First Monitoring Committee Report - The Role of Mixed-Phase Clouds on Climate

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1 Academic Background

I studied for my undergraduate degree here at the University of Reading, obtaining a first class honours degree in Meteorology (with a year in Oklahoma). Whilst in Oklahoma I studied a number of masters level and undergraduate courses complimentary to those studied at Reading. Courses that I have taken to date that are relevant to my research are: Atmospheric Physics, Climate Change, Cloud Physics (Masters, Oklahoma), Data Analysis, Numerical Methods for Environmental Science, Numerical Weather Prediction, Radar Meteorology (Oklahoma) and Remote Sensing.

My undergraduate dissertation title was "Evaluating forecasts of the evolution of the cloudy boundary layer using radar and lidar observations". This project compared boundary layer cloud forecasts from 6 forecast models with observations of cloud made by the radar and lidar at Chilbolton. To do this I created diurnal composites of model cloud and that observed by the radar and lidar. The major findings of this research were that all but one of the models analysed placed boundary layer cloud too low. The degree by which the cloud was too low is approximately constant throughout the day, however the diurnal change in cloud height was apparent in most of the models. Model performance decreased as model resolution decreased, however whether this is as a direct cause of resolution change or just incidental is unknown. This has obvious impacts for climate modelling, where low level cloud is a major uncertainty. I was awarded the Undergraduate Project Prize for my dissertation.

2 Aims of Project

One of the major uncertainties in future climate change is how the properties of clouds and their radiative effect on the atmosphere will change (Mitchell et al., 1989; Senior and Mitchell, 1993). The difference between the radiative impacts of ice crystals and water droplets are large, with water droplets being much more reflective to short-wave radiation than ice crystals. Water clouds therefore have a much higher albedo than ice clouds of equal water content because water droplets are smaller and exist in higher numbers. Mixed-phase clouds contain a mixture of water droplets and ice crystals, and can exist at temperatures between 0 and -40 degrees C. Under global warming the liquid and ice distributions in these clouds are expected to change, which would affect the way that they interact with incoming solar radiation and hence act as a climate feedback. However, a big challenge to predicting the magnitude and sign of this effect is that such clouds are represented very crudely in the numerical models used for climate prediction, and hence providing reliable predictions of climate change using these models is tough . Recent observations (Hogan et al.,

2003) (Figure 1.) have shown that layers of water droplets can exist in thin layers (around 150-300 m thick) atop ice clouds. They are shown to occur in 27% of clouds between -5 and -10 degrees C. In these cases the liquid water dominates the short-wave radiative impact of that cloud. However, the layer of liquid water is far thinner than any NWP or climate model and is therefore not going to be resolved correctly or at all.

The reasons as to why the this layer of water is present above ice clouds is not fully understood. This project will attempt to understand how and why they form and to then infer how the distribution of mixed phase clouds is likely to alter under climate change. The problem will be tackled with a combination of simplified 1D modelling and analysis of high-resolution ground-based radar and lidar observations. The role and interactions of the various physical processes that occur in mixed-phase clouds will be investigated, in particular radiative transfer, turbulent mixing, phase changes and nucleation. Later in the project work will likely involve some or all of the following: analysis of simultaneous aircraft and radar measurements currently being gathered, analysis of new spaceborne radar and lidar data from CloudSat / Calipso on the A-train of satellites, and working towards a new representation of mixed-phase clouds in 3D numerical models of the atmosphere.

3 Work to date

I started off this term reading a number of papers to familiarise myself with mixed-phase clouds, why they are important, and theories as to how and where they form (e.g. Hogan et al., 2003; Korolev and Field, 2008; Hogan et al., 2004). I have also read papers on single column modelling and cloud parameterisation schemes (e.g. Lock et al., 2000; Betts, 1973) .

My future work will involve testing cloud parameterisations, in order to be able to do this I have been working on building a single column atmospheric model from scratch in Matlab. This model has prognostic variables of specific humidity, q, and θ_L, which is conserved in reversible wet adiabatic motion (Betts, 1973). The model is currently able to advect and diffuse these quantities and therefore resolve cloud and cloud free regions. Given constant forcing the model can also respond to produce an Ekman spiral. The next stage in development will be to include a radiation scheme and an apropriate mixing scheme and then to test how well it performs given some observed initial conditions.

In the coming weeks I hope to have the model at a stage where the main structure and physics are in place. At this stage I will initialise the model with temperature and moisture profiles from observations or model output and see how my model performs. I will then be able to implement different parameterisations of how the model handles sub grid scale processes and see how these impact the model performance.

I have also spent time this term writing up my undergraduate dissertation into a paper with the intention of submitting to Geophysical Research Letters in the very near future. This has involved a fair amount of work reproducing figures, checking data and rewriting the content of the paper in a style suitable for submission, as well as getting to grips with LaTeX and re-familiarising myself with Matlab. The paper is now written and is in the process of being revised prior to submission. I will complete and submit this paper, hopefully in the very near future, which will then allow me to concentrate further on my current work.

4 Courses

As I completed by undergraduate degree at Reading, I have been exempted from formally taking courses this year. However, I have been sitting in on the Numerical Methods course as this is

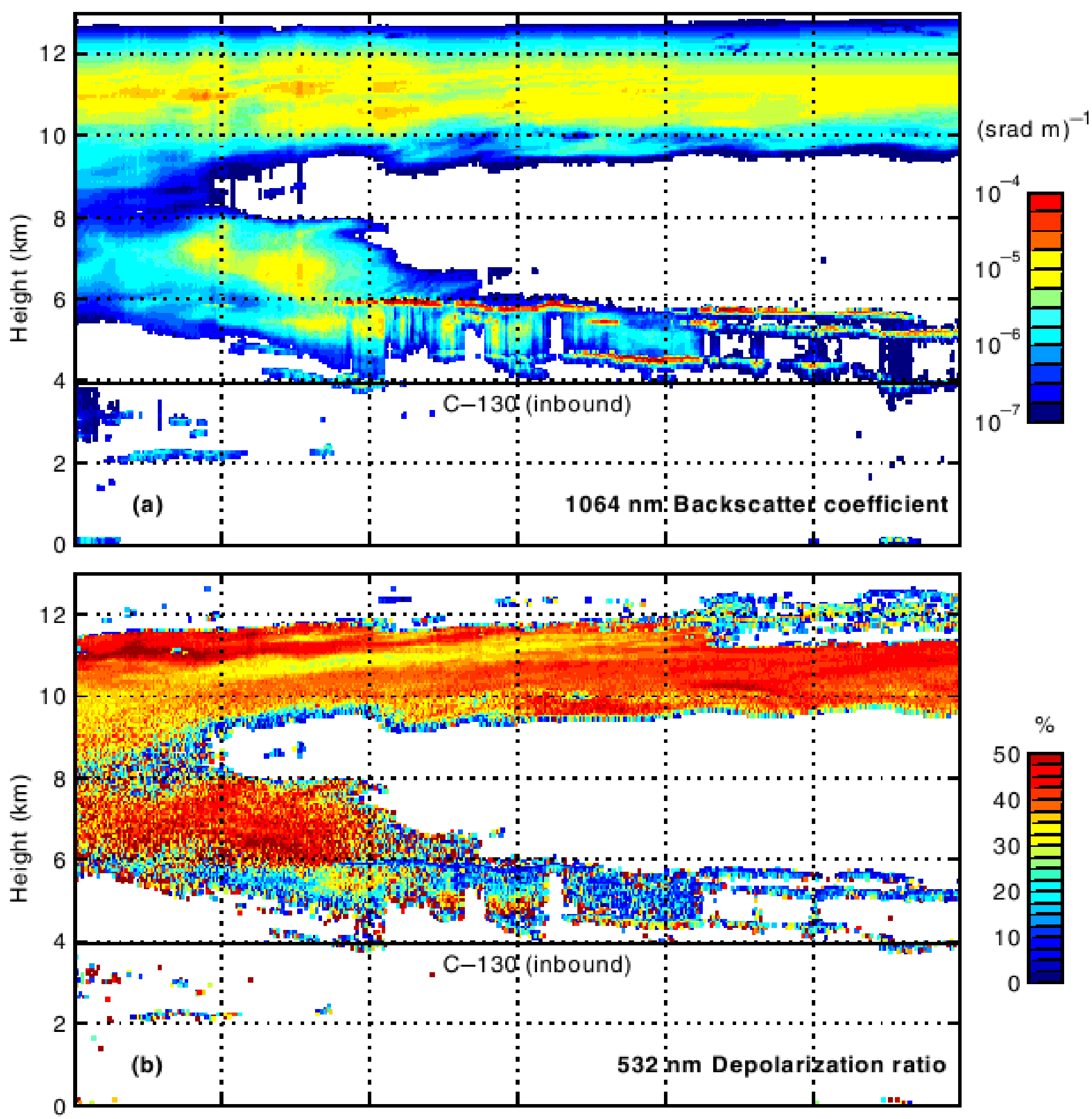

Figure 1: Figure from Hogan et al. (2003) showing mixed phase clouds. The majority of the cloud shown is ice cloud, as the lidar backscatter in the top panel is small and the depolarization ratio in the lower panel is large. However, at around 6km there exists a layer of high lidar backscatter and and weak depolarization ratio, indicative of a liquid water layer, around 150m deep.

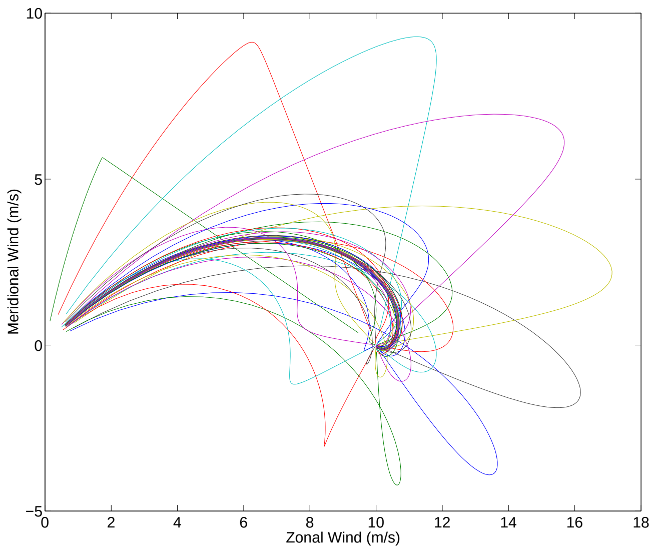

Figure 2: This figure shows the output from my model when solving for the Ekman spiral. One line is drawn every 100 minutes and the wind profile can be seen to oscillate before converging to the familiar Ekman spiral.

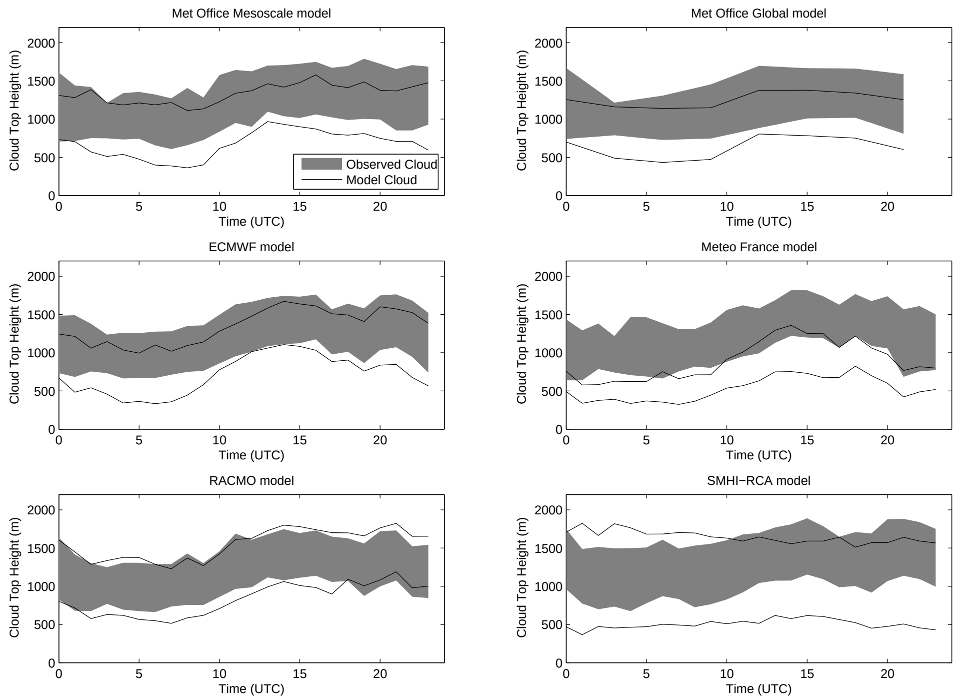

Figure 3: Plot taken from the paper I am writing showing diurnal composites of the observed cloud (shaded) and model cloud (lines) throughout the day for the 6 models analysed.

particularly relevant to work I am currently doing. I have found this course very useful. Next term I will be sitting in on more courses relevant to my PhD work, these are likely to include Remote Sensing, Climate Change and Numerical Modelling. I also hope to attend the ECMWF 9 day training course in the spring on parameterisation of diabatic processes.

5 Transferable Skills

Throughout this term I have been using UNIX, which I was not familiar with before. I have also been using Matlab to build my model and analyse data and I have started to use LaTeX to produce written reports including the paper I am writing. I have also given a talk to Radar Group about my undergraduate research, which has allowed me to further practice my presentation skills. I have been attending the Monday and Tuesday seminars to further increase my breadth knowledge of Meteorology and have also been attending Radar Group meetings for a more in depth discussion of relavant topics.

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