AEROSOL IMPACTS ON THE MICROPHYSICS OF MIXED PHASE CLOUDS

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1. INTRODUCTION

In this paper we investigate the aerosol indirect effect in mixed phase layer clouds, and consider the roles of the aerosol in both droplet and ice crystal nucleation.

The “Aerosol Properties, PRocesses And Influences on the Earth’s climate” (or APPRAISE) programme is a UK Natural Environment Research Council (NERC) directed research programme set up to look at the science of aerosols and their effects on climate. One project in particular within APPRAISE is funded to investigate the Aerosol-Cloud Interactions occurring within Mixed Phase Clouds.

2. THE APPRAISE CLOUD PROJECT

Objectives:
• To determine the nucleating ability of specific ice nuclei and the initiation and development of ice in mixed phase clouds.
• To determine how aerosol particles control the cloud microphysics and dynamics in mixed phase clouds
• To determine the type and phase partitioning of absorbing material above below and within clouds and the role of this material in ice nucleation.
• To reduce the uncertainty in the contribution of indirect radiative forcing by better understanding the role of aerosols in the microphysics of mixed phase cloud.

The NERC APPRAISE cloud project consists of a consortium of UK Universities working in collaboration with the Met office and European collaborators. It has the aim of performing, laboratory, modelling and field studies over the UK (and elsewhere*) that address the question of how ice forms in clouds and in particular how this is determined by the properties of the aerosol entering into cloud. Having improved the understanding of these processes, the objective is then to begin to improve the treatment of ice formation in global scale models.

The main thrust of the UK fieldwork involves the use of the UK FAAM (Facility for Airborne Atmospheric Measurement) BAe146 research aircraft flying in the vicinity of a suite radars and lidars operated at the Chilbolton Observatory in Hampshire, southern England (facilities include a scanning 3-GHz Doppler polarization radar, a 94GHz cloud radar, and a suite of lidars and radiation instrumentation). The aim is to make insitu measurements of the microphysical properties of a variety of mixed phase clouds at the same time as these clouds are being investigated remotely by the radars and lidars. The main cloud types to be studied are winter-time stratocumulus, altocumulus, frontal layer clouds, cirrus and convective clouds (should the opportunities arise).

3. METHOD

During winter 2007–2008, flights were made (and during winter 2008–2009 will be made) in the vicinity of Chilbolton, using the FAAM BAe146 research aircraft. This was (will be) equipped with a comprehensive range of instrumentation to measure the ice and liquid phase microphysics of the cloud and the size distribution and size resolved chemical composition of the aerosols.
entering cloud. The aircraft flew horizontal legs below cloud, in cloud and above cloud top on a radial towards and away from Chilbolton observatory. The vertical separation of in-clouds legs was selected so as to investigate key regions of interest for the cloud microphysics of the system, features which were determined from an initial profile through the cloud system and from the simultaneous observations of the radars and lidars. Passes below cloud base were undertaken in order to investigate the aerosol entering the cloud whilst passes above cloud top were used to investigate any ice crystal seeding that was occurring from above and for the effects of entrainment.

In May 2008 flights were also undertaken in the mid-level orographic wave clouds forming in the air as it flows over the Alps in Switzerland. These were carried out as part of EUCAARI (the European Integrated project on Aerosol Cloud Climate and Air Quality Interactions) and in conjunction with measurements made on the ground at the Jungfraujoch high Alpine research station (which is a GAW site).

4. RESULTS

Results from two flights, B337 and B338, carried out on the mornings of the 15th and the 17th of January 2008, respectively, in the area around and to the west of Chilbolton are presented. On both these occasions, the mid level clouds investigated were associated with the passage of occluded frontal systems through the region (see Figure 1 above for B338).

On each occasion, temperatures at cloud top were significantly colder than -35 deg C, and there was evidence that ice crystal formation had occurred following the freezing of haze droplets. Observations using the CPI (Cloud Particle Imager) probe showed the presence of a large concentration of small pristine Bullet Rosette crystals, the preferred habit of ice growing at these ambient temperatures and humidities. Lower in these clouds the CPI showed that these ice crystals had grown to larger sizes and had developed into more complex shapes. This occurs as other crystal habits continue the growth of the crystals from their original pristine form as the ambient temperature and humidity change. At much lower levels (but at still significantly cold temperatures < -15 deg C) reduced concentrations of much larger crystals were observed. These were generally complex aggregates of the crystal
forms seen higher up in the clouds. For these lower regions, aggregation appears to be the dominant method of crystal growth, forming snowflakes which sweep out the smaller crystals as they fall through the cloud.

![Figure 3: Change in Ice crystal Habit observed by CPI during profile ascent in flight B338 from 4000 to 9000m](image)

Occasionally, at mid levels in the cloud there was evidence of fragmentation of crystals. These fragments were rounded and aged, which together with their rarity suggests that crystal fragmentation may be taking place as a form of secondary ice formation in certain regions.

![Figure 4: Observations of a pocket of broken crystals at -24degC (5800m) during flight B338](image)

In lower cloud layers, mixed phase conditions were observed with evidence of HM splinters growing in a narrow region bounded by regions of aggregates from aloft. On both occasions (B337 and B338) at the time of sampling, the lower level mixed phase cloud layers (cloud tops around -6 deg C) were separated completely from the mid/higher cloud levels by a totally cloud free region. This is best illustrated by the time history plot of radar reflectivity presented in Figure 5 for January 17th (coinciding with flight B338).

![Figure 5: Merged radar reflectivity times series plot for morning of January 17th - as observed by the 3.5GHz cloud radar at Chilbolton.](image)

5. MODELLING

Detailed modelling of the cloud formation on the aerosols, particularly their ability to produce water droplets and ice crystals, is ongoing to aid interpretation of data. The model used is based on the ADDEM model (Topping 2005) which includes a description of the full range of aerosol chemistry including the effects of organic material. Ice nucleating properties of the aerosols are derived from recent studies at the AIDA environment chamber (eg see Crawford et al., ICCP 2008). A full description of mixed phase cloud microphysics is used including that of secondary ice crystal production and the evolution of precipitation.

Results of this and earlier work indicate that in widespread stratiform rainfall there are often regions of embedded convection, which contain high values of liquid water content. In such regions at temperatures just below freezing many small ice splinters are produced as supercooled liquid drops freeze on collision with larger ice particles by the Hallett-Mossop (HM) mechanism.
These splinters then rise in the cloud and grow rapidly to produce the high concentrations of large ice crystals observed. The HM process was found to be the dominant source of ice crystals in many systems. However, for clouds that lay entirely outside the HM zone primary ice crystal nucleation was important, and the dominant source of ice formation where cloud top temperatures fell below –30degC.

In all cases the glaciation process (and hence the cloud dynamics and precipitation formation) were sensitive to the aerosol population entering the cloud, through both water droplet activation and primary ice nucleation (Choularton et al., ICCP 2008).

In addition to the detailed cloud process modelling described, the WRF mesoscale model is also being used to simulate the dynamics and microphysics of the frontal system clouds that are typically observed over Chilbolton. Over the region of interest (the southern half of the UK), the model grid is nested down to a horizontal resolution of 1km. Output from the model will be validated using a variety of products, including ground-based measurements of reflectivity from the Chilbolton radar, analyses of precipitation rates from the Met Office NIMROD system, and in situ microphysical measurements from the FAAM BAe 146 aircraft (eg on APPRAISE flight B338).

For the B238 case study, initial model simulations have been performed using NCEP analysis data to drive the model. Analysis has focused on the ability of the model to capture the general pattern of weather experienced on the day. Radar reflectivity structure from the Chilbolton radar between 0900 and 1300GMT (Figure 5) reveals the presence of some low level cloud (up to 1.5km), and some colder, thicker cloud aloft, separated by a dry layer between approximately 1.5km and 3.5km deep. The reflectivity structure from the model shows that the model has difficulty in simulating the observed gap in the cloud.

However, a tephigram comparison of the NCEP analysis profile over Southern England with a radiosonde ascent from Herstmonceux (both at 1200UTC) reveal that the NCEP analysis is too wet in the upper half of the troposphere, which may be contributing to the deficiencies in the simulation. Given the sensitivity of the model output to initial conditions, repeat simulations will be performed using ECMWF analyses. Also the technique of observation nudging (i.e. gently forcing the model towards the radiosonde data) will be employed in an attempt to achieve the best possible simulation using the default WRF microphysics options.

**Figure 6**: Simulated radar reflectivity from WRF model at nearest gridpoint to Chilbolton for Jan 17th case study

### 6. FUTURE WORK

Detailed data interpretation and analyses examining linkages between aerosol and cloud microphysical properties will continue, including work using the detailed process model. Flights in wave clouds over the Alps will proceed in May 2008 to examine further the interaction between aerosols properties and the microphysics and formation of ice in these “natural laboratories”. Flights in the clouds forming over Chilbolton in winter 2008/9 will coincide with a major ground based intensive measurement campaign at the site. Mesoscale model simulations using
the WRF model will continue in an attempt to pinpoint deficiencies and improve the simulation of the systems observed during flights but also over a longer period of observations using the radar and lidar facilities.

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