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Parameterizing secondary ice production in Arctic mixed-phase clouds

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The representation of Arctic mixed-phase clouds (MPCs) in global climate models (GCMs) is becoming a widely acknowledged challenge, which highlights the necessity of revisiting the microphysical parameterizations associated with this type of clouds. The relatively sparse ice-nucleating particles (INPs) in the Arctic region (Wex et al., 2019) cannot always account for the high ice crystal number concentrations (ICNCs) found in Arctic MPCs. This indicates the presence of additional ice multiplication processes, known as secondary ice production (SIP), that can rapidly enhance the few primary ice crystals (e.g., Korolev and Leisner, 2020). All GCMs include parameterizations of primary ice production (PIP), but they still lack description of some important SIP processes.

In this study we propose a new approach towards parameterizing SIP in polar stratiform clouds. The new parameterization encompasses the use of the ice-enhancement factor (IEF), which is a multiplication factor applied to primary ice crystals, to consider the effect of the three most important SIP mechanisms, namely the Hallett-Mossop (HM), the ice-ice collisional break-up (BR) and the droplet-shattering (DS) process. The derivation of the IEF parameterization is based on two-year regional climate simulations over the Ny-Ålesund station performed by the mesoscale Weather Research and Forecasting model (WRF) with augmented cloud microphysics (Sotiropoulou et al., 2021; Georgakaki et al., 2021) to account for all the SIP mechanisms. The WRF simulations indicate that the mean production rates of SIP can be up to 5 orders of magnitude higher than PIP at warm subzero temperatures higher than -10 ˚C. The production of secondary ice particles in the simulated Arctic clouds is found to be dominated by the BR process, with the contribution of DS and HM being substantially smaller. Machine learning techniques are then used to automatically detect patterns in the WRF dataset and to extract a parameterized expression of the IEF as a function of key thermodynamic and microphysical parameters. The newly developed formulation can effectively be implemented in GCMs with double-moment representations of the ice hydrometeors, which is expected to improve the modeled liquid-ice phase partitioning and therefore, the representation of radiation patterns and precipitation processes.

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