Evaluating Arctic meteorology modelled with the Unified Model and Integrated Forecasting System

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Introduction

With accelerating Arctic warming, we need suitable numerical models to predict how the atmosphere will change on short weather prediction and longer climate time scales. However, models across all scales are notoriously poor at reproducing the Arctic boundary layer and the persistent mixed-phase clouds which commonly form within it. Therefore, there is an urgent need to evaluate model performance, diagnose weaknesses in, and develop improved schemes for representing Arctic meteorology.

State-of-the-art models such as the **Met Office Unified Model (UM)** and **European Centre for Medium-Range Weather Forecasting (ECMWF) Integrated Forecasting System (IFS)** are crucial tools for forecasting future Arctic change. Here, we evaluate their performance with comparison to observations made during the **Arctic Ocean 2018** expedition [1], where a suite of remote-sensing instrumentation was active aboard the Swedish icebreaker *Oden* measuring summertime Arctic cloud and boundary layer properties. *Oden* drifted with an ice floe for approximately 1 month, from mid-Aug to mid-Sep 2018, as shown in *Fig. 1*. By using the **Cloudnet algorithms** [2], we systematically compare between cloud fractions simulated in our models and measured with our remote-sensing instruments.

Methods

We use the global **IFS** (with 9 km grid size) and nested operational **UM_RA2M** (with 1.5 km grid) to simulate the entire drift period of the expedition. The ship's position was extracted from these datasets to provide a timeseries of 2D diagnostics (e.g. temperature, humidity, cloud fraction) to run **Cloudnet** comparisons with similar measured data.

36-hour forecasts were performed with each model, with the first 12 hours discarded to avoid spin up issues, thus producing daily forecast products (00 UTC - 00 UTC) for analysis with **Cloudnet**. To provide our observational comparison, **Cloudnet** ingests Doppler cloud radar, Doppler lidar, radiometer, and radiosonde data, producing cloud fractions, and liquid and ice water contents. Here, we additionally compare our model results directly with temperature and water vapour mixing ratio (WVMR) measurements from the 6-hourly radiosondes launched during the expedition.

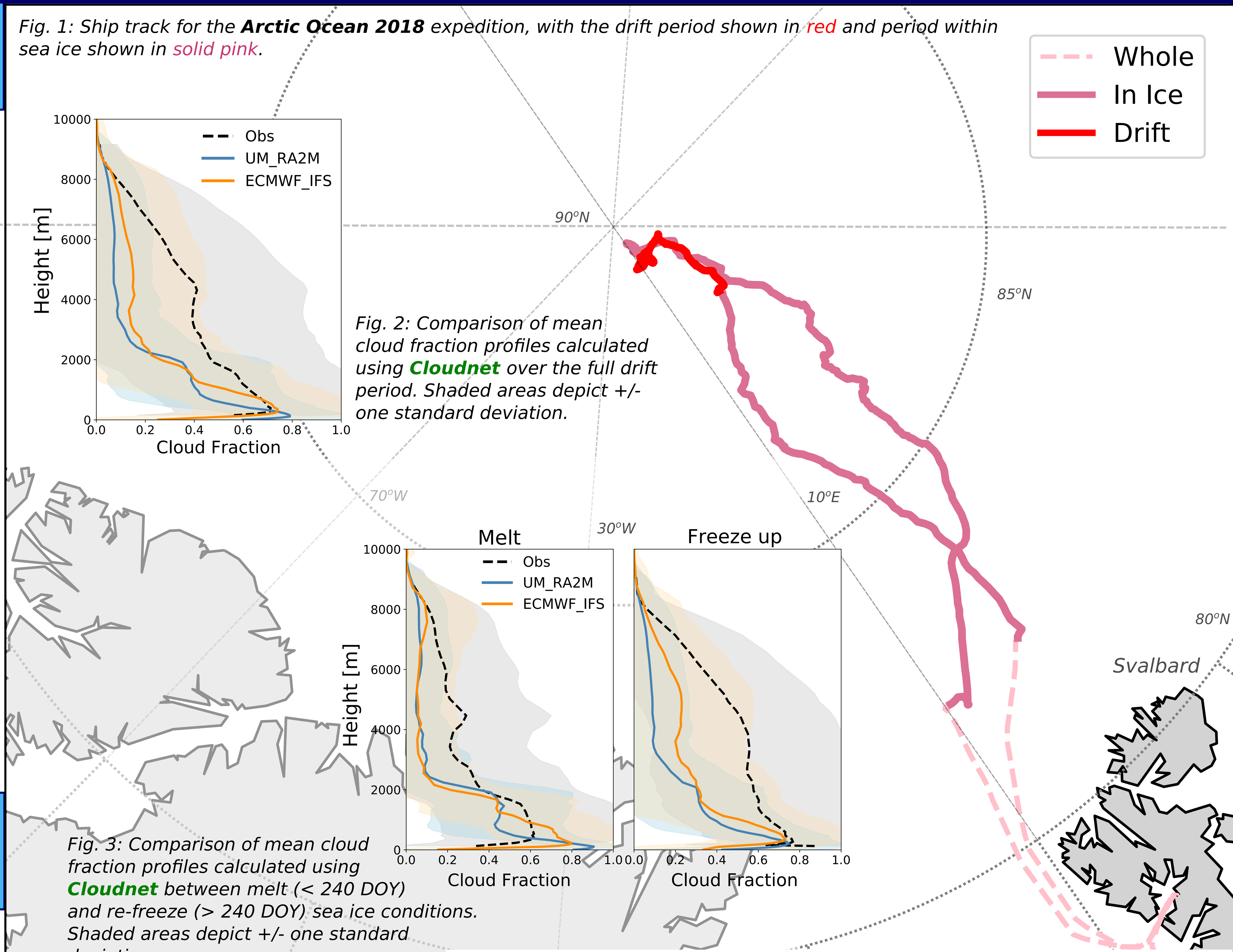

*Fig. 1: Ship track for the **Arctic Ocean 2018** expedition, with the drift period shown in red and period within sea ice shown in solid pink.*

*Fig. 2: Comparison of mean cloud fraction profiles calculated using **Cloudnet** over the full drift period. Shaded areas depict +/- one standard deviation.*

*Fig. 3: Comparison of mean cloud fraction profiles calculated using **Cloudnet** between melt (< 240 DOY) and re-freeze (> 240 DOY) sea ice conditions. Shaded areas depict +/- one standard deviation.*

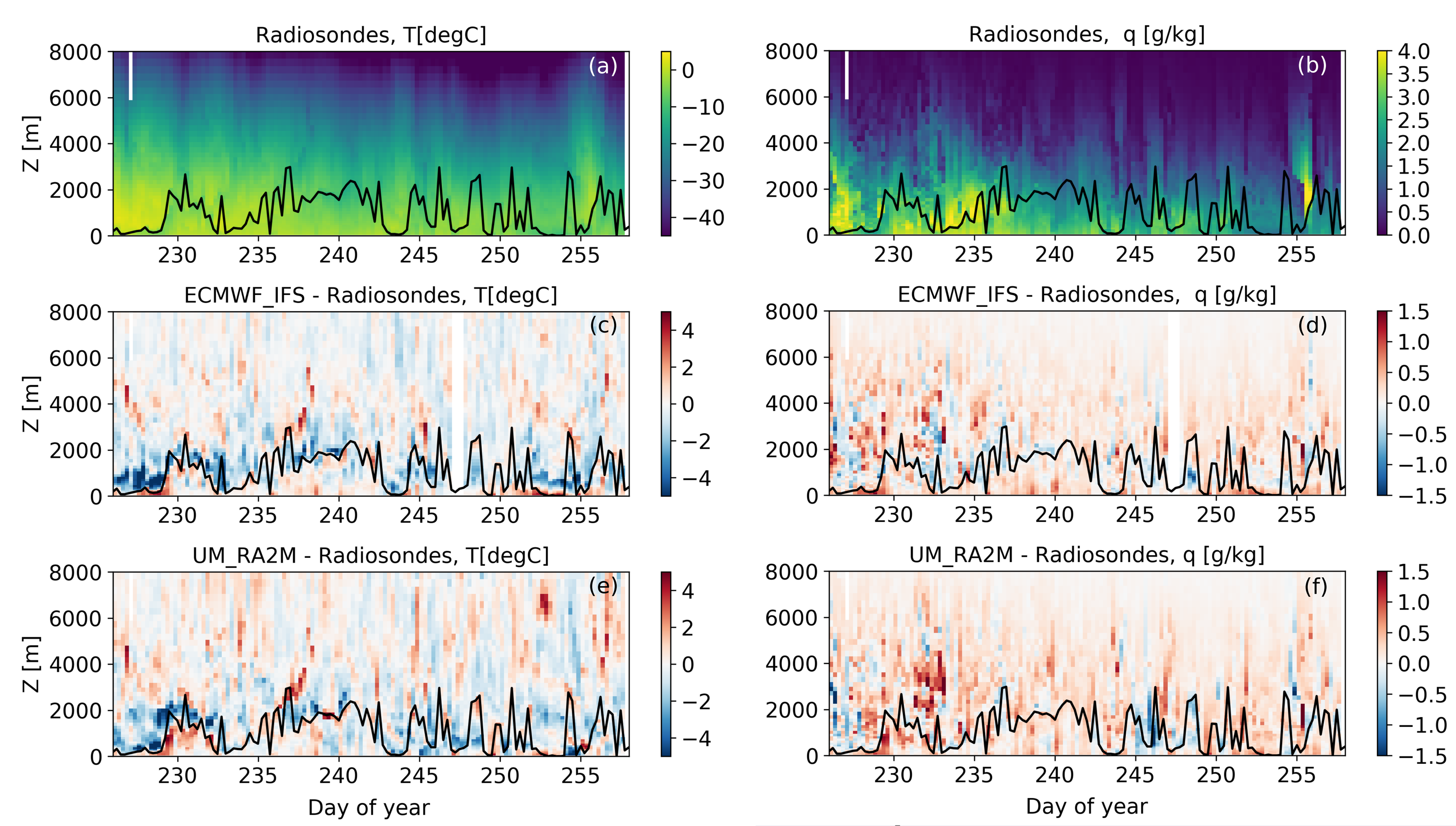

*Fig. 4: Timeseries of **measured** temperature (left) and water vapour mixing ratio (WVMR, right) from the radiosondes (top), in addition to **IFS** (middle) and **UM_RA2M** (bottom) anomalies with respect to these data. Boundary layer inversion base height determined from radiosondes [1] indicated (black line) in each panel.*

Results

Observations show that there were **few cases of single-layer stratocumulus clouds**, atypical for the season [1]. Higher altitude (>2 km) multi-layer clouds occurred frequently during the expedition, and both models **fail to reproduce the observed cloud fraction** (*Fig. 2*). Model-observation agreement is poorest aloft (up to 8 km). Both models additionally overestimate the occurrence of low (<1 km) clouds when the sea ice was melting (*Fig. 3*). This agreement with observations improves when the sea ice began to refreeze; however, the **underestimation of cloud aloft remains consistent regardless of sea ice conditions**.

When high clouds are measured/modelled, any frozen precipitation below will also be classed as cloud by **Cloudnet**. Therefore, some of the discrepancy aloft may be due to precipitating clouds in reality with little-to-no precipitation in our models. By treating all cloud ice the same, it may be difficult to distinguish between multi-layered clouds with **Cloudnet** if any are precipitating.

Differences between measured and modelled cloud fraction may also be partially explained by the modelled thermodynamic structure: **both models are too moist**, while **strong temperature biases exist in the vicinity of the identified boundary layer inversion** (*Fig. 4*). Temperature and WVMR anomalies are greatest in the lowest 2 km of the atmosphere, indicating that the model representation of the boundary layer could be culpable for the poor agreement between the modelled and observed low-level clouds.

Conclusions / Further Work

The **UM** and **IFS do not capture observed cloud fractions measured over Aug-Sep 2018 in the high Arctic,** with poorest agreement aloft (>2 km; *Fig. 2*) and towards the surface when the sea ice was melting (*Fig. 3*).

Both models fail to reproduce the thermodynamic structure of the troposphere (*Fig. 4*), with **largest anomalies in temperature and WVMR towards the boundary layer**.

Next, we will investigate further whether the models' misrepresentation of the boundary layer is responsible for the poorly captured cloud fractions.

References

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