Comparing High Latitude DOE ARM Observations and E3SM Simulations between Northern and Southern Hemispheres

Neel Desai[1], Minghui Diao[1], Yang Shi[2,3], Xiaohong Liu[2] | [1] Department of Meteorology and Climate Science, San Jose State University, San Jose CA, [2] Department of Atmospheric Sciences Texas A&M University, College Station TX, [3] Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge MA

Introduction and Objectives

High-latitudinal cloud cover, cloud phase and underlying microphysics play an important role in determining the polar surface radiation budget and needs to be analyzed to evaluate polar amplification behavior for each hemisphere. In this study, we:

1. Compare cloud macrophysical and microphysical properties observed using remote sensing measurements from two DOE ARM field campaigns COMBLE and MARCUS from the northern and southern high-latitudinal regions respectively.

2. Evaluate DOE E3SMv2 simulation results for both campaigns and compare the results against the observations.

Remote Sensing Measurements

We compare remote sensing measurements from 2 campaigns:

1. DOE ARM Measurements Of Aerosols, Radiation, And Clouds over the Southern Ocean (MARCUS) ship-based campaign from Oct 2017 to March 2018 over the Southern Ocean (Fig. 1a).

2. DOE ARM Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE) ground-based campaign from December 2019 to May 2020 in northern Scandinavia (Fig 1b).

3. The MARCUS campaign was divided into polar region (latitude > 60 S) and mid-latitude region (latitude < 60 S).

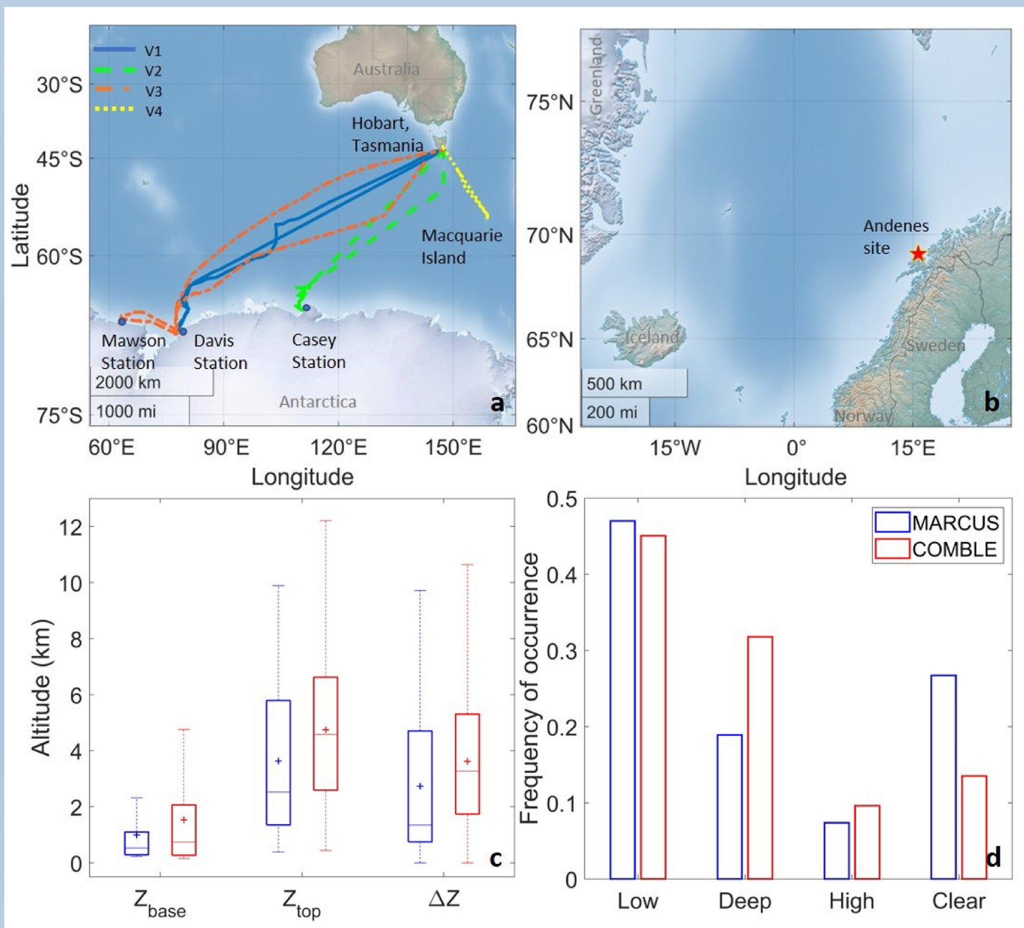

Fig. 1 (a) location of ship tracks during MARCUS, (b) location of COMBLE, (c) shows box plots of cloud base, cloud top and cloud thickness while (d) shows fraction of cloud type during MARCUS and COMBLE.

Cloud properties

Cloud macrophysical properties such as cloud base, top heights and cloud thickness were obtained using the ARM ARSCL VAP.

Clouds are divided into three categories based on cloud base (Z_{base}) and cloud top (Z_{top}) heights:

Z_{base} < 3 km & Z_{top} ≤ 3 km = low clouds

Z_{base} ≤ 3 km & Z_{top} > 3 km = deep clouds

Z_{base} > 3 km & Z_{top} > 3 km = high clouds

Cloud phase was identified using a combination of lidar, radar, microwave radiometer and sounding measurements following Desai et al., (2023).

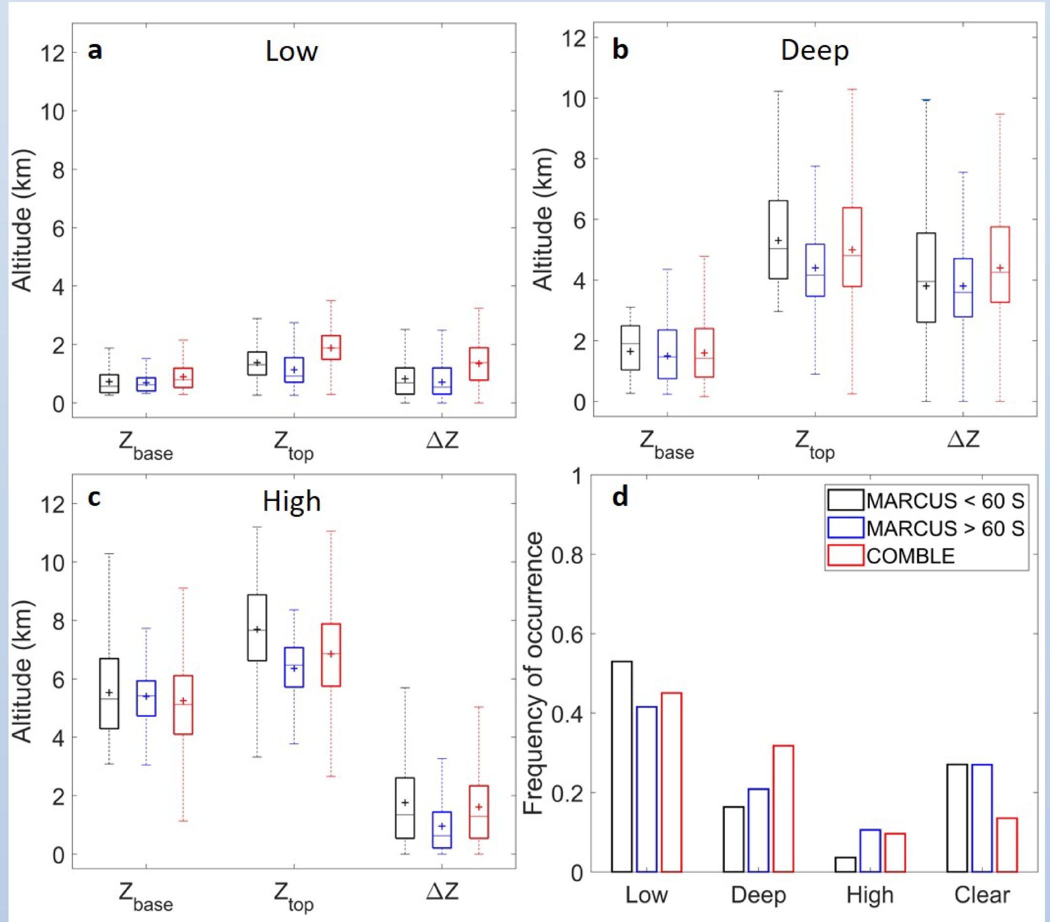

Fig 2: Cloud base, cloud top heights and cloud thicknesses when the MARCUS campaign is divided into regions < 60S (black) and > 60S (blue).

Results: Observations

1.A comparison of cloud base, cloud top heights and cloud thickness considering all cloud categories suggest that median cloud top heights and cloud thickness are higher during COMBLE compared to MARCUS (Fig. 1c,d) .

2.Low level stratiform clouds are thicker during COMBLE compared to both regions of MARCUS (Fig. 2a) whereas deep (Fig. 2b) and high cloud (Fig. 2c) thickness values during COMBLE are closer to the values observed for MARCUS < 60 S compared to MARCUS > 60 S.

3.A statistical analysis of cloud phase occurrence frequencies with respect to temperature shows lower ice phase (~70%) for stratiform clouds during COMBLE compared to both MARCUS regions (~80%) between -25 and 0 °C (Fig. 3a-c)

4.Cloud phase frequencies for deep and high clouds are similar between MARCUS < 60 S, MARCUS > 60 S and COMBLE (Fig. 3d-i)

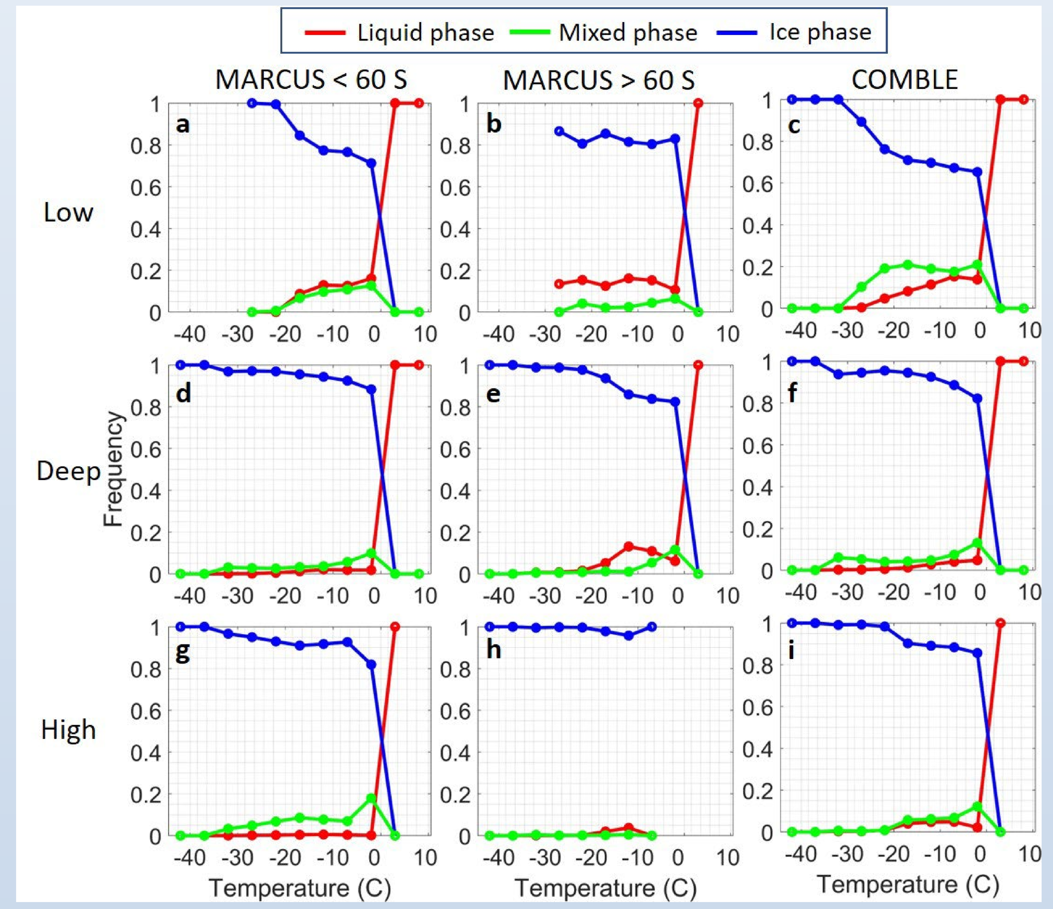

Fig 3: Cloud phase occurrence frequency for low-level (a-c), deep (d-e) and high (g-i) clouds is shown for MARCUS < 60 S, MARCUS >60 S and COMBLE observations

DOE E3SMv2 simulations:

DOE EAMv2 (1 deg, 72 levels) Energy Exascale Earth System Model (E3SMv2) was nudged towards the MERRA-2 temperatures and simulations were conducted for both MARCUS and COMBLE campaigns. The output was co-located with observations.

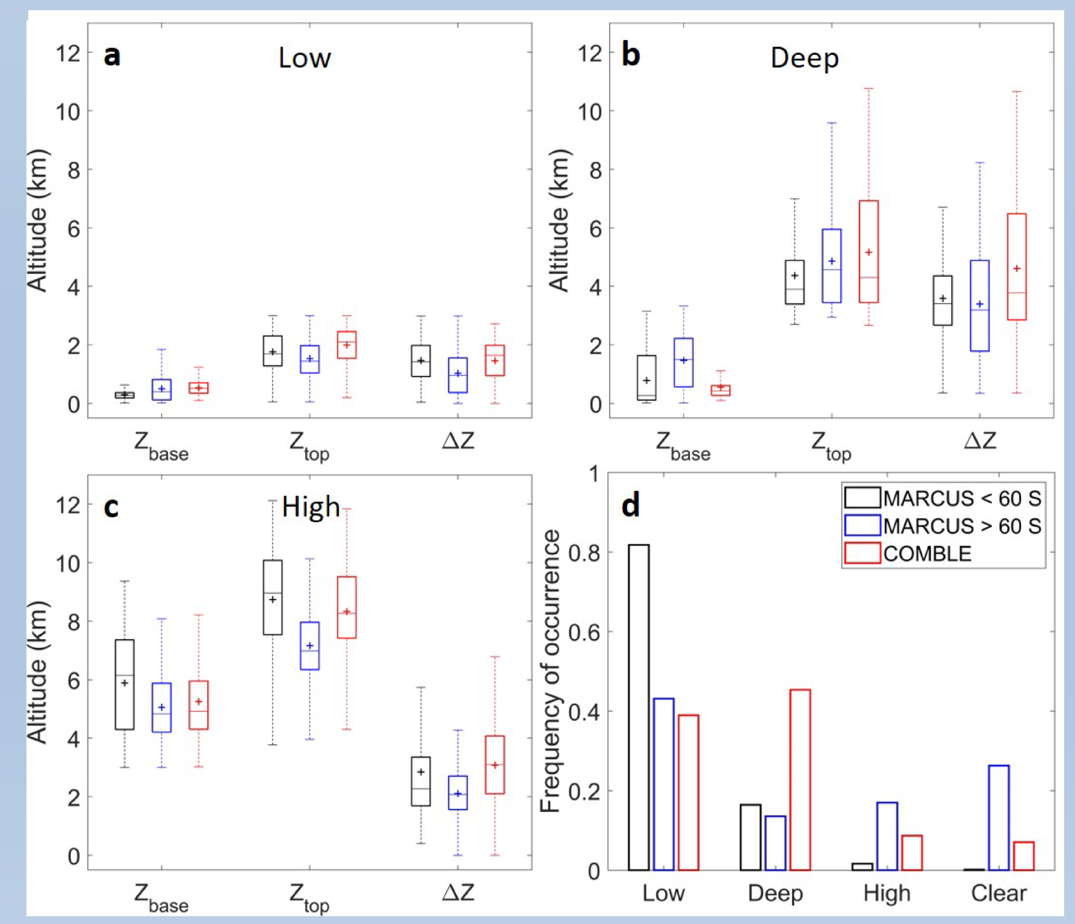

Fig 4: Cloud base, cloud top heights and cloud thicknesses obtained using E3SMv2 simulations when the MARCUS campaign is divided into regions < 60 S (black) and > 60 S (blue).

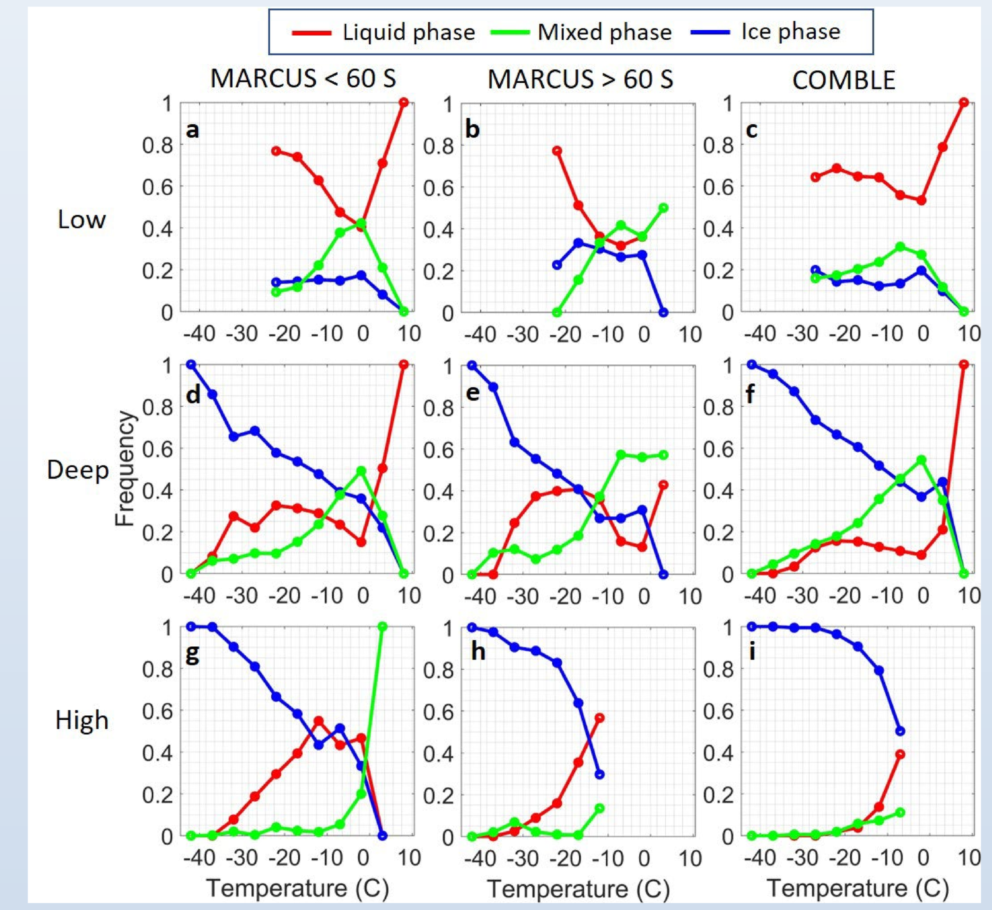

Fig. 5 E3SMv2 cloud phase occurrence frequency for low-level (a-c), deep (d-e) and high (g-i) clouds for MARCUS < 60 S, MARCUS > 60 S and COMBLE.

Comparison of Relative Humidity:

To investigate the reason for the bias in cloud phase between the observations and the model, the relative humidity (RH) bias for each cloud phase was obtained as:

$$\Delta RH = RH_{model} - RH_{obs}$$

The observations were spatially averaged to the E3SMv2 grid size and the ΔRH was calculated for each pixel. The values were also separated by each cloud phase.

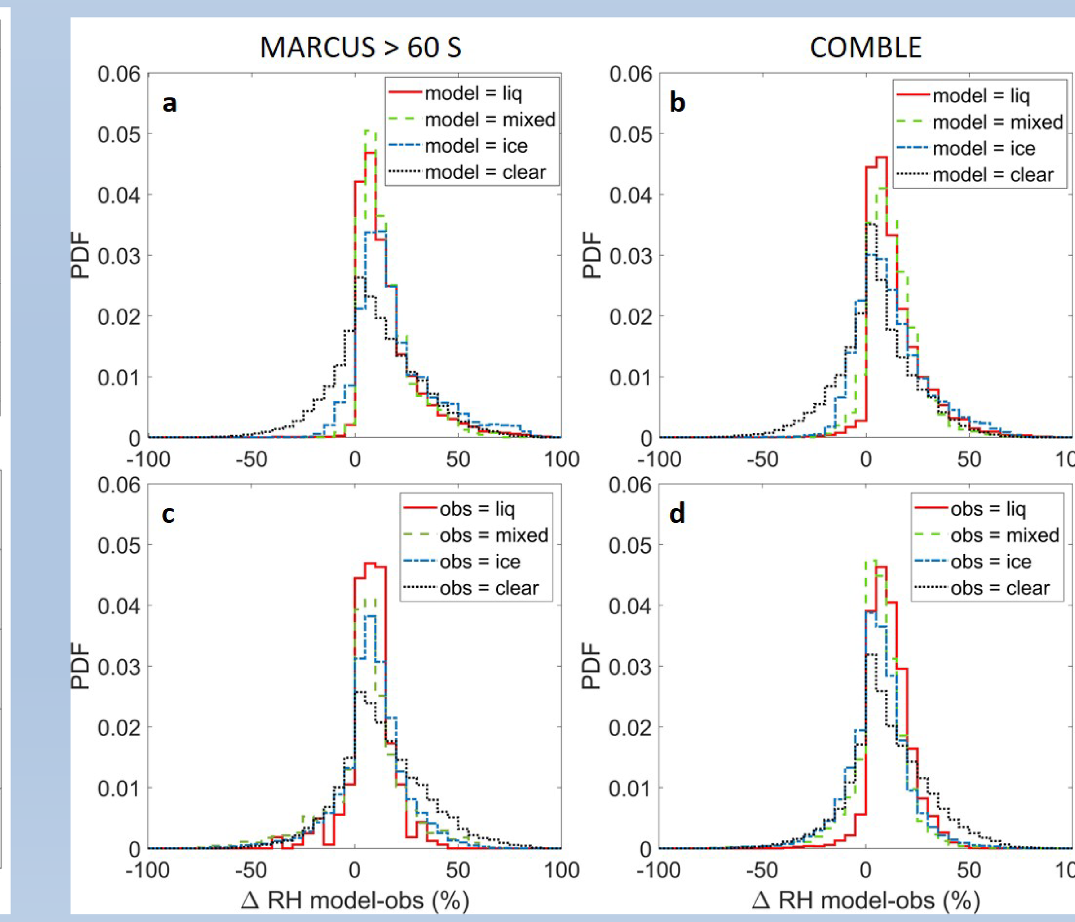

Fig. 6 Difference in Relative Humidity between model and observations for each pixel and different modeled and observed cloud phases during MARCUS > 60 S and COMBLE.

Results: E3SMv2 simulations

1.Modeled cloud base, cloud top heights, cloud thickness values (Fig. 4a-c) show good agreement with observations for all cloud categories during MARCUS and COMBLE.

2.This suggests E3SMv2 is able to simulate cloud macrophysical properties well compared to observations.

3.However, E3SMv2 results suggest higher stratiform and lower clear sky cloud fraction for the MARCUS < 60 S compared to observations.

4.E3SMv2 cloud phase frequency analysis shows considerably more cloud liquid and lower cloud ice phase for low-level stratiform and deep clouds (Fig. 5a-f) compared to observations (Fig. 3a-f).

5.The bias in E3SMv2 cloud phase is likely due to higher relative humidity values in the model compared with observations for each cloud phase (Fig. 6)

6.This likely results in higher liquid and mixed phase clouds in the model compared to observations.

Acknowledgments

- Department of Energy (DOE) Atmospheric System Research (ASR) Grant DE-SC0021211.
- DOE Research Development and Partnership Pilot (RDPP) Grant DE-SC0023155
- This research used resources of the National Energy Research Scientific Computing Center; a DOE Office of Science User Facility supported by the Office of Science of the U.S. Department of Energy

References

- Desai, N., Diao, M., Shi, Y., Liu, X., & Silber, I. (2023). Ship-based Observations and Climate Model Simulations of Cloud Phase over the Southern Ocean. Journal of Geophysical Research: Atmospheres, e2023JD038581.

Contact: neel.u.desai@sjsu.edu

U.S. DEPARTMENT OF ENERGY | Office of Science