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The relative contribution of secondary ice processes in Alpine mixed-phase clouds

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In-situ observations of mixed-phase clouds (MPCs) forming over mountain tops regularly reveal that ice crystal number concentrations (ICNCs) are orders of magnitude higher than ice-nucleating particle concentrations. This discrepancy has often been attributed to the influence of surface processes such as blowing snow and airborne hoar frost. In-cloud secondary ice production (SIP) processes may also explain this discrepancy, but their contribution has received less attention.
Here we explore the potential role of SIP processes on orographic MPCs observed during the Cloud and Aerosol Characterization Experiment (CLACE) 2014 campaign at the mountain-top site of Jungfraujoch in the Swiss Alps using the Weather Research and Forecasting model (WRF). The Hallett-Mossop (H-M) mechanism, included in the default version of the Morrison scheme in WRF, is ruled out since the simulated clouds were outside the active temperature range for this process. This study investigates if the implementation of two additional SIP mechanisms in WRF, namely collisional break-up (BR) between ice hydrometeors and frozen droplet shattering (DS), can bridge the gap between observed and modeled ICNCs. DS is inefficient in the examined conditions due to a lack of sufficiently large raindrops to trigger this process. The BR mechanism is likely important in Alpine MPCs, but the process is activated only within seeder-feeder situations, when precipitation particles are seeding the low-level MPCs inducing their glaciation. At times when a cloud exists near the ground, blowing snow ice particles may be mixed among supercooled liquid droplets and thus contribute significantly to ice growth, but they cannot account for the observed ICNCs. Our findings indicate that outside the H-M temperature range, ice-seeding and blowing snow can initiate ice multiplication in the Alps through the BR mechanism, which is found to elevate the modeled ICNCs up to 3 orders of magnitude, providing a better agreement with in-situ measurements. This highlights the importance of considering both SIP and surface-based processes in weather-prediction and climate models.