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Mechanisms of Ice Multiplication Mediating the Effect from Aerosols on a Cold-based Convective Storm

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Recent published intercomparisons of cloud models have indicated that they are typically unable to predict the observed microphysical properties of cold clouds. In particular, predicted concentrations of ice are too low. It has been suggested that missing processes of secondary ice production involving fragmentation of ice may be the reason.

Equally, recent aircraft observations with the most modern probes have confirmed the classic dilemma: observed ice concentrations in precipitating clouds with tops warmer than about -36 degC (the threshold for spontaneous freezing of all cloud-liquid) are orders of magnitude higher than coincident concentrations of ice nucleus (IN) aerosol particles. In the absence of IN, no ice would form in such clouds. The inevitable implication from such aircraft observations is that the first ice forms in such clouds from the action of IN and then grows to form ice precipitation that then fragments somehow, with the possible growth of fragments to form more ice precipitation ('ice multiplication').

Laboratory observations have identified several mechanisms of fragmentation but these have not been completely characterised. In our recent published papers (2017 and 2018), we circumvented this issue by pooling published laboratory observations of fragmentation and fitting it with theoretically justified formulae. We showed the fragmentation dominated ice concentrations for some cases. This was done for fragmentation in ice-ice collisions, which depends on collision kinetic energy (CKE) and morphology of ice. It was also done for fragmentation of freezing drizzle and raindrops, for which two modes were demonstrated. The first mode was spherical freezing of a drop. The second mode involved accretion of a drop by a more massive ice particle, depending on CKE again.

In the presentation, the role of these fragmentation processes is shown for simulations of an observed case of a cold-based convective storm over the US High Plains. The 'aerosol-cloud model' (AC), with an electrification component, predicts the dependency of cloud properties on environmental factors: aerosol conditions (IN, cloud condensation nuclei [CCN]), instability ('Convective Available Potential Energy' [CAPE]) controlling updraft speeds and cloud-base temperature. Use of innovative tagging tracers reveals the components of the ice concentration arising from the various types of ice multiplication.

The dominant role of fragmentation by graupel-snow collisions in the simulated storm acts to diminish the sensitivity of cloud properties with respect to changes in aerosol loading (IN and CCN). The ice concentration is always maintained close to its theoretical upper limit for mixed-phase conditions. Simulated cloud properties such as liquid contents and lightning flash rates are shown to depend strongly on CAPE and cloud-base temperature, both factors controlling the vigour of the cloud dynamics.

In summary, such overlooked processes of fragmentation of ice must be represented by cloud models generally, if they are to be realistic for cold-based convection.