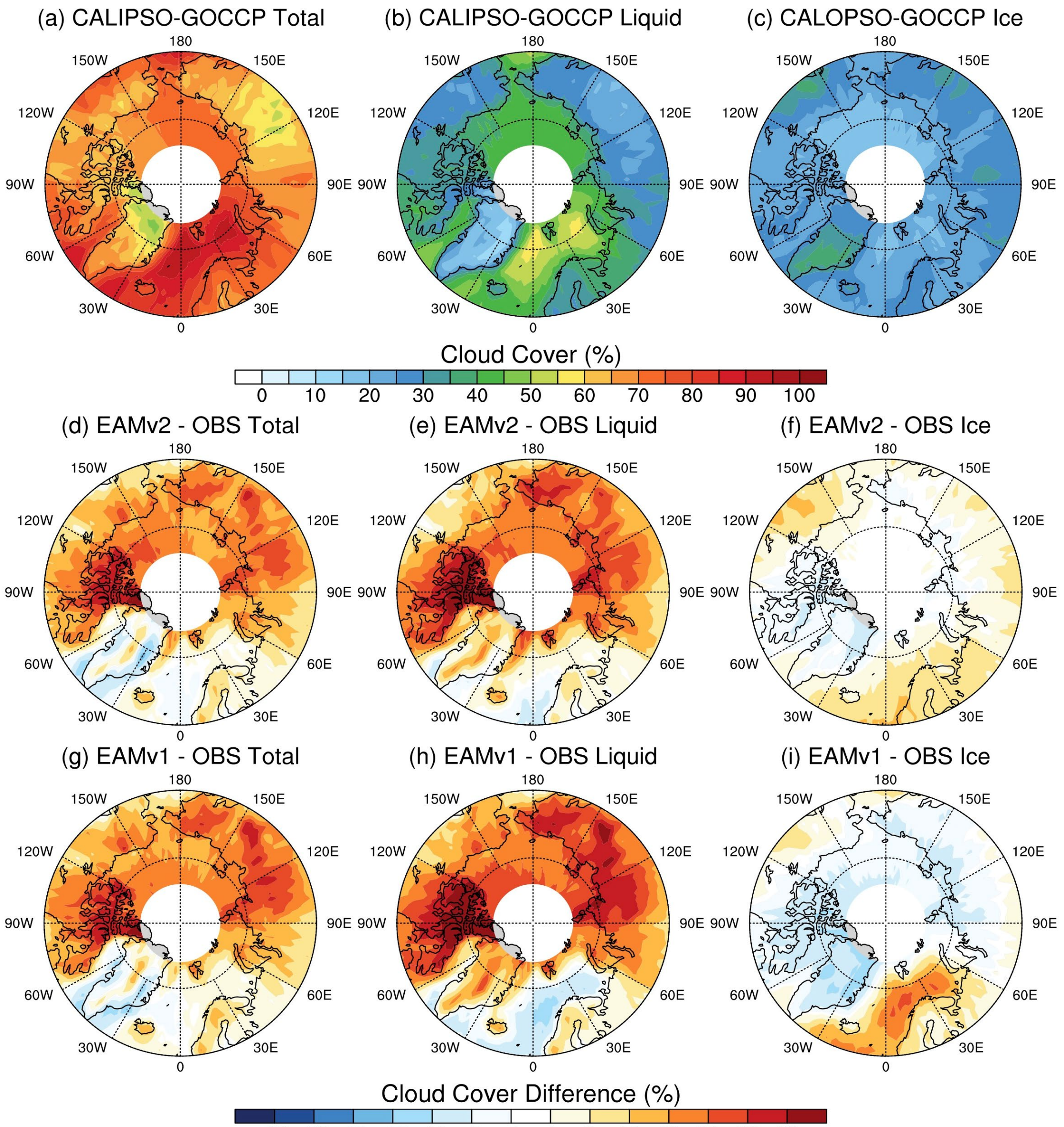
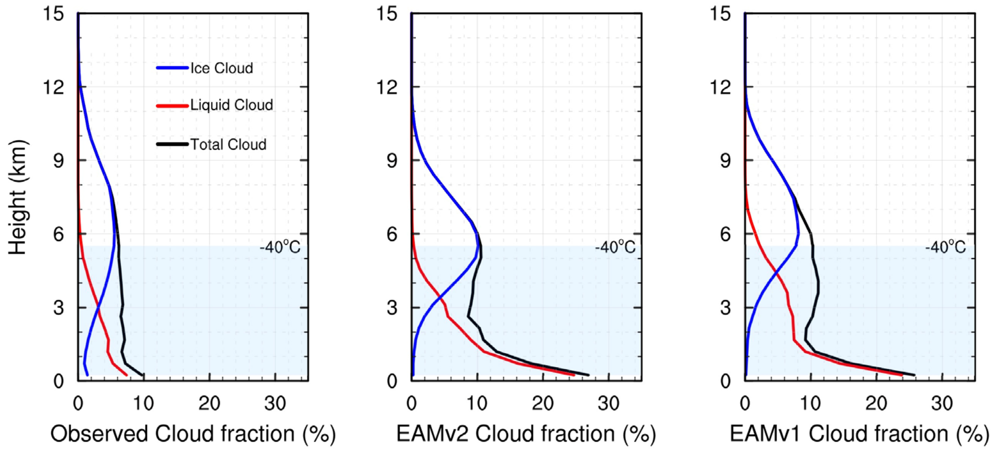
Importance of supercooled liquid water for aerosol indirect forcing and cloud feedback

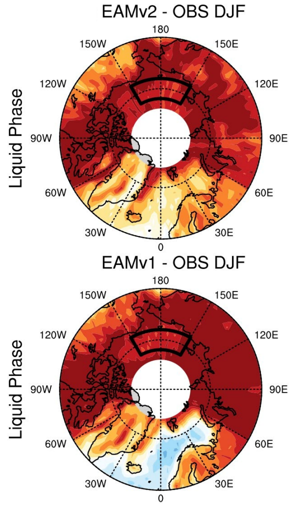
Xiaohong Liu[1], Xi Zhao[1], Meng Zhang[2], Shaocheng Xie[2], Mark Zelinka[2], Stephen Klein[2], Po-Lun Ma[3]

[1]Texas A&M University, [2]Lawrence Livermore National Laboratory, [3]Pacific Northwest National Laboratory

E3SM Arctic Cloud Phase Evaluation with CALIPSO-GOCCP



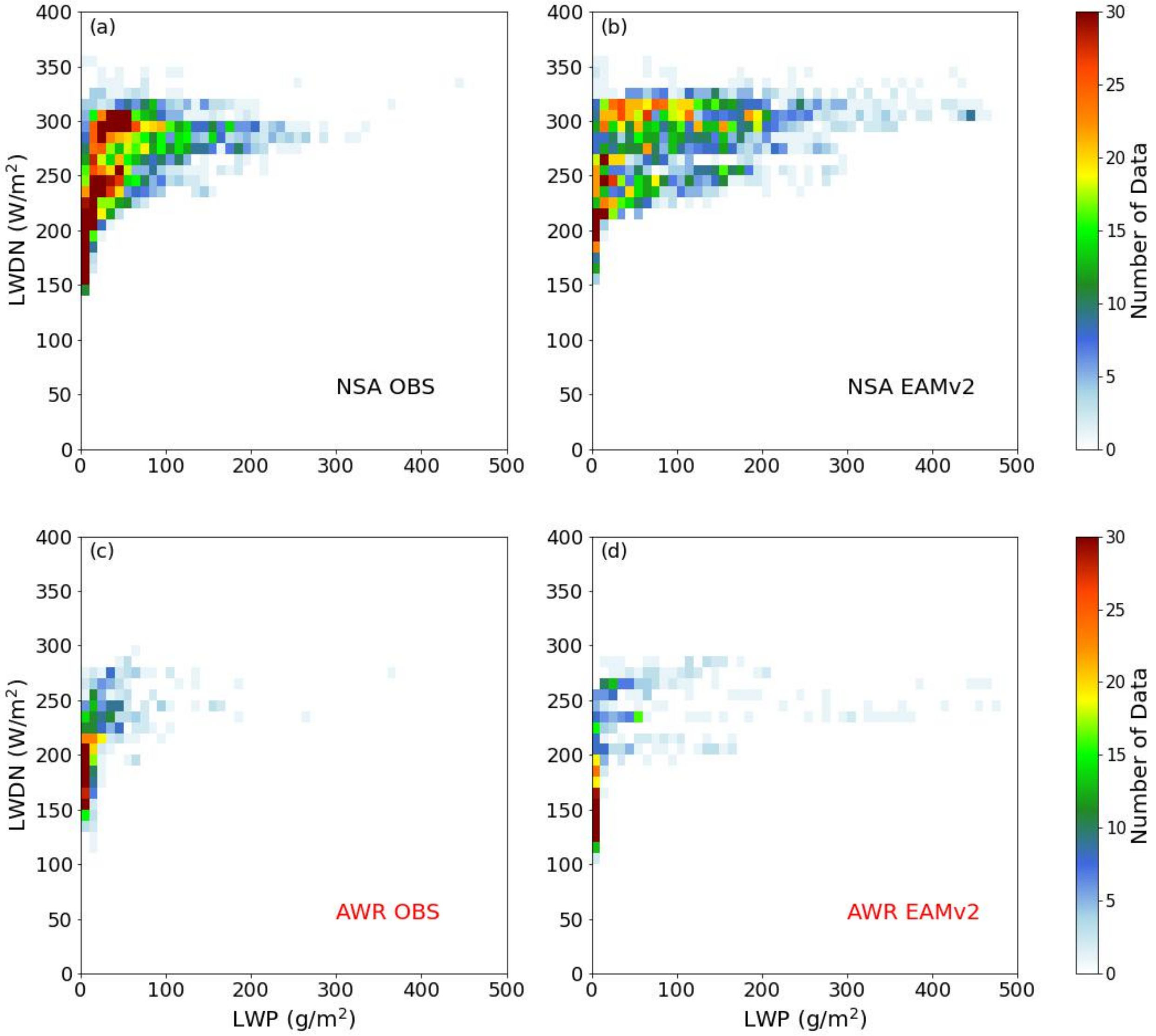




- Overestimated total cloud cover in the Arctic is mainly caused by liquid phase clouds, which are mostly at altitudes below 3km.

Zhang et al. (2022). JGR (in press)

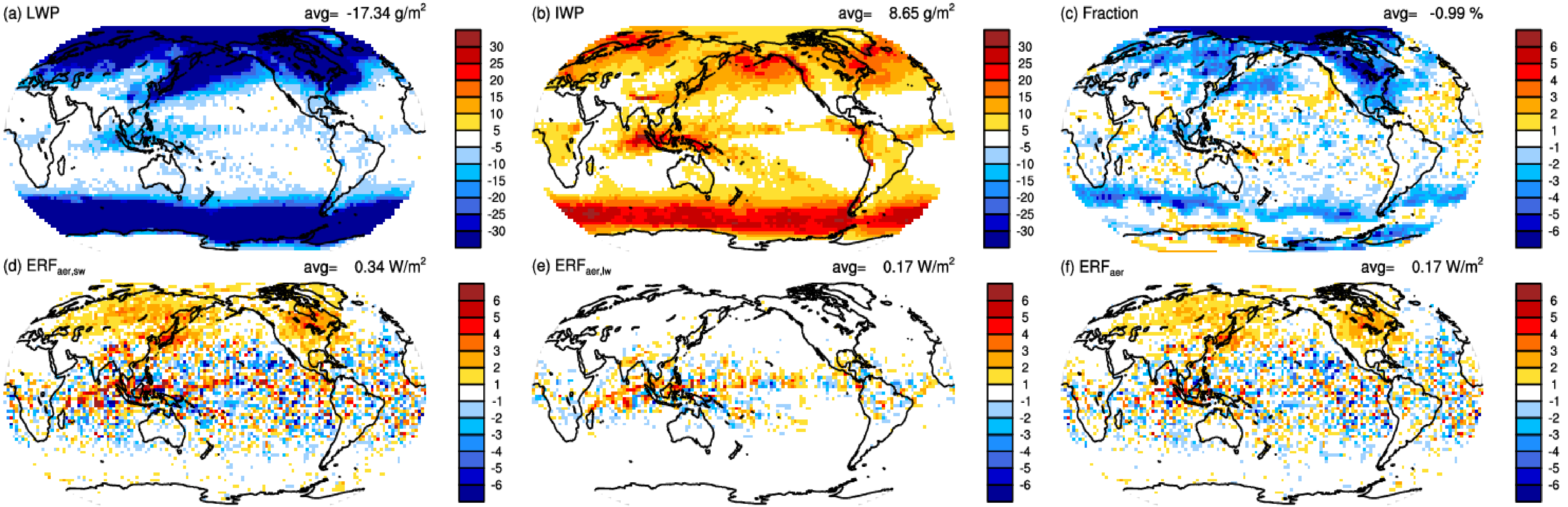
E3SM cloud liquid water evaluation with ARM data at Utqiagvik (NSA) and McMurdo (AWR)



- Simulated stratiform mixed-phase clouds (SMPCs) are temporally collocated with ARM observed SMPCs at both sites;
- The model overestimates occurrence of large LWP values (> 200 g/m^2) which leads to more occurrence of large downwelling LW radiation at surface

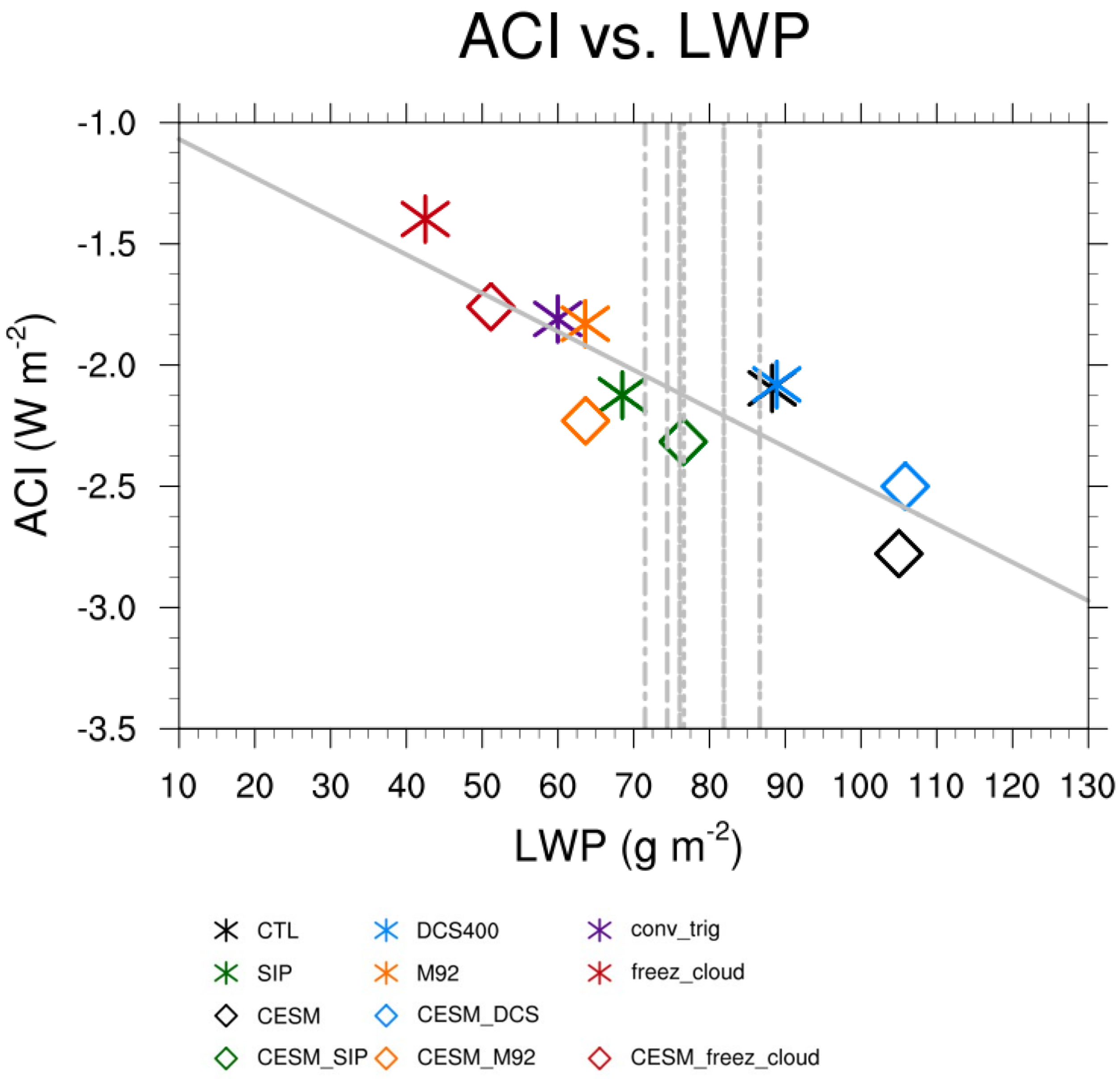
Zhang et al. (2022) to be submitted

Importance of supercooled liquid water for ACI



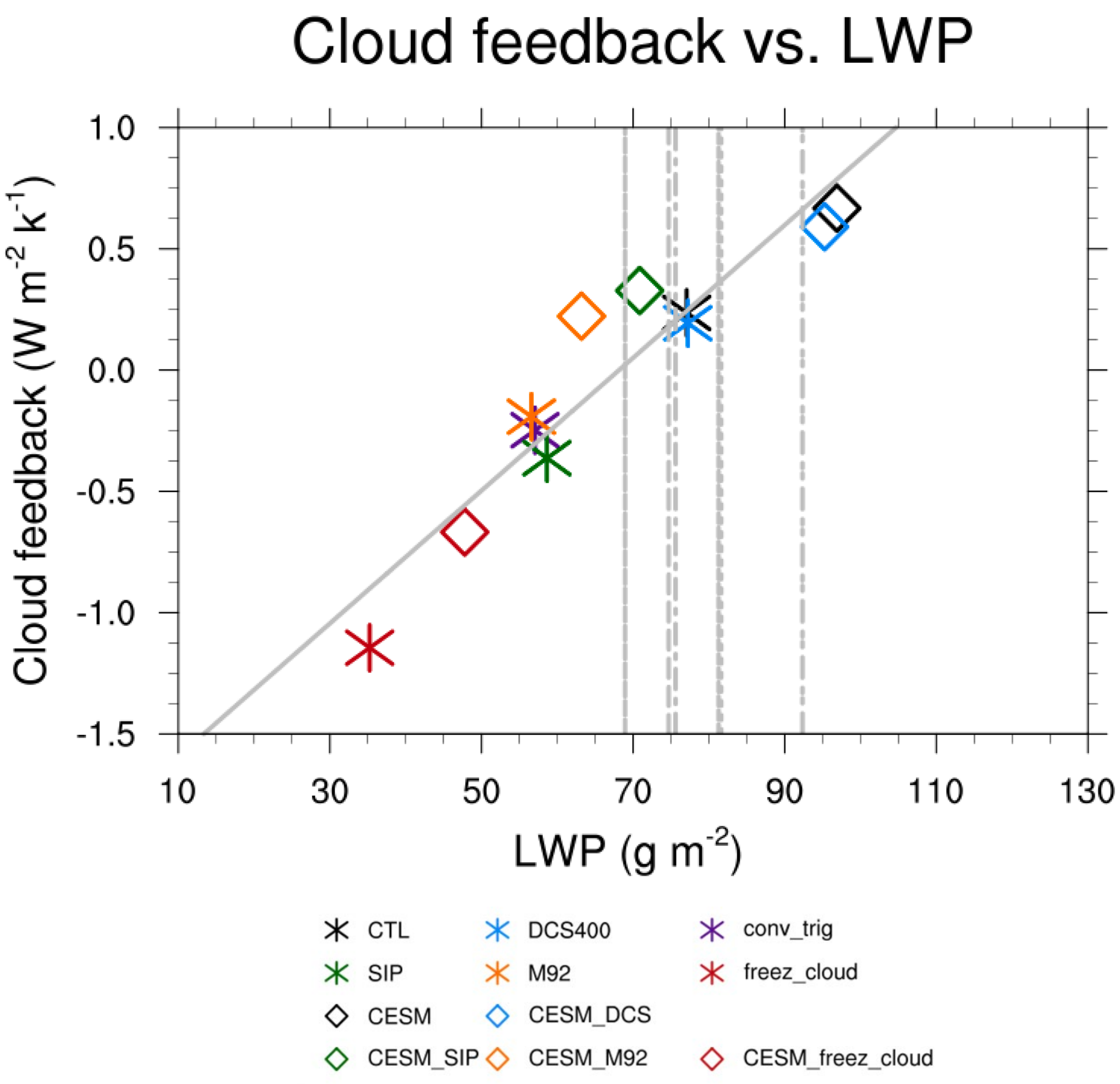
Impacts of freezing supercooled liquid (< -5°C) on (a) LWP, (b) IWP, (c) cloud fraction, (d) $ERF_{aer,sw}$, (e) $ERF_{aer,lw}$, and (f) ERF_{aer}, simulated by E3SMv2.

LWP and ACI over NH (30-90oN)



- **ACI is linearly proportional to LWP**

Cloud feedback and LWP over SH (30-90S)



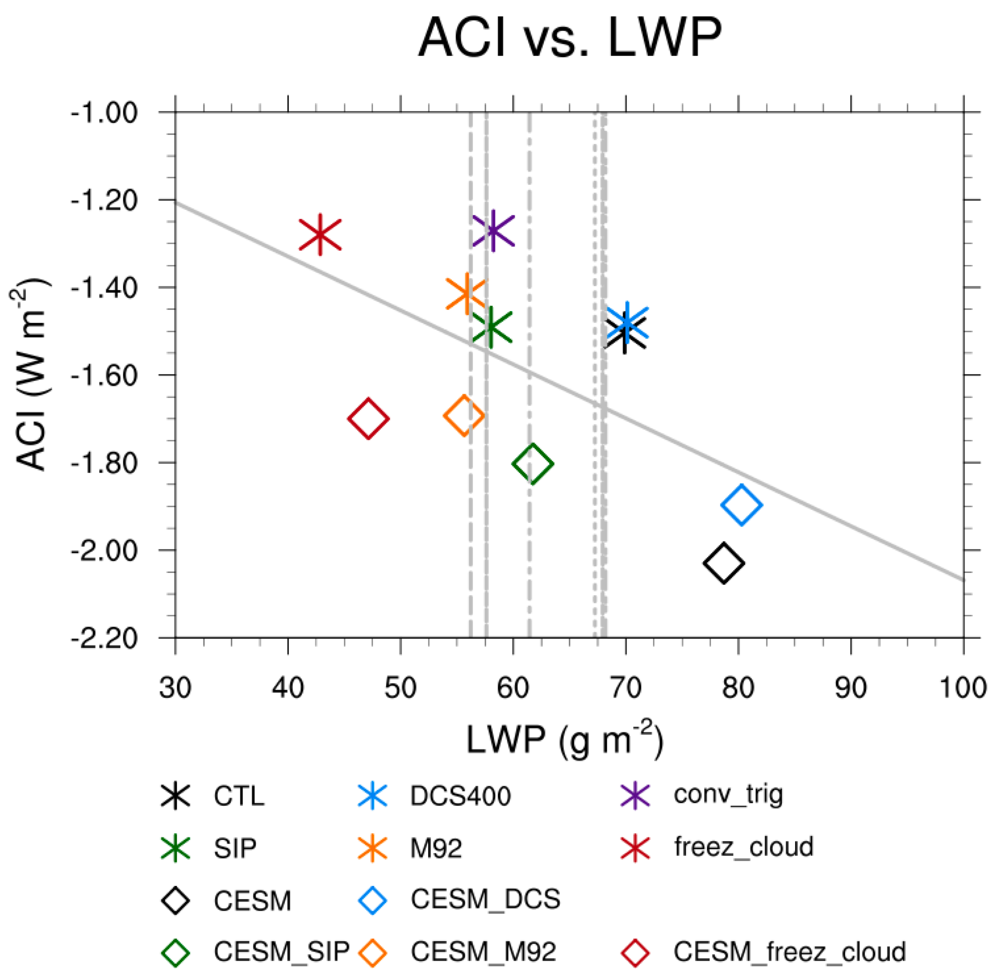
Cloud feedback and LWP over SH (30-90 S) have a good correlation, consistent with previous studies (e.g., Tan et al. 2016), but we use LWP instead of cloud phase.

Summary

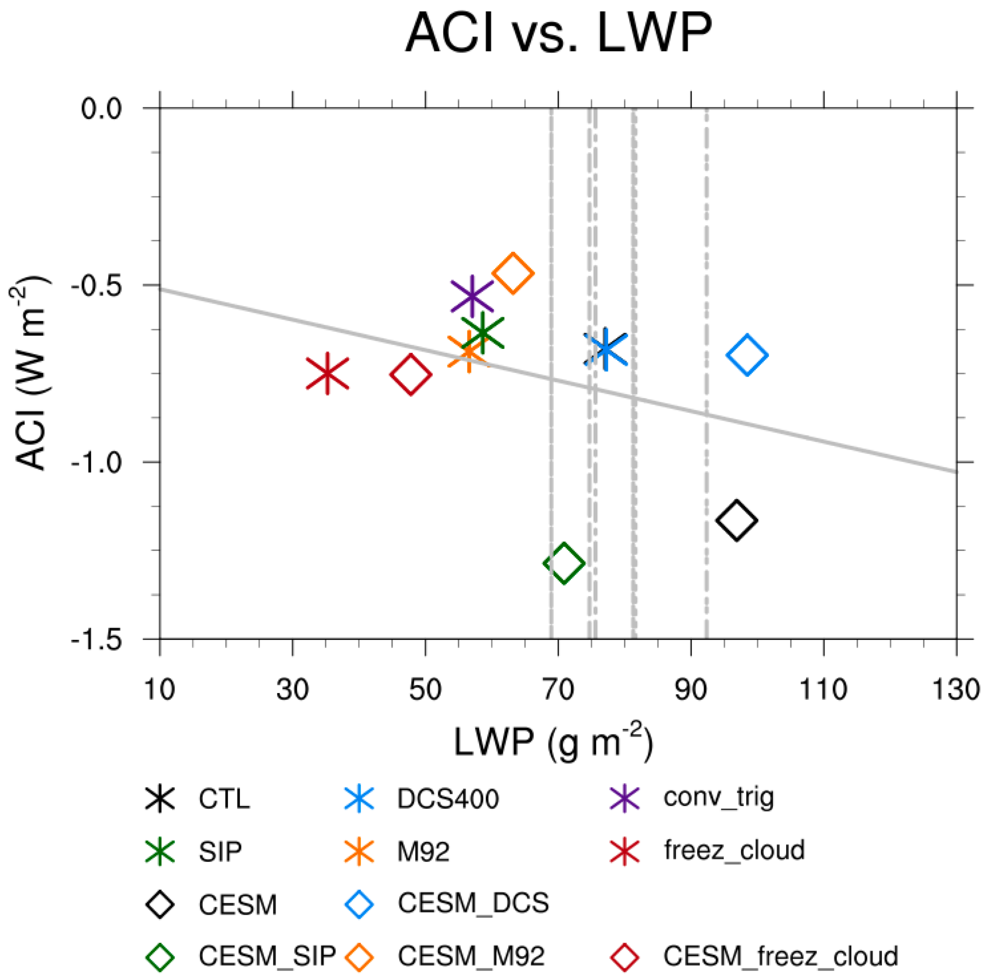
- Compared to the CALIPSO-GOCCP and ARM data, E3SM model overestimates supercooled liquid clouds at high latitudes ⟹
    - Too strong aerosol-cloud interactions (ACI)
    - Too strong cloud feedback, and higher climate sensitivity
- Further improvements of cloud and aerosol processes in E3SM for better simulation of supercooled liquid clouds
    - Secondary ice production

ACI and LWP

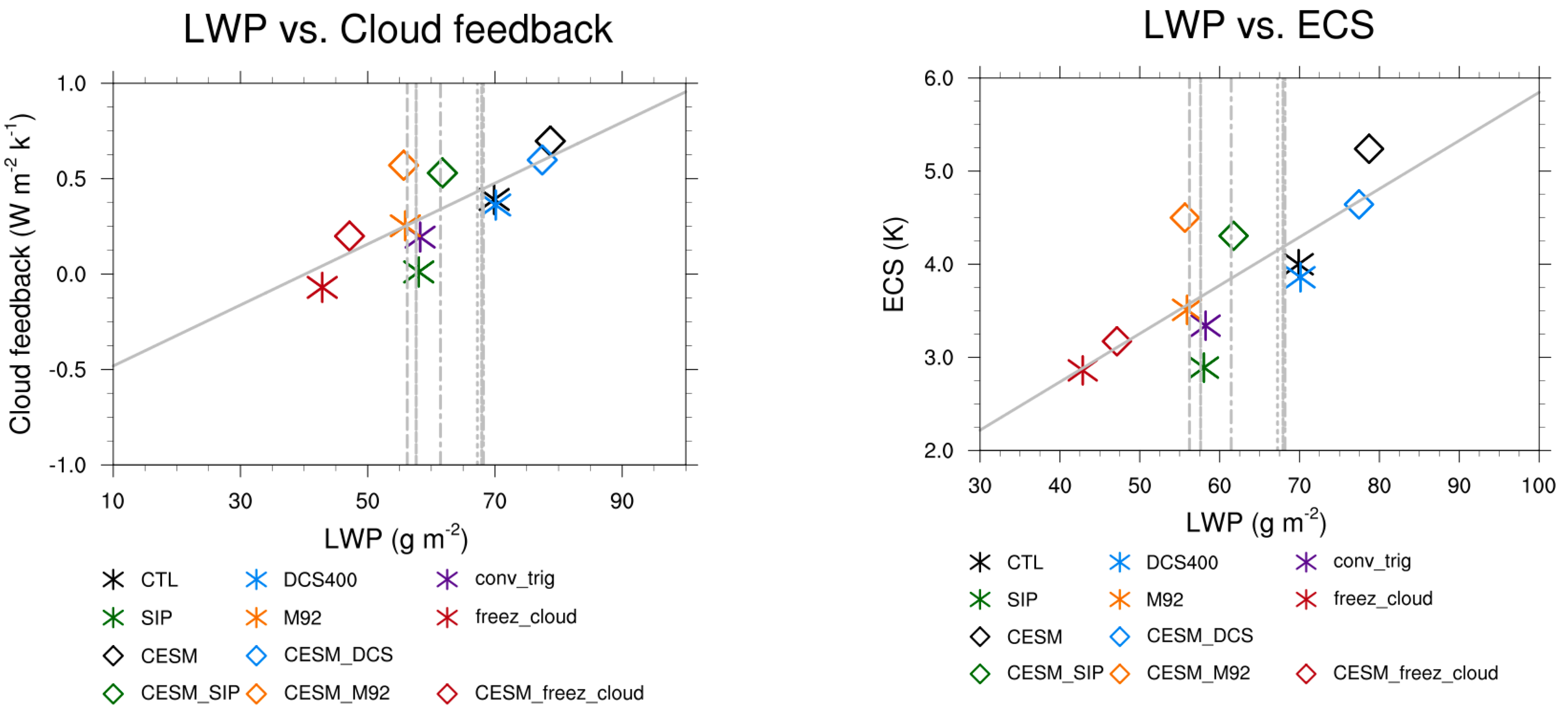
Global



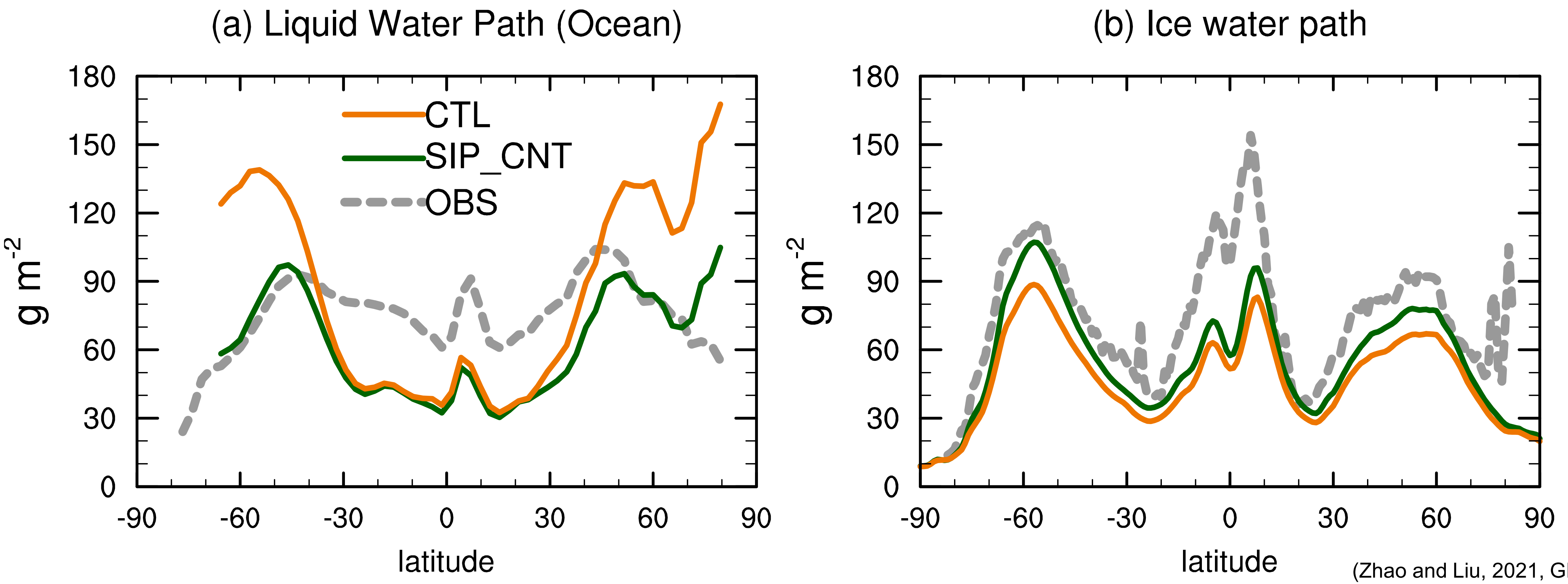
SH: 30-90S



Cloud feedback and LWP (global)



Impact of secondary ice production (SIP)



(Zhao and Liu, 2021, GRL)

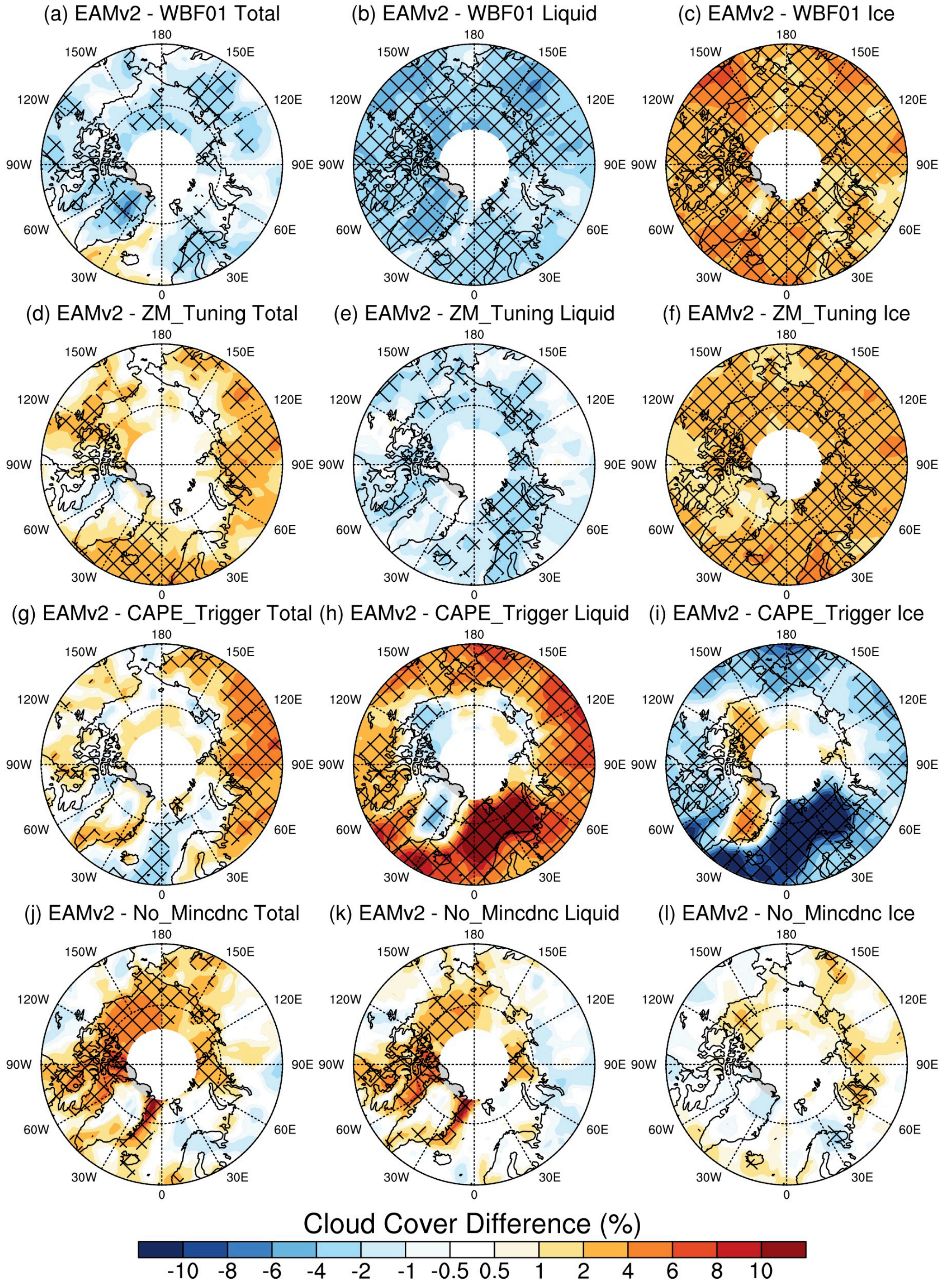
- Global LWP reduced by **–22%** due to SIP
- SWCF, LWCF, and net CF changed by 2.1, −1.0, and 1.1 W m^{-2}, respectively

- ECS reduced from **5.5** to **4.4** K
- ACI reduced from -2.0 to -1.8 W m^{-2}

Understanding Model Behavior Changes

Model Experiment	Model Setup
WBF01	Set the scaling factor on the WBF process back to v1
ZM_Tuning	Set tuning parameters related with deep convection to default values used in v1
CAPE_Trigger	Turn off the new dCAPE-ULL trigger and use the default CAPE trigger in v1
No_Mincdnc	Remove the minimum cloud droplet number concentration (CDNC) of 10 cm^{-3}

- Tunings in the WBF process and ZM convection scheme increase simulated ice cloud and decrease liquid cloud in the Arctic.
- Using the dCAPE-ULL trigger in EAMv2 offsets the increased cloud ice, but it is responsible for the improved cloud phase over Norwegian Sea and Barents Sea.
- The minimum CDNC also increases simulated liquid cloud over the Arctic Ocean, while it has minimal influence on cloud ice.



Antarctic Cloud Phase Evaluation with CALIPSO-GOCCP