Mixed-phase

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1. Introduction

Mixed-phase clouds are challenging to predict in operational models. This presentation covered a number of areas of research relating to mixed-phase clouds in order to highlight some challenges and suggest some approaches to tackling this phenomenon. The first part provided an overview of how the Met Office Unified Model simulated a cold air outbreak. The second part was a reminder of the potential artefacts associated with ice crystal measurements. The third part introduced some new theoretical ideas about turbulence and mixed-phase that may be important for subgrid representation.

2. A cold air outbreak

The Met Office Unified Model was used to simulate a cold air outbreak using a nested model configuration close to the operational UKV settings (at vn7.7, 1.5km grid spacing, see Field *et al*., 2013 for more details). The analysis from 12 UTC 31st January 2010 indicates a strong flow from the north located between a polar low feature ('P' in Fig. 1), to the north west of the Faroe Islands, and Iceland. In the satellite image (Fig. 1) the clouds begin as low level stratiform cloud in the north and then eventually break up into open cellular convection.

The main shortcomings of the model are highlighted in Figure 1 and 2. Figure 1c and Figures 2d,h show that the control model is not able to reproduce the extensive stratiform cloud between the Faroes and Iceland or the associated top of atmosphere outgoing short wave radiation signal. Inspection of Figures 2b,f show that the control model is not reproducing the observed liquid water path.

To overcome these two problems a number of hypotheses were tested involving the role of ice in the formation of precipitation and the nature of the boundary layer mixing when the flow is strongly sheared. The best improvement to the model simulation was obtained through: i) inhibiting ice nucleation to temperatures lower than -18C, and ii) changing the boundary layer diagnosis to allow the appearance of well mixed, stratocumulus topped boundary layer when the boundary layer flow was strongly sheared. Both of these changes taken together were able to improve the liquid water path (Fig 2j) and introduce stratiform cloud where it was observed (Figs. 1d, 2l).

Even though the liquid water path was improved, the amounts of liquid present in the convective regions are still too low when compared to aircraft observations (not shown). This suggests that at ~1km grid spacings the explicit prediction of liquid is still underpredicted and would benefit from an improved treatment of mixed-phase cloud processes.

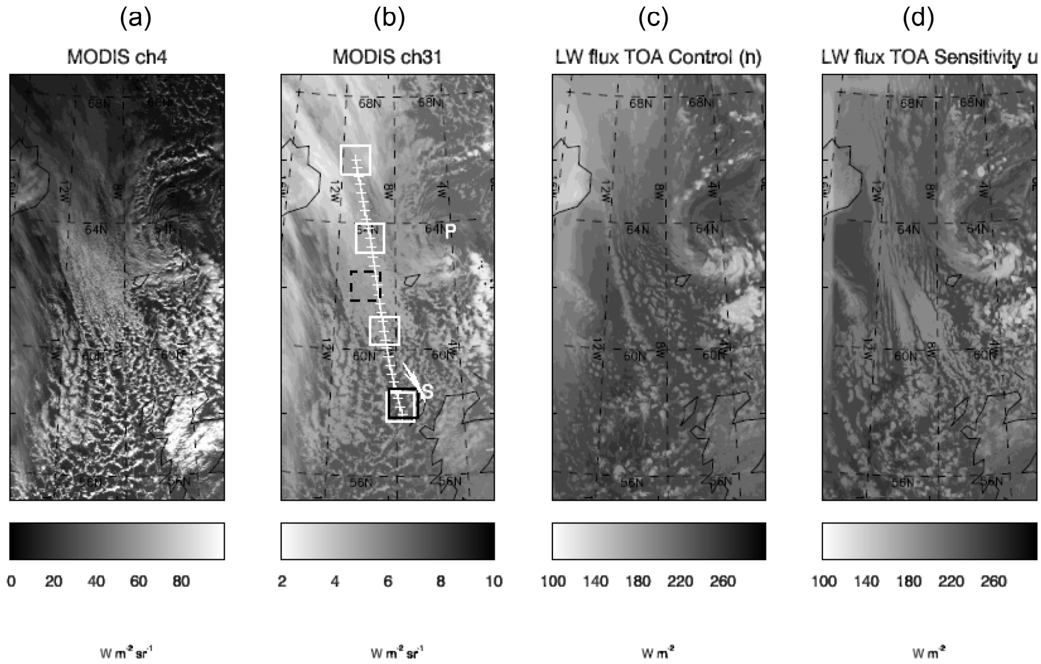

Figure 1: (From Field et al 2013 QJRMS in press) Comparison of MODIS channel 4 (visible, 550 nm, [a]) and 31 (infrared, 10 microns, [b]) [W m^{-2} sr^{-1}] with outgoing LW from the control model (h, [c]) and sensitivity experiment (u, [d]) [W m-2]. Panel b contains the polar low feature indicated by a white 'P'. The sonde positions are very close to each other and are marked by a white 'S'. The aircraft runs used in the paper are marked by the white arcs. The Lagrangian trajectory is marked as a white line extending from 66N11W with plus marks half hour intervals from 0UTC to 15UTC. White boxes indicate the locations of the Lagrangian boxes used for Figures 8,9. The black box indicates the region used for comparison with the aircraft data. The black dashed box indicates the region over which the MODIS retrievals of droplet number, cloud top temperature/pressure and cloud water path were averaged. The images are for 31st January 2010 12 UTC

2.1. Measurement artefacts

Microphysical process rates depend upon the representation of the ice phase particle size distribution (PSD). Therefore, ensuring that the ice PSD is accurate is a requirement for the realistic simulation of mixed-phase (and ice only) processes and clouds. One problem that has been reinvestigated in the last few years is the effect of particles shattering on measurement instruments as they are sampled by aircraft (e.g. Korolev et al. 2011) leading to the artificial measurement of high concentrations of small ice particles. Figure 3 shows an example of this problem for ice crystals sampled in an anvil during a tropical campaign. The telltale sign of this problem occurring during sampling (Fig. 3a) is the predominance of particles with short interarrival times (the elapsed time between particles arriving in the sample volume). The histogram of interarrival times shows that there are two populations of particles: the ones belonging to the long interarrival time mode are real particles and the ones associated with the short interarrival time mode are shattered debris. The fraction of particles associated with the shattered particle mode increases as the mean size of the ice PSD becomes larger (Fig 3c). Recently, new probe tip designs and software filtering algorithms have been introduced to reduce the effects of this problem.

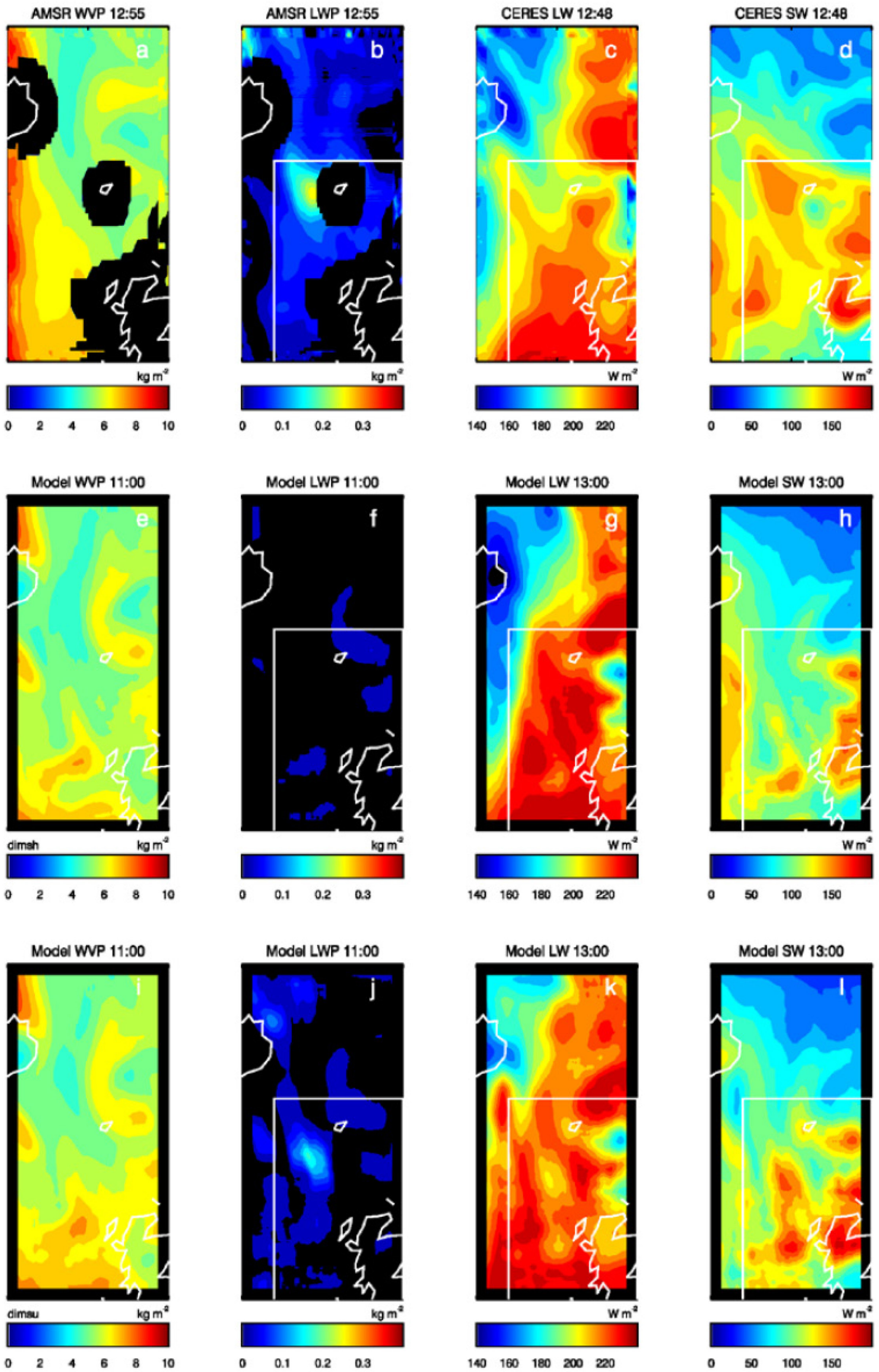

Figure 2. From Field et al. 2013 QJRMS in press. Comparison of satellite data (a-d) with the control (dimsh) model (e-h) and sensitivity experiment (dimsu). a,e,i integrated water vapour column, b,f,j liquid water path, c,g,k Long wave flux at the top of the atmosphere, d,h,l Short wave flux at the top of the atmosphere. All data have been smoothed by a 100km top-hat function. Black indicates zero value or missing data.

Parametrizations derived using measurements that pre-date the introduction of the corrective tips and interarrival time filtering may be biased. Such a bias in the representation of the ice PSD will propagate to biases in microphysical process rates important for ice and mixed-phase cloud. Therefore, existing parametrizations need to be tested to assess whether they are affected by this problem. Figure 4 shows a comparison for different moments of the ice phase PSD for two different representations used in the Unified Model. The newer representation is based on observations where interarrival time filtering has been carried out (but no antishatter tips employed). The moment predictions are plotted against observations taken using anti-shatter tips and filtering software. It can be seen that the higher moments (>2nd) are generally producing similar results between the two PSD representations and some correspondence to the observations. The lower moments, such as the one proportional to diffusional growth of ice (first moment), are overestimated by the older PSD representation. All things being equal, this overestimate would lead to a larger sink of vapour to the ice phase and a subsequent suppression of the liquid phase. Therefore, it is important to assess current ice-phase representations in models in the light of this shattering artefact.

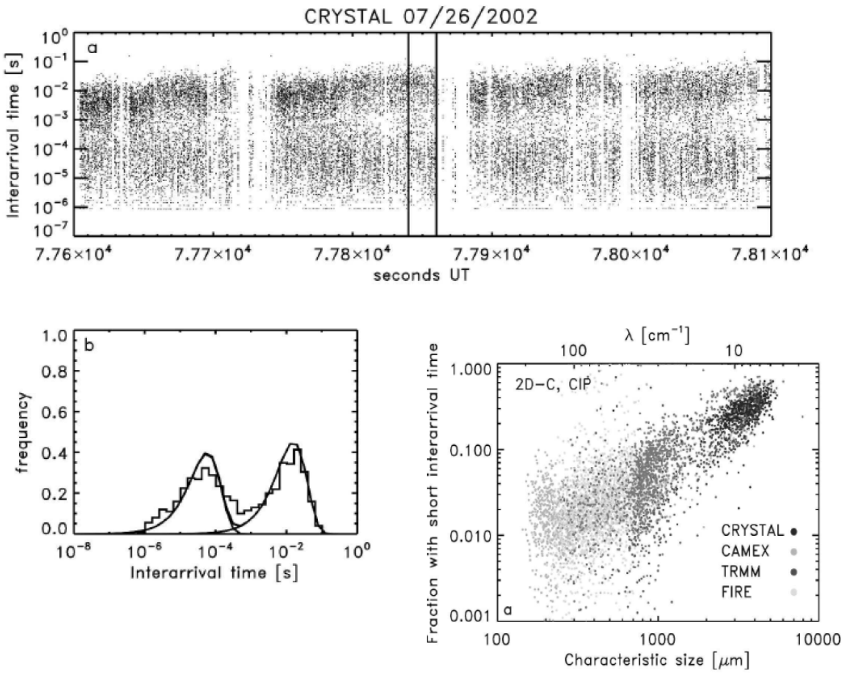

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Figure 3. Adapted from Field et al. 2006. Interarrival time data for the CRYSTAL flight (07/26/2002). a) 500 s of interarrival times from the 2D-C probe. Each point represents the interarrival time of a particle. b) The stepped line is a histogram (binned logarithmically) of the 20 s of interarrival times bracketed by the vertical lines in a). The solid lines represent the best fit function. c) Composite of results from many flights. 10-s fraction of measured PSD contributed by shattered particles as a function of mean size of the PSD

3. Theoretical approach

The maintenance of mixed-phase cloud is a complex balance of dynamical effects that can act to promote the presence of liquid water and the sink of water vapour to the ice phase that acts to deplete the liquid water via the Wegener-Bergeron-Findeisen effect and riming. Previous theoretical work has focused on understanding the evolution of mixed-phase for simplified dynamical environments, but here we briefly described some results of a theoretical approach that considers mixed-phase in a turbulent environment (Field et al. 2013 – currently in review).

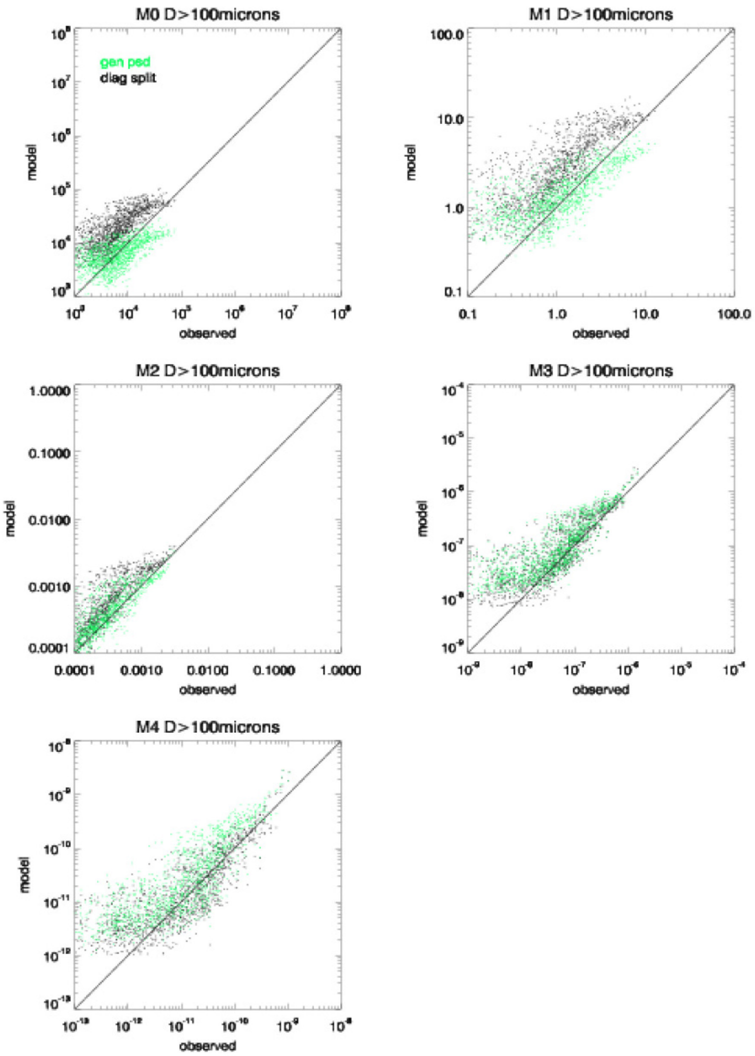

Figure 4: Comparison of moments of two representations of the ice phase PSD used in the Unified Model. Black: older version PSD. Green: newer version PSD where interarrival time filtering was used on the dataset that to produce the PSD parametrization. The predictions are plotted against the aircraft observations (10-s data) using antishatter tips and interarrival time filtering for sizes larger than 100 microns. (Kalli Furtado, in preparation).

The aim of the approach is to predict the amount of supercooled liquid water and cloud fraction present in a pre-existing ice cloud when turbulence is introduced, given that the characteristics of the turbulence and the ice cloud are known. By making some simplifications to the equation describing the evolution of ice supersaturation, a stochastic differential equation is formed. The solution to this equation delivers an expression for the variance of the supersaturation with respect to ice as a function of the parameters describing the turbulence and the ice cloud. Once the supersaturation distribution with respect to ice is known, the mixed-phase cloud properties can be predicted including mixed-phase cloud fraction, mean liquid water content and liquid water distribution by consideration of the part of the distribution above water saturation (Fig 5 right). This approach was tested by comparison to Large Eddy Simulation results from decametre resolution simulations of mixed-phase cloud in a turbulent environment and produced good agreement between the theory and model (Fig. 6).

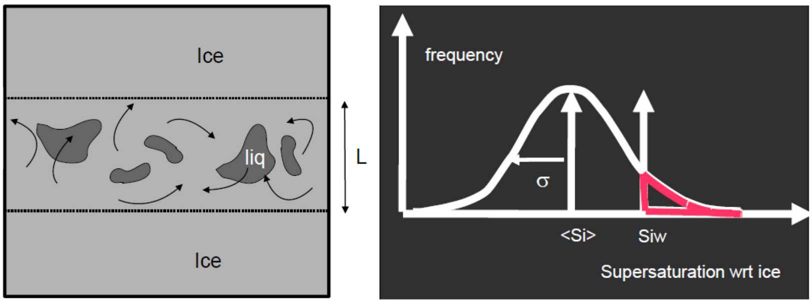

Figure 5 Left) Schematic of turbulent mixed-phase environment. Turbulence is constrained to a layer with thickness L embedded in an ice environment. The turbulence promotes the production of transient liquid regions that are depleted by the ice. Right) Schematic of the theoretical approach. The theoretical approach predicts the width of the supersaturation (with respect to ice) distribution in the turbulent region. The part of the distribution above liquid water saturation is the mixed-phase liquid part of the region turbulent zone.

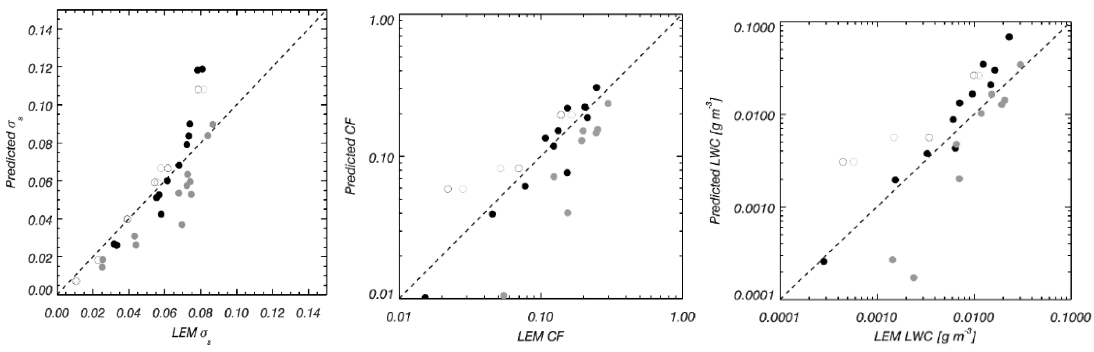

Figure 6 Adapted from Field et al. 2013 QJRMS in review. a) Scatter plot of predicted σ_s and the Large Eddy Model (LEM) derived width of the supersaturation distribution when liquid water is included. Black symbols represent: low shear simulations. Grey symbols: High shear simulations. Solid: BASE – simplified microphysics. Open: FULL- full microphysics.b) Same as a) but for mixed-phase cloud fraction. c) Same as a) t for domain mean supercooled liquid water content.

4. Conclusions

The treatment of mixed-phase in operational models is challenging. This presentation demonstrated for one mixed-phase situation how it was possible to improve the liquid water amounts and cloud characteristics of a cold air outbreak simulation by suppressing the nucleation of ice to colder temperatures (T=-18C) and changing the treatment of the boundary layer. The amount of liquid produced in the improved simulations was still not sufficient to match the observations.

It was noted that mixed-phase and ice process parametrizations based on older measurements affected by ice crystal shattering need to be tested. Incorrect PSD representations could lead to artificially large vapour sinks to the ice phase.

Theoretical approaches that predict mixed-phase conditions should be explored further to aid in the development subgrid process rates that affect the evolution of mixed-phase conditions.

References:

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