Hemispheric Comparisons of Ice and Mixed-Phase Cloud Properties based on In-situ Observations and DOE E3SMv1 Model

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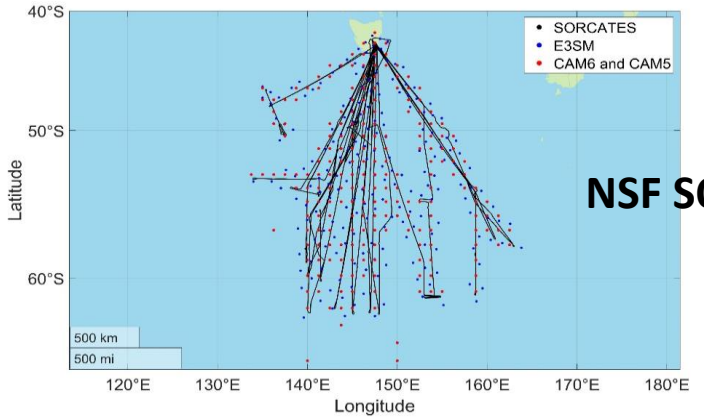
Image from NASA worldview

Motivation to Improve Understanding of Ice and Mixed-Phase Clouds

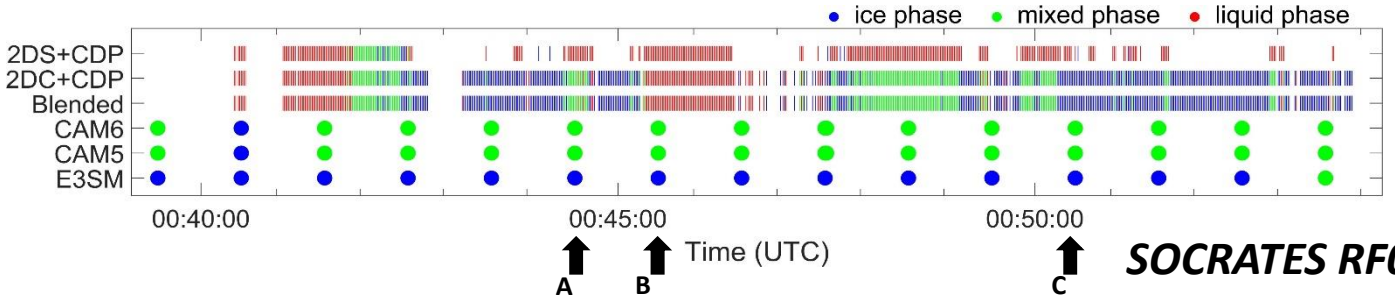
Motivation

1. Ice and mixed-phase clouds have highly complex macrophysical and microphysical properties

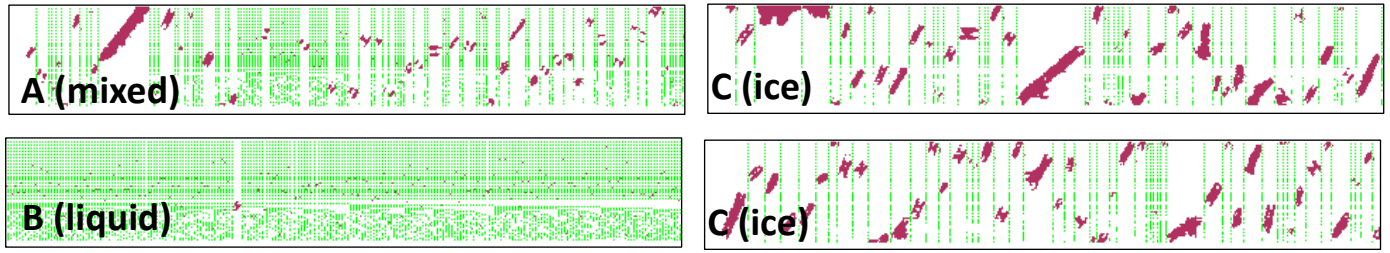
2. Evaluation of global climate model simulations of ice and mixed-phase clouds often relies on spaceborne observations



NSF SOCRATES campaign



SOCRATES RF03



Yang, C.A.*, M. Diao, A. Gettelman, K. Zhang, J. Sun, W. Wu, G. McFarquhar, Ice and Supercooled Liquid Water Distributions over the Southern Ocean based on In Situ Observations and Climate Model Simulations, Journal of Geophysical Research: Atmosphere, 126, e2021JD036045. https://doi.org/10.1029/2021JD036045, 2021.

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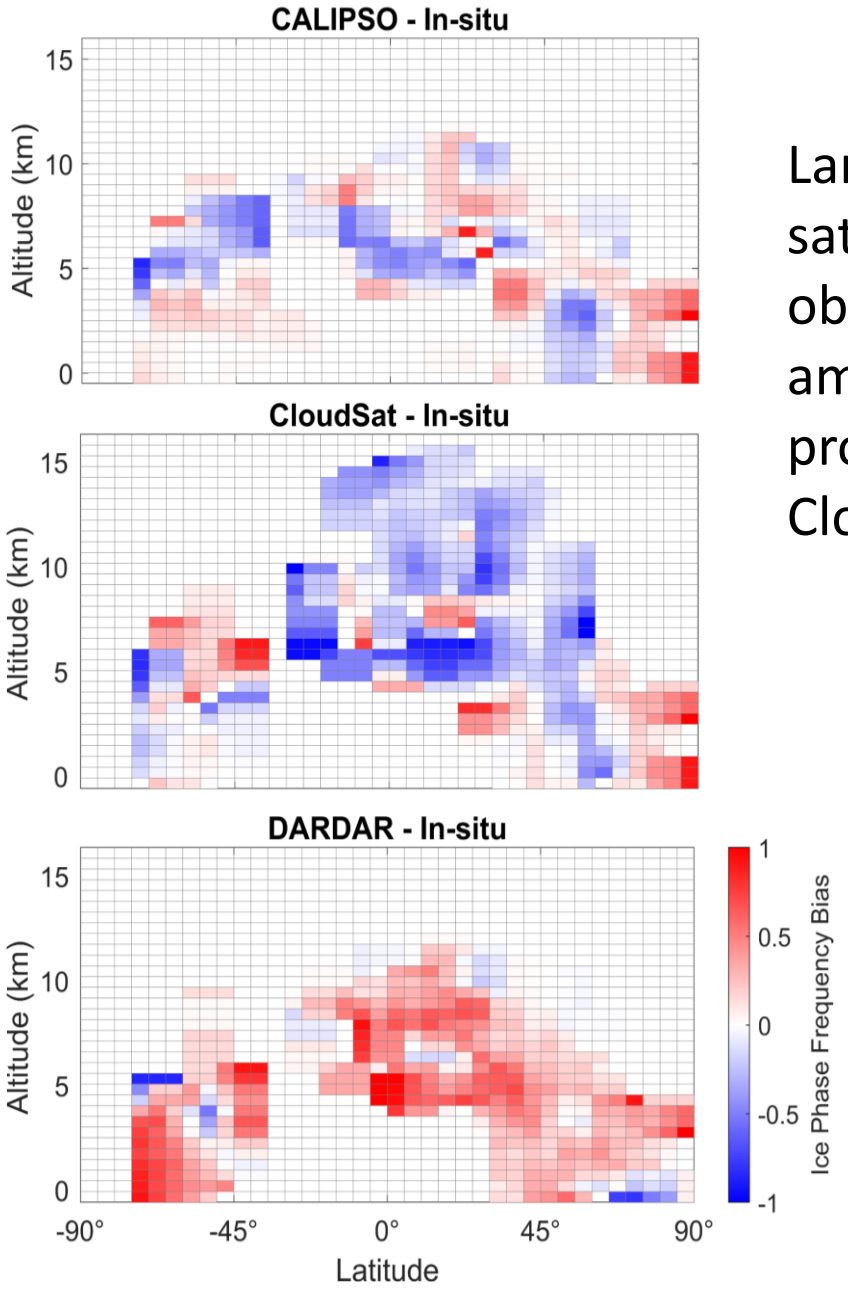
Topics of this presentation:

(1) Hemispheric comparisons of three cloud thermodynamic phases

(2) Comparisons with E3SMv1 and v2

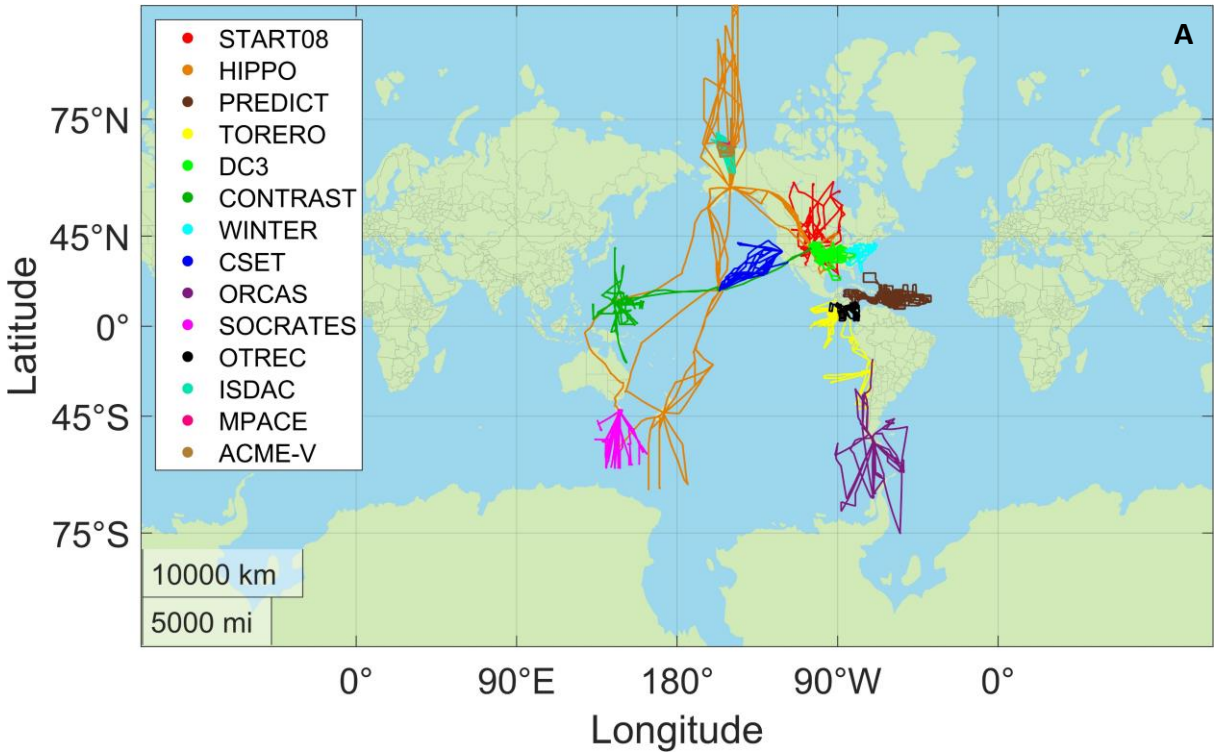
(3) Secondary ice production in observations and simulations

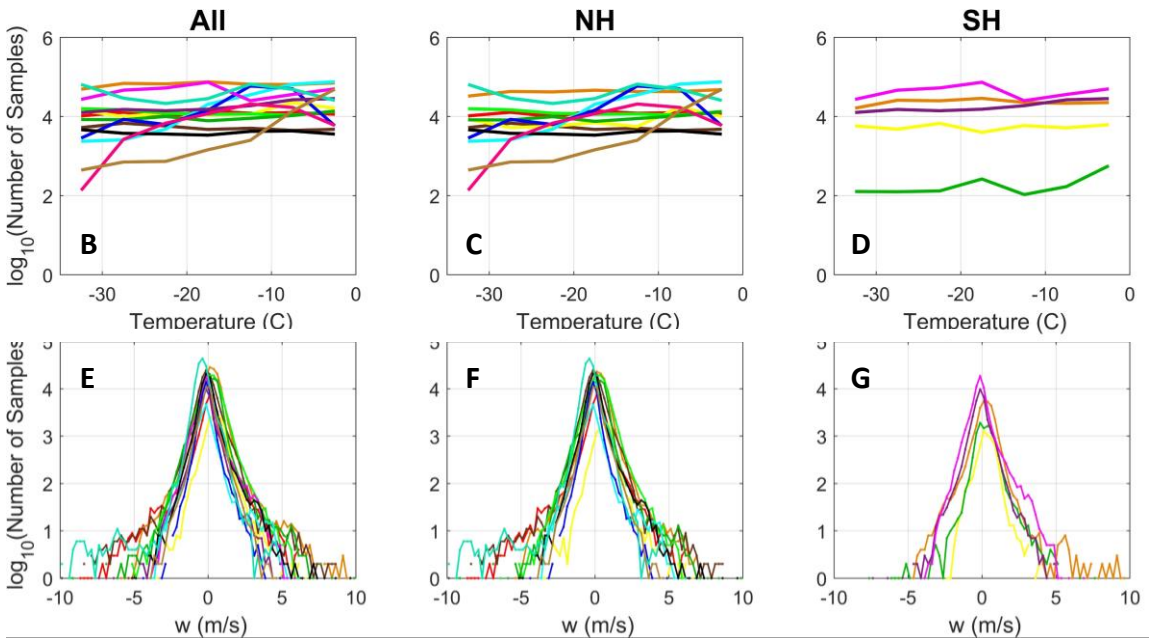


Large differences between satellite and in-situ observations, as well as among three satellite products – CALIPSO, CloudSat and DARDAR

Wang, D., M. Diao & C.A. Yang, to be submitted

Developing A Global-Scale In-Situ Observation Dataset



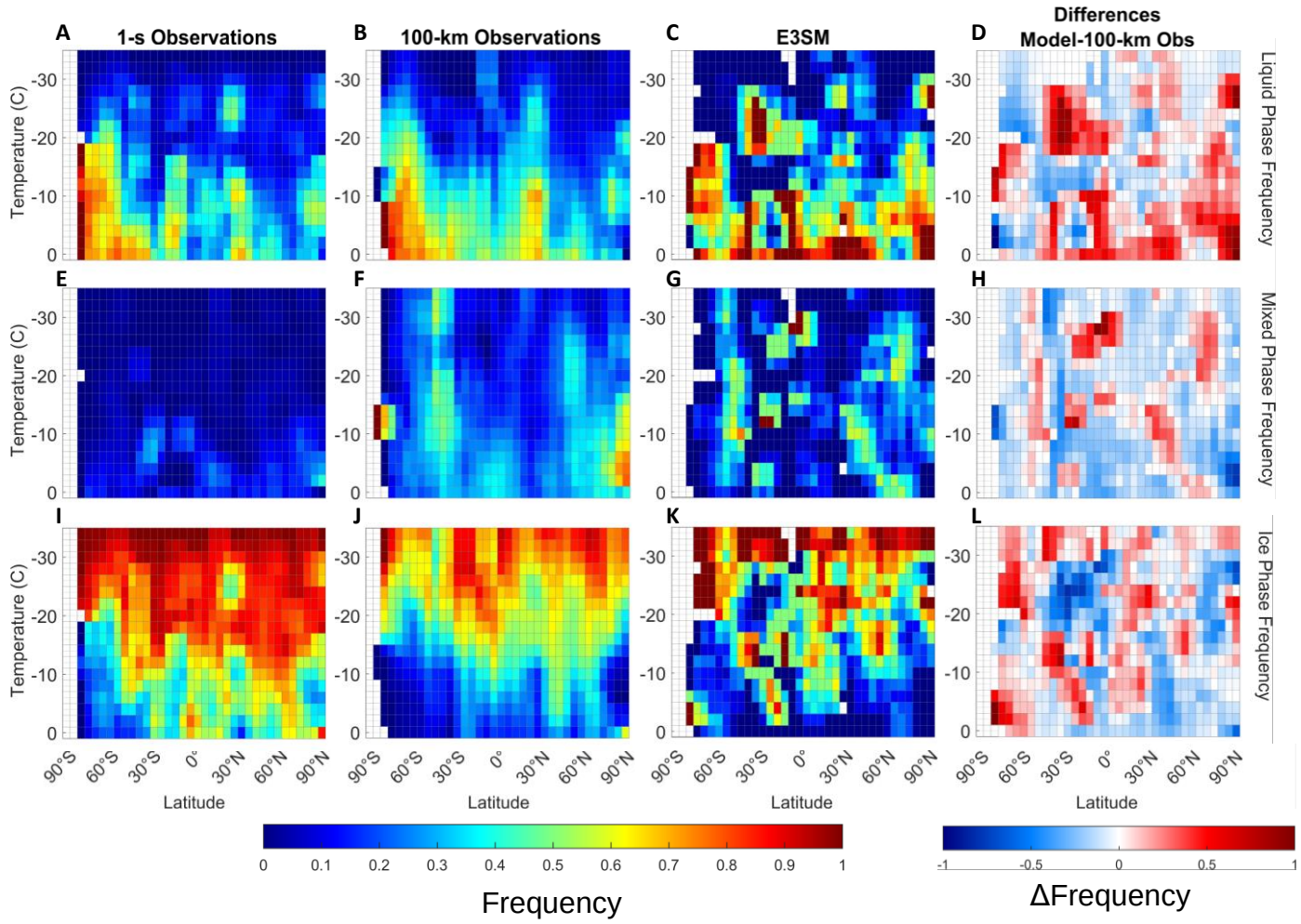


- Aircraft-based in-situ observations at 1 Hz resolution

- A total of 14 campaigns: 11 NSF flight campaigns and 3 DOE campaigns (M-PACE, ISDAC, ACME-V)

- Typical cloud probes include Fast-2DC, CDP, 2DS and FSSP

Hemispheric Comparisons of Cloud Phase Frequencies



Liquid phase freq

Mixed phase freq

Ice phase freq

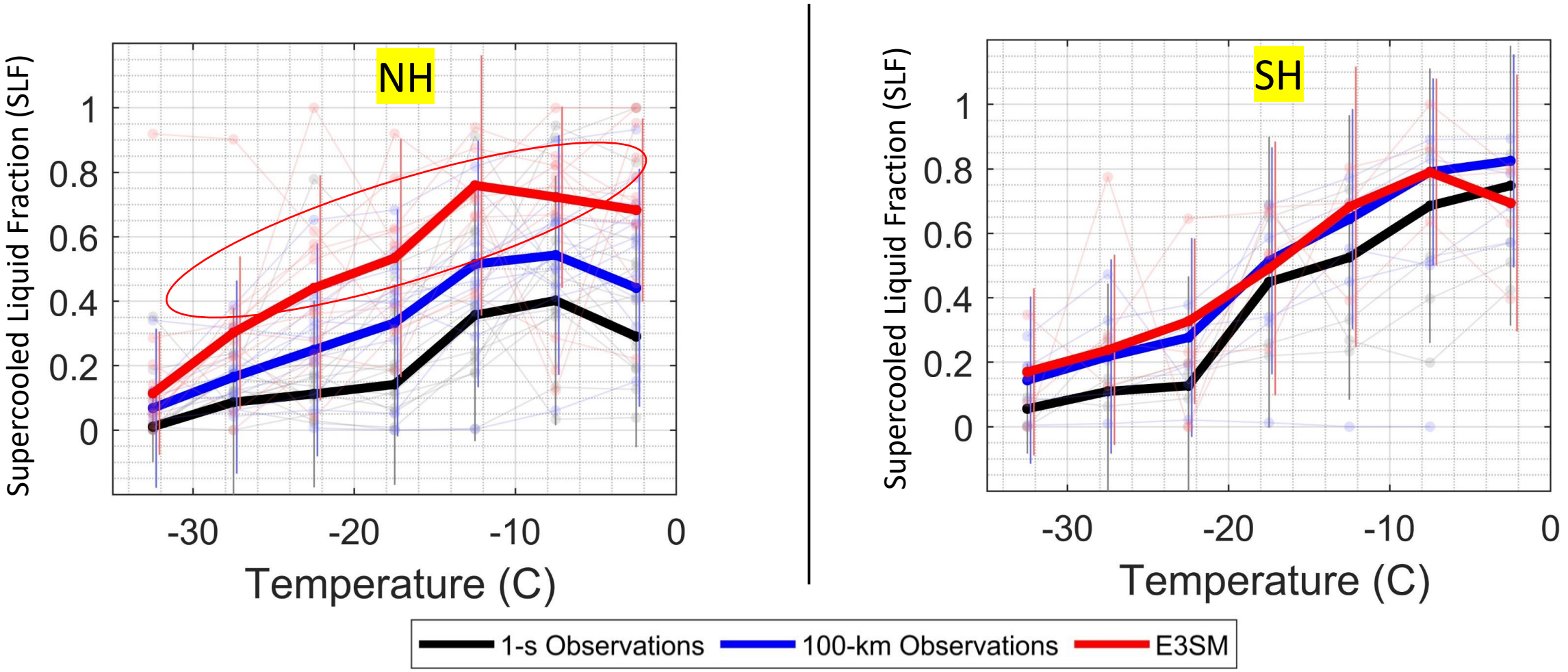
North Hemisphere (NH);
Southern Hemisphere (SH)

1. A spatial-aware comparison between in-situ observations and E3SMv2/EAMv2 simulations

2. Model simulations miss the hemispheric differences of cloud phase frequencies for all three phases

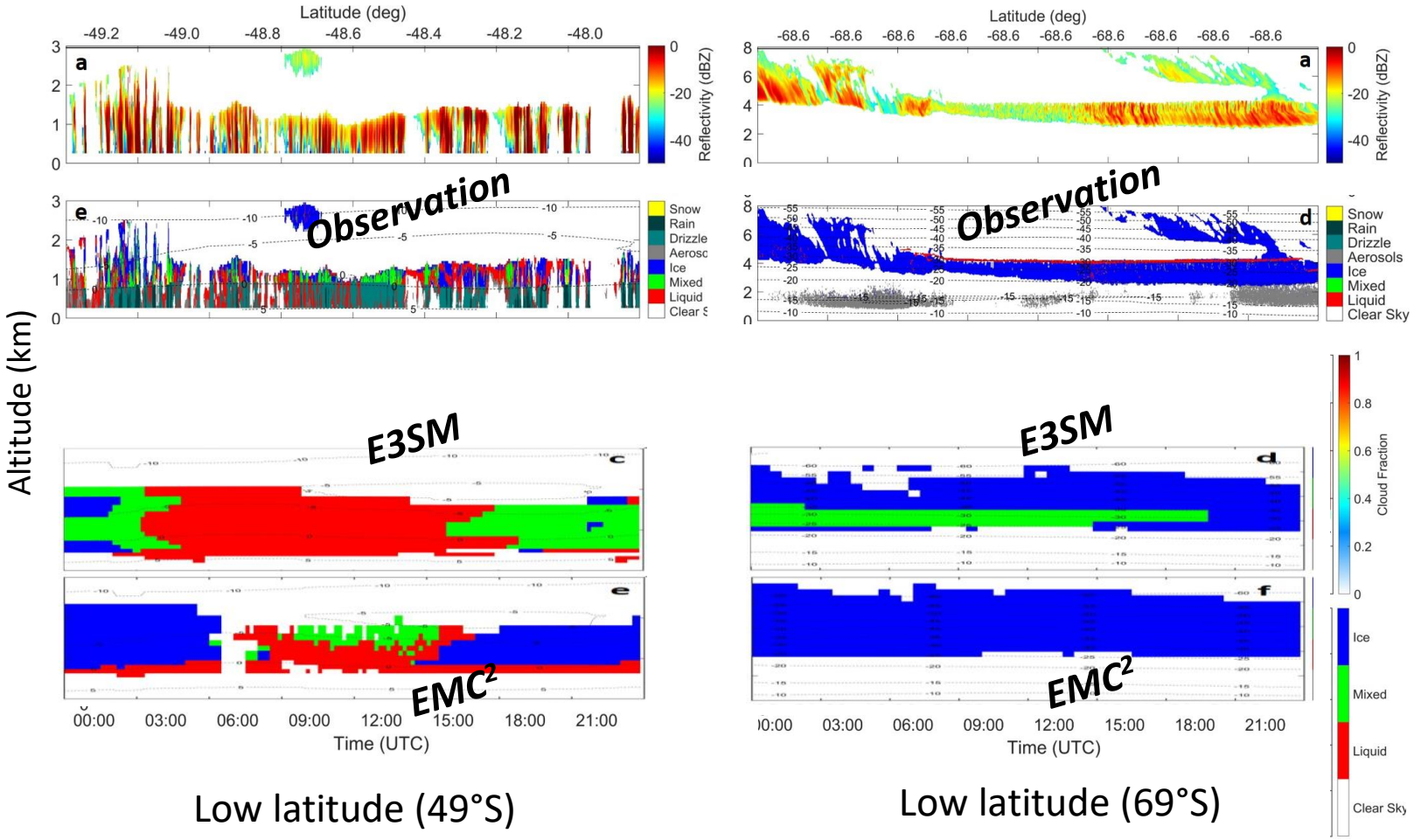
Yang, Diao, et al., in prep

Supercooled Liquid Fraction (SLF) in the Two Hemispheres



- SLF is calculated as liquid water content / (ice water content + liquid water content) at 1 Hz, then average in each temperature bin
- In-situ observations show higher SLF in the SH than NH.
- E3SMv2 shows higher SLF in the NH than SH.

Spatial Heterogeneities of Cloud Phases in DOE MARCUS Campaign



Low latitude (49°S)

Low latitude (69°S)

Ice-topped clouds, with pockets of ice and liquid below 0°C

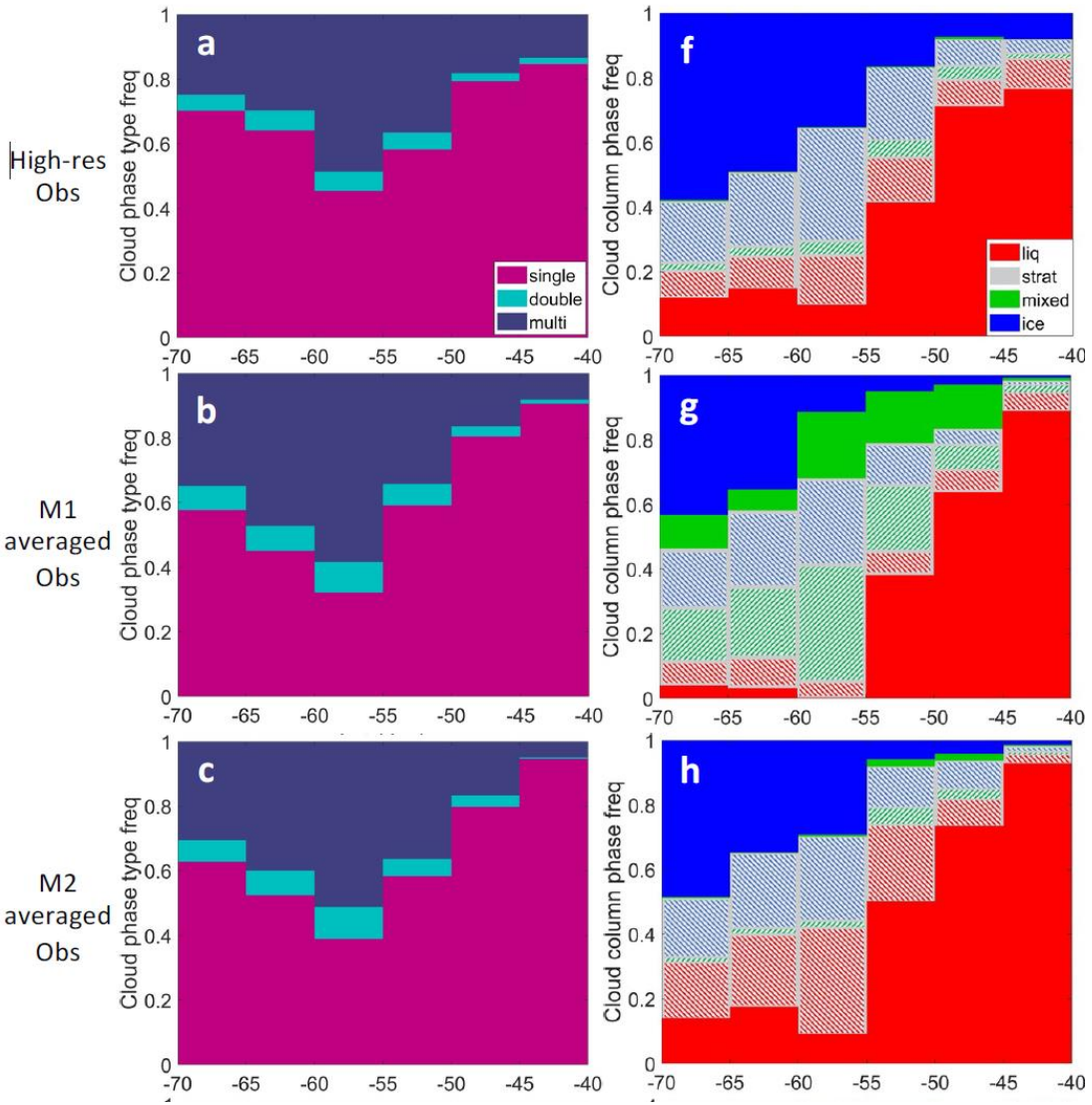
Thin liquid cloud top with streaks of ice layers below

Using lidar & radar to identify cloud phases in MARCUS campaign

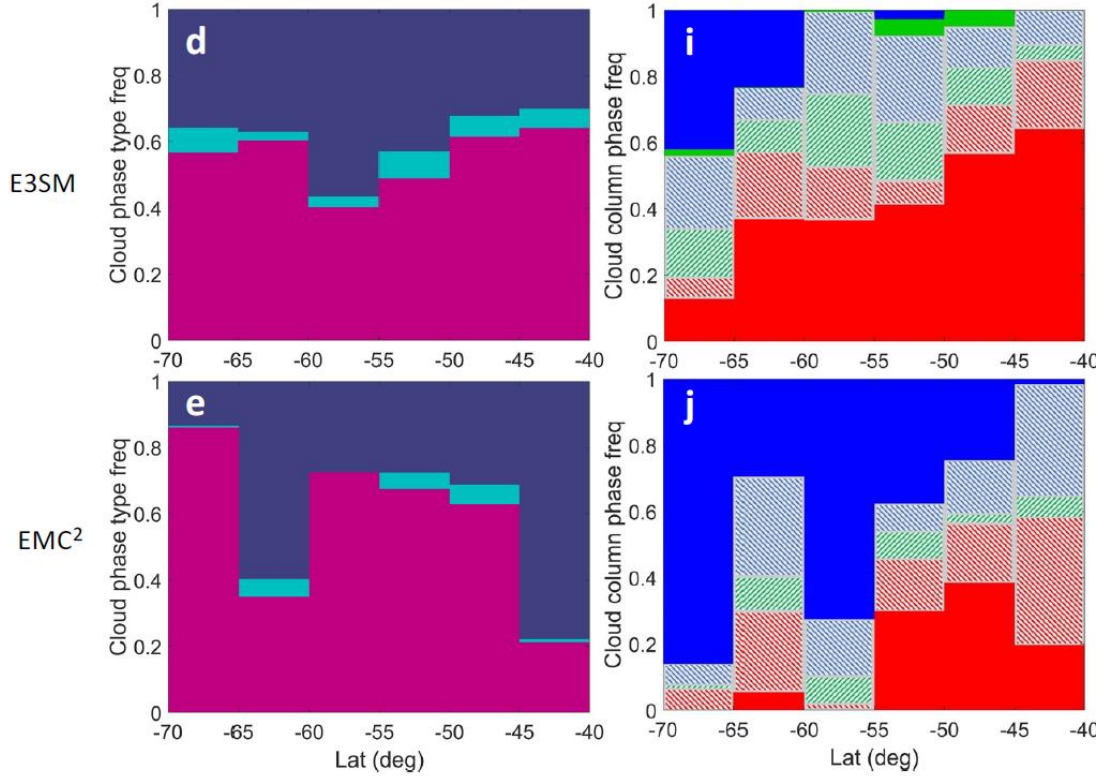
Spatial heterogeneity – which type of ice phase cloud column does E3SM model mis-represent?

Desai, N.*, M. Diao, Y. Shi, X. Liu, and I. Silber. Ship-based Observations and Climate Model Simulation of Cloud Phase over the Southern Ocean, Journal of Geophysical Research: Atmospheres, 128, e2023JD038581. https://doi.org/10.1029/2023JD038581, 2023.

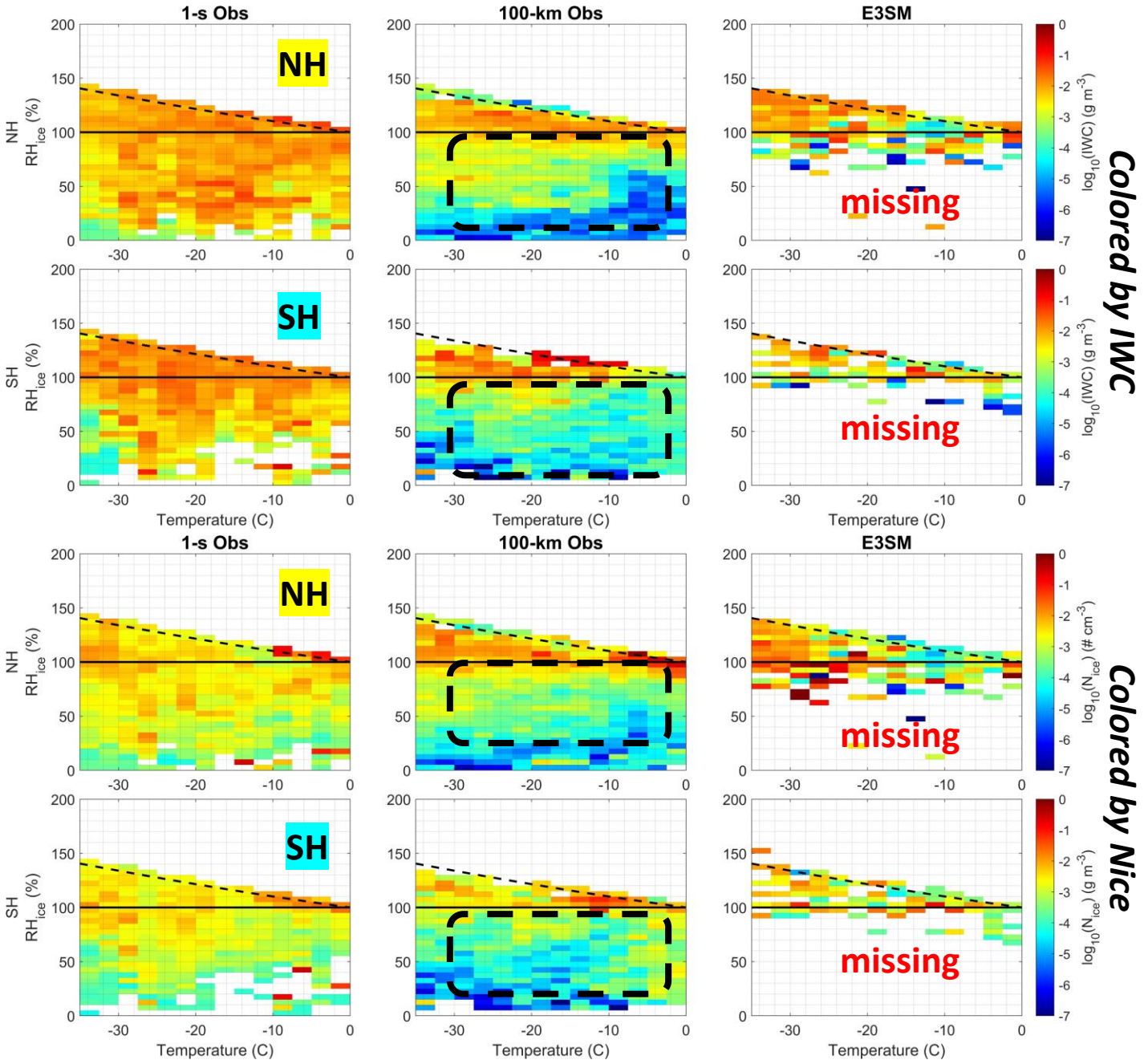
Impacts of Spatial Heterogeneities on Cloud Phase Frequencies



1. E3SMv1/EAMv1 shows similar frequency of single-phase or multi-phase cloud columns
2. Model mostly mis-represent pure ice phase columns, indicating the lack of spatial heterogeneity is *not* the main reason for this mode bias.



Desai et al. 2023



Secondary ice production processes

1. At ice sub-saturated conditions, observations show high IWC and high Nice in NH, indicating secondary ice production (SIP)

2. E3SMv2/EAMv2 model do not show much ice phase at this condition, potentially underestimating ice phase due to SIP

3. Model shows better agreement near ice saturation.

Summary

Hemispheric comparisons of three cloud phases:

- Observations show higher ice phase freq in NH, and higher SLF in SH
- E3SMv2/EAMv2 shows opposite hemispheric differences for both

Diagnosis of the reasons behind underestimation of ice phase in simulations

- Spatial heterogeneity: E3SMv1/EAMv1 underestimates ice phase especially when the entire cloud column is ice
- Thermodynamics: E3SMv2/EAMv2 underestimates ice phase especially for sub-saturated condition, indicating **underestimation of SIP processes**, while the simulated near ice saturation is closer to the observations.