Can glaciogenic cloud seeding with a UAV be utilized to study fundamental aspects of ice formation and growth?

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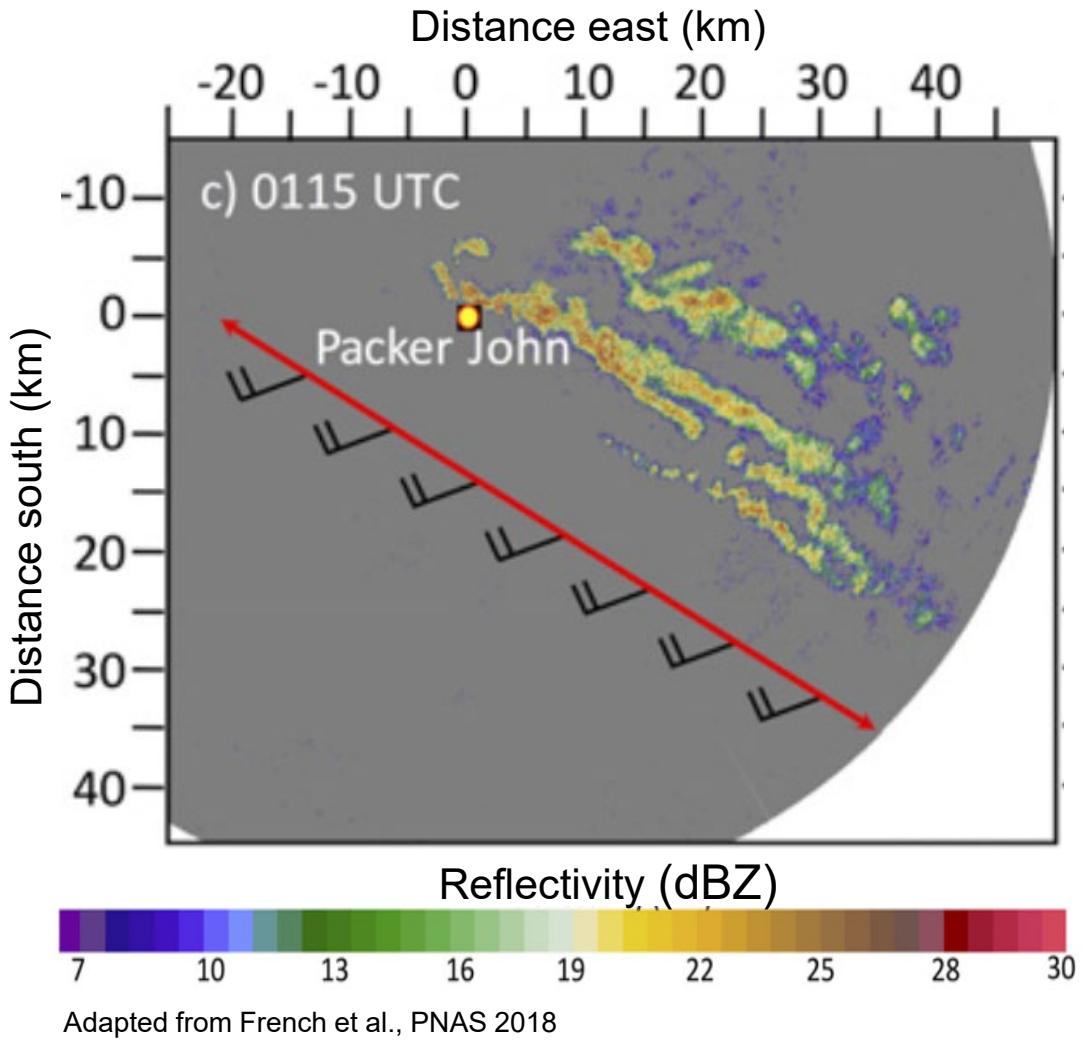
Study ice formation and growth with glaciogenic seeding?

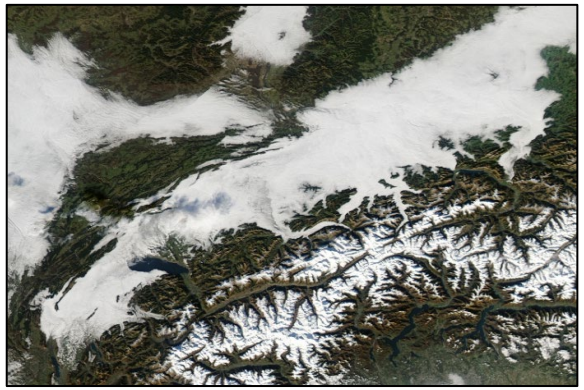


Adapted from French et al., PNAS 2018

From satellite observations: ≈ **70%** of global precipitation originates **from ice-phase processes**
(Mülmenstädt et al., 2015, & Heymsfield et al., 2020)

Supercooled low stratus

Courtesy J. Henneberger



Nov 14, 2018: worldview.earthdata.nasa.gov

CLOUDLAB 2021 - 2026

Use low stratus clouds as a natural lab to gain insights into the diffusional growth of ice crystals

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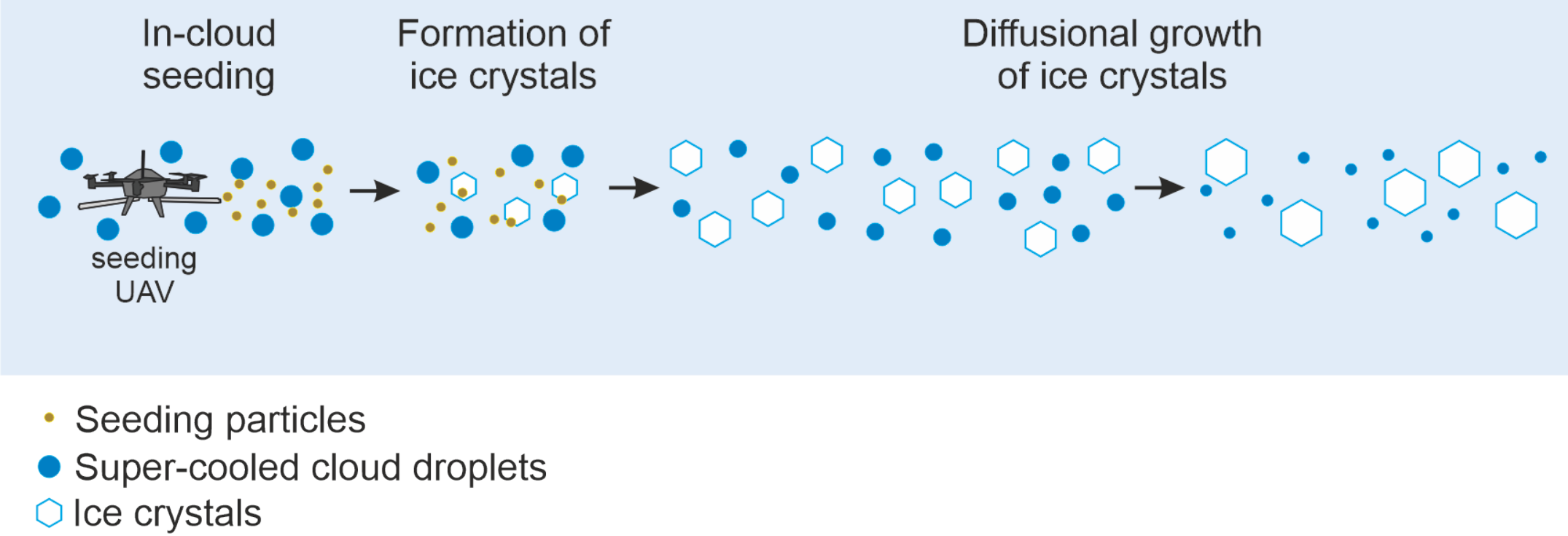
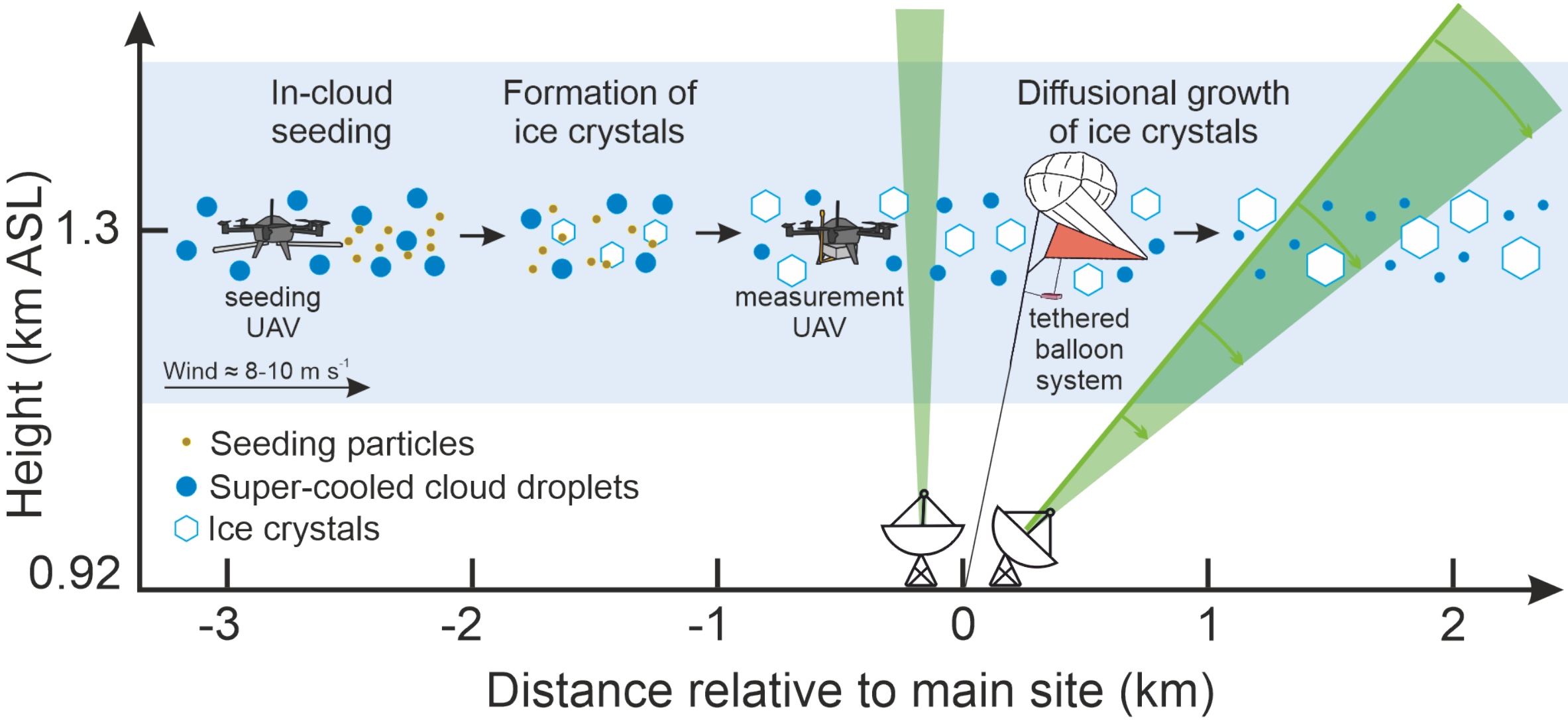
Glaciogenic cloud seeding in CLOUDLAB

Miller et al., AMT, 2024



Glaciogenic cloud seeding in CLOUDLAB

Henneberger, Ramelli et al., BAMS, 2023



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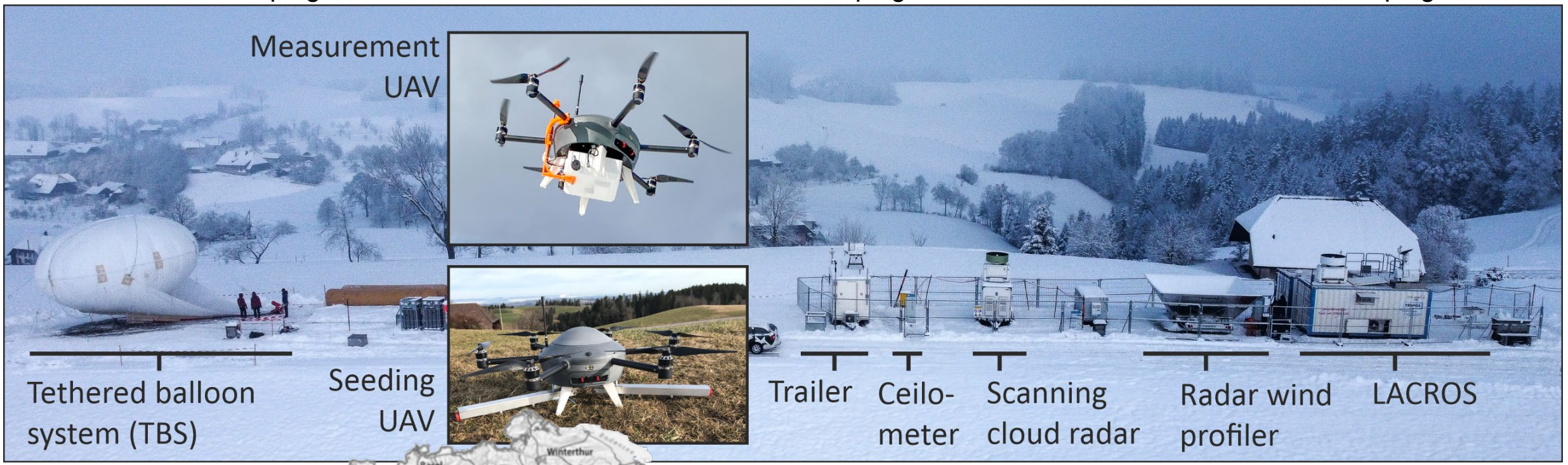
Instrumentation in CLOUDLAB

Henneberger, Ramelli et al., BAMS, 2023

Jan '22 – Mar '22: 1st field campaign

Dec '22 – Feb '23: 2nd field campaign

Dec '23 – Feb '24: 3rd field campaign



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Eidgenössisches Departement des Innern EDI
Bundesamt für Meteorologie und Klimatologie MeteoSchweiz
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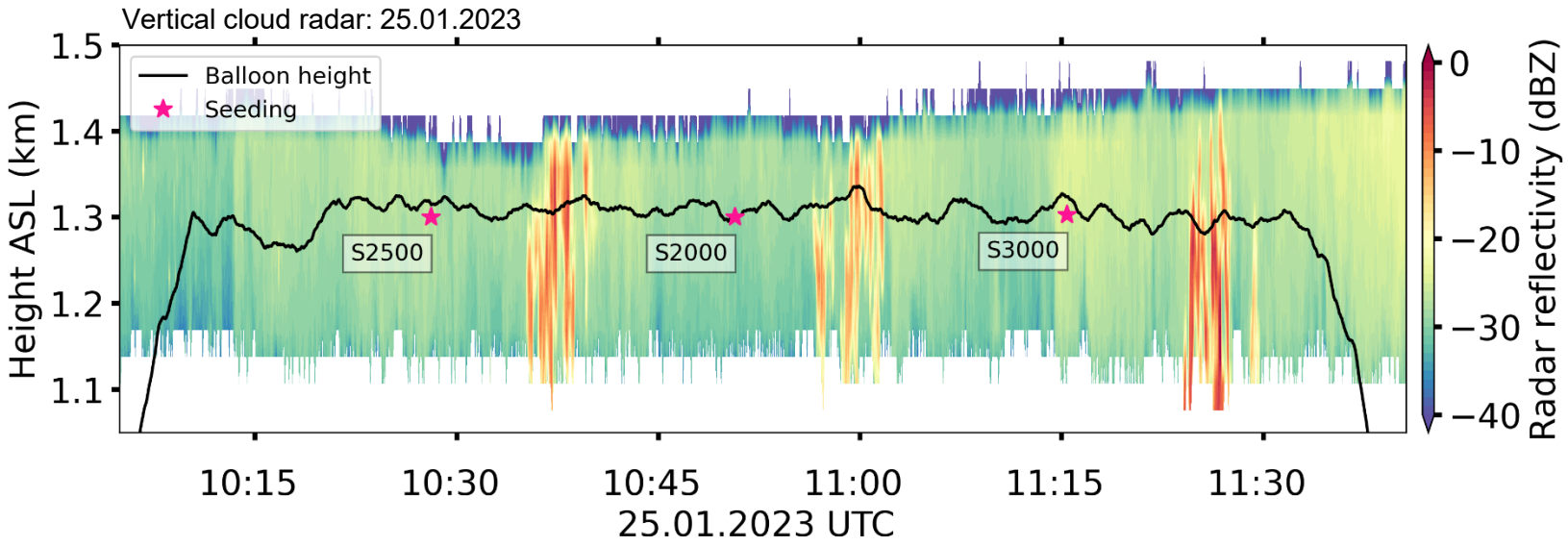
Can we detect a seeding signal?

In-cloud seeding: Remote sensing observation

Henneberger, Ramelli et al., BAMS, 2023



	S2000	S2500	S3000
Distance	2000 m	2500 m	3000 m
Wind speed	8 m/s	8.3 m/s	8 m/s
Growth time	4 min	5.2 min	6.3 min
Radar refl.	**-15 dBZ**	**-13 dBZ**	**-11 dBZ**

UAV seeding mission:

- 4 x 400 m legs perpendicular to wind direction
- 2000 m, 2500 m and 3000 m upstream of the main site

Seeding signal:

- Radar reflectivity 10 – 25 dBZ above the background

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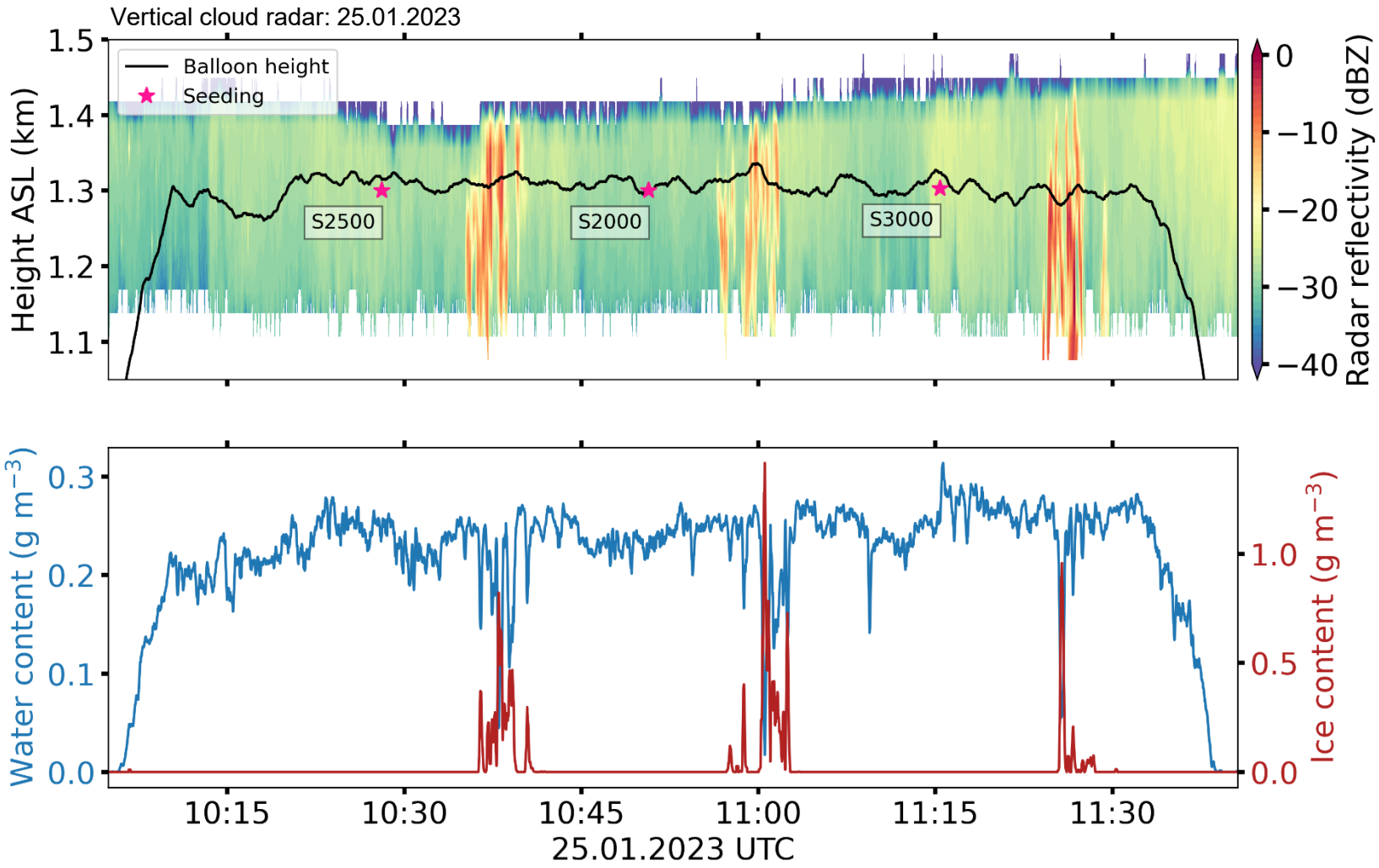
In-cloud seeding: In-situ observation

Henneberger, Ramelli et al., BAMS, 2023

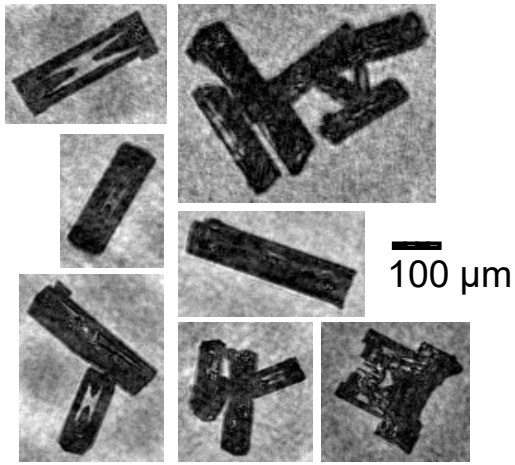


UAV seeding mission:

- 4 x 400 m legs perpendicular to wind direction
- 2000 m, 2500 m and 3000 m upstream of the main site

Seeding signal:

- Radar reflectivity 10 – 25 dBZ above the background
- High ice crystal content and reduction in water content



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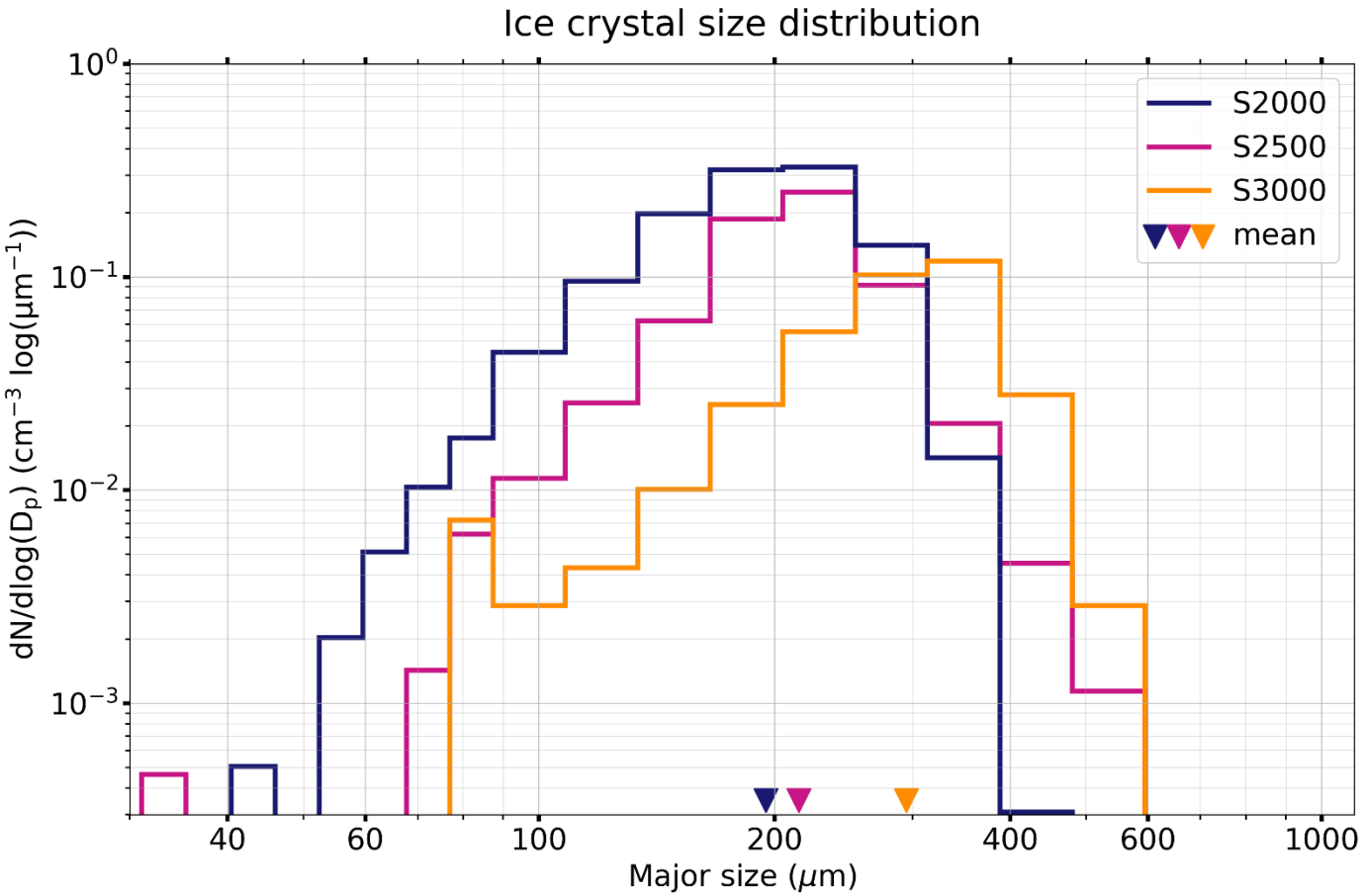
In-cloud seeding: Ice crystal growth

Ramelli et al., in preparation



	S2000	S2500	S3000
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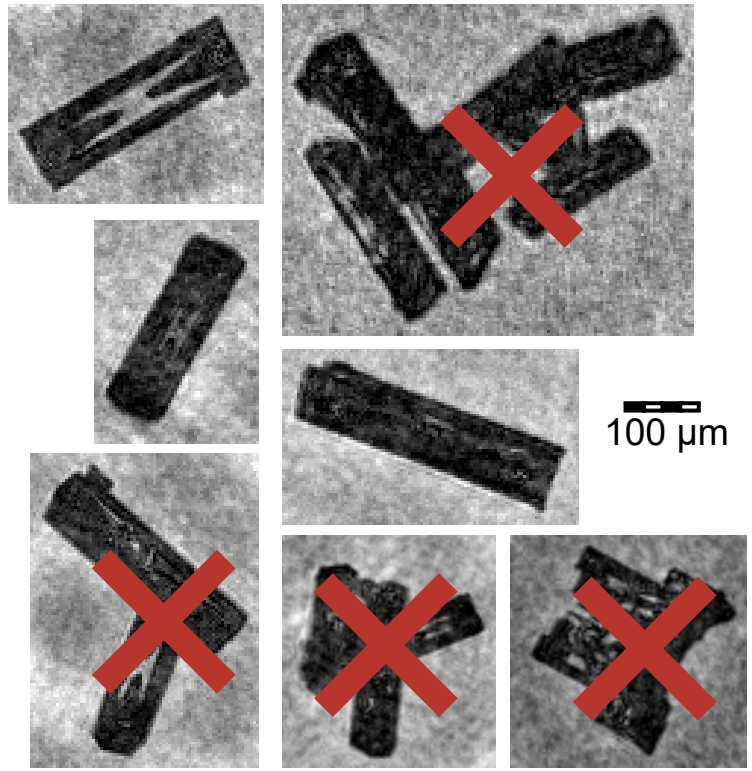

CLOUDLAB approach works!

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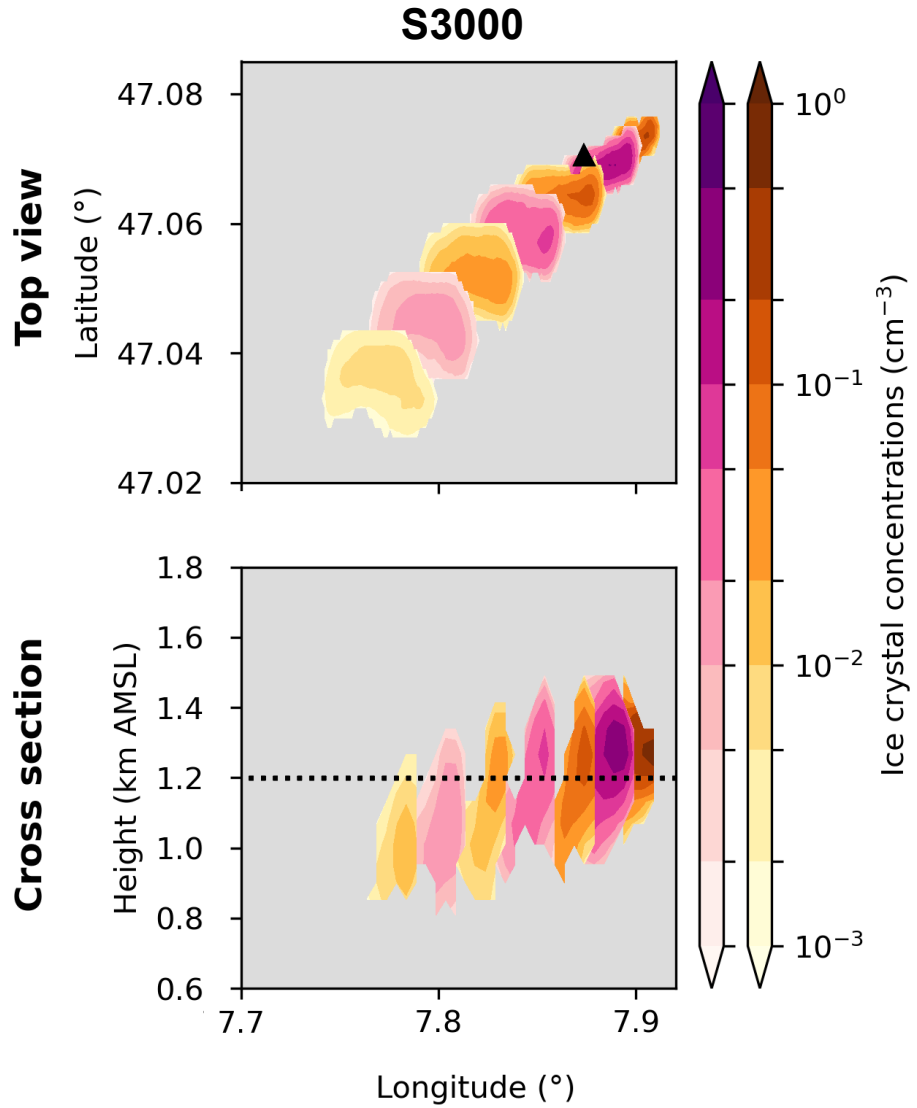
ICON large eddy simulations (dx = 130 m)

Omanovic et al., ACP, in discussion



ICON simulation

- reproduce long-lasting low-level cloud
- enabling seeding simulation

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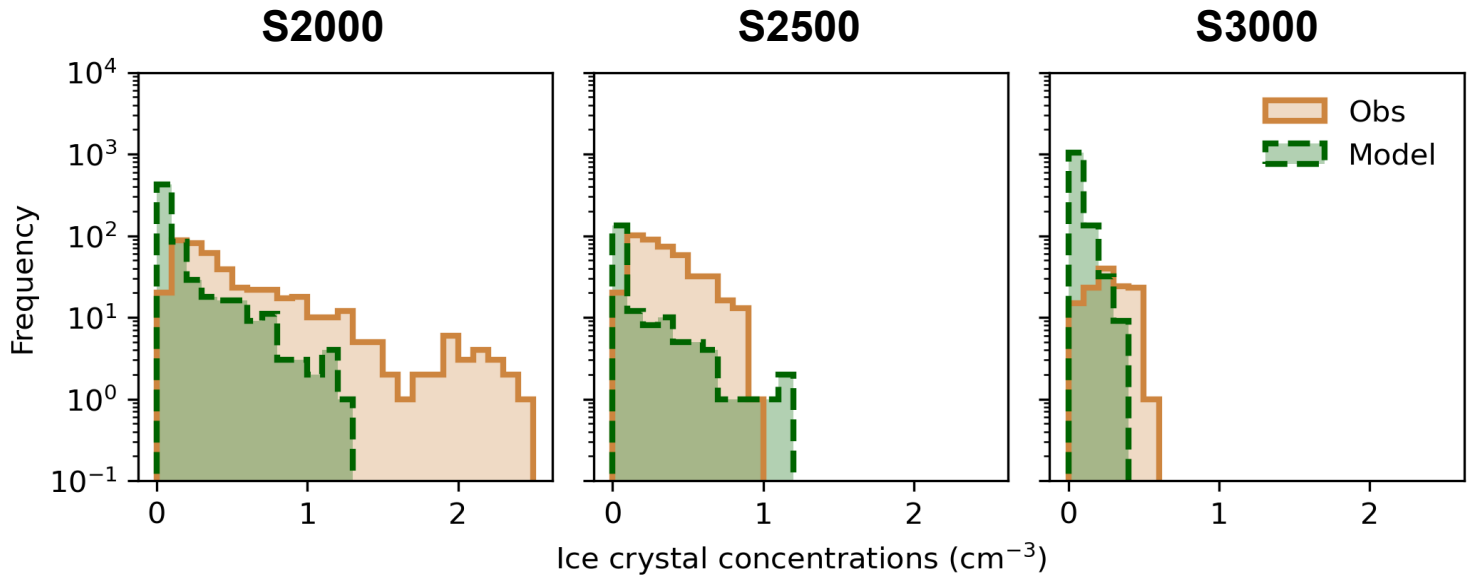
ICON large eddy simulations (dx = 130 m)

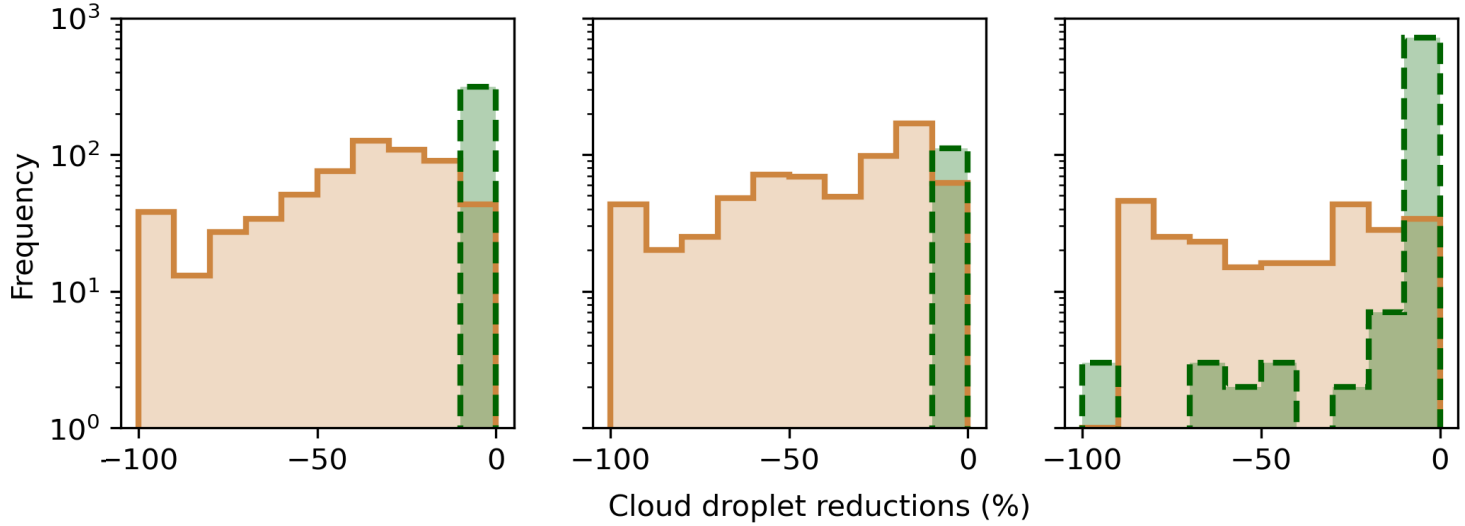
Omanovic et al., ACP, in discussion

Ice crystal concentration (cm^{-3})



model reproduce the high ice crystal concentrations reproduces

Cloud droplet concentration reduction (%)



model could not reproduce as strong reductions in cloud droplet concentrations

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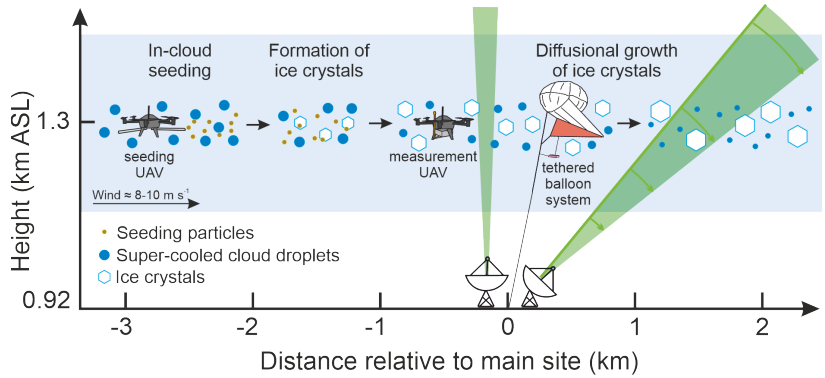
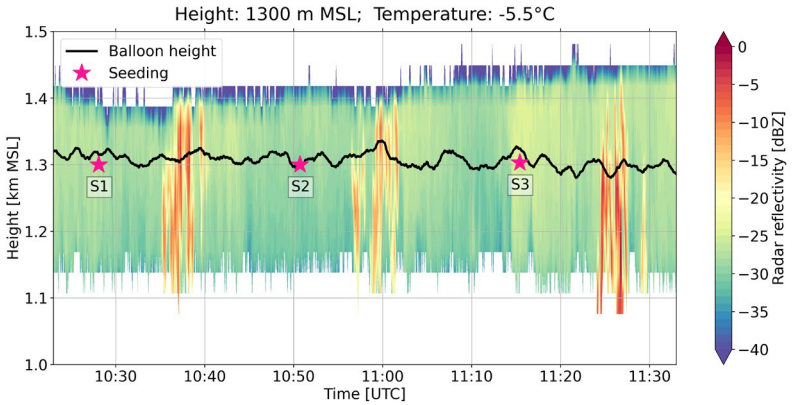
Conclusions:

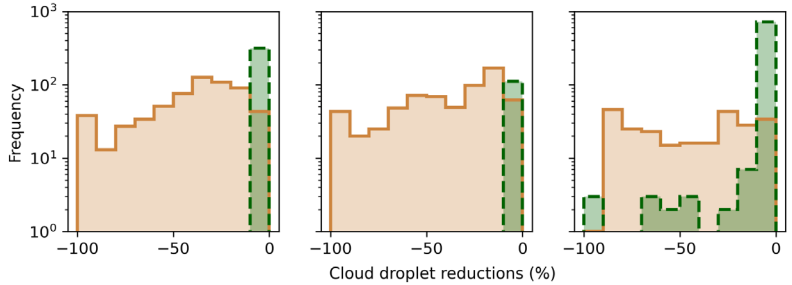
- We successfully conducted 70 glaciogenic seeding experiments of stratus clouds from a UAV:
  - Radar reflectivities 10-25 dB higher than the background
  - Ice crystal concentrations above 1000 L^{-1} and reduction in water content
  - Ice crystal sizes grow with increasing distance to the seeding

- Simulated seeding experiments reproduced the high ice crystal concentrations, but not the strong reduction in cloud droplets concentrations

Henneberger, Ramelli et al., BAMS, 2023







Omanovic et al., ACP, in discussion