Meeting report

Ice in the troposphere, 23 April 2008, Manchester

The Mason Gold Medal was awarded to *Prof. Tom Choularton* and the meeting combined his presentation on *Microphysics and Chemistry of Water and Ice Clouds* with three shorter presentations. The meeting was introduced by *Dr Steven Dobbie* (University of Leeds), who along with many of the later speakers highlighted both the current uncertainties and the range of scales of interest.

Dr Ben Murray (University of Leeds) focused his talk on the homogeneous nucleation of ice – i.e., nucleation without solid nuclei. He reviewed recent work which shows that for any inorganic solution droplets, the temperature of homogeneous freezing could, assuming equilibrium, be described by the water activity, or alternatively by ambient relative humidity. Many aerosols found in the upper tropical troposphere are, however, organic. Dr Murray then described laboratory experiments showing suppression of the homogeneous freezing of organic droplets at temperatures relevant to the upper tropical troposphere. This may explain the recent aircraft observations of atmospheric supersaturations exceeding those expected in the presence of inorganic solution droplets. It was hypothesized that this suppression of homogeneous nucleation was due to a rapid increase in the viscosity of the droplets at these temperatures, and the formation of glasses – i.e. amorphous solids.

Dr Robin Hogan (University of Reading) discussed remote sensing of cloud properties from space. The recent Atmospheric Model Intercomparison Project (AMIP) showed the wide variations in the total mass of ice in the atmosphere between such models, and highlighted the need to evaluate and test these models with observational data. Ground-based LiDAR and radar instruments in a handful of locations have been used to do this as part of the CloudNet project for some time, but until recently satellite products have provided very little information on the vertical structure of clouds. This has changed with the recent launch of satellite-borne radar and LiDAR instruments, CloudSat and Calipso, which, along with other instruments such as MODIS, form part of the A-Train. Dr Hogan's talk focused on recent results from these exciting new instruments. He initially described a variational scheme to retrieve cloud properties from these instruments. This uses the complementary sensitivities of radar (to large particles) and LiDAR (to small particles) as well as *a-priori* information and MODIS radiances. This allows smoothly varying retrievals from clouds where only parts of any cloud are observable by any particular instrument (Figure 1). This facilitates evaluation of global cloud properties from models

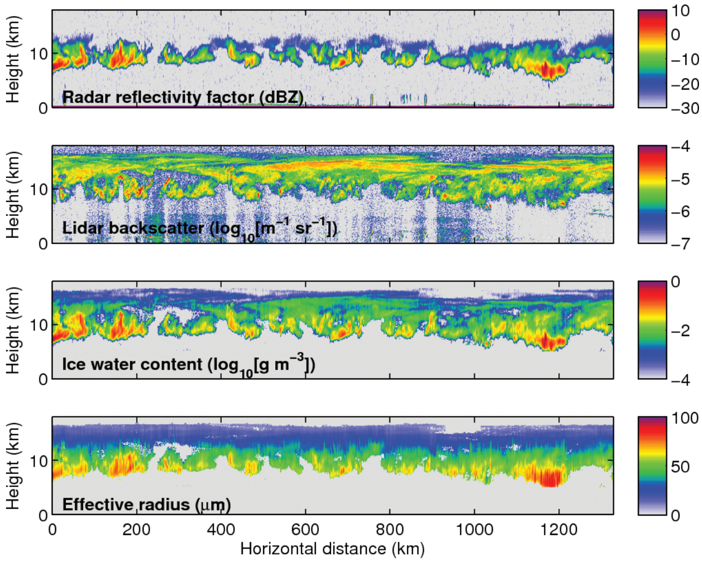

Figure 1. (Top two panels) CloudSat and CALIPSO observations of ice cloud over the Indian Ocean on 17 July 2006; (bottom two panels) ice water content and effective radius retrieved by the variational algorithm of Delano and Hogan (2008).

that tend to show too little variability in ice water content (IWC) at any given temperature. Dr Hogan then discussed the scales of variability observed in both tropical and mid-latitude ice clouds, using Fourier analysis of IWC.

The third paper on ice in numerical weather prediction and climate models was co-authored by *Dr Richard Forbes* (ECMWF) and *Dr Keith Williams* (Hadley Centre, Met Office). Dr Forbes described the three main impacts of ice clouds on weather and climate i.e. their role in the hydrological cycle, their direct radiative effects (cooling by low-level water clouds and warming by thin, upper-level ice clouds), and their feedbacks onto atmospheric dynamics. Such feedbacks can occur as a result of radiative impacts, or from latent heat effects, which, due to the slower fallspeed of snow compared with rain, can be more vertically localized. This can generate downdraughts not only on the cloud-scale, but also enhance low-level winds in cyclones and the generation of 'sting-jets'. Dr Forbes highlighted three scales: the microphysical scale, the cloud scale and the meso/synoptic scale. In weather and climate models the unresolved scales must be parameterized. This means parameterizing not only microphysical processes, but also many in-cloud circulations and much sub-grid variability. For example, circulations can generate higher super-saturations and so nucleation, or maintain layers of supercooled liquid water. The scales that must be parameterized clearly vary between models, but subgrid variability must still be parameterized in the latest operational weather prediction models with grid-spacings of order 1 km. In climate models, cloud radiative forcing provides a significant uncertainty; analysis of the representation of clouds by 'cloud regime' has allowed the regimes where models perform poorly to be quantified. Much of the variance between climate models is due to the radiative feedback from cloud and most of the variance between models in cloud feedback is from low, water, clouds. There is evidence, however, that if some of the high cloud regimes were more accurately simulated, this variance might actually increase.

Prof. Tom Choularton's Mason Gold Medal seminar described recent results from research into three cloud regimes: stratocumulus, mixed-phase layer clouds and deep tropical convection. Using observations of two pollution plumes from London affecting stratocumulus clouds, Prof. Choularton showed that the observed cloud droplet number concentrations appeared to be quite insensitive to the observed balance between organic and sulphate aerosol in the plumes. It was shown that this is expected if the aerosols are internally mixed, with the addition of sulphate to the organic aerosol allowing them to act as cloud condensation nuclei (CCN). Such internal mixtures were suggested by the observations of the London plumes, explaining the similar cloud droplet number concentrations observed. This effect suggests that the aerosol indirect effect will decline less than expected with reducing sulphate emissions.

Results from the high-altitude Jungfraujoch observatory in Switzerland were used to describe the sharp boundaries observed between ice and liquid in mixed-phase layer clouds. The role of the entrainment of snow into updrafts containing only supercooled

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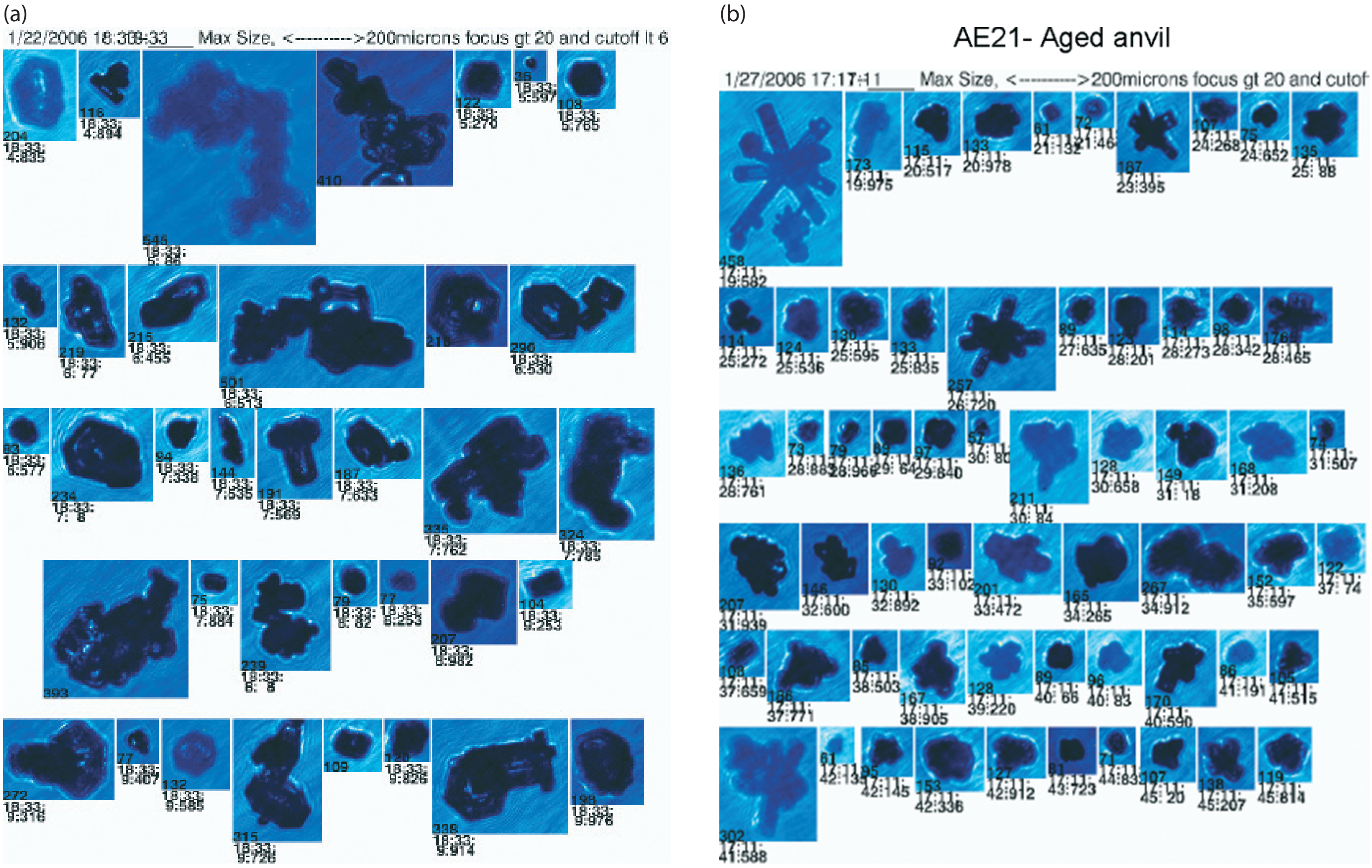

Figure 2. Images of ice crystals detected by Manchester University's Cloud Particle Imager mounted on the Airborne Research Australia's Egret Aircraft flying in anvils from Hector clouds over the Tiwi islands. (a) Crystals characteristic of those close into the main convective cell with large irregular crystals and aggregates including chain aggregates. (b) Crystals characteristic of an aged anvil featuring bullet rosette type crystals and small irregular crystals.

liquid was discussed, and how this allows riming, splintering and so rapid depletion of liquid water by the Bergeron-Findeisen process. Observations from the Cloud and Aerosol Characterization Experiments (CLACE) at Jungfraujoch suggested icy regions of the clouds contained increased concentrations of sulphate, nitrate and organic aerosols, and residues from ice particles contained both silica and carbon compounds. It was hypothesized that carbon compounds in inorganic solution droplets could act as effective ice nuclei.

Finally, Prof. Choularton presented modelling and observations of Hector thunderstorms. These deep and intense convective systems form regularly over the Tiwi islands in northern Australia, as a result of the collision of sea breezes and organization of convection by storm outflows. Simulations using the Met. Office large eddy model suggested that moderate numbers of CCN should lead to the most intense convection, since this allowed the largest mass of supercooled liquid water droplets to reach levels where they freeze homogeneously. The factors controlling the intensity of observed Hector storms were then analysed statistically. This supported the hypothesis that moderate CCN loadings led to more intense Hector systems, although wind and low-level humidity were the two most important factors. In addition, observational data from the cirrus anvil outflows from Hector showed the anvil was initially dominated by large aggregated ice particles, which sedimented relatively quickly, but then freezing of haze droplets could occur, allowing bullet rosettes to form (Figure 2).

In summary, the meeting not only highlighted some recent advances in understanding ice processes, but also the difficulties in representing our current knowledge of the complex ice processes that occur in the Earth's atmosphere in numerical models. This is clearly most challenging for the low-resolution climate models, results from which show the significant contribution that ice clouds make to the uncertainty in our current predictions of climate change.

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