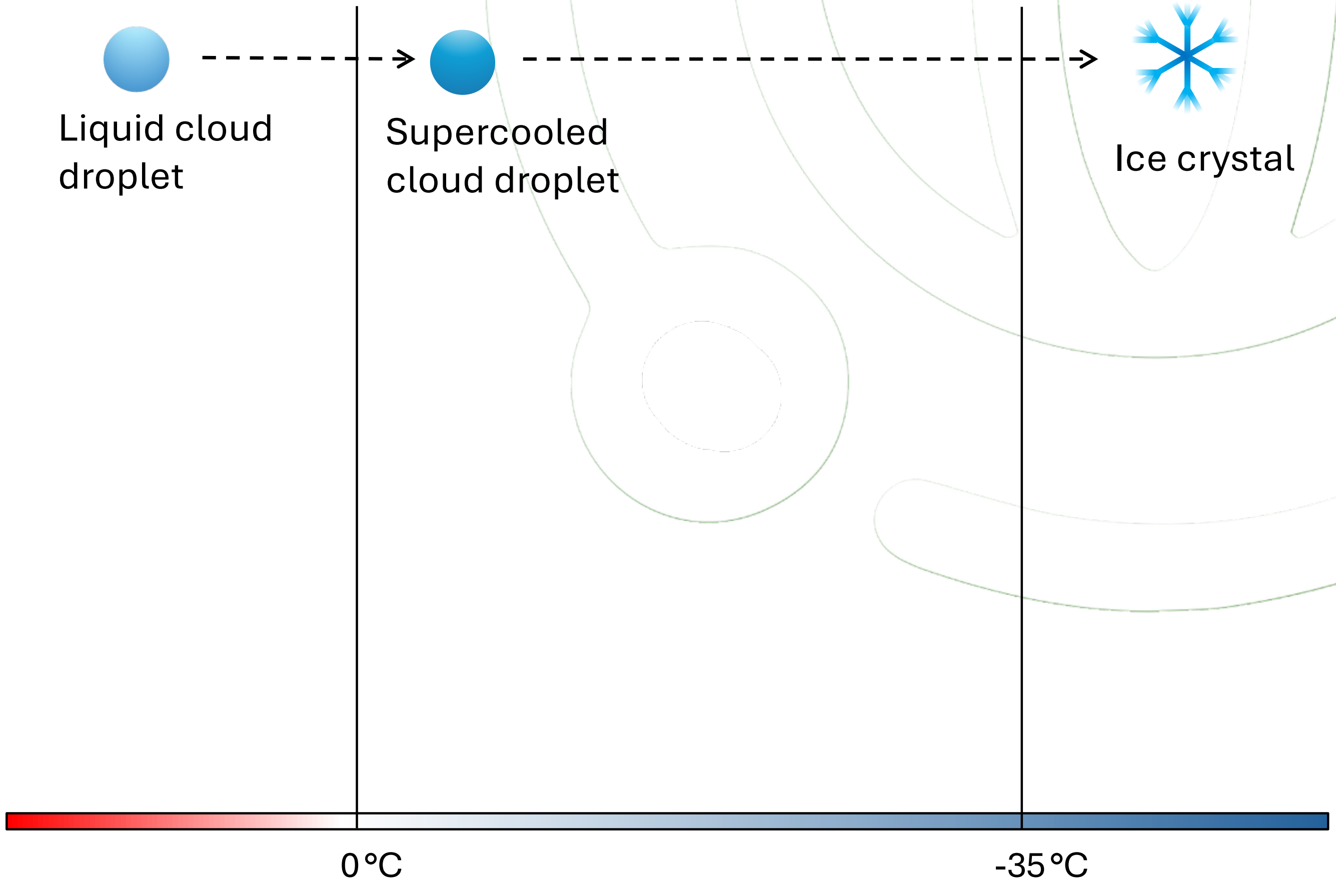
More surface → low albedo

Small droplets → Less precipitation

Precipitation → Long cloud lifetime

INTRO – Ice nucleating particles

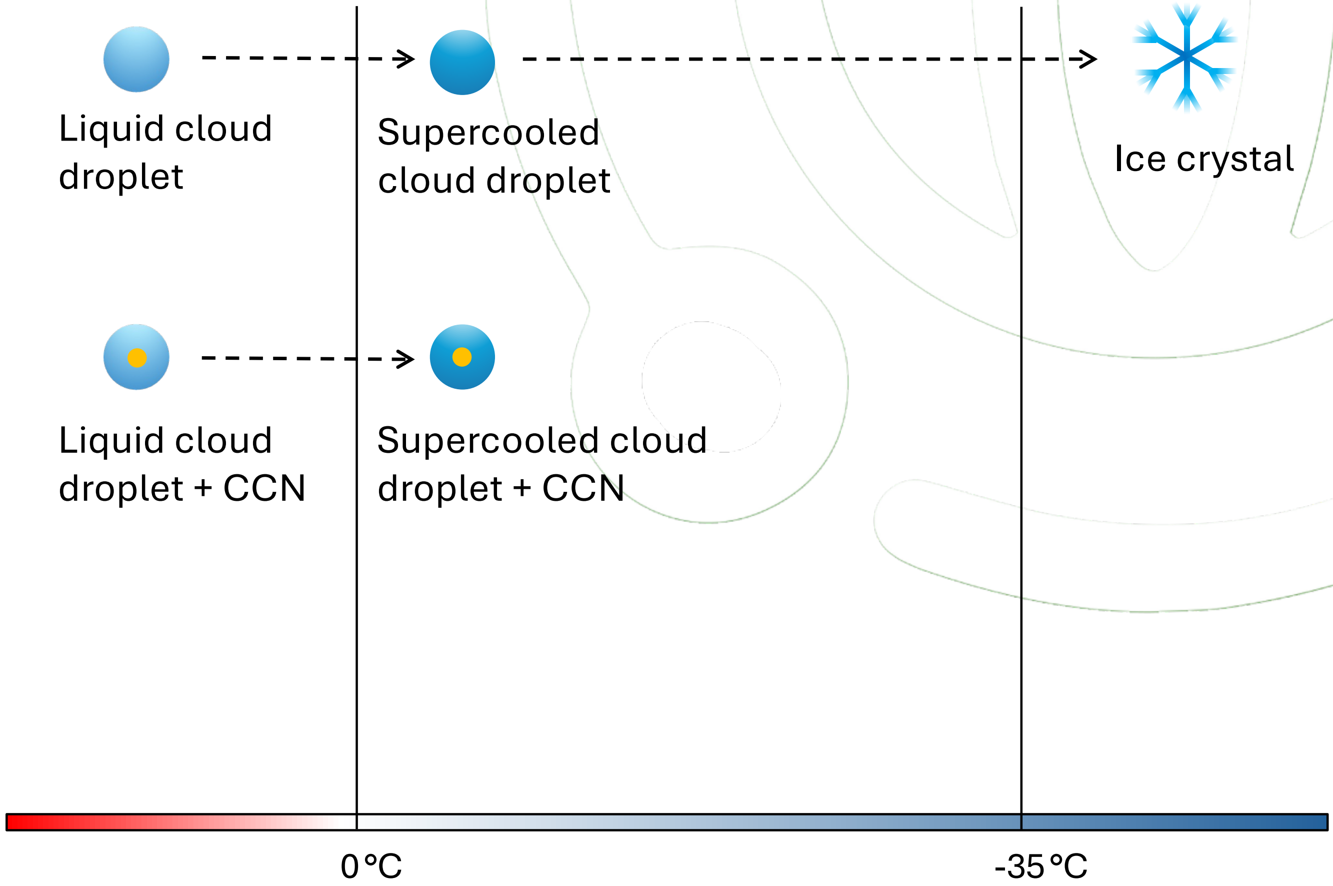
Homogeneous freezing
(Freezing without aerosol)



INTRO – Ice nucleating particles

Homogeneous freezing
(Freezing without aerosol)

Supercooling
without freezing

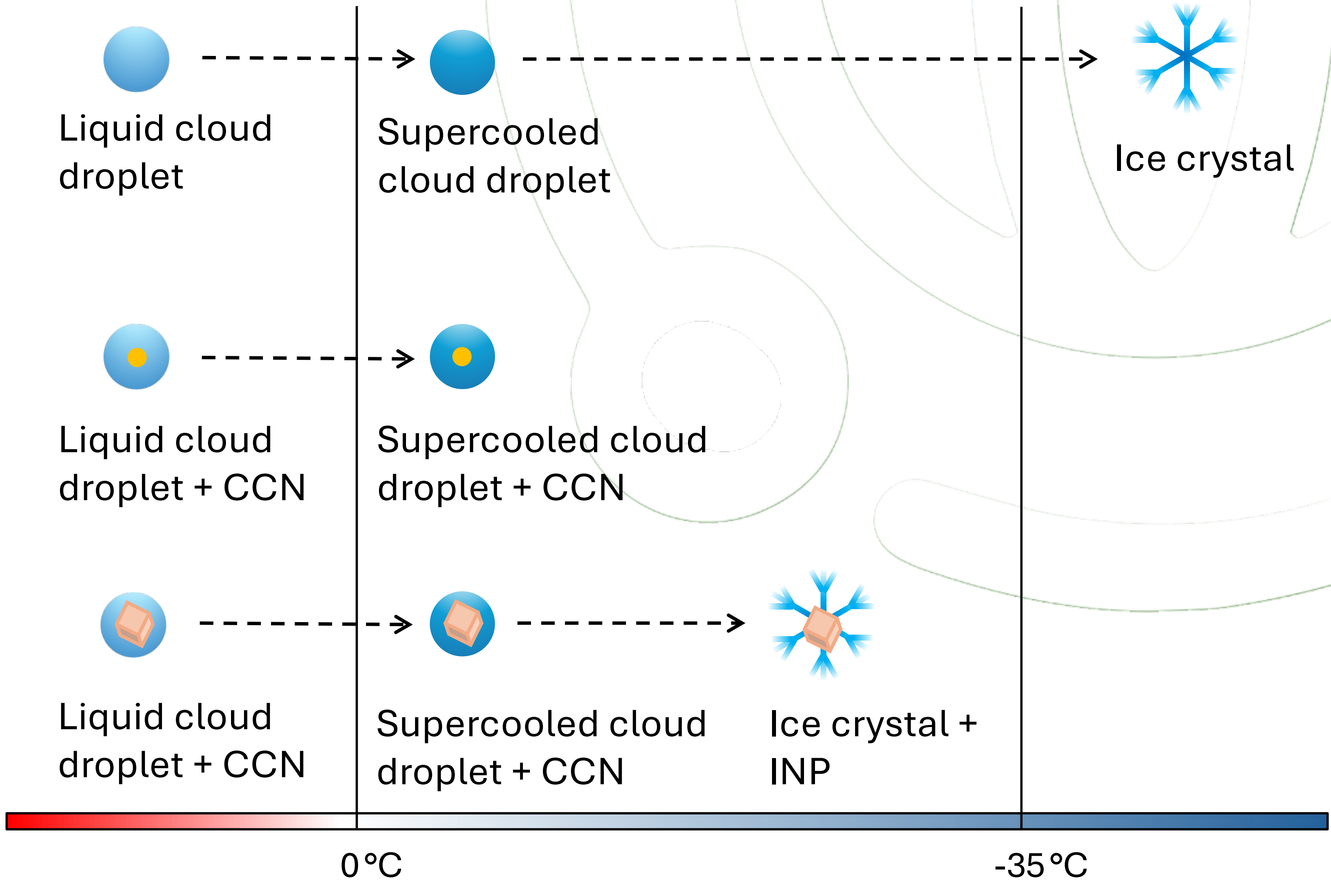


INTRO – Ice nucleating particles

Homogeneous freezing
(Freezing without aerosol)

Supercooling without freezing

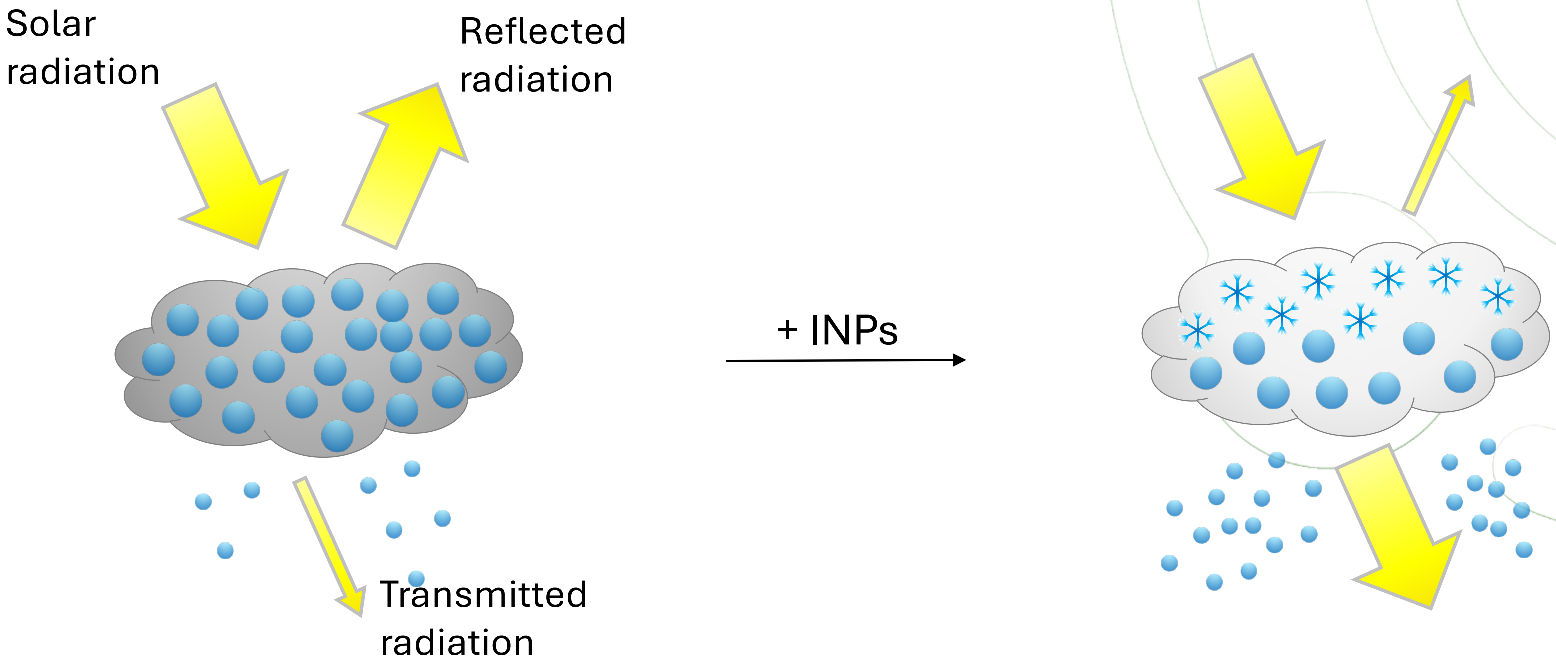
Heterogeneous freezing
– Immersion freezing
(Freezing with aerosol)



An INP (ice-nucleating particle) provides support to form an ice crystal at a temperature warmer than -35°C

INTRO – INP impact on cloud properties

The glaciation effect



- Less precipitation
- Increased cloud lifetime
- Cloud optically thick

- More precipitation
- Decreased cloud lifetime
- Cloud optically thin

Questions

Would CCN and INP complement your research project?

INTRO – Cloud measurements in ACTRIS-RI

The mission is to characterize clouds to improve the knowledge about their feedback on the Earth's climate

Three components

Cloud amount

Cloud altitude

Cloud optics

ACTRIS Centre for Aerosol Remote Sensing (CARS)

Centre for Cloud In Situ Measurements (CIS)

INTRO – Topical Centre for Cloud In-Situ Measurements

ITINERIS

One of the central facilities of ACTRIS-RI
CIS mission divided in 4 units

1. Centre for Cloud Ice Nucleation
   Karlsruhe Institute of Technology, DE
2. Centre for Cloud Particle Properties
   Laboratorie de Météorologie Physique, FR
3. Centre for Cloud Water Chemistry
   Leibniz Institute for Tropospheric Research, DE
4. Centre for Cloud Ambient Intercomparison
   GeoSphere Austria, AT

INTRO – Topical Centre for Cloud In-Situ Measurements

ITINERIS

CIS mission divided in 4 units
Setting standard operation procedure for of 11 variables

1 Centre for Cloud Ice Nucleation

Karlsruhe Institute of Technology, DE

- INP number conc.
- INP temp. spectrum

2 Centre for Cloud Particle Properties

Laboratorie de Météorologie Physique, FR

- Droplet number conc.
- Droplet size distribution
- Ice number conc.
- Ice number size distr.

3 Centre for Cloud Water Chemistry

Leibniz Institute for Tropospheric Research, DE

- Water inorganic ions conc.
- Water organic carbon concentration
- Water carboxylate conc.

4 Centre for Cloud Ambient Intercomparison

GeoSphere Austria, AT

- Liquid water content
- Droplet effective diameter

INTRO – Topical Centre for Cloud In-Situ Measurements

ITINERIS

Setting standard operation procedure for of 11 variables
2 mandatory & 9 specializing

1 Centre for Cloud Ice Nucleation

Karlsruhe Institute of Technology, DE

- INP number conc.
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SPECIALIZING

2 Centre for Cloud Particle Properties

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SPECIALIZING

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MANDATORY

INTRO – Today's focus

Describe the instruments and standard operation procedures to measure

1

Centre for Cloud Ice Nucleation

Karlsruhe Institute of Technology, DE

- INP number conc.
- INP temp. spectrum

SPECIALIZING

4

Centre for Cloud Ambient Intercomparison

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MANDATORY

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SPECIALIZING

Centre for Aerosol In-Situ

European Centre for Aerosol Calibration and Characterization

Leibniz Institute for Tropospheric Research, DE

- CCN number conc.

SPECIALIZING

4

Centre for Cloud Ambient Intercomparison

GeoSphere Austria, AT

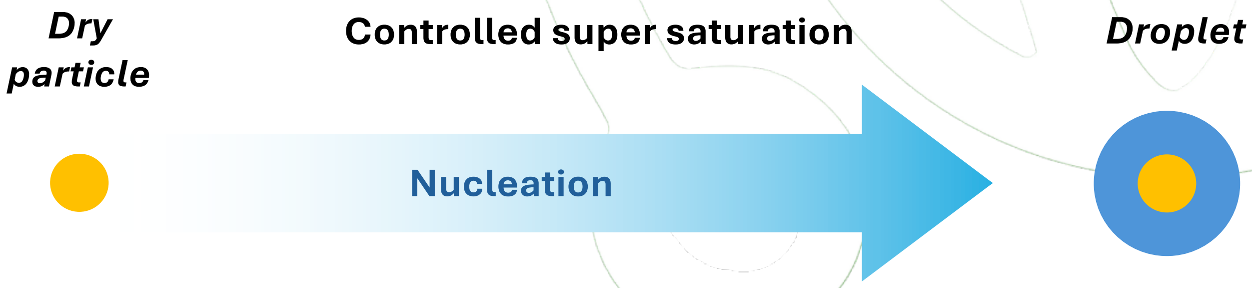
- Liquid water content
- Droplet effective diameter

MANDATORY

CCN – The CCN counter

Cloud condensation nuclei counter (CCNC)

Droplet Measurement Technologies, Colorado, USA



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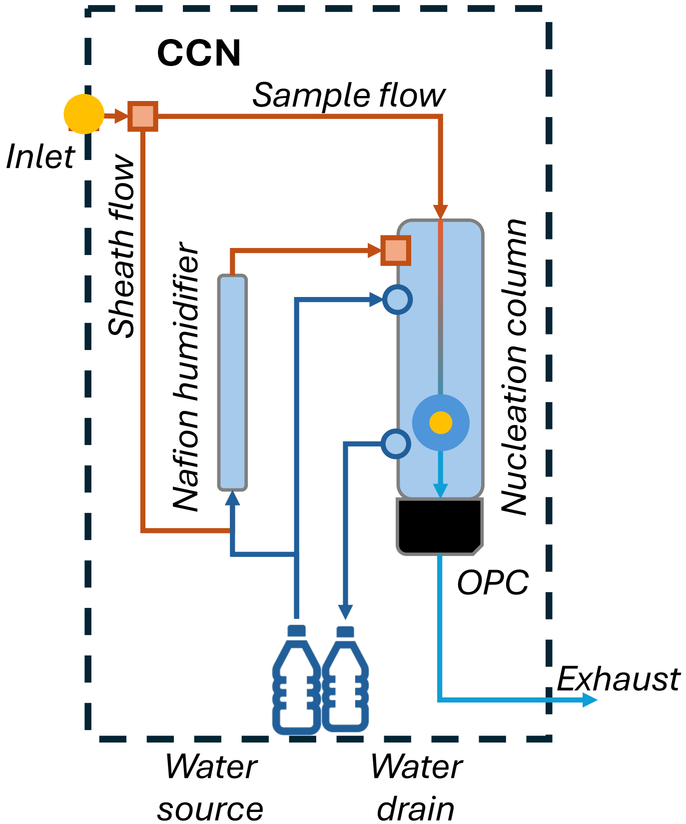
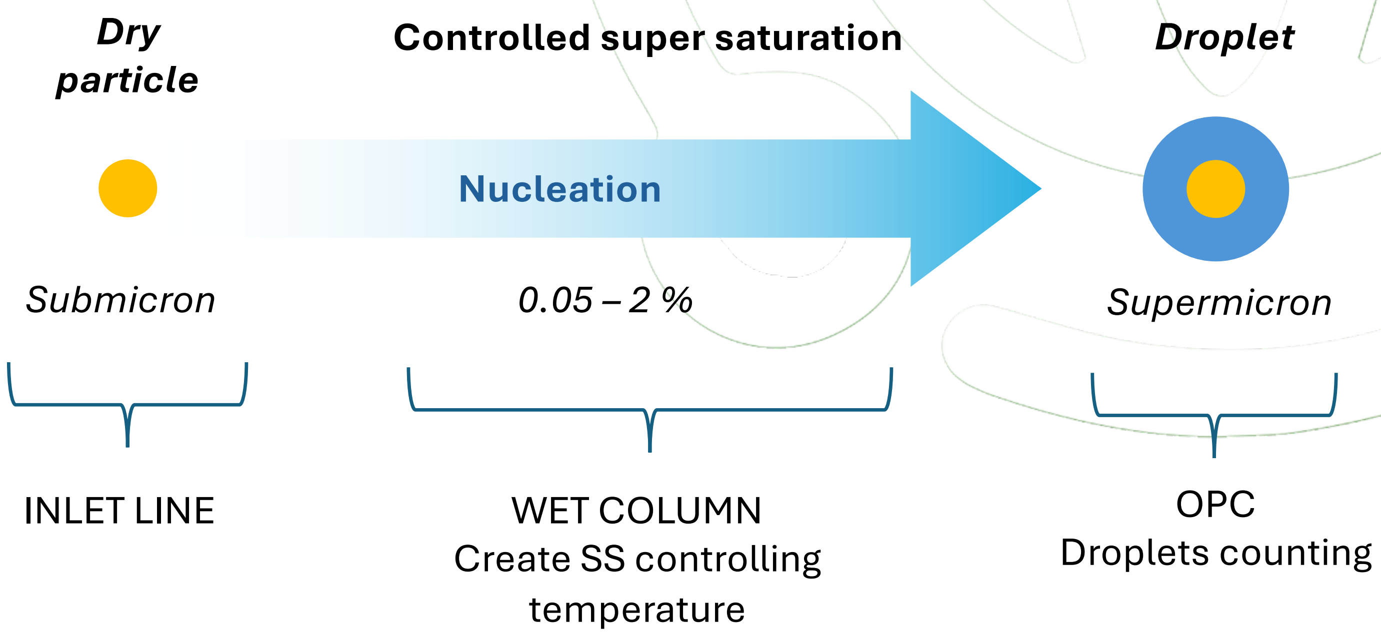
Cloud condensation nuclei counter (CCNC)
Droplet Measurement Technologies, Colorado, USA

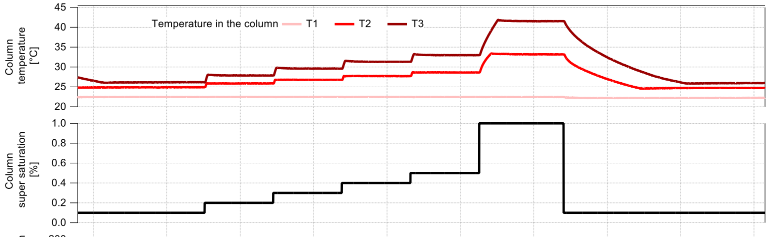




Number concentration droplets = Number concentration CCN

CCN – Standard operation procedure

Traditional approach varying the supersaturations by stepping the temperature
Constant flow rate



T-ramp to change the SS

CCN – Standard operation procedure

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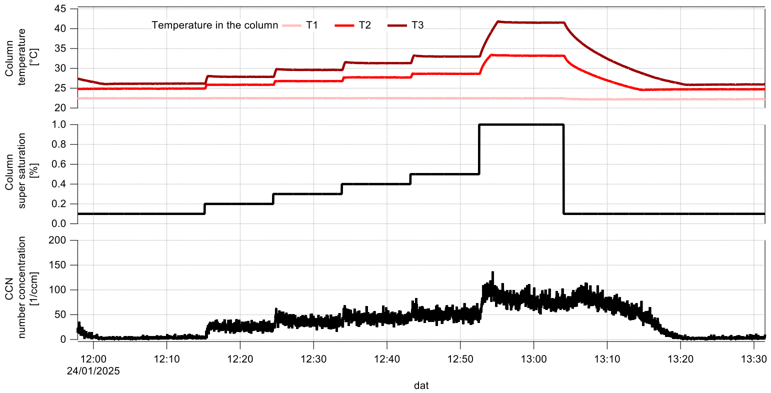
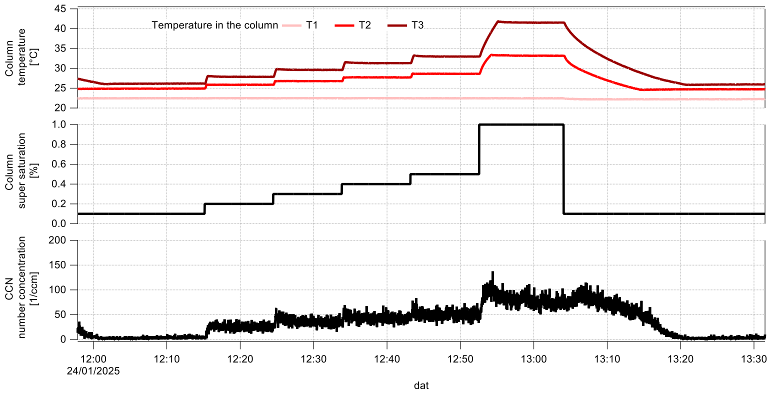


T-ramp to change the SS

One full SS cycle per hour
Mandatory range: 0.1-0.5%
Usual: 0.1, 0.2, 0.3, 0.5, 1.0 %

CCN – Standard operation procedure

Traditional approach varying the supersaturations by stepping the temperature
Constant flow rate



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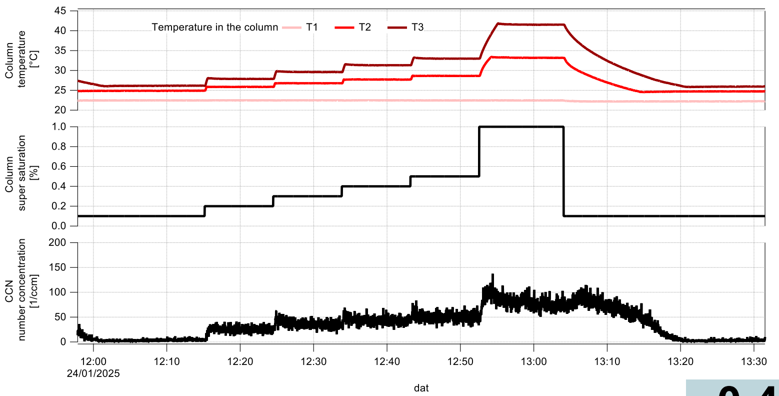
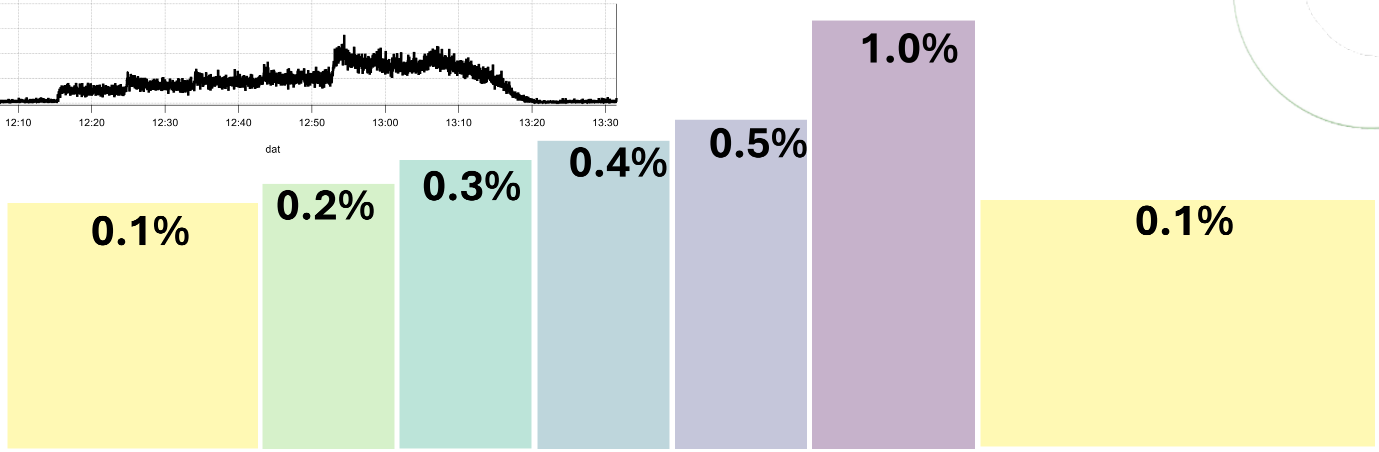
Slow response to T&SS
0-5000 cm-3

CCN – Standard operation procedure

Traditional approach varying the supersaturations by stepping the temperature
Constant flow rate





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One full SS cycle per hour
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Slow response to T&SS
0-5000 cm-3

CCN – Measuring requirements

Are you thinking of getting a CCNC ?

- You need constant supply of milliQ water
- You need fresh room temperature → the instrument can warm efficiently but has only passive cooling
- Attention to concentration (< 5000 cm-3) → too many particle compete for water vapor impeding SS conditions
- Perform regular flow calibration (6 months) → air speed control heat and water diffusivity
- Perform SS calibration (once per year) → calibration unit (SMPS) plus ammonium sulfate
- Complementary measurement
  → CPC for activated fraction calculation
  → SMPS and ACSM for Koehler theory closure

THIS IS NOT A PLUG AND PLAY INSTRUMENT

CCN - EBAS data coverage

Data coverage of absorption coefficient

Data coverage of CCN number concentration

Hyytiala, FI → 2013-2024
Jungfraujoch, CH → 2012-2014
Cape Grim, AU → 2013-2023
Vavihill, SW → 2008-2016
Zeppelin, NO → 2007-2019

Questions

Could you do CCN measurements at your station?

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SPECIALIZING

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SPECIALIZING

4

Centre for Cloud Ambient Intercomparison

GeoSphere Austria, AT

- Liquid water content
- Droplet effective diameter

MANDATORY

INP - Center for Cloud Ice Nucleation (CCIce)

Hosted by: Karlsruhe Institute of Technology (KIT), Germany

Facility:
- Cloud simulation chamber (AIDA)
- Service chamber for intercomparison and calibration
- Mobile INP instruments

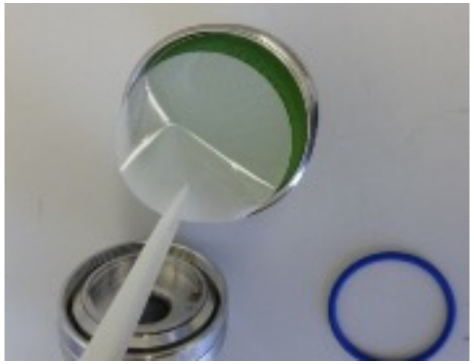
Mission:
- Provide specializing requirements for observational platforms
- Provide high quality long-term data on INP concentrations

INP - How to measure INPs variables

3 instruments to measure 2 specializing variables

Offline method

Online methods

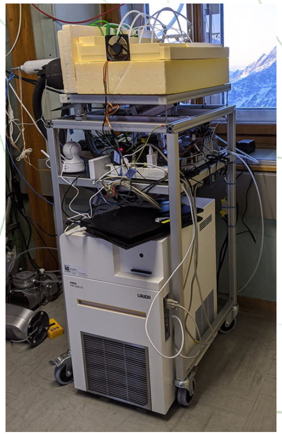


Filter based
-25°C < T < 0°C
Res = 1d - 1w

INP temperature spetra

Expansion chamber
-30°C < T < -10°C
Res = min- h

INP temperature spetra
INP number concentration

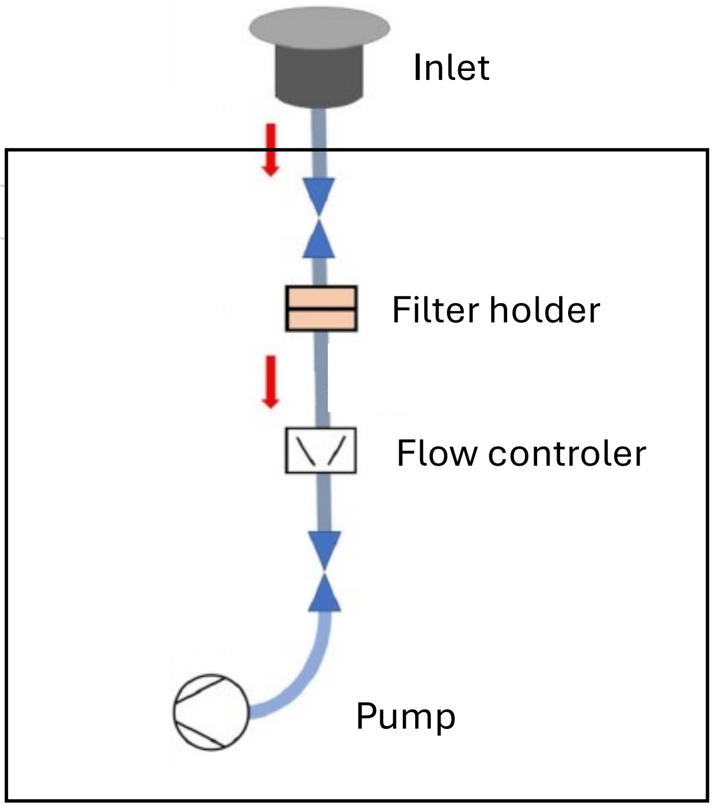


Continuous flow diffusion chamber
-30°C < T < -20°C
Res = min - h

INP number concentration

INP - Filter measurements

Step 1
Filter sampling



INP - Filter measurements

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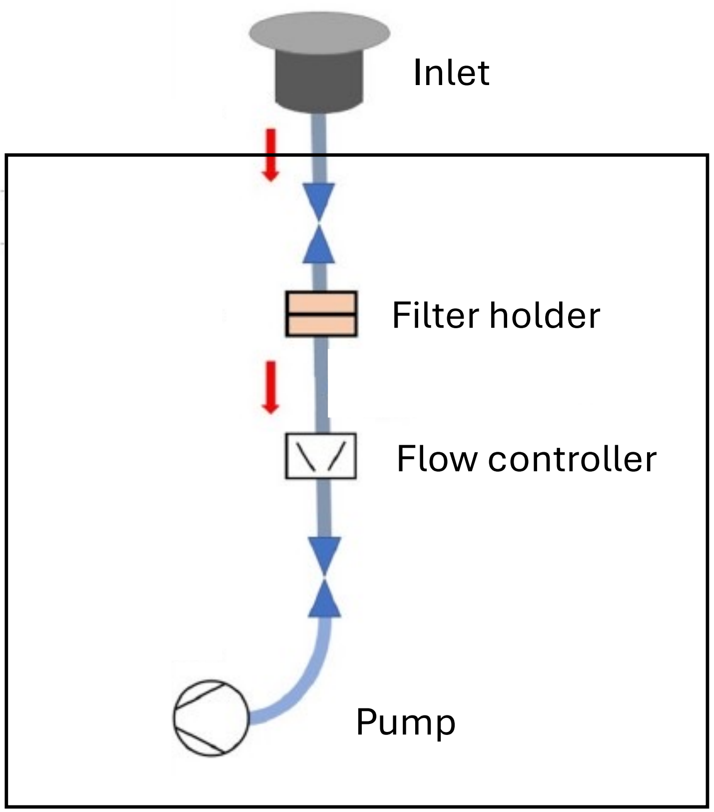
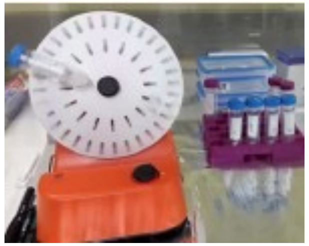


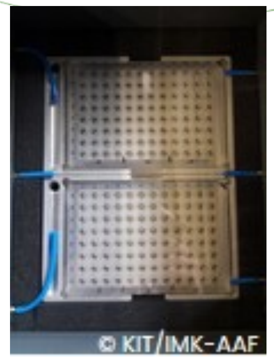
Step 2
Filter analysis



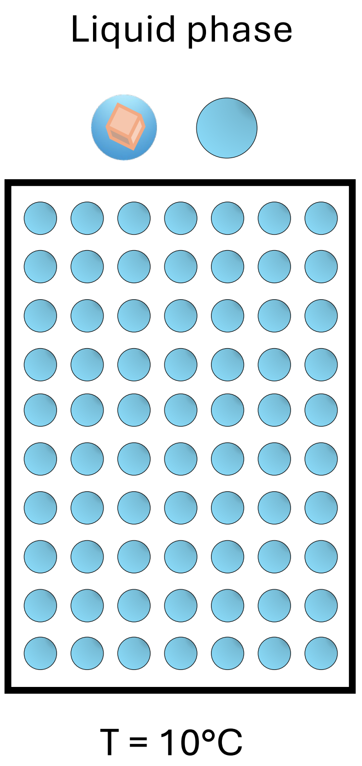
Wash off filter in water

Distribute water in wells

Cool down wells from 0°C to -28°C



INP - Filter measurements



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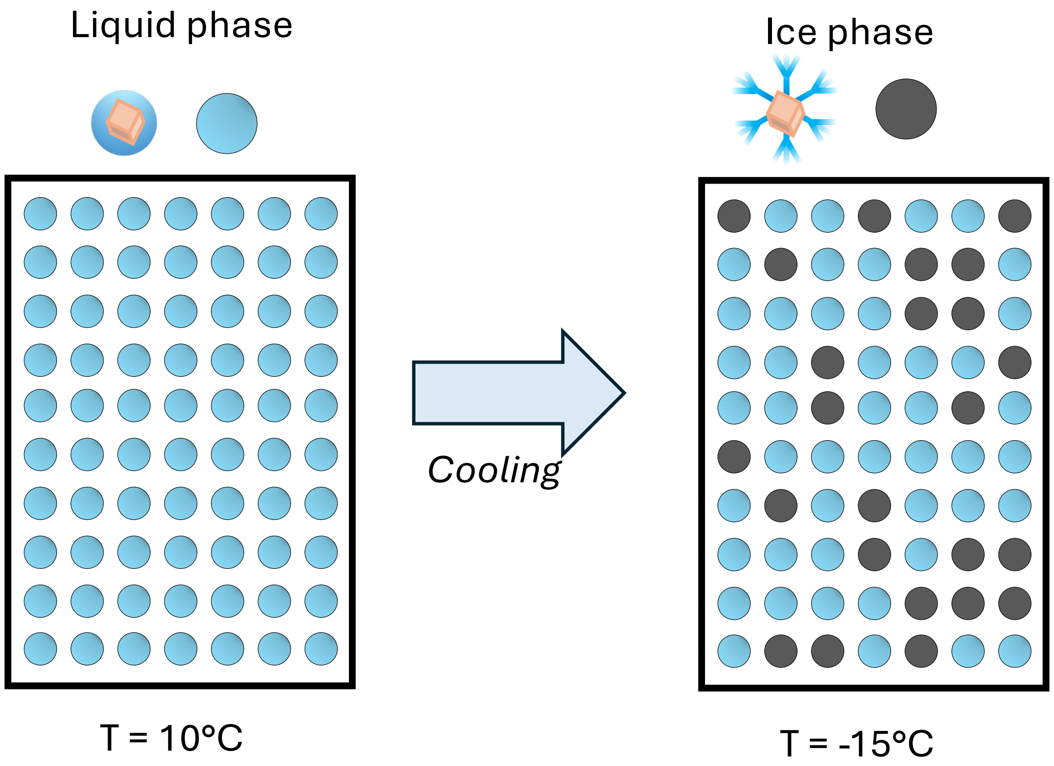
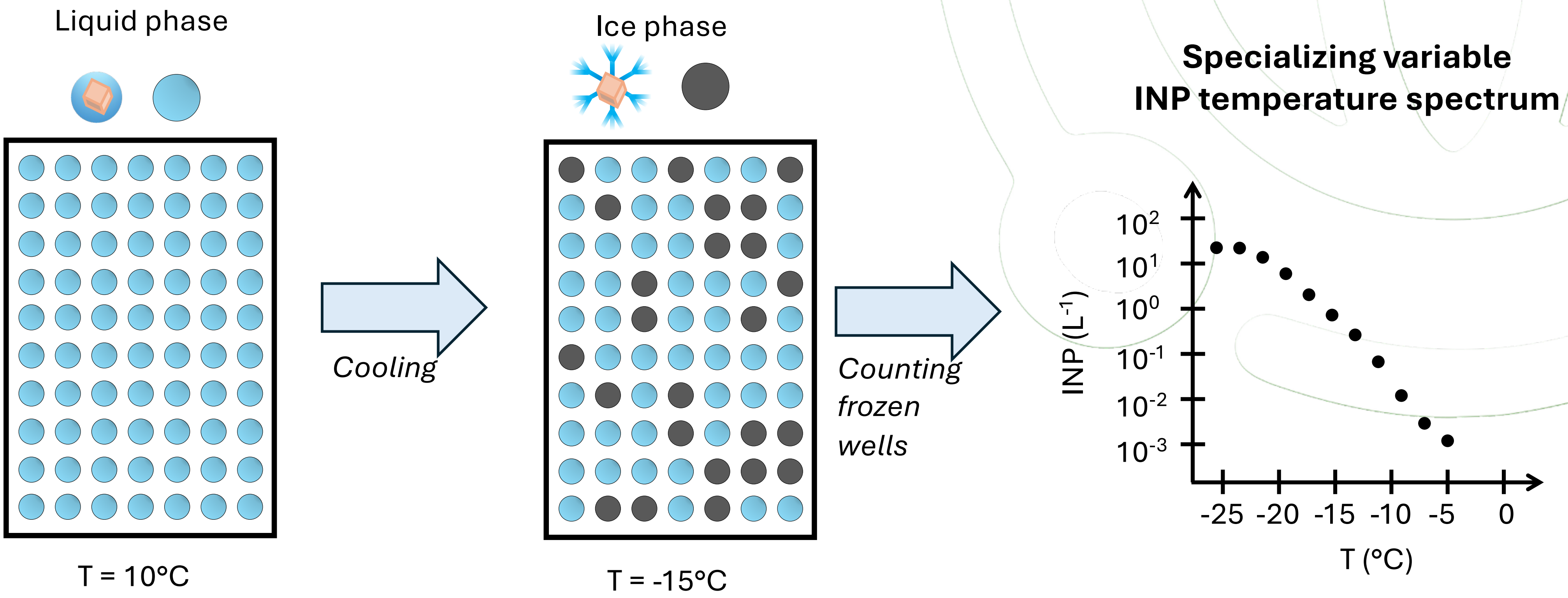


Change in brightness

INP - Filter measurements



Change in brightness

SOP – INP filter measurements

And what if you would like to do filter measurements?

- Flow box in the laboratory
- Consumables: filters, gloves, centrifuges tubes, petri dishes, tips for pipettes, aluminum foil
- Weekly handling blank filter
- Monthly leak test
- Annual participation in validation experiments
- Annual calibration of the temperature sensors
- Data treatment procedures still in development

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INP - Expansion chamber

PINE (Portable Ice Nucleation Experiment) – only available expansion chamber
Commercially available from Bilfinger Nuclear & Energy Transition GmbH

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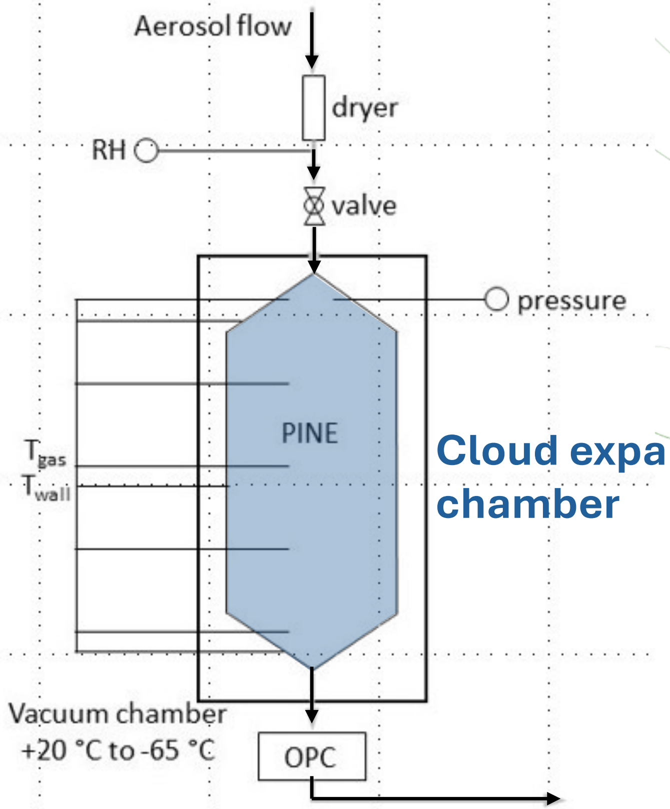
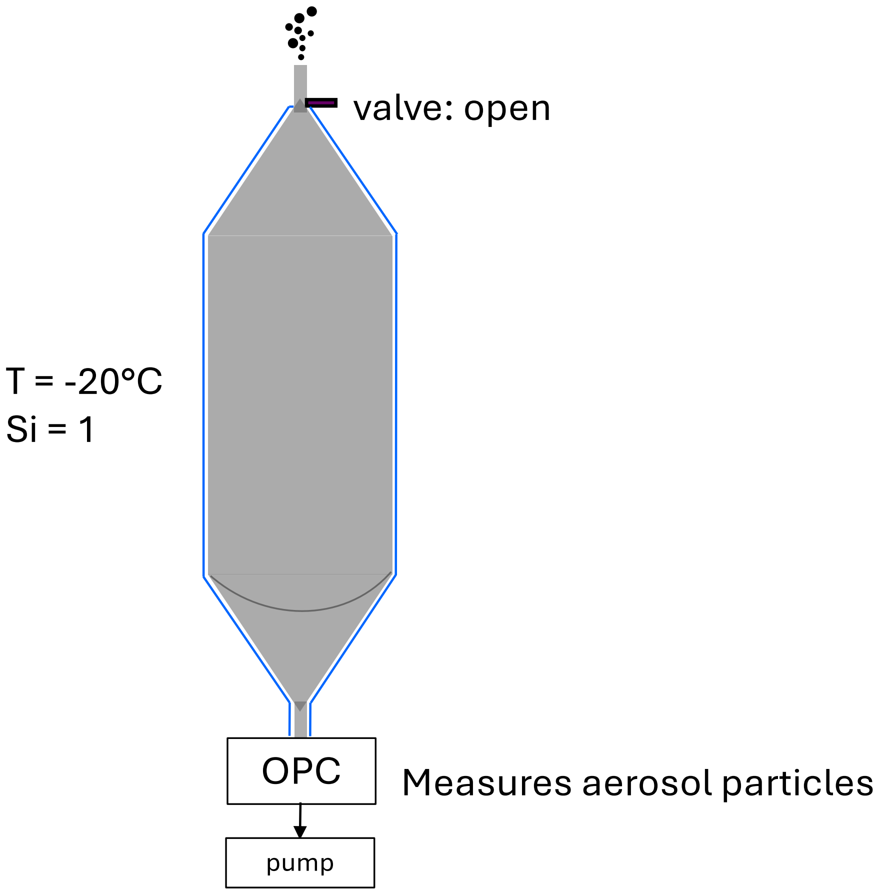


Cloud expansion chamber

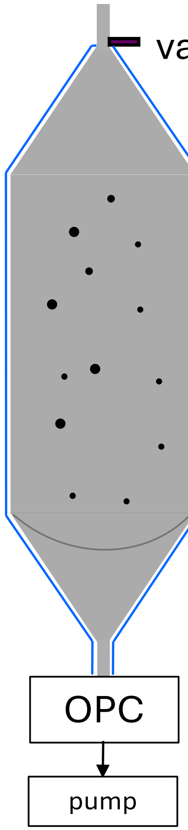
INP - Working principle of PINE



INP - Working principle of PINE

valve: open

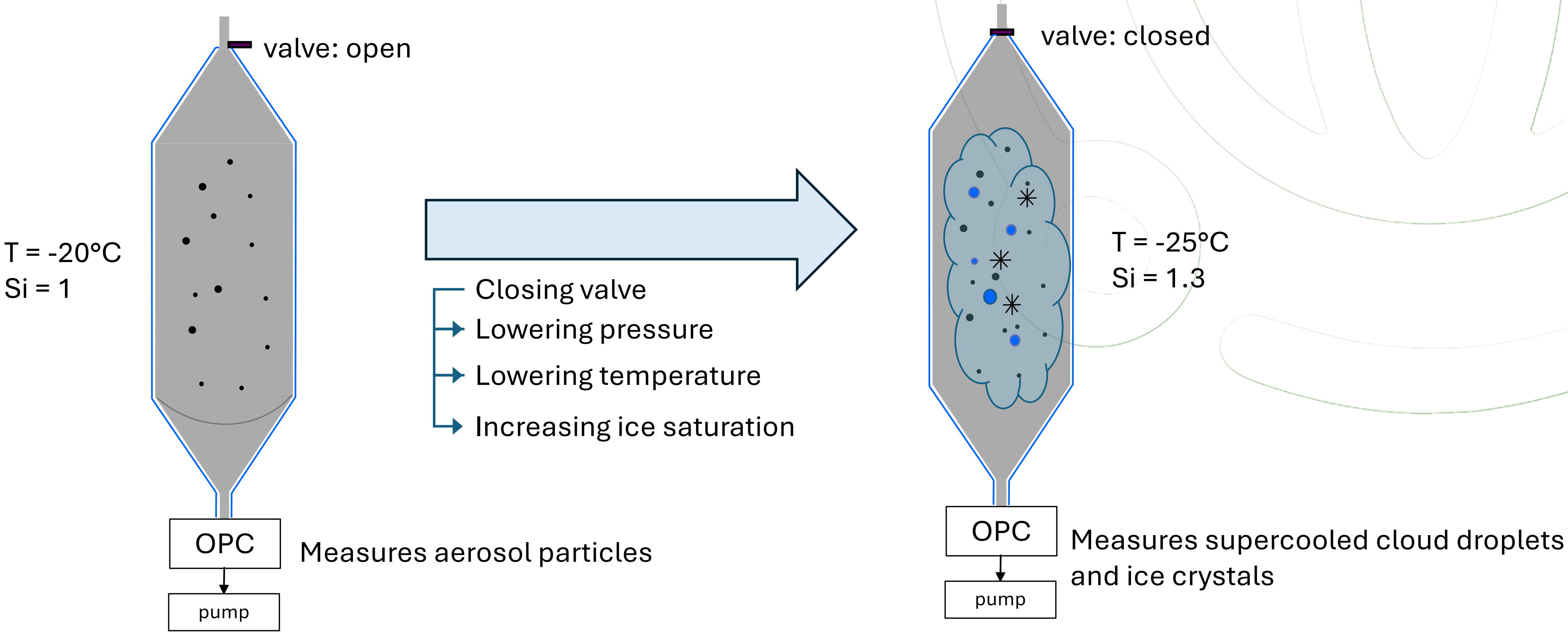
T = -20°C
Si = 1



Measures aerosol particles

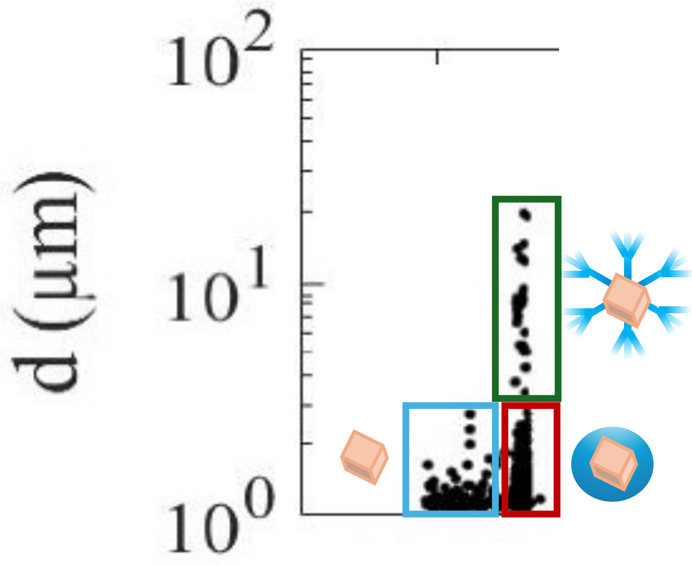
- Closing valve
- Lowering pressure
- Lowering temperature
- Increasing ice saturation

INP - Working principle of PINE



INP - Working principle of PINE

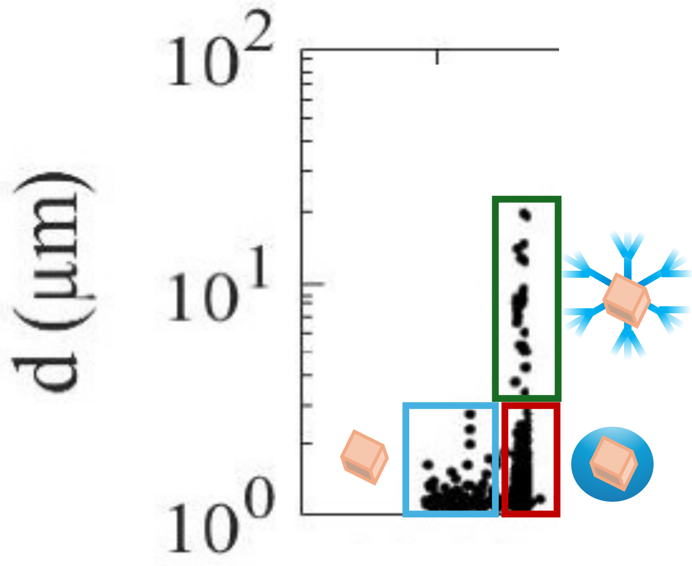
How do we distinguish supercooled cloud droplets from ice crystals?



Ice crystals are optically larger

INP - Working principle of PINE

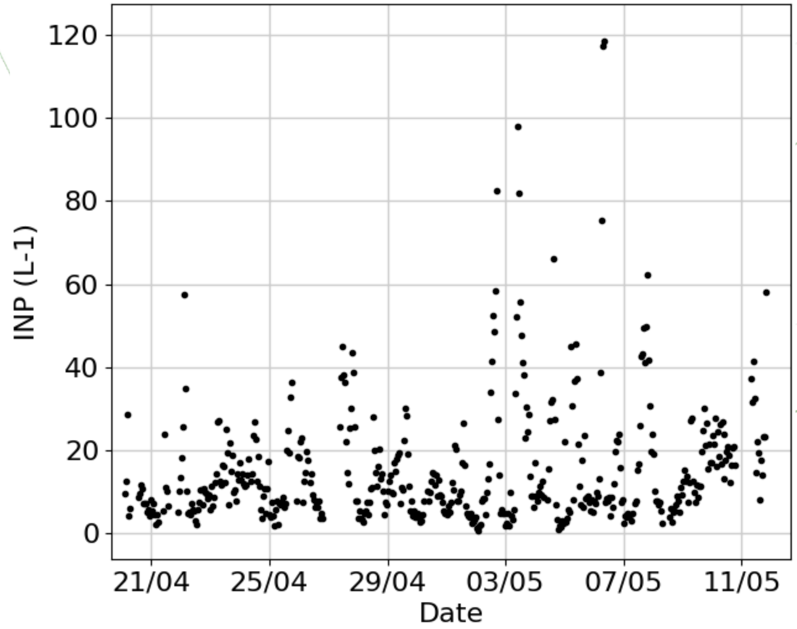
How do we distinguish supercooled cloud droplets from ice crystals?



Ice crystals are optically larger

After hours/days/weeks of measurements...

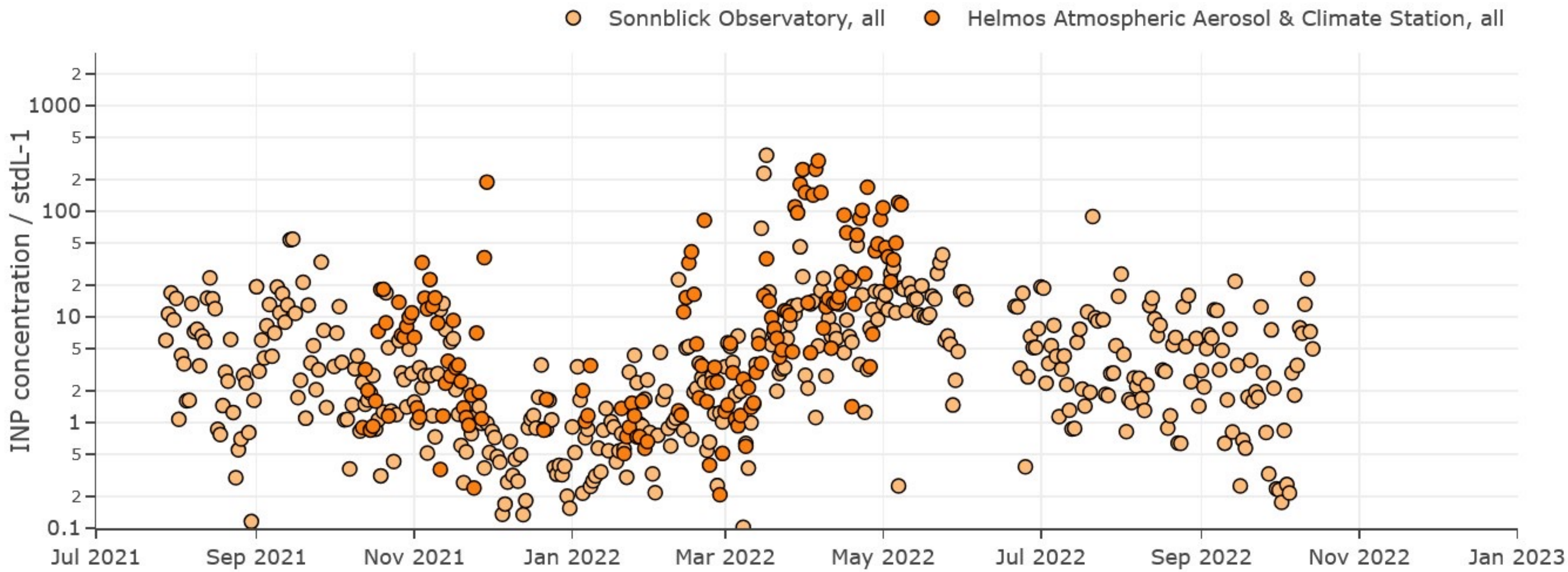
Specializing variable INP number concentration



INP – Example PINE long-term measurements

ITINERIS

Specializing variable
INP number concentration

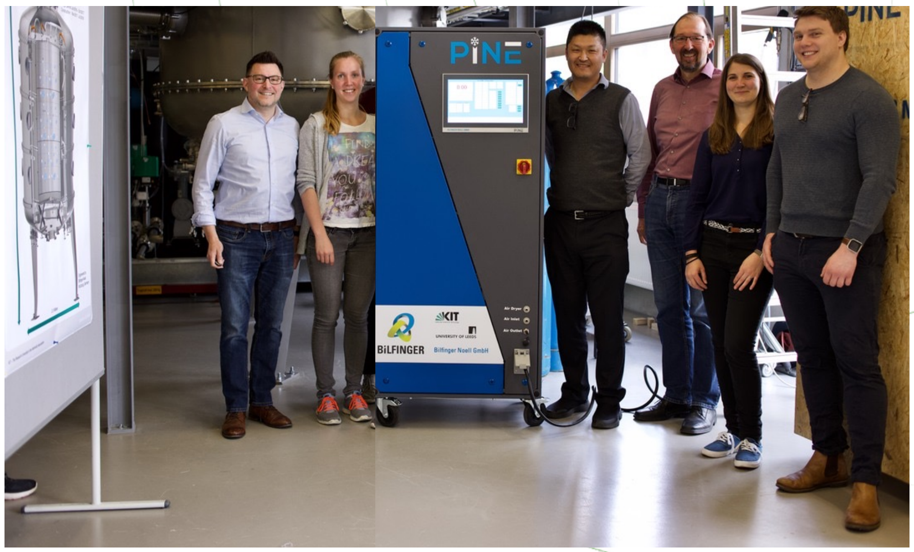


Graph taken from PINE data dashboard (https://pcp.imk.kit.edu/pine-dashboard)

SOP - PINE

And what if you would like to buy a PINE?

- Weight of 200 kg, size of 0.80 m x 0.60 m x 1.83 m
- Daily background test
- Every day at 11 pm operation of PINE at -25 °C for 1 hour
- Weekly leak test
- Weekly defrosting of the chamber
- Annual participation in validation experiments
- Software for data treatment for L0, L1, L2 data available on GitHub, but not yet ebas data submission



Questions

Could you do INP measurements at your station?

INTRO – Today's focus

ITINERIS

Describe the instruments and standard operation procedures to measure

1

Centre for Cloud Ice Nucleation

Karlsruhe Institute of Technology, DE

- INP number conc.
- INP temp. spectrum

SPECIALIZING

Centre for Aerosol In-Situ

European Centre for Aerosol Calibration and Characterization

Leibniz Institute for Tropospheric Research, DE

- CCN number conc.

SPECIALIZING

4

Centre for Cloud Ambient Intercomparison

GeoSphere Austria, AT

- Liquid water content
- Droplet effective diameter

MANDATORY

CLOUDS : EUROPEAN CENTER FOR CLOUD AMBIENT INTERCOMPARISON (ECCINT)

ECCINT is located at Mt. Hoher Sonnblick (3.106 m asl)
at the Sonnblick Observatory in Austria
SONNBLICK TOUR

A bit of history

1886 → First meteorological observations
1890 → First "cloud research" on thunderstorms
2003 → First PVM study
2016 → Integration into ACTRIS
2018-20 → Implementation of ECCINT topic into CIS
2025-26 → ECCINT will start operation

Mission

Responsible for the mandatory integrated cloud probes
Support cloud in situ National Facilities

CLOUDS : Definition of mandatory variables

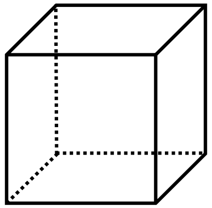
Liquid water content - LWC

Mass of liquid water droplets suspended in a unit volume of air within a cloud

$$LWC = \frac{mass\ of\ water\ [g]}{Volume\ of\ air\ [m^3]}$$

Water mass

Air volume

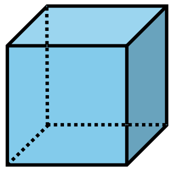


Droplet effective radius - r_e

Area-weighted average radius of cloud droplets

$$r_e = \frac{droplets\ number\ * droplets\ volume [m^3]}{droplets\ number\ * droplets\ area\ [m^2]}$$

Water volume



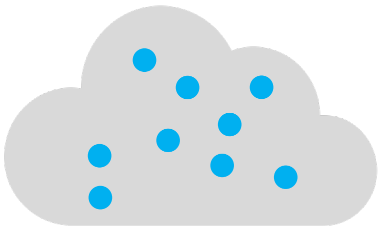
Water surface

CLOUDS : importance of mandatory variables

LWC & r_e define opacity and precipitation likelihood

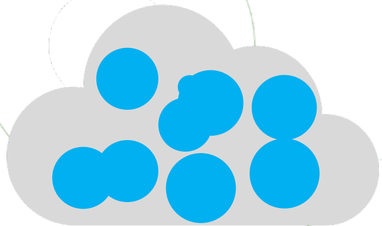
LWC defines how much water is present in the cloud
r_e defines how water is distributed

Cumulus cloud LWC = 3 g/m^3
Low radius



High surface to volume ratio
High reflectivity
LOW OPACITY

Cumulus cloud LWC = 3 g/m^3
High radius



Low surface to volume ratio
Low reflectivity
HIGH OPACITY

Increasing LWC → increase precipitation severity

CLOUDS : cloud probes

Optically based outdoor probes
Liquid water content and effective radius

Open cavity technique

Particle volume monitor
PVM

Gerber, USA
Discontinued

Sampling technique

Fog monitor
FM-100

DMT, USA
Commercial

Ground-Based Fog and Aerosol Spectrometer
GFAS

DMT, USA
Commercial

Cloud droplet analyzer
CDA

PALAS, DE
Commercial

CLOUDS : ECCINT intercomparison campaigns

Two intercomparison 2022-2024
Sonnblick observatory

Ground-Based Fog and Aerosol Spectrometer GFAS

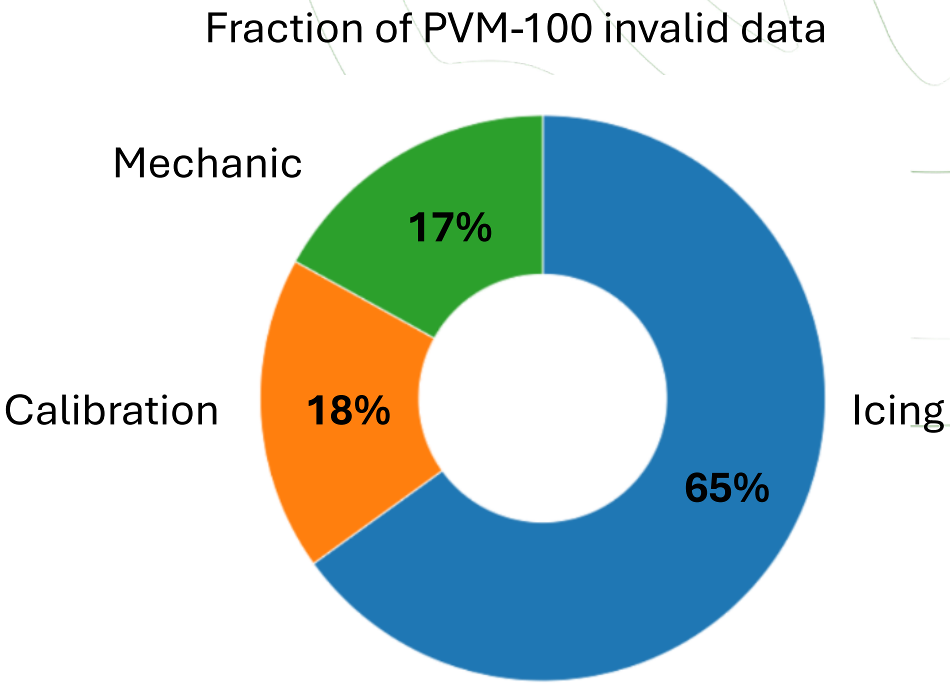
Particle volume monitor PVM

Fog monitor FM-100

Cloud droplet analyzer CDA

CLOUDS : ECCINT intercomparison outcome

Most recurring problems for cloud probes



CLOUDS – Measuring requirements

And what if you want to become a CIS national facility?

- You must be in cloud or fog
- You must measure LWC and r_e
- Full time job → 24/7 monitoring
- Sampling resolution → 1s
- Better have complementary observations for cloud identification: RH, webcam, visibility

CLOUDS – Measuring requirements

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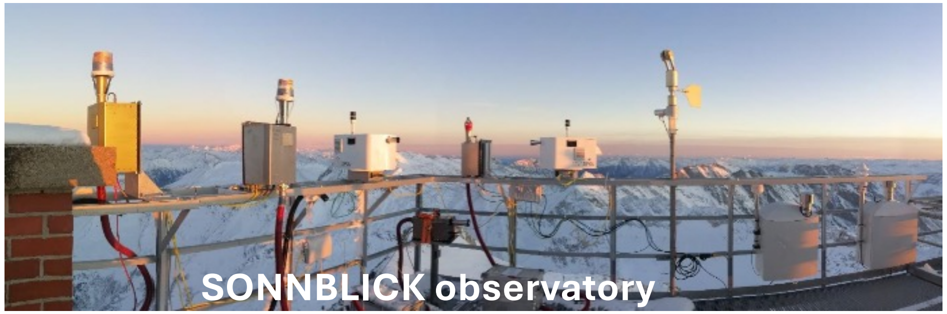
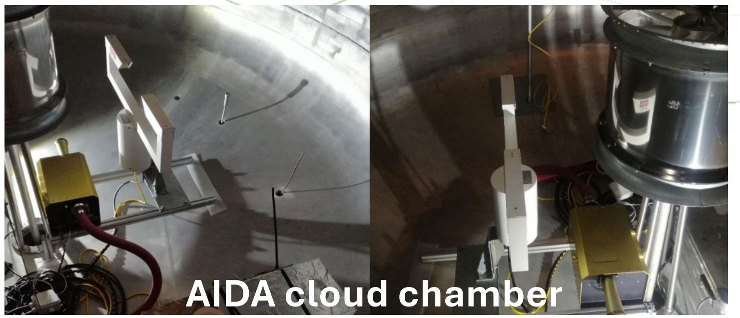
ECCINT
ambient observation



CIS central facility
Chamber testing



THIS IS A WORK IN PROGRES

Questions

Could you to LWC measurements at your station?

CONCLUSIONS

CCN NUMBER CONCENTRATION	CAIS-ECAC	Specializing	Full SOP Data submission possible
INP NUMBER CONCENTRATION	CIS-CCice	Specializing	Preliminary SOP Data submission not yet possible
INP TEMPERATURE SPECTRUM	CIS-CCice	Specializing	Preliminary SOP Data submission not yet possible
LIQUID WATER CONTENT EFFECTIVE RADIUS	CIS-ECCINT	Mandatory	SOP in discussion Data submission not yet possible

Outline for Monte Cimone

ITINERIS

- **2014**
- **2015** – Filter based INP measurements
- **2018**
- **2021** – Start of CCN measurements
- **Oct.2024** – Liquid cloud chemistry ATMO-ACCES
- **Jul. 2025** – TNA ITINERIS INP filter validation
- **2025** – Start of PINE INP measurements; LWC – re measurement; Water Cloud sampling
- **2026** – Labelling procedure CIS-NF

Questions

Which of the measurements would you include in your line of research/at your station?

For what would you use cloud in-situ measurements?

Which of these measurements you can't include in your observatory, because you cannot fulfill the requirements?

Are you working with clouds in your project; if not would you like to work more with clouds; if yes with what (CCN, INP, cloud micro physics, et al.)

ITINERIS

THANKS!

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(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

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Ministero dell'Università e della Ricerca

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