

# Ice Nucleating particle concentrations in the Arctic Free Troposphere

Jonas Schaefer<sup>1</sup>, Sarah Grawe<sup>1</sup>, David Simon<sup>1</sup>, Markus Hartmann<sup>1</sup>, Bruno Wetzel<sup>1</sup>, Jörg Hartmann<sup>2</sup>, Benjamin Kirbus<sup>3</sup>, Laura Köhler<sup>2</sup>, Zsafia Jurányi<sup>2</sup>, Andreas Herber<sup>2</sup>, Manfred Wendisch<sup>3</sup>, Silvia Henning<sup>1</sup>, Mira Pöhlker<sup>1,3</sup>, Frank Stratmann<sup>1</sup>

<sup>1</sup>Leibniz Institute for tropospheric research (TROPOS), Leipzig

<sup>2</sup>Alfred-Wegener-Institut (AWI), Bermerhaven

<sup>3</sup>Leipzig Institute for Meteorology, University of Leipzig

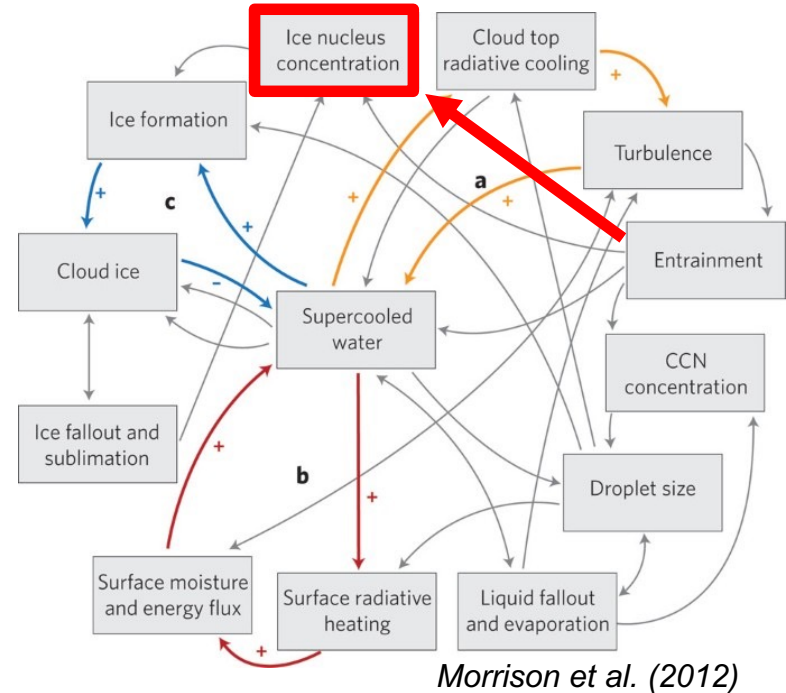


**TROPOS**  
Leibniz Institute for  
Tropospheric Research

# Why are free tropospheric INP important?

- Free tropospheric INPs may entrain into Arctic mixed-phase clouds, initiating ice formation
  - altering cloud lifetime and radiative properties

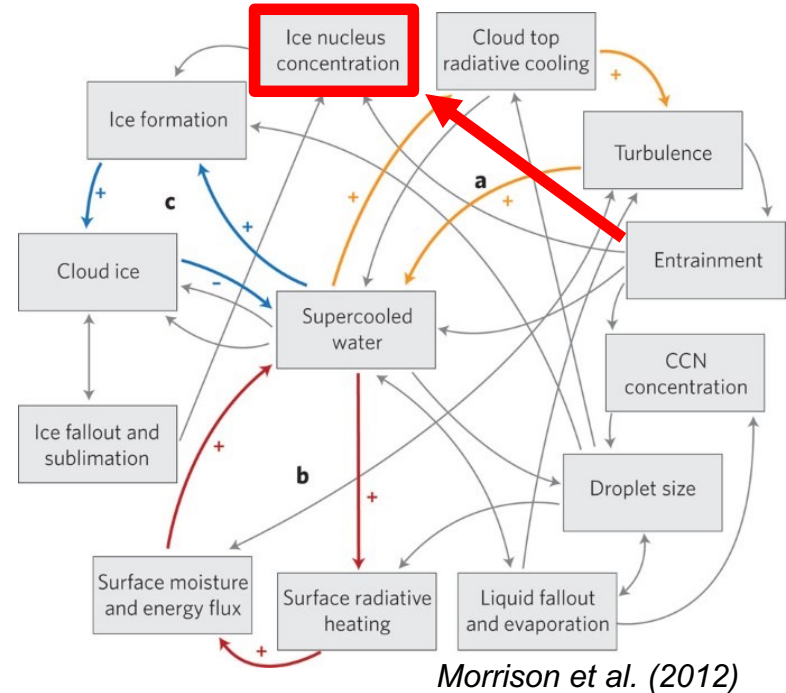
## Interplay of Arctic mixed-phase clouds



# Why are free tropospheric INP important?

- Free tropospheric INPs may entrain into Arctic mixed-phase clouds, initiating ice formation
  - altering cloud lifetime and radiative properties
- Measurements of free tropospheric INP in the Arctic are extremely sparse

## Interplay of Arctic mixed-phase clouds



# Filter sampling with HERA on Polar 6



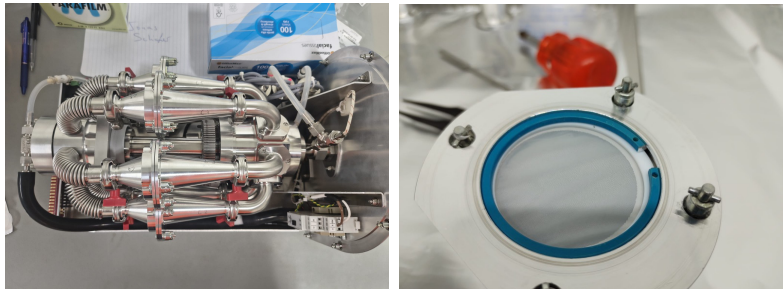
Aerosol Inlet

# Filter sampling with HERA on Polar 6



Aerosol Inlet

- **HERA** (Grawe et al. 2023)
- 30 - 40 lpm sampling flow rate
- 0.8  $\mu\text{m}$  polycarbonate filter
- 6 filters available per flight



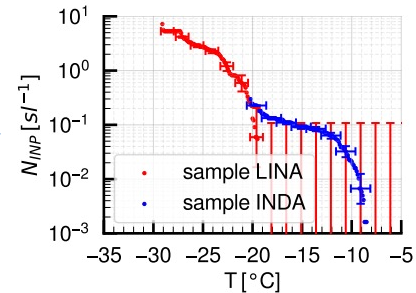
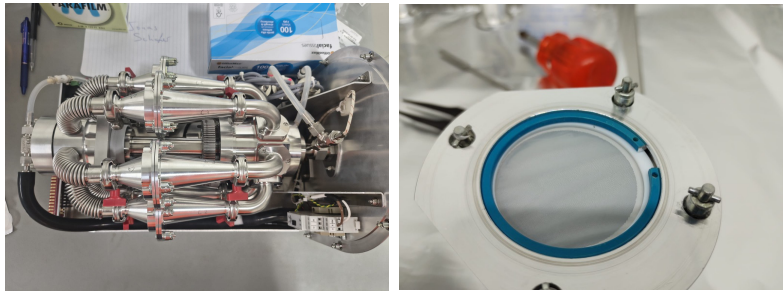
# Filter sampling with HERA on Polar 6



Aerosol Inlet

- **HERA** (Grawe et al. 2023)

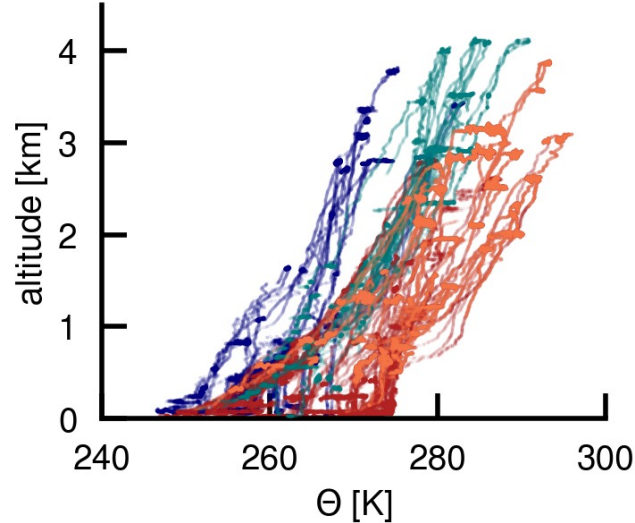
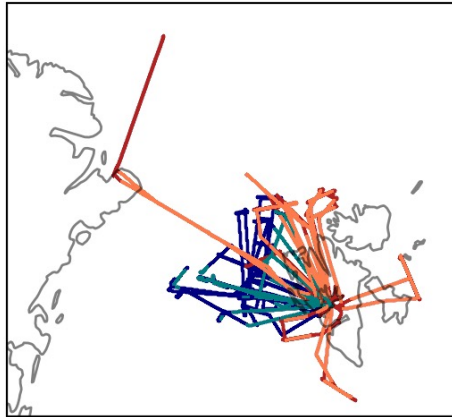
- 30 - 40 lpm sampling flow rate
- 0.8  $\mu\text{m}$  polycarbonate filter
- 6 filters available per flight



# Campaigns

HALO-AC<sup>3</sup>: 20 March – 10 April 2022

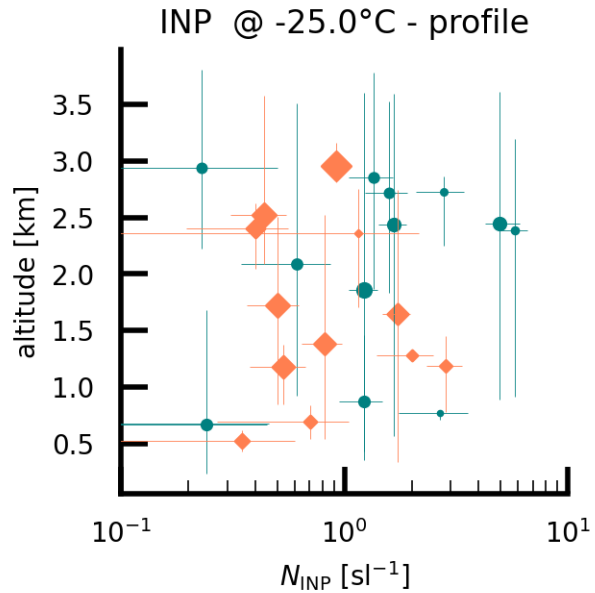
BACSAM2: 7 April – 29 April 2024



- HALO-AC3 - entire track
- HALO-AC3 - FT sample
- BACSAM2 - entire track
- BACSAM2 - FT sample

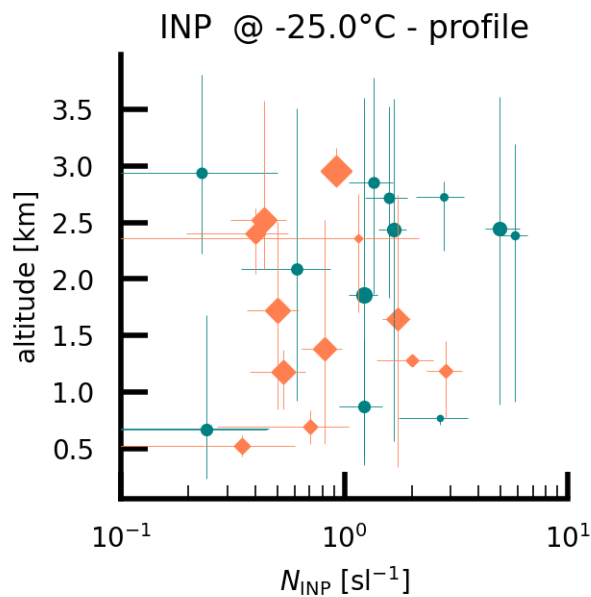
- 81 INP samples
- 35 samples in Arctic free troposphere ( → above atmospheric boundary layer and clouds)
  - ~38 hours of sampling
  - ~60 sm<sup>3</sup> air sampled

# Vertical profile of free tropospheric INP concentrations

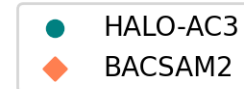
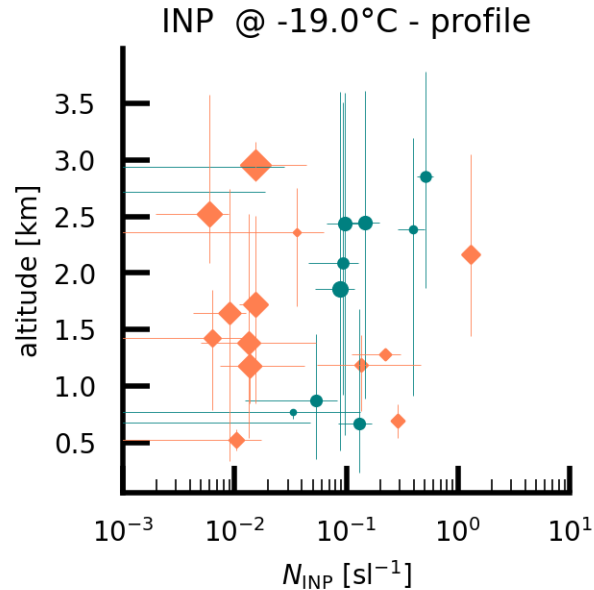


- no pattern recognizable

# Vertical profile of free tropospheric INP concentrations



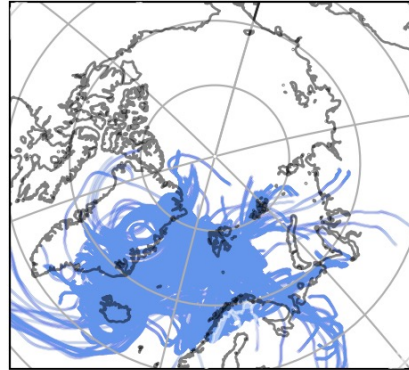
- no pattern recognizable



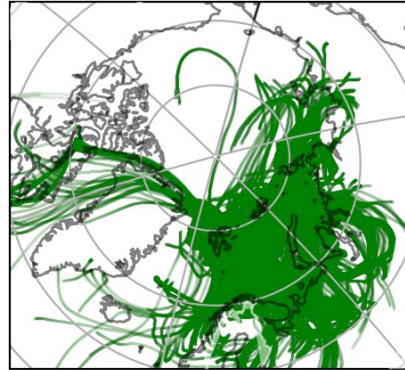
- higher INP concentrations during HALO-AC3 than during BACSAM2
- higher variability in higher altitude

# 5-Day backward Trajectories of free tropospheric filter samples

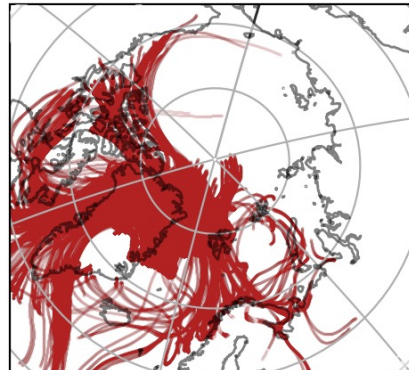
Atlantic  
n = 8



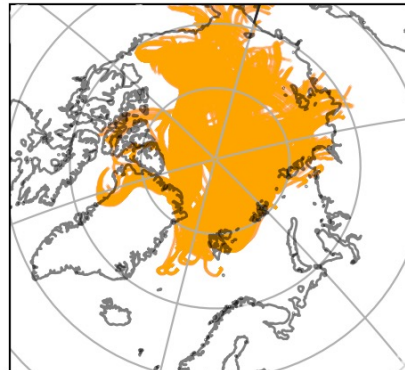
Europe/Asia  
n = 16



Canada/Greenland  
n = 9



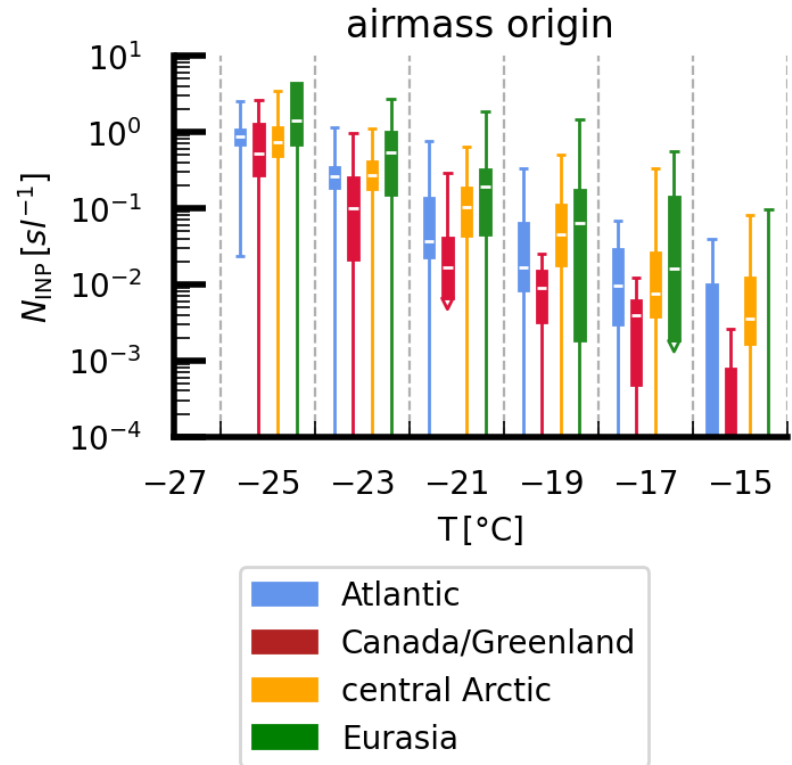
Central Arctic  
n = 10



# INP concentration in different air masses

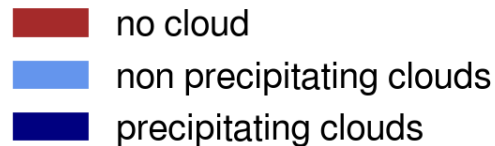
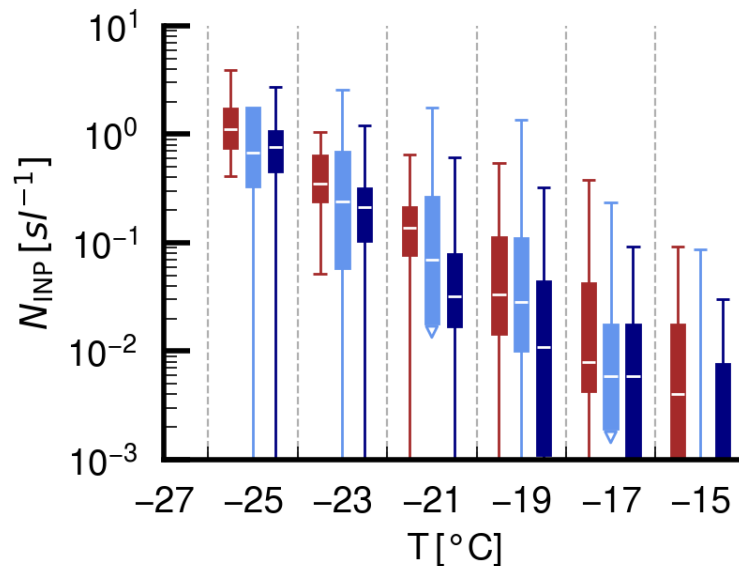
INP concentration in air masses originating from:

- higher concentration from Europe/Asia and central Arctic
- lower concentration from Canada/Greenland and Atlantic

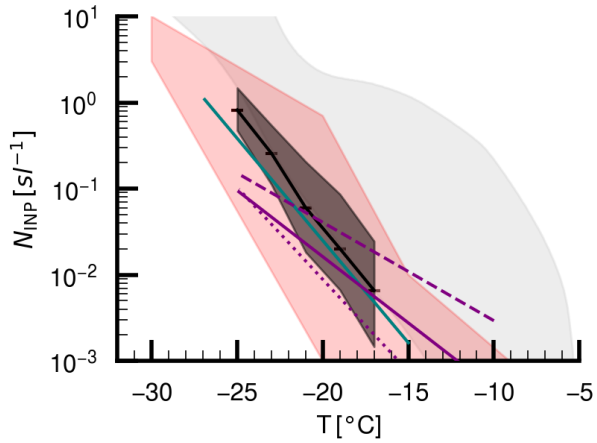


# Precipitation history of clouds

- Lower INP concentrations when air comes from precipitating clouds



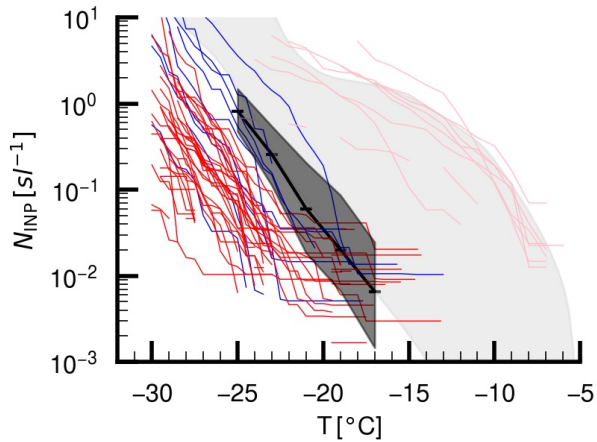
# Comparison to ground measurement



- median FT INP concentrations
- IQR - HALO-AC3 and BACSAM2
- Petters & Wright (2015)
- Andenes spring - Gjelsvik et al. (2025)
- ⋯ Villum winter - Sze et al. (2023)
- - - Villum summer - Sze et al. (2023)
- Villum winter - Sze et al. (2023)
- MOSAiC Winter - Creamean et al. (2022)

- FT INP concentrations below typical mid-latitude INP concentrations
- FT INP concentrations are similar to those of long-term ground measurements

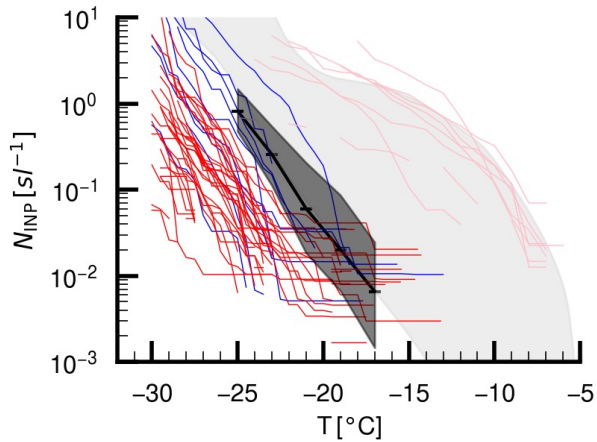
# Comparison to other airborne measurements



- median FT INP concentrations
- IQR - HALO-AC3 and BACSAM2
- Petters & Wright 2015
- ARCSIX - above cloud, summer 2024
- CEASAR - above cloud, spring 2022
- ACAO - above cloud, spring 2022  
Raif et al. (2024)

- FT INP concentrations below typical mid-latitude INP concentrations
- FT INP concentrations are similar to those of long-term ground measurements
- FT INP concentrations from HALO-AC3 + BACSAM2 INP concentration are between those from ARCSIX, CEASAR (lower) and ACAO (higher)

# Comparison to other airborne measurements



- median FT INP concentrations
- IQR - HALO-AC3 and BACSAM2
- Petters & Wright 2015
- ARCSIX - above cloud, summer 2024
- CEASAR - above cloud, spring 2022
- ACAO - above cloud, spring 2022  
Raif et al. (2024)

- FT INP concentrations below typical mid-latitude INP concentrations
- FT INP concentrations are similar to those of long-term ground measurements
- FT INP concentrations from HALO-AC3 + BACSAM2 INP concentration are between those from ARCSIX, CEASAR (lower) and ACAO (higher)

## Summary

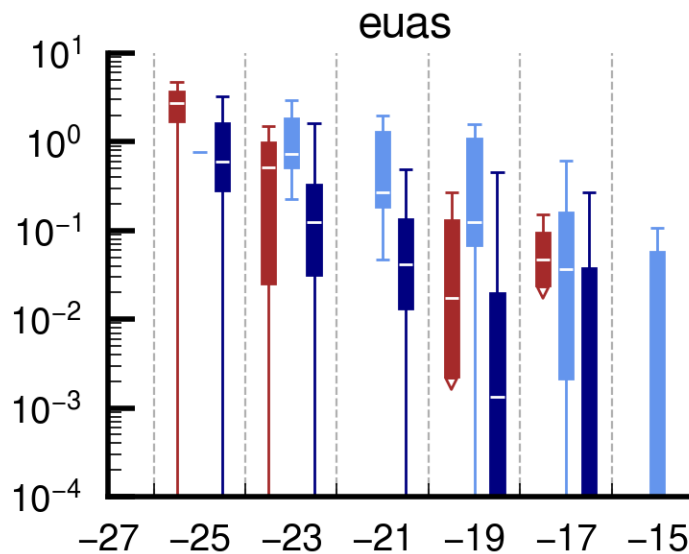
- Low INP concentrations in Arctic free troposphere
- Dependence on:
  - Air mass origin regions
  - Air mass precipitation history
- Work in progress...

Thanks for your attention

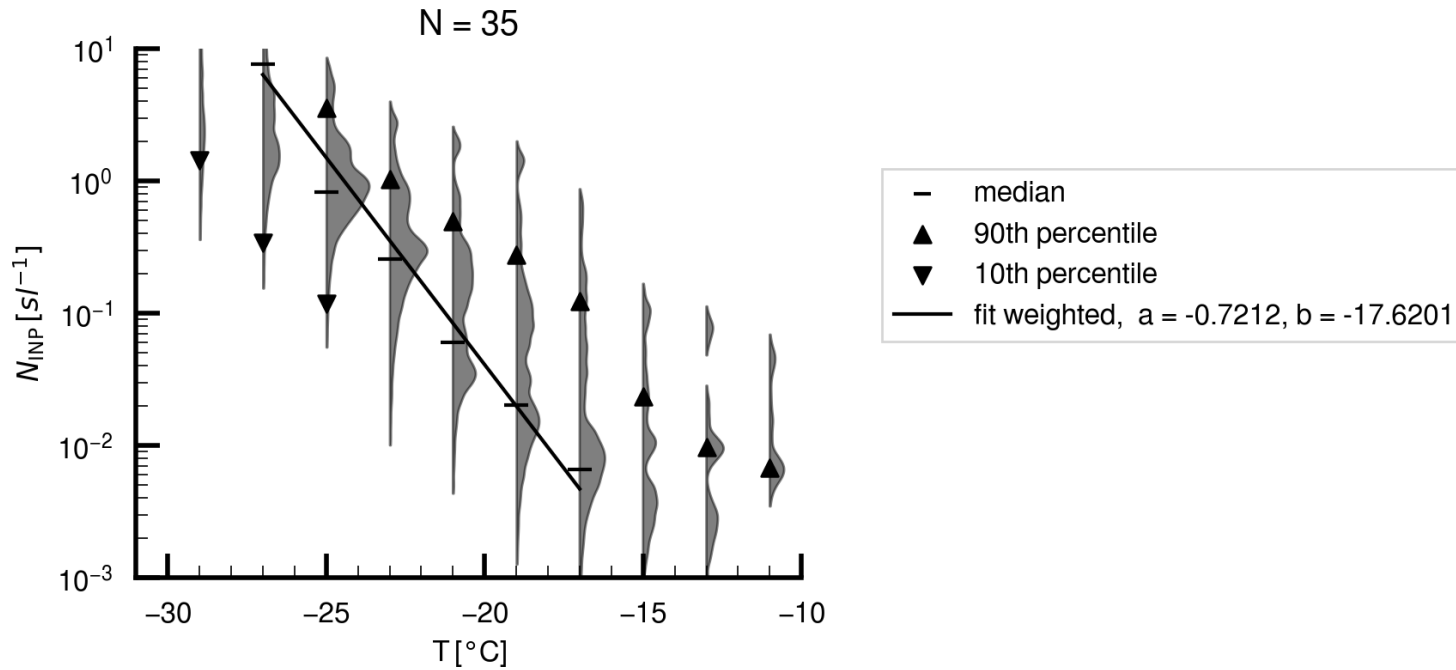


# Precipitation history of clouds

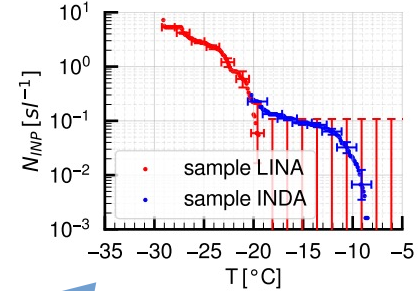
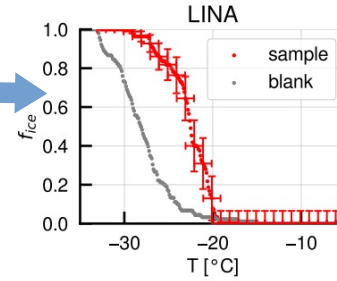
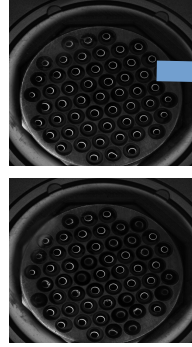
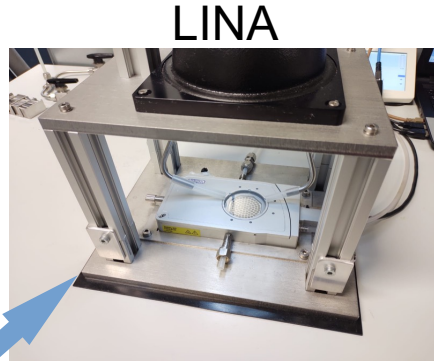
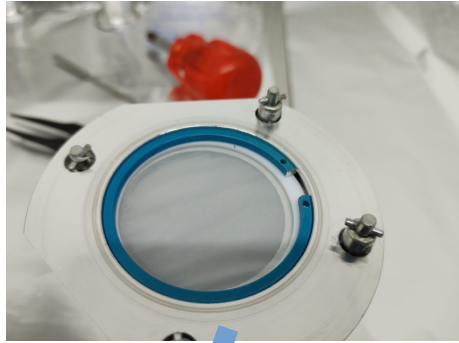
- Lower INP concentrations when air comes from precipitating clouds
  - Preferential INP scavenging?



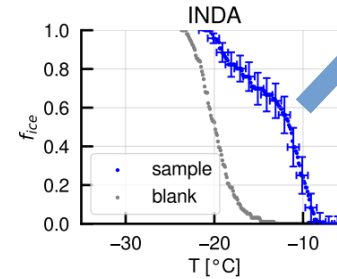
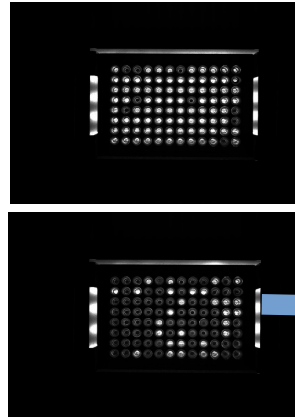
# INP-Spectra in the Arctic free troposphere



# offline INP analysis with INDA and LINA

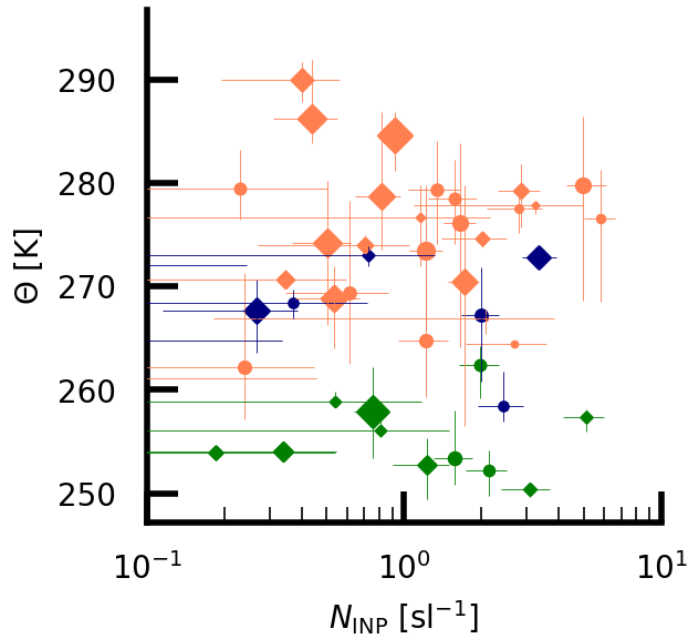


$$N_{INP}(T) = -\frac{\ln(1 - f_{ice}(T))}{V_{air} \frac{V_d}{V_w}}$$

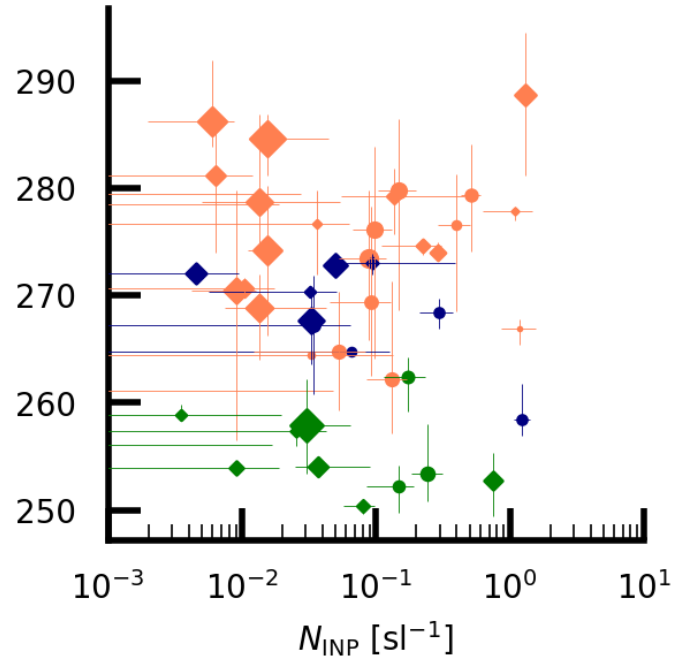


# Theta – INP

## INP @ -25.0°C - profile



## INP @ -19.0°C - profile



- Free troposphere
- low over open ocean/MIP
- low over ice

