Natural seeding by ice clouds over Switzerland

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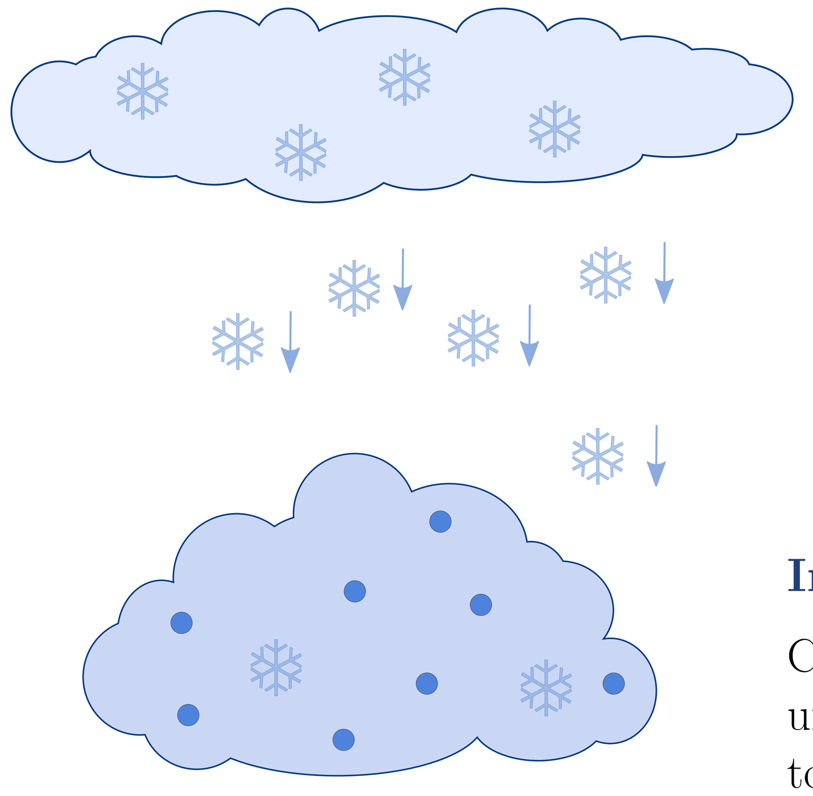

Fig. 1: Natural cloud seeding

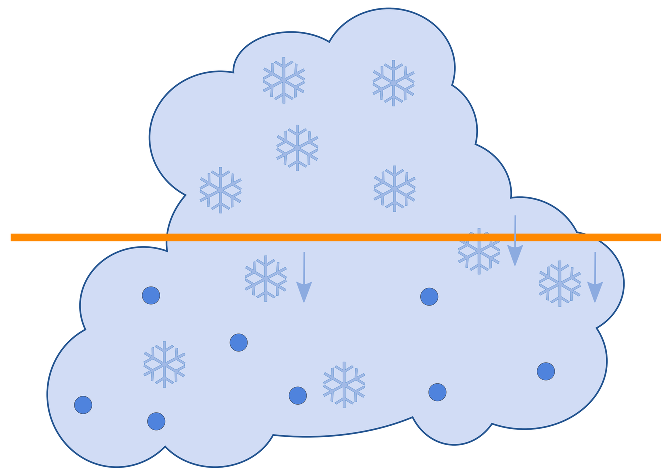

Fig. 2: In-cloud seeding

Introduction

Clouds and their feedbacks represent one of the largest uncertainties in climate projections. As the ice phase influences many key cloud properties and their lifetime, its formation needs to be better understood in order to improve climate and weather prediction models. Natural cloud seeding can **trigger glaciation** in clouds (Fig. 1). Via the seeder-feeder mechanism, it has been shown to **enhance precipitation formation**. In this study, we estimate the occurrence frequency of the seeder-feeder mechanism over Switzerland from satellite data, and investigate its impact in a modelling case study.

Occurrence frequency of natural cloud seeding

Methods

We used cloud cover data from the **DARDAR satellite product** (Delanoë and Hogan, 2008; Ceccaldi et al., 2013) to derive the occurrence frequency of ice clouds ($T < -35\,°C$) over liquid/ice/mixed-phase clouds ($T > -35\,°C$) and the distance in between (Δz_{il}). DARDAR data is derived from CloudSat and CALIPSO satellite data and contains atmospheric profiles with 60 m vertical and 1.4 km horizontal resolution. We used data from April 2006 through October 2017 ($\approx$ 2200 tracks through our domain, Fig. 3).

We combined the DARDAR data with **sublimation calculations** to investigate whether ice crystals sedimenting from the ice cloud base would sublimate before or reach the lower cloud top, a necessary prerequisite for cloud seeding. The calculations were conducted separately for each satellite data measurement, using relative humidity and temperature profiles from ERA5 reanalysis data as input.

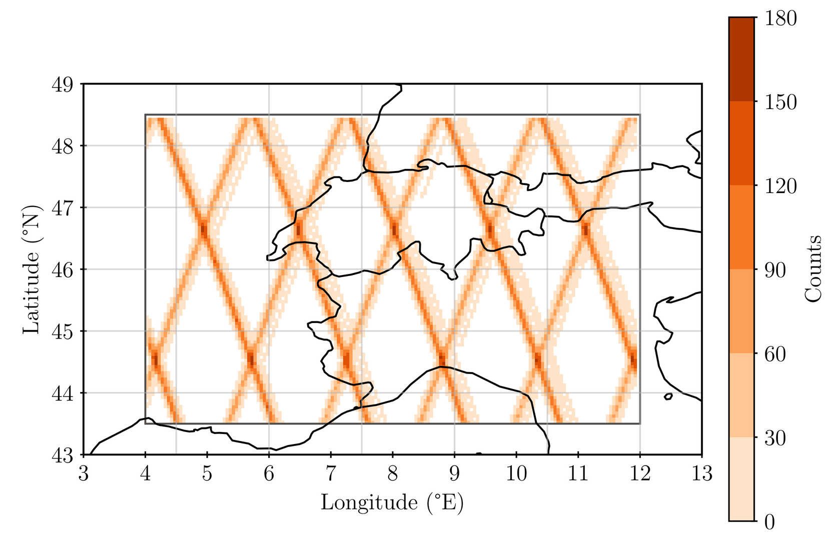

Fig. 3: Distribution of the CloudSat and CALIPSO tracks in the study domain (2006-2017)

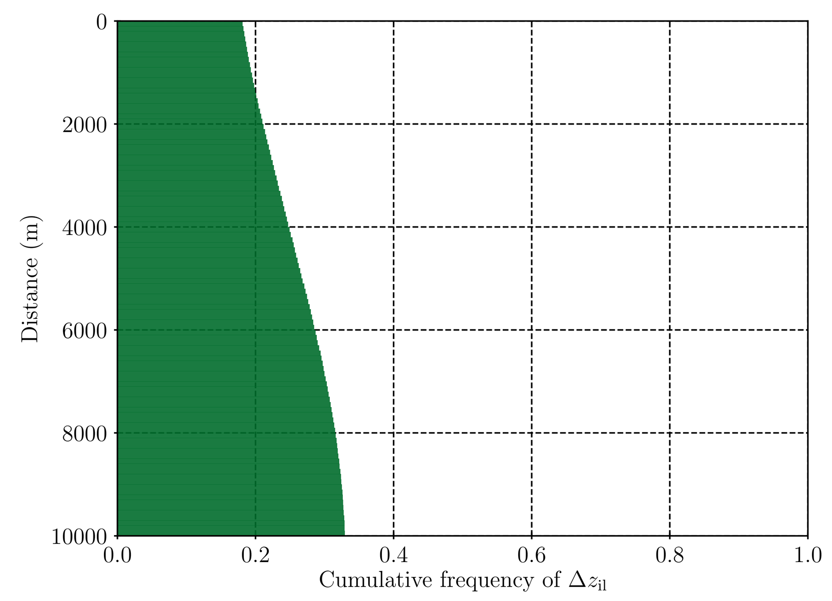

Fig. 4: Average distribution of distances between ice cloud base and lower cloud top (Δz_{il}).

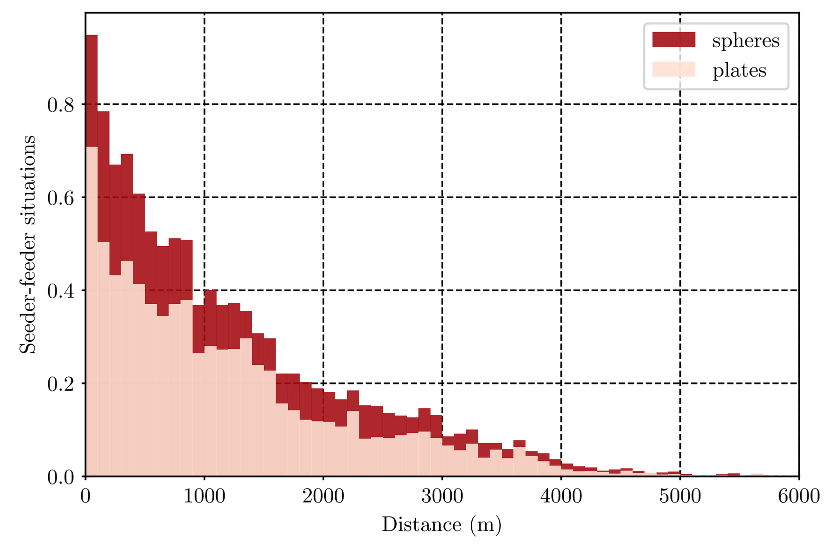

Fig. 5: Fraction of distances where the ice crystal reaches the lower cloud layer (assuming spherical and plate-like ice crystals)

Results

- Two different cases of **between cloud distances**:
  - $\Delta z_{il} > 100$ m, 15 % of measurements: classical seeder-feeder situation with one ice cloud above a lower cloud (Fig. 1, 4)
  - $\Delta z_{il} < 100$ m, 18 % of measurements: the two clouds are connected → potential for in-cloud seeding (Fig. 2, 4)
- A significant number of ice crystals **do not sublimate while sedimenting** between the two cloud layers (Fig. 5).
- Assuming plates, ice crystals sublimate later than when assuming spheres; e.g. for $\Delta z_{il} = 2$ km: 20 % of spherical ice crystals survive, 10 % of plate-like ice crystals survive → **shape distinction** is important (Fig. 5)

Effect of natural cloud seeding in COSMO

Methods

We simulated a case study, on 18.05.2016, chosen from the satellite data to contain seeder-feeder situations, with the regional weather and climate model Consortium of Small-Scale Modeling (COSMO). We compared a five member **control ensemble** to a **sensitivity simulation**, in which all **sedimenting ice fluxes were set to 0 outside of clouds**.

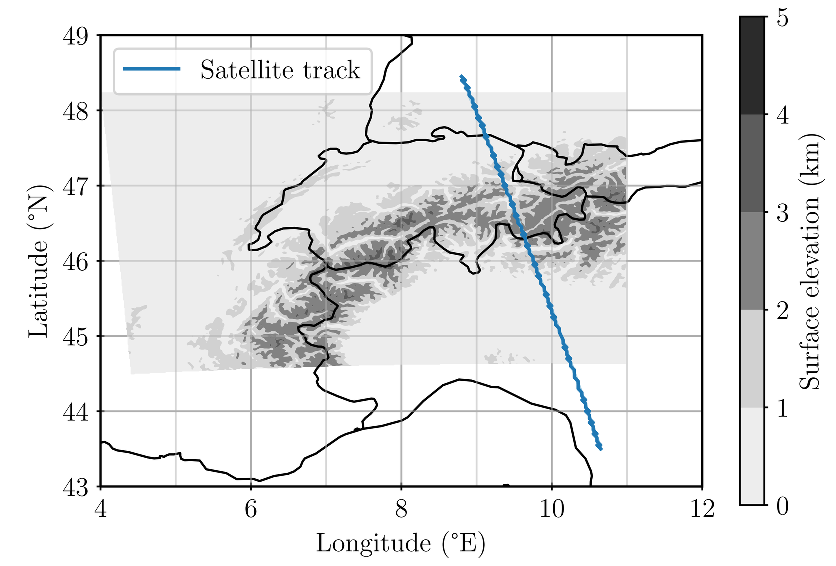

Fig. 6: COSMO study domain

Results

- Cloud droplet mass concentration (Fig. 7):
  - Below 4 km: less ice → **less conversion to cloud droplets** by melting or shedding → reduced cloud droplet mass concentrations
  - Above 4 km (temperatures are too cold for melting or shedding to occur): less ice → **more moisture available** for droplet growth → increased cloud droplet mass concentrations
- Ice crystal mass concentration (Fig. 8):
  - Above 7 km: missing ice crystals → missing sublimation → warmer atmosphere → **increased updrafts** → **increased ice formation** → increased ice crystal concentrations. This is a confounding influence from the removal of sedimenting ice crystals → need a more specific inhibition of natural cloud seeding to isolate the seeding effect
  - Below 7 km: missing ice crystals → further **reduced ice formation (inhibited WBF process)** → ice crystal mass concentration decrease

  → overall, **ice crystal mass concentrations are reduced** in this sensitivity simulation

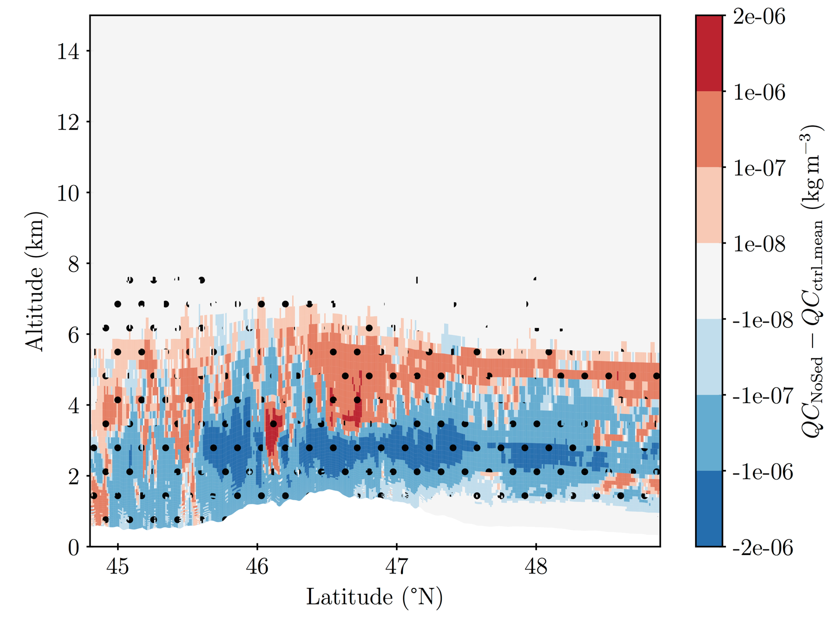

Fig. 7: Cross section (longitudinal and time mean over 13 h) of the cloud droplet mass concentration, difference between the sensitivity simulation and the control ensemble mean

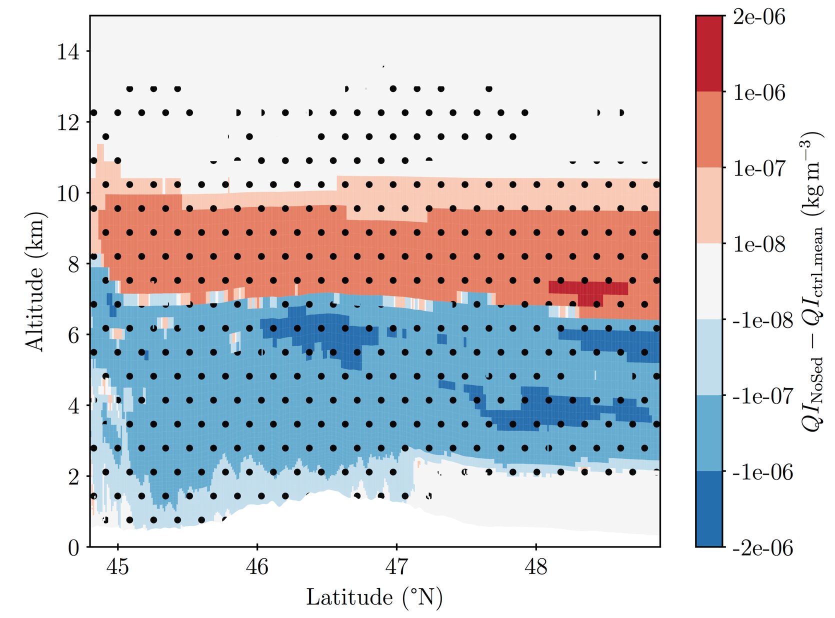

Fig. 8: Same as above for ice crystal mass concentration

Conclusions

- Natural cloud seeding/seeder-feeder situations occur **frequently over Switzerland** (33 %)
- **Seeding ice crystals reach lower cloud layers** in a significant number of cases
- **Inhibiting natural ice seeding reduces total ice crystal mass concentrations** and reduces ($<$ 4 km)/increases($>$ 4 km) cloud water mass concentrations in the COSMO case study

References

Ceccaldi, M., J. Delanoë, R. J. Hogan, N. L. Pounder, A. Protat, and J. Pelon (2013). "From CloudSat-CALIPSO to EarthCare: Evolution of the DARDAR Cloud Classification and Its Comparison to Airborne Radar-Lidar Observations". In: *Journal of Geophysical Research: Atmospheres* 118.14, pp. 7962–7981. ISSN: 2169897X. DOI: 10.1002/jgrd.50579.

Delanoë, Julien and Robin J. Hogan (2008). "A Variational Scheme for Retrieving Ice Cloud Properties from Combined Radar, Lidar, and Infrared Radiometer". In: *Journal of Geophysical Research* 113.D7, p. D07204. ISSN: 0148-0227. DOI: 10.1029/2007JD009000.