Confronting the ECMWF/IFS with real observations from the central Arctic

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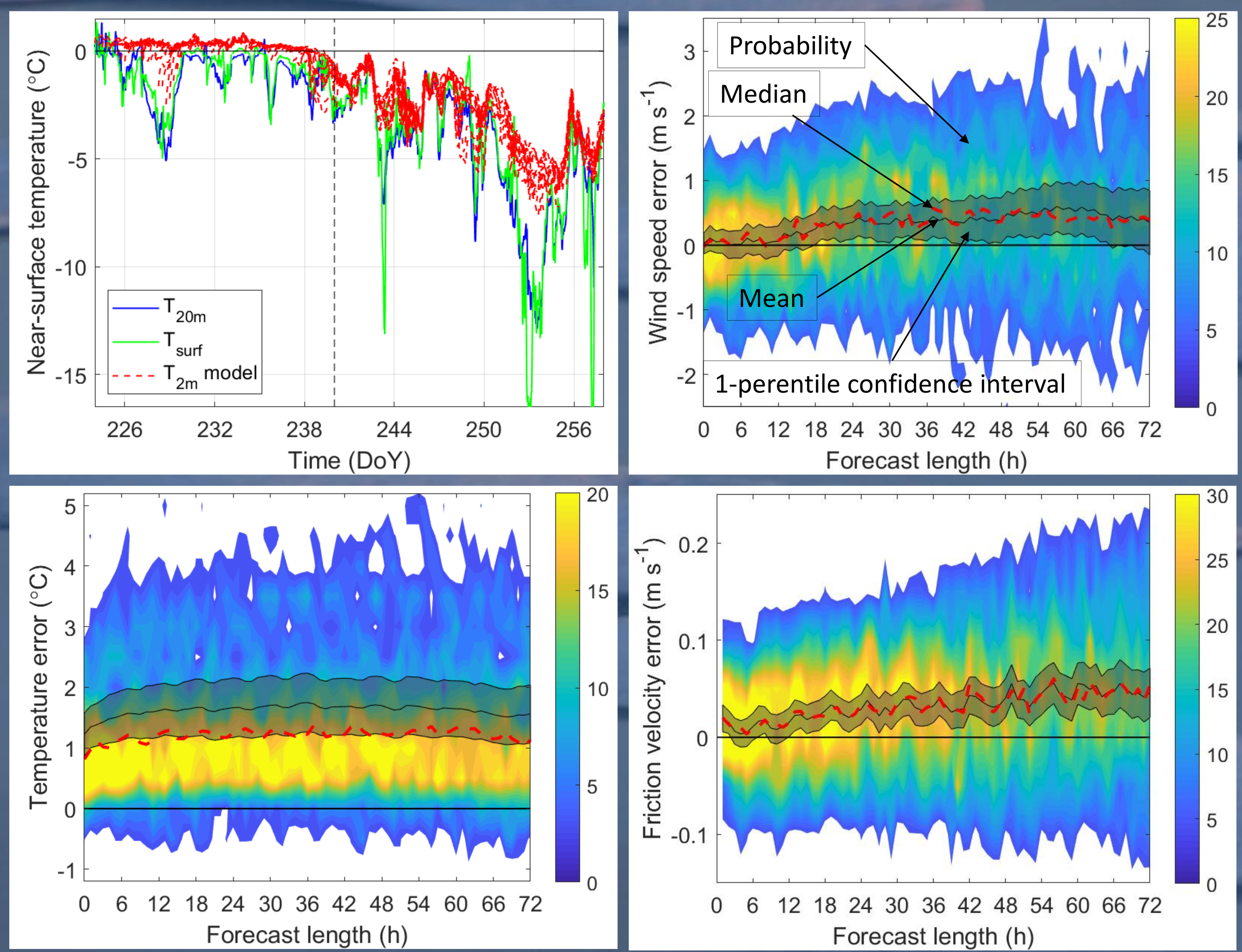
What?

An extensive suite of instruments were deployed on the research icebreaker *Oden,* moored to and drifting with the ice close to the north pole for about one month in August/September 2018. Observations of atmospheric processes, clouds and atmospheric vertical structure are utilized to evaluate 6-hourly operational forecasts with the ECMWF IFS- model .

Why?

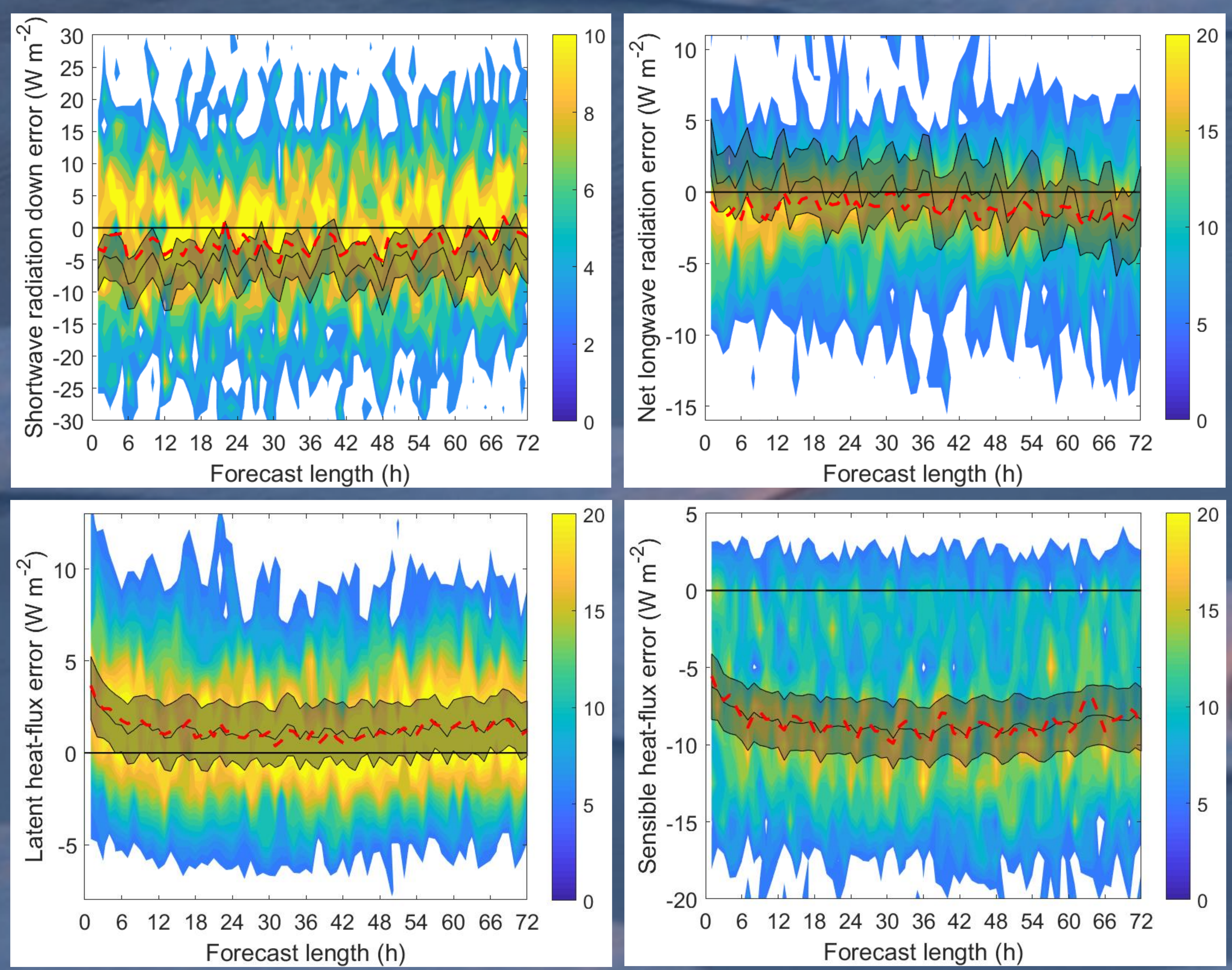
Many systematic model errors comes from inadequate parameterizations in the models. To deal with these systematic model errors require going beyond simple metrics based on averaged surface observations and to start evaluate processes and process relationships through the whole atmosphere. This of course requires process-level observations.

Errors at the surface…



Near-surface air temperature is nearly always too warm (lower panel). This happens fast in the model also when initial conditions are better (upper panel) and this error is larger when temperature is below freezing.

Near surface wind-speed error (top panel) is small initially but increases gradually to ~0.5 ms^{-1} during day 1; then stays quasi-steady. Consequently, a positive surface momentum flux error (lower panel) also grows with forecast length.



The surface energy budget terms also have systematic errors. The error in incoming shortwave radiation is negative, consistent with overestimated clouds but net longwave radiation the error is close to zero. While being too warm, the model atmosphere is loosing excess heat to the surface; the model atmosphere is more stably stratified than the observed. Additionally, for reasons not yet understood, most parameterized variables feature an annoying 6-hour cycle.

Laying the puzzle…

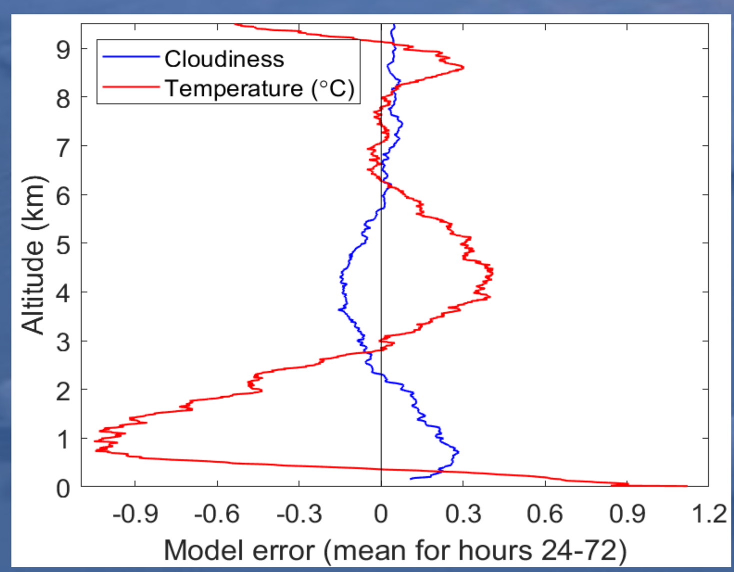
Winds are (surprisingly?) accurate, likely because soundings were assimilated. However, in spite of this thermodynamics have substantial systematic errors.

* Lower atmosphere is too warm and moist. During melt skin temperature is locked near 0°C, but during freeze-up skin temperature is also too warm, although slightly less than the lower atmosphere.
* The too warm surface drives a small positive bias in latent heat flux. The sensible heat fluxes has a larger negative bias, while less radiation reaches the surface compared to observations.

The near-surface temperature warm bias comes from the atmospheric model, while the sea ice is trying to cool the atmosphere. Hence, processes in the atmospheric model are responsible, neither the surface energy budget nor the sea-ice or ocean models.

More puzzles…

* The temperature bias has a pronounced vertical structure.
* There is a substantial diurnal cycle in the modelled boundary-layer temperature, absent in reality.
* The IFS has too much low clouds, with a maximum error around 500 m tapering off upward around 1 km.



The temperature errors is related to the IFS clouds, see above. Too much absorption of solar radiation in the boundary-layer generates the too warm boundary layer while too much cloud-top cooling generates the cold bias around ~1km. So why is there is too much clouds in IFS?

Hypothesis

The overestimation of low clouds causes a positive feedback between clouds, radiation and vertical mixing.

1) An effect of the excessive clouds is a diurnal heating & cooling signal temporally reducing static stability …

2) … which in turn allows parameterized convection to occasionally transport water vapor out of the very moist boundary layer to the lower free troposphere …

3) … where it condenses into excessive clouds, and the positive feedback loop is closed.

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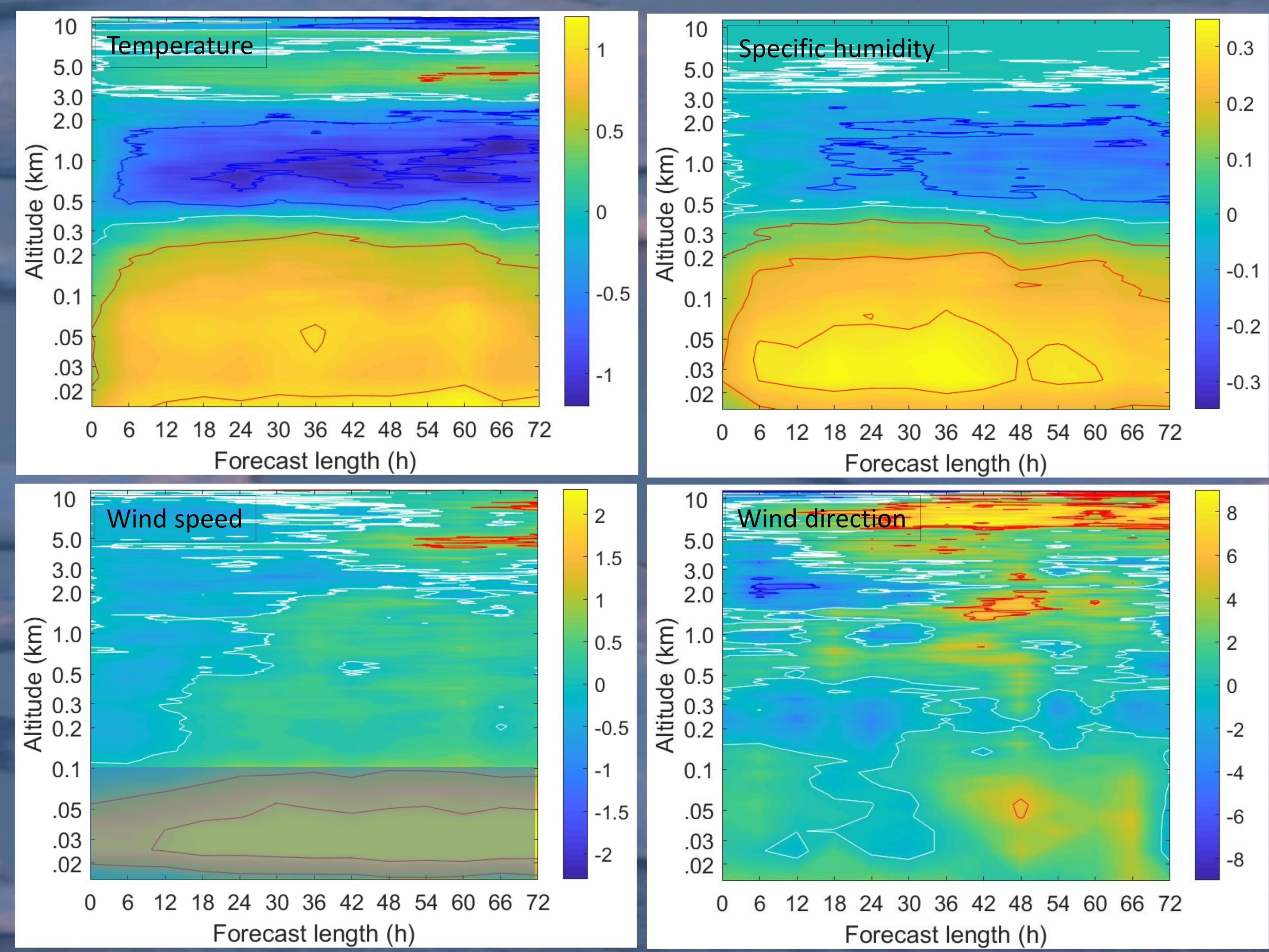
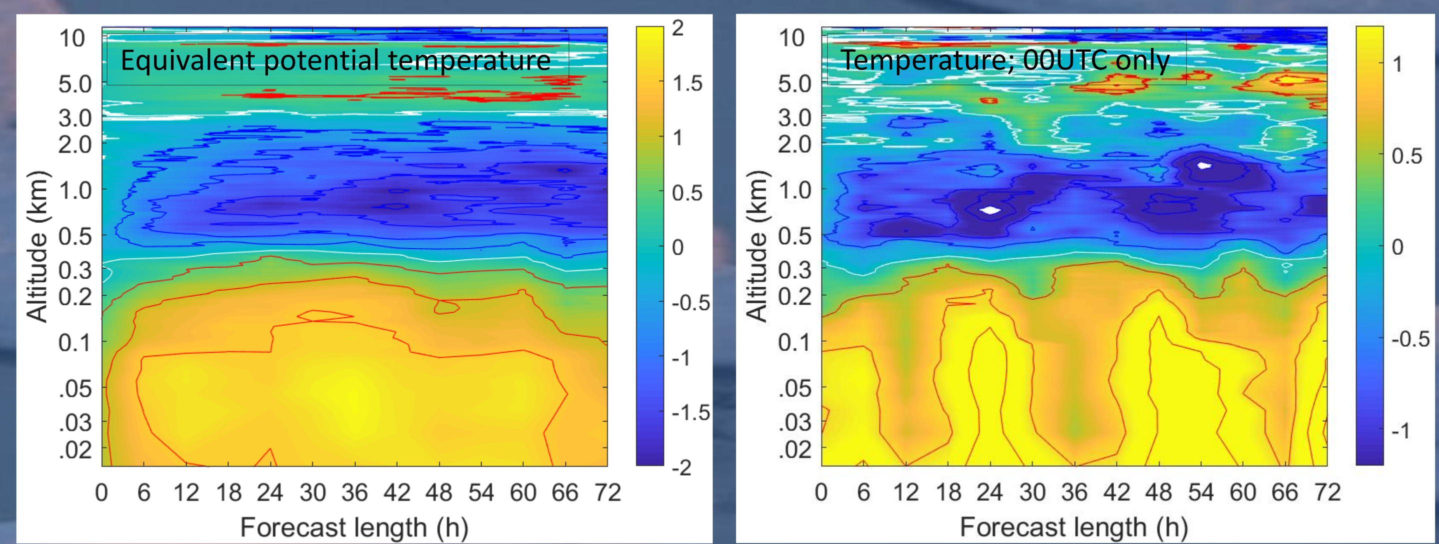
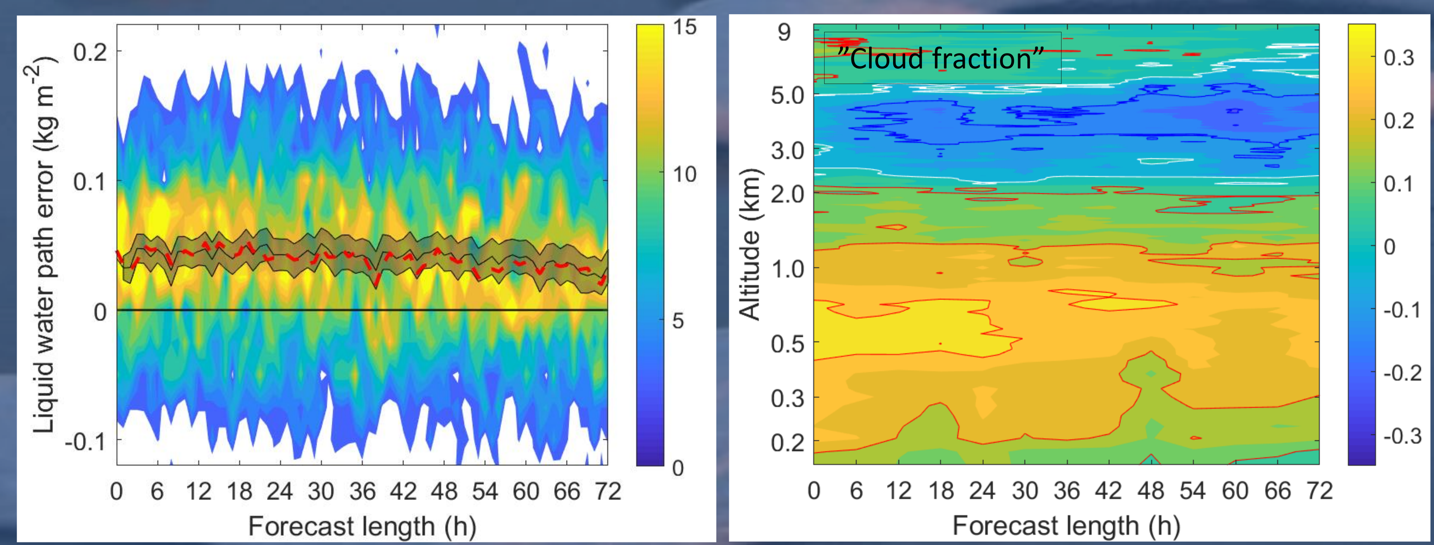
… and aloft!



Median forecast error as a function of height for temperature (°C), specific humidity (g kg^{-1}), wind speed (m s^{-1}) and direction (°), based on four forecasts per day. Note the boundary-layer warm & moist bias and the cold & dry bias ~1km. The large (shaded) positive wind-speed bias at <100 m is an artifact from soundings being launched in the lee of the ships infrastructure. In fact, winds were very good; likely a consequence of the data assimilation of the soundings.



Combining temperature and moisture biases, an even larger bias in stratification appear (left). The equivalent potential temperature difference between surface and 1 km is on average reduced by 4 K. Evaluating the temperature bias using only one forecast per day (00UTC, right) reveals a pronounced diurnal cycle. This temporally enhances biases in static stability further .



Modeled liquid (left) and ice water (not shown) paths are too large, mostly because there is excess clouds (right). In fact IFS has no periods with clear conditions atr all during the expedition; the summer Arctic is very cloudy but there were clear periods observed.