Reference Radiative Convective Equilibrium Climate in the Community Atmospheric Model

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RCEMIP (Radiative Convective Equilibrium Model Intercomparison Project)

- Goals and objectives.

-Do atmospheric models of radiative convective equilibrium (RCE) converge to a robust climate state?

-What is the response of clouds to warming and the climate sensitivity in RCE?

-Can RCE simulations inform future model development?

-Models: global parameterized, cloud Resolving, large-eddy simulations, single column, global cloud resolving

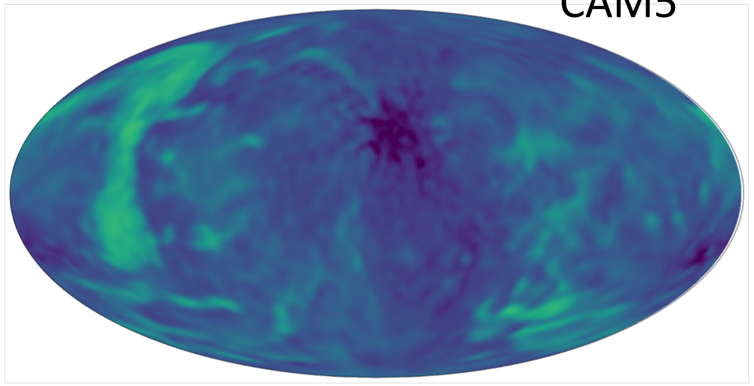
- RCE is: Homogeneous horizontal boundary conditions (temperature, pressure, ozone), no rotation, uniform insolation.

Wing et al., 2018

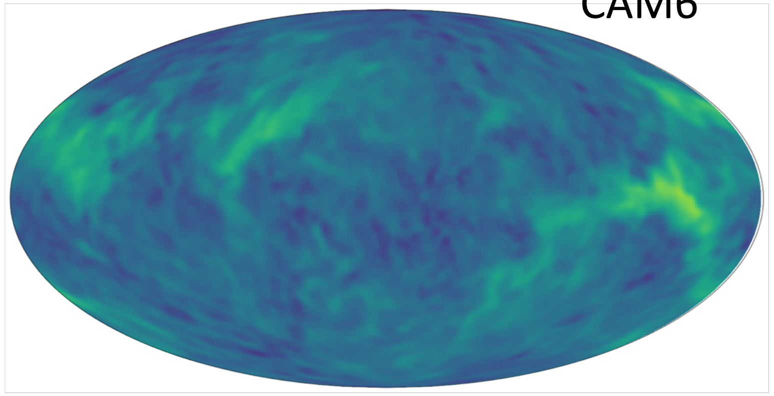
CAM5 and CAM6 Participation in RCEMIP

- Kevin Reed and Brian Medeiros (and probably others) have worked to include CAM5 and CAM6 in RCEMIP.
- New compset: The RCEMIP setup in CAM has been officially released as the QPRCEMIP configuration
- Initial results of the full ensemble of models can be found in Wing et al., 2020 and Becker and Wing, 2020. A more detailed analysis of CAM5 and CAM6 results has been submitted to JAMES (Reed et al.)

CAM5



CAM6



Precipitable Water, Wing et al., 2020

CAM5 vs CAM6

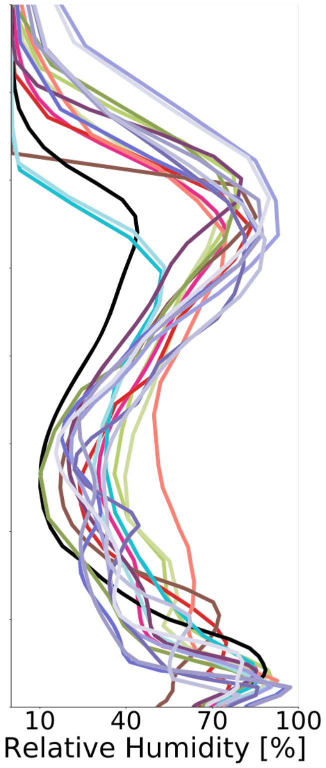
Model Name	CESM1 (CAM5)	CESM2 (CAM6)
Scheme/Component/Item		
Dynamical Core	FV default (SE used here)	Same as CAM5
Radiation	RRTMG	Same as CAM5
Turbulence	- BL (moist turb) - Grid-scale condensation - Shallow-convection	CLUBB
Deep Convection	Zhang-McFarlane	Zhang-McFarlane (minor changes)
Cloud Micro-Physics	MG1 (Mrrsn & Gman, 2008)	MG2 (Gman & Mrrsn, 2015)
Orog Drag	TMS (turb mtn stress)	New (Bejaars et al., 2004)
Grid Spacing	nominal 1 deg	Nominal 1 deg
Vert Levels	30 (2.26 hPa top)	32 (2.26 hPa top)
Prog. Variables (dyn)	u,v,T, dry air mass, tracer mass	Same as CAM5
Prog. Variables (phy)	ql, qi, black C, organic C, sea salt, dust, sulfate	Same as CAM5 plus qi and qs
Conserved Variables	AAM, total moist energy, total water mass, momentum, dry mass	Same as CAM5

Lauritzen et al., 2018, 2019
Williamson et al., 2015

RCEMIP

- Basic findings from Wing et al. 2020, surprises in the results…

RCE, Parameterized Convection



RCE, CRM, Explicit Convection

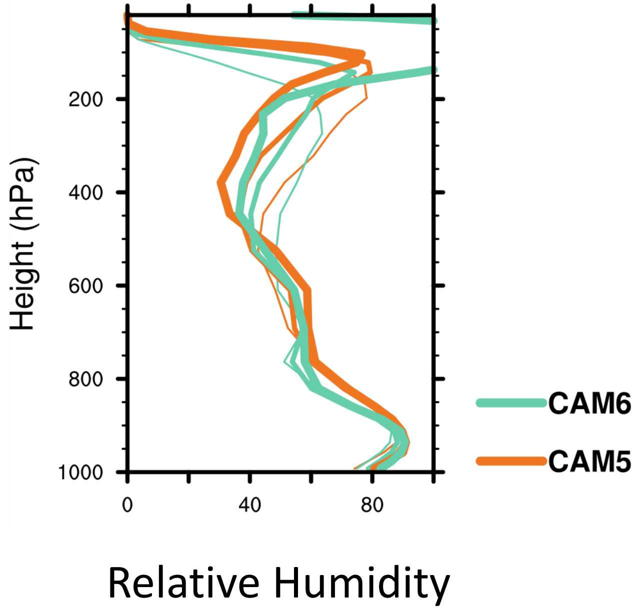
Key Points:

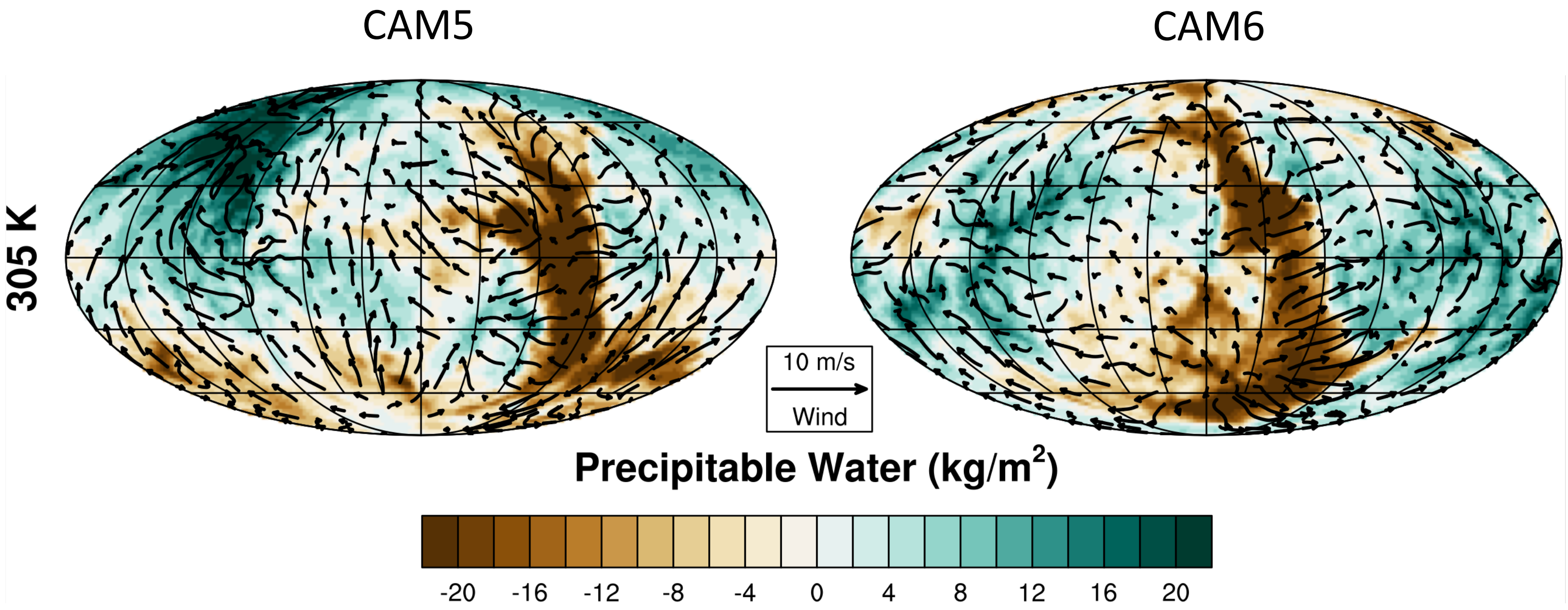
- Temperature, humidity, and clouds vary substantially across the models
- There is no consistency in how self-aggregation depends on warming
- GCMs do show a mean increase of convective aggregation with warming

Wing et al., 2020
Becker and Wing, 2020

Results: CAM5 and CAM6

- CAM5 and CAM6 look remarkably similar





Results: CAM5 and CAM6

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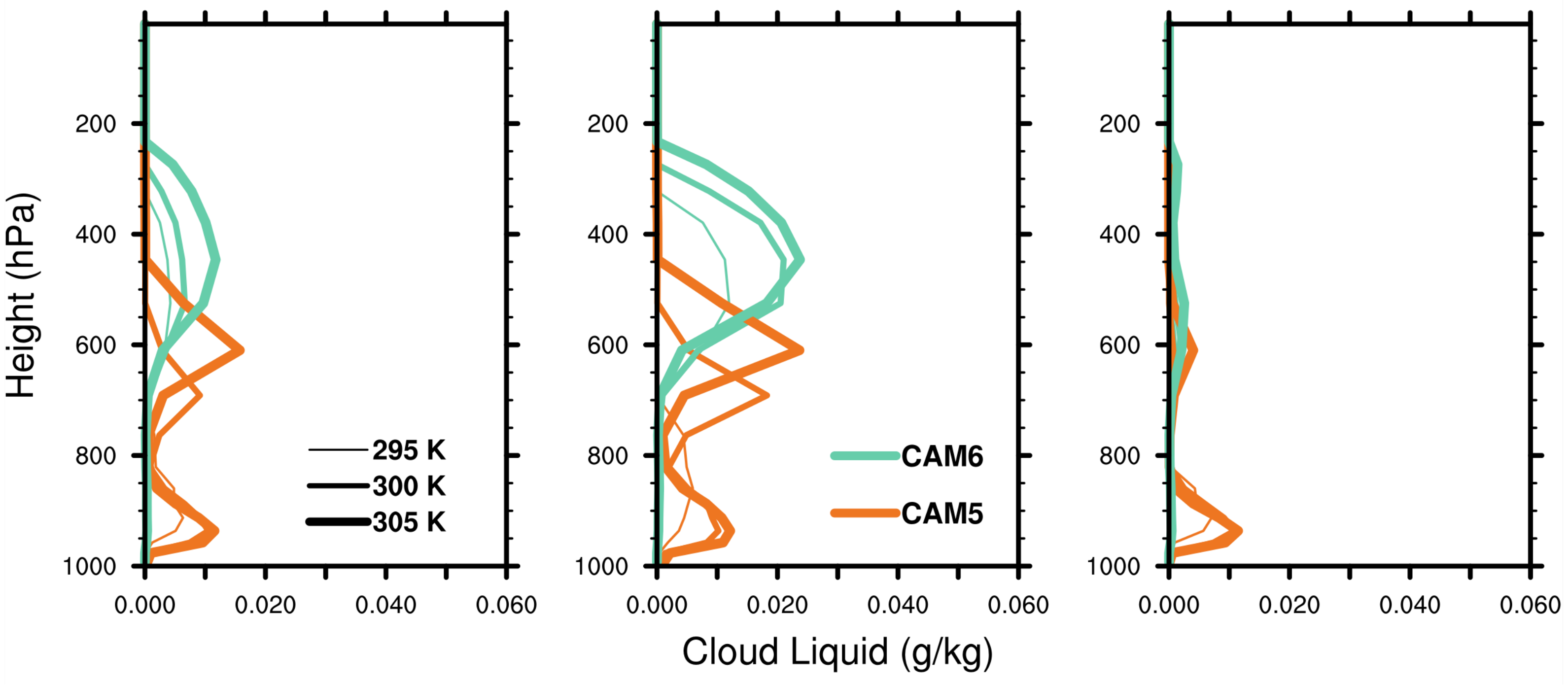
- CAM5: larger mean precipitation rates, more precipitable water, larger cloud fraction and lower OLR
- The subsidence fraction inconclusive between the models

Model	SST (K)	$\overline{\mathrm{P}}$ (mm/day)	$\overline{\mathrm{PW}}$ (kg/m^2)	$\overline{\mathrm{CF}}$	$\overline{\mathrm{OLR}}$ (W/m^2)	$\overline{\mathrm{SF}}$
	295	2.43	23.43	0.61	239.83	0.71
CAM5	300	3.34	36.64	0.57	257.91	0.74
	305	3.99	54.65	0.51	271.52	0.74
	295	2.28	21.41	0.56	245.42	0.70
CAM6	300	2.93	31.72	0.49	260.68	0.77
	305	3.74	51.48	0.96	270.63	0.76

Results: CAM5 and CAM6

- CAM5 and CAM6 look substantially different:

- CAM6 shows a surprising lack of cloud liquid below 700 hPa for all three experiments.
- Cloud Liquid peaks above 700 hPa are substantially higher up compared to CAM5.
- Hypothesis: CAM6 boundary layer too diffuse leading to strong vertical transport of cloud liquid



Mean

Subsidence

Upwelling

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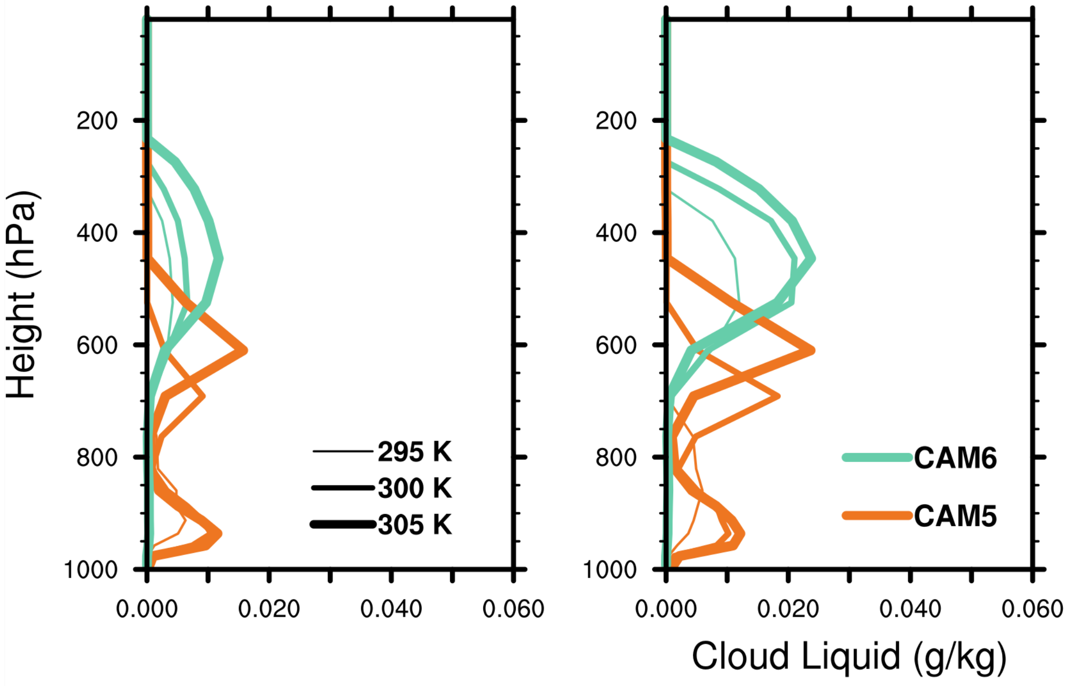
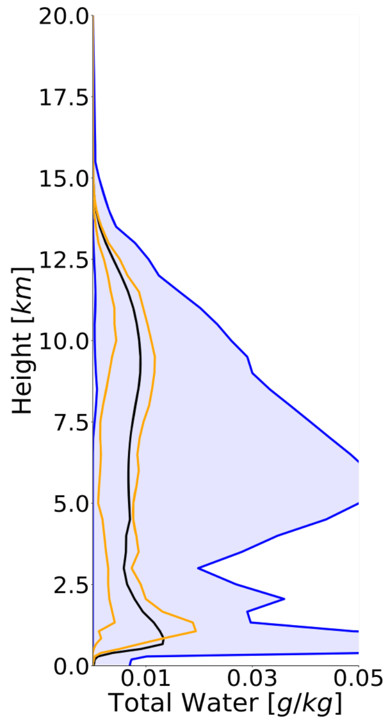


Mean

Subsidence



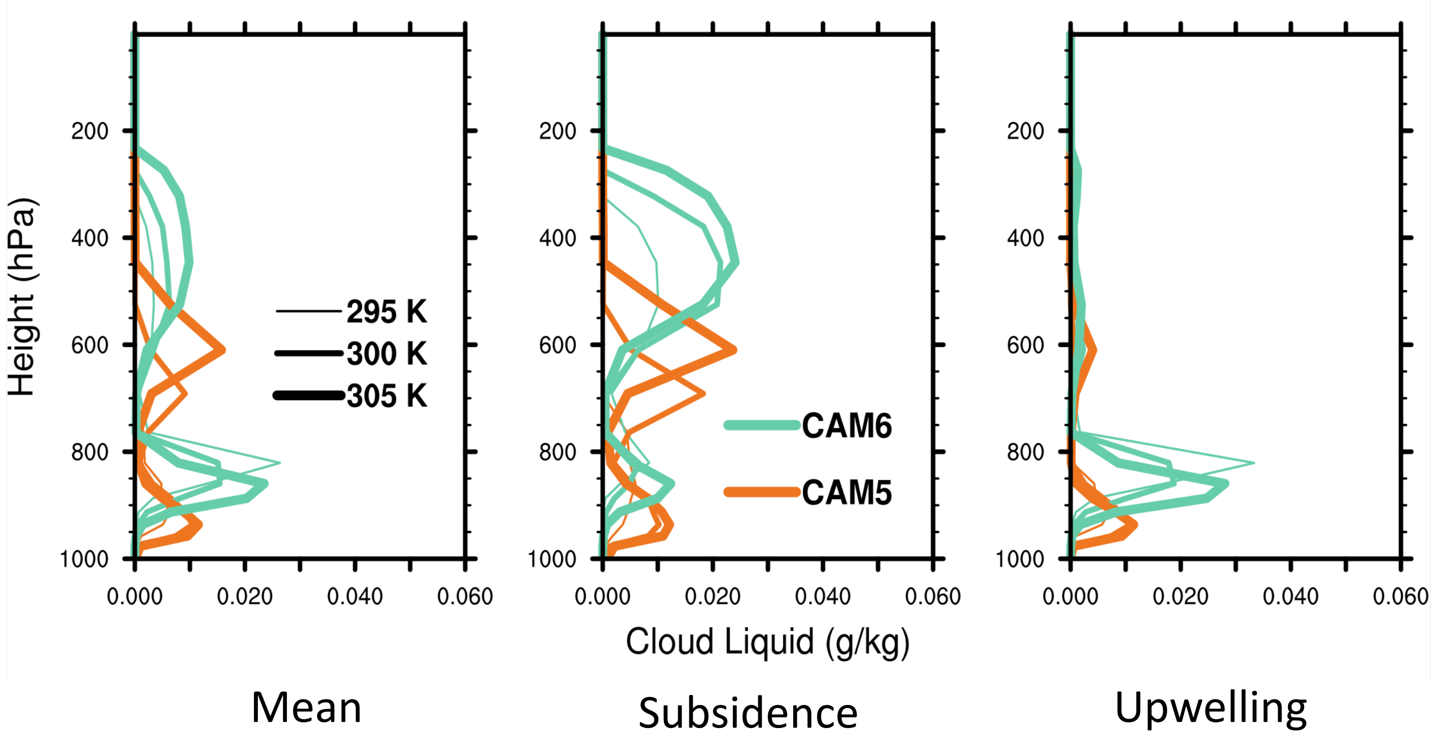
RCEMIP
Wing et al., 2020

Results: CAM5 and CAM6

- CAM5 and CAM6 look substantially different:

- Decreasing the width of vertical velocity PDF in CLUBB is expected to decrease upward vertical mixing and increase low-level clouds (Gettelman et al., 2019).

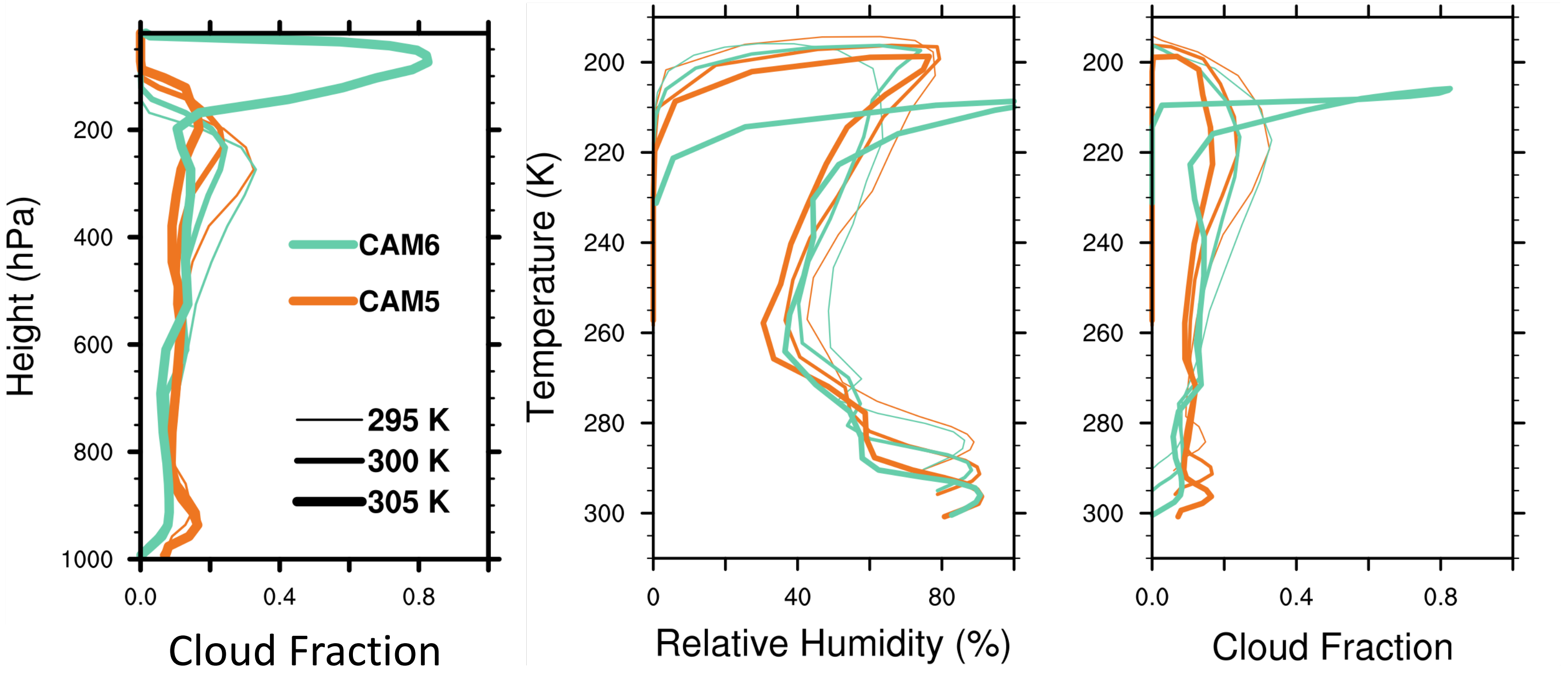
- Peaks of cloud liquid are still higher up in CAM6 than in CAM5.



Results: CAM5 and CAM6

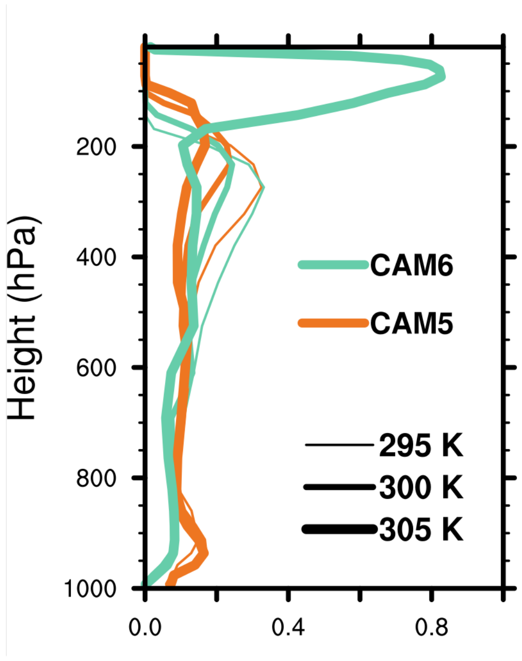
- The CAM6 eyesore:

- For the experiment with a constant SST of 305K CAM6 produces what appears to be unrealistically large upper level clouds and a RH of 100%.
- Experiments with decreased ice concentration number show decreasing upper level cloud.
- Experiments with decreased gamma (width of w PDF) do not impact (much) the anvil cloud fraction.

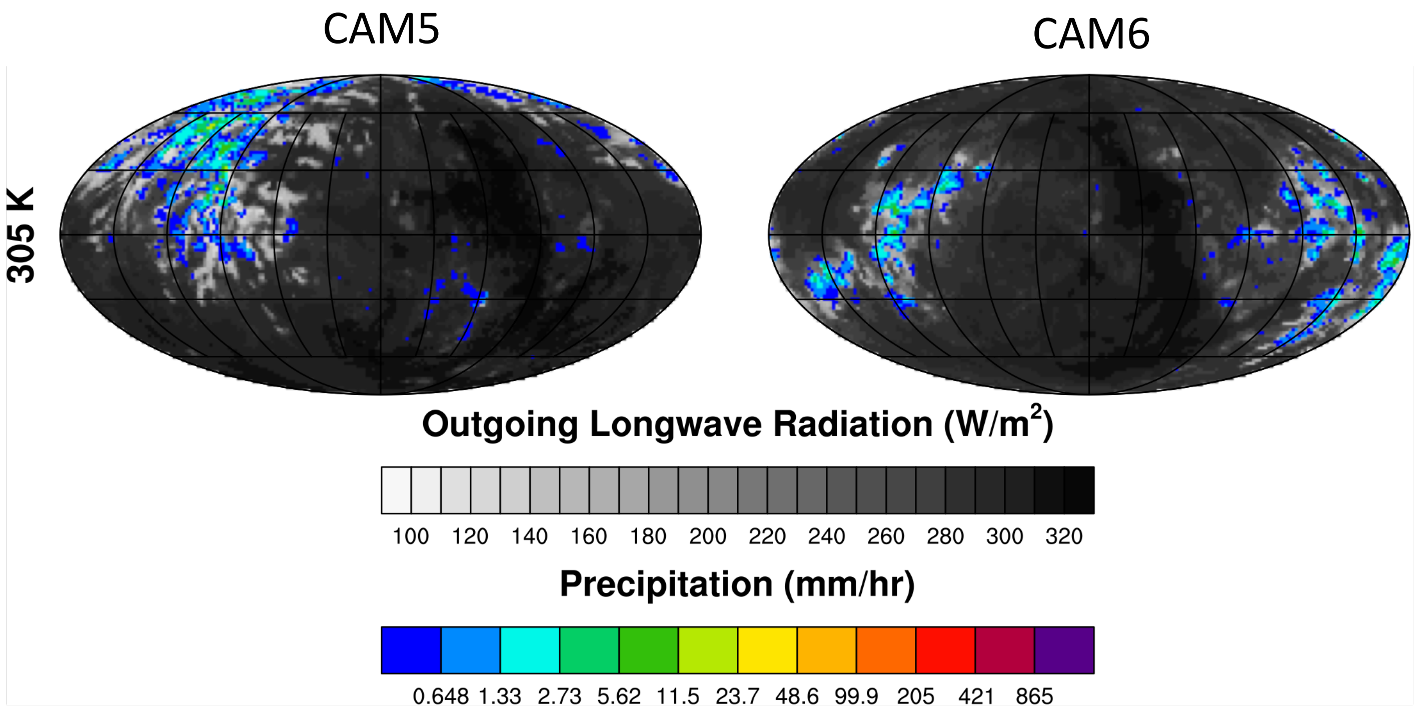


Results: CAM5 and CAM6

- The CAM6 eyesore:



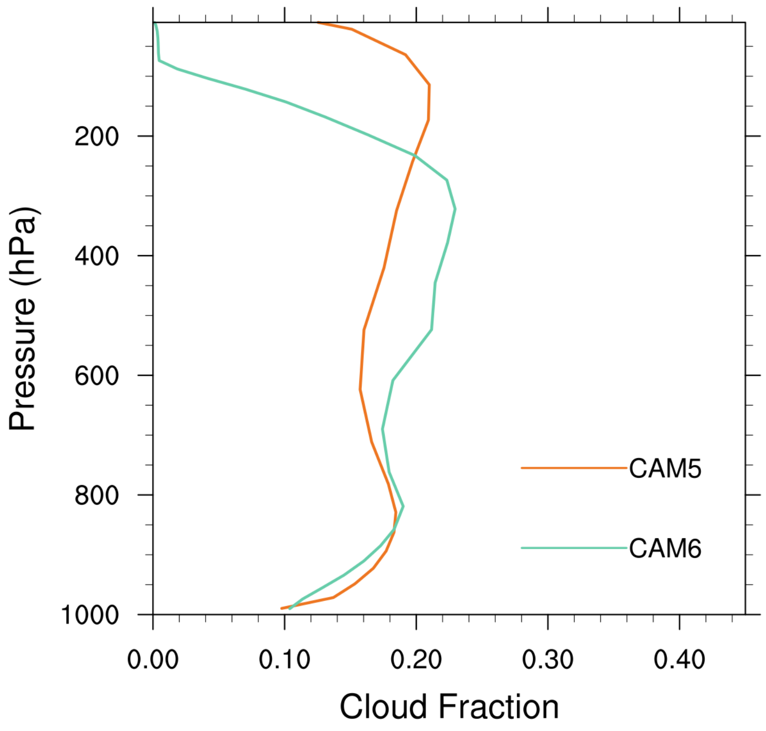
Cloud Fraction



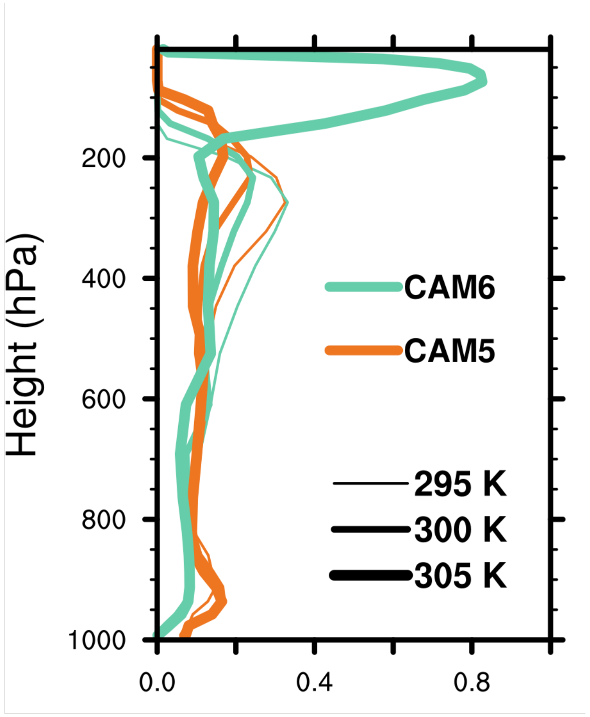
- The OLR and domain mean statistics do not seem to dominate the OLR or global mean statistics.

How similar are the clouds in RCE to those in CESM1 and CESM2?

Global Mean Cloud Fraction from Pre-Industrial Control



RCE



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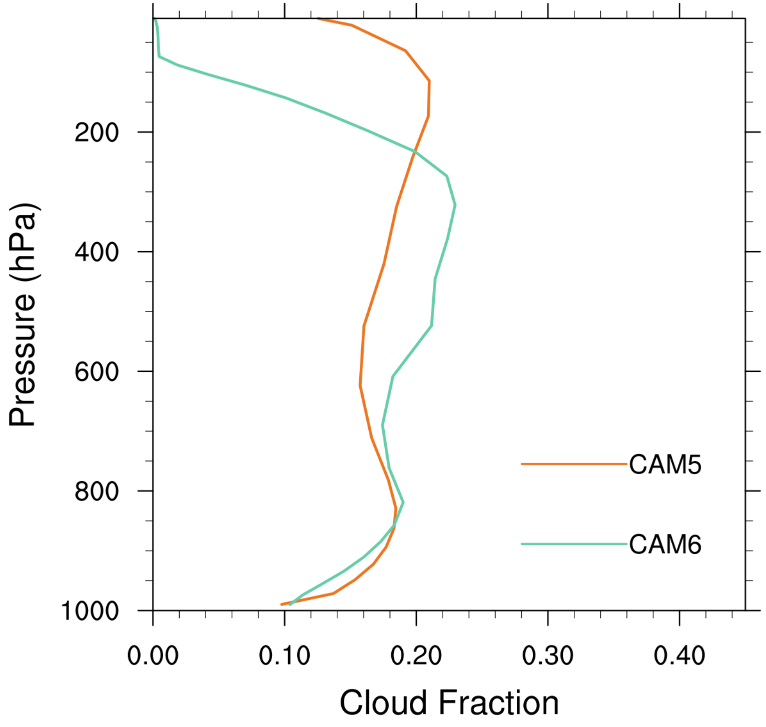
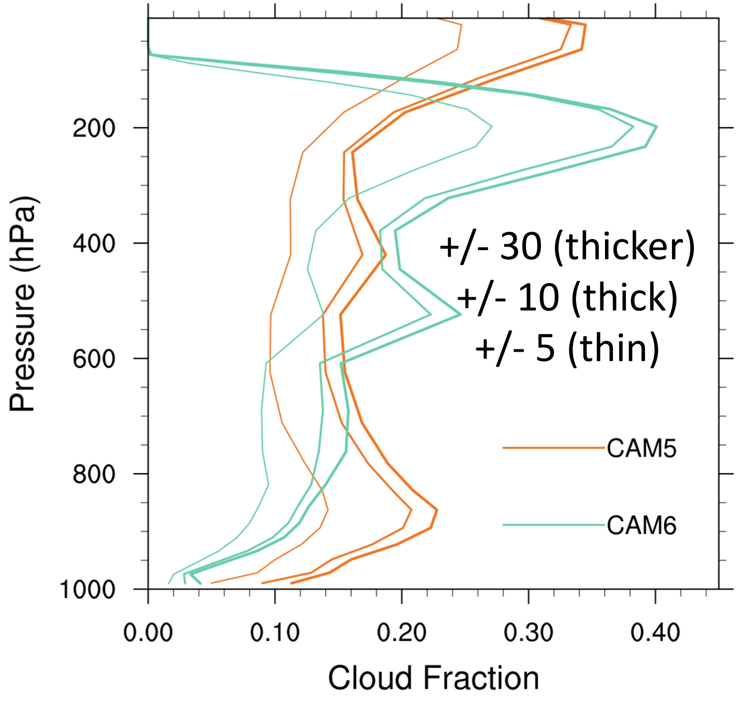
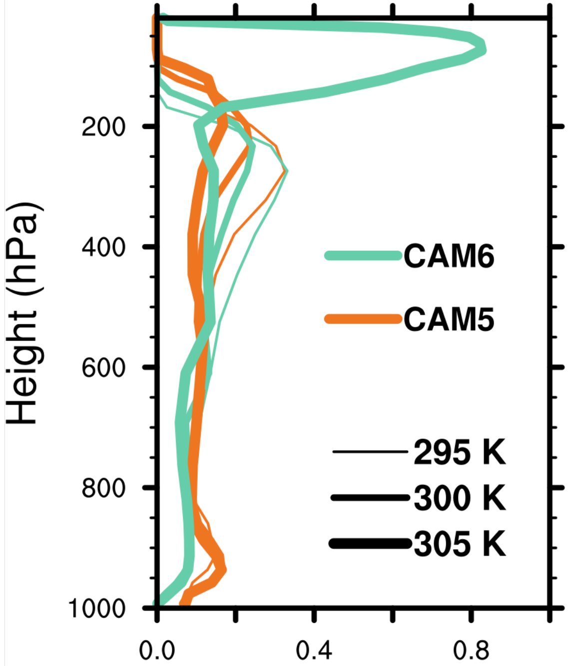


Tropical Cloud Fraction from Pre-Industrial Control

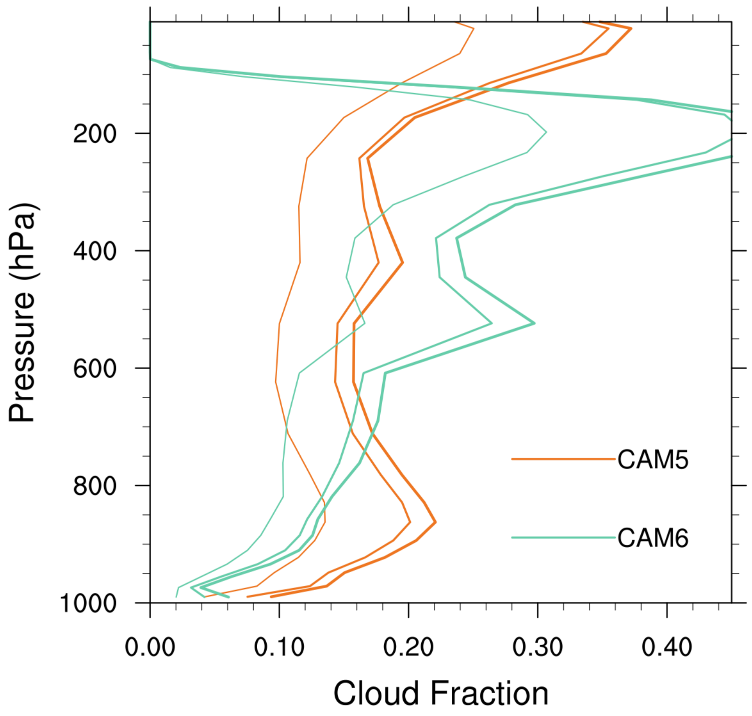


RCE

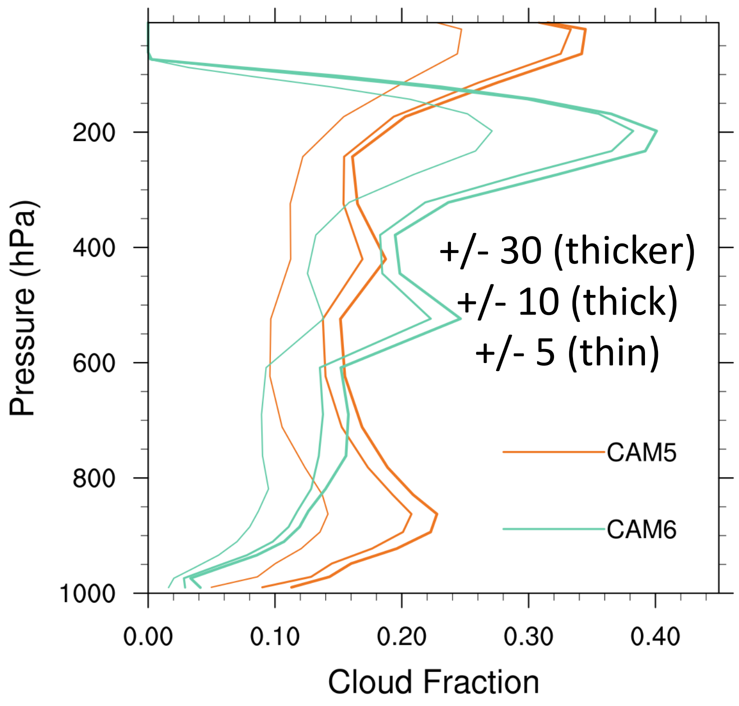


How similar are the clouds in RCE to those in CESM1 and CESM2?

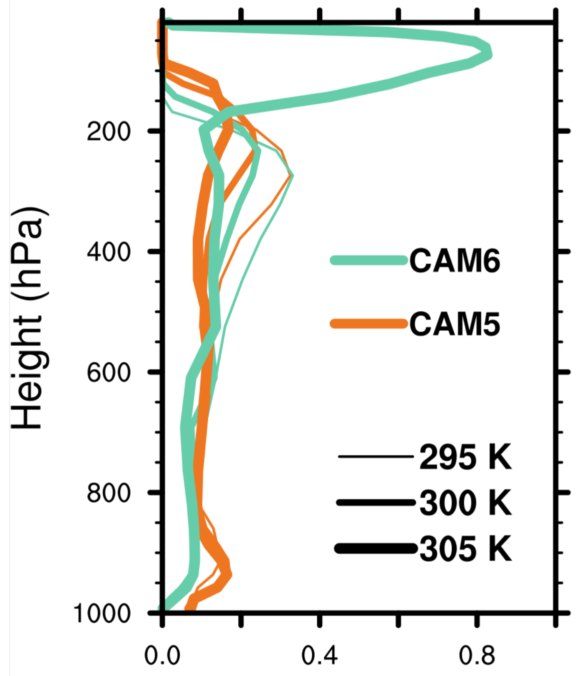
Global Mean Cloud Fraction from AMIP



Tropical Cloud Fraction from Pre-Industrial Control



RCE



Climate Feedback Parameters and Climate Sensitivity

- Well documented increase of sensitivity with model version
- Can we use simpler model configurations to understand the driving factors of the climate sensitivity?
- CAM6 305K case remains perplexing and highlights the need to better understand the connection between deep, shallow, and low-level clouds in the tropics.

Model	Sensitivity (K)	Method	Configuration	Reference
CAM4	3.2	2xCO_2	GCM & SOM	Gettelman et al. (2012)
CAM5	4.0	2xCO_2	GCM & SOM	Gettelman et al. (2012)
CAM5	4.0	2xCO_2	GCM & SOM	Gettelman, Hannay, et al. (2019)
CAM6	5.3	2xCO_2	GCM & SOM	Gettelman, Hannay, et al. (2019)
CAM4	1.7	+4K	Aquaplanet	Medeiros et al. (2015)
CAM6	2.5	+4K	Aquaplanet	Presented here
CAM5	0.8;1.7	+5K	RCEMIP	Presented here
CAM6	1.2;1.5	+5K	RCEMIP	Presented here

For CESM Sensitivity analysis see Meehl et al., 2020, Bacmeister et al., 2020

Conclusions

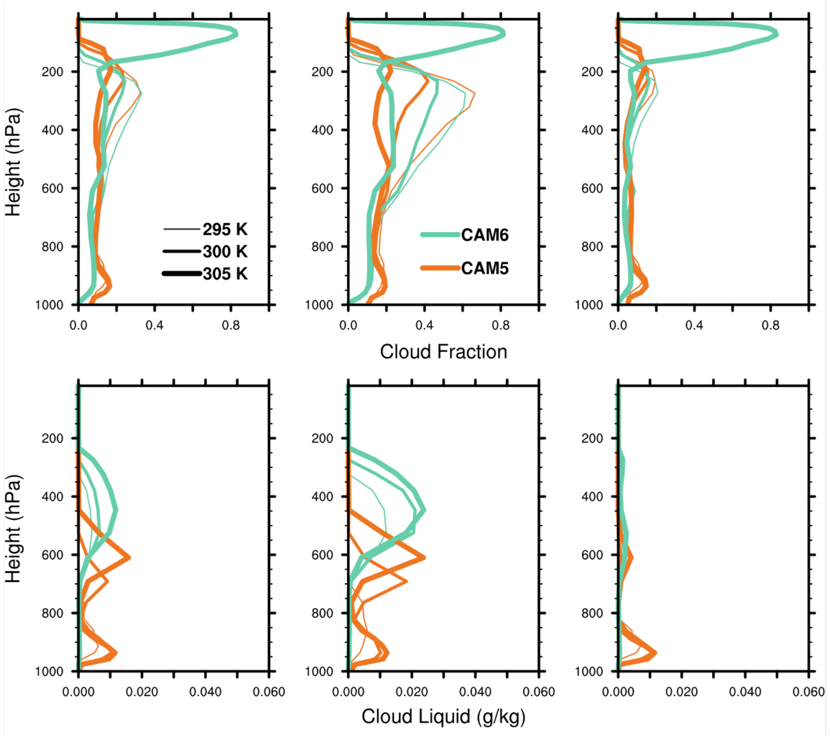
- A new compset has been released, allowing users to easily run RCE experiments with CAM models.
- These experiments are relatively inexpensive and provide a useful framework for both testing parameterizations and advancing our understanding.
- CLUBB appears to decrease cloud fraction and nearly eliminate cloud liquid in the tropical lower troposphere in RCE, piControl, and AMIP. Is CLUBB overly diffusive?

Papers documenting and using the RCE CAM compset:

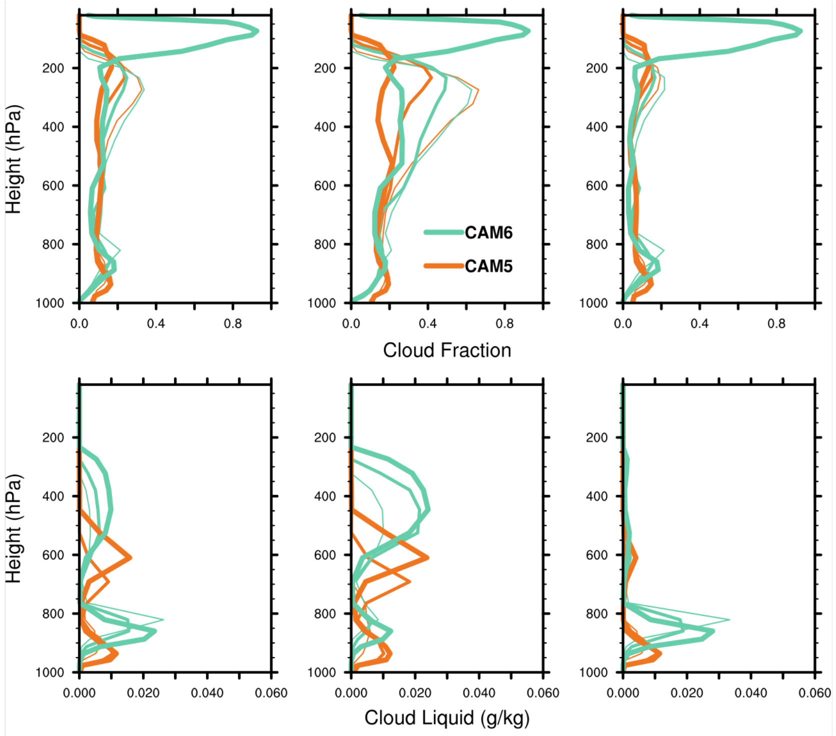
Reed et al., Reference RCE climate in the Community Atmospheric Model, *submitted*

Silvers et al., The Response of the Large-Scale Tropical Circulation to Warming, *in preparation*

Gamma sensitivity studies in CLUBB:



gamma = 0.308



gamma = 0.1