Overview of Ice Nucleating Particle Findings from CAESAR and ARCSIX

Russell Perkins

Colorado State University

Arctic Workshop 6-2-2026

NSF Cold Air outbreak Experiment in the Sub-Arctic Region (CAESAR)

- NCAR RAF C-130
- February-April 2024
- Lead PI's
  - Paquita Zuidema (University of Miami)
  - Bart Geerts (University of Wyoming, soon NCAR RAF)
  - Greg McFarquhar (University of Oklahoma)

NASA Arctic Radiation Cloud Aerosol Surface Interaction Experiment (ARCSIX)

- NASA Wallops P3, NASA Langley G3, Spec Leerjet
- May-June and July-August 2024
- Lead PI Sebastian Schmidt (CU Boulder)

Both Measured:
In situ aerosol, INP, cloud microphysics, remote sensing

Lots of instrument PI's for both campaigns!

The rest of the CSU Team:

Bo Chen
Ryan Patnaude (now at NOAA)
Kevin Barry
Camille Mavis
Drew Juergensen
Oren Dutton
Jessie Creamean
Paul DeMott
Sonia Kreidenweis

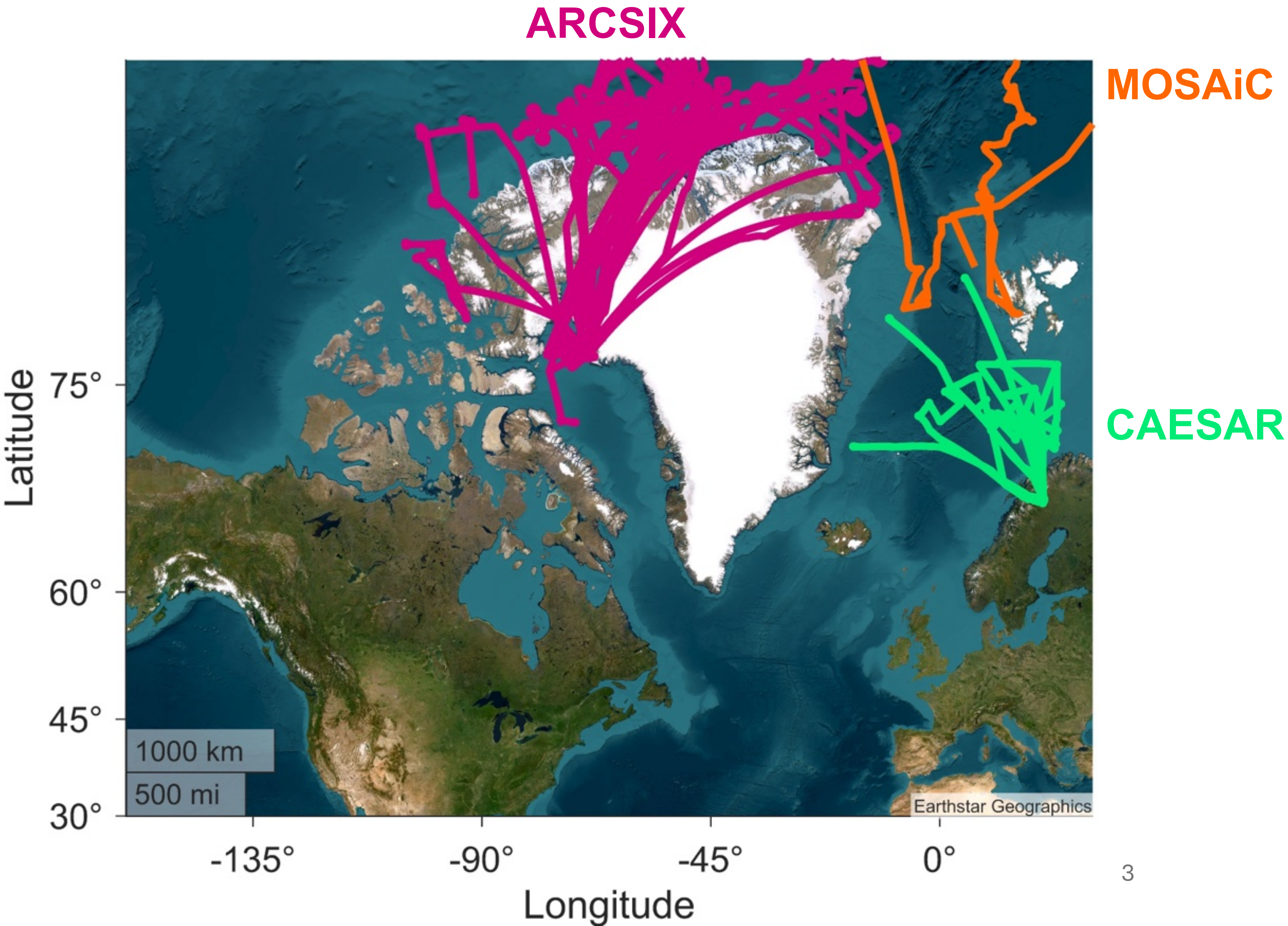
Support for this work is given by: NSF AGS-2150040, NASA 80NSSC22K1759P00002, U.S. DOE ARM facility (DE-AC05-76RL01830), ASR program (DE-SC0022046, DE-SC0019745).

Recent field campaigns aim to close the gaps by providing ground and airborne INP observations

May-June
July-August
2024

October 2019-
September
2020

February-April
2024



Primary Ice Production (PIP)

Let's stick with the mixed-phase temperature regime for now!

0 to ~-38 °C

All primary ice is from heterogeneous nucleation (you need an INP)

Kanji, Z. A.; Ladino, L. A.; Wex, H.; Boose, Y.; Burkert-Kohn, M.; Cziczo, D. J.; Krämer, M. Overview of Ice Nucleating Particles. *Meteorological Monographs* **2017**, *58*, 1.1-1.33.

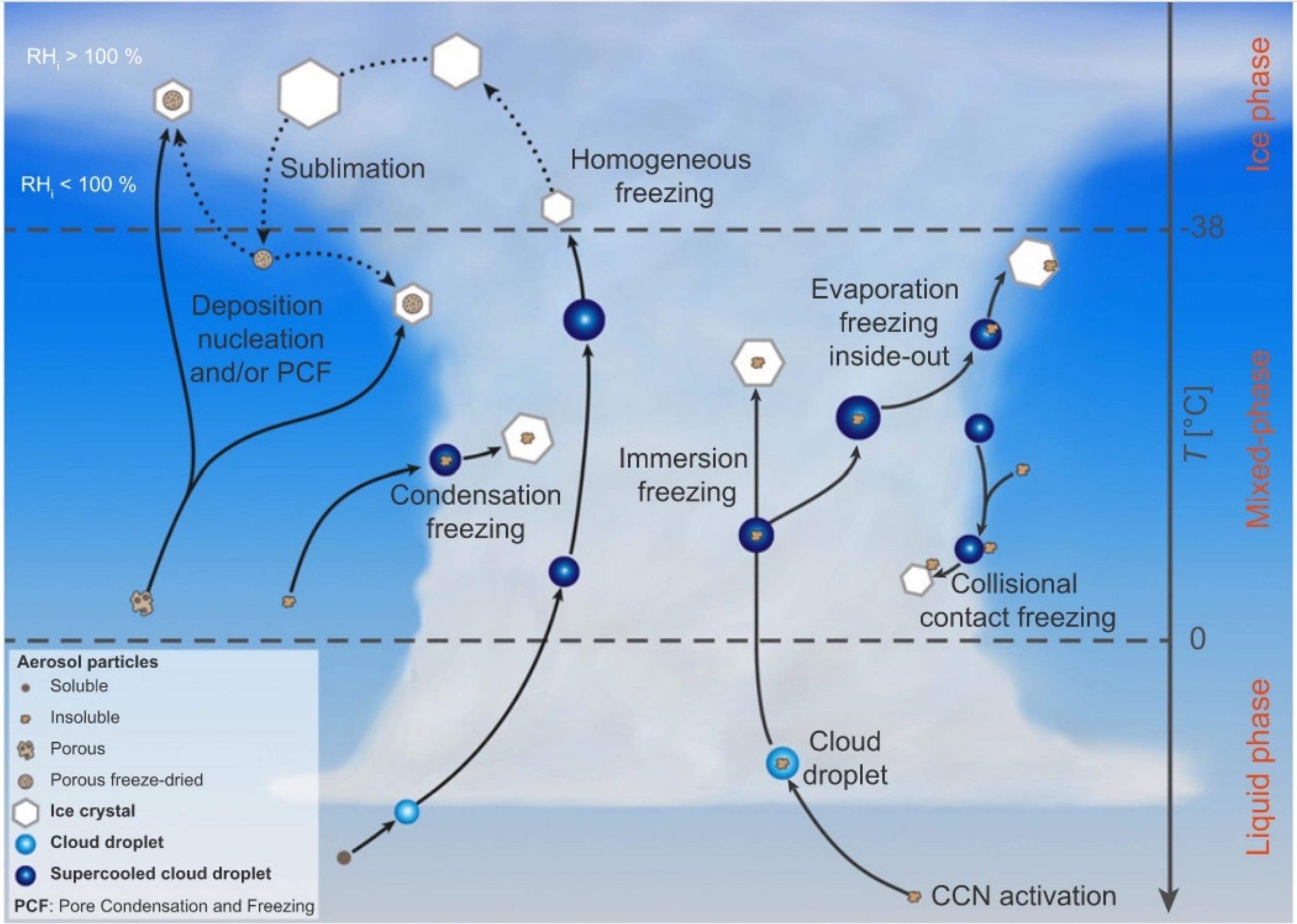
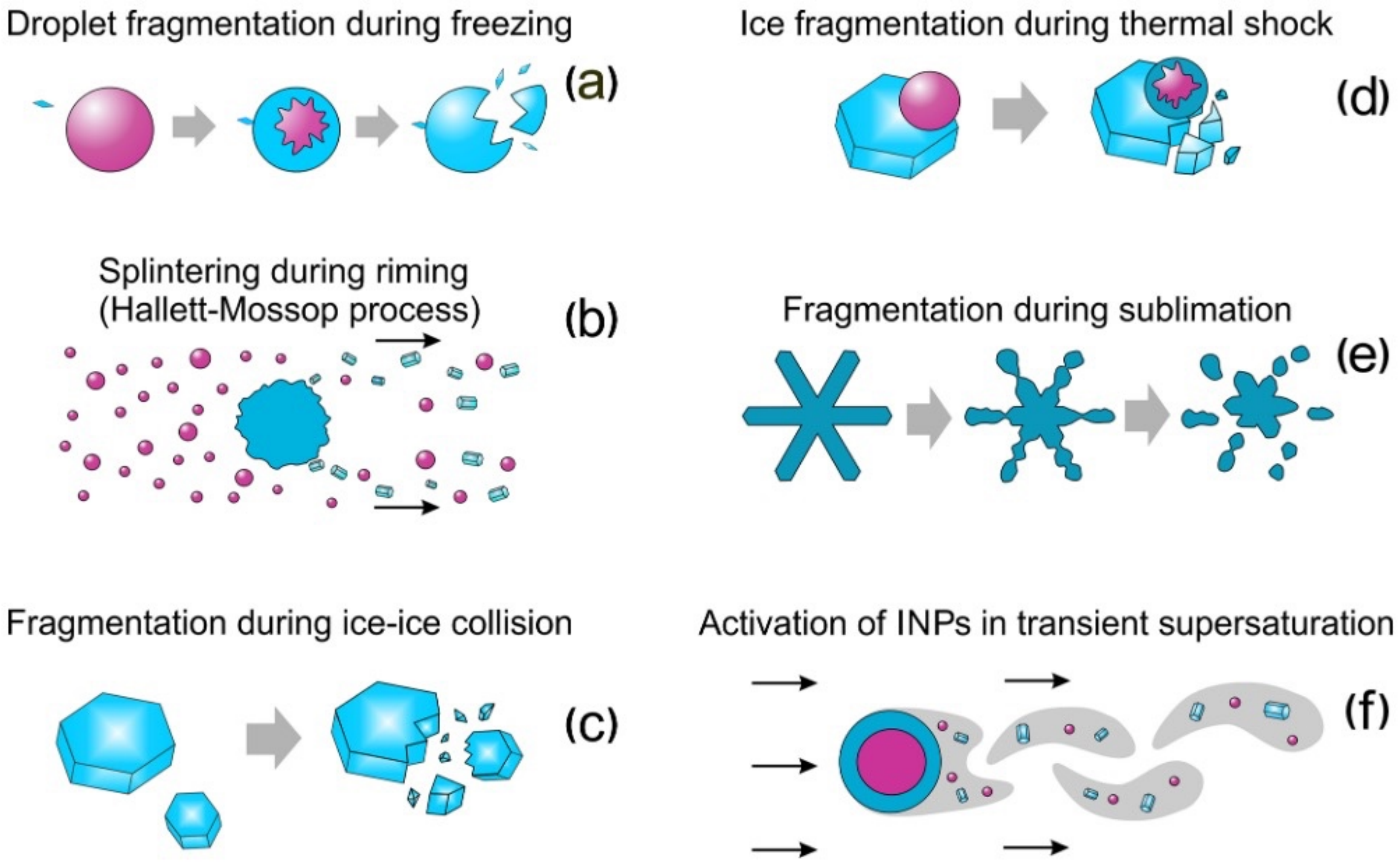


FIG. 1-1. Schematic depicting known primary ice nucleation pathways possible in the atmosphere.

Secondary Ice Production (SIP)



SIP processes may not be well parameterized or understood.

It is likely there are SIP processes we are missing entirely!

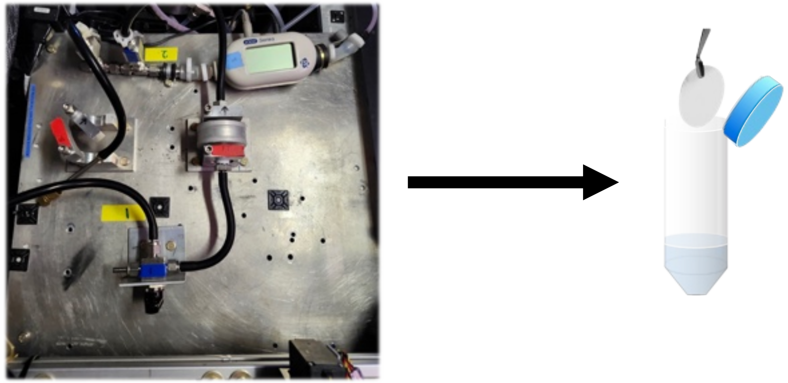
SIP depends on PIP, we still need good INP characterization.

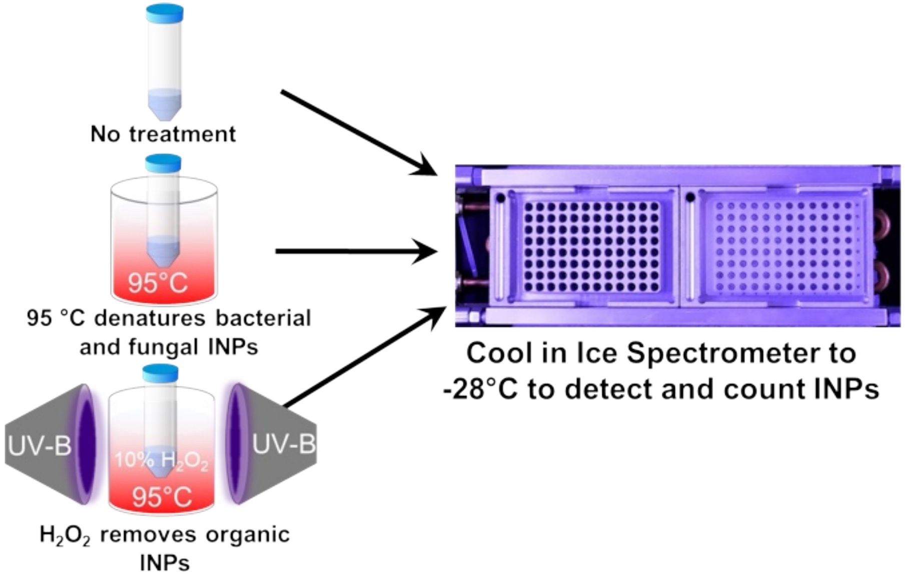
Warm-freezing INPs may be particularly important for SIP.

Korolev, A.; Leisner, T. Review of Experimental Studies of Secondary Ice Production. *Atmospheric Chemistry and Physics* **2020**, *20* (20), 11767–11797.

INP Sampling Strategies

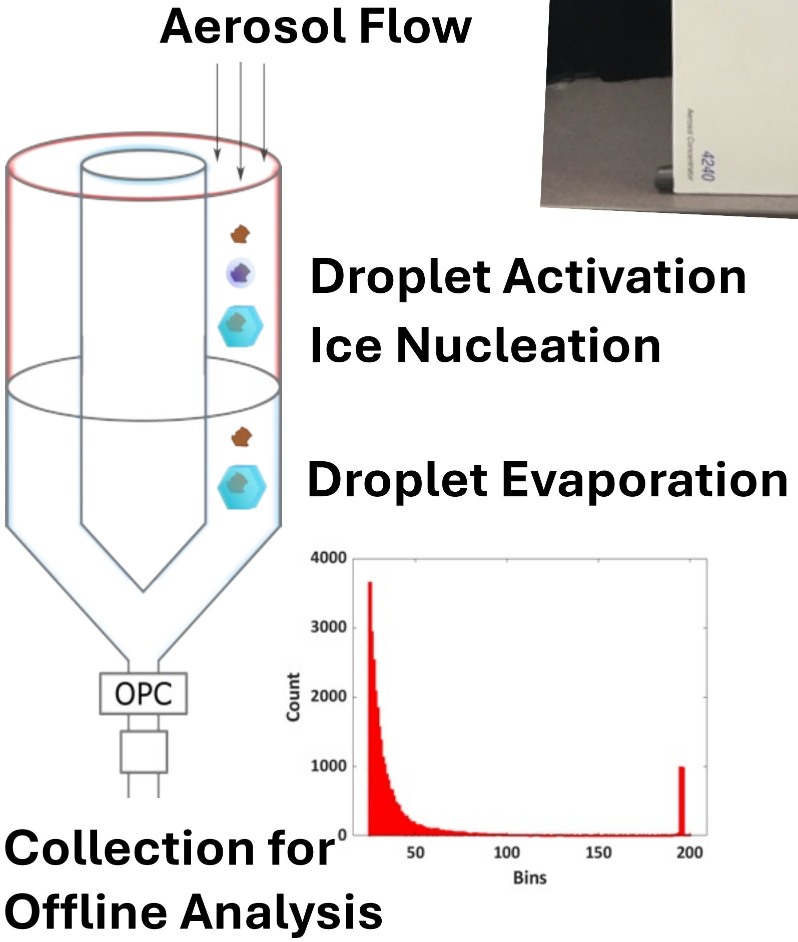
Offline



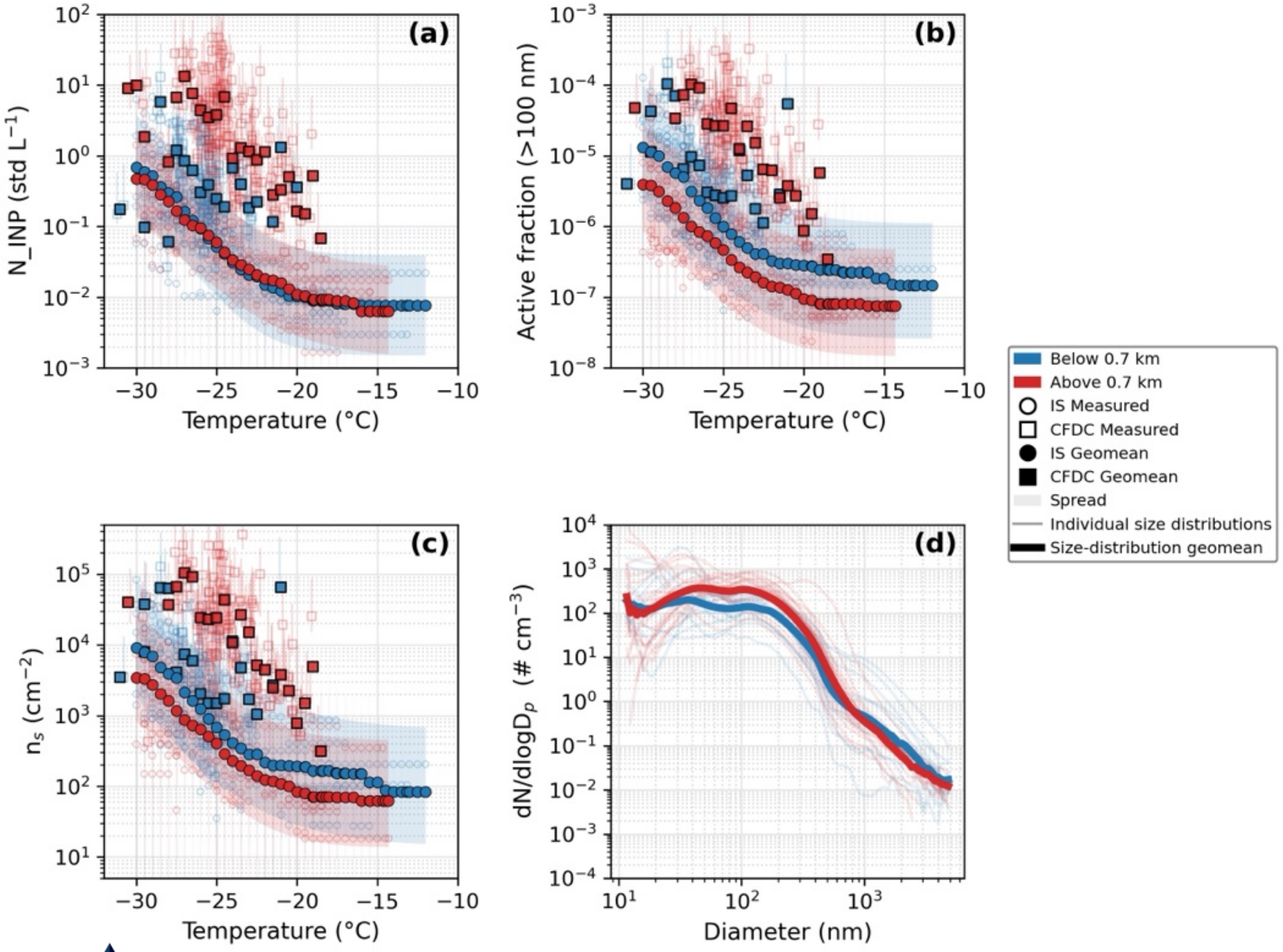


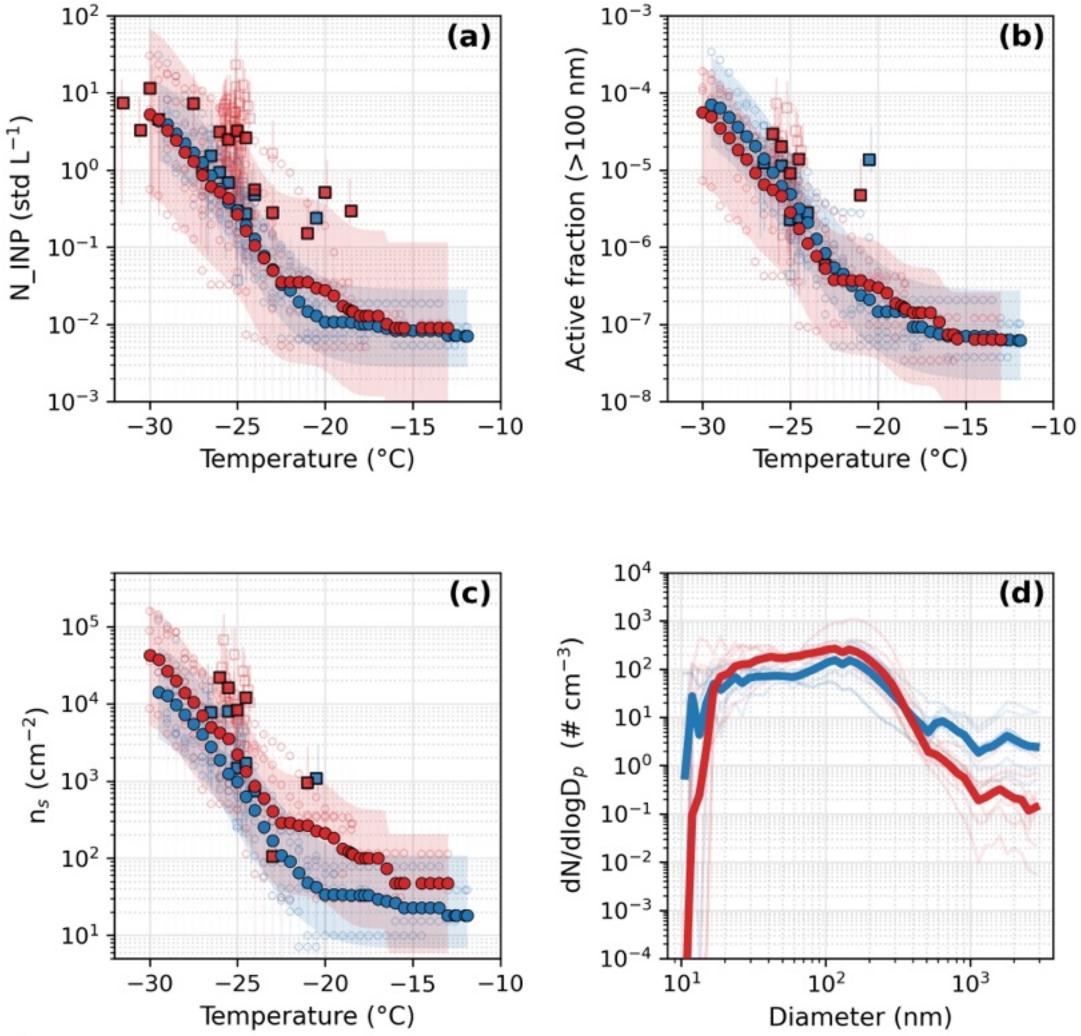
Online

Upstream Aerosol Concentrator



Altitude dependence and Aerosol Normalizations

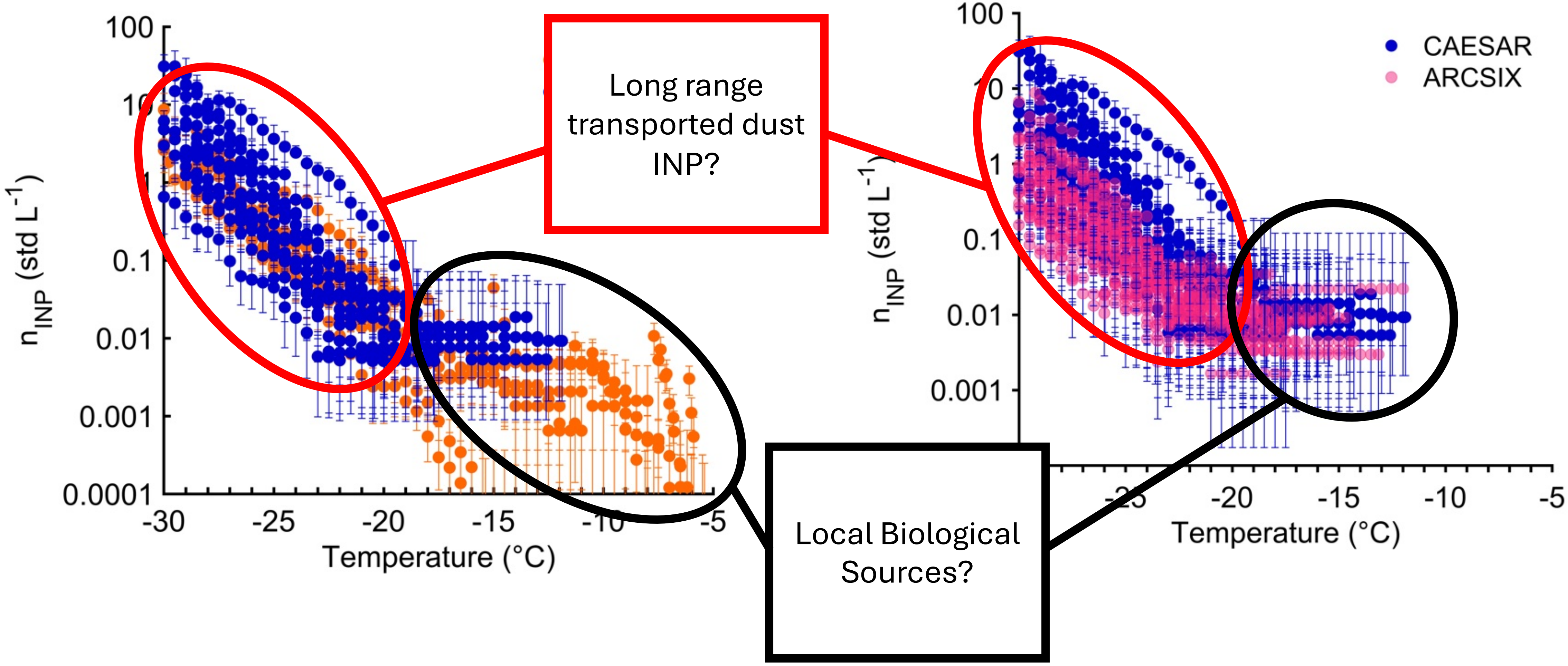




Strong Altitude Dependance
-> Long range transport?

Weak Altitude Dependance
-> Local sources? Mixing?

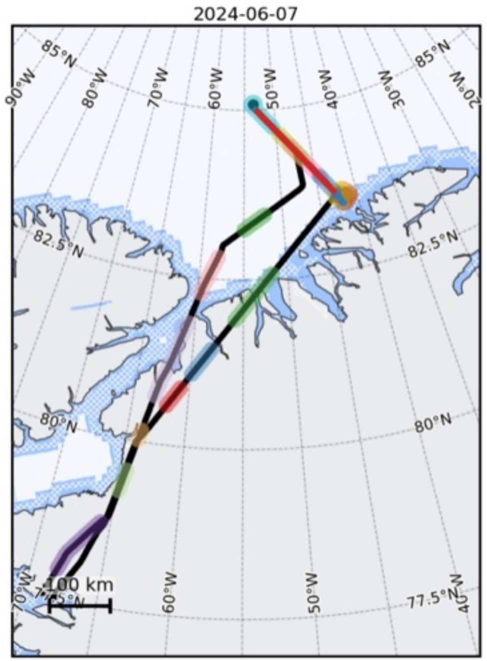
CAESAR INP concentrations agree well with MOSAiC, on the higher end of ARCSIX measurements

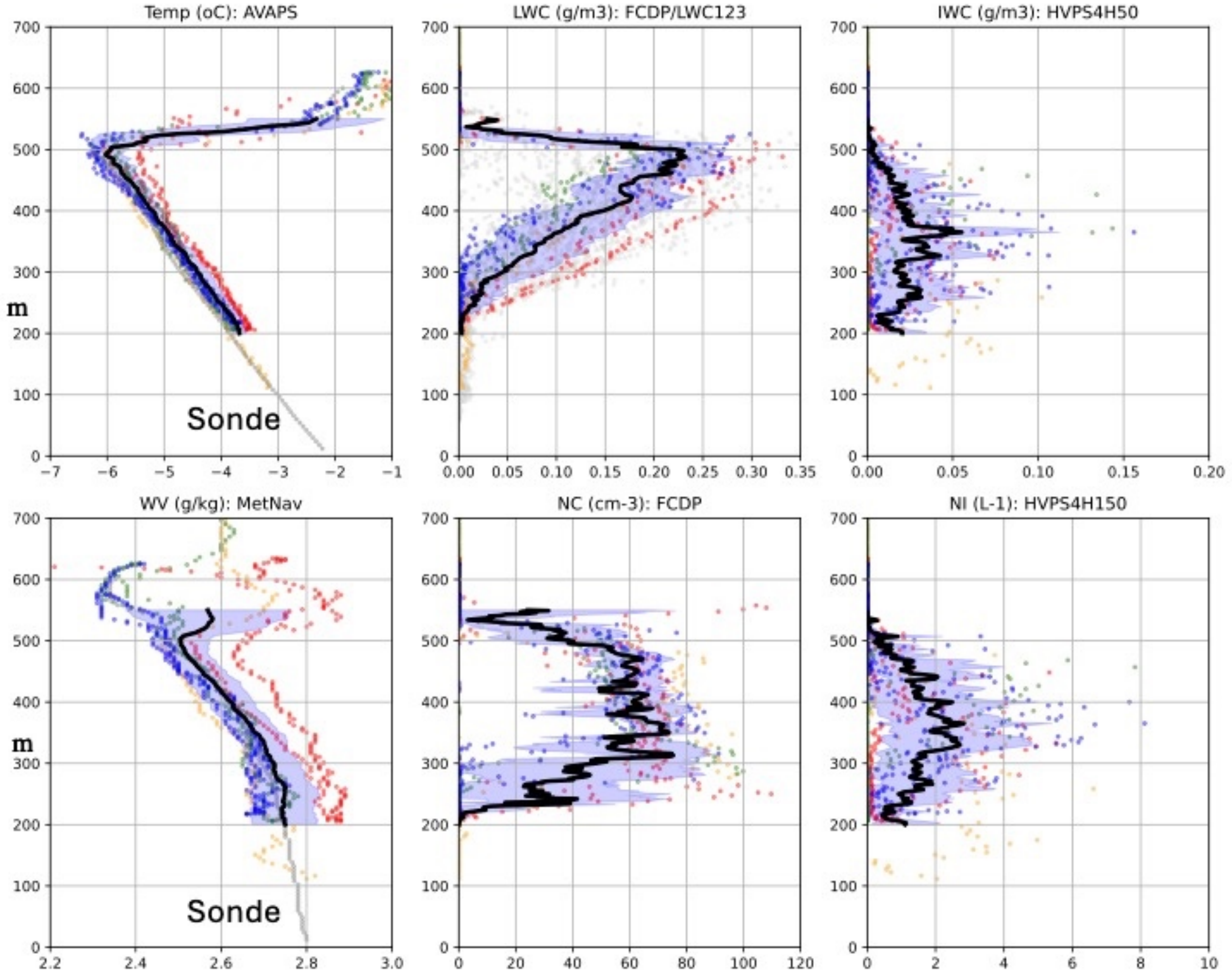


ARCSIX Cloud Wall Case

Analysis from ARCSIX Aerosol Working Group

- Cloud wall sampling was performed with P3 legs above-, in-, and below- cloud, and co-located G3 overflights.
- The cloud temperature is ~-6 to -4 °C, and is mostly liquid but with a significant quantity of ice.
- No evidence of riming, poor conditions for known SIP mechanisms.

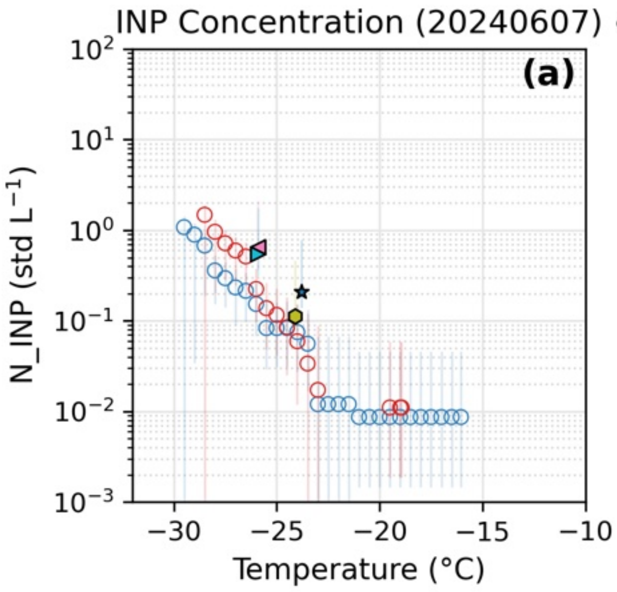


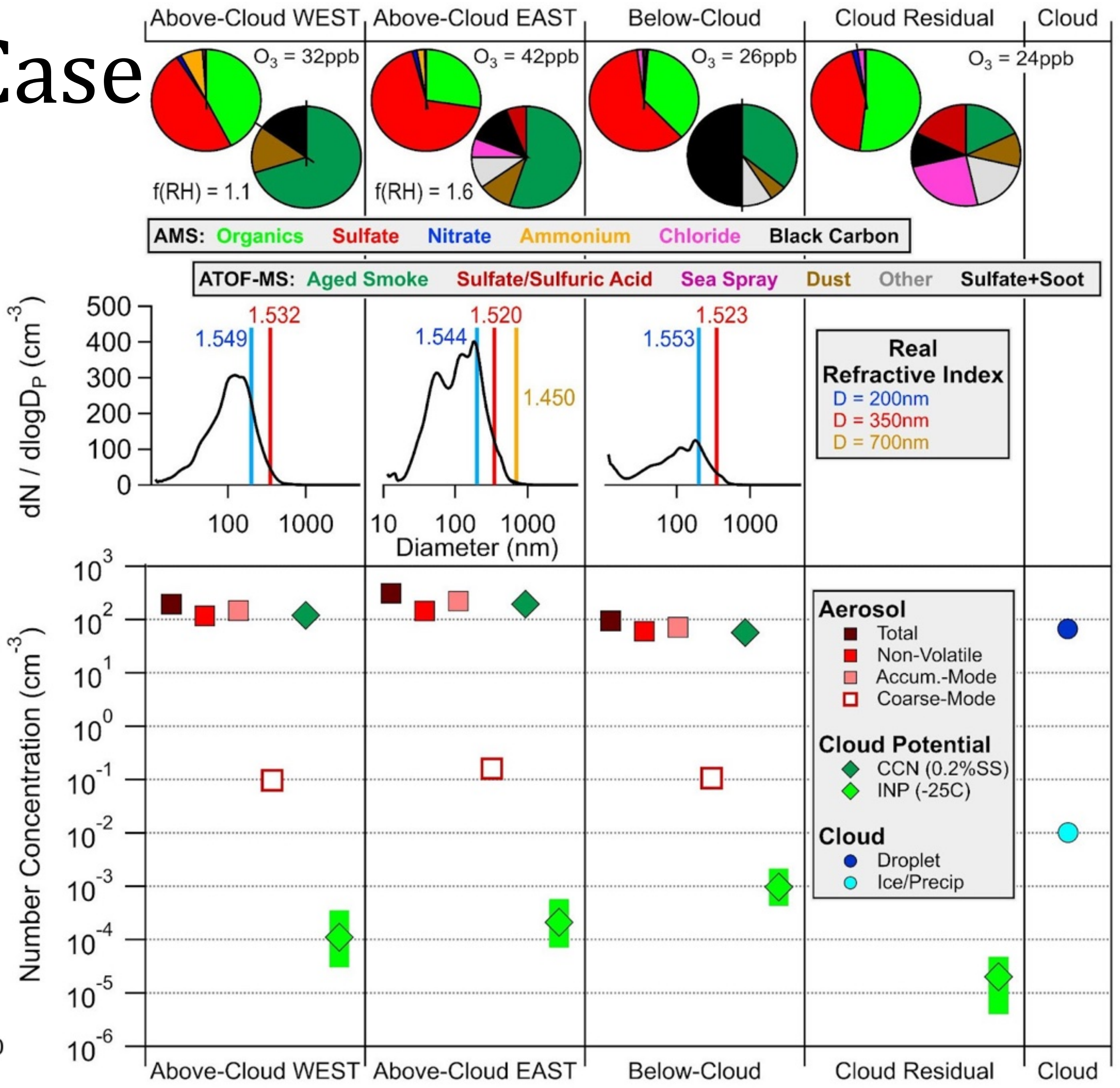


ARCSIX Cloud Wall Case

Analysis from ARCSIX Aerosol Working Group

- Online INP measurements in green at ~-25 C are:
- Highest below-cloud, despite lower aerosol concentration, but still 10x lower than ice crystal concentrations!
- INP depletion in cloud through precipitation removal? Or too small to activate as drops.
- Good agreement between online and offline samples.
- Will be ~3-6 orders of magnitude lower at the appropriate cloud temperature!

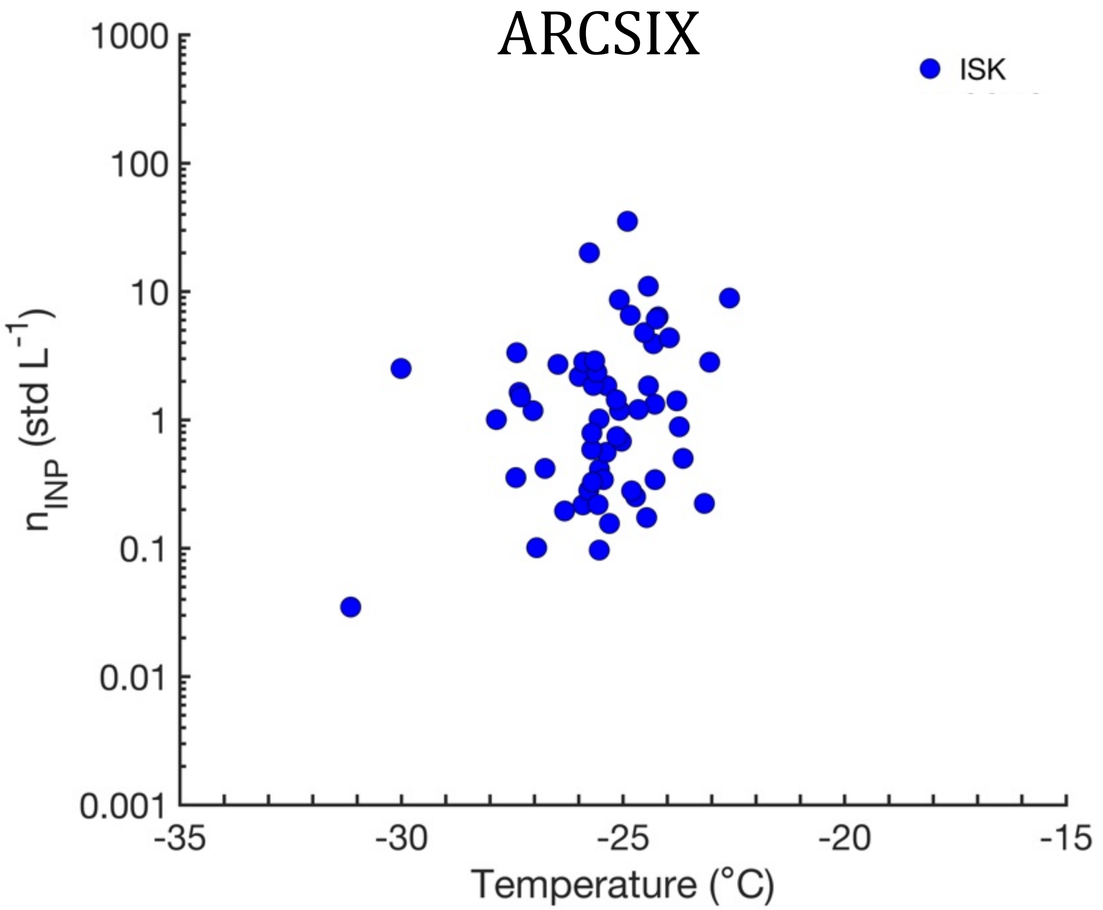


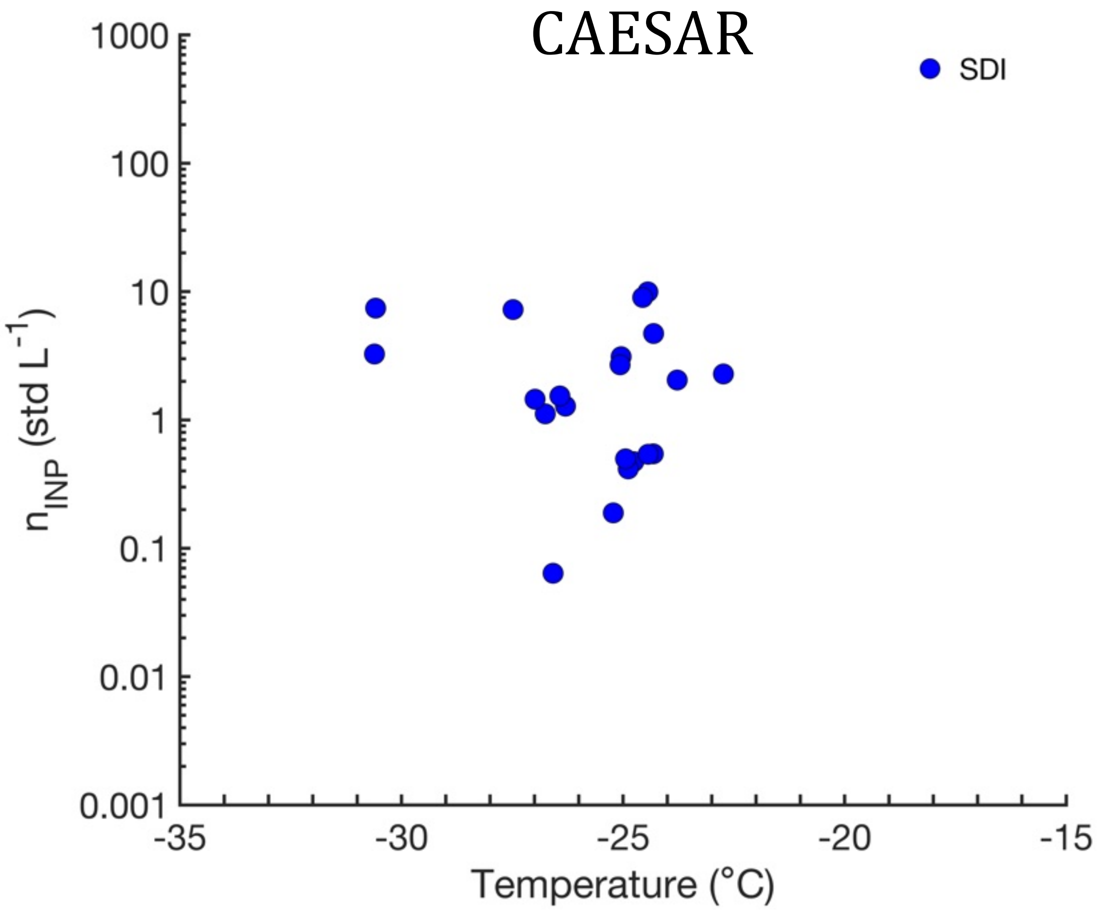


CAESAR and ARCSIX Conclusions

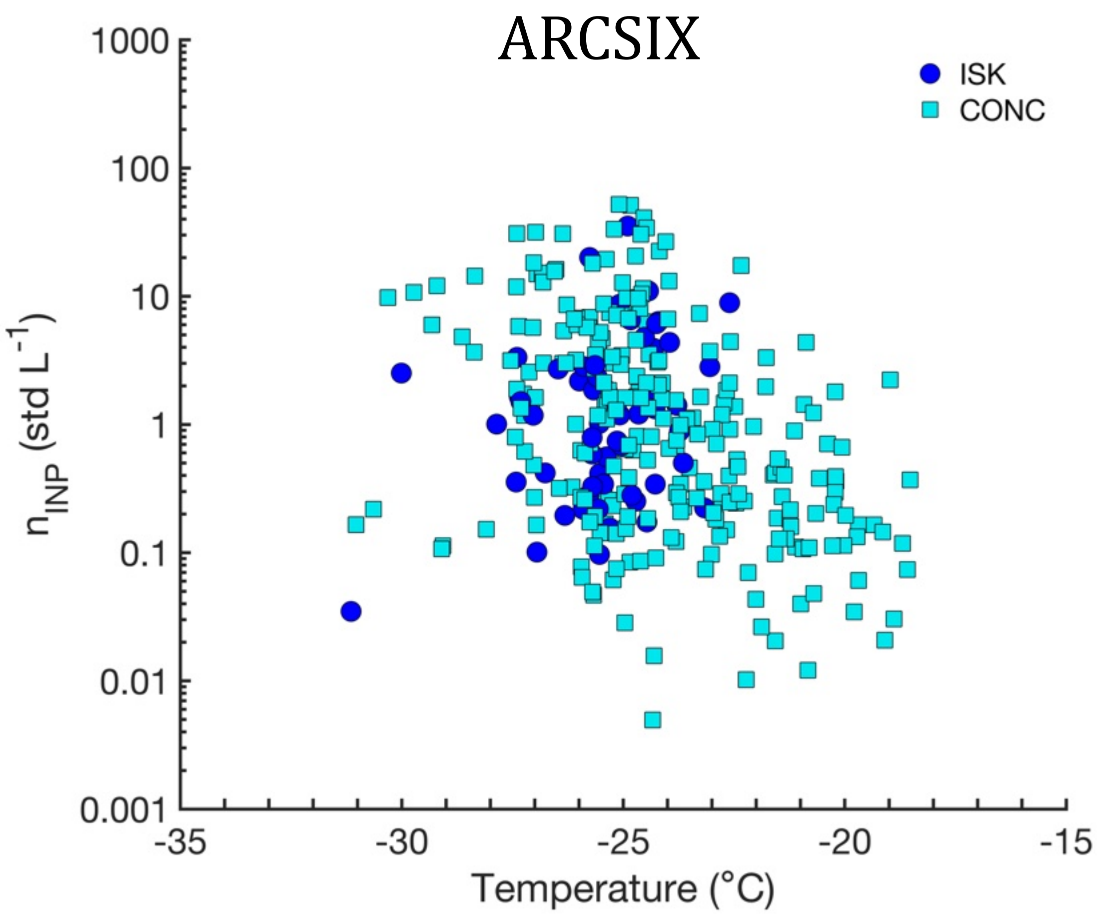
- INPs from polar aircraft measurements agree well with previous surface-based MOSAiC measurements
- Enhancements below or above cloud were flight dependent
- The detected low-temp INPs appear mostly mineral from treatment spectra – but not tied to bulk aerosol measurements.
- Strong evidence of SIP in low-level Arctic clouds, mechanism unknown.

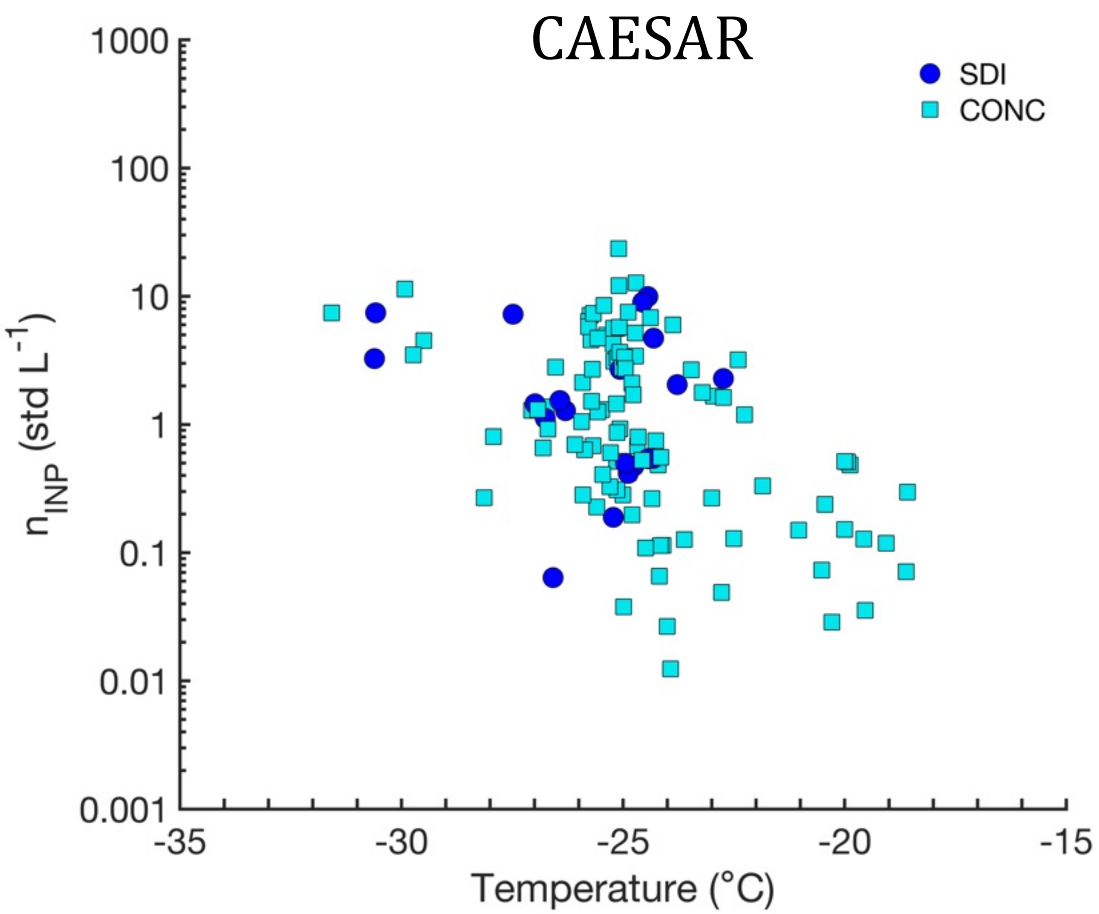
Improvements in INP measurements with concentrator



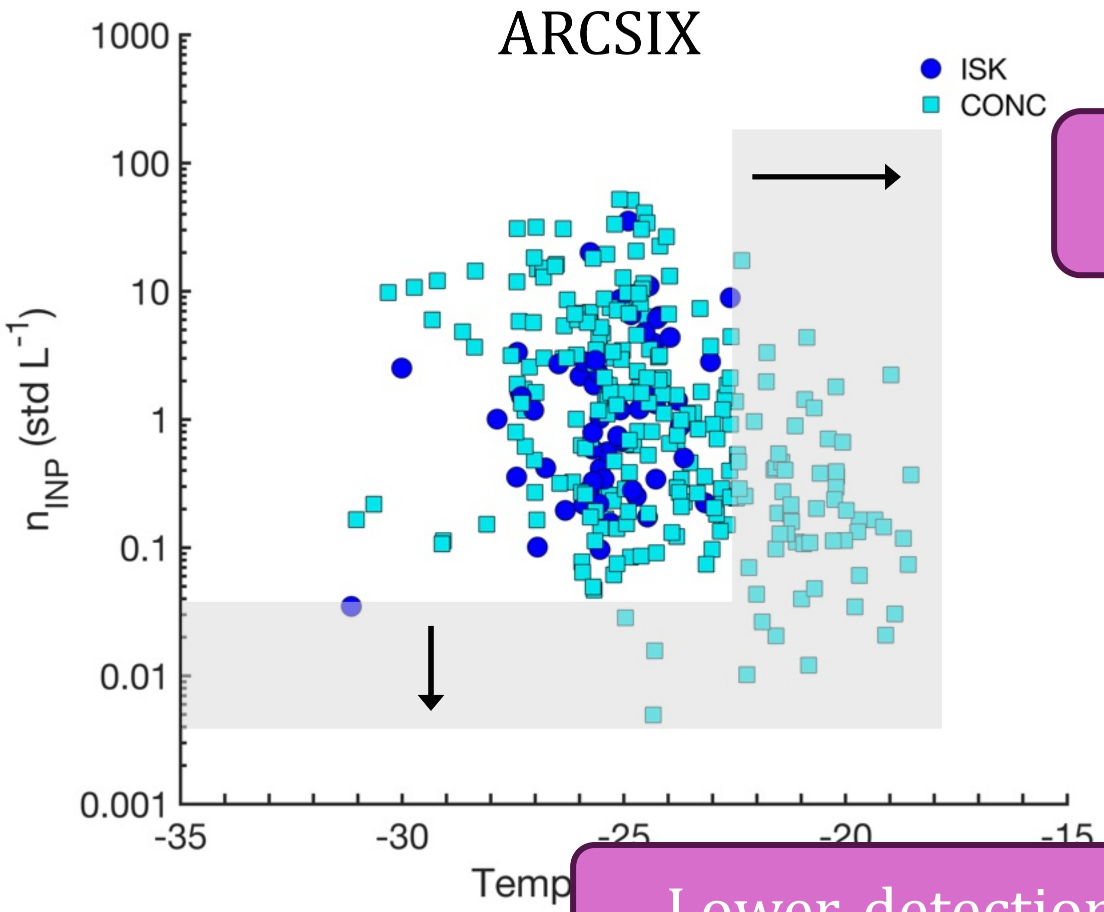


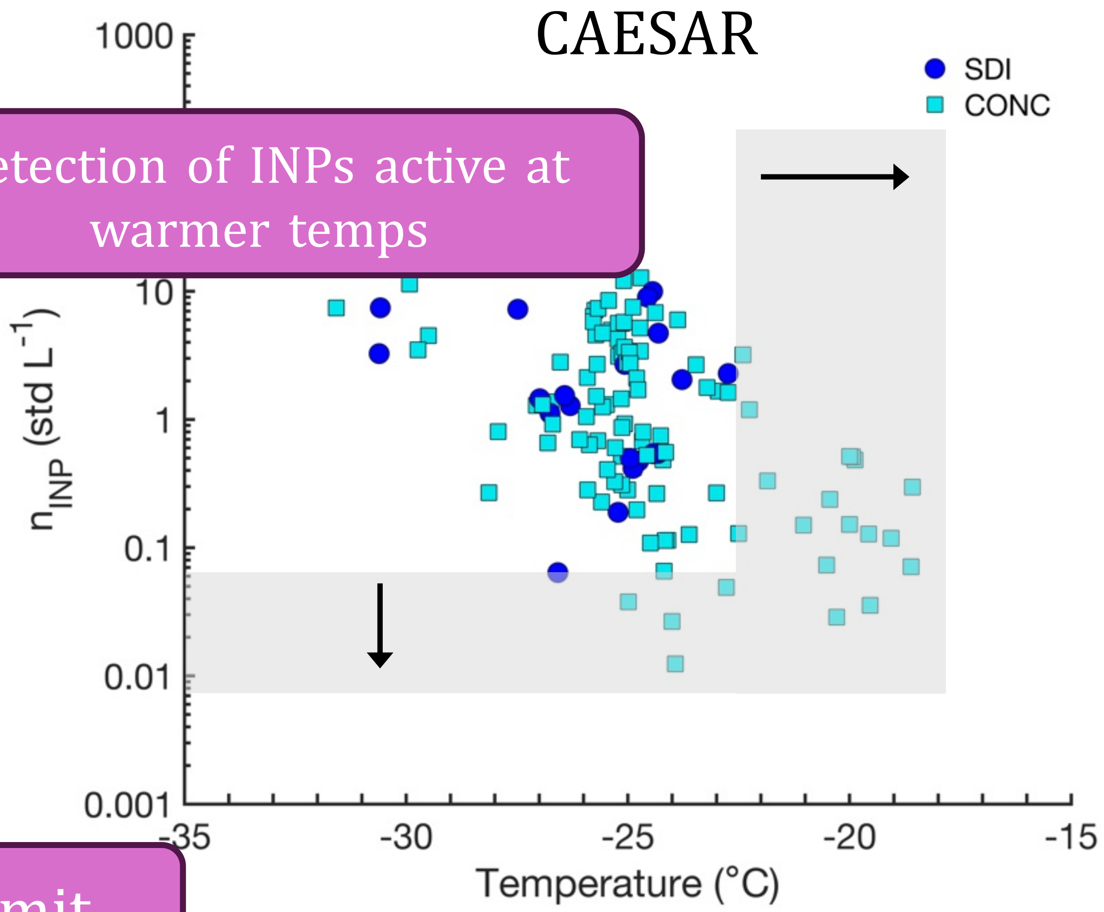
Improvements in INP measurements with concentrator





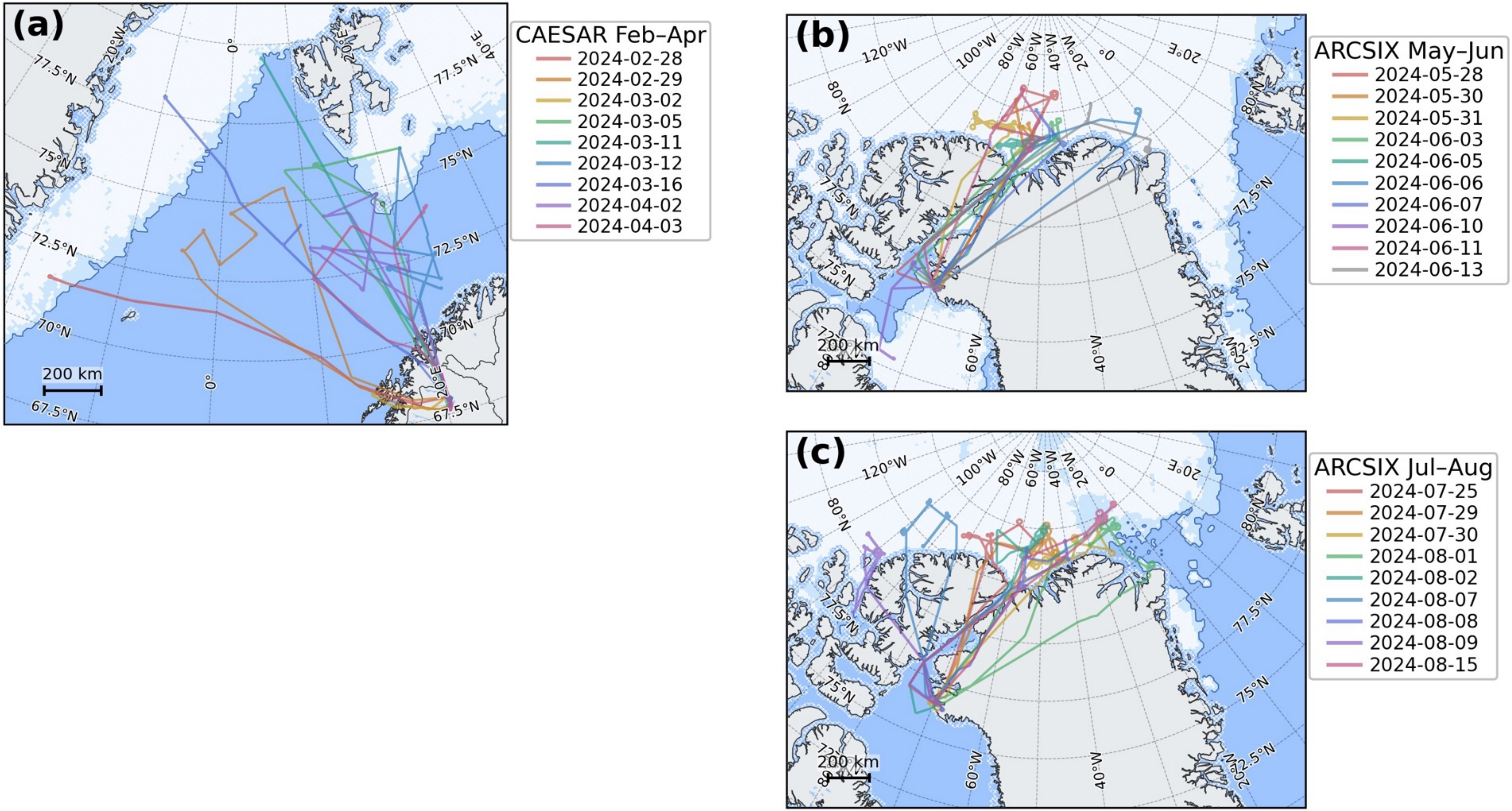
Improvements in INP measurements with concentrator





Detection of INPs active at warmer temps

Lower detection limit


(a)
CAESAR Feb–Apr
2024-02-28
2024-02-29
2024-03-02
2024-03-05
2024-03-11
2024-03-12
2024-03-16
2024-04-02
2024-04-03
200 km
(b)
ARCSIX May–Jun
2024-05-28
2024-05-30
2024-05-31
2024-06-03
2024-06-05
2024-06-06
2024-06-07
2024-06-10
2024-06-11
2024-06-13
200 km
(c)
ARCSIX Jul–Aug
2024-07-25
2024-07-29
2024-07-30
2024-08-01
2024-08-02
2024-08-07
2024-08-08
2024-08-09
2024-08-15
200 km