New insights into ice formation in mixed-phase clouds through collocated in-situ and remote sensing measurements

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The processes responsible for ice crystal formation in clouds, in particular, secondary ice production (SIP) from existing ice, are insufficiently understood. In addition, the environmental conditions favorable for their occurrence are poorly characterized. In-situ measurements with a cloud imager allow for a detailed characterization of the cloud hydrometeors including the shape of the ice crystals but capture a limited volume and time span. Remote sensing can improve the coverage of cloud observation as the whole column of the atmosphere is measured autonomously. The combination of multiple techniques (e.g., lidar and radar) and advanced retrieval methods using polarimetric measurements enables the retrieval of cloud microphysical properties like the ice crystal number concentration. For an accurate retrieval, a priori knowledge of the size and shape of the ice crystal is needed which can be obtained from a cloud imager.

Here, we present collocated observations from a holographic cloud imager on a tethered balloon system with ground-based remote sensing instrumentation during campaigns in the Arctic (Ny-Ålesund AeroSol Cloud ExperimeNT (NASCENT)[1]) and the Alps (Role of Aerosol and CLouds Enhanced by Topography on Snow (RACLETS)). In-situ measurements are used to validate remote sensing retrieval for the concentration of aerosols, ice nucleating particles, and ice crystals. Using the validated remote sensing retrieval, a methodology was developed to derive ice multiplication factors resolved in height and time from remote sensing observations [2]. This methodology has the potential to be extended to a larger dataset to constrain the condition in which SIP occurs.

Both in the Arctic and in the Alps, SIP occurred for most of our observations between cloud temperatures of -2 °C to -30 °C. In the Alps, a median ice multiplication factor of 80 was observed and the updraft and turbulence caused by the orography enhanced the ice formation. In the Arctic, high concentrations of small pristine ice crystals, used as a proxy to identify cloud regions with SIP, coincided with the presence of large frozen and broken drops, providing evidence for SIP during the freezing of drizzle drops. We suggest that intensified formation of drizzle drops in the clean Arctic environment enhances SIP upon freezing.

References:

[1] Pasquier, J. T., R. O. David, G. Freitas, R. Gierens, Y. Gramlich, et al., 2022: The Ny-Ålesund Aerosol Cloud Experiment (NASCENT): Overview and First Results. Bulletin of the American Meteorological Society, in review, 2022

[2] Wieder, J., Ihn, N., Mignani, C., Haarig, M., Bühl, J., Seifert, P., Engelmann, R., Ramelli, F., Kanji, Z. A., Lohmann, U., and Henneberger, J.: Retrieving ice nucleating particle concentration and ice multiplication factors using active remote sensing validated by in situ observations, Atmos. Chem. Phys. Discuss. [preprint], https://doi.org/10.5194/acp-2022-67, in review, 2022.