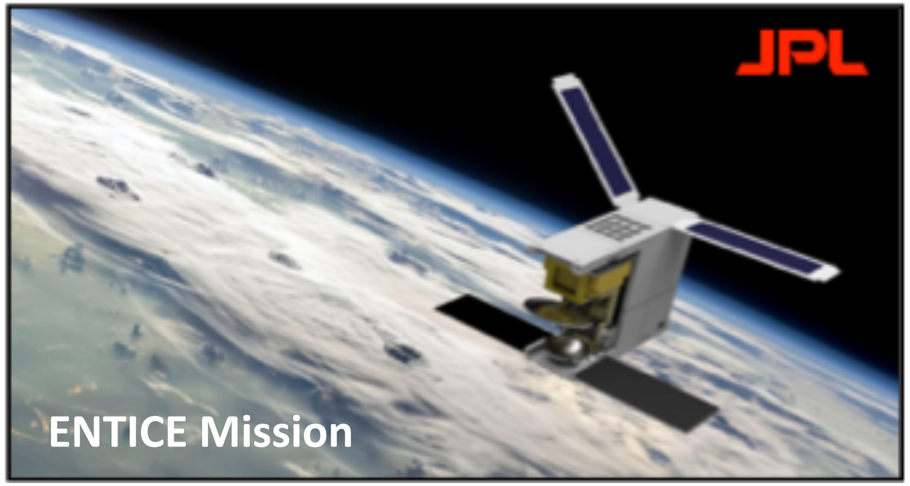

Impact of Cloud Ice Particle Size Uncertainty in GCM and Implications for Future Satellite Missions

Hui Su[1], Yuan Wang[2], Jonathan H. Jiang[1], Feng Xu[3], Yuk L. Yung[2]

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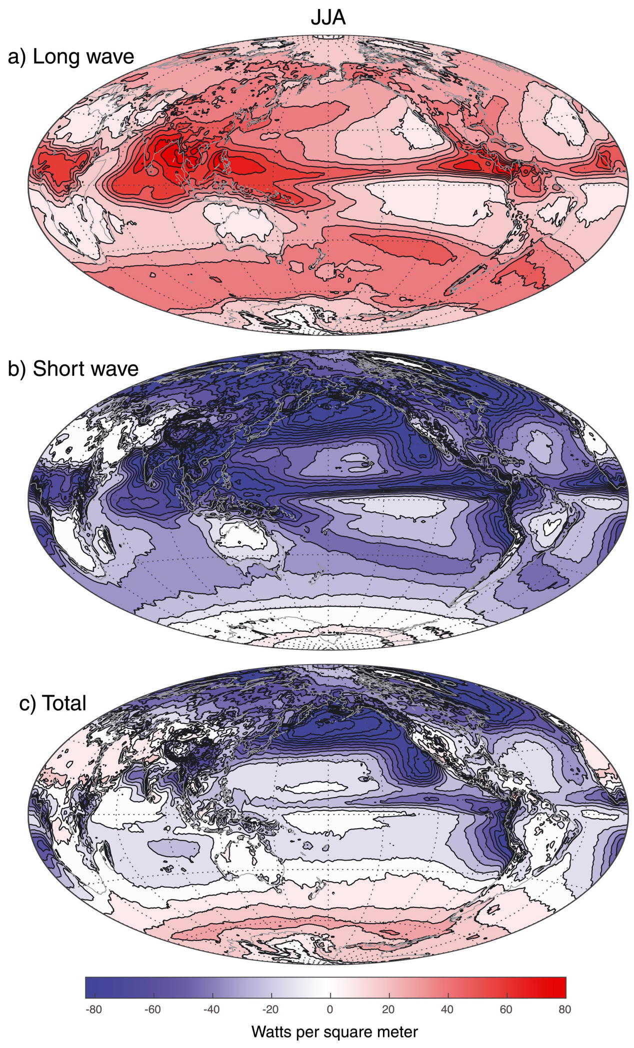
[2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA

[3]University of Oklahoma, Norman, OK

- Wang, Y., H. Su, J. H. Jiang, F. Xu, Y. Yung *Impact of Cloud Ice Particle Size Uncertainty in A Climate Model and Implications for Future Satellite Missions*, **J. Geophys. Res.** 125, 6, doi.org/10.1029/2019JD032119, (2020).



CERES Cloud Radiative Forcing
[*Hartmann and Berry*, 2017]

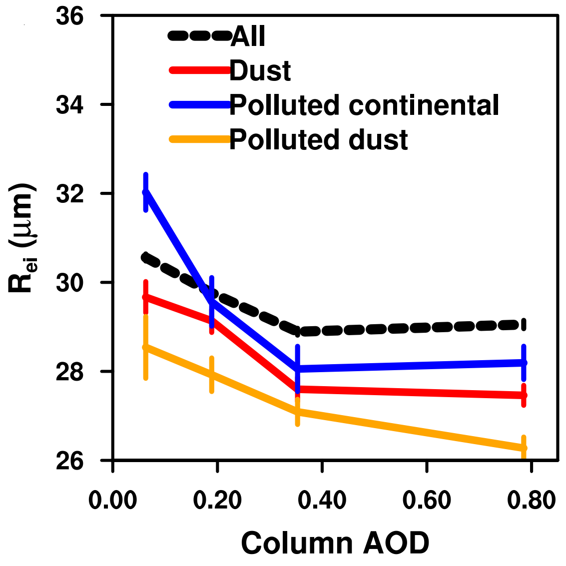
Ice Particle Size

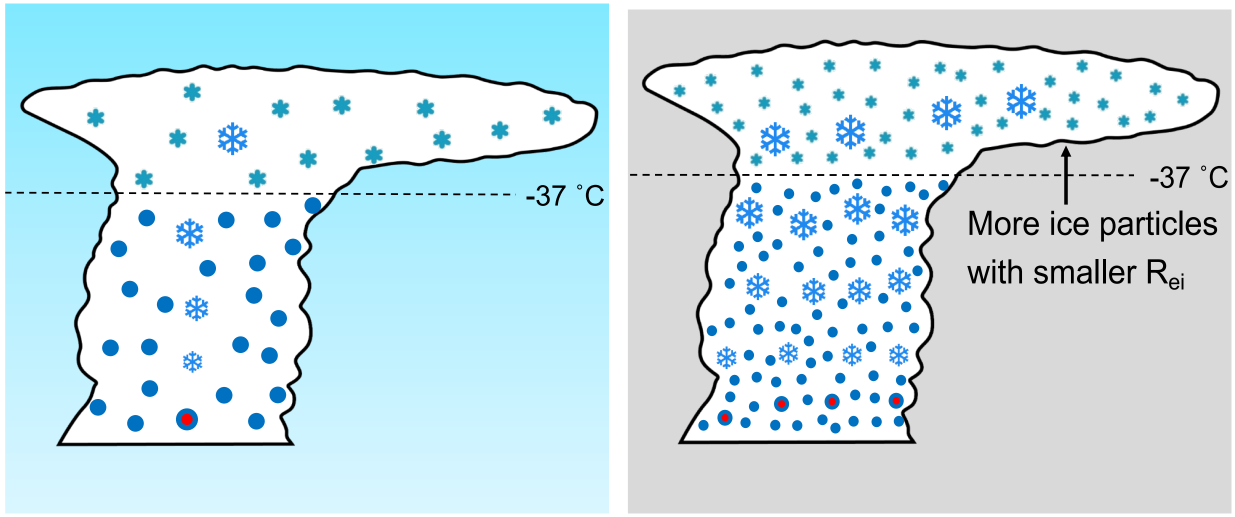
- **Directly linked to radiation budget;**
- **Affects climate sensitivity;**
- **Critical for determining ice particle fall velocity, which is directly linked to precipitation rate;**
- **Alter alters the efficiency of mixed-phase and ice microphysics;**
- **Plays a pivotal role in aerosol-cloud interactions;**
- **Critical for reducing IWC and precipitation rate retrieval uncertainty;**
- **Sensitive to environmental conditions.**

Rei Illustrates Different Microphysical Pathways of Ice Formation

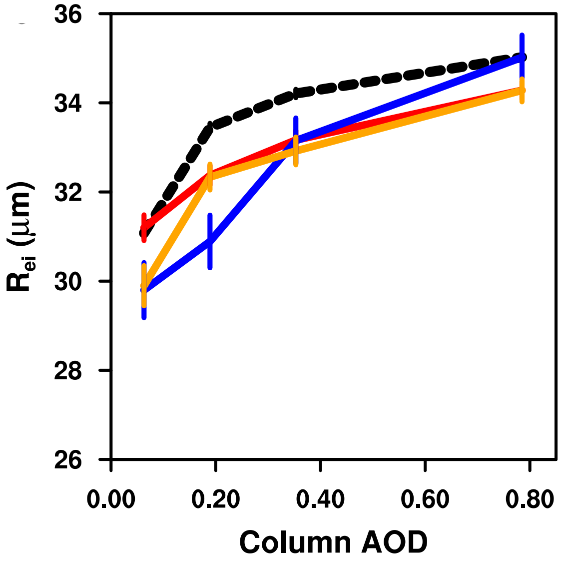
Zhao, Wang et al., *Nature Geoscience*, 2019

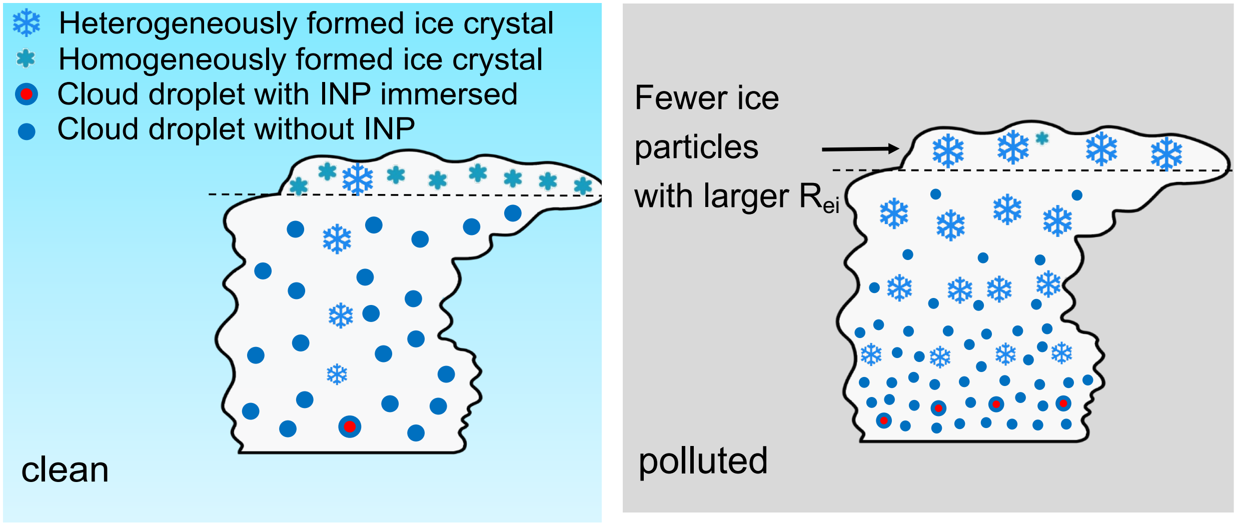
>67 percentile CAPE





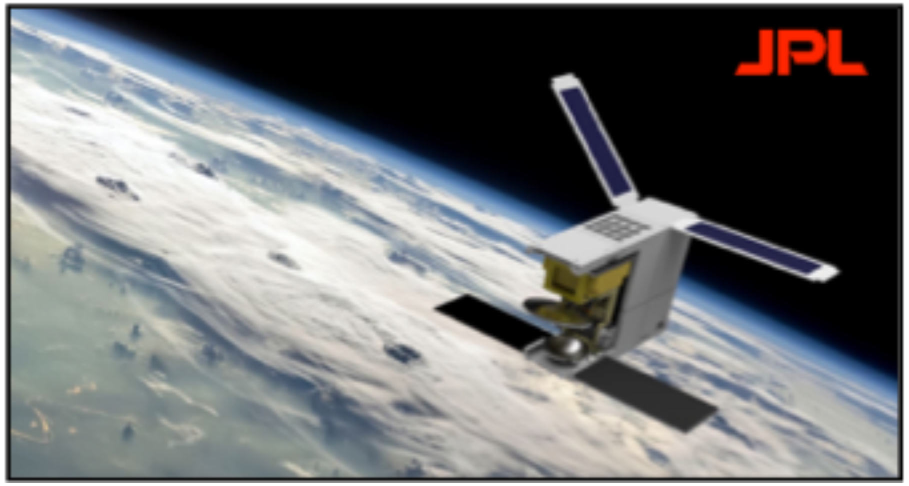
<33 percentile CAPE

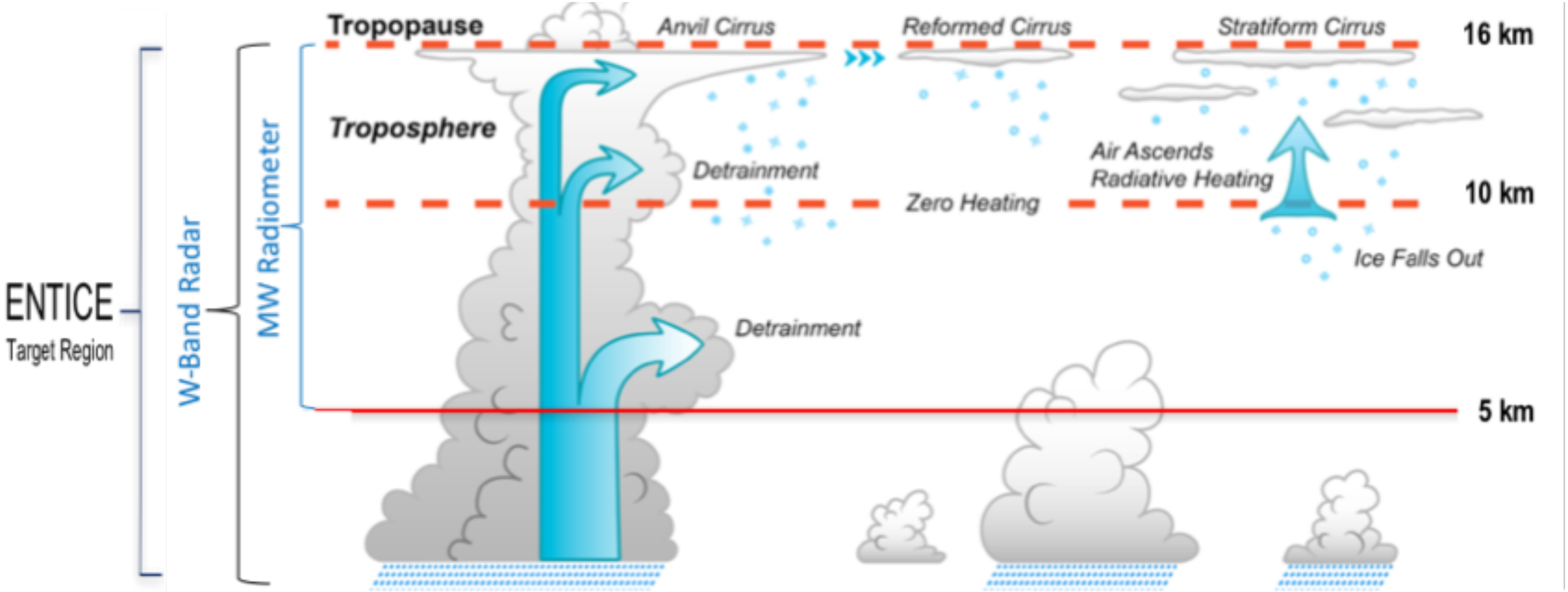


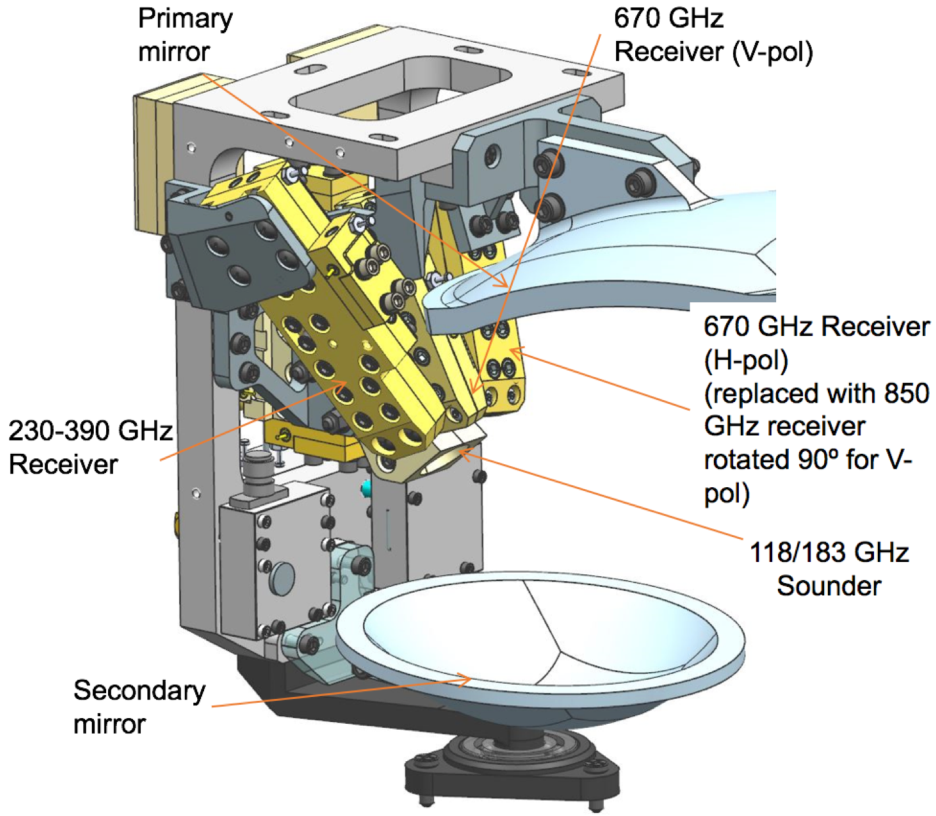


ENTICE

ENTICE is a proposed Earth Venture Mission that will provide the first-ever global measurements of ice cloud particle size and density profiles, together with atmospheric temperature and humidity, which will enable accurate quantification of ice cloud radiative effects and advance our understanding of ice cloud microphysical processes.







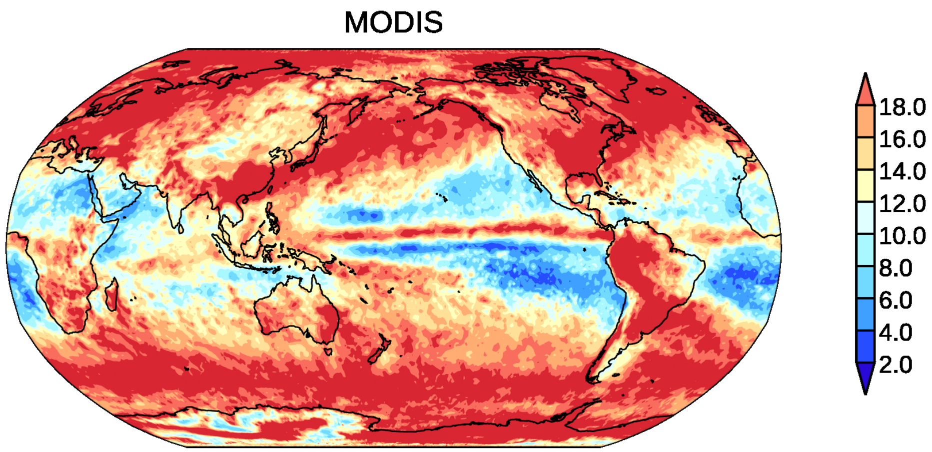
BASIC MEASUREMENTS

- **Vertical profiles:**
  - Ice Water Content – IWC (mg/m^3)
  - **Ice Particle Equivalent Sphere Effective Diameter – D_e (μm)**
  - Atmospheric Temperature – T (K)
  - Water Vapor Mixing Ratio – H_2O (kg/kg)
  - Relative Humidity – RH (%)
- **Precision:**
  - **De: 25%**; IWC: 25%; IWP: 20%; H_2O: 20%; RH: 20%; T: < 1.5K

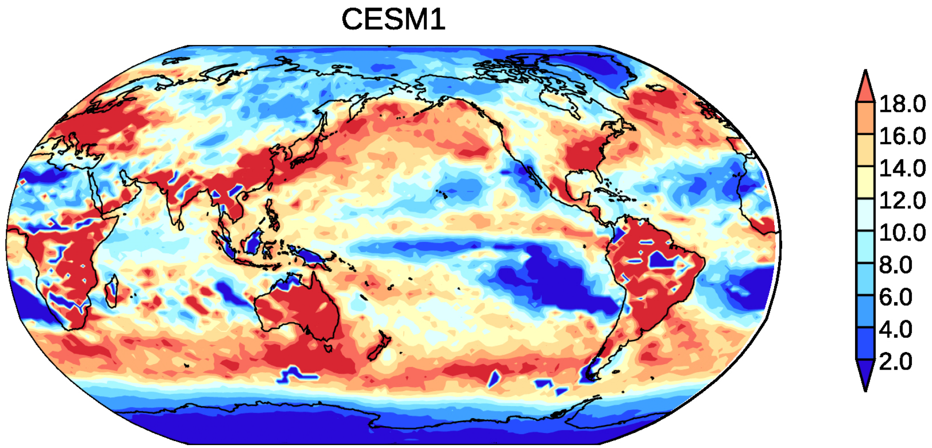
Fidelity of Ice Clouds in CESM1

Ice Cloud Optical Thickness

Global: 16.2
Tropical: 13.2



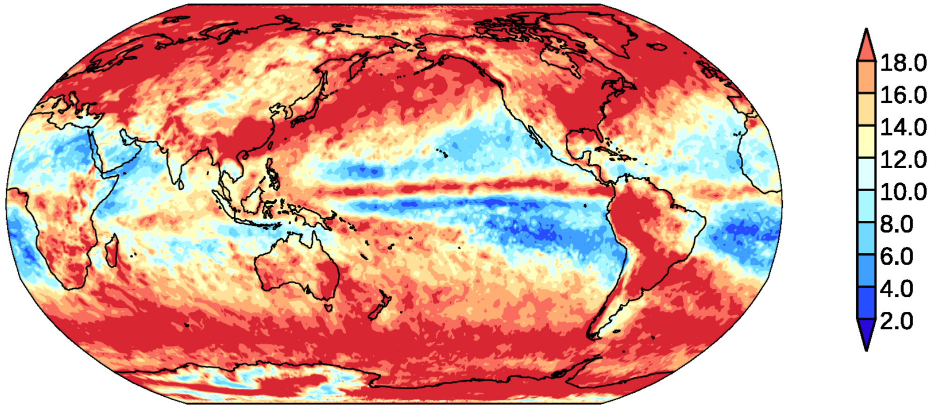
Global: 13.0
Tropical: 12.8



Fidelity of Ice Clouds in CESM1

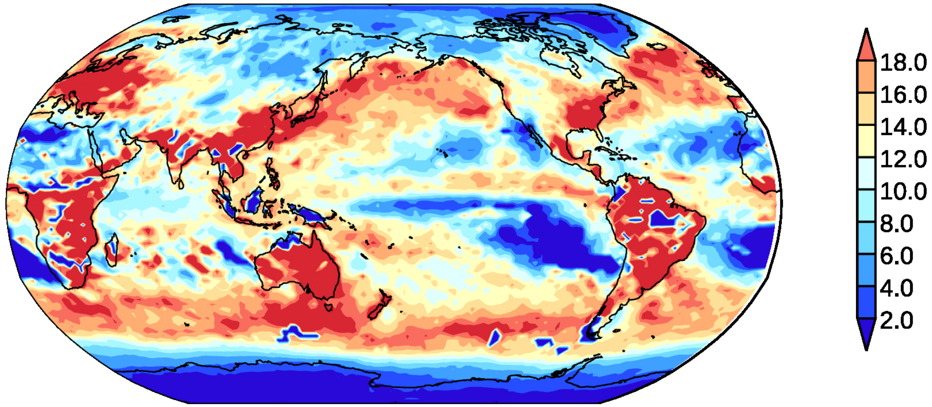
Ice Cloud Optical Thickness

MODIS



Global: 16.2
Tropical: 13.2

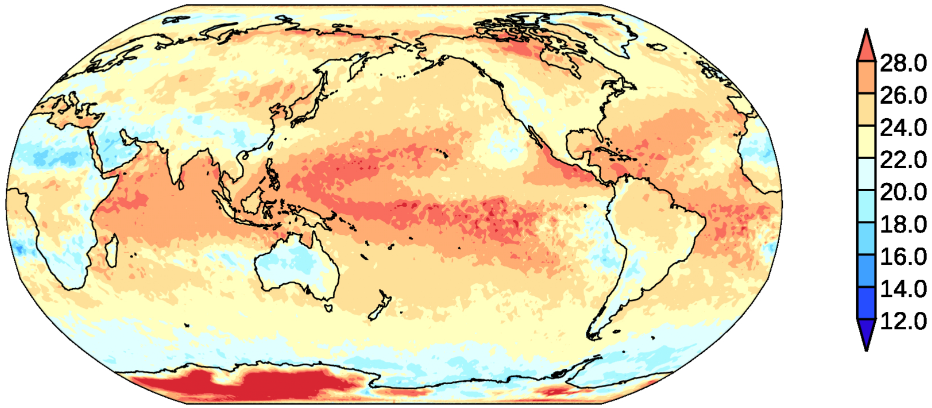
CESM1



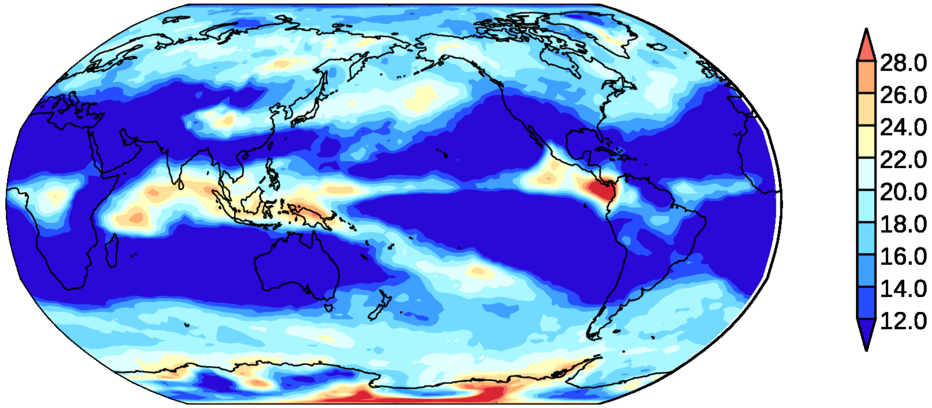
Global: 13.0
Tropical: 12.8

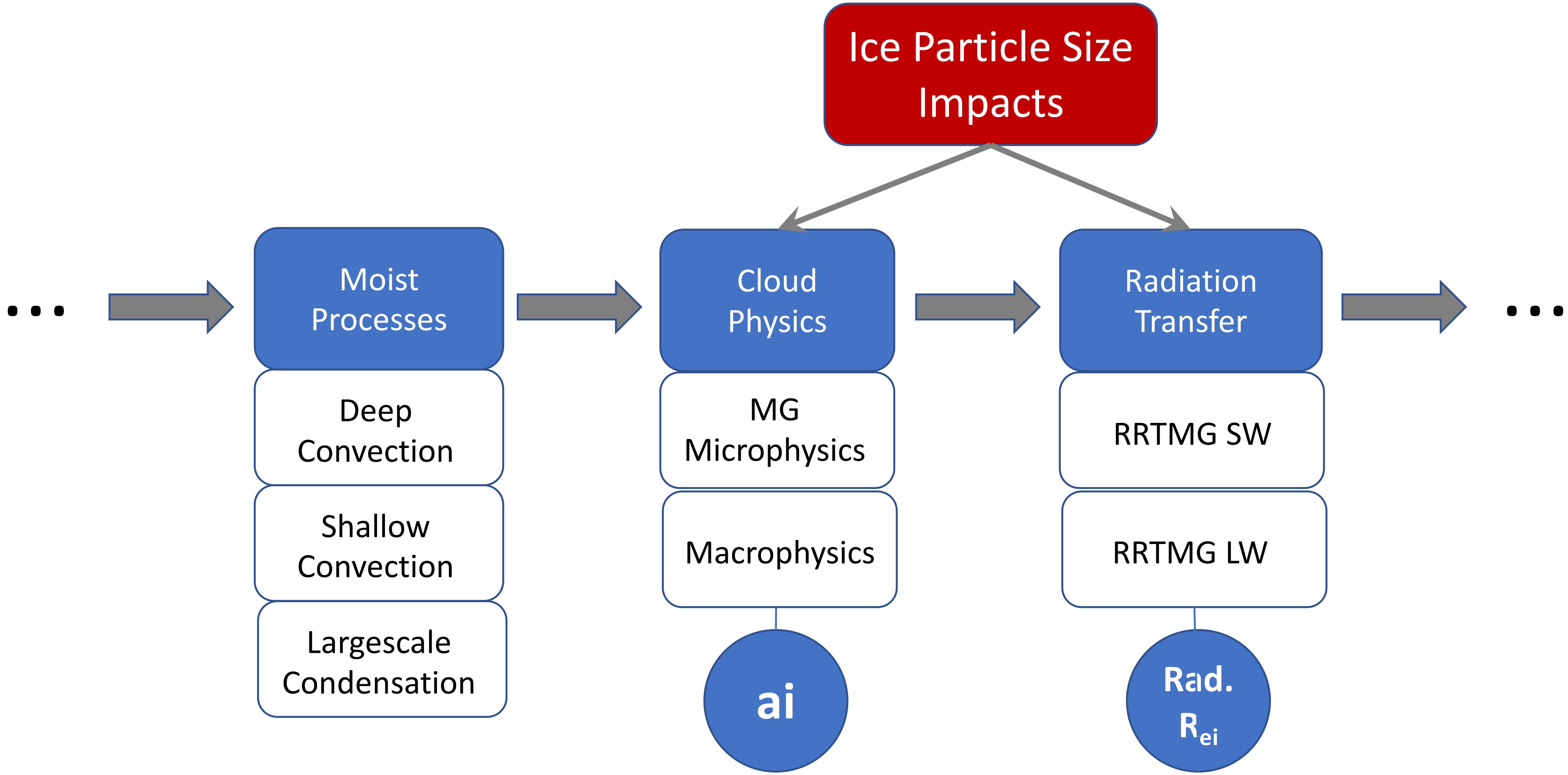
Ice Cloud Effective Radius (cloud top)

MODIS



CESM1





$V_{fall}=ai*D_{ei}$^bi

(def: ai = 700, bi=1)

NCAR CESM1

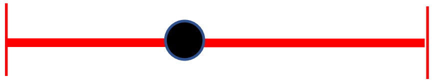
Observing System Simulation Experiment (OSSE) Type Design

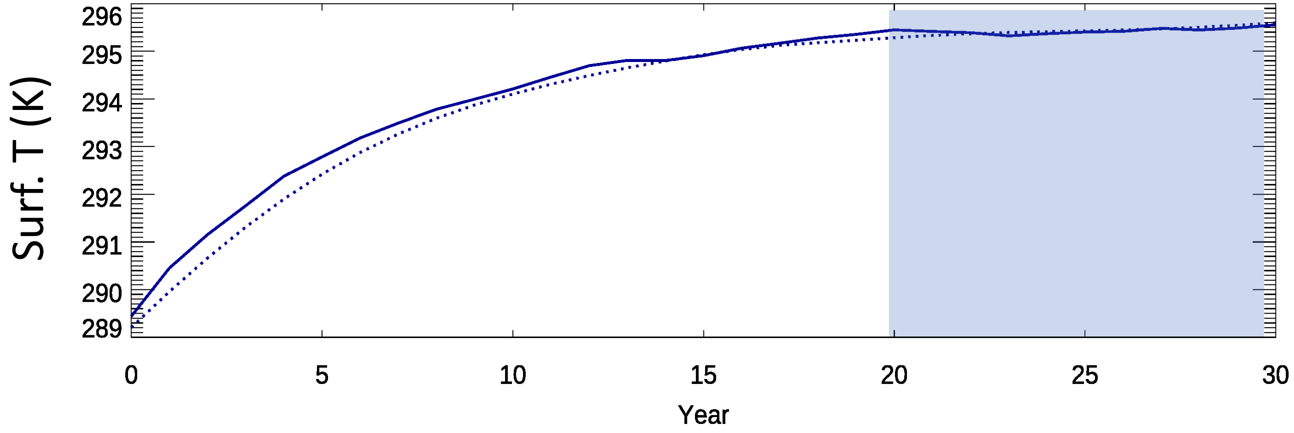
Experiment Purpose	Parameter Perturbed	Fractional Changes	Uncertainty Range	Integration Time
R_{ei} influence on cloud distribution and lifetime	ai in R_{ei} fall speed calc	−50% / +100%	CESM	30 years
		−25% / +25%	ENTICE	30 years
R_{ei} influence on radiation	RR_{ei} in radiation transfer	−50% / +100%	CESM	30 years
		−25% / +25%	ENTICE	30 years
Snow particle size (R_{es}) influence	as and RRes	All above	All above	30 years
To quantify climate sensitivity	All above with $4\times CO_2$	All above	All above	30 years

Atmosphere Model coupled with a slab ocean

Current Rei Range in CESM: +100%/−50%

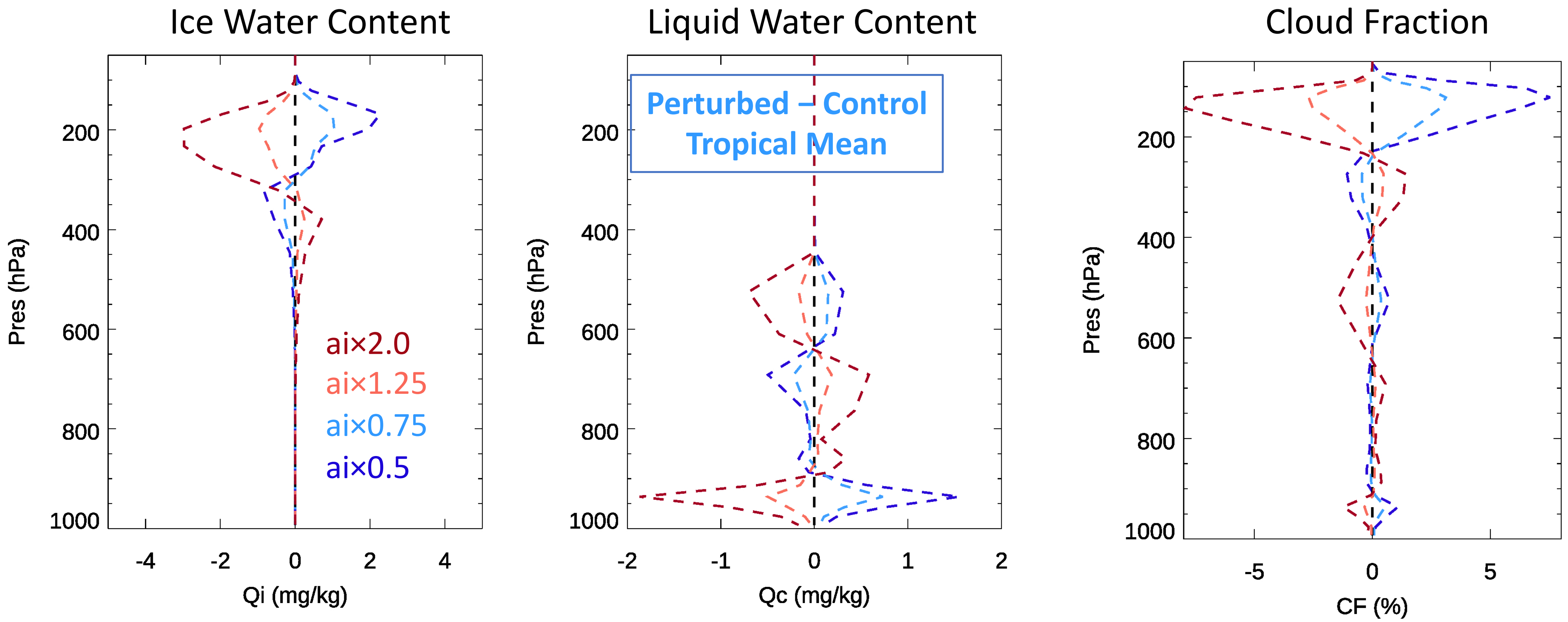
ENTICE Constrained Rei Range: +/− 25%





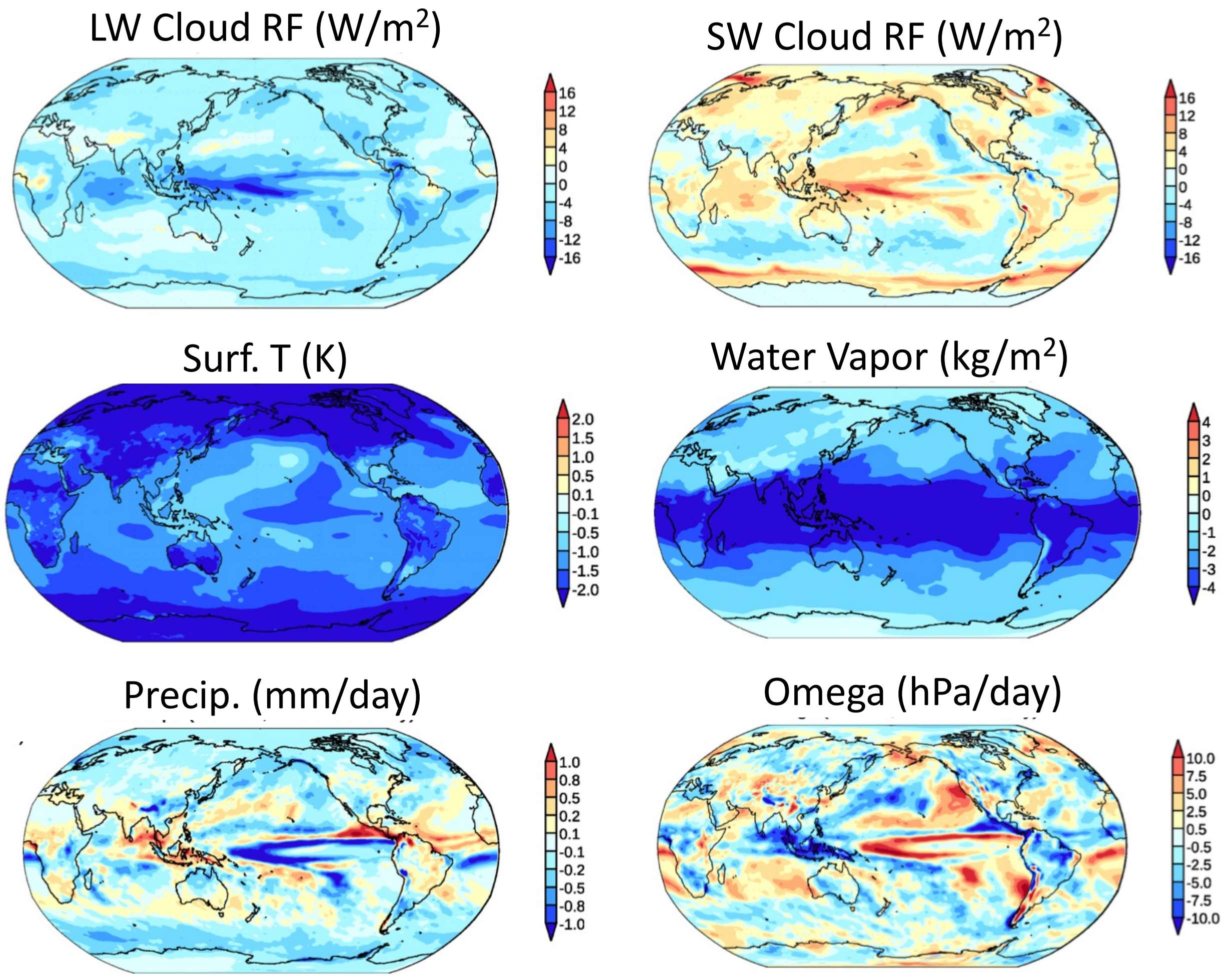
$4\times CO_2$

Cloud Vertical Profile Changes by Ice Fall Speed

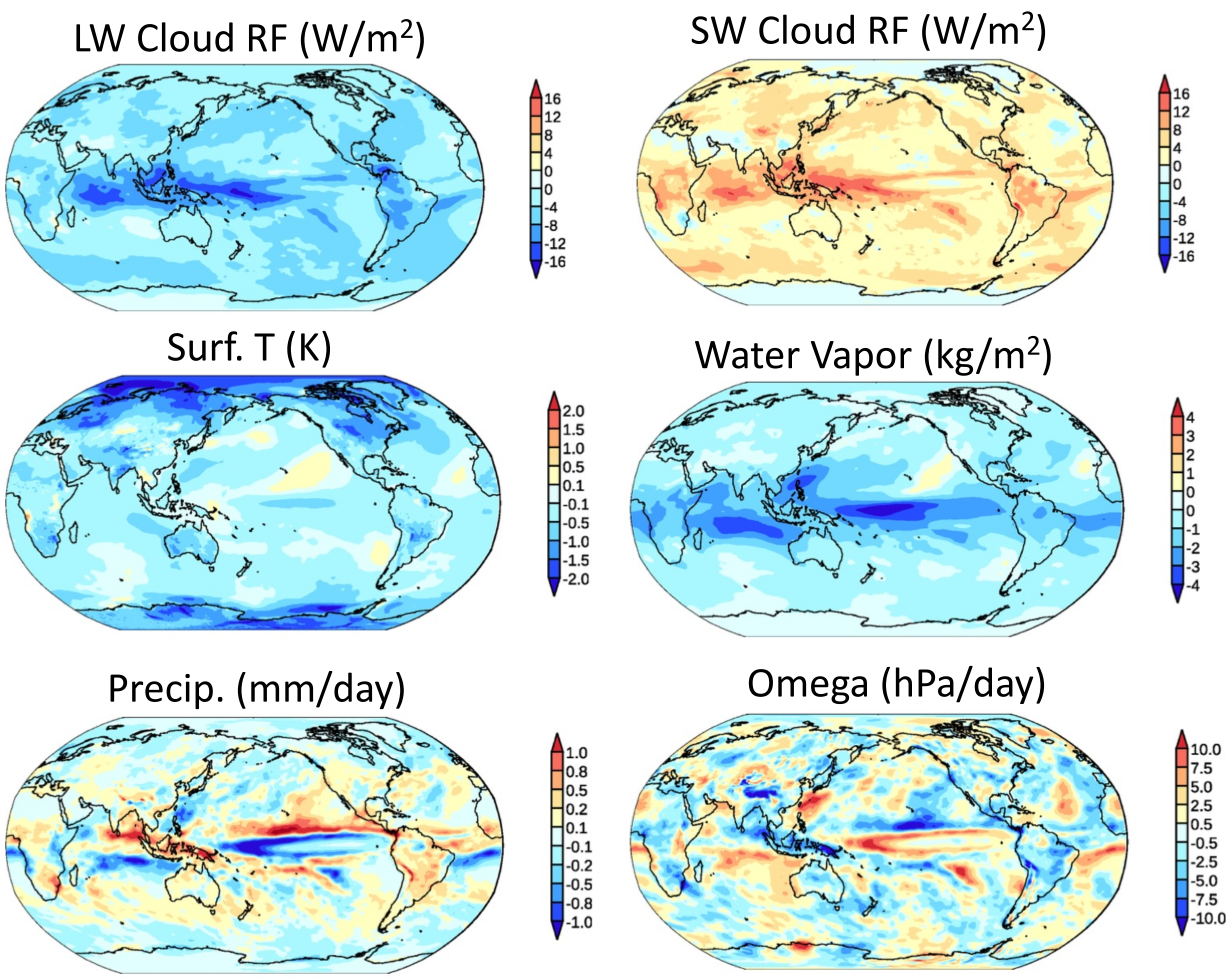


- Larger ice particles settle faster, reducing ice above 350 hPa but enhancing below.
- A reduction in low cloud with larger Rei, due to strong water vapor reduction in PBL.
- General monotonicity holds for cloud responses.

Atmospheric Changes by Increasing R_{ei}

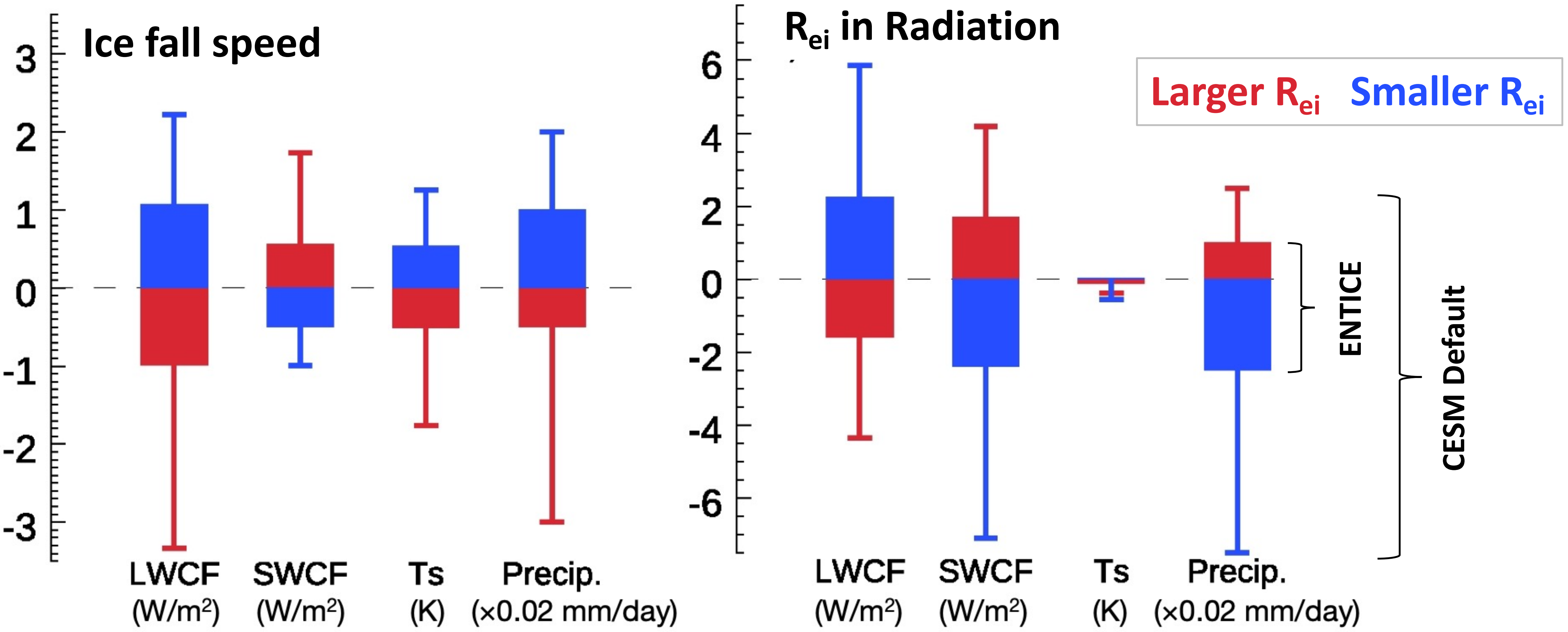


Doubling ai



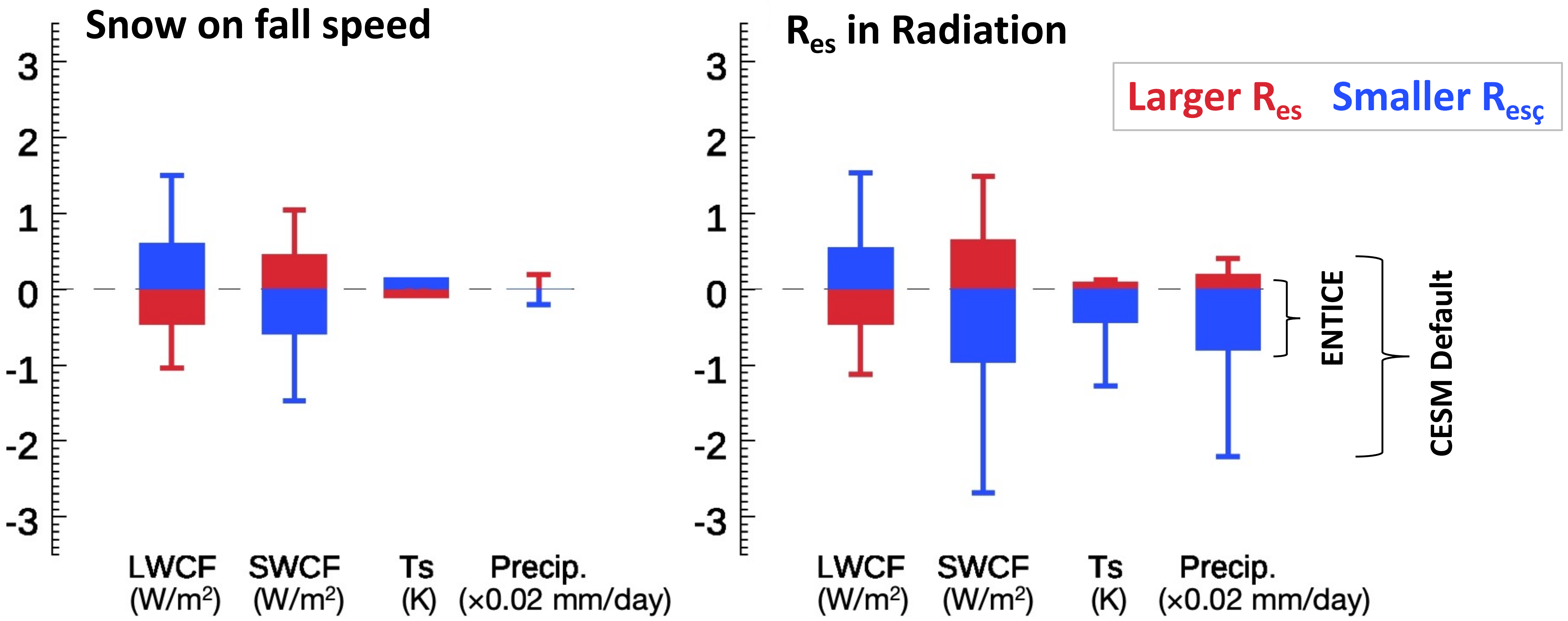
Doubling R_{ei} in radiation

Observational Constraints on Climate Mean States via R_{ei}



- The improvement rate ($1-\text{range}_{ENTICE}/\text{range}_{CESM}$) is about 65%, .
- Muted temperature but significant precip. responses to R_{ei} in radiation.
- General monotonicity generally holds for climate responses.

Observational Constraints on Climate Mean States via R_{es}

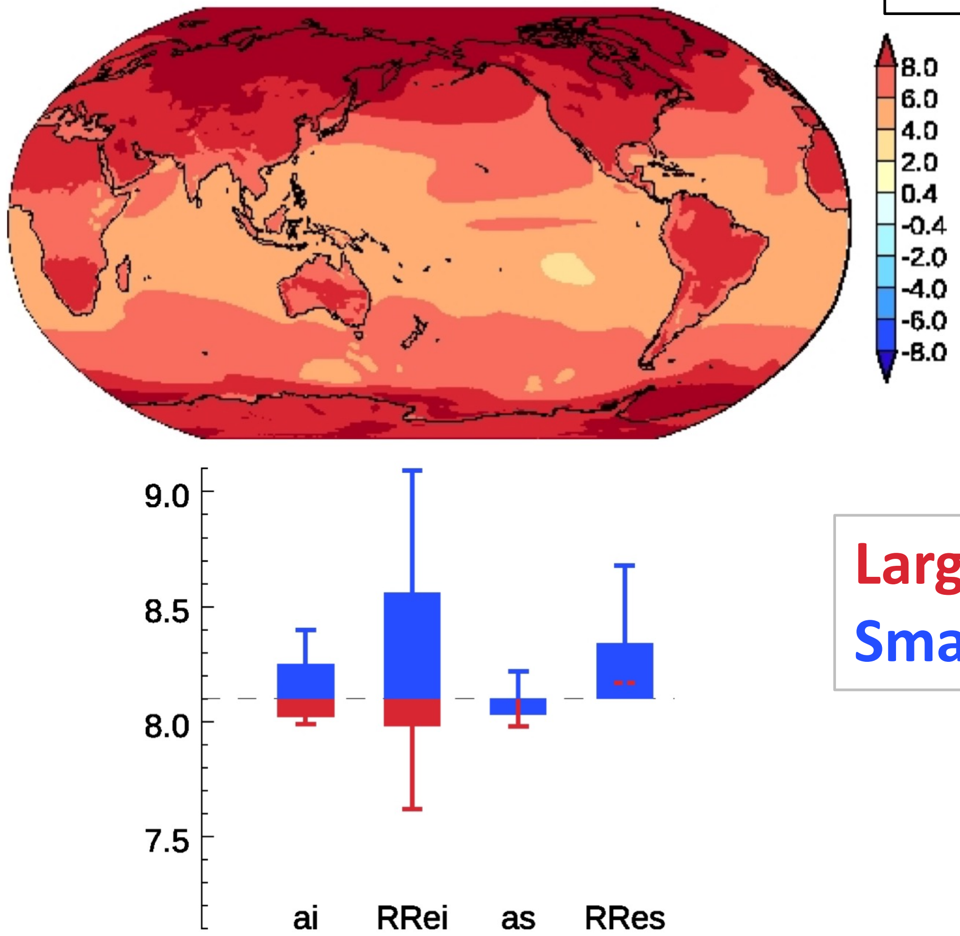


- Much less sensitivity to snow particle size.
- R_{es} effect in radiation is more important than that in microphysics.

Equilibrium Climate Sensitivity

$4\times CO_2$ – PI

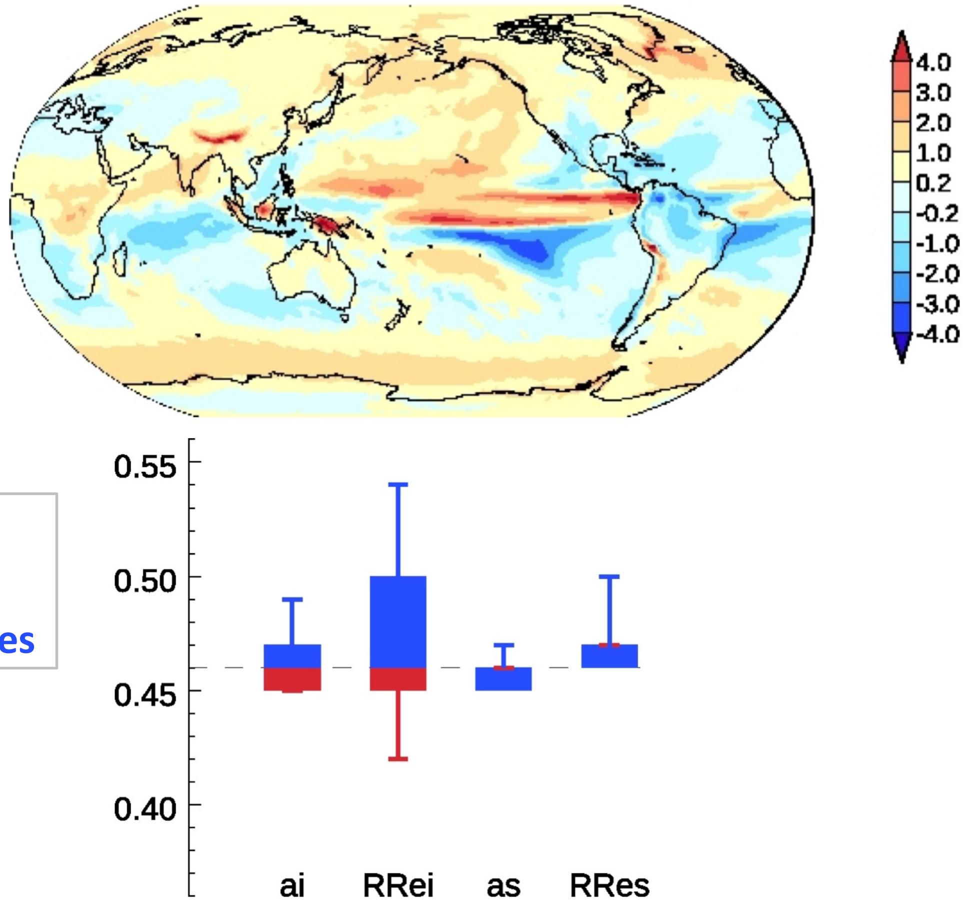
ΔTs (G=8.10, T=5.93 K)



Larger R_{ei}/R_{es}

Smaller R_{ei}/R_{es}

ΔPrecip. (G=0.46, T=0.35 mm/day)



- Ice/snow related parameters can cause a relative change of climate sensitivity from +12.3% to −6.2%..
- ENTICE is expected to reduce the R_{ei} related climate sensitivity uncertainty by 60%.

Summary

- Climate mean states are sensitive to ice particle size.
- A future satellite mission concept ENTICE (radiometer + radar) shows great potential in constraining R_{ei} within 25% uncertain range.
- Our OSSE-type study shows ENTICE can reduce R_{ei} related climate uncertainty by 60%.
- Changes in ice particle size in radiation are important in ECS, with smaller ice particle size, larger climate sensitivity.
- Snow particle size is less important than R_{ei} in determining climate state/sensitivity.

- Wang, Y., H. Su, J. H. Jiang, F. Xu, Y. Yung "Impact of Cloud Ice Particle Size Uncertainty in A Climate Model and Implications for Future Satellite Missions", *J. Geophys. Res.* **125**, 6, https://doi.org/10.1029/2019JD032119, (2020).