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Microphysical properties of mid-latitude frontal clouds

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Frontal systems associated with mid-latitude cyclones generate large regions of cloud which can perturb the regional radiation balance, as well as precipitate large quantities of water to the surface. Predictability of the spatial distribution and temporal development of the radiative properties and precipitation associated with frontal clouds requires knowledge of the microphysical processes acting, as well as the dynamical forcing.

We present in-situ and remote sensing data obtained from frontal clouds in the vicinity of the Chilbolton Facility for Atmospheric and Radio Research (CFARR), in the southern region of the United Kingdom. Range Height Indicator (RHI) scans from the 3 GHz dual polarisation Doppler CAMRa (Chilbolton Advanced Meteorological Radar) were conducted along a radial where concurrent in-situ measurements of microphysical properties were obtained. The in-situ measurements were obtained from the UK Facility for Airborne Atmospheric Research (FAAM) BAe146 aircraft. A vertical pointing 35 GHz Doppler cloud radar was also operating at the CFARR site. Case studies were simulated using the Advanced Research WRF (Weather Research and Forecasting) model version 3.1 using the dual moment Morrison microphysics scheme which predicts the mixing ratios and number concentrations of hydrometeors in 5 categories (droplets, rain, ice, snow and graupel). The WRF simulations were run on 4 domains nested from 12 km to 1 km horizontal resolution and initialised/driven at boundaries by GFS data.

Nucleation at cloud top was seen as the primary source of ice at the time of measurement for the deep frontal cases where cloud top temperatures were approximately -35^{o}C. However, one case with lower cloud top height/temperature (approximately -25^{o}C), while still containing ice, was capped with a layer of supercooled liquid water at cloud top. The ice nucleated at cloud top grew via deposition/aggregation into snow. Pristine plate-like ice crystals were frequently observed (temperature approx. -20^{o}C) in regions of high differential reflectivity (identified by the CAMRa). Embedded convection originating from near the surface was observed frequently and was associated with the production of regions of supercooled water within the frontal cloud. High number concentrations (peaking over 100 L^{-1}, typically 40 L^{-1}) of ice crystals were found in the temperature range -3^{o}C to -8^{o}C. These ice crystals were relatively small (300 μm in length compared to over 1 mm for the snowflakes) and appeared to be un-rimed columns based on in-situ imagery. The high ice crystal concentrations are most likely a result of Secondary Ice Production (SIP) resulting from the Hallett-Mossop (HM) process of rime splinter ejection. The horizontal extent to which SIP appeared to influence ice number concentrations was 10's of km and contained a significant amount of condensate (peak over 0.5 g m^{-3}). WRF simulations of the cases do not appear to reproduce the regions of high ice crystal concentration in the temperature range -3^{o}C to -8^{o}C, despite the inclusion of the HM process in the Morrison microphysics scheme used. It appears the HM process is important in controlling the transfer of water into/within frontal systems which contain significant amounts of supercooled water. Further through the release of latent heat of fusion the HM process can have an important influence on the dynamical structure of the cloud and hence the inability of the WRF model to adequately simulate this process may affect the ability of the model to forecast the evolution and precipitation from the weather system.