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A study of ice formation by primary nucleation and ice multiplication in shallow precipitating convective clouds

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The microphysics of shallow precipitating supercooled cumulus clouds have been investigated as part of the NERC APPRAISE programme. In-situ aircraft measurement of cloud microphysics properties using the Facility for Airborne Atmospheric measurement BA146 aircraft were made in conjunction with remote sensing observations from Radar and Lidar platforms at the Chilbolton Radar Facility in Hampshire UK. Isolated convective cumulus and shallow convective cumulus clouds were present spanning the temperature range of ∼+4.5 to – 19 °C and ∼-1 to -7 °C with approximate cloud depths of 2.95 km and 0.95 km respectively. Both clouds were observed to precipitate.

The first case featured a narrow isolated convective cloud (∼ 10 km across) which persisted for several hours. Supercooled droplets were found throughout the clouds vertical extent with predominantly ice at cloud top. At the lower levels low concentrations of rimed ice and graupel (up to 10 L-1) were present along side some supercooled drizzle. A constant altitude run at ∼ -11 °C showed an increased ice number concentration of around 50 L-1 where the majority of ice crystals were lightly rimed column crystals, suggesting secondary ice processes had occurred. Similar ice crystals were found to be advected in a strong updraught (up to 4 ms-1) to higher levels within the cloud with ice number concentrations approaching 100 L-1.

The second case studied a narrow but extensive line (∼100 km) of shallow convective cloud consisting of supercooled droplets throughout and rimed ice and columns at higher levels. Ice crystals were found in regions with relatively low number concentrations (up to 20 L-1 of rimed primary ice) and also with regions of high concentration of columns (200 L-1) at temperatures consistent with the Hallett-Mossop process.

There is strong evidence for the Hallett-Mossop process producing the high ice number concentrations observed in each case; ice number concentrations were considerably higher than can be explained by primary nucleation alone and supercooled droplets and rimed ice coexisted in regions conducive to the Hallett-Mossop process occurring. In the first study calculated ice splinter production rates were consistent with the observed ice number concentrations. In the second study it was necessary to relax the constraint that only droplets greater than 24 μm are capable of generating ice splinters to achieve consistency.

The clouds and their formation were modelled using WRF. It was found that the overall synoptic situation was well simulated and the convective clouds were captured. The WRF simulations were used to investigate the sensitivity of the cloud to the treatment of the microphysics. The simulations were performed using the Morrison microphysics scheme, which includes dual-moment representations of cloud liquid water, rain, cloud ice, snow and graupel). Results from the second case study described above showed that the H-M secondary process was important to the development of the precipitation via the ice phase and had an impact on the structure of the convective cloud. When H-M was turned off in the WRF simulation, it was interesting that the dynamical structure and cloud top height of the clouds was only slightly affected and precipitation was still produced. Ice formation was now by primary nucleation only and although a reduction was seen in the total number concentration of ice crystals, the concentration of graupel remained high enough (several per litre) to sustain the precipitation from the cloud.