Lack of INP and precipitation in supercooled stratus clouds over the Swiss Plateau might be explained by upwind INP activation and removal

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Introduction - Supercooled liquid clouds in Switzerland

Location:
Eriswil (ERI), CH, over the Swiss Plateau
Scenery:
- Persistent slightly supercooled (T>-10°C) stratiform 'Bise' clouds
- Thermodynamically and aerosol controlled natural environment
- Lack of heterogeneous ice formation in supercooled stratus clouds
- Lack of precipitation not reproducable by model simulations

Approach:
PolarCAP (Fig. 1a) in colaboration with Cloudlab (EU project) of ETH Zurich
- Two winter campaigns 2022-2024
- Unique constellation of ground-based remote sensing and in-situ observations (Fig. 2)
- INP (ice-nucleating particle) sampling in ERI and Hohenpeißenberg (HPB)

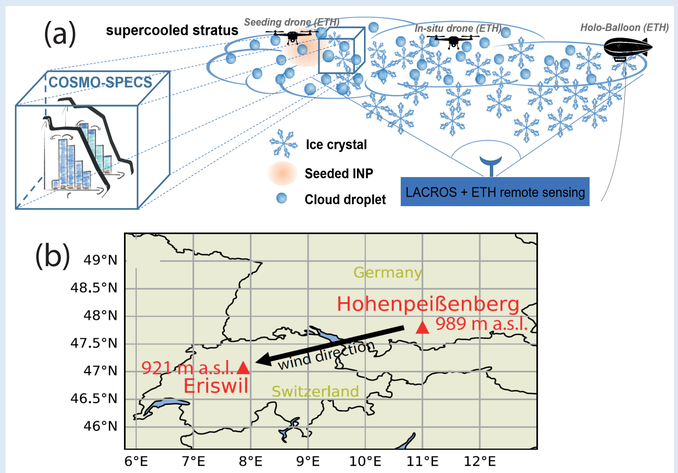


Fig. 1: (a) Sketch of the project idea. Seeding of supercooled (0 to -10°C) liquid clouds. Use remote sensing and model results.
(b) Map showing locations of Hohenpeißenberg (47.80°N, 11.00°E) and Eriswil, Switzerland (47.07°N, 7.87°E). Northeasterly winds close to the ground are indicated with the black arrow.

Campaign - In situ and remote-sensing

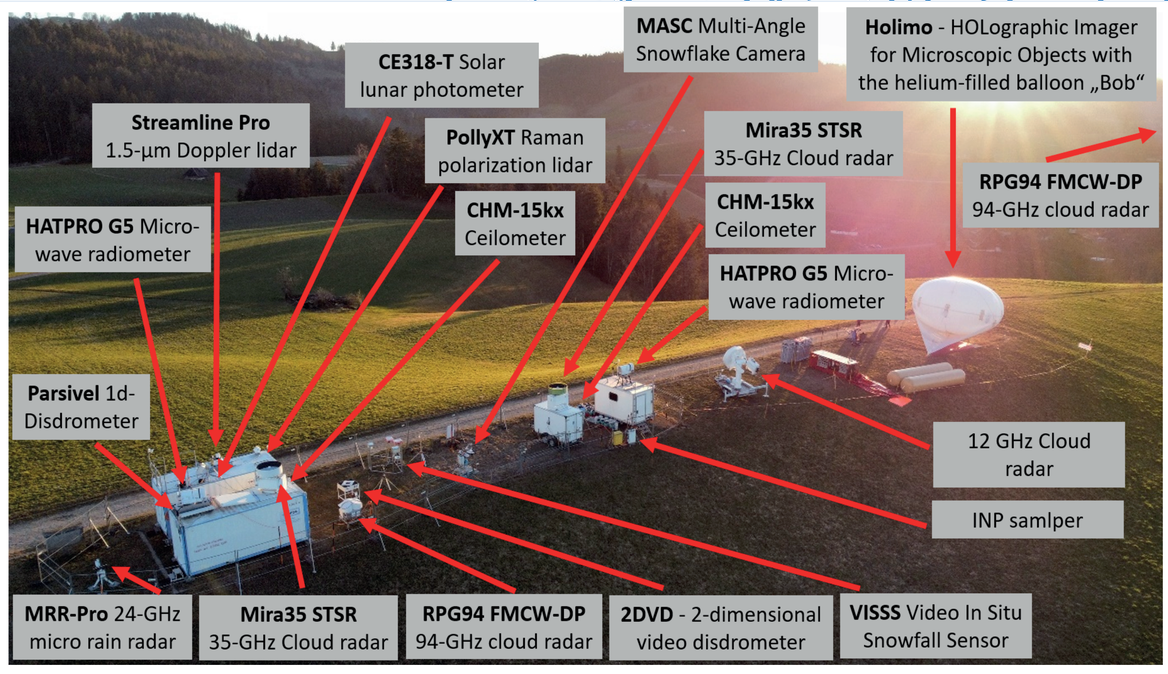
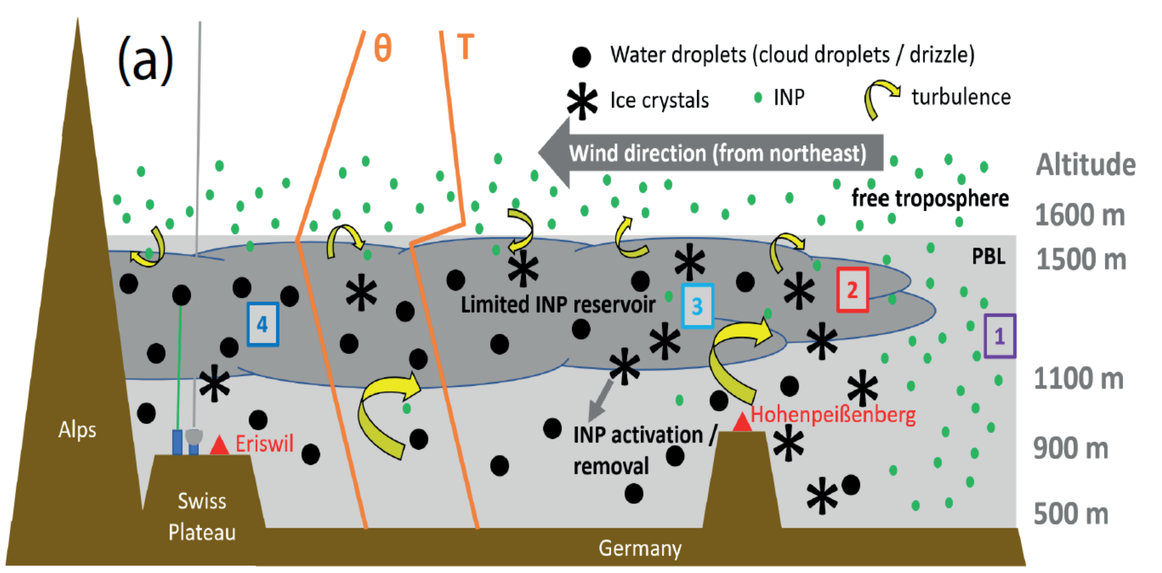


Fig. 2: Instrumental setup of CLOUDLAB and PolarCAP campaign in Eriswil, Switzerland.

Hypothesis: INP removal in cold Bise cloud



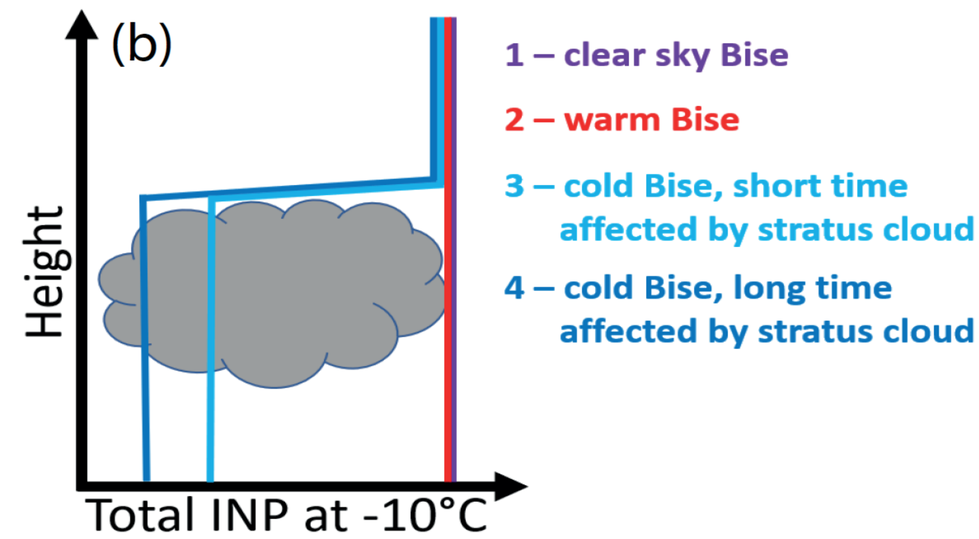


Fig. 3: (a) Scheme of a cold Bise situation where both, Hohenpeißenberg (HPB) and Eriswil (ERI) are situated in the planetary boundary layer (PBL). b) The situations 1-4 indicated in (a) the hypothetical ice-nucleating particle (INP) concentrations at -10°C are shown as a vertical profile in terms of height.

Figure 3 highlights the approach of the INP contrast study
- Figure 3 shows a situation of a cold Bise (cloud top temperatures below 0°C) for HPB and ERI, both within the PBL in northeasterly winds
- INP form primary ice in the Bise cloud and with this process the INP are removed quite fast within a cold Bise cloud
- A lack of biological INP at the Bise cloud temperatures is visible in ERI and HPB for a cold Bise situation which results in very low ice crystal numbers in the cloud
- The Bise cloud in the PBL is thermodynamically coupled with the surface, so it consumes the INP in the entire PBL
- The INP reservoir in the free troposphere is unaffected by the INP consumption. Via turbulent mixing at the cloud top free tropospheric INP would be entrained into the Bise cloud
- Turbulent mixing is a source for ongoing primary ice formation within the Bise cloud and could explain the observed minimal snowfall in Eriswil

Results: Spatial contrast in INP (Hohenpeißenberg - Eriswil)

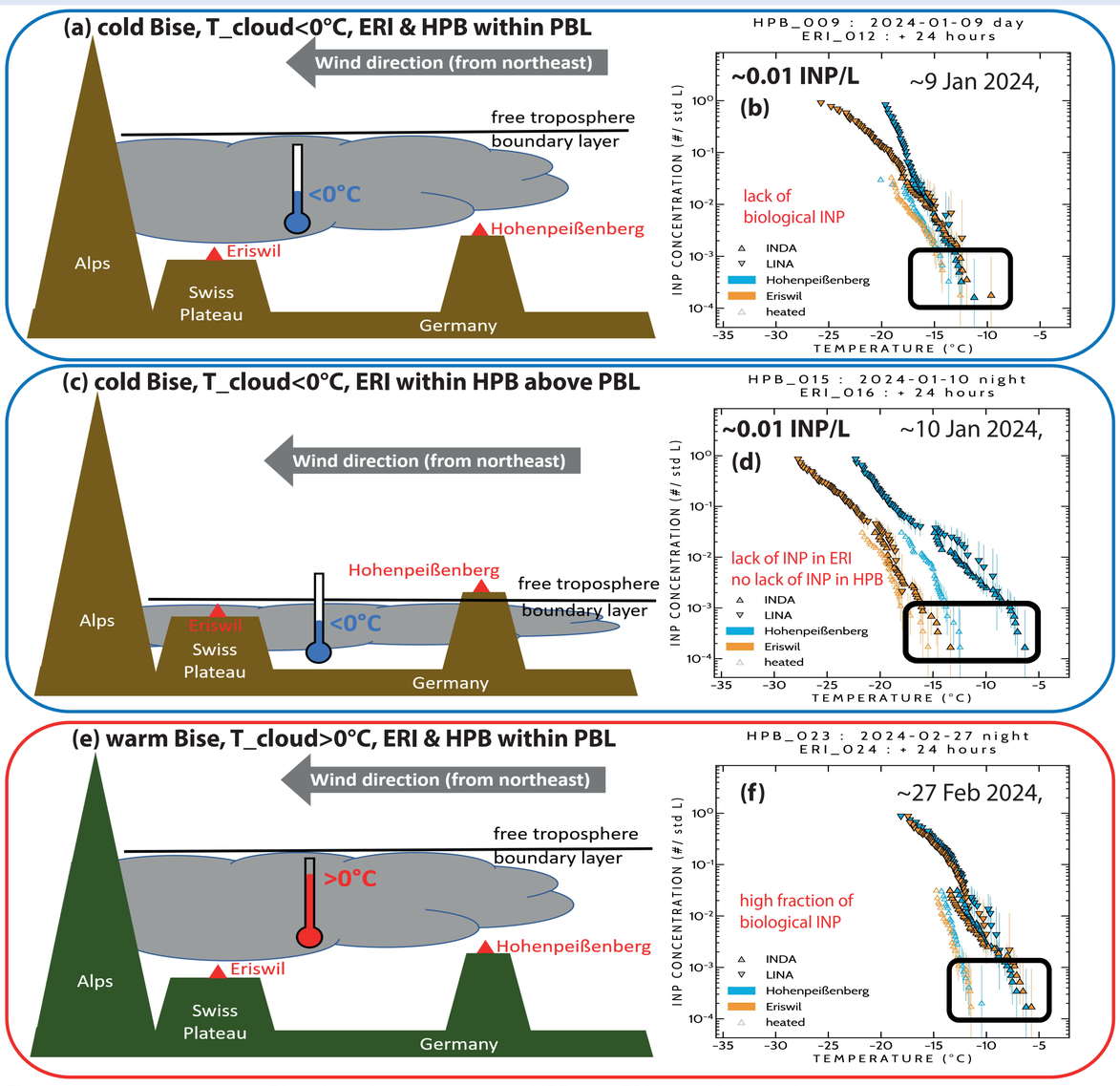


Fig. 4: (a) scheme of a cold Bise situation where both, HPB and ERI were situated in the planetary boundary layer (PBL) b) for the situation in (a): INP samples at Eriswil and Hohenpeißenberg on 9 Jan 2024, (c) and (d) same as (a) and (b) but for a situation where HPB was located in the free troposphere and ERI in the PBL on 10 Jan 2024, (e) and (f) same as (a) and (b) but for warm Bise situation and on 27 Feb 2024

- Wind directions from Hohenpeißenberg towards Eriswil
- A lack of biological INP is visible in ERI and HPB for a cold Bise situation (cloud-top temperatures below 0°C) when both sites were within the PBL (Fig. 4a, b)
- In the planetary boundary layer in a cold Bise situation in Eriswil there was a lack of INP, however, on the same day HPB was located in the free troposphere and showed a higher fraction of biogenic INP (Fig. 4c, d)
- For cloud temperatures above 0°C (warm Bise, Fig. 4e, f) ERI and HPB showed higher biological INP

Discussion and Summary

- INP characterization in HPB and ERI for different Bise situations
- Lack of INPs at -10°C in ERI and HPB during cold Bise within the PBL
- If HPB was located in the free troposphere, there were higher INP concentrations found, including biological INP
- During warm Bise situation higher INP concentrations at ERI and HPB with no big differences between both places
- Results indicate that INP reservoir is depleted quite quickly within a cold Bise cloud. The reservoir for new INP might be located in the free troposphere. Only via turbulent mixing between planetary boundary layer and free troposphere INP might be mixed into the Bise cloud