Investigating the Microphysics of Arctic Mixed-Phase Clouds using Large Eddy Simulations: The Importance of Liquid-Dependent Ice Nucleation

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1. Introduction

Small-scale microphysical processes are poorly represented in cloud and climate models and contribute toward **significant uncertainties in modelling the polar regions** of our planet[1].

To address this, the Aerosol-Cloud Coupling and Climate Interactions in the Arctic (**ACCACIA**) Campaign was conducted in the European Arctic, utilising the FAAM BAe-146 aircraft to make detailed atmospheric observations in spring 2013.

Measurements from ACCACIA are used here to validate the ability of a Cloud-Resolving Model to reproduce the Arctic mixed-phase clouds observed.

Data from two wing-mounted instruments - the Cloud Droplet Probe (**CDP**) and 2-Dimensional Stereoscopic (**2DS**) probe - and a downward-facing **lidar** is presented for comparison with the model.

The model was initialised with temperature and vapour mixing ratio profiles measured by a **dropsonde** released during the first section of the case study chosen (flight number B762 on 23rd March 2013, Fig. 1).

2. Model Description

The Large Eddy Model (**LEM**) - developed by the UK Met Office – resolves turbulent motions to allow cloud evolution to be studied in isolation from large-scale meteorological features.

Ice nucleation is modelled using the **Meyers**[2] parameterisation: a relationship for the **Deposition-Condensation** ice nucleation mode derived from mid-latitude field observations. This relationship is frequently used in models with a bulk microphysics scheme.

Predicts a primary ice number concentration - N_i - related to the supersaturation of water vapour with respect to ice - S_i - with constants a and b as follows:

$$N_i = \exp(a + b\{100(S_i - 1)\})$$

3a. Observed

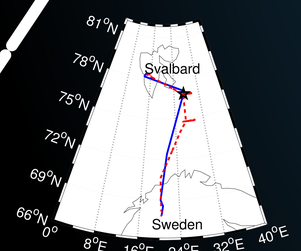

Fig. 1: Flight track of B762 showing section 1 (blue) and section 2 (red, dashed). Dropsonde release location is marked (black star). Observations from section 2 close to the dropsonde location are used for model comparison.

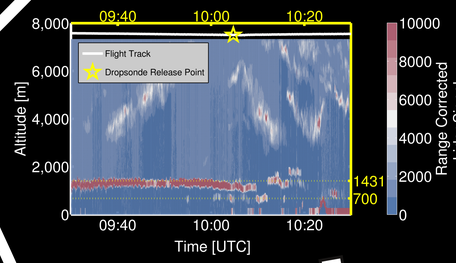

Fig. 2: Lidar data from section 1 of the flight. The strong signals below ~2000m are indications of a liquid cloud top. However, cloud depth cannot be inferred due to signal attenuation by the liquid layer. The maximum altitude achieved by section 2 observations is noted (~1431m).

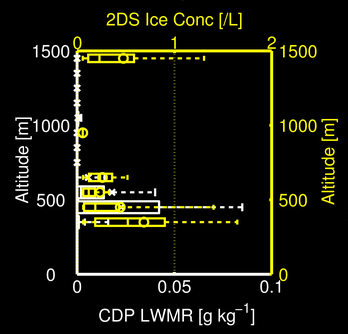

Fig. 3: Section 2 observations of ice concentration and LW mixing ratio from the 2DS and CDP instruments. Box edges: 25th and 75th percentiles, Median: |, and Mean: either O or X for the ice and liquid data respectively.

S_i only

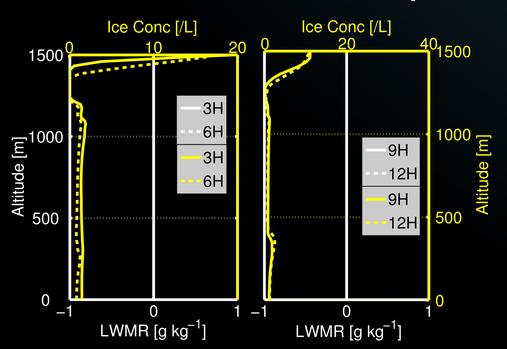

Fig. 4: Ice concentrations and LW mixing ratios output from the LEM using the standard Meyers parameterisation for ice nucleation. No liquid water is modelled, with ice production via deposition nucleation (no water present) above 1200m. Suggests that the rate of deposition ice nucleation is over-predicted.

3b. Modelled

Better agreement with observations when ice nucleation is **restricted to occur only when liquid water is present.**

S_i and S_w required

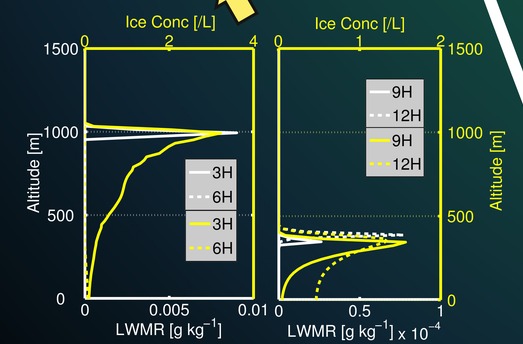

Fig. 5: Ice concentrations and LW mixing ratios output from the LEM when ice nucleation is restricted to occur when both water and ice saturation are reached. A cloud is formed at ~1000m which dissipates within 6 hours, while another forms at ~500m when the model run time reaches 9 hours. A liquid layer is consistently modelled at the cloud tops with ice below.

4. Conclusions

- Improved agreement of liquid and ice profiles with Arctic observations when ice nucleation is limited to occur at water and ice saturation. Suggests that the **Meyers parameterisation overestimates the rate of deposition ice nucleation in this case.**

- Suggestion that other ice nucleation mechanisms (e.g. **Immersion freezing**) may have influence in the Arctic environment. This conclusion has been reached by other authors modelling the mixed-phase clouds in this region (e.g. de Boer et al. 2011[3]).

5. Further Work

- Further development required to **improve LW mixing ratio agreement** with observations.

- Sensitivity studies to **identify limitations of the restricted version** of the Meyers parameterisation, with comparison to other observations during the ACCACIA springtime campaign.

- Further investigation into this improved representation by incorporating a **double-moment microphysics scheme** (e.g. Morrison et al. 2005[4]) into the LEM to additionally model droplet number concentrations.

6. References and Acknowledgements

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