Increased cloud liquid water in climate models enhances both aerosol indirect forcing and cloud radiative feedback

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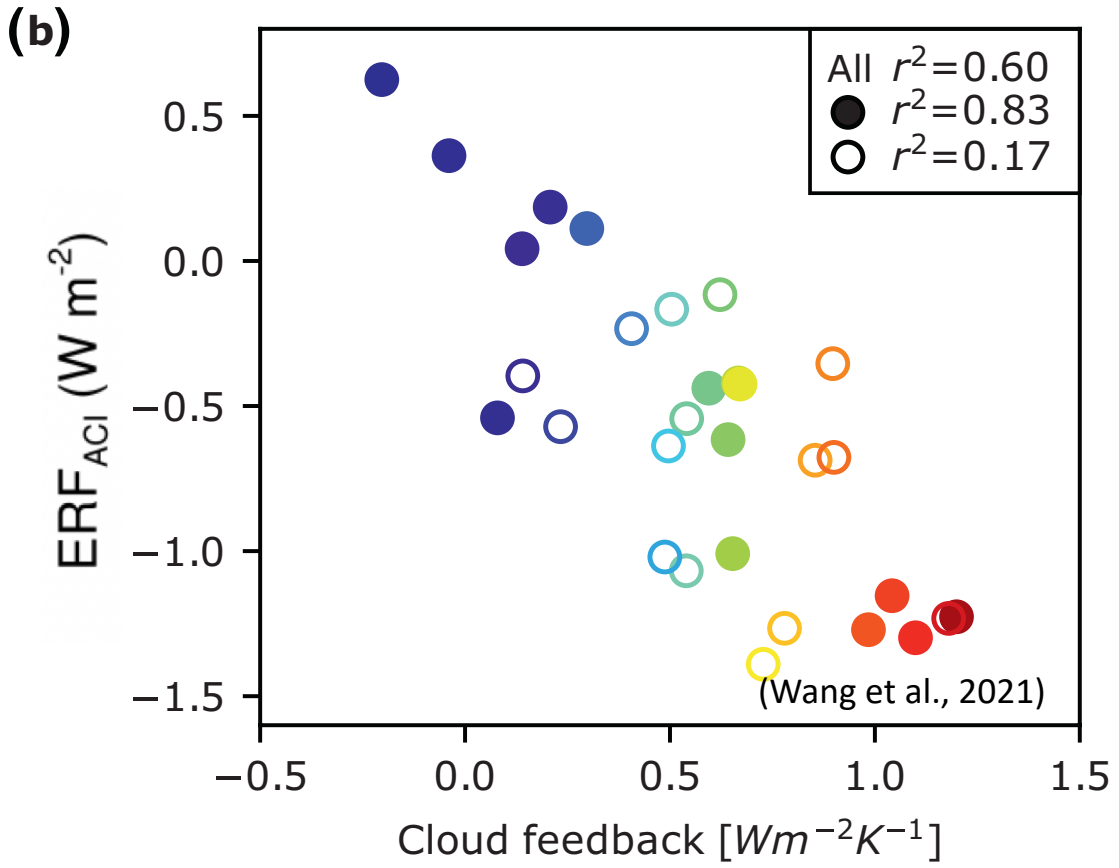
Motivation



ERF$_{ACI}$:

effective radiative forcing of anthropogenic aerosols

Cloud feedback:

the response of clouds to the climate change.

- Climate model with a stronger positive cloud feedback also has a stronger cooling from aerosol indirect forcing due to anthropogenic aerosols
- Why?

Experiments

Purpose: perturbed the cloud glaciation--- how the ERF_{ACI} change

Less liquid
More ice

Model Experiment	Model Setup
CTL	Default **CESM2 and E3SM_V2** model
DCS	Same as CTL, but set the threshold on cloud ice and snow autoconversion process from 195 μm to 400 μm.
ConvTrig	Same as CTL, but turn off the new trigger of convection and use the old trigger
SIP	Same as CTL, but add SIP from raindrops freezing breakup and ice-ice collisional breakup
M92	Same as CTL, but use Meyer et al. (1992) scheme for ice nucleation in mixed-phase clouds instead of CNT
FreezCloud	Same as CTL, but assume all condensation to be ice phase when cloud temperature is smaller than –5℃

Method

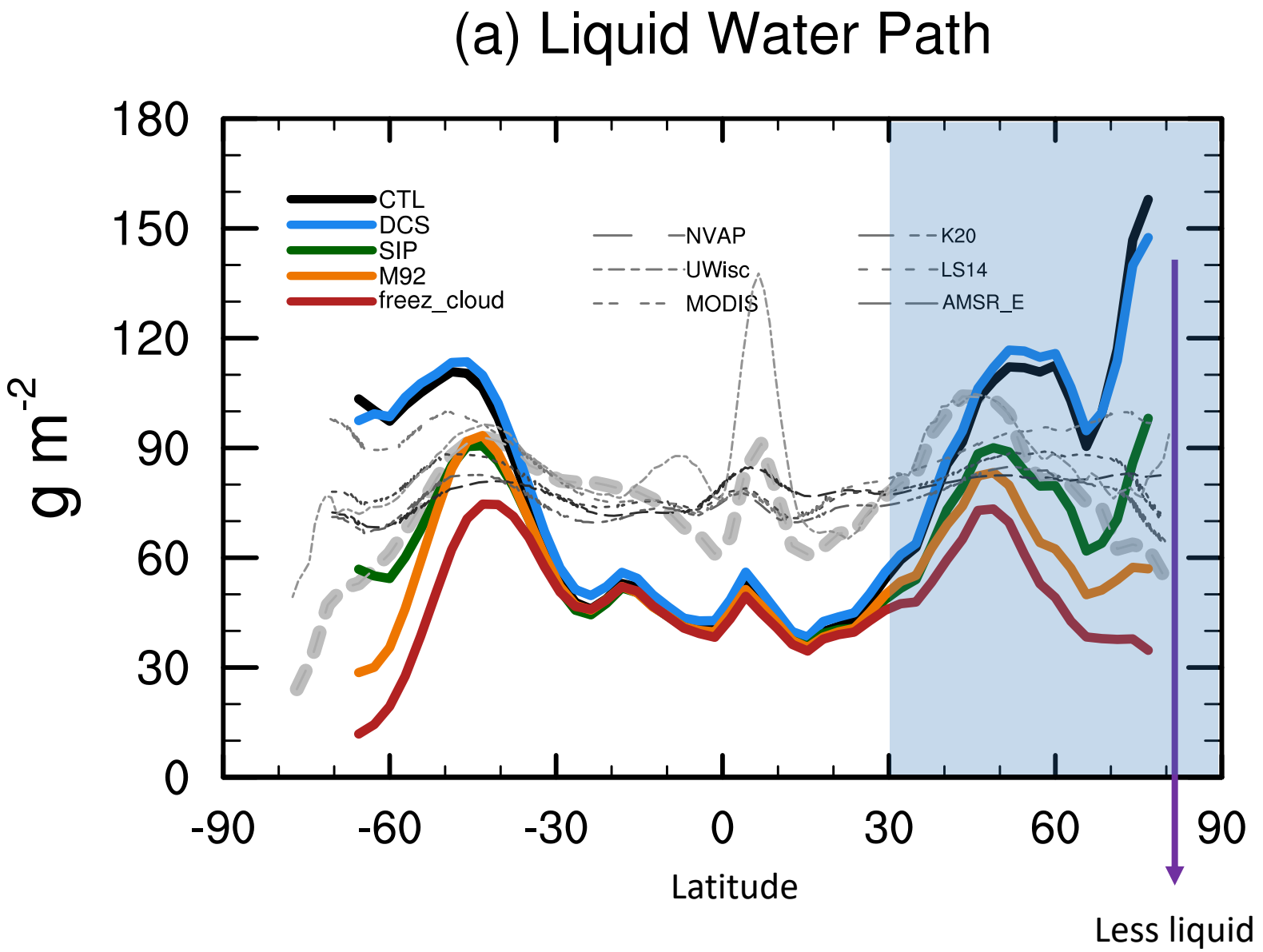
- **ERF_{ACI}:** effective radiative forcing of anthropogenic aerosols
  - **Calculation:** PD and PI experiments
    - For each simulation, adding a diagnostic calculation of radiation (F_{clean}) in which all the aerosols have been removed
    - Direct radiative forcing: $\Delta(F - F_{clean})$
    - Cloud radiative forcing: $\Delta(F_{clean} - F_{clear,\ clean})$ (Ghan, 2013)

- **Cloud feedback:** the response of clouds to the climate change.
  - **Calculation :**PD and PD+4K_SST experiments
    - Diagnostic package (Zelinka et al., 2021; 2022) to calculate cloud feedback components.

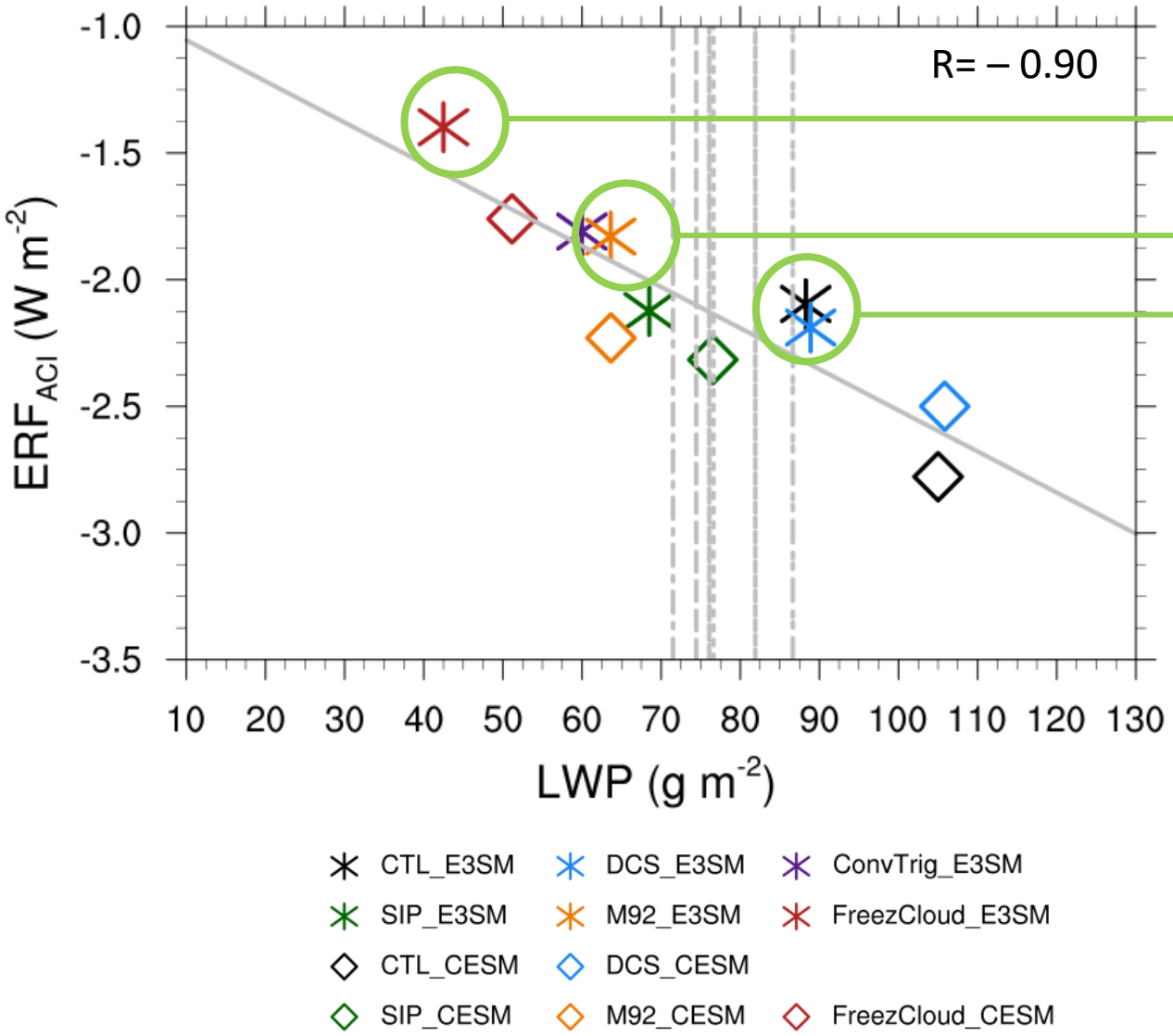
Outline

- Motivation
- Method
  - Model and Experiments
- Results
  - Relationship between LWP and ERF_{ACI}
  - Relationship between LWP and cloud feedback
  - Relationship between ACI and cloud feedback

LWP


(a) Liquid Water Path
180
150
120
90
60
30
0
g m-2
CTL
DCS
SIP
M92
freez_cloud
NVAP
UWisc
MODIS
K20
LS14
AMSR_E
-90
-60
-30
0
30
60
90
Latitude
Less liquid

LWP and ERF_{ACI} over NH (30-90°N)



Low liquid : FreezCloud

Medium liquid : M92

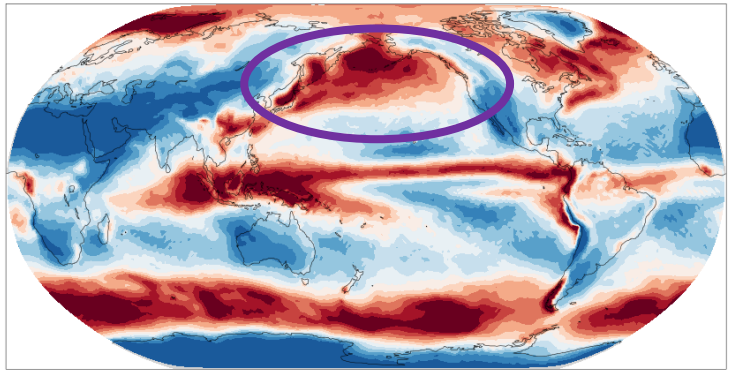
High liquid: CTL

- **ERF_{ACI} shift is linearly proportional to the change of LWP**

LWP and ACI over NH

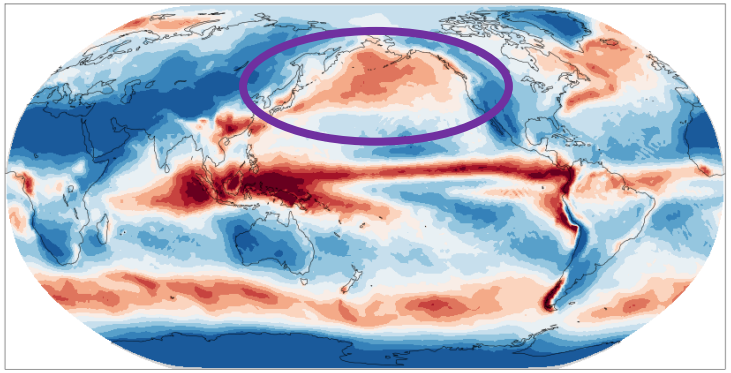
High liquid

LWP



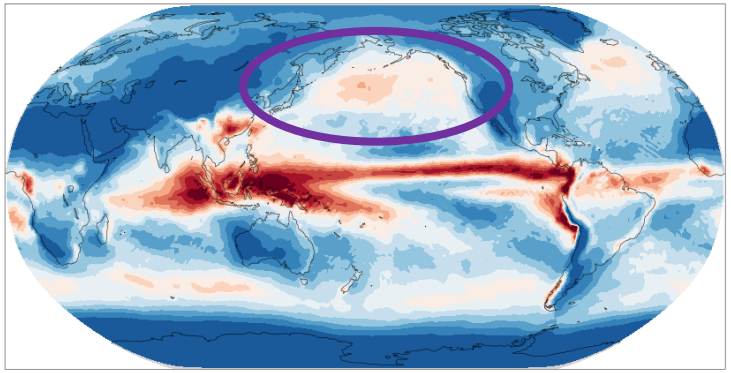
Medium liquid

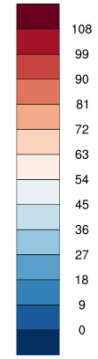
LWP



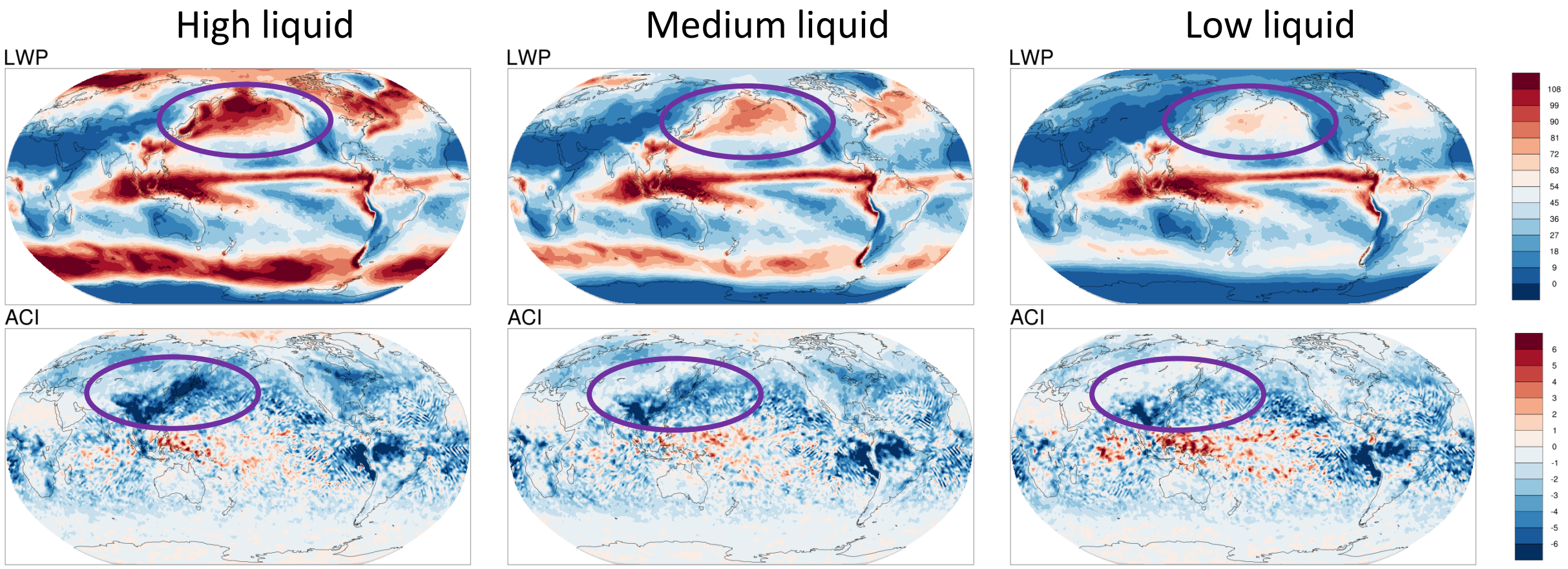
Low liquid

LWP





LWP and ACI over NH



With smaller LWP, the clouds are less susceptible to aerosol perturbations.

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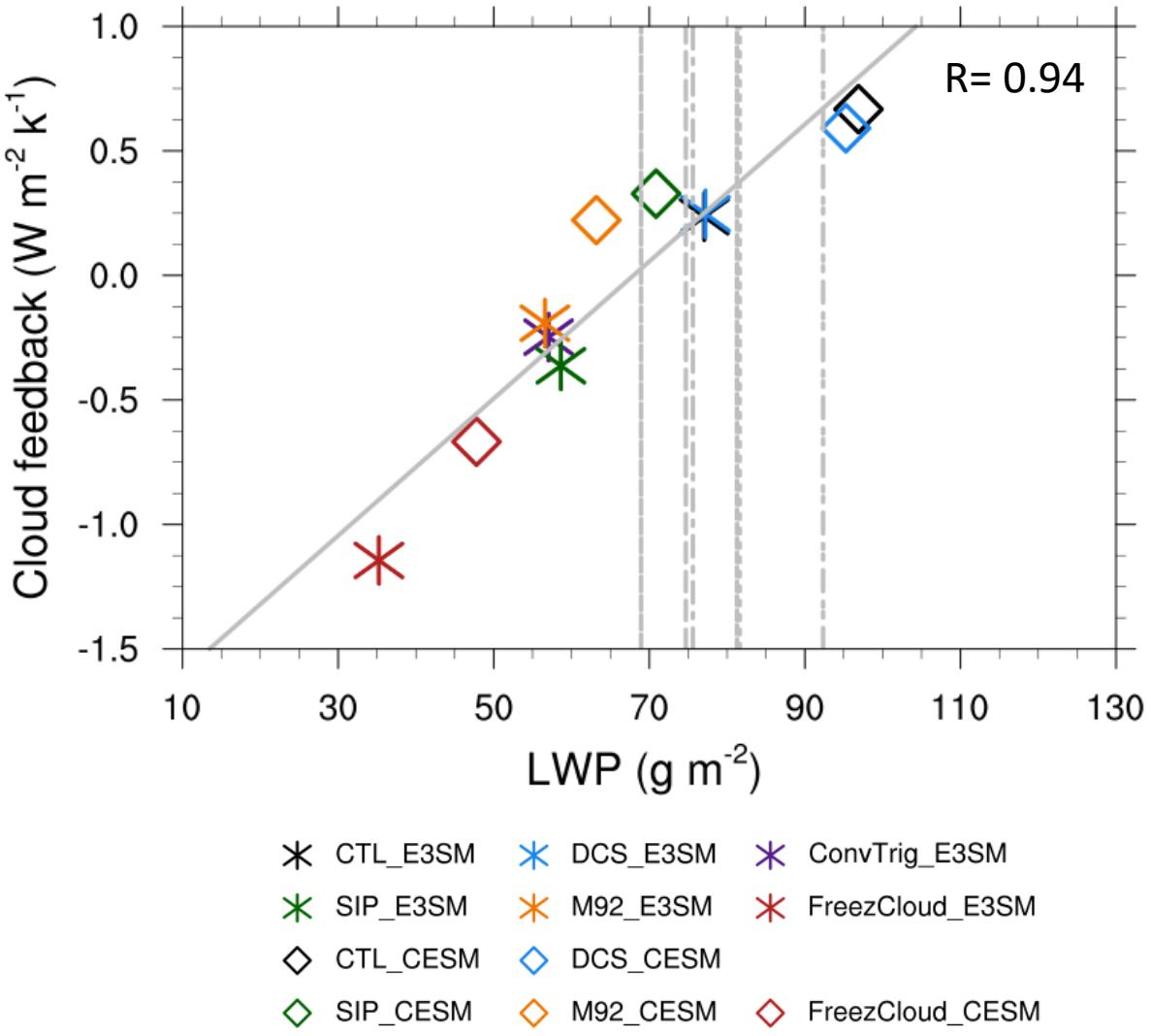
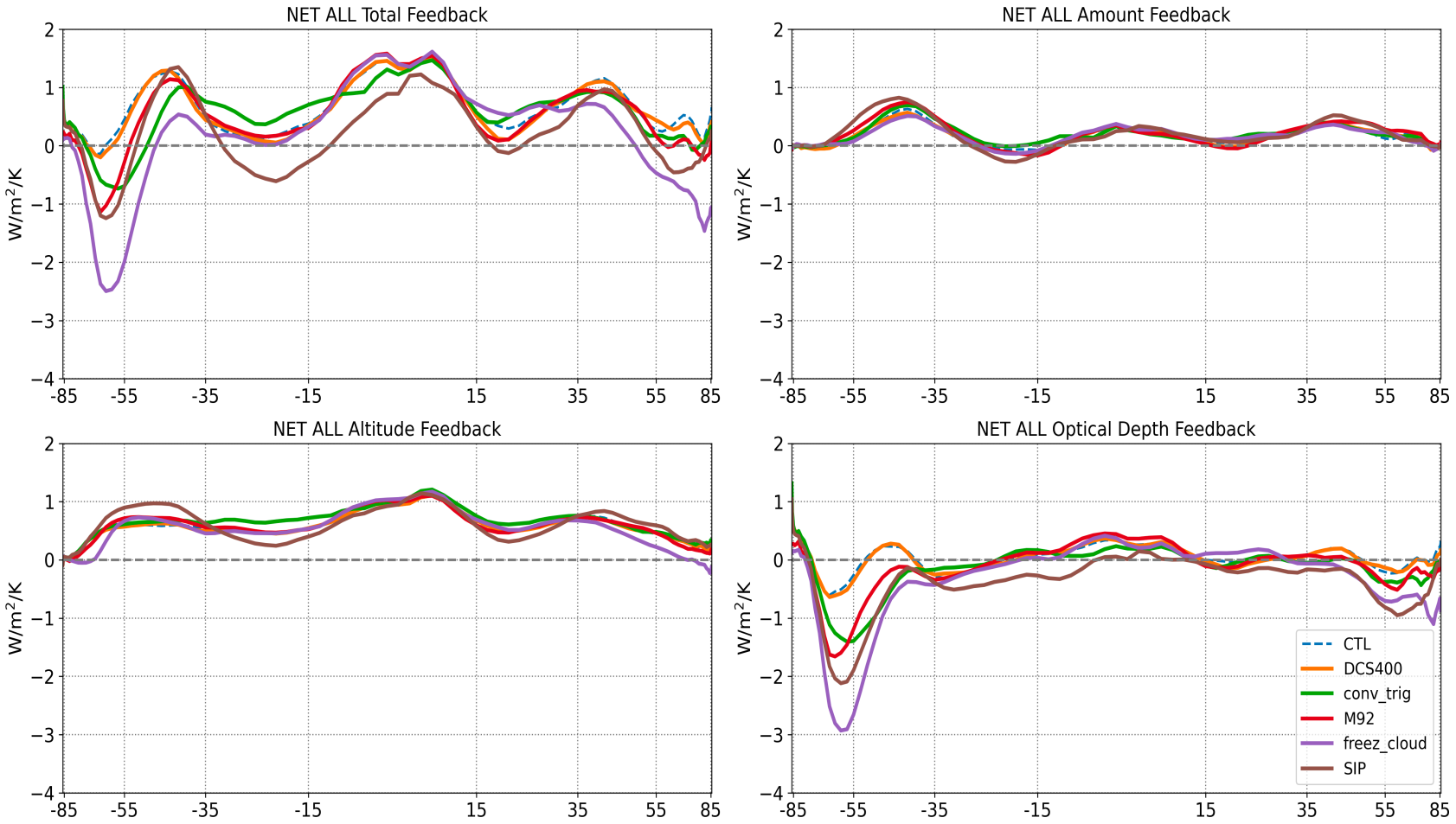
Cloud feedback and LWP over SH (30-90S)



Cloud feedback



Less LWP, more ice

When warming, more ice melting to liquid → cloud optical depth increase →stronger negative feedback

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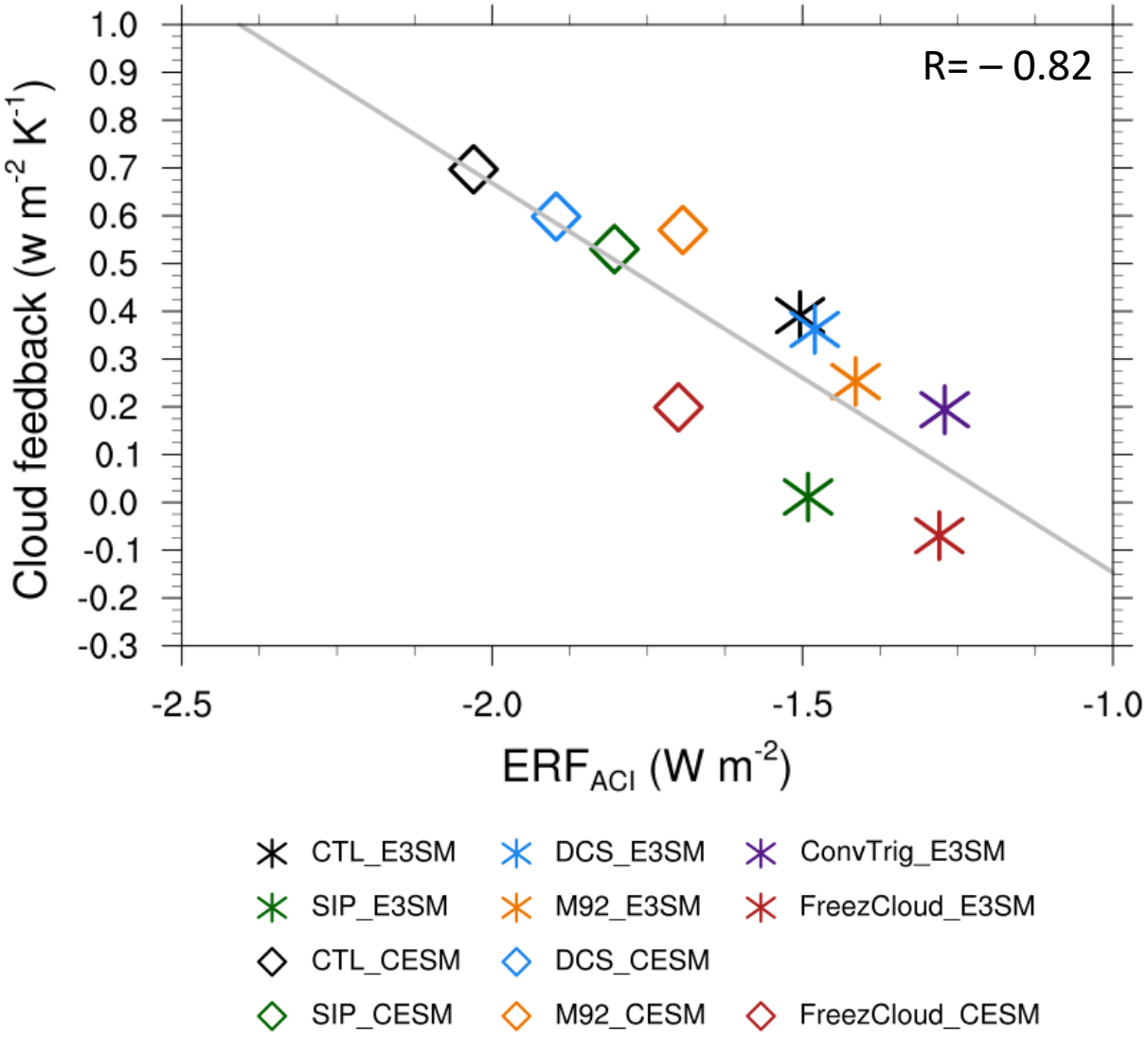
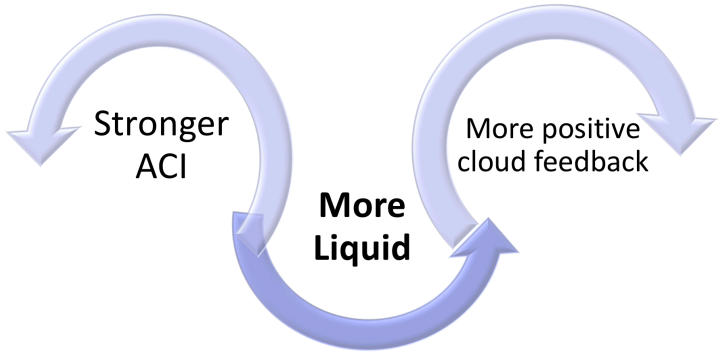
Cloud feedback and ERF_{ACI}



- the simulation with high LWP
  - More positive cloud feedback
  - stronger cooling effect from ERF_{ACI}
  - Offset each other

Summary

- New finding:
  - ERF_{ACI} monotonically decreases (stronger) with increasing LWP
  - With smaller LWP, the clouds are less susceptible to aerosol perturbations.



- Confirmed:
  - Relationship between LWP and cloud feedback
  - Stronger ACI — Higher ECS