Cloud-resolving Modeling of Aerosol Indirect Effects in Idealized Radiative-convective Equilibrium with Interactive and Fixed Sea Surface Temperature

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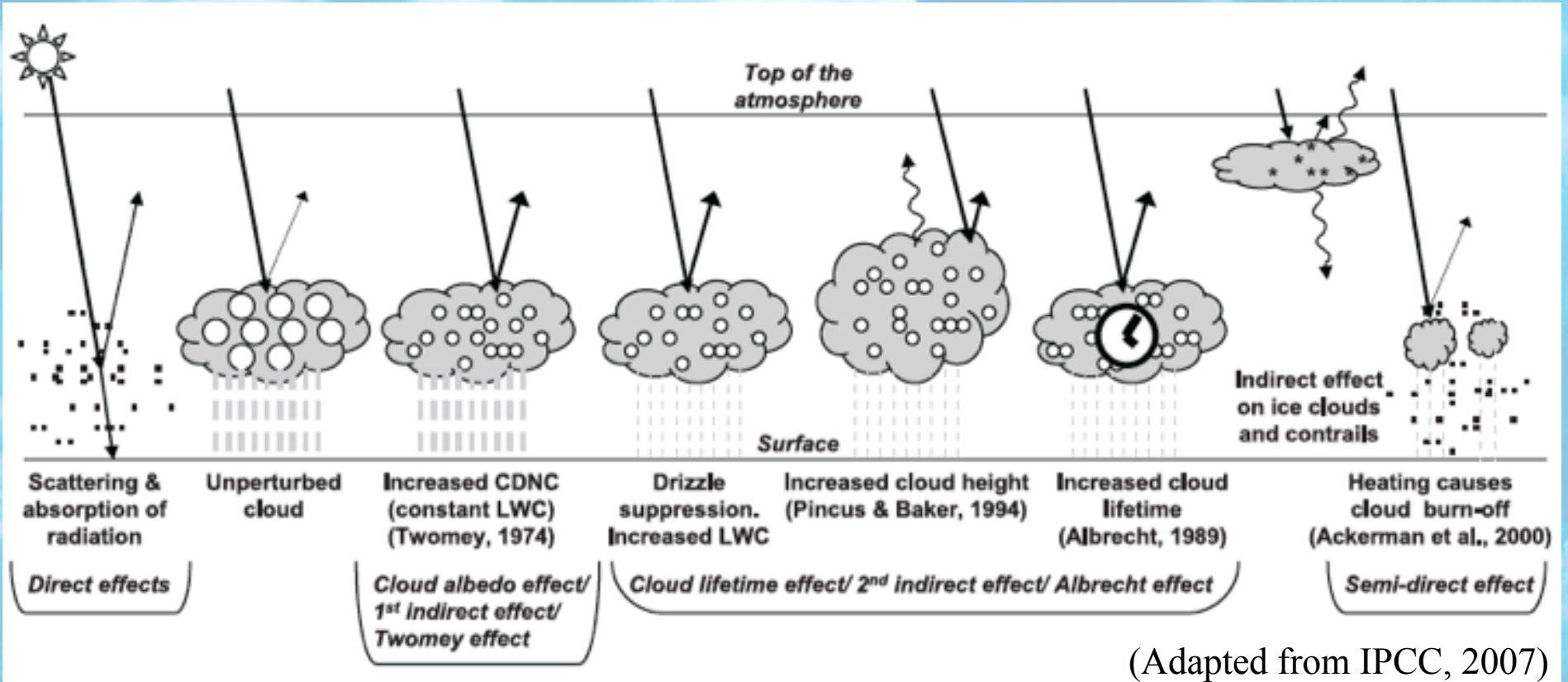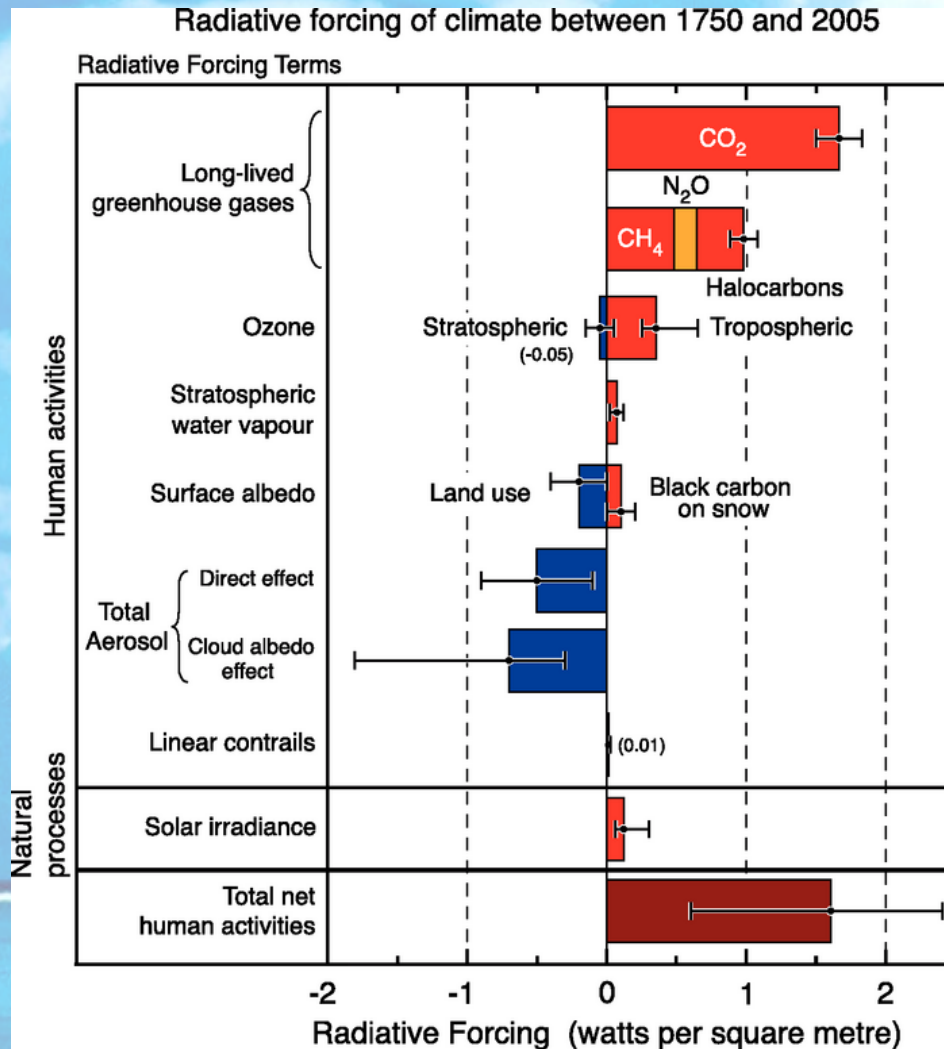Cheng-En Yang

Outline

- Introduction

- Motivation

- Methodology

- Results

- Conclusion

Introduction

| Scattering & absorption of radiation | Unperturbed cloud | Increased CDNC (constant LWC) (Twomey, 1974) | Drizzle suppression. Increased LWC | Increased cloud height (Pincus & Baker, 1994) | Increased cloud lifetime (Albrecht, 1989) | Heating causes cloud burn-off (Ackerman et al., 2000) |

Direct effects

Cloud albedo effect/ 1st indirect effect/ Twomey effect

Cloud lifetime effect/ 2nd indirect effect/ Albrecht effect

Semi-direct effect

Top of the atmosphere

Surface

Indirect effect on ice clouds and contrails

(Adapted from IPCC, 2007)

Motivation

Radiative forcing of climate between 1750 and 2005

(Adapted from IPCC, 2007)

- Large uncertainty in aerosol indirect effects

- Aerosol-cloud parameterization in general circulation models (GCMs) ⇒unable to resolve cloud processes explicitly

- High-resolution 2D/3D Large-eddy simulation and cloud-resolving models have used either interactive or fixed SSTs, not both.

- What are the differences between using interactive or fixed SSTs with the same model?

Radiative-Convective Equilibrium (RCE)
Idealization of Tropics

Radiation

Microphysics

No explicit lateral tra
in/out the doma
(which is doubly peri

Transport by convection

Turbulence

Precipitation

Surface Fluxes

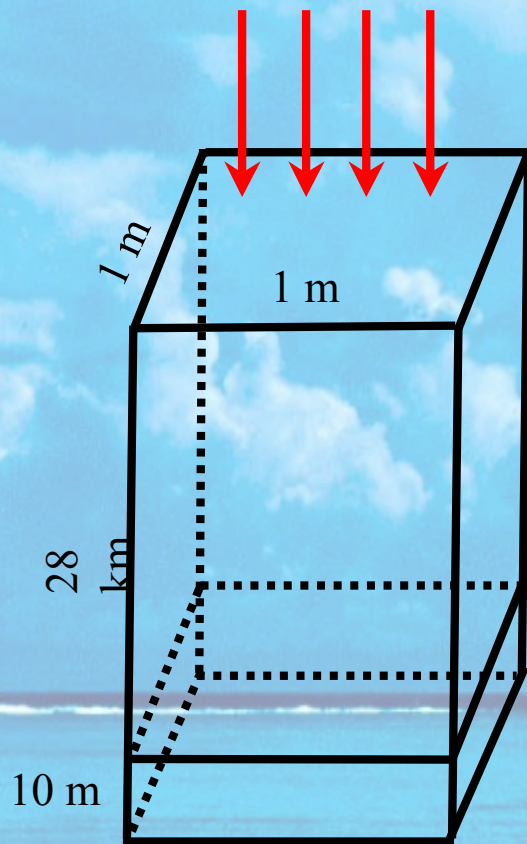Ocean Heat Reservoir
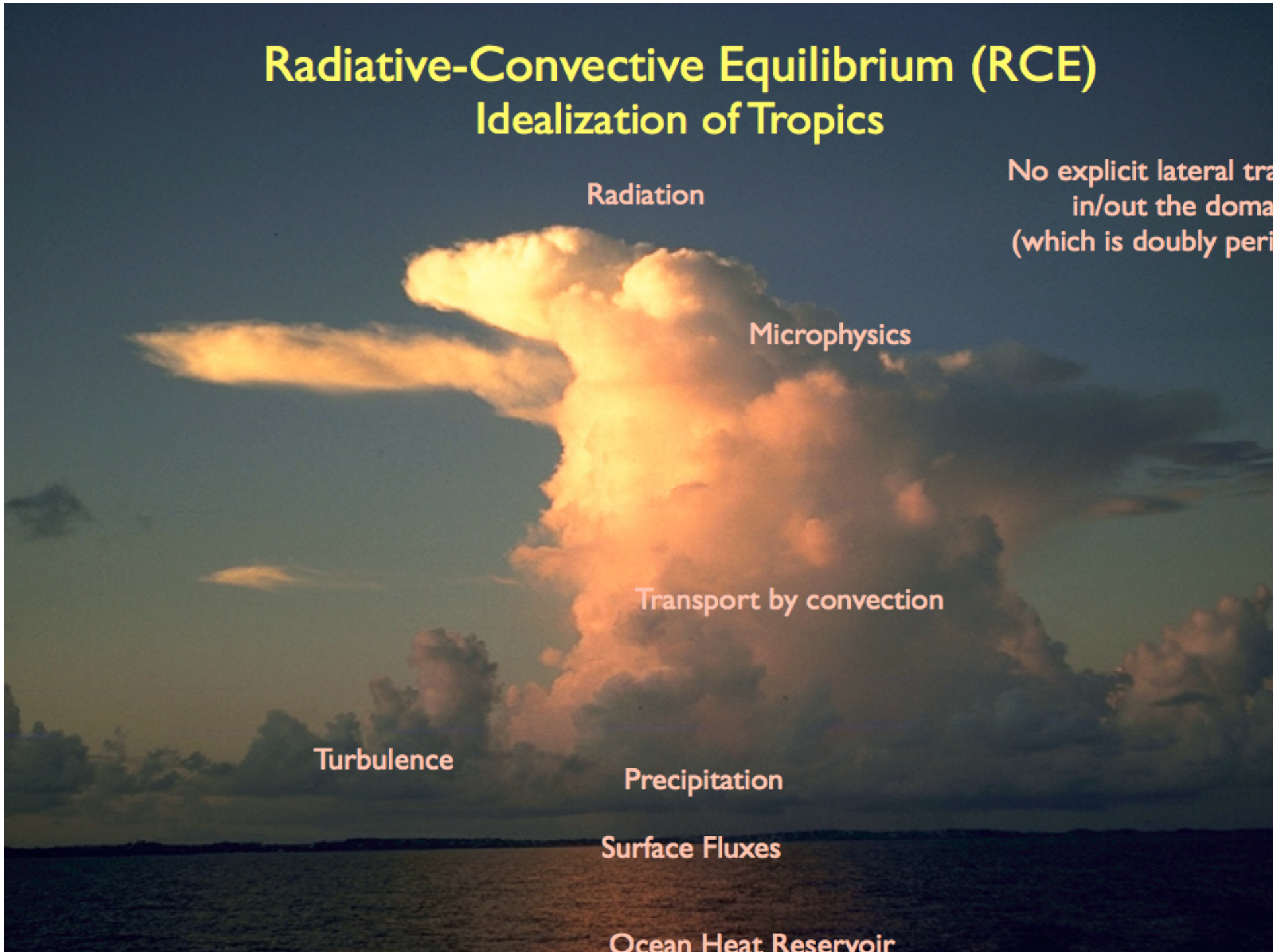
Model Descriptions
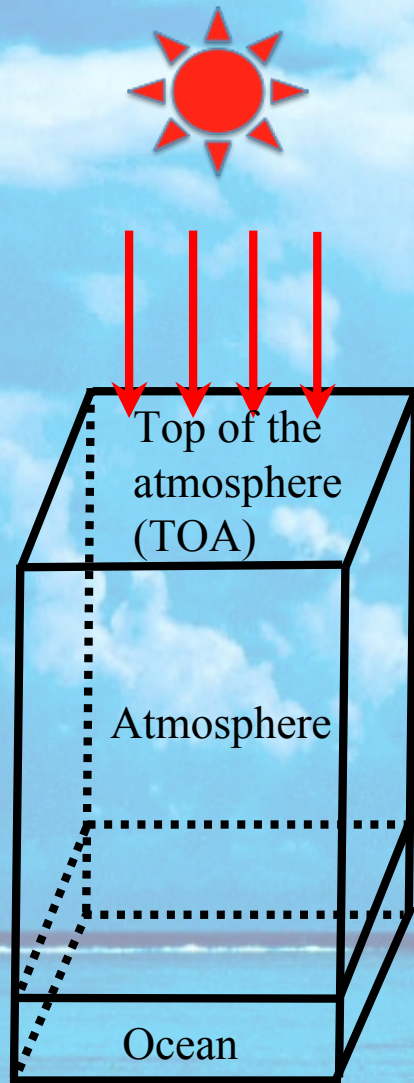
- System for Atmospheric Modeling (SAM6.8)

    - 10-m slab ocean model

    - 2-moment cloud microphysics (Morrison 2005)

    - Interactive radiation (RRTM), surface fluxes

Experimental Design

	Interactive SST (ISST)		Fixed SST at 300 K (FSST)	
Case	CCN (cm^{-3})	Case	CCN (cm^{-3})	
IA100*	100	FA100*	100	
IA200	200	FA200	200	
IA500	500	FA500	500	
IA1000	1000	FA1000	1000	
IA2CO2	100			

- 128 x 128 x 64 grids

- 700 simulation days

1 m

1 m

28 km

10 m

Control Runs

|ISST-FSST|
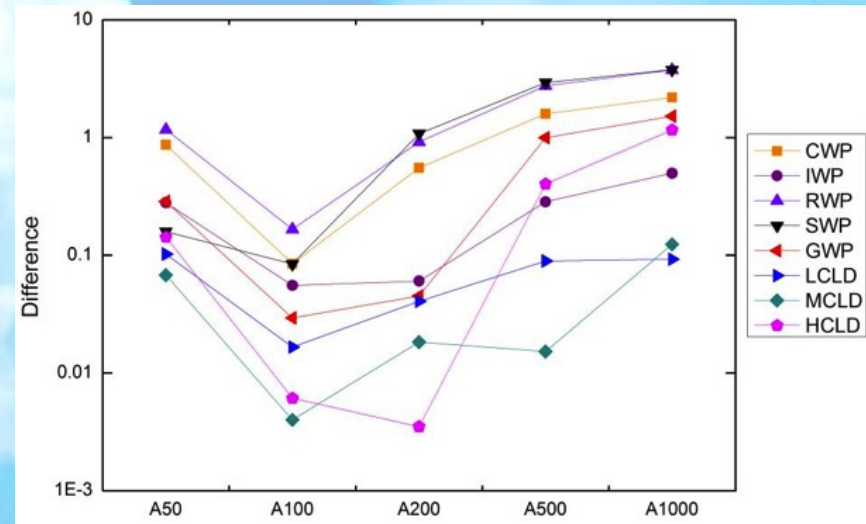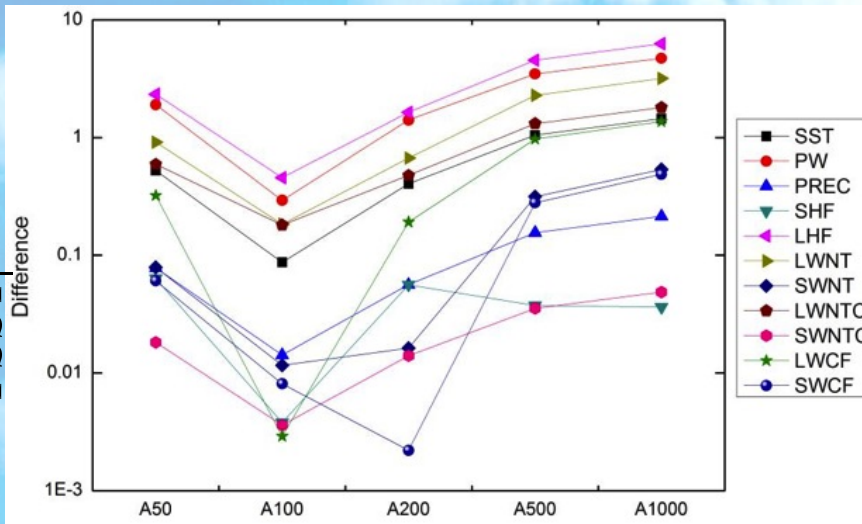
Differences between ISST and FSST controls (A100) are generally smaller than differences between ISST and FSST cases with difference CCN count (by design), so that A100 cases for ISST and FSST are basically identical.
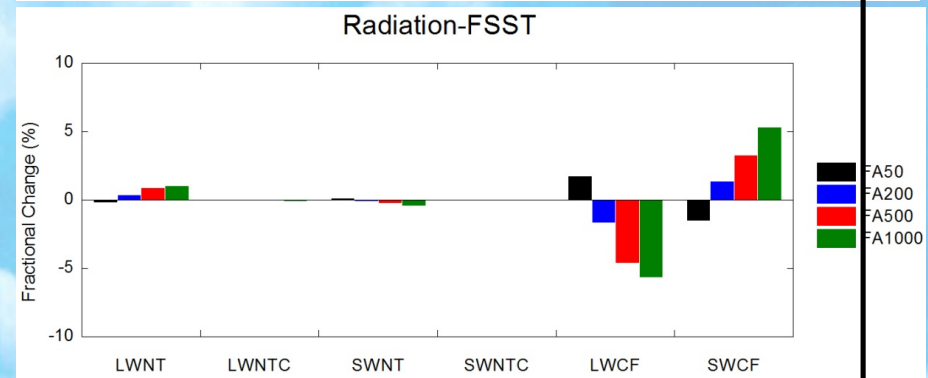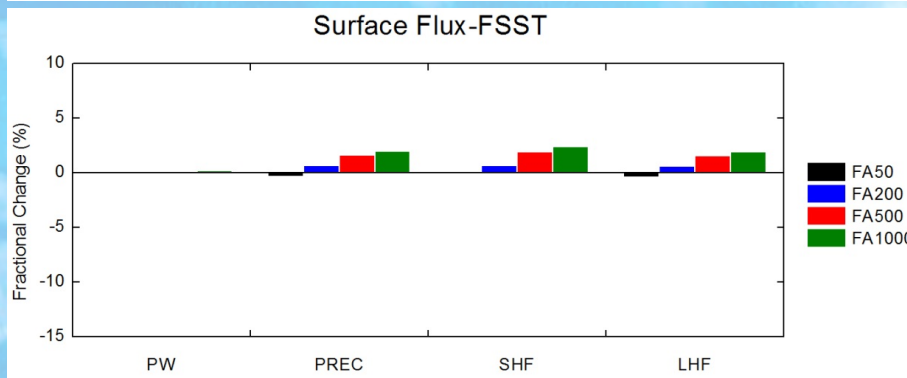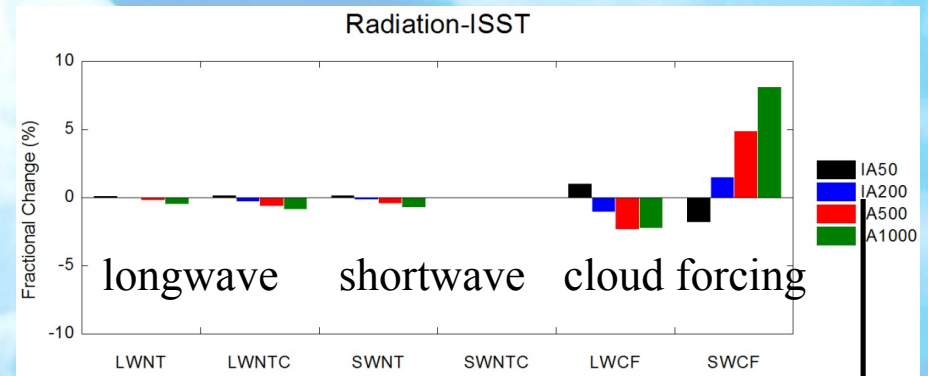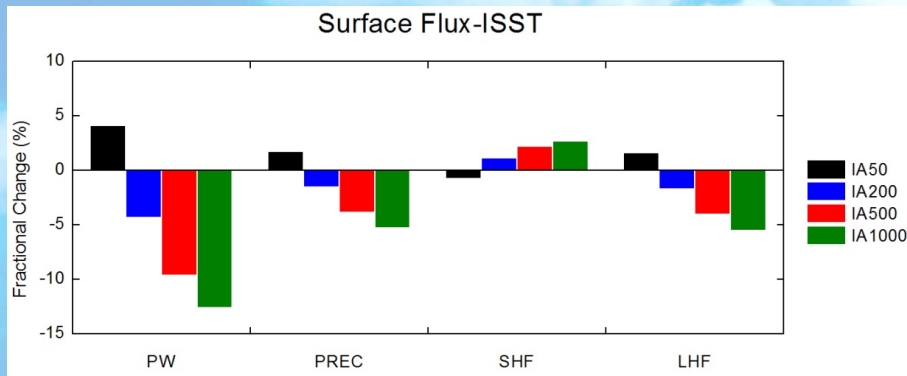
Aerosol Indirect Effects (AIEs) on SST
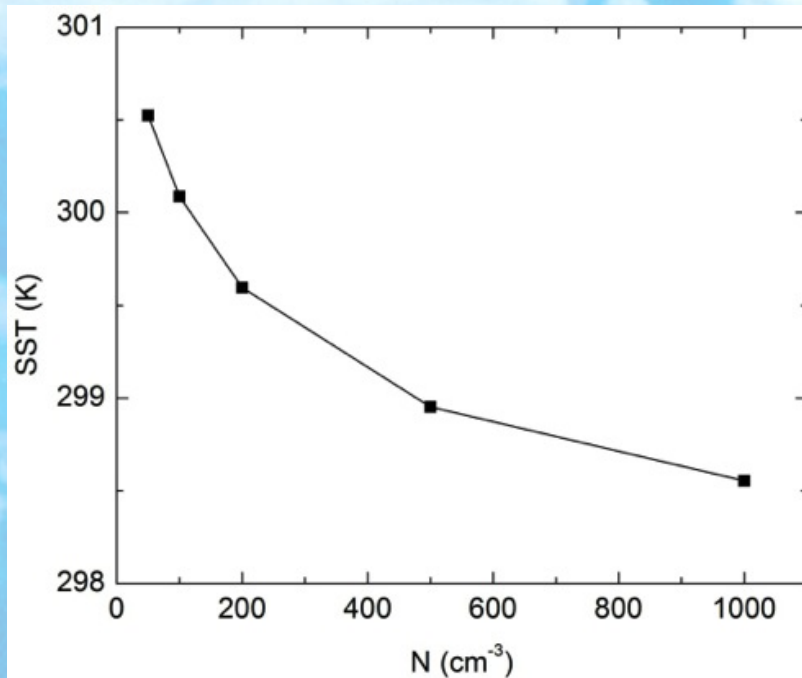
Cooling effect
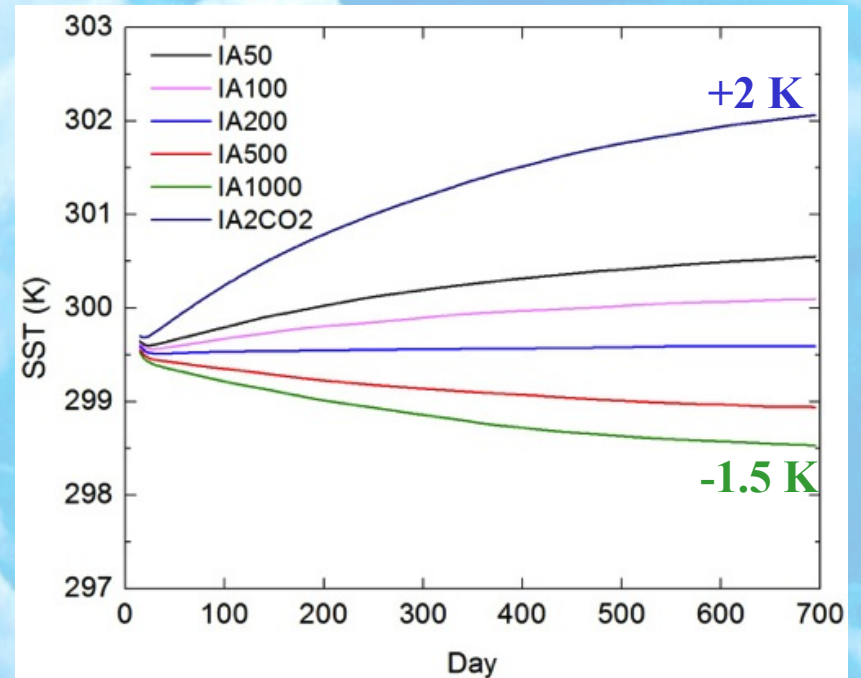
Mitigation of the
greenhouse effect

Aerosol Indirect Effects

Surface Flux-ISST

Radiation-ISST

longwave   shortwave   cloud forcing

Surface Flux-FSST

Radiation-FSST

- Precipitable water, surface precipitation ⇒by SST ⇒latent heat flux

- Small difference in sensible heat flux ⇒by constant insolation

- LW at TOA ⇒ISSTs by SST; FSSTs by cloud fractions

- Decreased SW at TOA

- Cloud forcing ⇒LW ↓ ; SW ↑

Aerosol Effects on Clouds
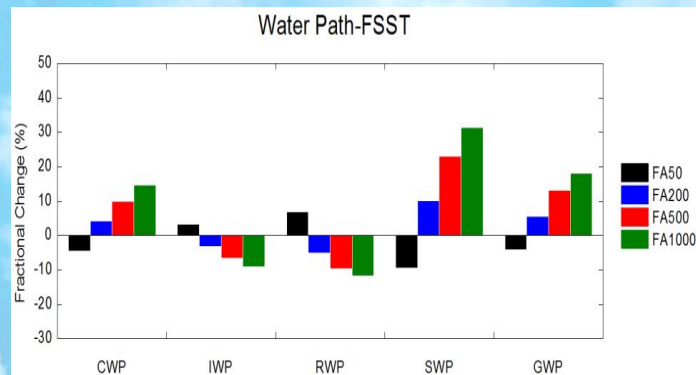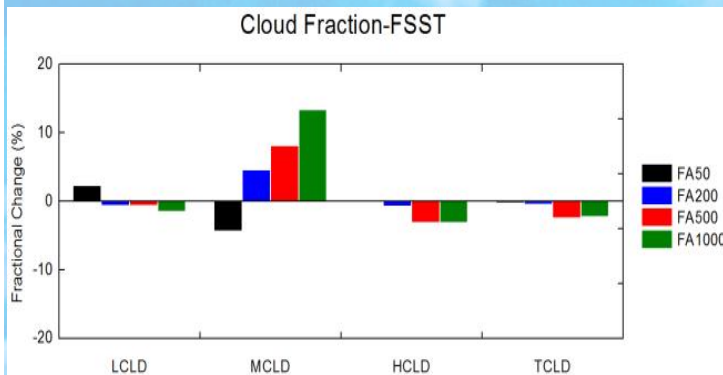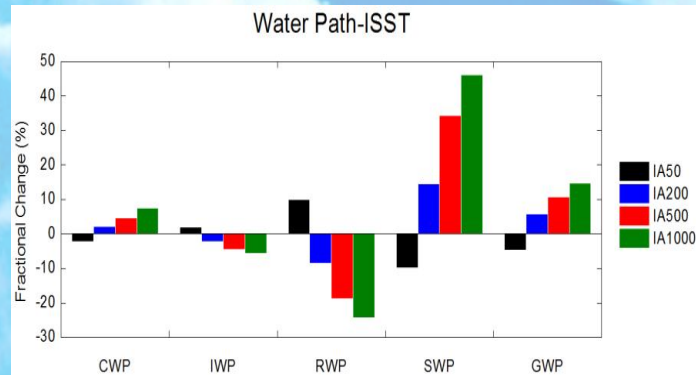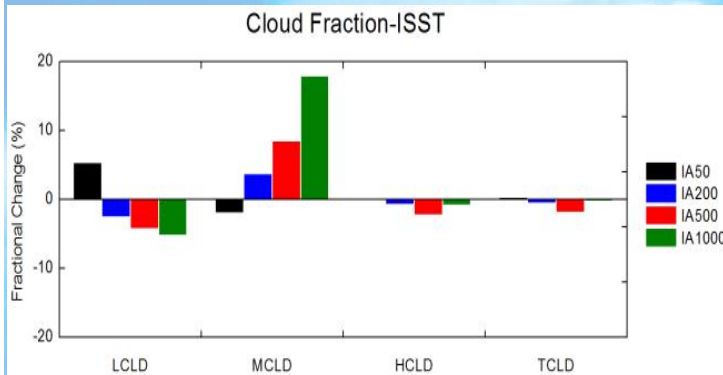
CWP: cloud water path

IWP: ice water path

RWP: rainwater path

SWP: snow water path

GWP: graupel water path

- Small variations in cloud fractions

- High-level cloud dominates (~90%)

- Relative large changes in mid-level cloud

- Increasing CWP, SWP, GWP; decreasing IWP, RWP
  ⇒reduced low- and high-level clouds; enhanced mid-level clouds

- Fail to apply the Albrecht effect in FSSTs

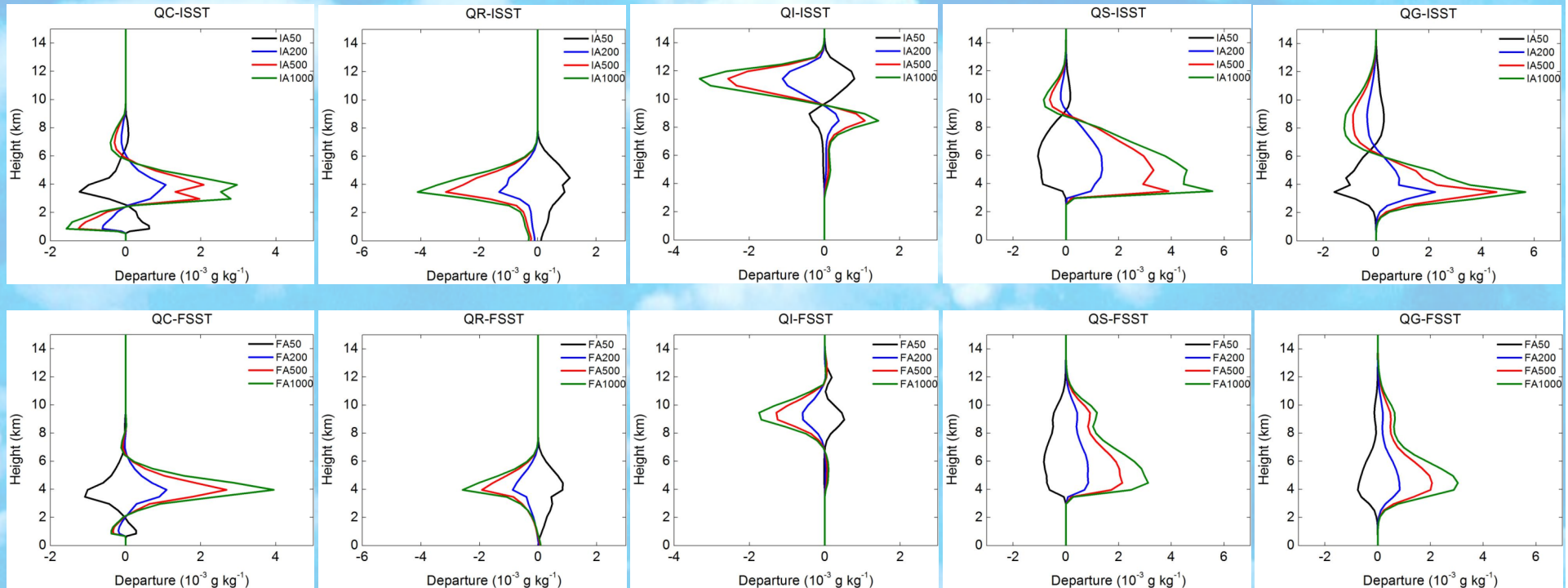# Profiles of Hydrometeor Mixing Ratio

Cloud liquid water Rainwater Cloud ice Snow Graupel

- Positive-shifting patterns in FSSTs

- Reduced rainwater (lower level) and cloud ice (higher level)

- Enhanced snow and graupel

- Opposite trend in cloud ice at lower high-level
  ⇒by dynamic effect

Profiles of Hydrometeor Number Concentration

Cloud liquid water   Rainwater   Cloud ice   Snow   Graupel
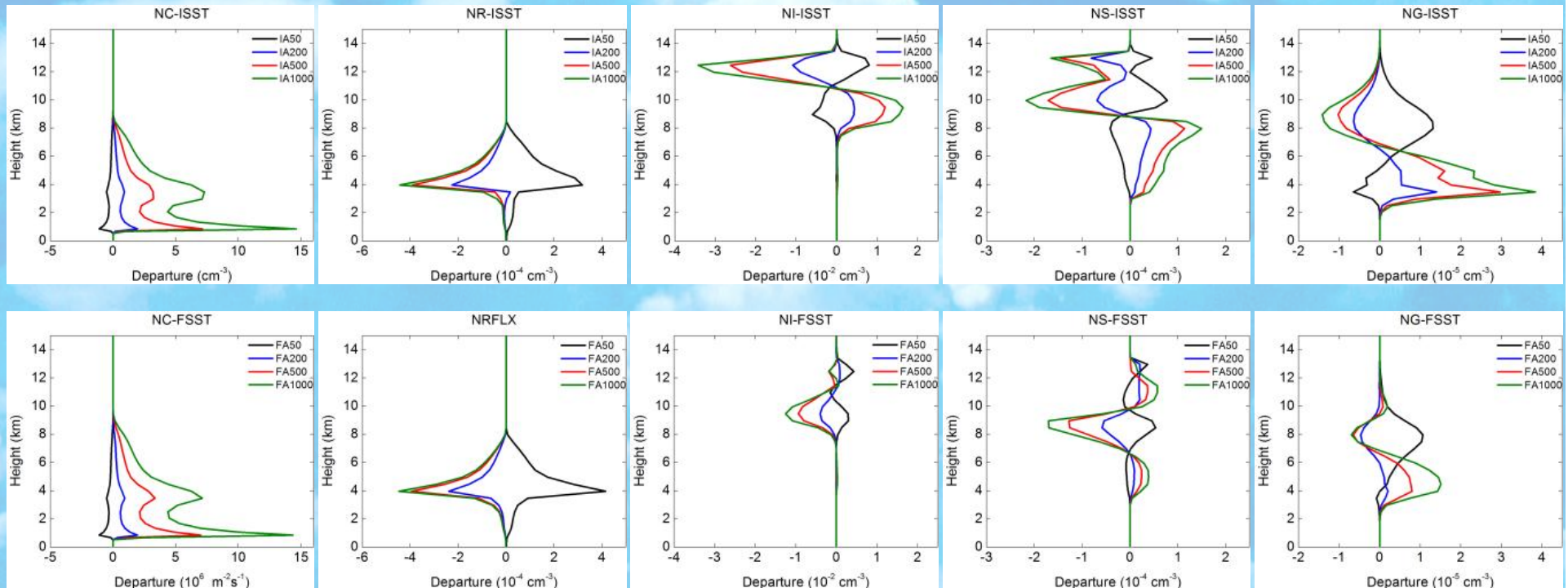
- Broadening size distribution
  - ISSTs: cloud liquid water (low-level)
  - FSSTs: cloud liquid water (low-level); snow and graupel (high-level)

- Small differences in cloud liquid water and rainwater
- Opposite trends in cloud ice
- Smaller magnitude in cold water
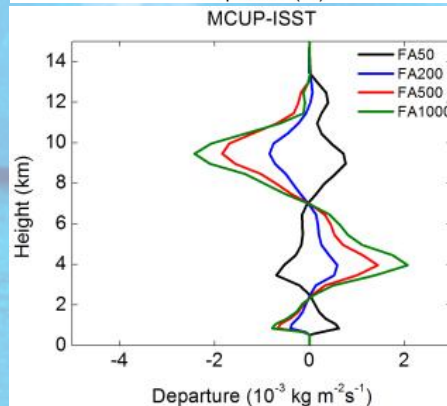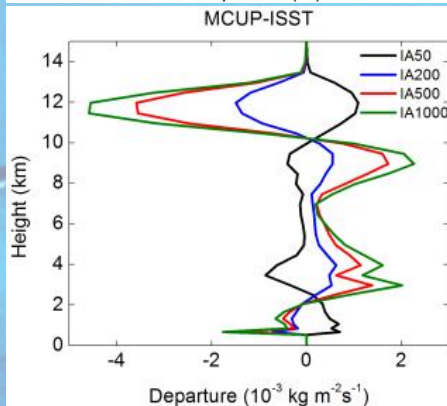
Profiles of Cloud Properties

- Reduced precipitation at low-level ⇒dryer boundary layer in ISSTs
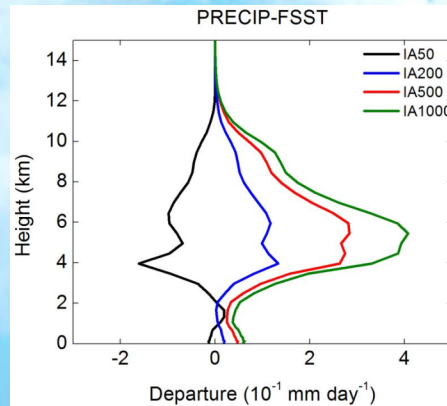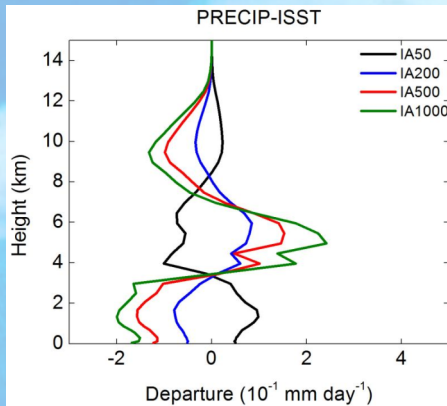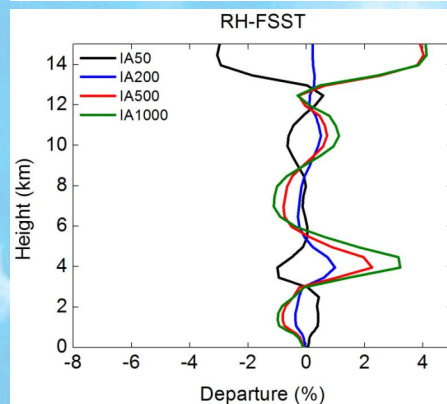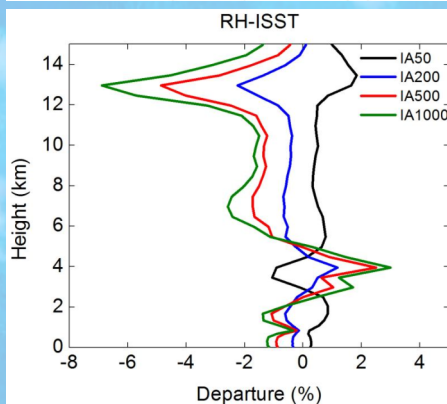
- Increasing precipitation at mid-level ⇒stronger updraft

- Reduced precipitation at high-level ⇒weak updraft

- Opposite trend in updraft at lower high-level (7-10 km)

Conclusion

- Indirect aerosol effects by increasing marine CCN counts to lower levels than continental levels can substantially alleviate the warming effect by doubling CO_2

- Increasing CCN reduces LWCF but enhances SWCF

- Opposite sign of feedback in surface precipitation between interactive and fixed SST cases