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Investigating secondary ice processes in the regional COSMO model

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The co-existence of ice crystals and supercooled liquid water droplets in clouds play a significant role in the formation of precipitation in the mid-latitudes. After primary production of ice through homogeneous and heterogeneous nucleation, secondary processes cause ice crystals to multiply rapidly enabling mixed-phase clouds to glaciate. A secondary ice formation process occurring between -3 and -8 [U+1D52]C is called the Hallett-Mossop (HM) process. The HM process occurs at warmer temperatures than any other secondary ice formation process and therefore dominates ice multiplication in the early stages of the cloud's existence.

The discrepancy between the concentration of ice nucleating particles (INPs) and the ice crystal number concentration (ICNC) observed in many studies remains unresolved and limits our understanding of precipitation amount, location and intensity in the Alps. Modelling studies with the COSMO model and a two-moment cloud scheme conducted at the Jungfraujoch show that the simulated ICNC is underestimated by an order of magnitude in mixed-phase orographic clouds during winter when compared to observations (Henneberg et al., 2017). Because temperatures were at and below –15 [U+1D52]C, the HM process was ruled out. The COSMO model doesn't include any other ice multiplication scheme than HM. Yet, measurements of INPs and ICNCs indicate that ICNCs exceed INPs by several orders of magnitude. This discrepancy between the observations and the model may be explained with other secondary ice formation processes, such as frozen droplet shattering, and breakup through collisions between ice hydrometeors (Sullivan et al., 2018).

Our study investigates the impact of the additional in-cloud secondary ice processes on precipitation formation and how they impact surface precipitation. The COSMO and a two-moment cloud scheme are used that includes secondary ice processes described by Sullivan et al. (2018). We simulate orographic mixed-phase clouds in an idealized two-dimensional flow over two bell-shaped hills with a valley that is 300 m deep. Including rime splintering, droplet shattering and breakup shows an increase in the total mass fraction and total number concentration of frozen cloud hydrometeors over both hills. This increase in ice number concentration results in a precipitation increase by a factor of 2 and 1.5 over the first hill and the second hill respectively. We hypothesize that an increase in ICNC result in the growth of hydrometeors, through riming or diffusion, to precipitable size providing that there is enough water vapour within the cloud. There is no spatial shift in the precipitation at the first hill, however, the precipitation in the valley towards the windward side of the second hill decreases with an increase in ICNC. Furthermore, the precipitation increase on the lee side of the second hill is possibly associated with the advection of moisture from the valley to the lee of the second hill. Efforts towards understanding the interaction between cloud droplets and ice crystals and their influence on precipitation formation will also be discussed.