Improving the ECMWF model's representation of supercooled layers in Arctic mixed-phase clouds

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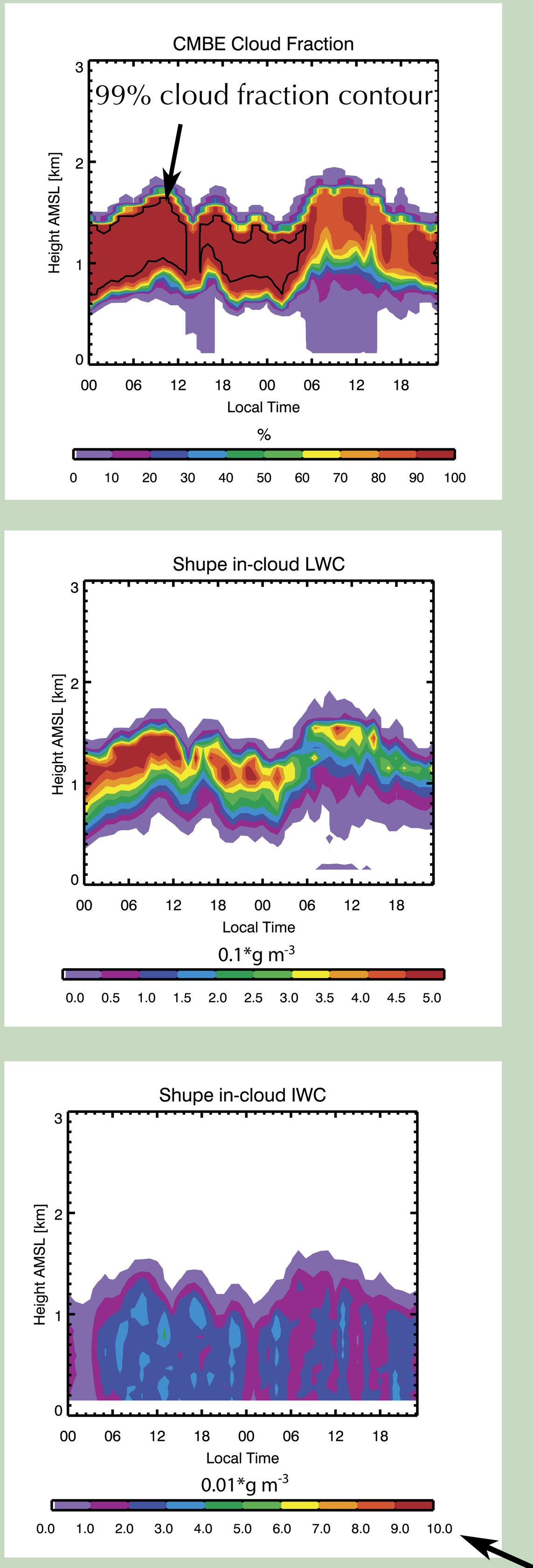
A single-layer Arctic mixed-phase cloud example

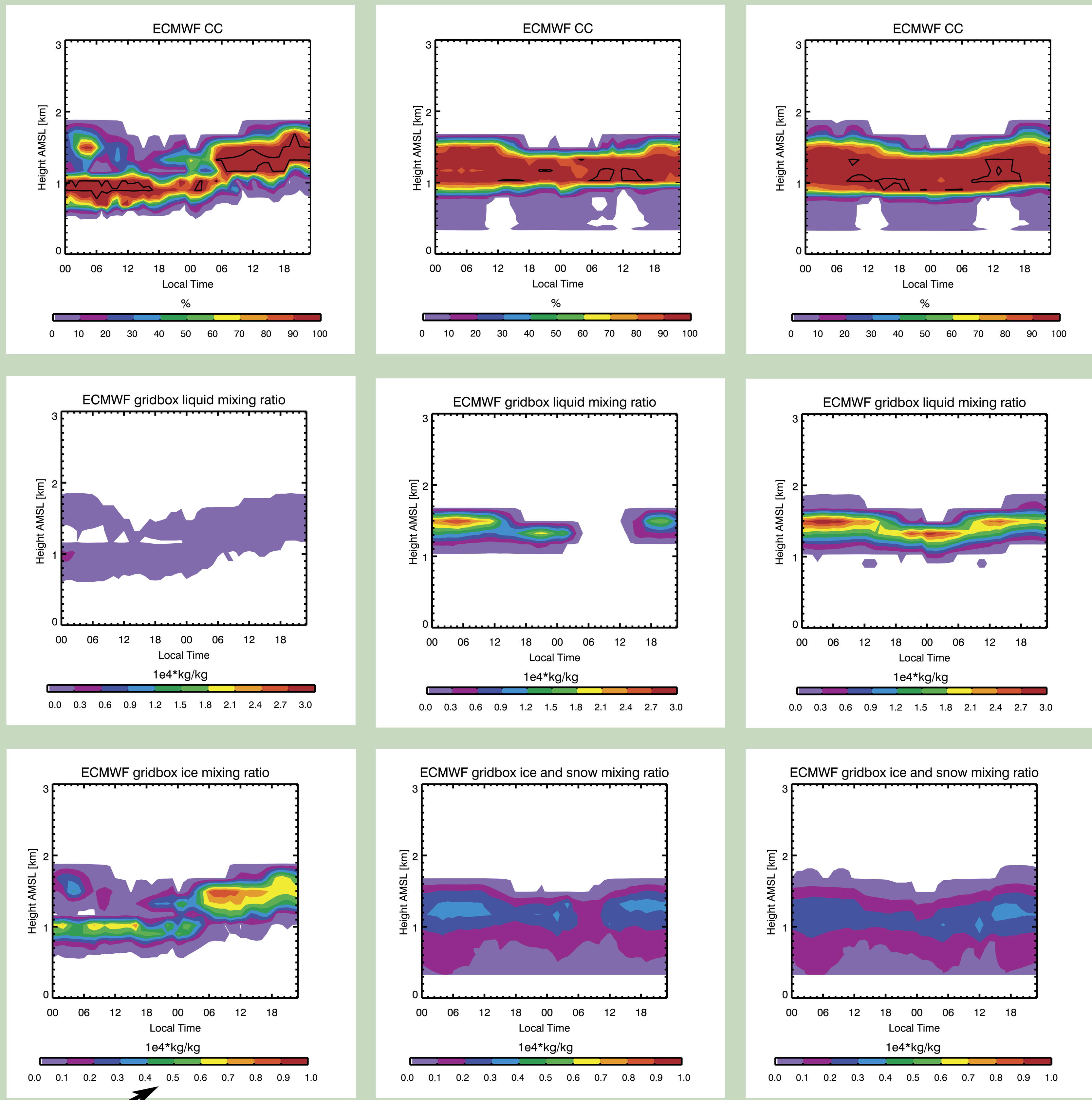
Shown below (left column) is a single layer Arctic mixed-phase cloud observed during M-PACE (Oct 8-9 2004) at the North Slope of Alaska. Three versions of the ECMWF IFS model were run for this period to assess how recent changes to the cloud scheme impact the model's ability to reproduce the observed cloud. The **OLD** (CY36R1) model uses a single prognostic variable for cloud condensate and applies a temperature-dependent function to partition the condensate into ice and liquid. The **NEW** cloud scheme introduced in CY36R4 has separate prognostic variables for liquid and ice, allowing a more physically-based representation of mixed-phase cloud. Ice deposition near the cloud top is reduced in the **LAYERS** experiment (CY37R3) to enhance the formation of supercooled liquid layers.

OBSERVATIONS



ECMWF MODEL VERSIONS

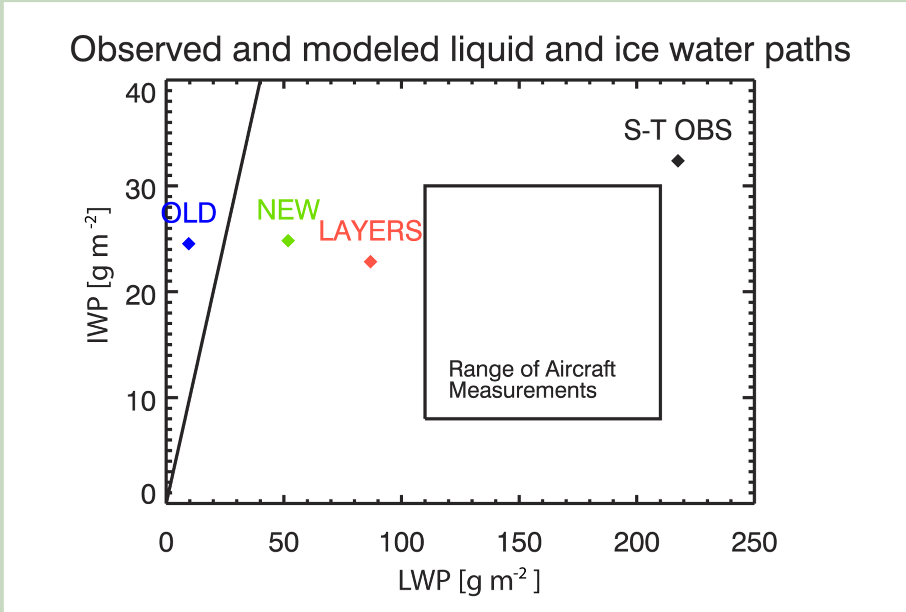
OLD **NEW** **LAYERS**

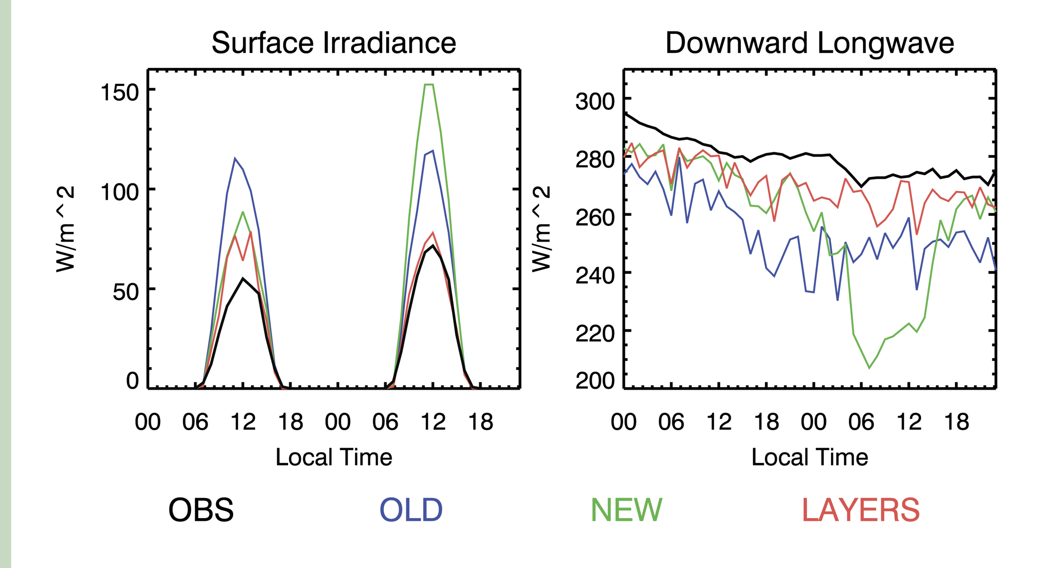


Note: different scales for observed (in-cloud) and modeled (box average) cloud water contents

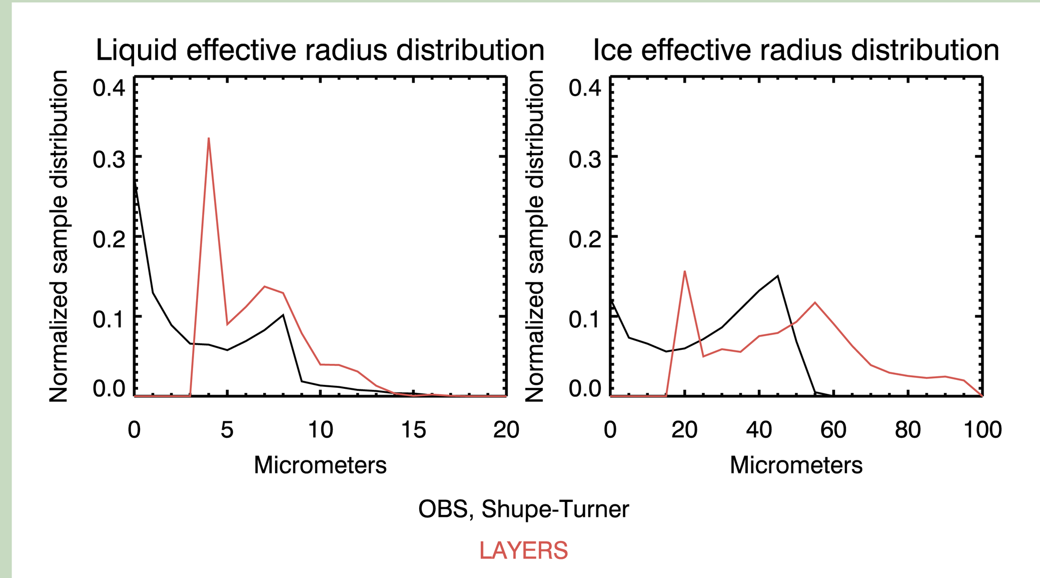
- The **diagnostic split** applied to the cloud condensate in the **OLD** scheme leads to a cloud dominated by ice with little supercooled liquid. During the first day, the model produces multiple layers with highest cloud fraction near the base.
- The **NEW** model's **ratio of liquid to ice** condensate is much improved. The liquid is confined to the upper half of the cloud, while ice formed inside the cloud sediments and is precipitated out. However, the **NEW** scheme is not able to maintain the liquid layer throughout the two-day period.
- These **supercooled liquid water layers** are the result of a fine balance between radiative cooling driving small-scale turbulent motions, production of water saturation and cloud liquid water droplets, the availability of ice nuclei, nucleation of ice crystals, deposition growth removing water vapor and fall-out of ice particles under gravity. These details are not fully resolved in the ECMWF model. The **LAYERS** experiment tries to encapsulate these processes in a simple parameterization which gradually reduces the ice deposition rate towards the top of the cloud. As a result, the model maintains the supercooled liquid layer better and the surface radiation is improved.

Mean **liquid** and **ice water paths** for the two-day period are marked in the figure to the right. The framed box shows the range of aircraft-derived observations (Klein et al. 2009), the black diamond the ground-based retrieval (Shupe-Turner) results. The model's liquid-to-ice ratio is much improved for the **NEW** and **LAYERS** experiments, though the liquid water path is still slightly underestimated.





In the **OLD** model version, the cloud's condensate exists primarily in the ice phase. The lack of liquid leads to an underestimated downward longwave **radiation** while surface irradiance is overestimated. The improved liquid-to-ice ratio in the **NEW** scheme reduces the LW and SW radiation biases, but only during the first day. The model is unable to maintain the liquid layer throughout the second day. With the **LAYERS** parameterization, the model maintains the liquid layer throughout, leading to reduced radiation biases overall.



In the liquid phase, the model's estimate of the **effective radius** is comparable to observations with values peaking at 7-8 μm. The maximum at 4 μm (and at 20 μm for ice radii) is due to a prescribed lower limit in the model. For the ice phase, the model tends to overestimate the effective radius, which enhances the shortwave bias particularly in the **OLD** model, where ice condensate dominates.

Summary

The ECMWF model's representation of supercooled liquid layers in Arctic mixed-phase clouds is much improved due to a new cloud scheme with separate prognostic variables for cloud liquid and ice, and a simple new parameterization that enhances the persistence of supercooled layers. Future developments will aim to link the parameterization more directly to model physical processes.

Klein et al., 2009: Intercomparison of model simulations of mixed-phase clouds observed during the ARM Mixed-Phase Arctic Cloud Experiment. I: single-layer cloud, *QJRMS*, **135**, 979–1002.

This work is supported by the ASR through a fellowship at ECMWF.

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