Modelling cloud break-up in cold air outbreaks and improving weather forecasting models

Supervisors (including Title; Dr, Prof etc):

Prof Tom Choularton, Prof Martin Gallagher, Dr. Paul Connolly, Dr. Gary Lloyd

External supervisors and institution (including Title):

Dr Steve Abel (Met Office)

Primary Contact Name and Email:

Prof Tom Choularton (choularton@manchester.ac.uk)

Introduction:

Cold-air outbreak (CAO) events in the mid-latitudes draw cold polar or continental air masses over a relatively warm ocean, resulting in a rapid increase in the surface fluxes of heat and moisture from the sea surface and the subsequent development of extensive boundary layer clouds. These multi-day events are common features to the north of the British Isles in winter, often bringing snow showers to populated areas and are associated with aviation hazards such as lightning and icing risks. Although the broad scale synoptic environments that initiate CAO's are well predicted by models, the ability of both weather forecast and climate models to simulate the clouds and precipitation in these events is poor, with models typically underestimating cloud condensate and cloud fraction Abel et al. (2017). The associated systematic cloud related radiative flux errors are thought to play a key role in the southern Ocean sea-surface temperature bias found in many global models Much of the challenge for numerical modelling arises from the need to represent complex interactions between the dynamics, cloud microphysics and convection in the shallow boundary layers that are typical in CAO's. Furthermore, the clouds are typically mixed-phase in nature (they contain supercooled liquid water and ice), for which there are a myriad of competing and poorly understood small-scale processes that need to be parameterized in models. It is clear that even at the 1.5 km grid-resolutions used in UK NWP "the depth of the boundary layer and size of the convective elements in these events is approaching model resolution". There is therefore a need to explore these model problems using higher resolution large eddy simulations that are capable of resolving the boundary layer dynamics and also to test if including additional complexity in the cloud microphysics scheme improves the simulations of mixed-phase clouds in the CAO regime.

Recent in-situ field observations over the eastern Atlantic reveal that large changes in the morphological structure of the cloud field (stratiform to open cellular convection) are driven by cloud microphysical processes and that precipitation induced decoupling of the boundary layer is important to the timing of the break-up (Abel et al. 2017). Both super-cooled liquid and solid precipitation play a role, with a seasonal enhancement in secondary ice production processes due to varying in-cloud temperatures also potentially contributing. The observed increase in precipitation at the transition appears to be effective at removing boundary layer aerosols, which have the potential to feedback on the subsequent evolution of the cloud field. Modelling this transition in cloud regimes is important for both NWP and climate models as it is associated with an increase in surface precipitation and a change in the radiative effect of the cloud field.

Project Summary

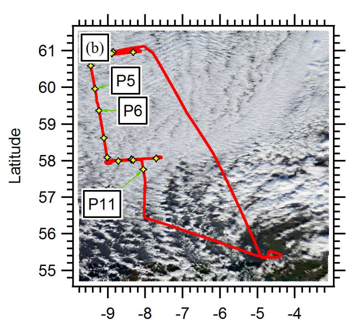
The focus of this PhD will be to perform large-eddy simulation studies with the Met Office/NERC Cloud Model (MONC) coupled with the new Met Office Cloud AeroSol Interaction Microphysics (CASIM) scheme to:

i) evaluate the relative role of precipitation versus surface fluxes (SST) in controlling the transition from stratiform to open cellular convection in marine cold air outbreaks.

ii) evaluate ice processes in the mixed-phase stratiform cloud layer to gain a better understanding of why in the microphysics schemes used in the Unified Model, ice is too effective at removing liquid water.

iii) explore the role of aerosol on the cloud microphysics development and the role of precipitation in removing aerosols from the boundary layer.

To achieve these aims the MONC model would be run in pseudo-Lagrangian modes (driven by the flow field from Unified Model simulations) to follow air trajectories where transition and development from marine stratocumulus cloud to cumulus would be examined and compared with both existing in-situ case studies and new case studies provided by the FAAM aircraft with the latter being tailored to the new model results. This activity would build on the work with the Unified Model recently published by Abel et al. (JAS, 2017).



Caption

An example of a cold air outbreak over the North Atlantic with cloud breaking up. Aircraft track to measure this is shown

References

Abel, S. J., Boutle, I. A., Waite, K., Fox, S., Brown, P. R. A., Cotton, R., Lloyd, G., Choularton, T. W. & Bower, K. N. 2017 In : Journal of the Atmospheric Sciences. 74, 7, p. 2293-2314 22 p.

The role of precipitation in controlling the transition from stratocumulus to cumulus clouds in a northern hemisphere cold-air outbreak