♍

CLUBB in the Community Atmosphere Model as part of CESM2 and Beyond

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Overview

- What is CLUBB? How is it used in CAM6 and CESM2?
- Recent encouraging results from coupled simulations
- CLUBB as a fully unified convective parameterization in CAM7?

What is CLUBB?

- CLUBB = Cloud Layers Unified By Binormals

- First developed by Golaz et al. (2002), Larson and Golaz (2003), maintained by University of Wisconsin Milwaukee (Vincent Larson's group)

➡ Higher Order Closure Parameterizations

  - The equations used in convective parameterizations require information about the sub-grid fluxes of heat, moisture, and (often) momentum. Diagnosing these fluxes is a major goal of most cloud models.

  - Rather than making assumptions to diagnose the terms, HOC parameterizations predict (prognose) these fluxes directly.

- CLUBB is an "Incomplete" third-order turbulence closure (predicting 9 second and third order moments), centered around a trivariate assumed double gaussian (binormal) PDF. $P(\theta_l, q_t, w)$

Classic Cloud Parameterizations

A cloud and turbulence parameterization needs to supply subgrid-scale fluxes of heat, moisture, and momentum (and PDFs of cloud fraction and liquid water for microphysics and radiation):

Moisture

$$\frac{\partial \bar{r}_t}{\partial t} = -\bar{w}\frac{\partial \bar{r}_t}{\partial z} - \frac{\partial}{\partial z}\overline{w'r_t'} + \overline{\text{Microphys}}$$

Heat

$$\frac{\partial \bar{\theta}_l}{\partial t} = -\bar{w}\frac{\partial \bar{\theta}_l}{\partial z} - \frac{\partial}{\partial z}\overline{w'\theta_l'} + \overline{\text{Radiation}} + \overline{\text{Microphys}}$$

Momentum

$$\frac{\partial \bar{u}}{\partial t} = -\bar{w}\frac{\partial \bar{u}}{\partial z} - f(v_g - \bar{v}) - \frac{\partial}{\partial z}\overline{u'w'}$$

$$\frac{\partial \bar{v}}{\partial t} = -\bar{w}\frac{\partial \bar{v}}{\partial z} + f(u_g - \bar{u}) - \frac{\partial}{\partial z}\overline{v'w'}$$

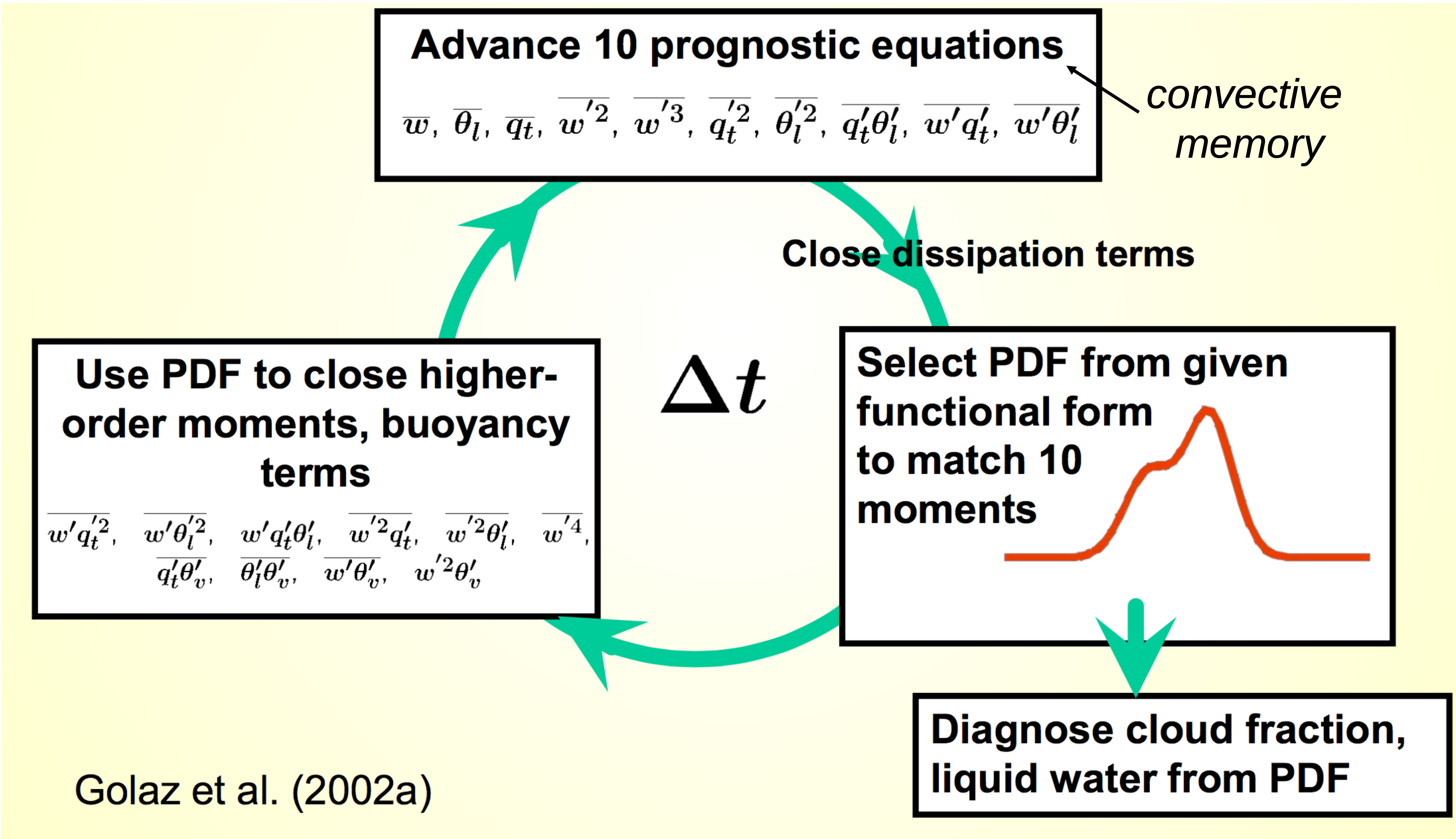
Red and Magenta = calculated by host model

Blue = calculated by parameterization

[1]Peter Stone of MIT.

V. Larson, “CLUBB: How it works”, AMWG Feb 2015

CLUBB Model Description



V. Larson, “CLUBB: How it works”, AMWG Feb 2015

CLUBB Model Description

$r_t'^2$ = Variance of total water (vapor+liquid) mixing ratio.

The $r_t'^2$ equation is derived by Reynolds averaging the advection-diffusion equation:

$$\frac{\partial \overline{r_t'^2}}{\partial t} = \underbrace{-\bar{w}\frac{\partial \overline{r_t'^2}}{\partial z}}_{\text{Mean Adv}} \underbrace{-\frac{\partial \overline{w' r_t'^2}}{\partial z}}_{\text{Turb Transport}} \underbrace{-2\overline{w' r_t'}\frac{\partial \bar{r}_t}{\partial z}}_{\text{Turb Prod}} \underbrace{-2\kappa\overline{\vec{\nabla} r_t' \cdot \vec{\nabla} r_t'}}_{\text{Dissipation}} \underbrace{+\frac{\partial}{\partial z}\left(K\frac{\partial}{\partial z}\overline{r_t'^2}\right)}_{\text{Background Dissip}}$$

For instance, the turbulent transport term, $w'r_t'^2$, is closed by integration over the PDF:

$$\overline{f(x)} = \int P(x) f(x) dx$$

This ensures a consistent closure for all terms closed using the PDF.

V. Larson, "CLUBB: How it works", AMWG Feb 2015

CLUBB Model Description

We use a three-dimensional PDF of vertical velocity, total water mixing ratio, and liquid water potential temperature:

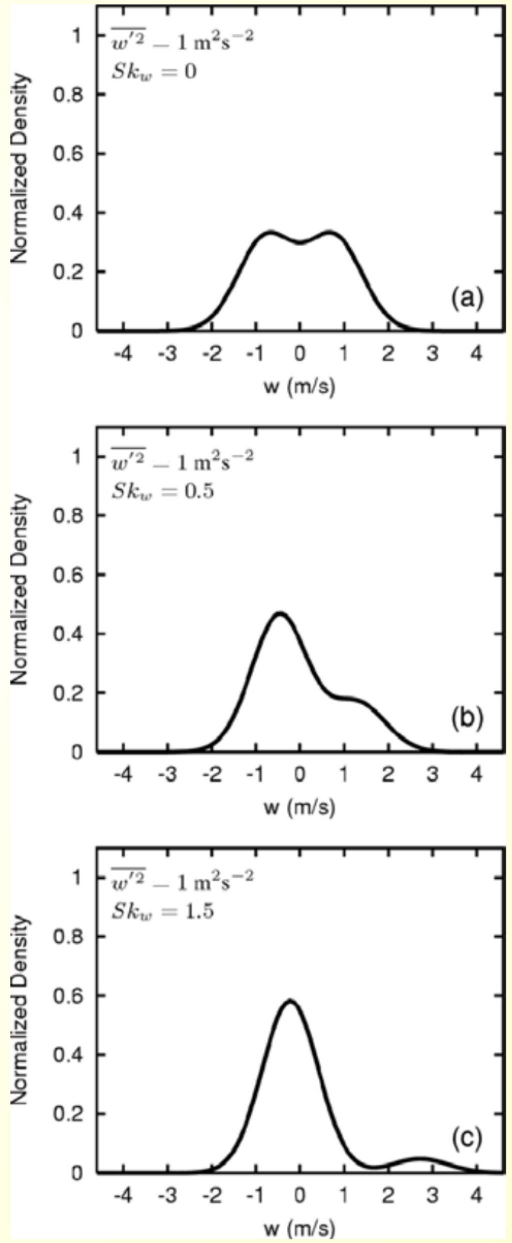
$$P = P(w, q_t, \theta_l)$$

CLUBB's PDF is multivariate.

A double Gaussian PDF is the sum of two Gaussians. It satisfies *three important properties*:

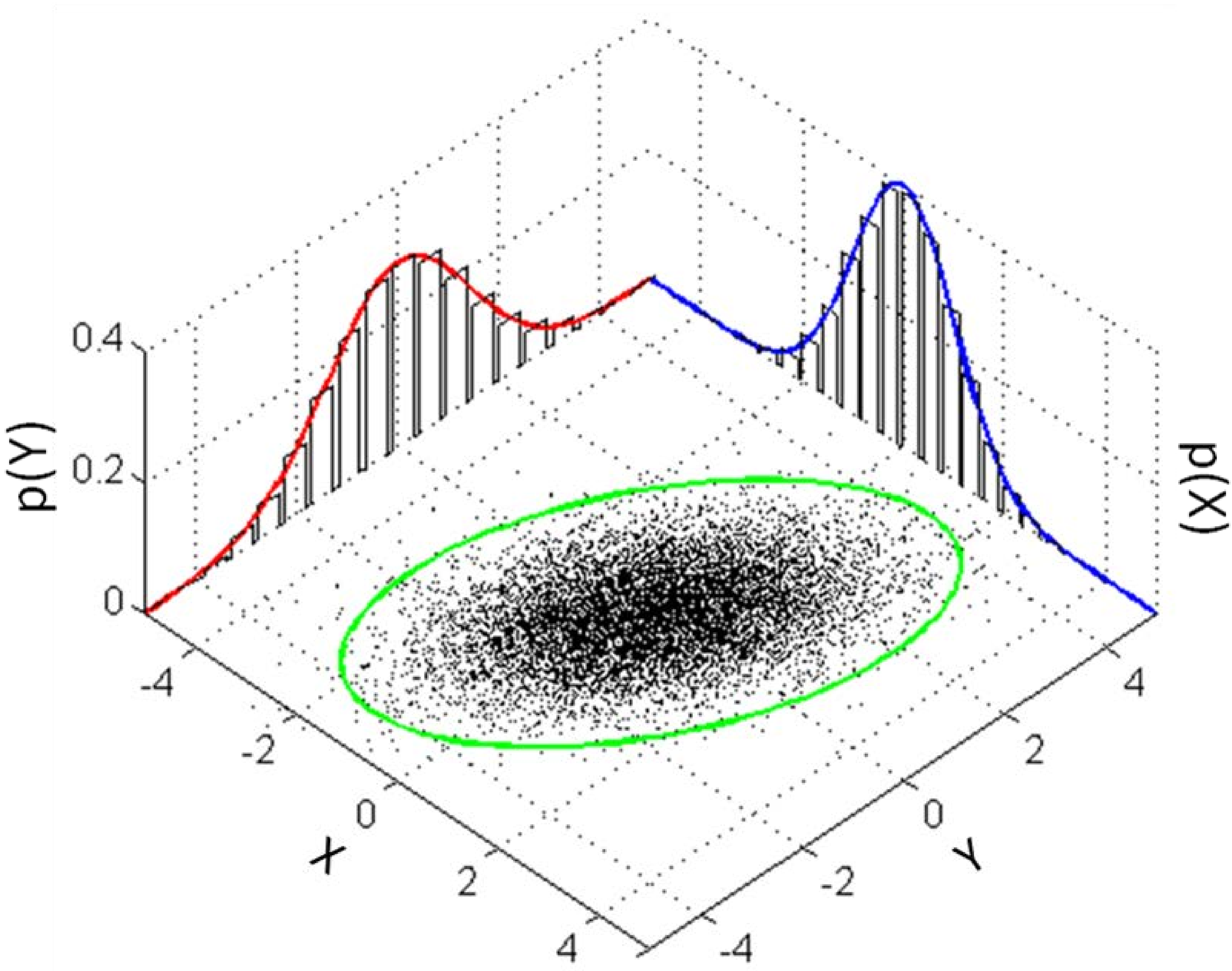
(1) It allows both negative and positive skewness.
(2) It has reasonable-looking tails.
(3) It can be multi-variate.

We do not use a completely general double Gaussian, but instead restrict the family in order to simplify and reduce the number of parameters.

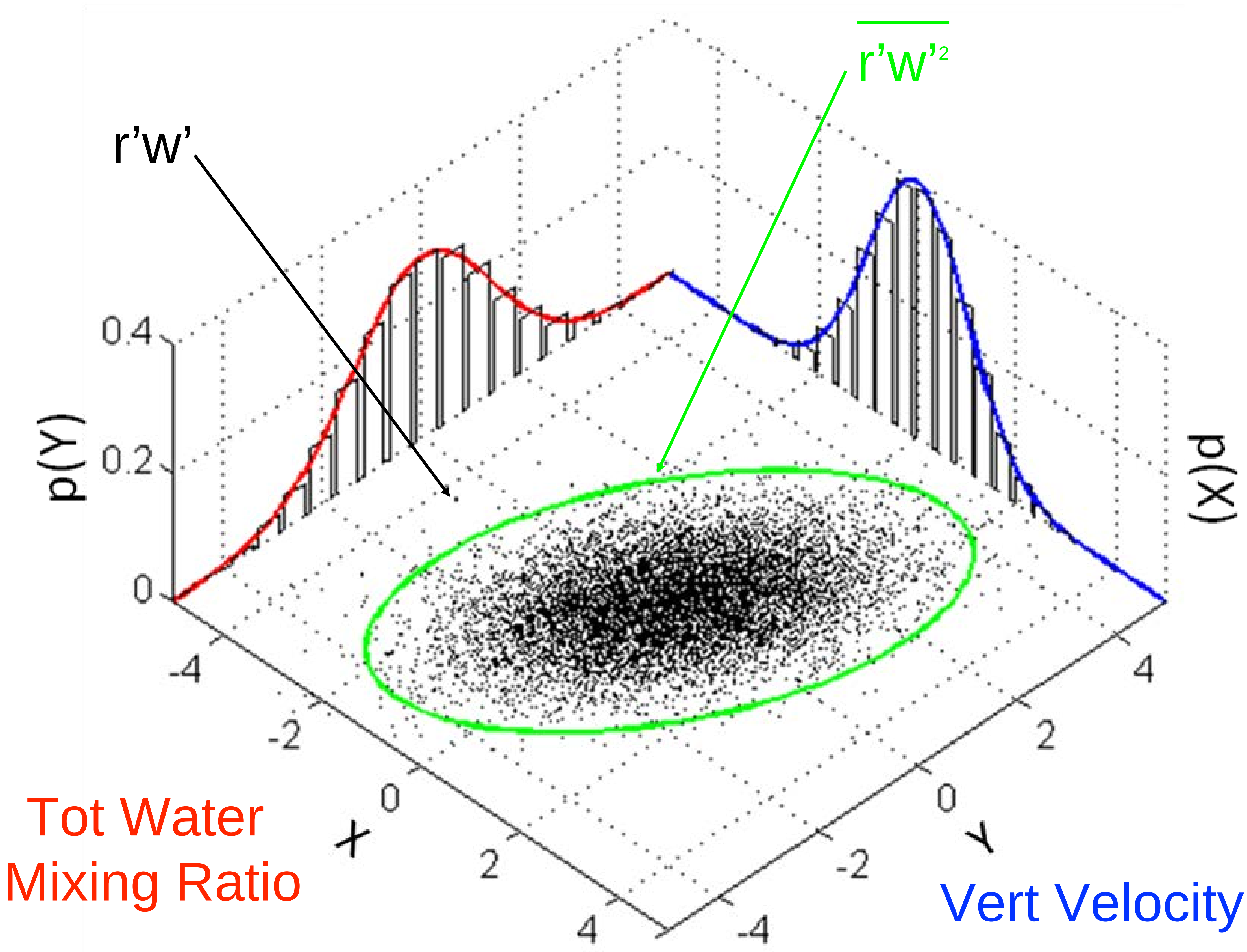


V. Larson, "CLUBB: How it works", AMWG Feb 2015

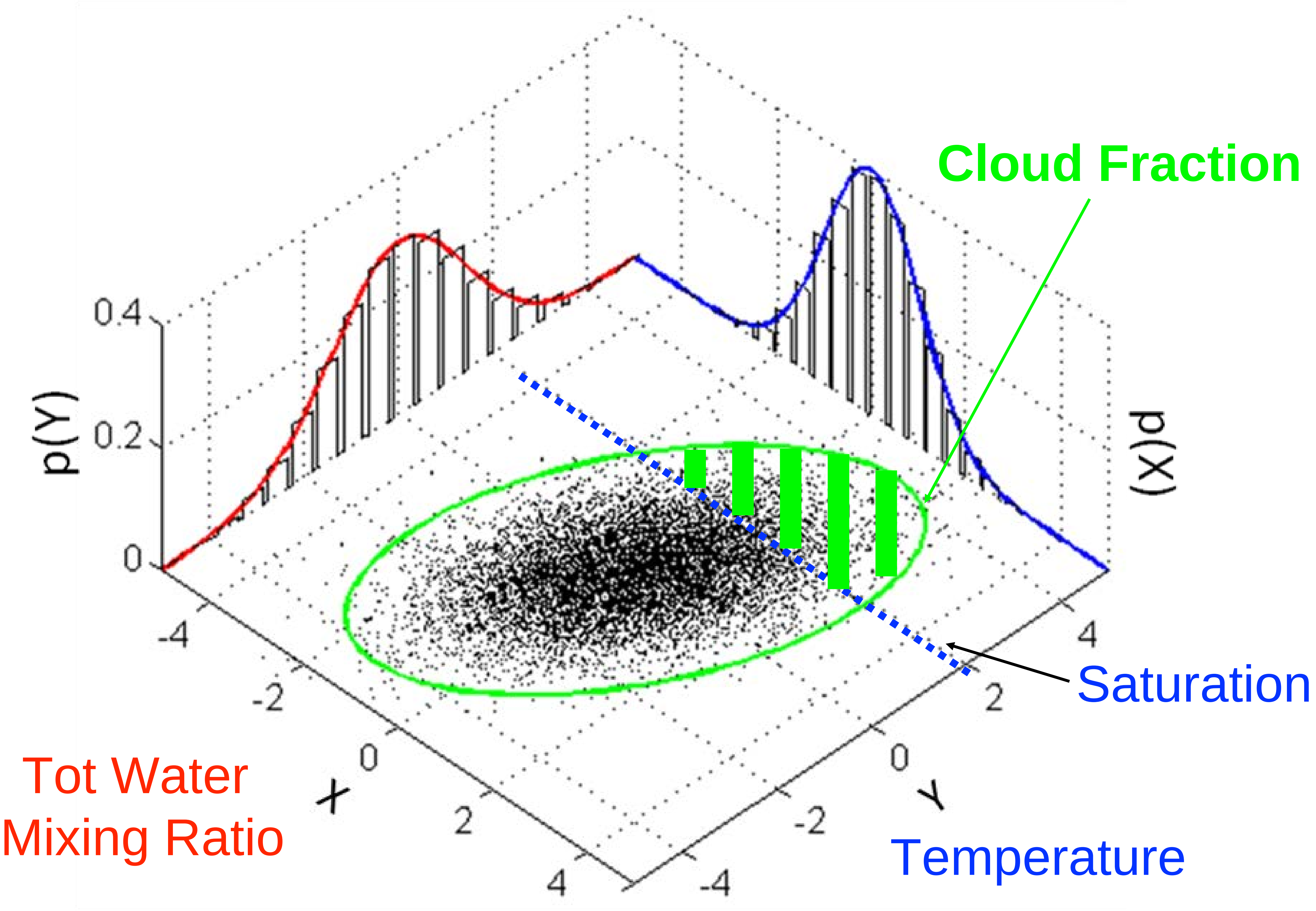
CLUBB Model Description



CLUBB Model Description



CLUBB Model Description



CLUBB Model Description

- Length scale contributes to scale insensitivity

$$\underbrace{\frac{\partial \overline{r_t'^2}}{\partial t} = -\bar{w}\frac{\partial \overline{r_t'^2}}{\partial z}}_{\text{Mean Adv}} \underbrace{-\frac{\partial \overline{w' r_t'^2}}{\partial z}}_{\text{Turb Transport}} \underbrace{-2\overline{w' r_t'}\frac{\partial \bar{r}_t}{\partial z}}_{\text{Turb Prod}} \underbrace{-2\kappa \overline{\vec{\nabla} r_t' \cdot \vec{\nabla} r_t'}}_{\text{Dissipation}} \underbrace{+\frac{\partial}{\partial z}\left(K\frac{\partial}{\partial z}\overline{r_t'^2}\right)}_{\text{Background Dissip}}$$

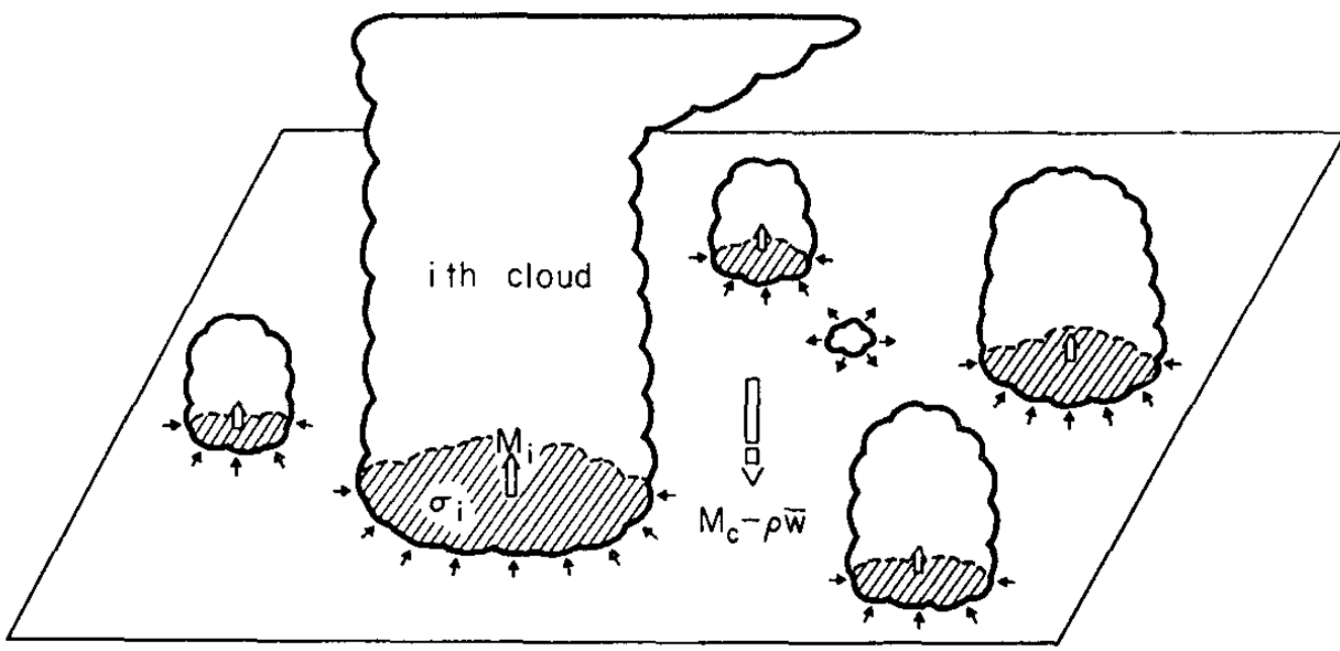
$$\kappa \propto \frac{C}{\tau_i}$$

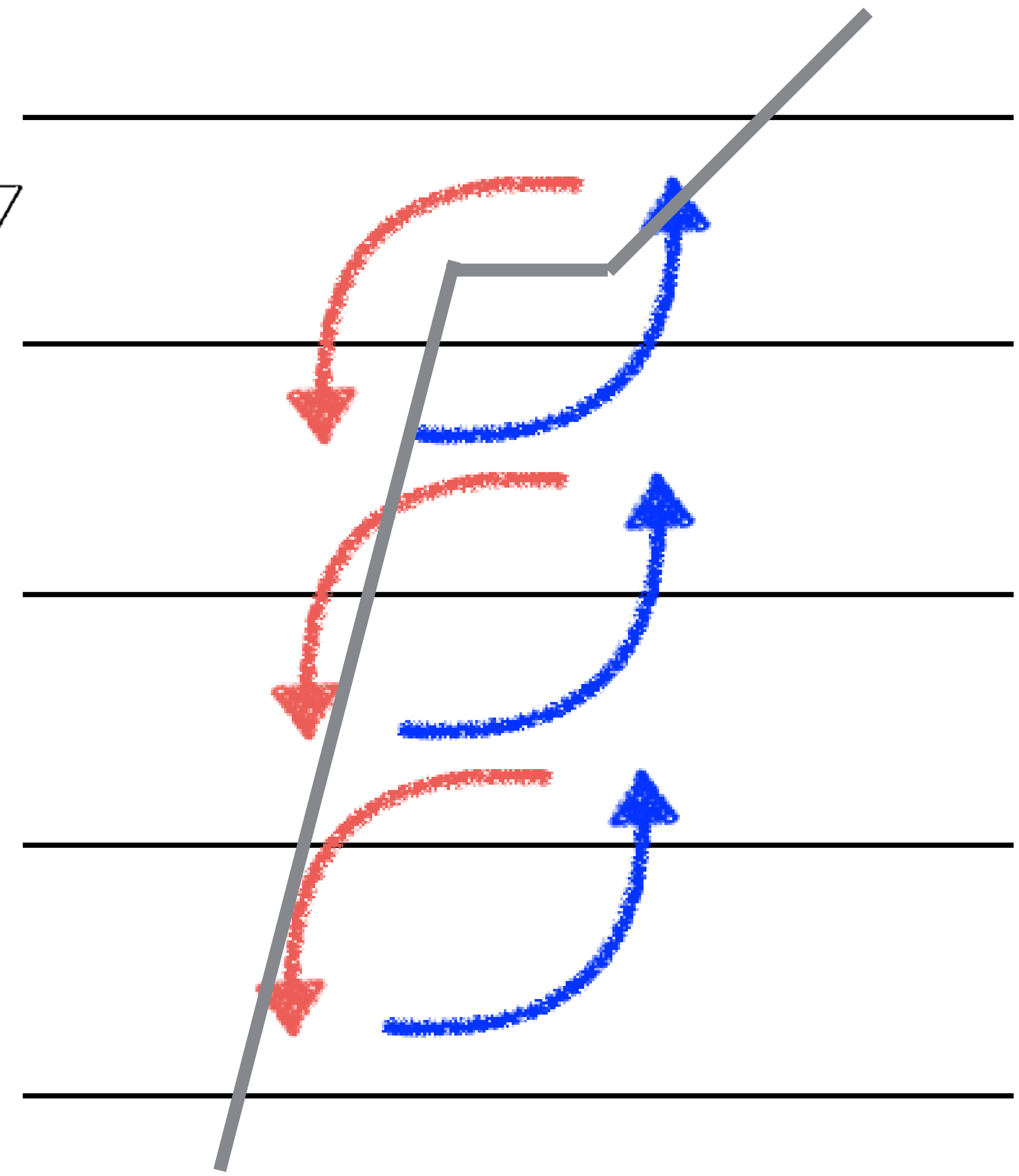
$$\tau_i = \begin{cases} \dfrac{L_i}{\sqrt{\bar{e}}}; & \dfrac{L_i}{\sqrt{\bar{e}}} \leq \tau_{\max} \\ \tau_{\max}; & \dfrac{L_i}{\sqrt{\bar{e}}} > \tau_{\max} \end{cases} \qquad i = 1, 2.$$

Eddy Length Scale

Characteristic Velocity

HOC vs Bulk Mass Flux





CLUBB Pros

- Prognostic terms for variances allows for better **cloud “memory”** across time steps.

- General moist turbulence parameterization can be used for many different cloud types (shallow, stratiform and PBL in CAM6). Using a single cloud and microphysical parameterizations allows for a ***unified representation*** *of aerosols across many cloud types*.

- **Constant turbulent mixing rather than undilute plumes triggered by unrealistic closures.**

- HOC parameterizations make no assumptions about the size of turbulence relative to the grid, and can be considered **“scale insensitive.”**

- **Higher order terms can be used by other parameterizations** such as microphysics or compared to cloud model or real-world variability.

CLUBB Cons

- **Significantly more expensive** than classic parameterizations with only diagnostic terms or a single prognostic variable.

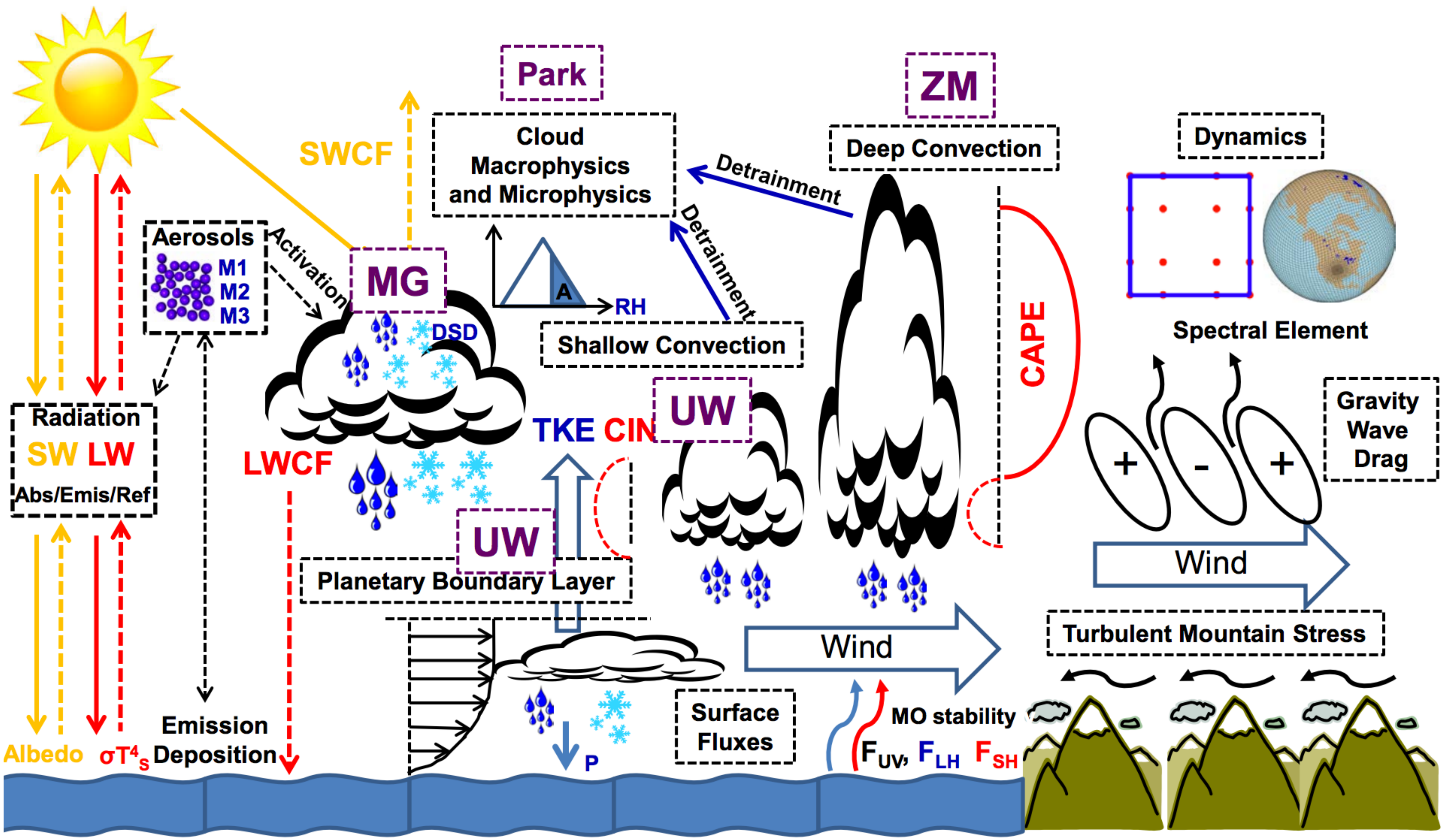
- Very **complicated equation set** that is not obvious in its relationship to clouds.

- Possibly excessive number of **tunable parameters**? Not exactly “plug-n-play.”

- Trouble with **precipitation** and how it interacts with the PDFs of cloudy layers.

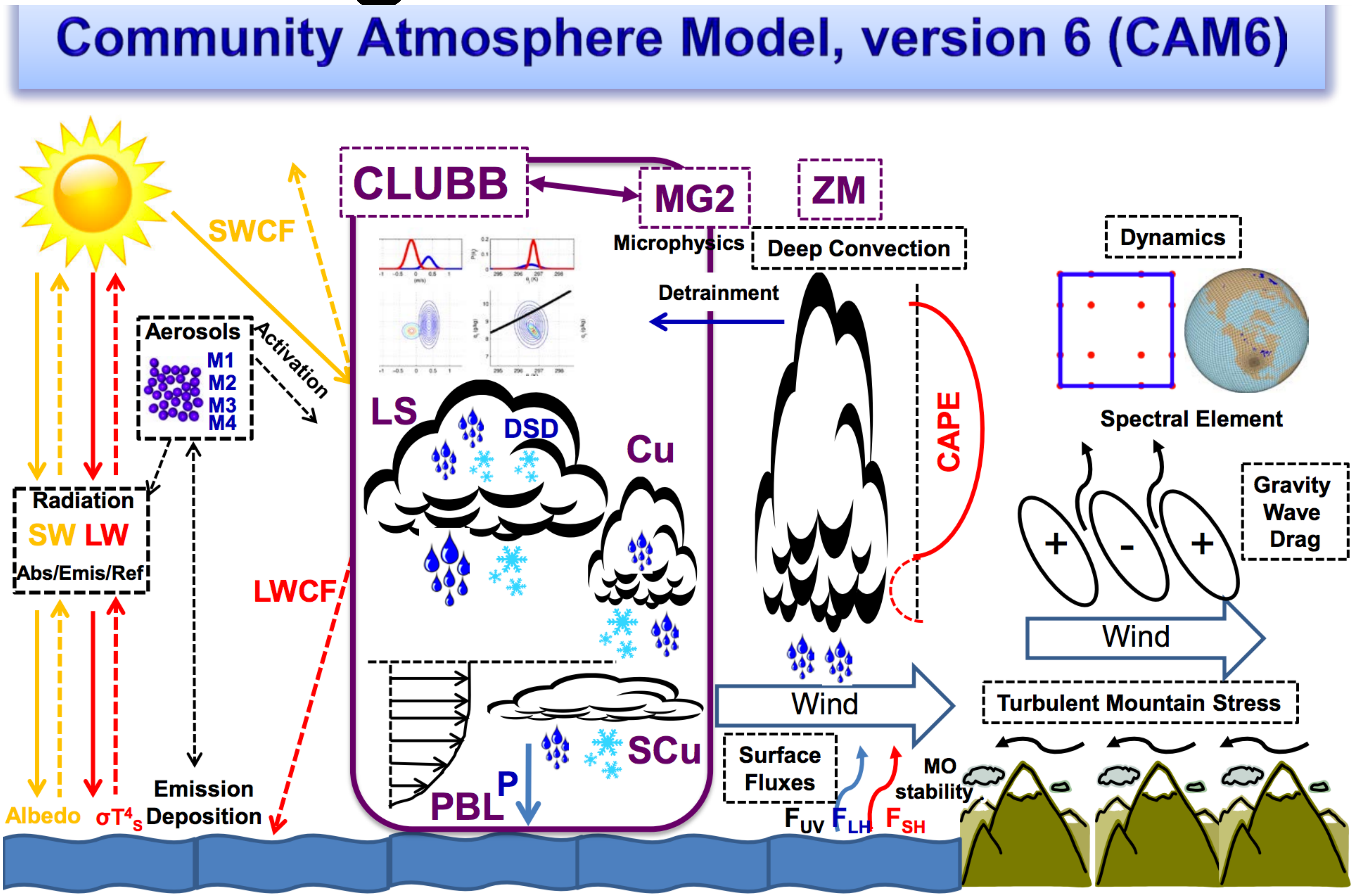
Subgrid Scale CAM

Community Atmosphere Model, version 5 (CAM5)



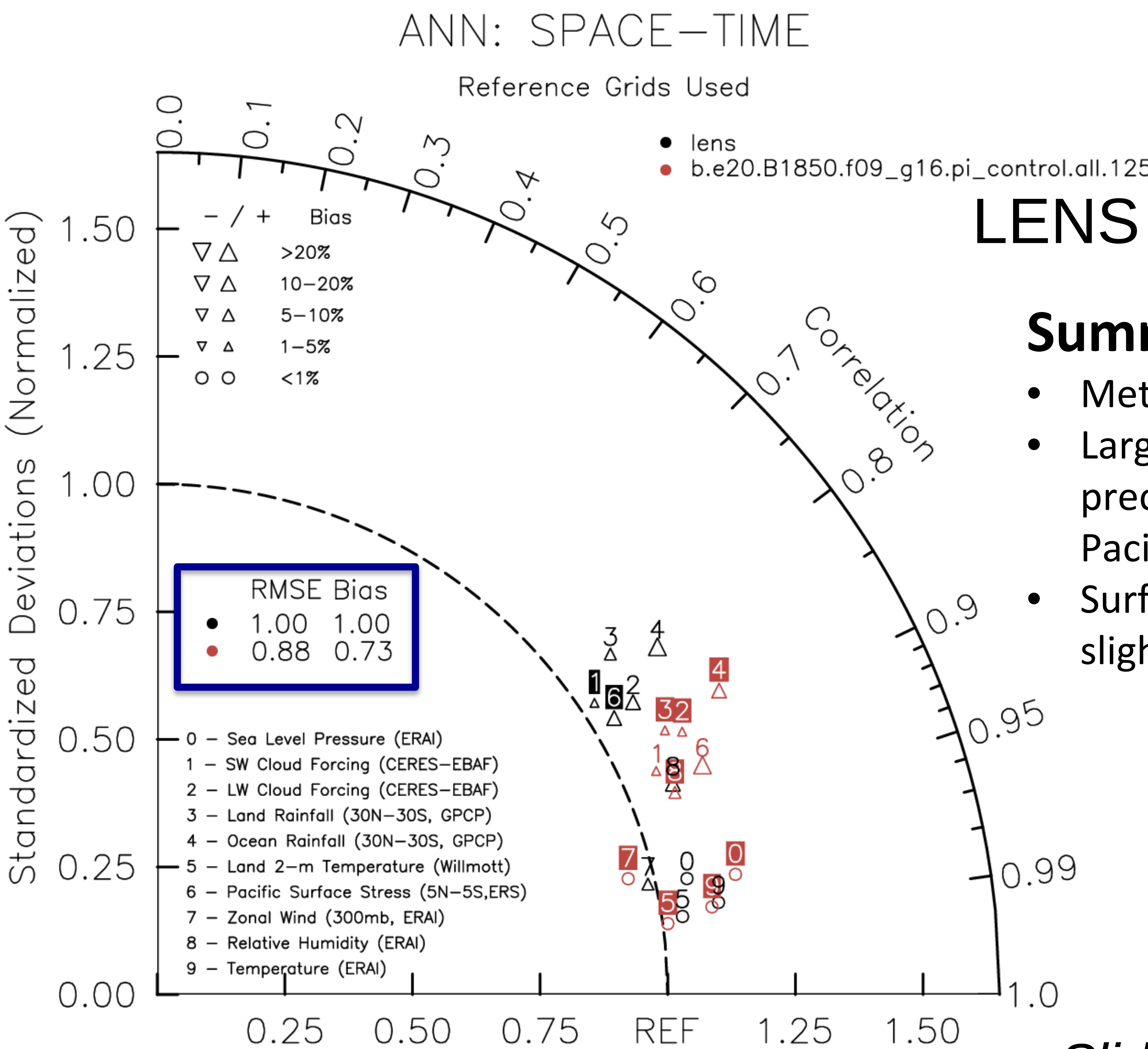
Rich Neale, Breckenridge 2016

Subgrid Scale CAM



Rich Neale, Breckenridge 2016

CAM6 in CESM2



LENS vs 125 Series

Summary

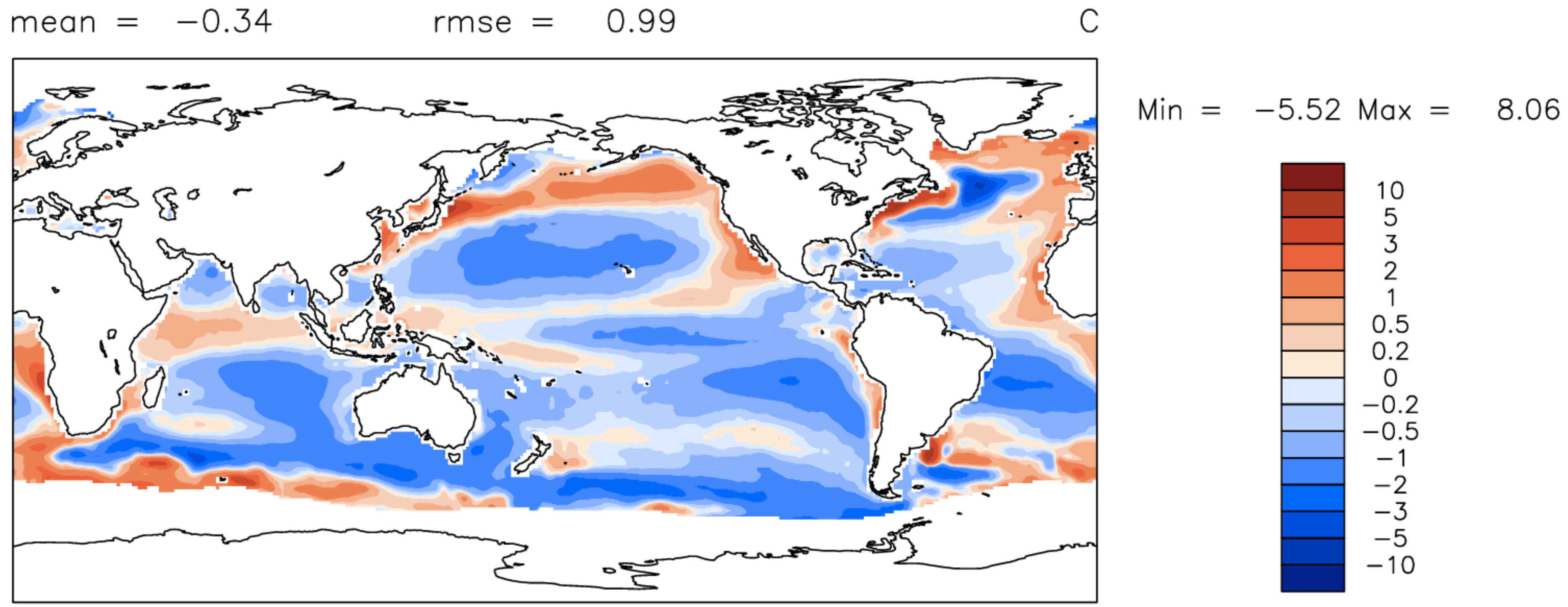
- Metric mean improved **bias** and **RMSE**
- Largest improvements in tropical precipitation (3,4), SWCF (1) and Pacific surface stress (6)
- Surface pressure field (0) degrading slightly (mostly variance)

Slide courtesy of Rich Neale

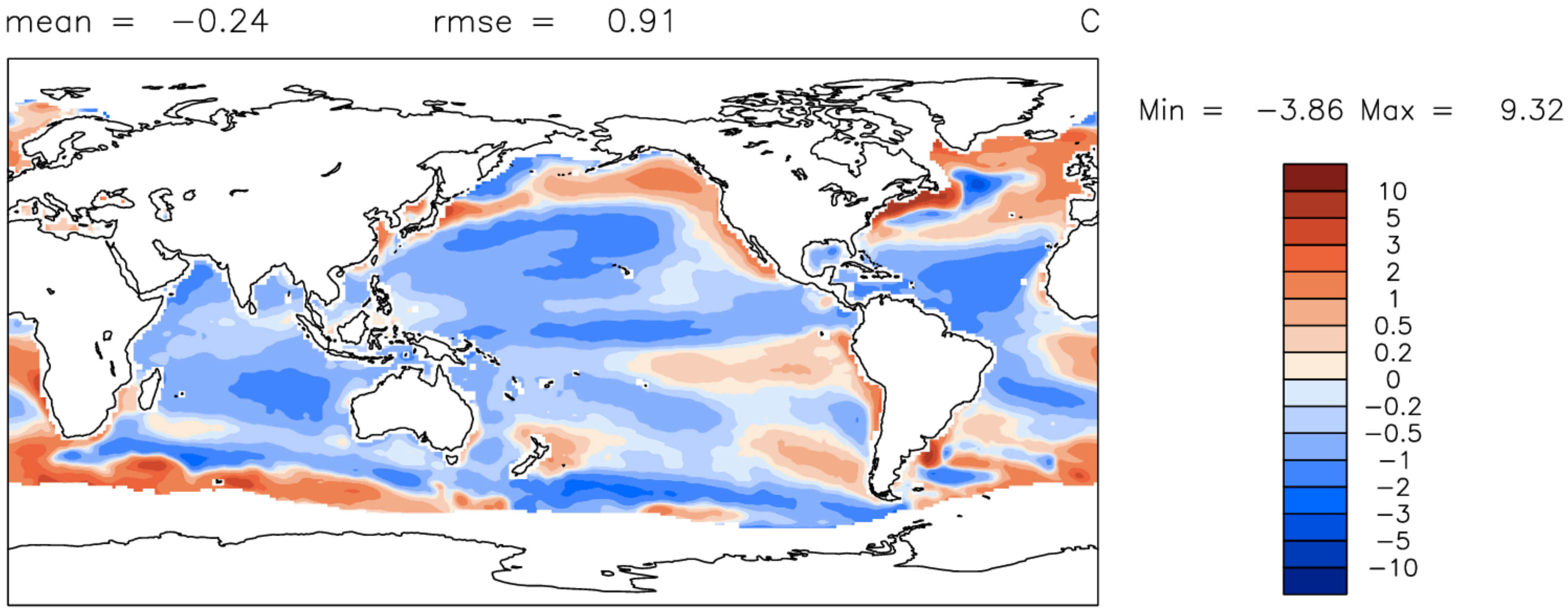
CAM6 in CESM2

Pre-industrial SST bias (Annual)

CESM2



CESM1 (LENS)



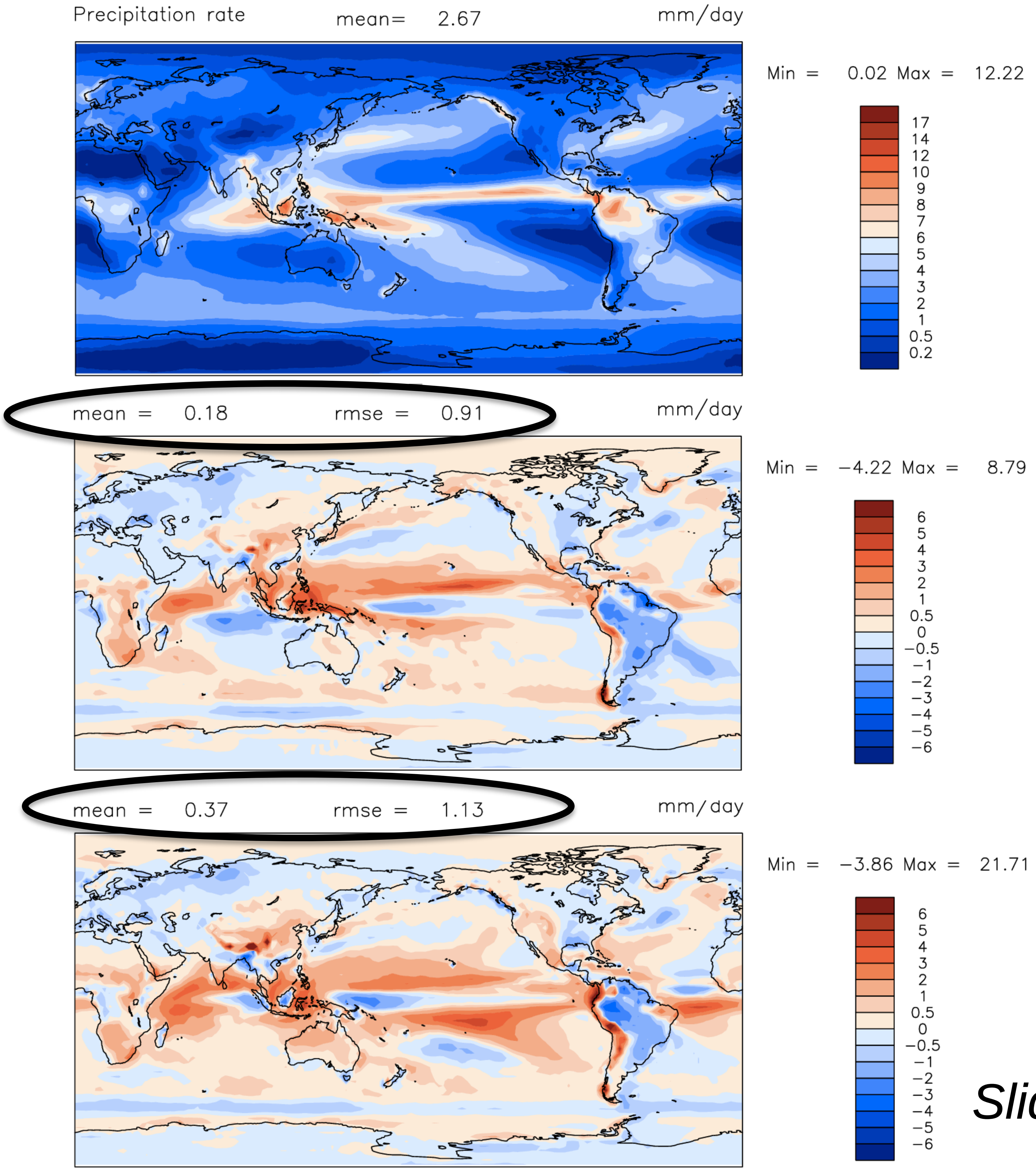
Slide courtesy of Rich Neale

Precipitation bias (Annual)

Obs. (GPCP)

CESM2

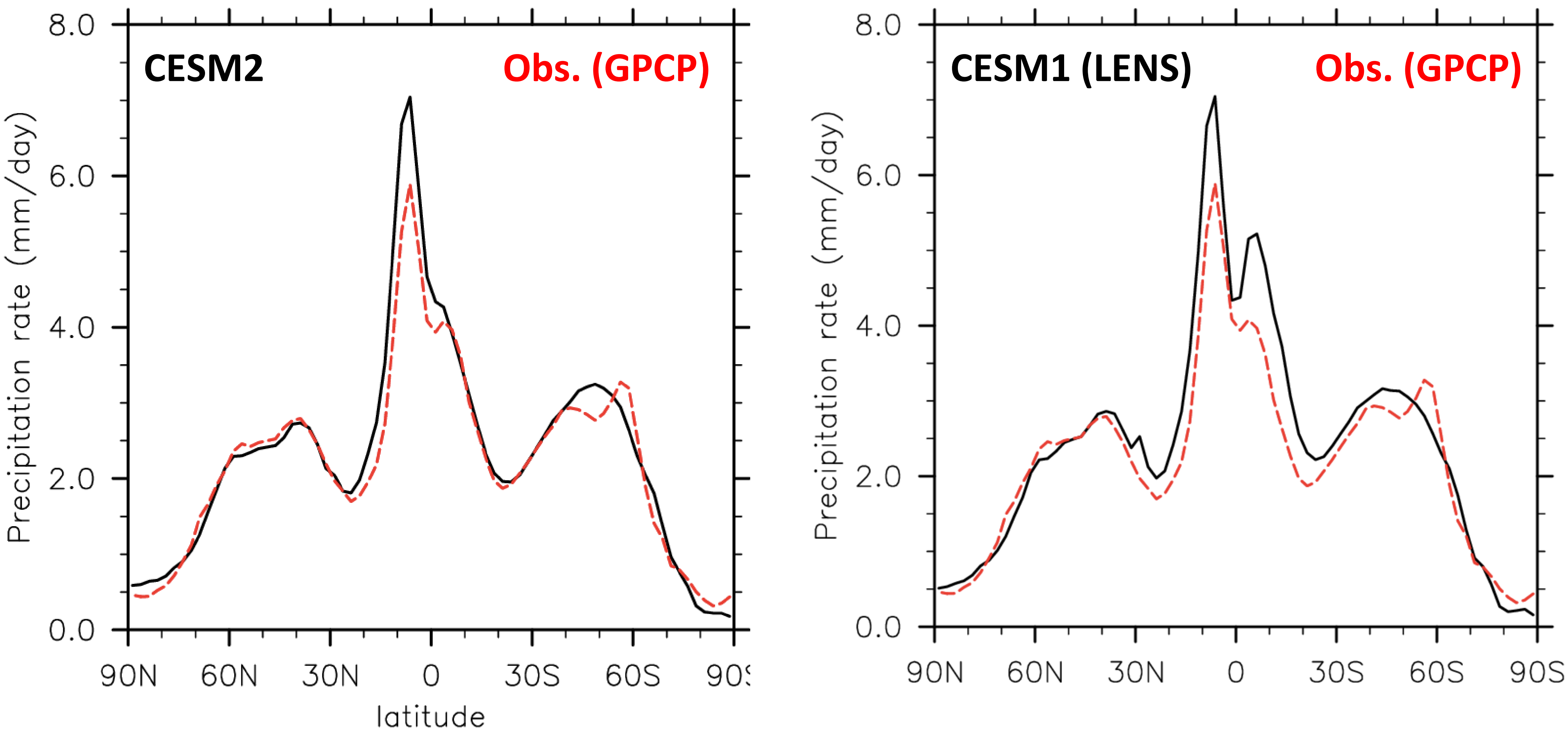
CESM1 (LENS)



Slide courtesy of Rich Neale

CAM6 in CESM2

Annual Mean Precipitation
(mm/day)
-Reduced double ITCZ



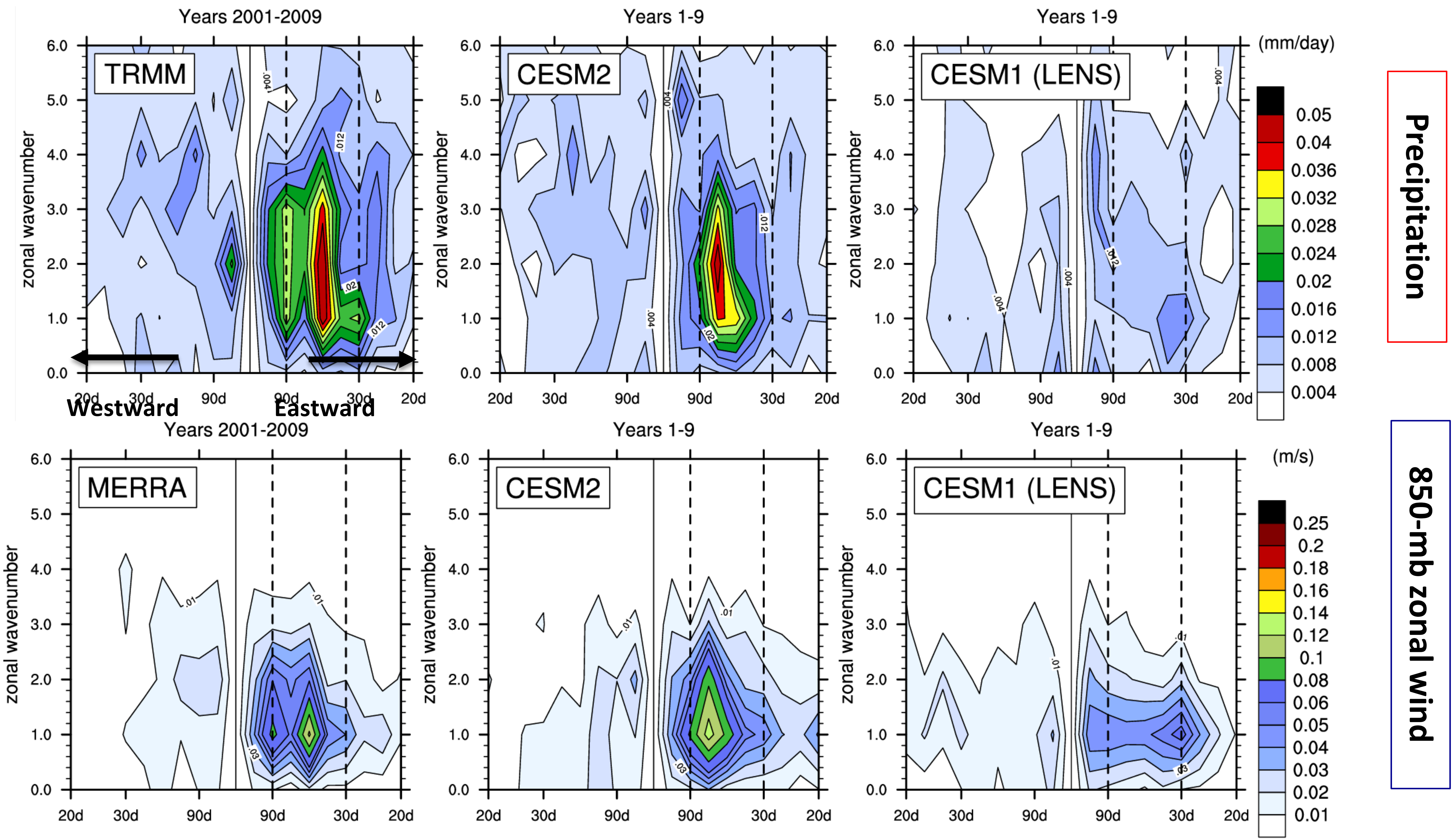
Slide courtesy of Rich Neale

Slide courtesy of Rich Neale

Wavenumber Frequency Spectra

- 10N-10S averaged
- 20-100-day band pass filtered
- MJO wave#1-3 and 30d-90d range
- Precipitation-flow coupling

Slide courtesy of Rich Neale



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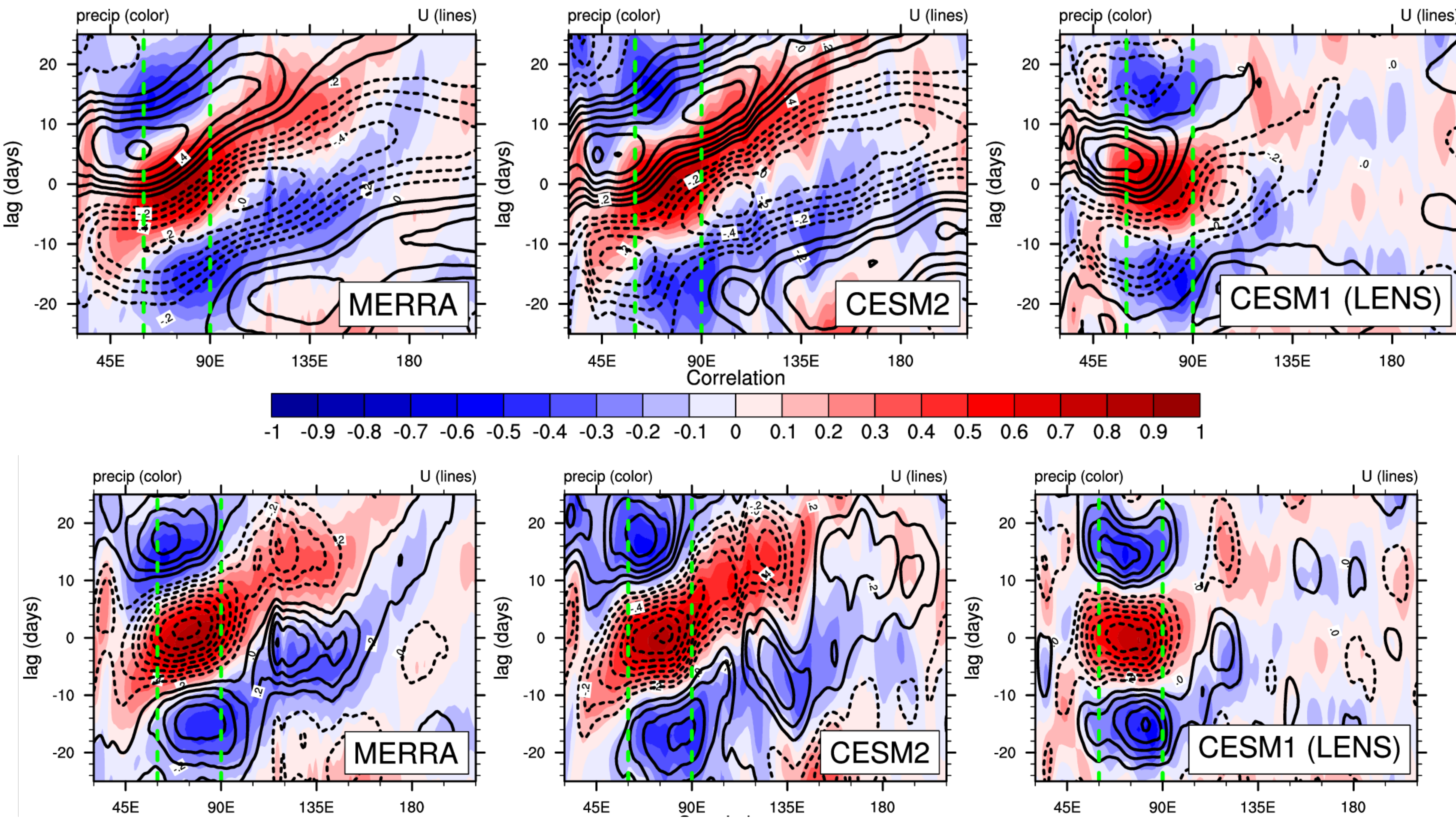
Precipitation

850-mb U



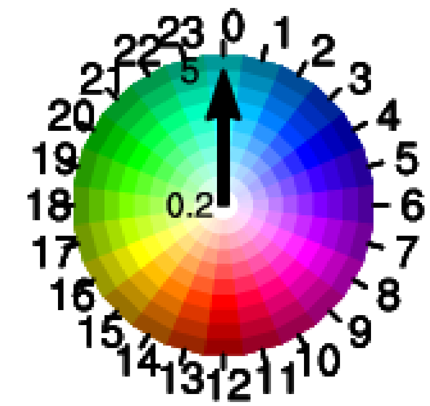
Precipitation

- Lag correlation with Indian-Ocean precip
- 20-100day band pass filter, 10S-10N
- 9 years, DJFMAM

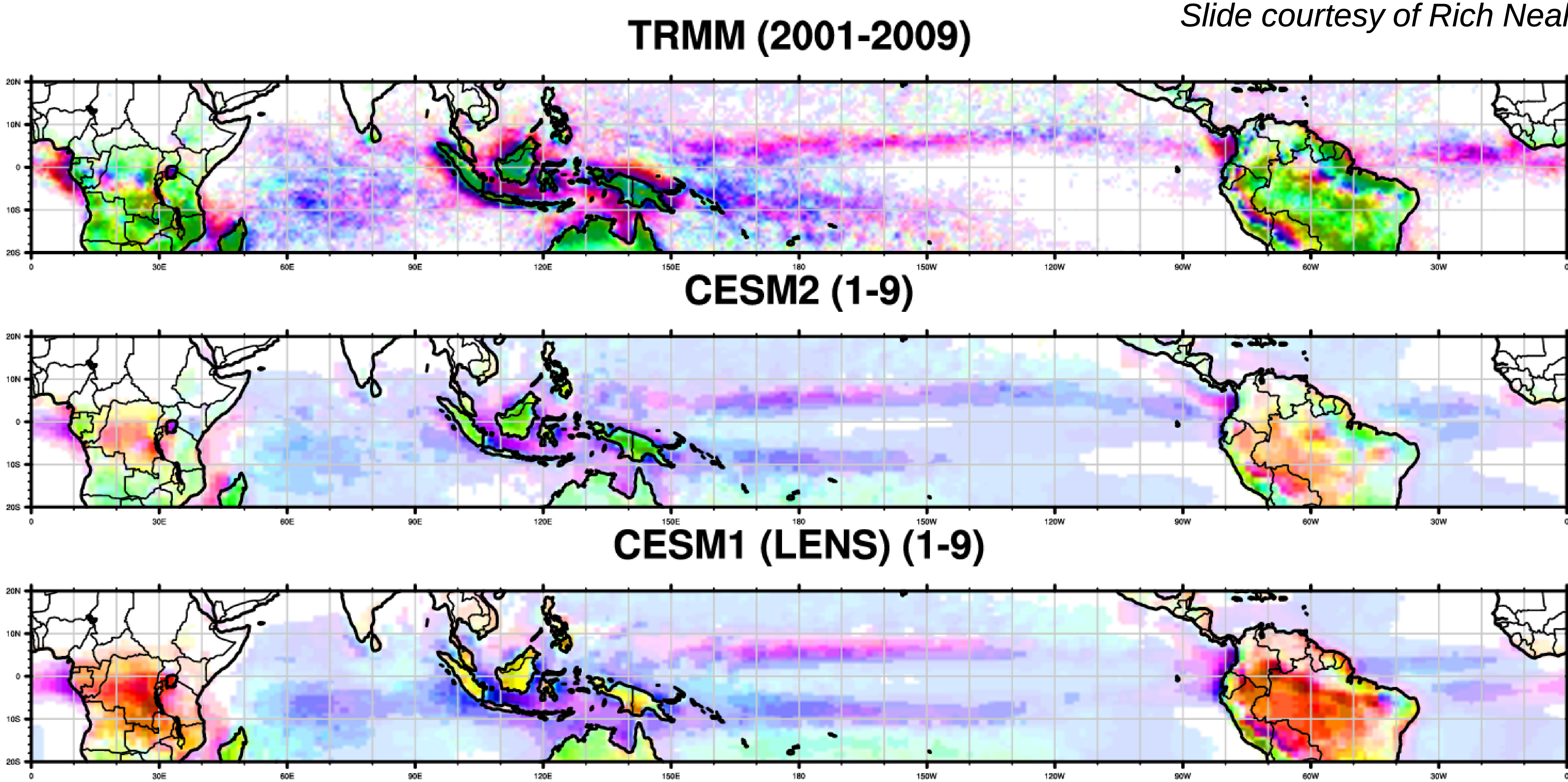
OLR

Diurnal Cycle of Precipitation (DJF)

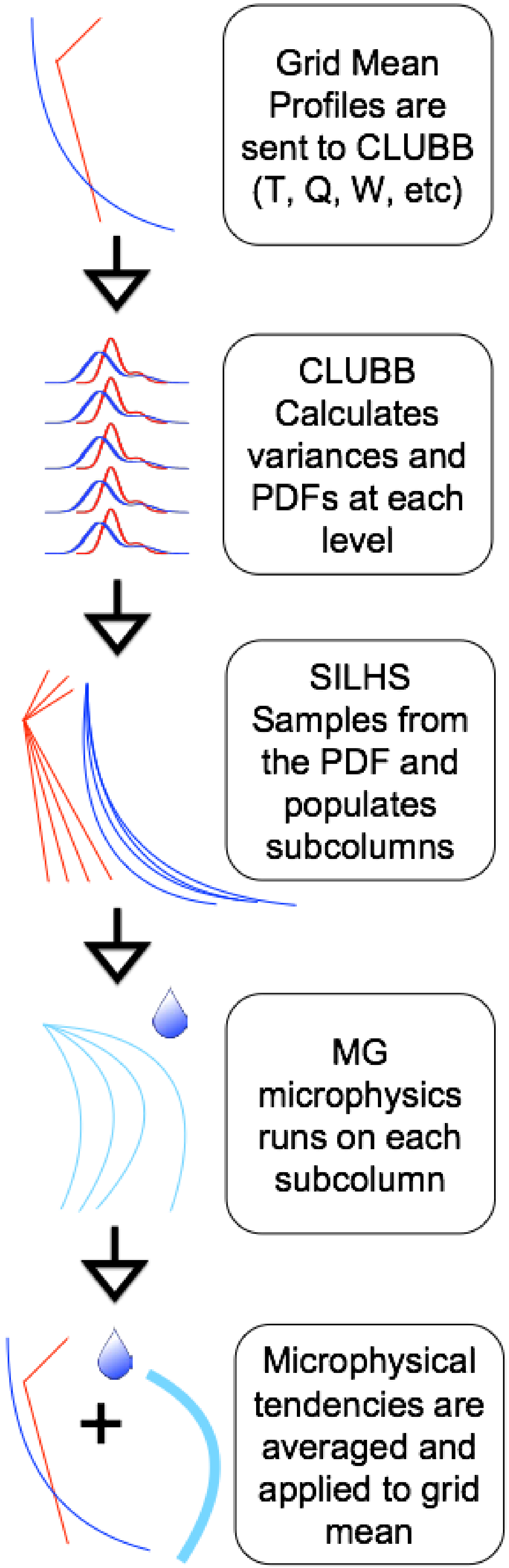
- Phase (color) and amplitude (hue)
- Too early over land on average
- ~8 hours too early in CESM1
- ~4 hours too early in CESM2
- Over Ocean amplitude too weak (timing good)



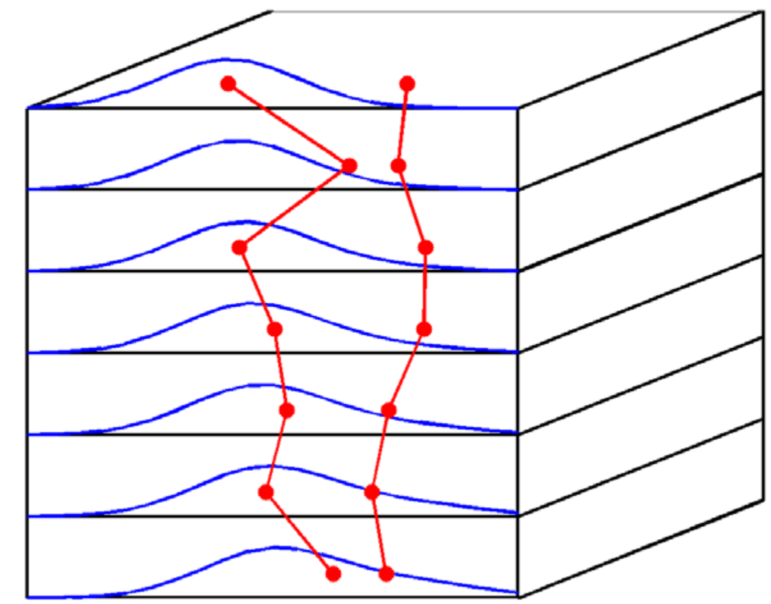
Slide courtesy of Rich Neale



CLUBB and Deep Convection



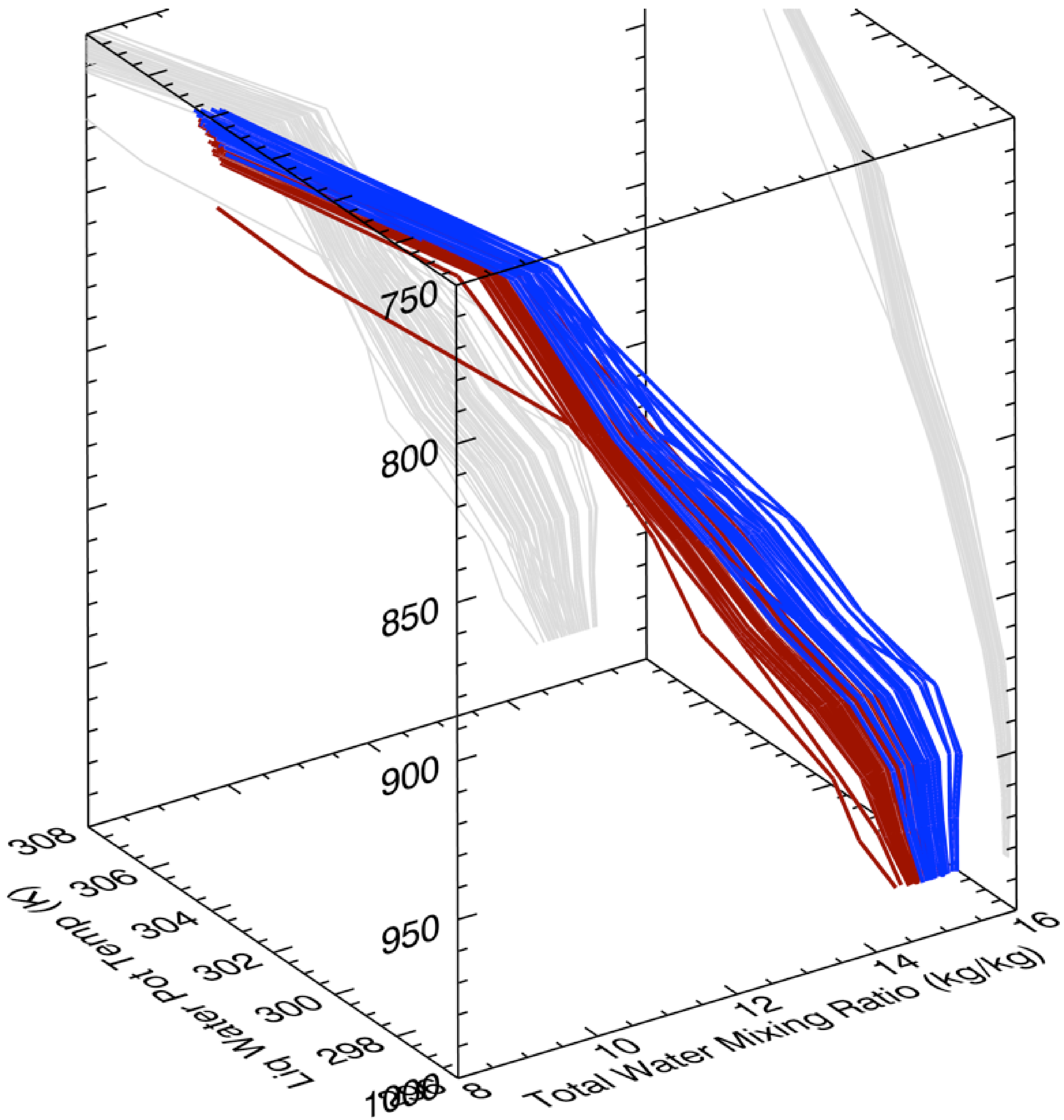
- Typically hard for HOC parameterizations to do deep convection because there is no imbedded microphysics.



- Need a way to tightly couple the HOC CLUBB scheme to a microphysics scheme…. Subcolumns!

What are Subcolumns?

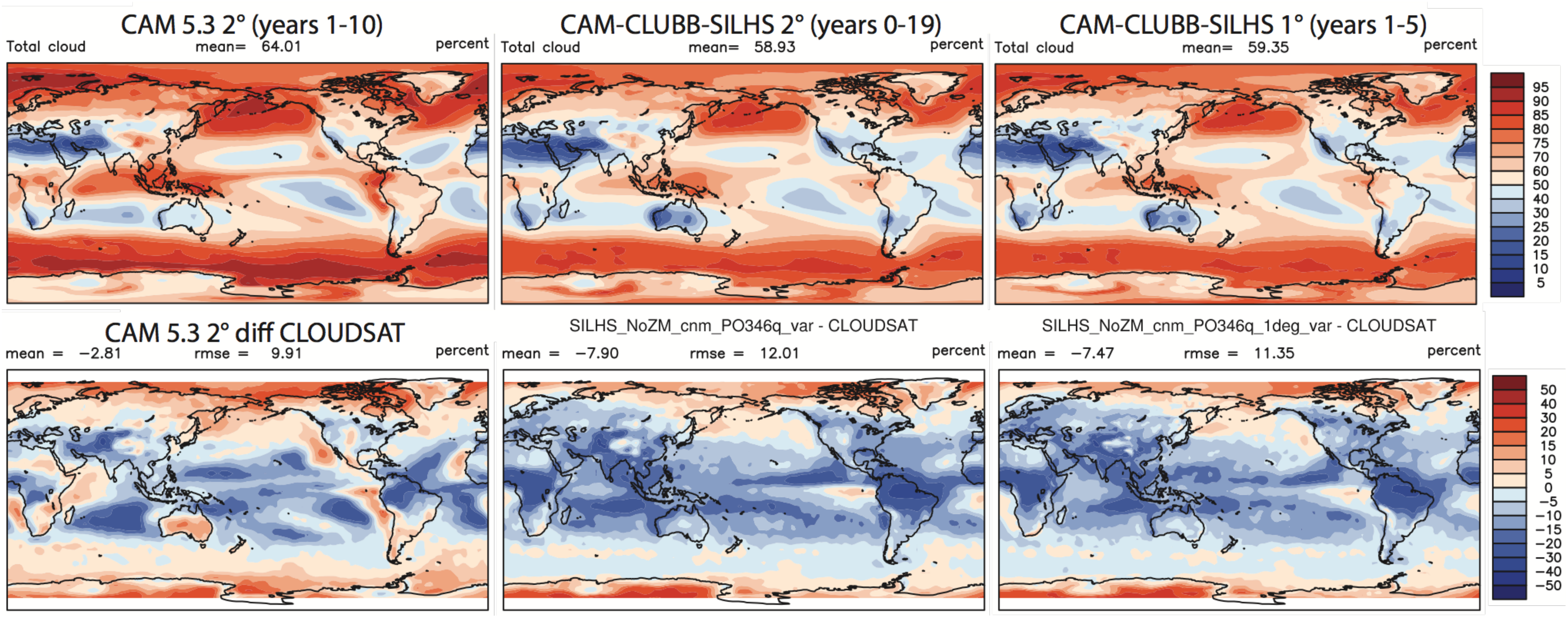
- A second dimension for grid columns in CAM
- A data structure that represents the model state within a GCM grid column
- Subcolumns have the same vertical resolution as the larger grid



The Benefits of Unified Convection and Unified Microphysics in CAM

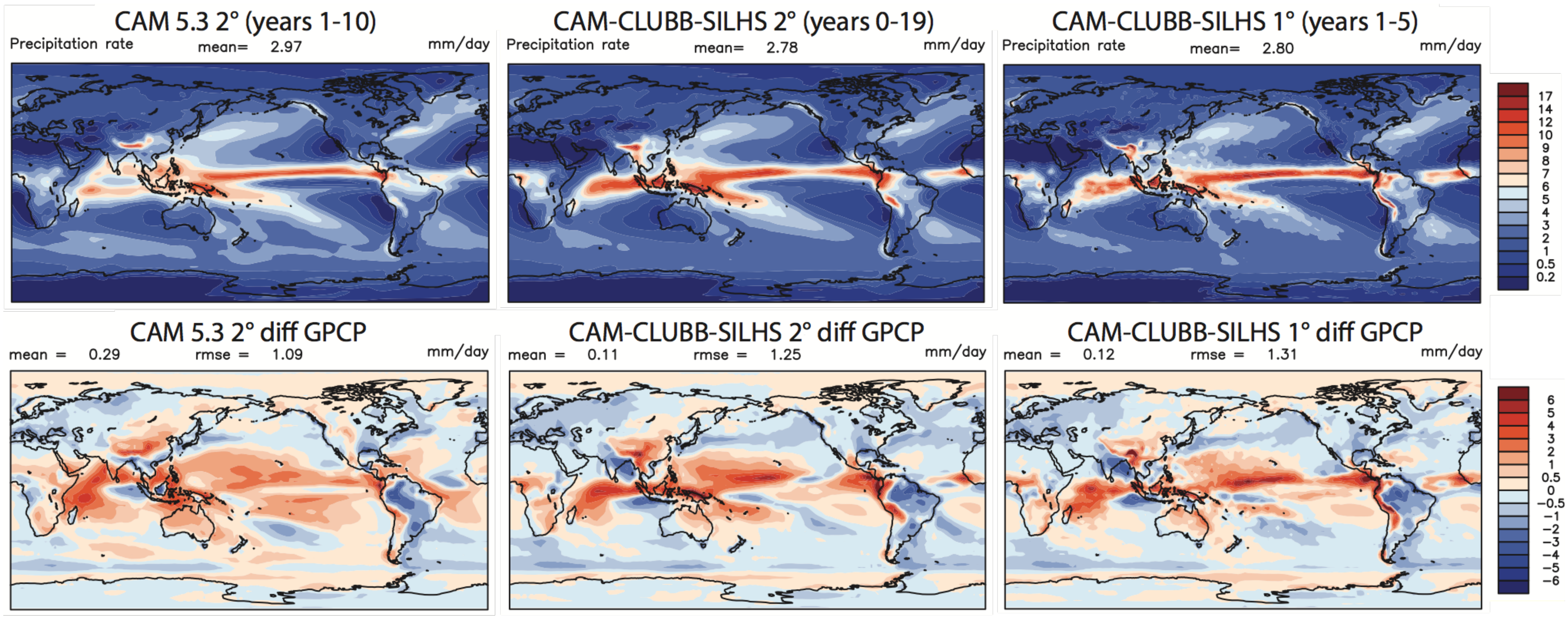
- ☑ Consistent treatment of clouds around the planet
- ☑ Simplifies budgets and tuning to a single tendency and parameter set
- ☑ Ability to simulate aerosol effects in all cloud types
- ☑ Theoretically scale insensitive convection makes increasing resolution easier
- ☑ More physically realistic

CAM-CLUBB-SILHS



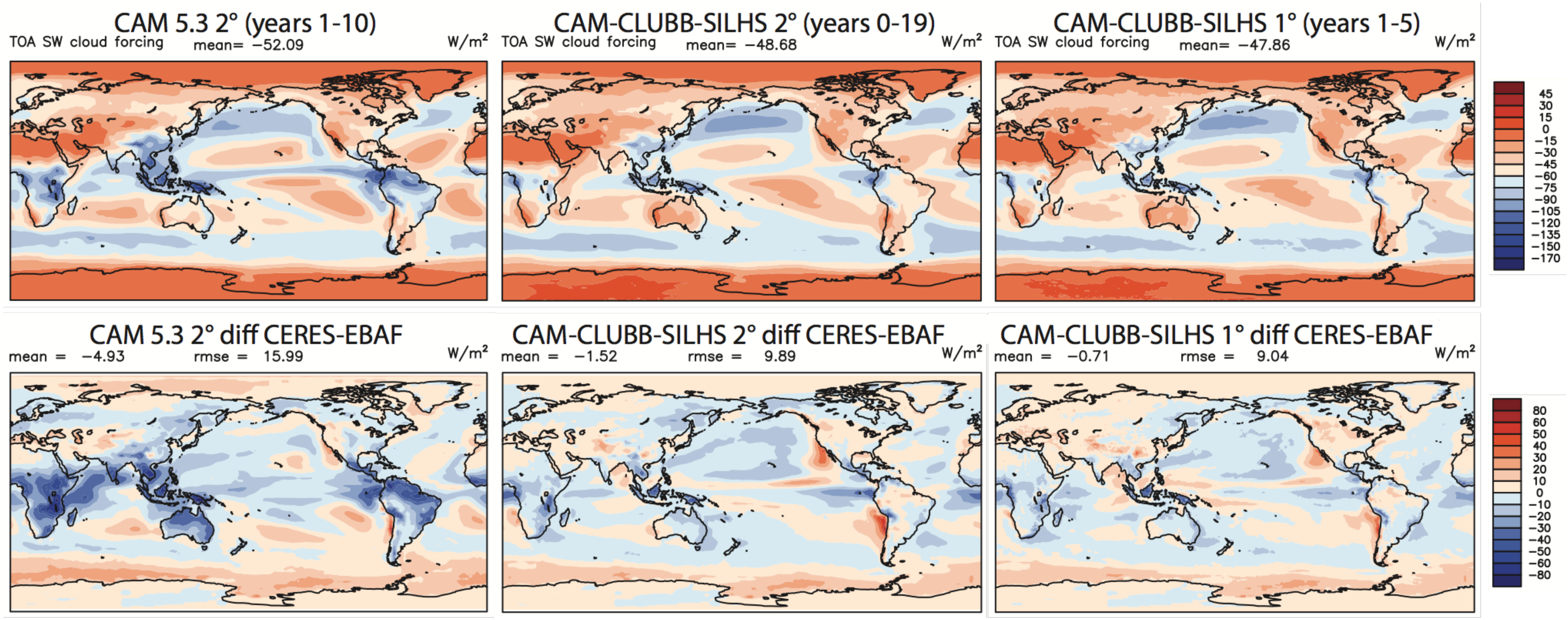
Thayer-Calder et al. 2015

CAM-CLUBB-SILHS



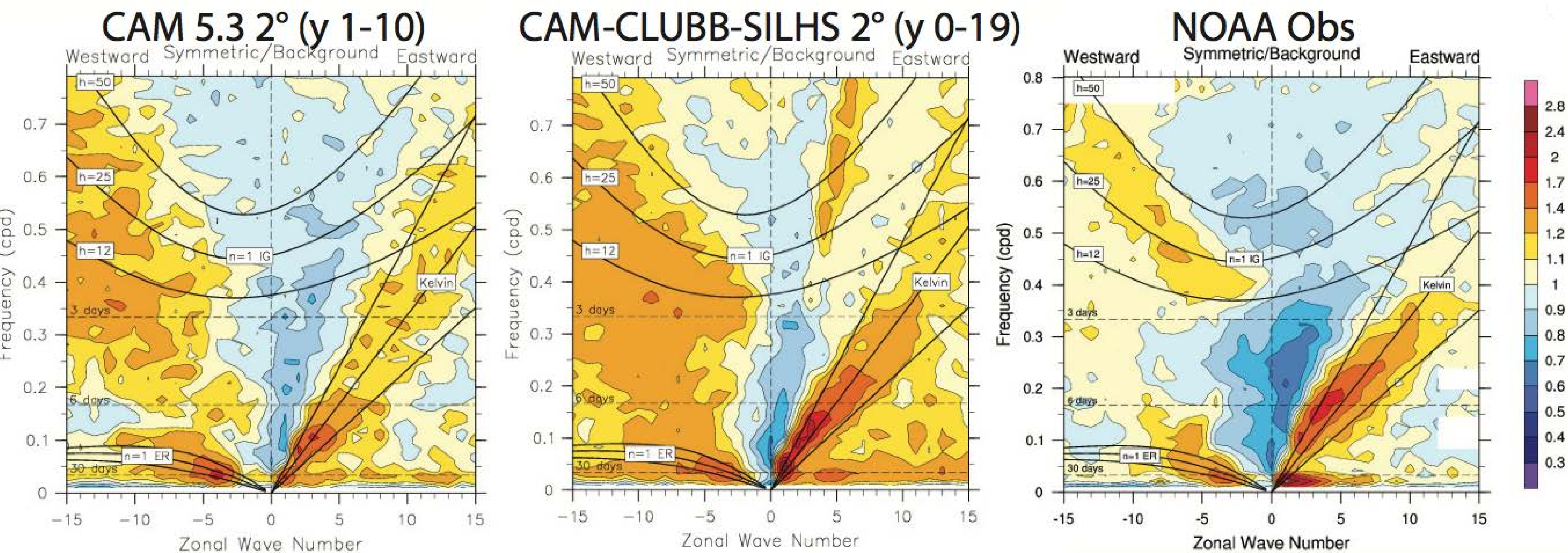
Thayer-Calder et al. 2015

CAM-CLUBB-SILHS



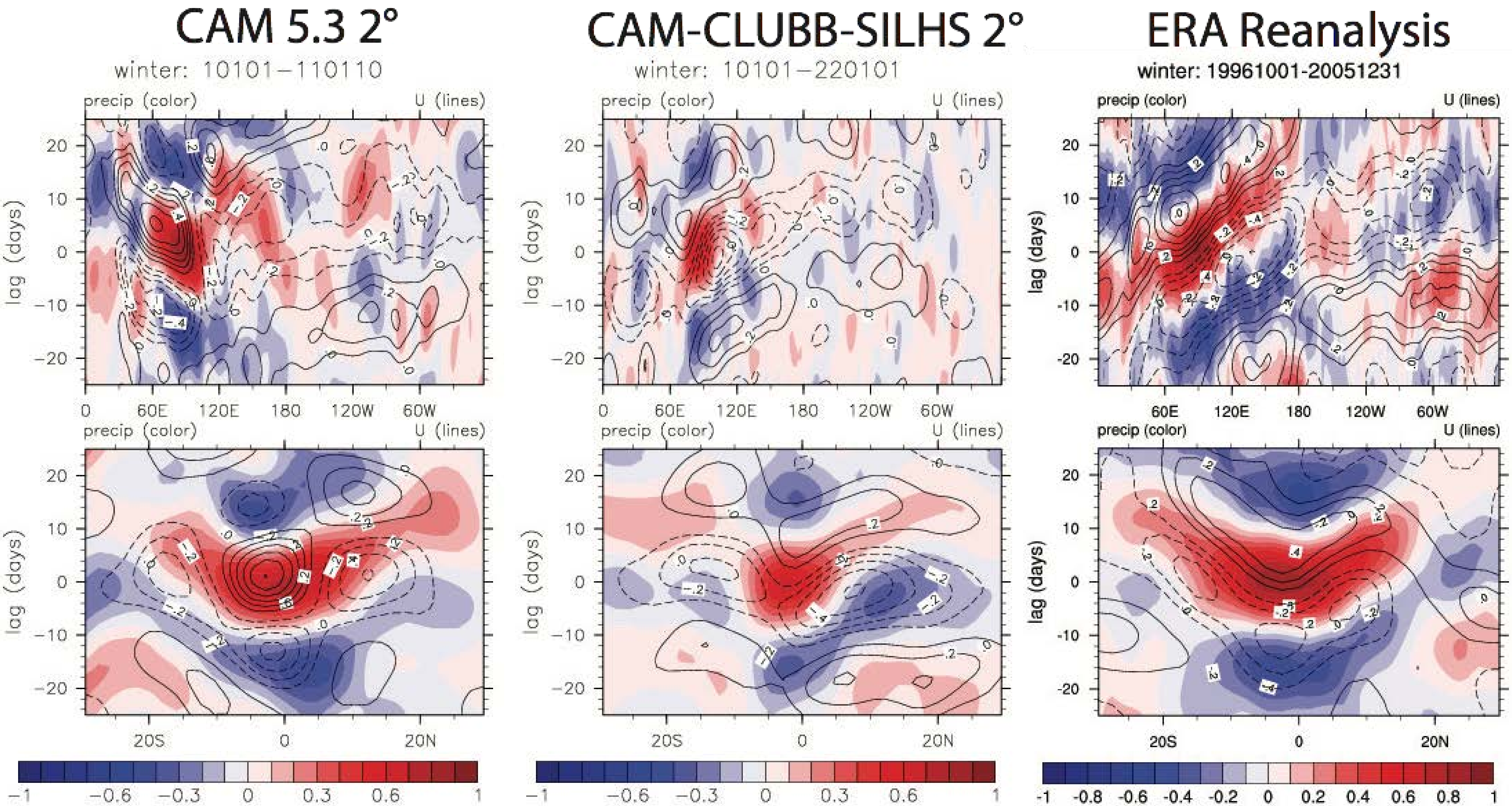
Thayer-Calder et al. 2015

CAM-CLUBB-SILHS



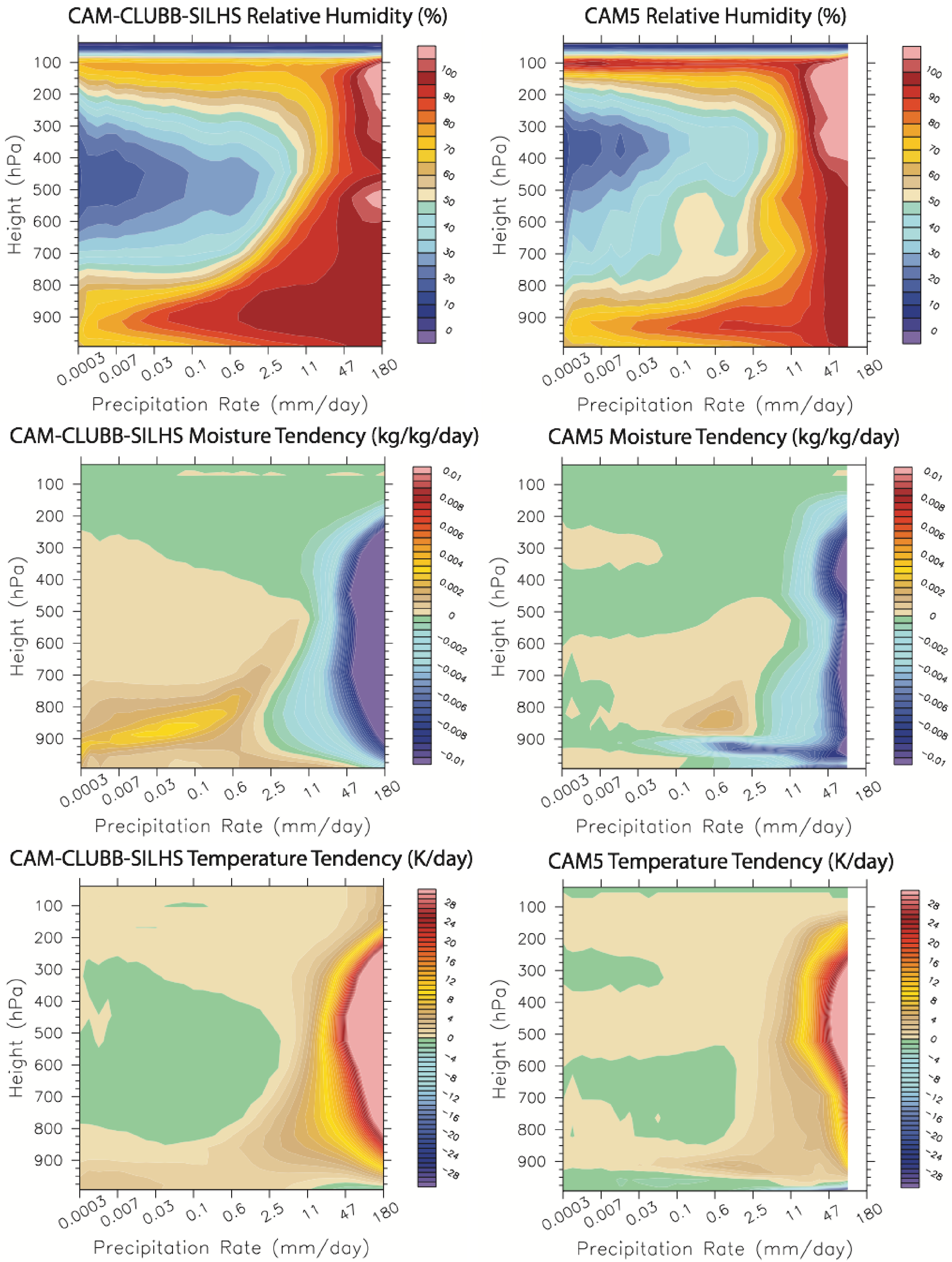
Thayer-Calder et al. 2015

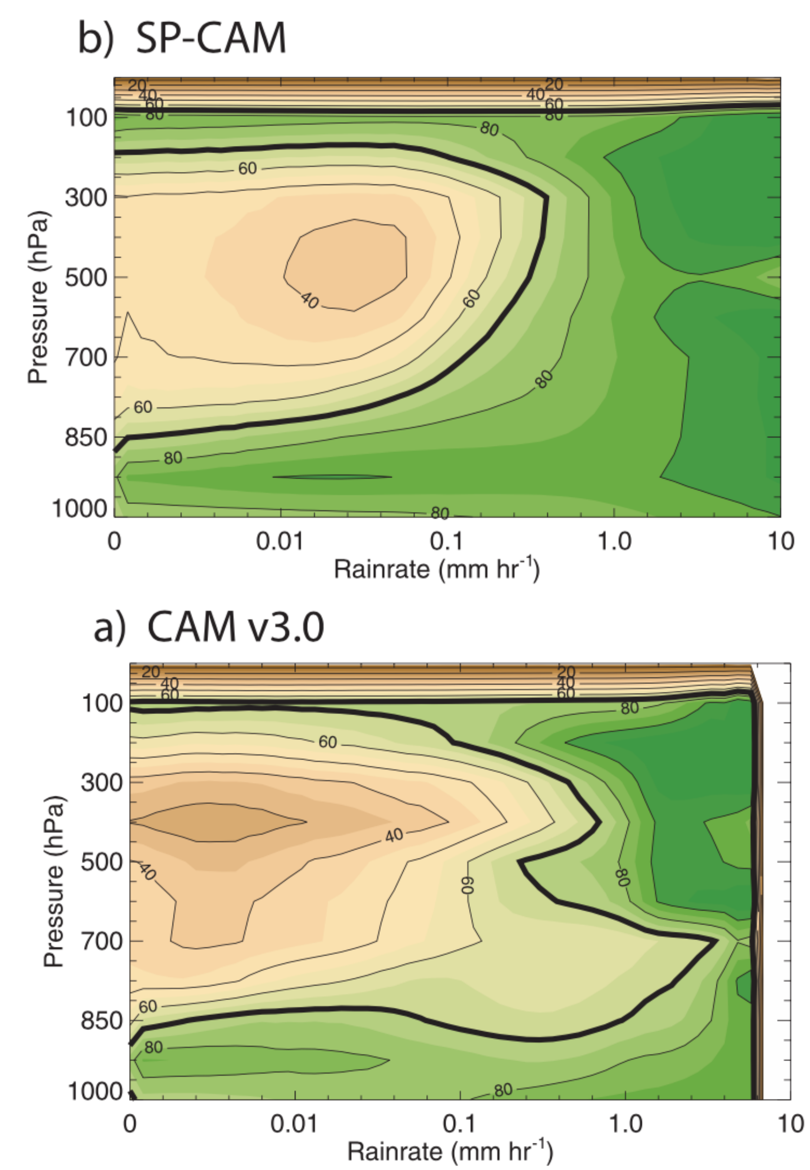
CAM-CLUBB-SILHS



CAM-CLUBB-SILHS

Thayer-Calder et al., 2015

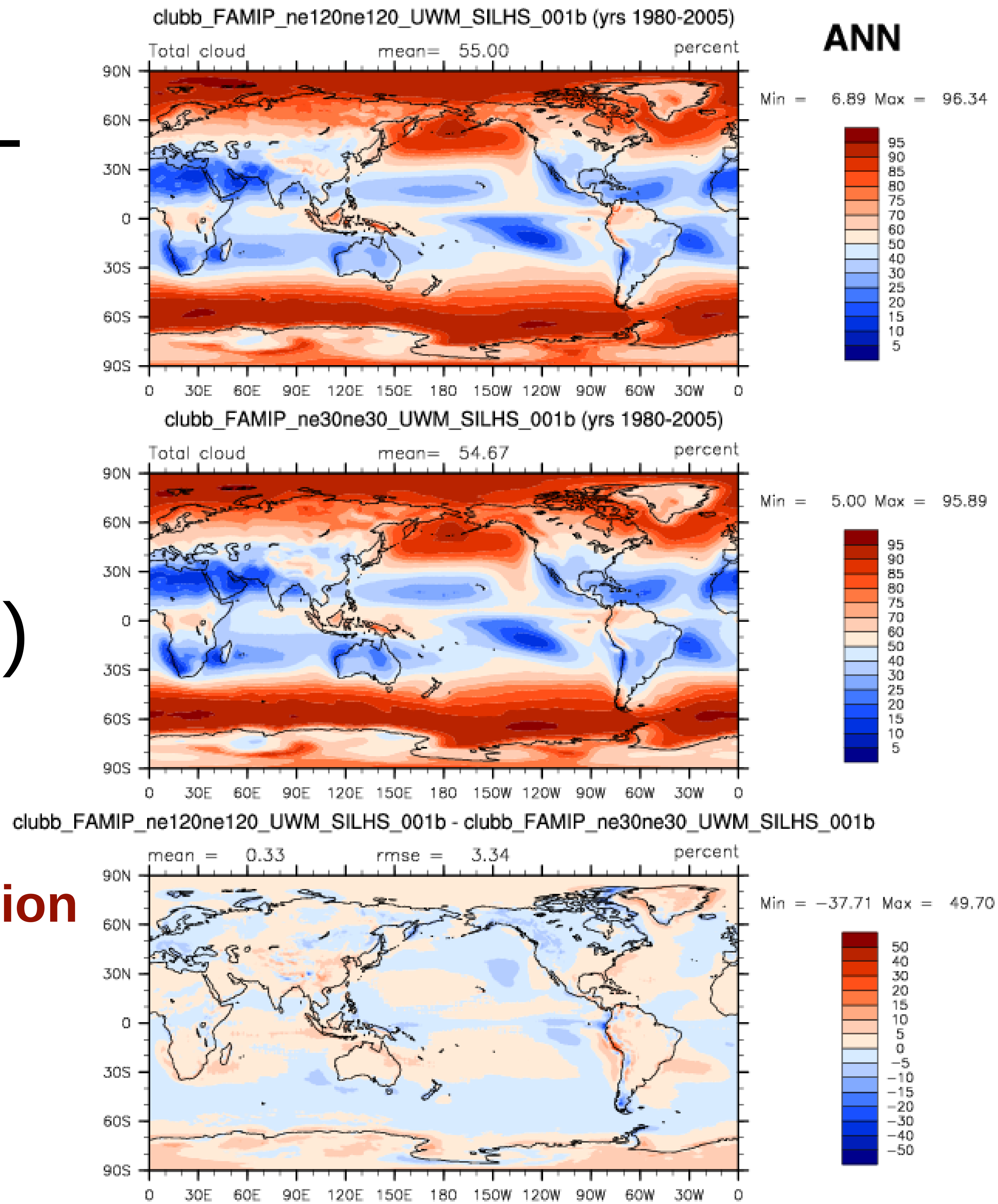




Thayer-Calder and Randall, 2009

CAM-CLUBB-SILHS

ne30 (1 deg) vs ne120 (28 km)



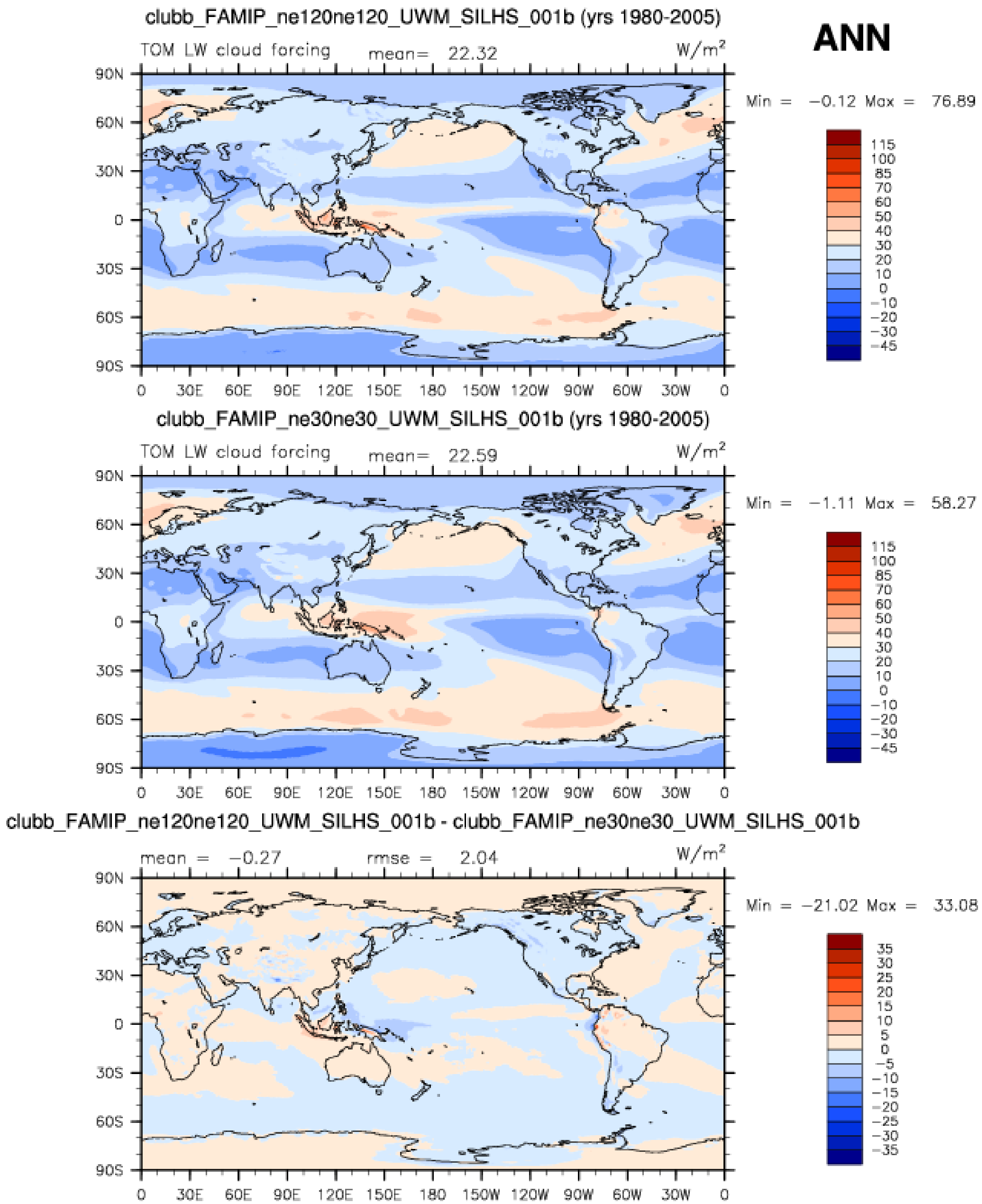
Cloud Fraction

Simulations by
Pete Bogenschutz

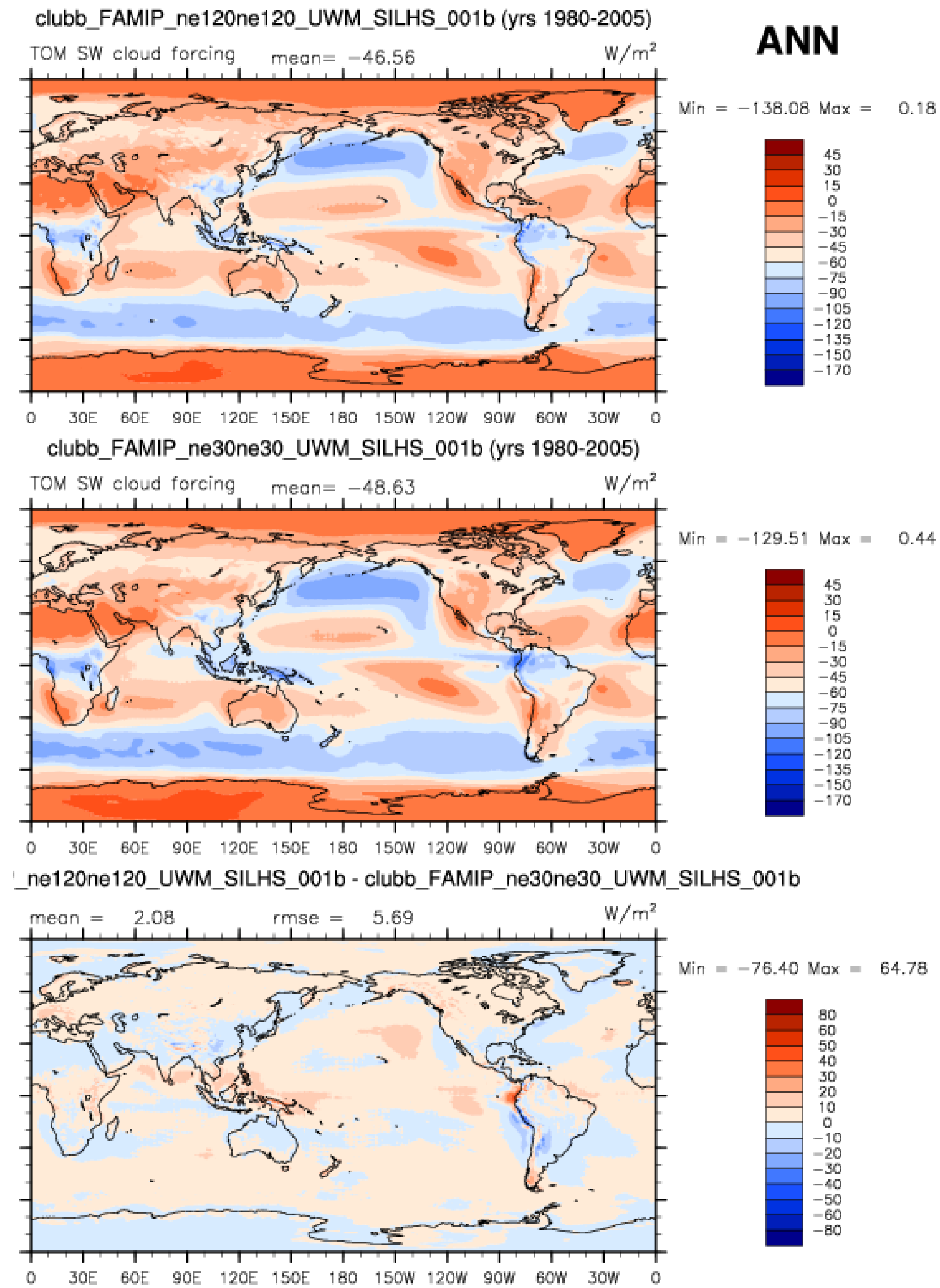
ne30 vs ne120

Simulations by Pete Bogenschutz

LWCF



SWCF

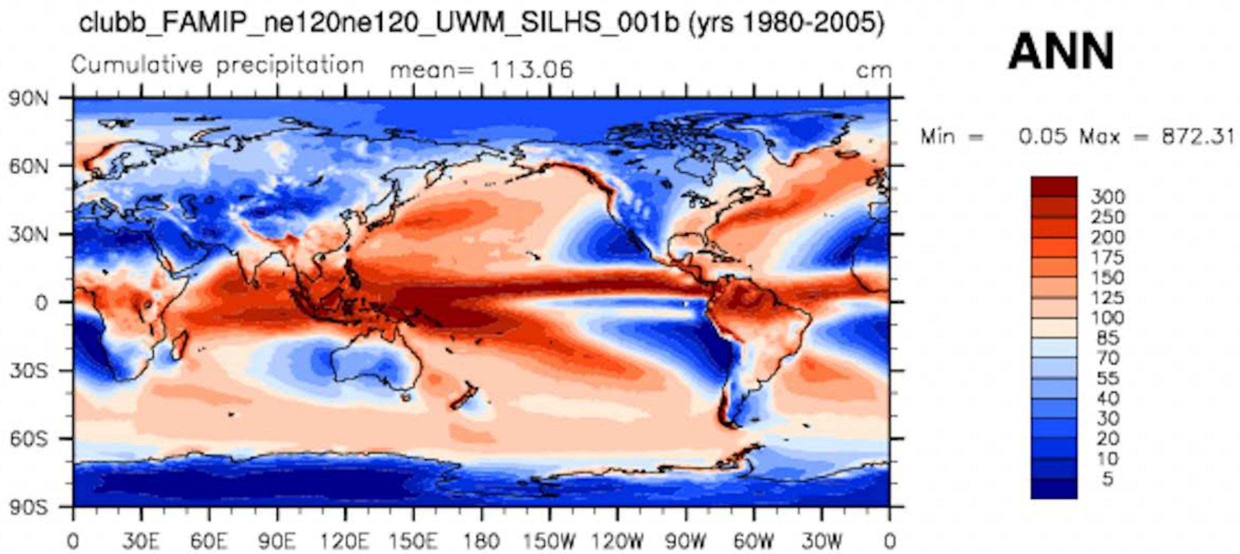


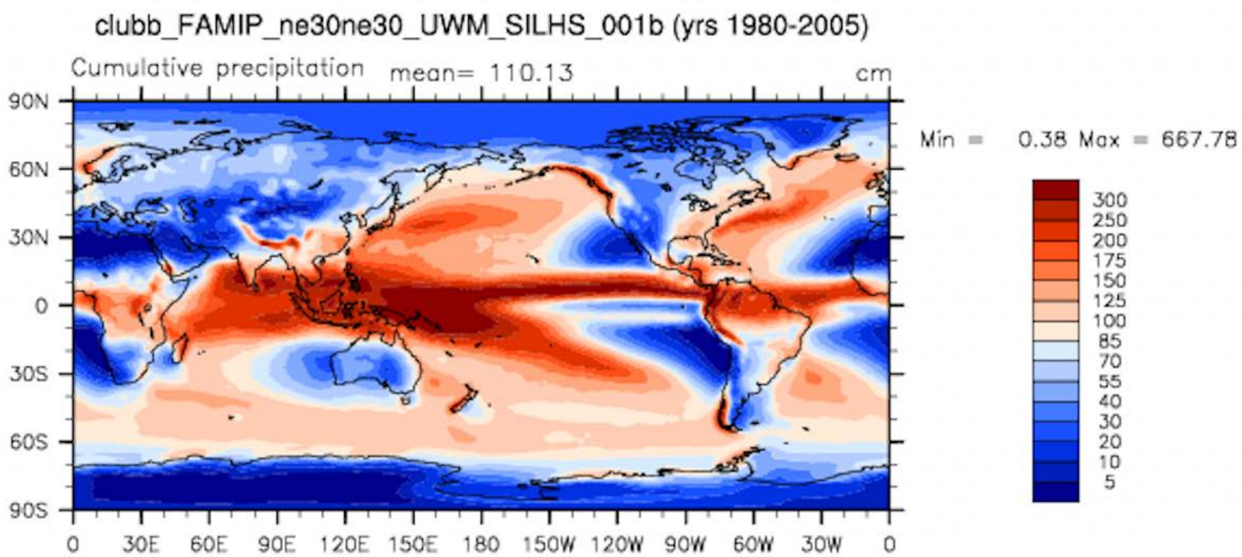
ne30 vs ne120

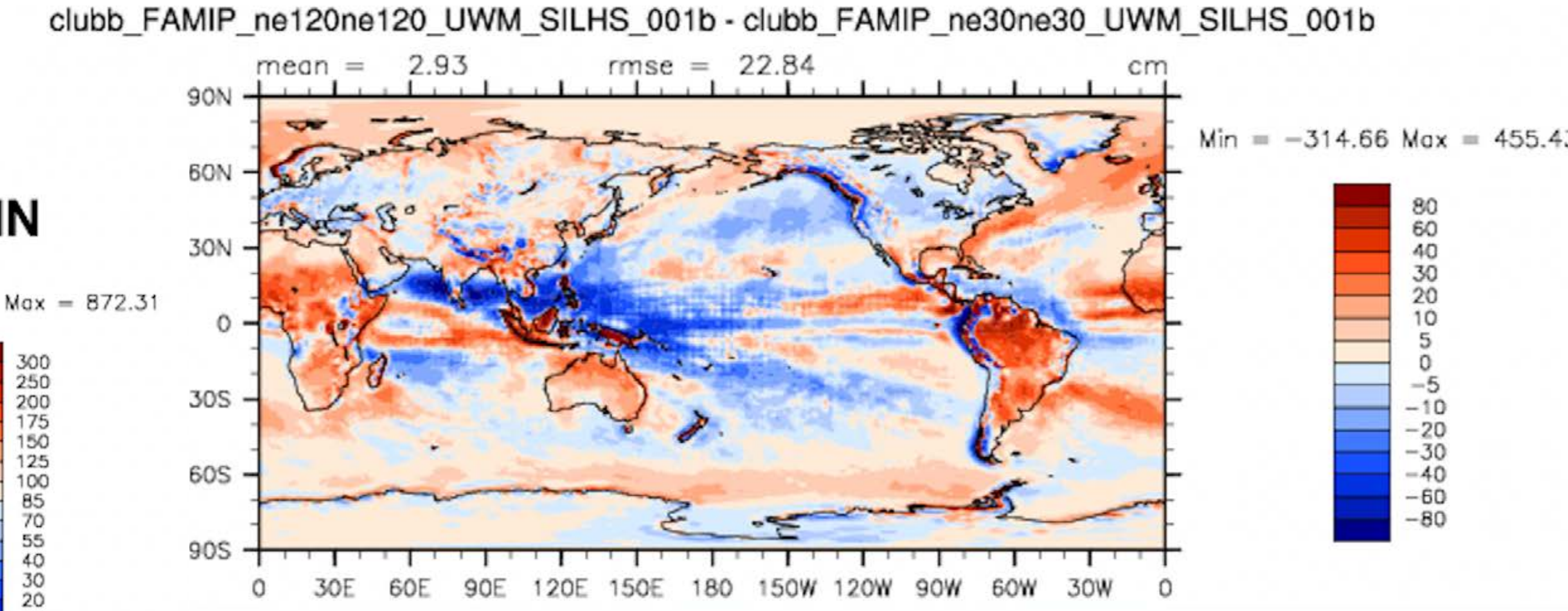
Simulations by
Pete Bogenschutz

Precip

ANN







Conclusions

- CLUBB is a Higher Order Closure Parameterization with a general mathematic framework for calculating moisture and temperature tendencies due to moist turbulence and convection.
- CLUBB integrates over a multi-variate binormal PDF to close higher order terms.
- CLUBB is expensive and complicated but includes scale awareness, convective memory, and the ability to simulate many cloud types with a single equation set.