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Investigating secondary ice production in springtime Arctic mixed-phase clouds

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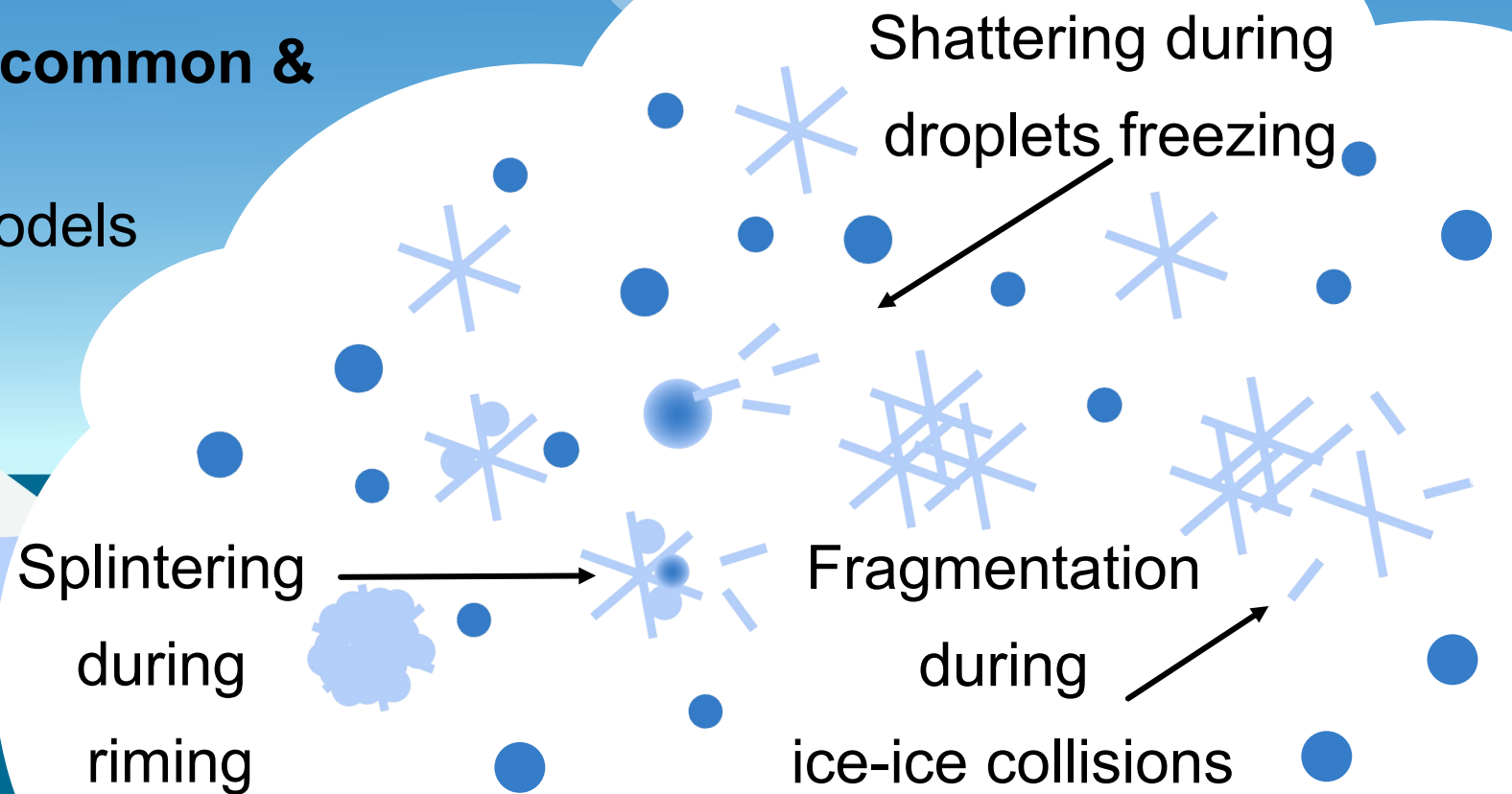
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What is Secondary Ice Production (SIP)?

- Primary ice formation through **Ice Nucleating Particles (INP)** at $T > -40^{\circ}\text{C}$
- Observations show $\text{INP} \ll$ ice crystal concentrations \rightarrow **SIP processes**
- High uncertainties **how common & which processes?**
- Poorly constrained in models



Data & instruments

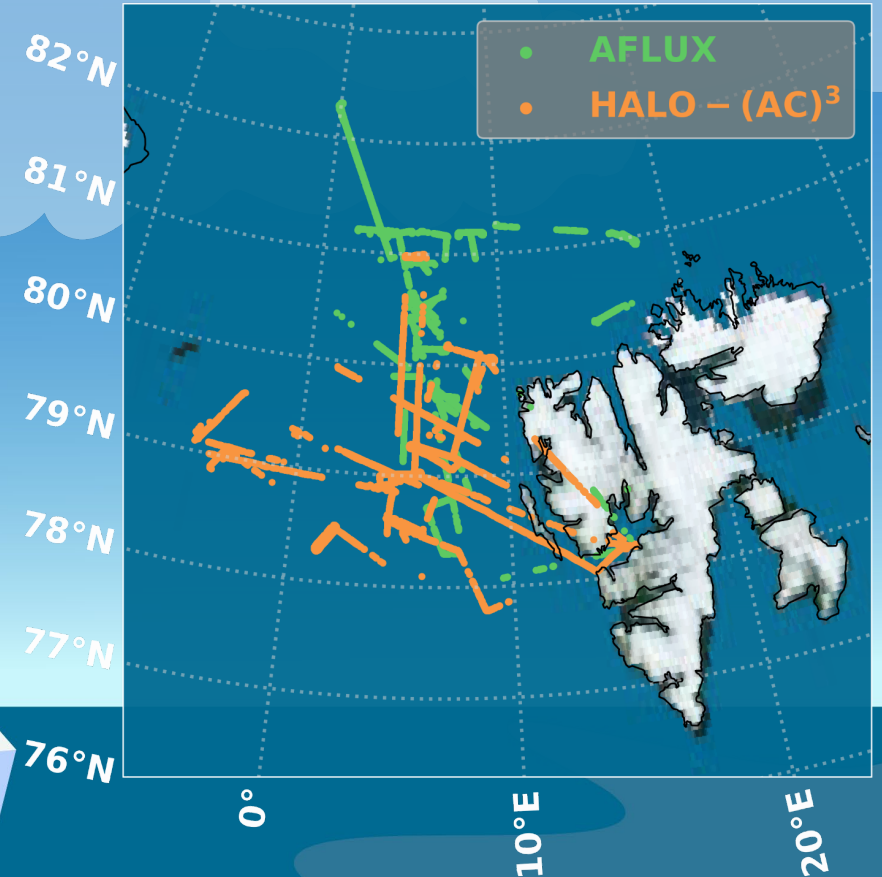
Airborne campaigns

- **AFLUX** (spring 2019)
- **HALO-(AC)³** (spring 2022)



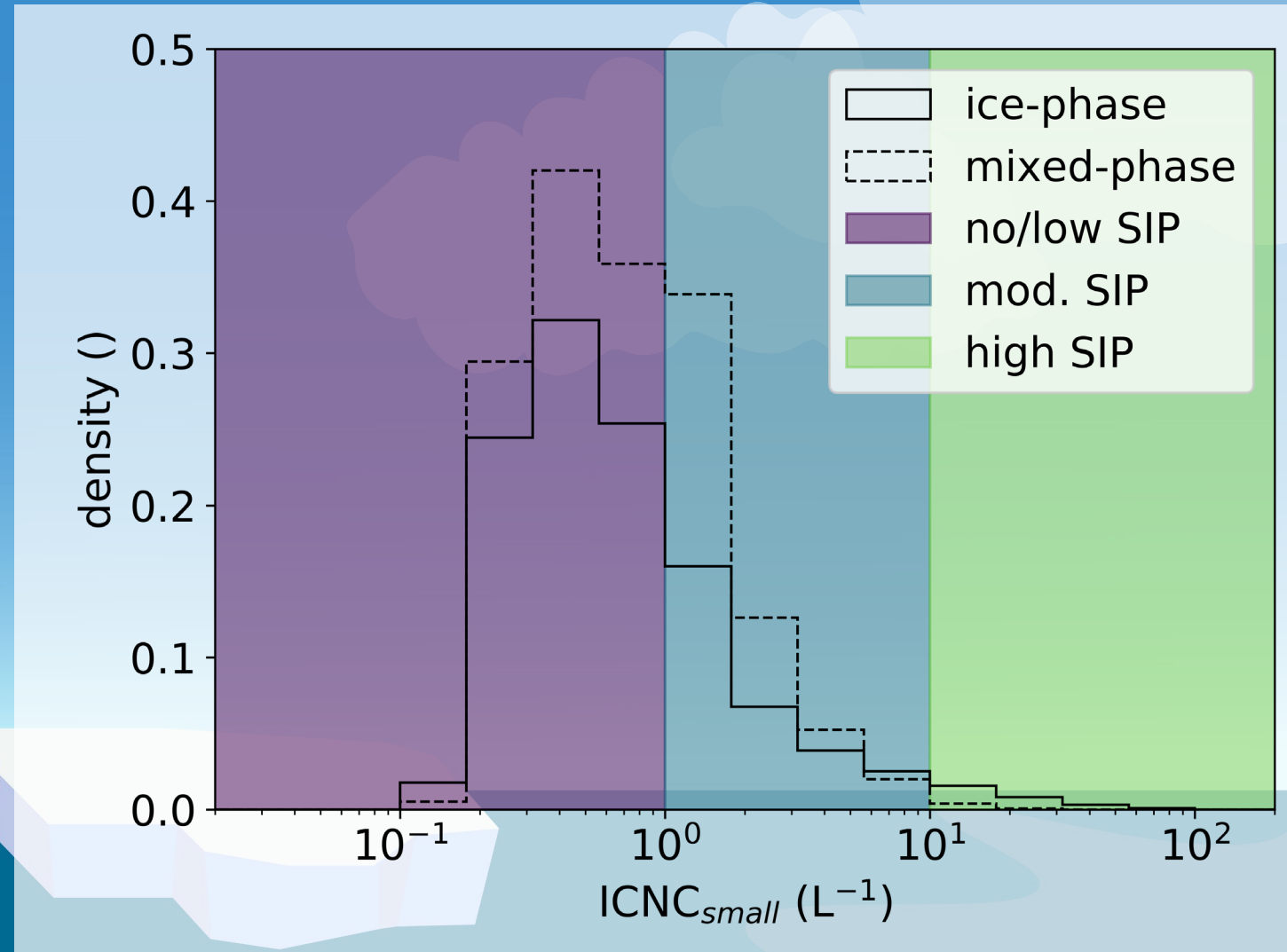
In-situ measurements

- Cloud probes: particle size, number concentration, shape, rime mass [1]
Cloud droplet probe (**CDP**), cloud imaging probe (**CIP**), precipitation imaging probe (**PIP**), **2D-S** stereo probe
- Polar Nephelometer: cloud phase

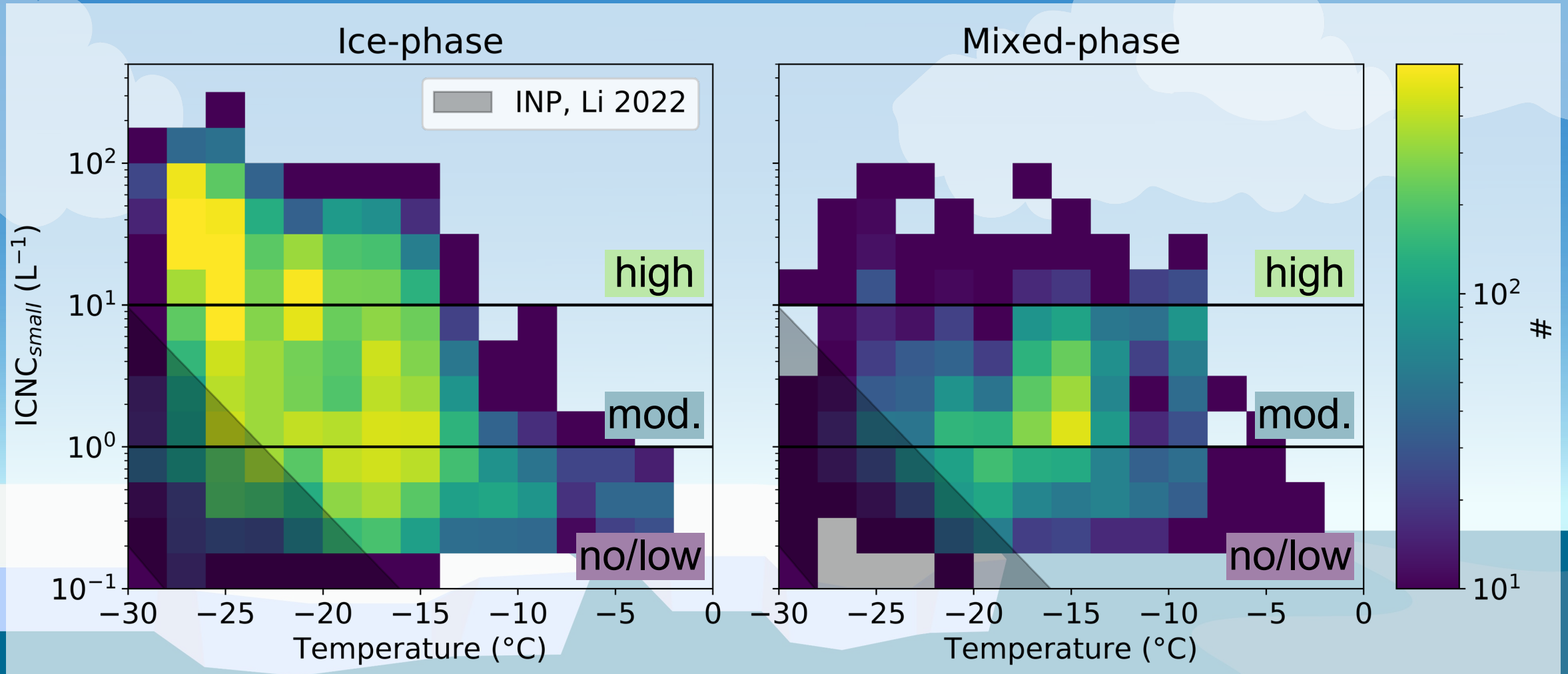


How to detect SIP?

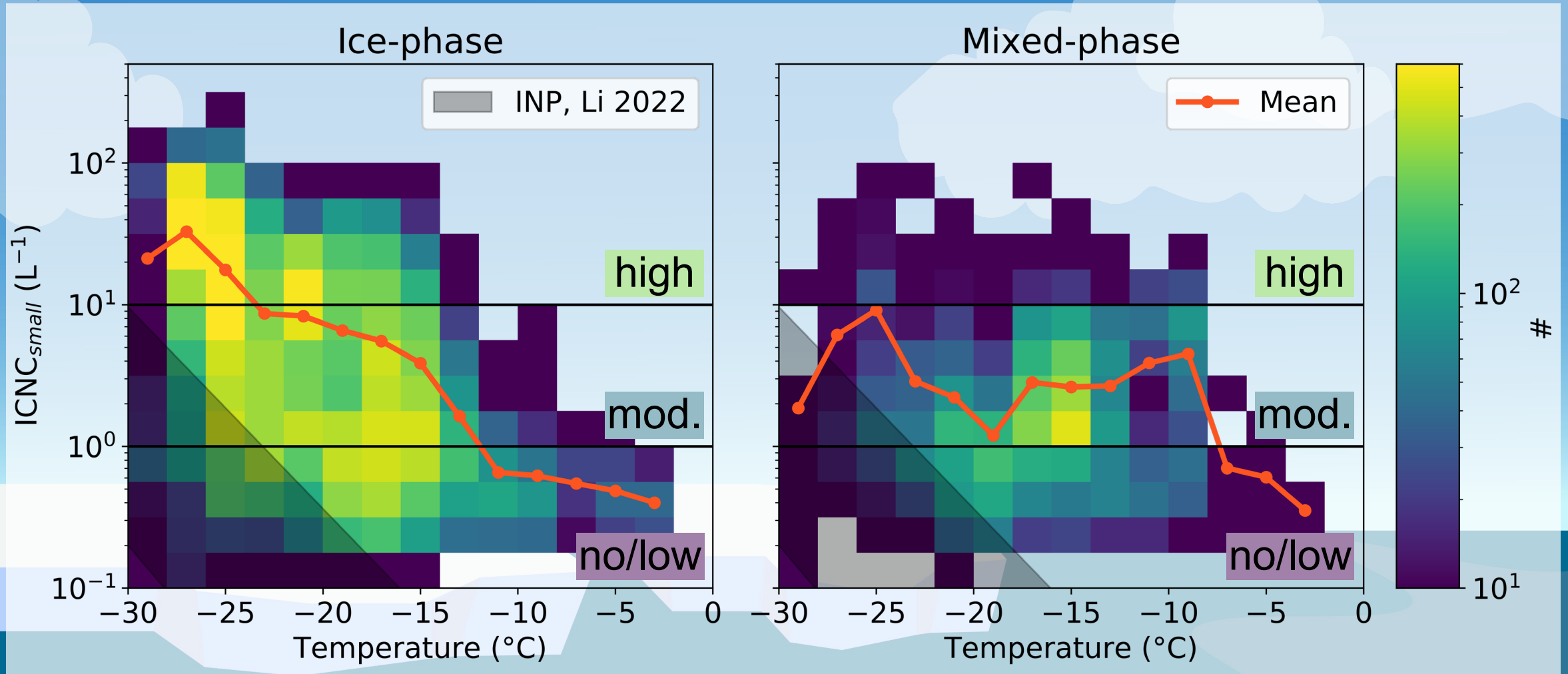
- High concentrations of small ice particles $ICNC_{small}$
 - CIP: diameter 82.5-112.5 μm
 - 2D-S: diameter 85-115 μm
- INP expected to be low ($T_{q10\%} > -25^{\circ}C$)



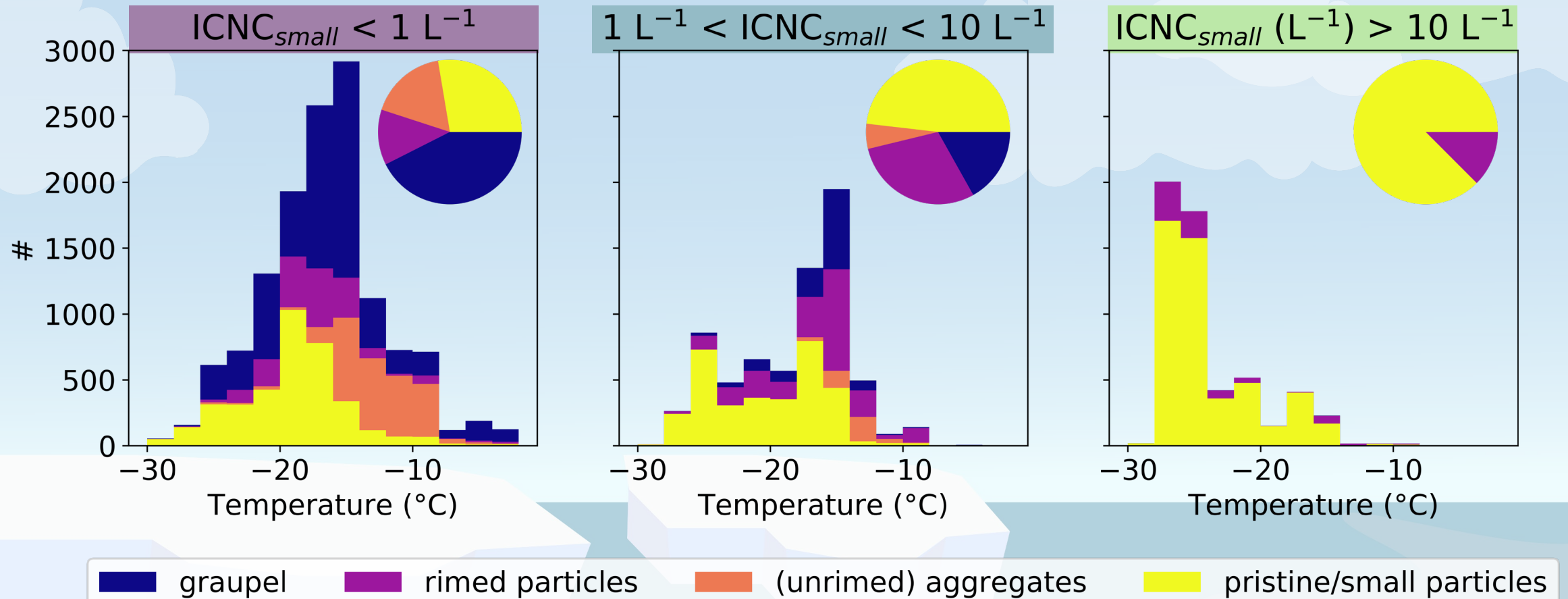
Temperature dependence of ICNC_{small}



Temperature dependence of ICNC_{small}



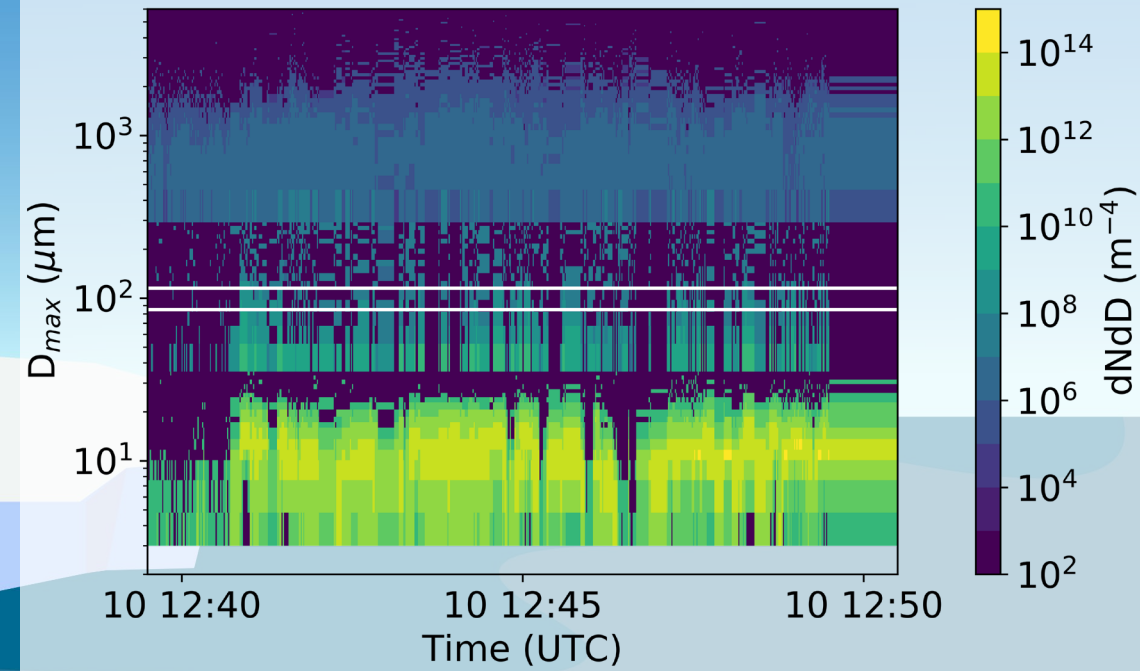
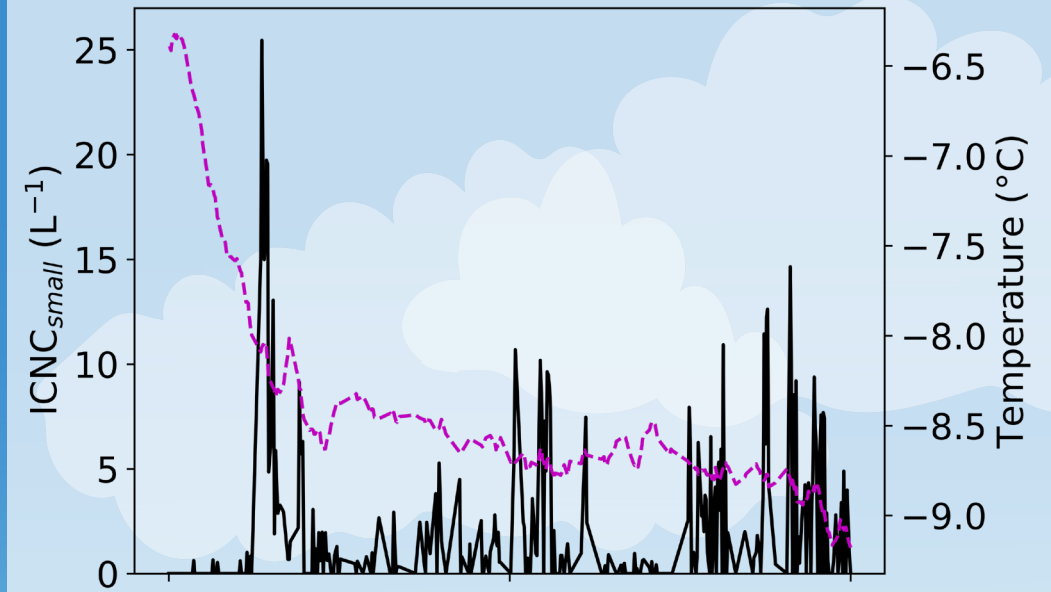
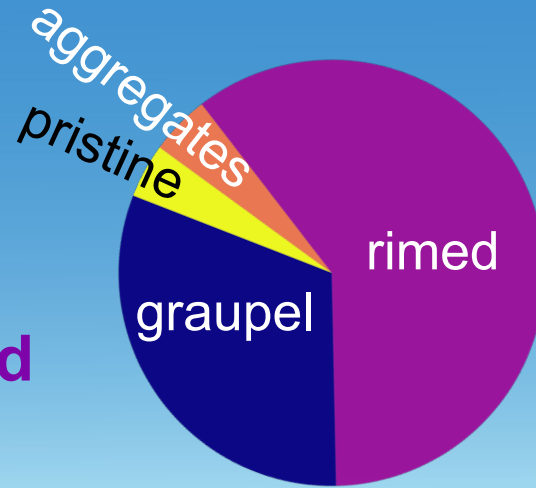
Signatures of riming and aggregation?



Case study: 10 April 2022

→ indications of rime-splintering or droplet shattering?

- $-10^{\circ}\text{C} < T < -6^{\circ}\text{C}$
- 12:37-12:50 UTC
- Over open ocean
- Predominately **rimed particles** & **graupel**





Sharing is
encouraged

Summary & outlook

- High concentrations of small ice particles indicate secondary ice production (SIP)
- $ICNC_{small} > 1 L^{-1}$ ($10 L^{-1}$) in 23.6% (4.0%) for $T -20^{\circ}C$ to $-10^{\circ}C$
- Case study: rime-splintering or droplet shattering?

Next: include more data sets (CAESAR, ACAO), combine with LES...

Abstract

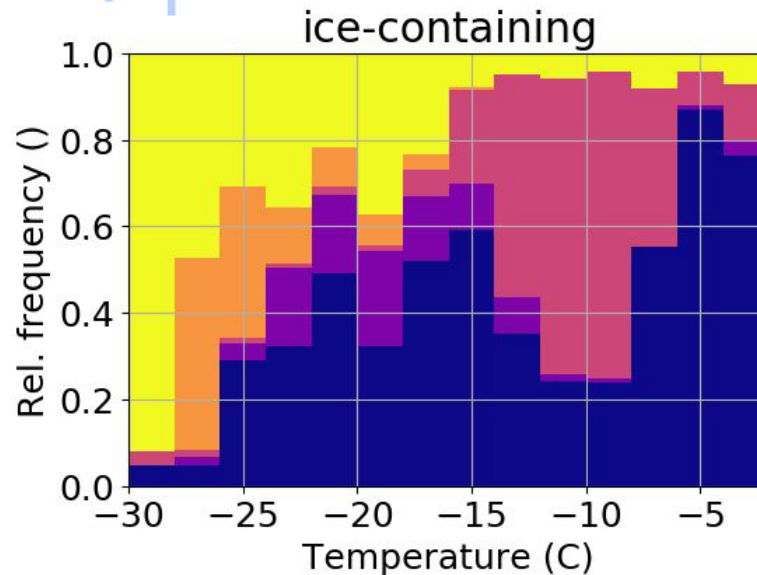
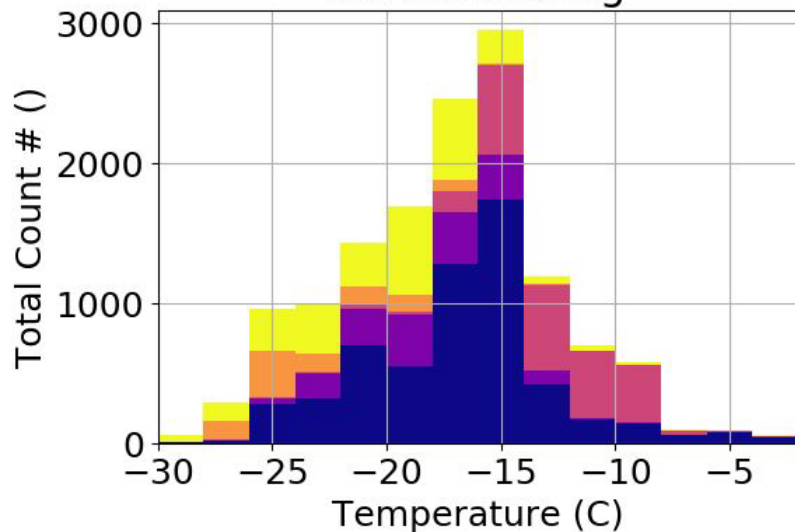
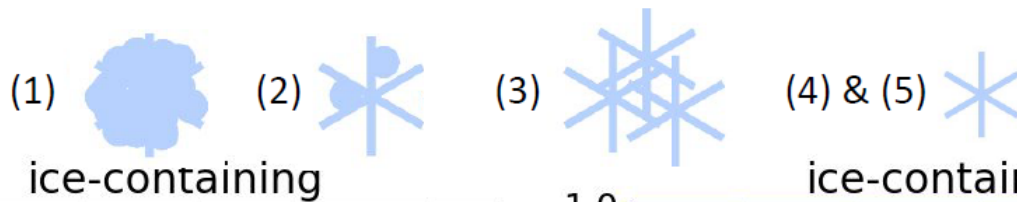
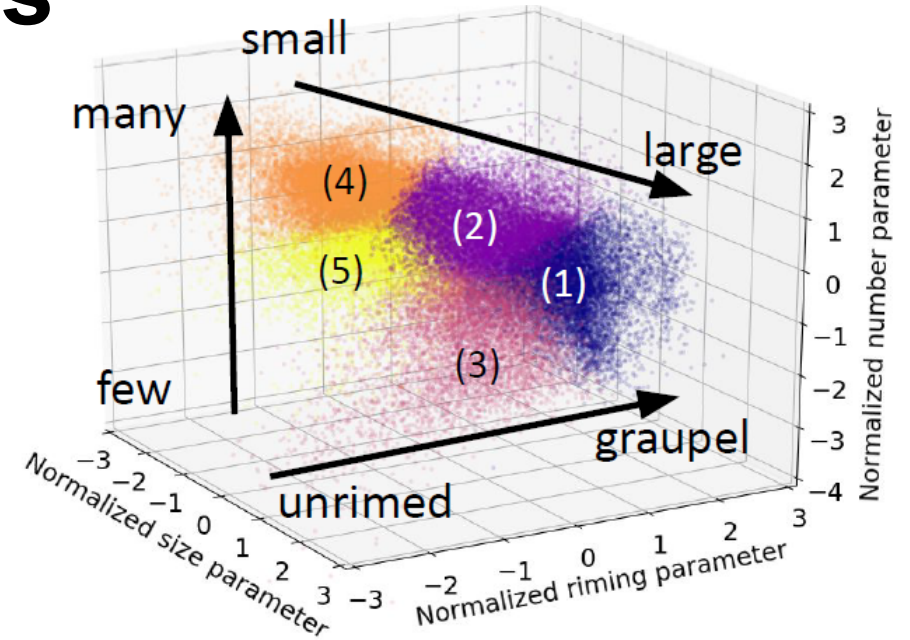


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Clustering particle populations

- K-means clustering → **5 clusters** using ice particle
 - **Number** (= Total number ice crystals with diameter 50 μm to 6 mm)
 - **Size** (= Mass median particle size)
 - **Riming** (= Normalized rime mass)



- (1) large rimed, graupel
- (2) rimed particles
- (3) large aggregates
- (4) unrimed, high number
- (5) unrimed, low number