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Utilization of airborne observations to assess model parametrizations of critical RH profiles in the Arctic Ocean

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Introduction

Atmospheric Global circulation Models (AGCMs) are a key tool in our capability to predict future climate under various scenarios. Specifically, over the Arctic Ocean, such a prediction tool is instrumental to our understanding and mitigation options of the rapidly changing climate under global warming. Among the various challenges of such models to made correct predictions, cloud cover and cloud phase are currently considered one of the toughest ones. Especially over the Arctic Ocean, clouds can greatly affect the surface energy budget, which in turn affect the freezing and thawing of the transient sea-ice during the summer and fall periods. One of the controlling parameters used in the AGCMs to predict cloud cover and phase is related to the sub-grid scale distribution of the total water within a model grid. This distribution is often simplified to be a flat ("top-hat") distribution with two parameters, namely the mean total water condensate within the grid, and the distribution width. The latter defines the critical relative humidity (RH_c) from which water begins to condensate and form a cloud. To date, the computation guidelines for the RH_c parameter rely partially on observations from satellite, which are based mostly from mid-latitude observations. Hence, RH_c values that are used for the Arctic Ocean do not necessarily represent the actual domain state and may benefit from incorporation of local in-situ observations that can shed more light on this parameter in this unique environment. Here we utilize ship and airborne campaigns over the Arctic Ocean to derive a better constraint for this parameter, testing the sensitivity of the GOES-5 AGCM model predictions of clouds and surface fluxes to the RHc values and comparing which values generate better agreement with our campaign measurements.

Datasets

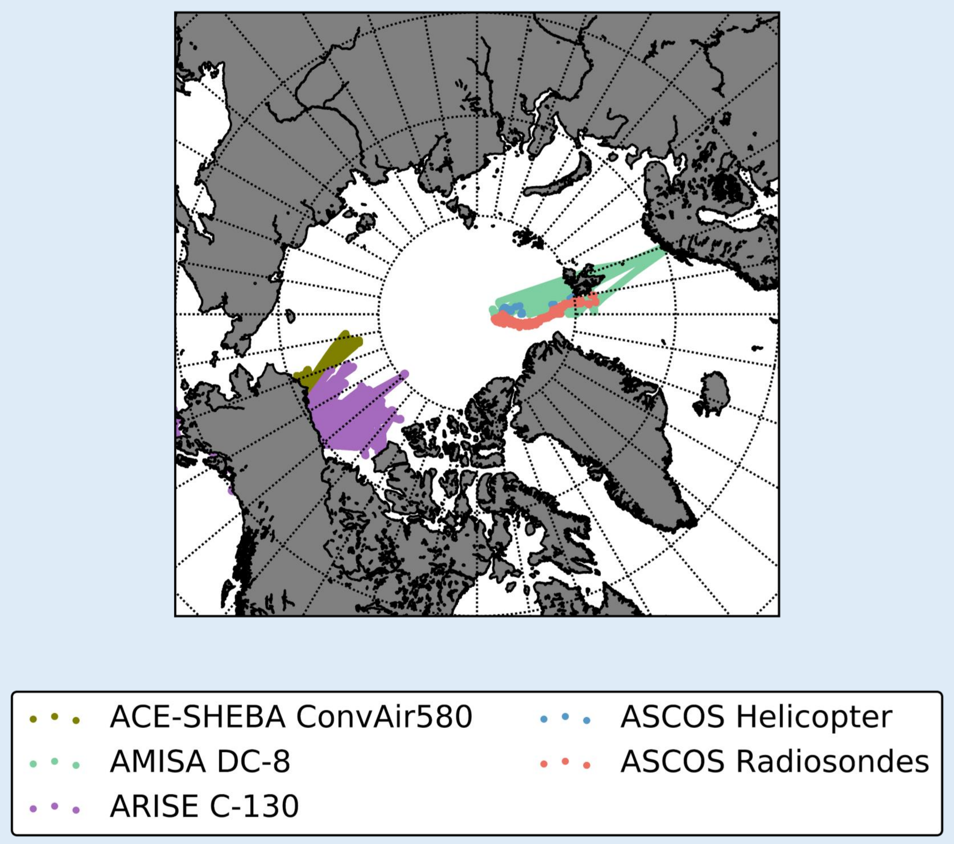

Figure 1: Here, we show the compiled available and relevant data-sets obtained from measurements over the Arctic Ocean during summer and fall periods, from shipborne and airborne vessels. The figure shows the location of the four datasets used for this analysis. The NASA **ARISE** (Arctic Radiation – IceBridge Sea&Ice Experiment) campaign acquired unique aircraft data on atmospheric radiation and sea-ice properties during the critical late summer-to-autumn sea-ice minimum (September-2014) over the Beaufort Sea on-board the C-130. The Arctic Summer Cloud Ocean Study (**ASCOS**) was deployed in the central Arctic Ocean on the Swedish icebreaker Oden during late summer 2008 (Aug-Sep). The **AMISA** project provided complimentary vertical profiling information to ASCOS during a few episodes, flying instruments on the NASA DC-8 research aircraft, based out of Kiruna, Sweden, and the FIRE-ACE campaign accompanied the SHEBA shipborne campaign during May-June on-board the UofW Convair-580.

Total Water sub-grid variability

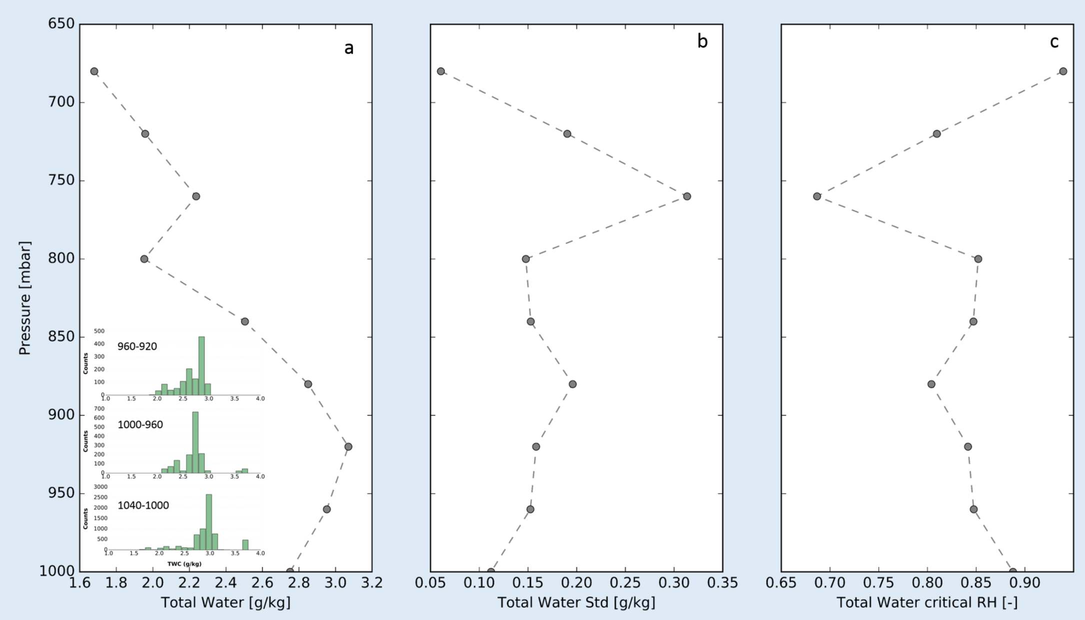

Figure 2: (a) mean total water amount for ASCOS 2008 helicopter profiles, aggregated into MERRA-2 grid, binned into pressure layers of 40 mbar, (b) standard deviation of the total water in a merra-2 grid-box, per pressure levels, based on a, and (c) critical relative humidity, which is defined as 1 minus the standard deviation within the GEOS-5 model grid-box. The insert in panel a shows an example total water amount distributions, corresponding for the three lowest pressure levels, within one merra-2 grid box for the ASCOS Helicopter dataset (center latitude of 75°N and longitude of 9°W). Overall, except for the high mode values, the distributions are pretty flat for the variety of TWC values, which means that the top hat assumption is valid here. The only exception is the high mode values, which correspond to RH at saturation (95-100%), as obtained from corresponding RH distributions (not shown).

RH_c observed over the Arctic Ocean

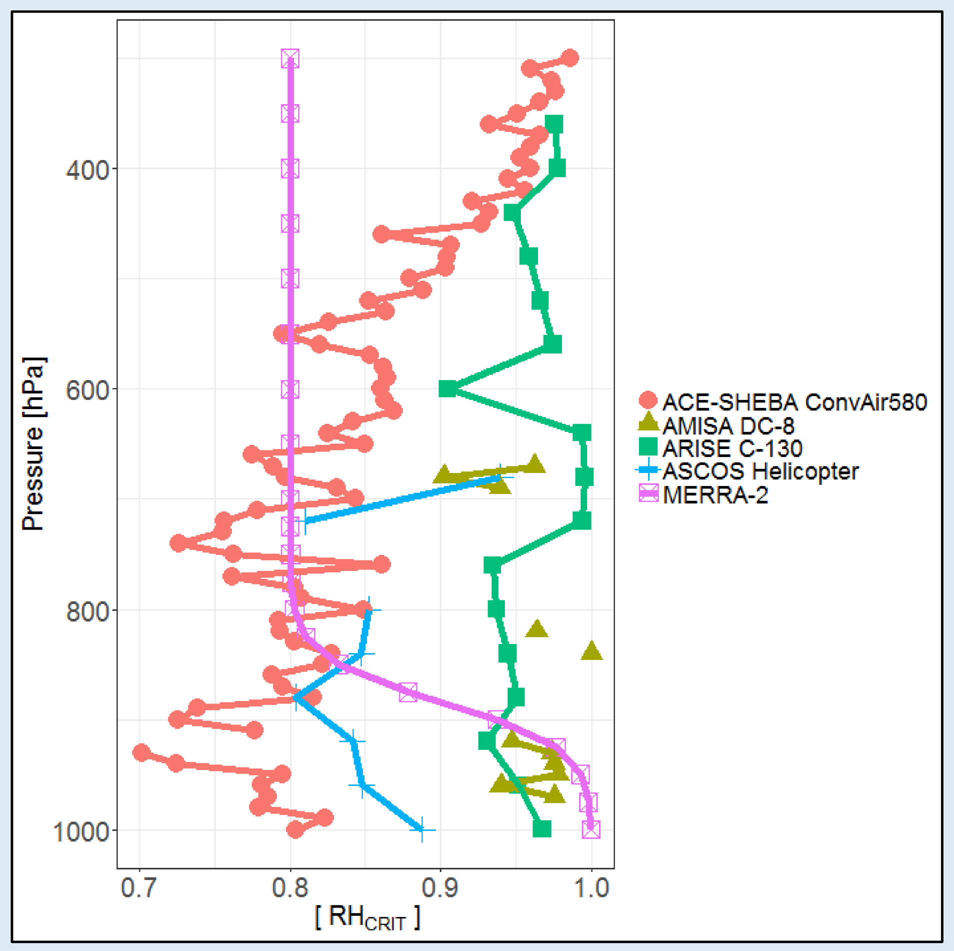

Figure 3:Vertical profiles of critical RH values derived from in-situ observations over the Arctic Ocean. These are aggregated campaign-wise data binned into the merra-2 spatial grids, by 40 hPa pressure levels. ACE-SHEBA convair-580, AMISA DC-8, ARISE C-130 and ASCOS Helicopter profiles include the total water amount per grid (the sum of water vapor, and cloud liquid and ice contents). In addition, MERRA-2 RH_c profile is shown in magenta, with a RH_c parameter value of 0.8 at the inflection point (800hPa). ARISE and AMISA values are the highest among all campaigns, with RH_c~0.95, representing probably a mixture of open-ocean and sea-ice surfaces, while ASCOS and FIRE-ACE are only slightly higher. Nevertheless, the profile shape is different for all campaigns compared to MERRA-2, and has a shallower gradient.

Sensitivity of LWP and IWP to RH_c

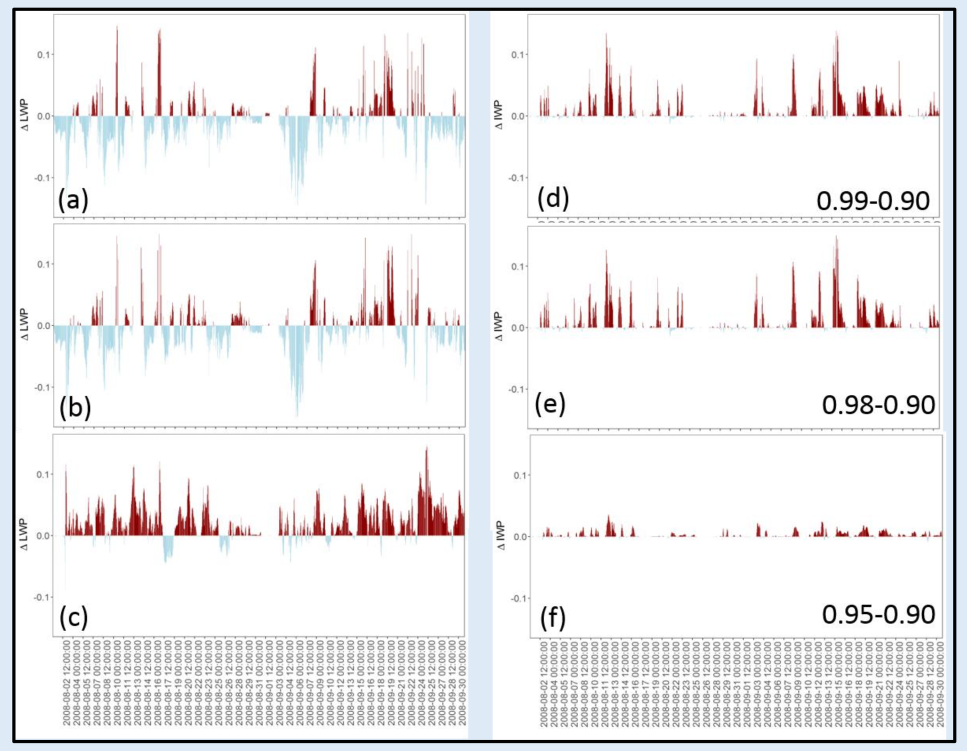

Figure 4: Liquid water path (LWP) differences (a-c) and Ice water path (IWP) differences (d-f) between RHc values of 0.99 (upper row), 0.98 (middle row), and 0.95 (lower row) and RHc values of 0.90 for the ASCOS campaign time period and location, as predicted by the GEOS-5 single column model simulations, driven by MERRA-2 boundary conditions.

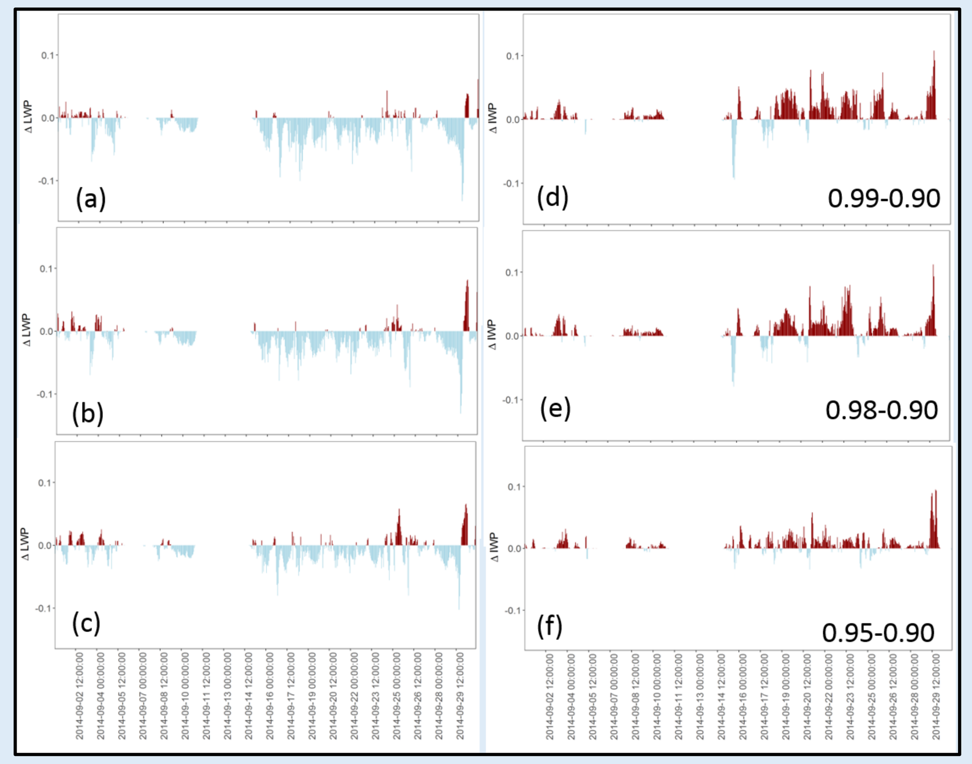

Figure 5: similar to Fig. 4, but for the ARISE campaign, with mean location over open water (opnw) surface.

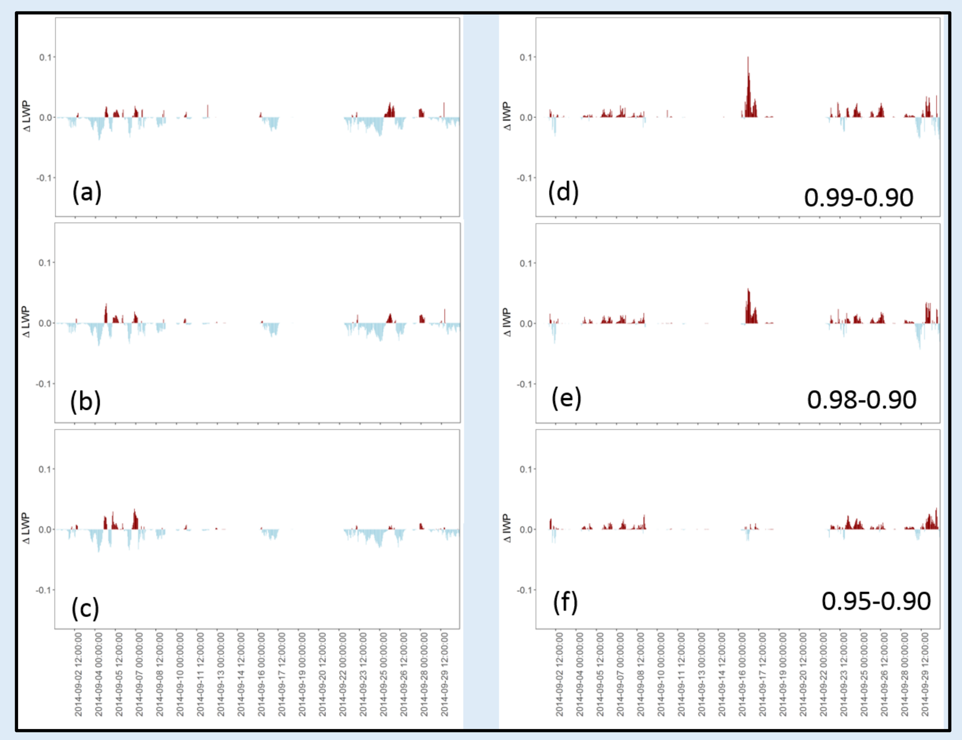

Figure 6: similar to Fig. 4, but for the ARISE campaign, with mean location over sea-ice surface.

SCM simulations compare with Obs.

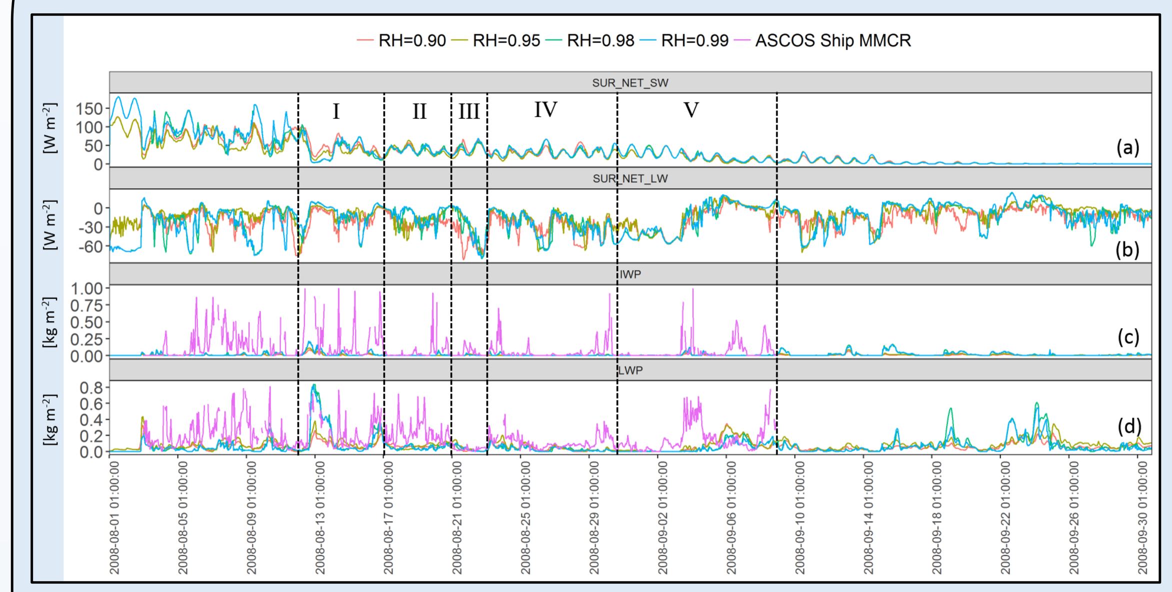

Figure 7: results from GEOS-5 SCM simulations for ASCOS campaign period and location, as described in the methods section for (a) net shortwave flux at the surface, (b) net longwave flux at the surface, (c) IWP, and (d) LWP. The different line colors represent simulations using different RHc values, as shown in legend. Magenta solid lines for IWP and LWP are calculated from integrating MMCR IWC and LWC hourly measurements from the *Oden* during ASCOS.

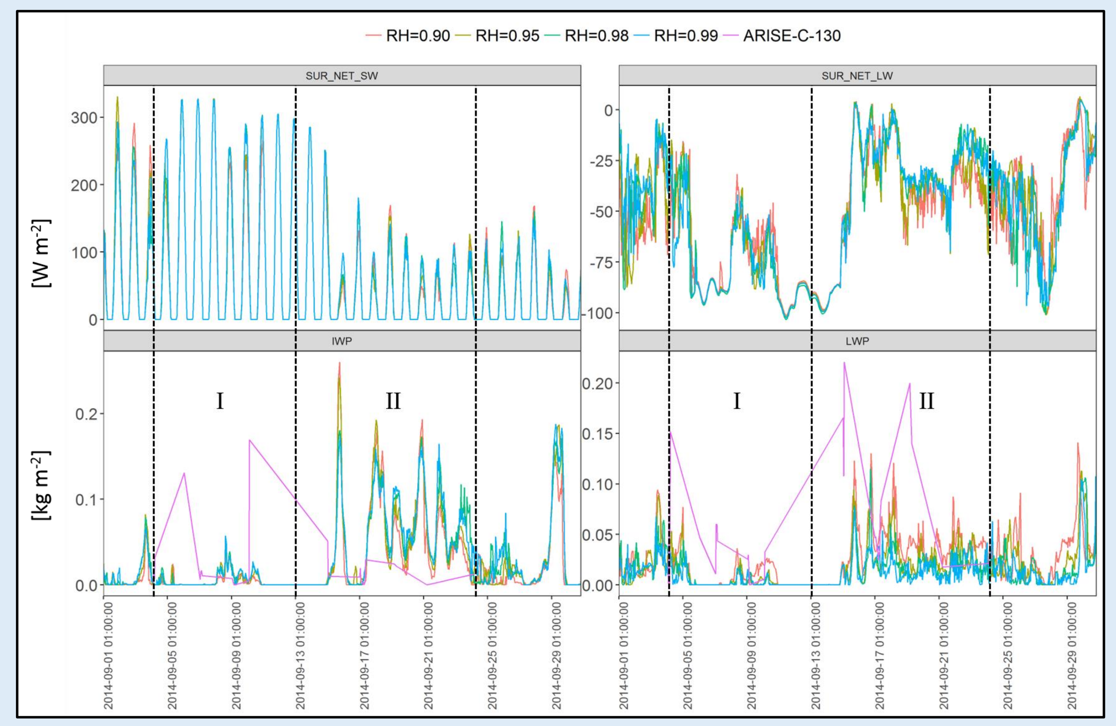

Figure 8: same as in Fig. 7 but for ARISE open-water simulations. Magenta solid lines for IWP and LWP are calculated from integrating IWC and LWC from ARISE aircraft profiles.

Conclusions

- In-situ RH_c values over the Arctic Ocean span a large range, which depends on time of year, surface type and the local turbulent flux and meteorological conditions near the surface.
- RH_c values near the surface and along the vertical seem to follow an increasing trend with the advancement of the melt season (higher toward September), which supports observations of higher RH and cloud fraction during this time of the year.
- The top-hat distribution shape used by the GEOS-5 model seems like a reasonable assumption in the characterization of the sub-grid variability within the model.
- The GEOS-5 RH_c tangent hyperbolic shape, which has the values decrease monotonically from the surface up to a critical pressure level (~800hPa as default) and is derived from AIRS observations over the globe seem less optimal for the Arctic Ocean, which shows a less monotonic behavior and often has an "inversion-like" shape up to this critical pressure.

Acknowledgments

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