Successes and Challenges on Implementing a Unified PDF-based Cloud Scheme into Multiple CMIP5 Models

Peter Bogenschutz[1], Huan Guo[2], Chris Golaz[2], Andrew Gettelman[1], Leo Donner[2], Hugh Morrison[1], Vincent Larson[3], Cheryl Craig[1], David Schannen[3]

[1]National Center for Atmospheric Research, Boulder, CO
[2]Geophysical Fluid Dynamics Laboratory, Princeton, NJ
[3]University of Wisconsin, Milwaukee, WI

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Cast of Characters

CAM5 (CESM)
NCAR

Pete Bogenschutz
Andrew Gettelman
Hugh Morrison
Cheryl Craig

AM3 (CM)
GFDL

Huan Guo
Chris Golaz
Leo Donner

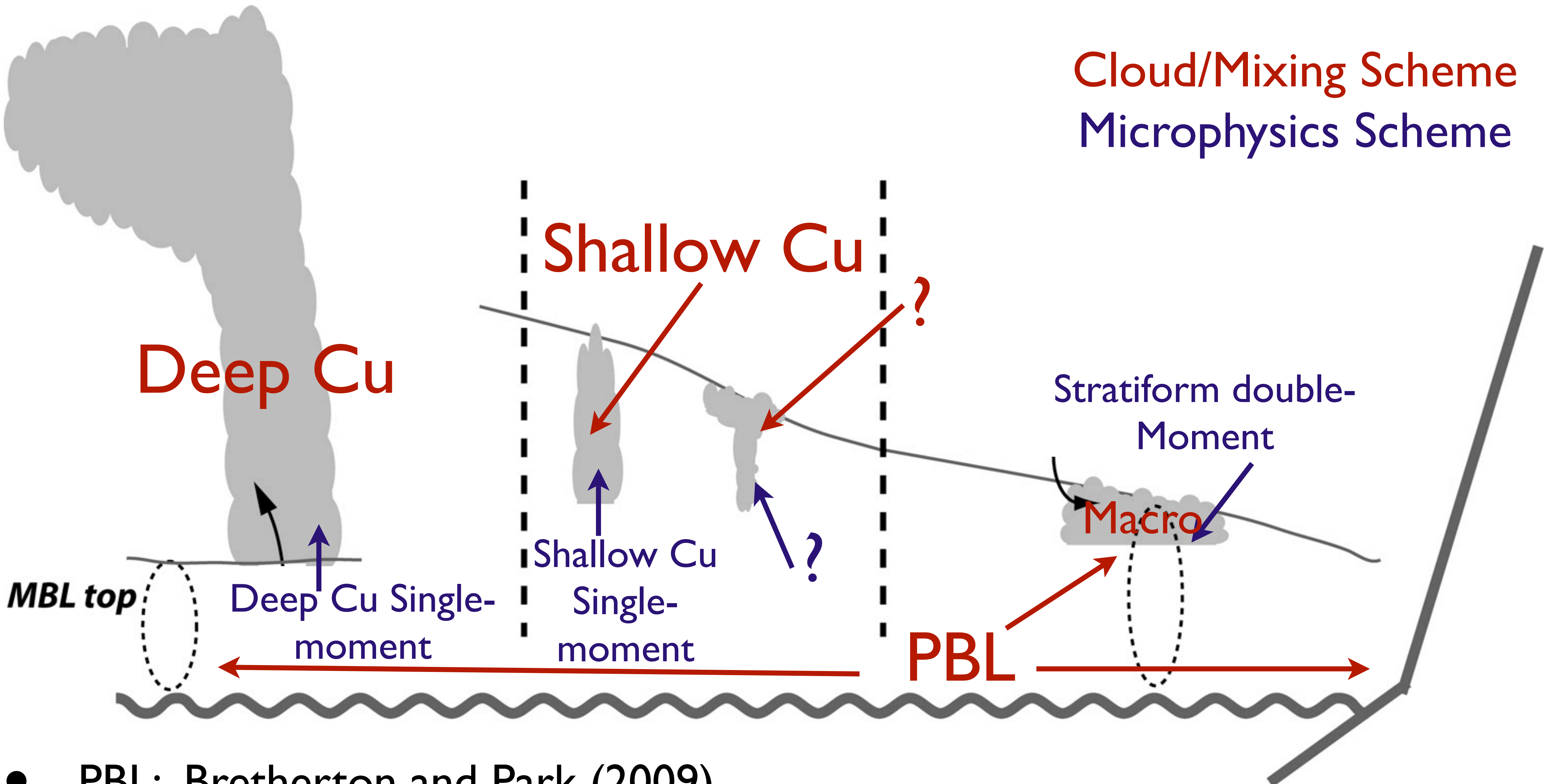
Fearless CPT leader: Vincent Larson

Other CPT Participants: Graham Feingold, Dan Grosvenor, Terry Kubar, Matt Lebsock, Seoung-Soo Lee, Rob Wood, Tak Yamaguchi,

π Motivation for New Schemes into AGCMs π

- Computation is now allowing global cloud resolving models and superparmaterized GCMs to emerge
- Despite this, it appears conventionally parameterized GCMs will remain the computational feasible route for long-term simulations/experiments for quite some time
- Further despite this, most conventionally parameterized AGCMs still use separate schemes for different atmospheric processes
- Let's examine this further...

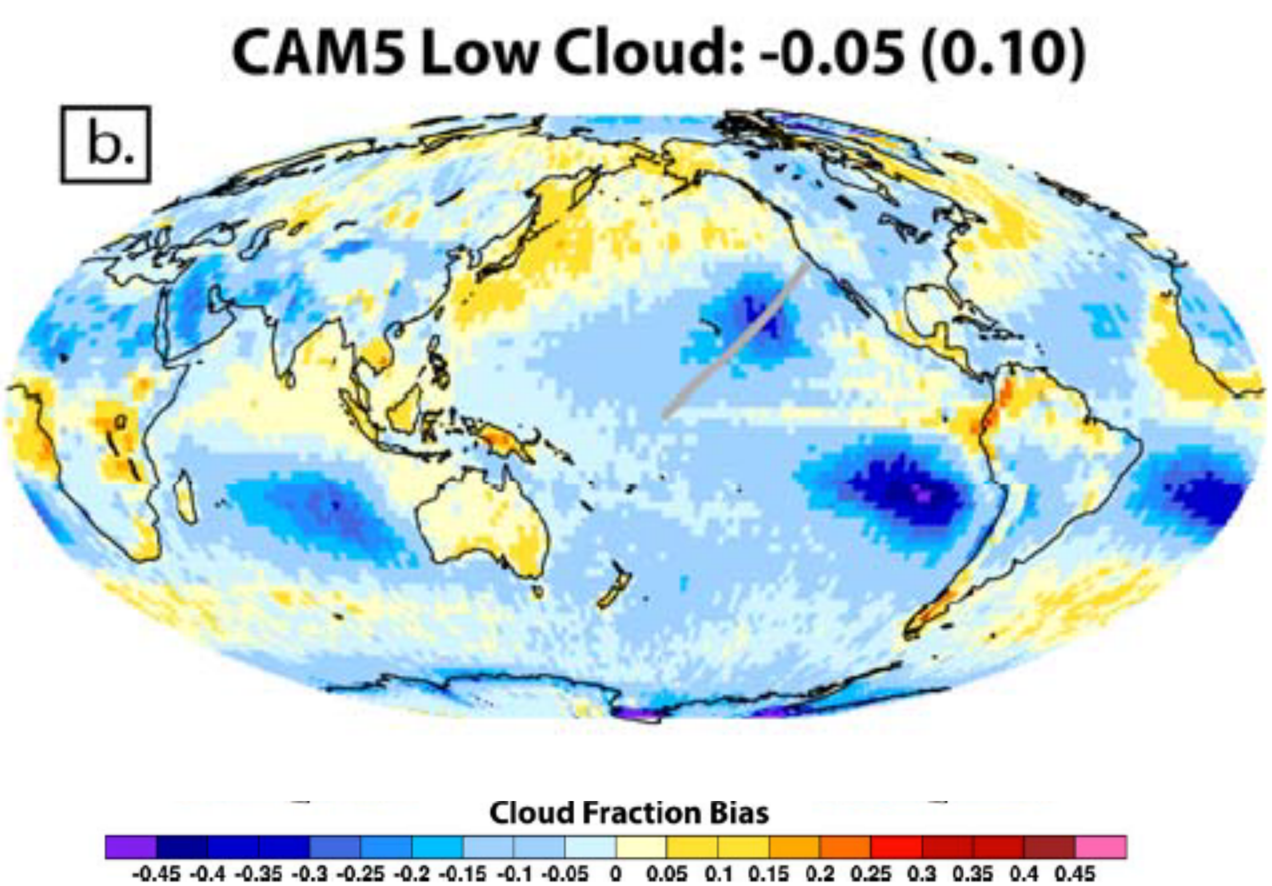
Community Atmosphere Model version 5 (CAM5)

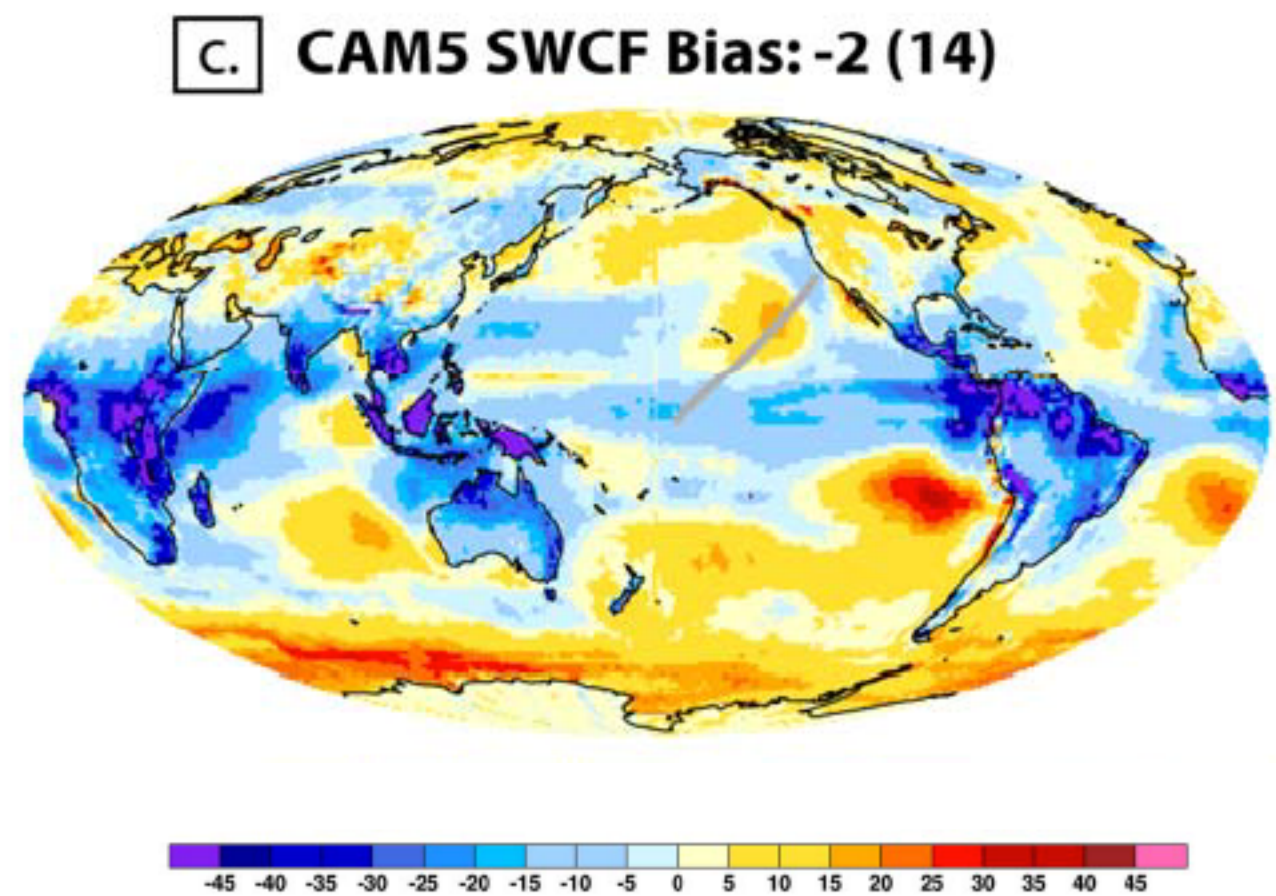


- PBL: Bretherton and Park (2009)
- Cloud Macrophysics: Park
- Shallow Cu: Park and Bretherton (2009)
- Deep Cu: Zhang and McFarlane (1995)
- Microphysics: Morrison and Gettelman (2008)

CAM5

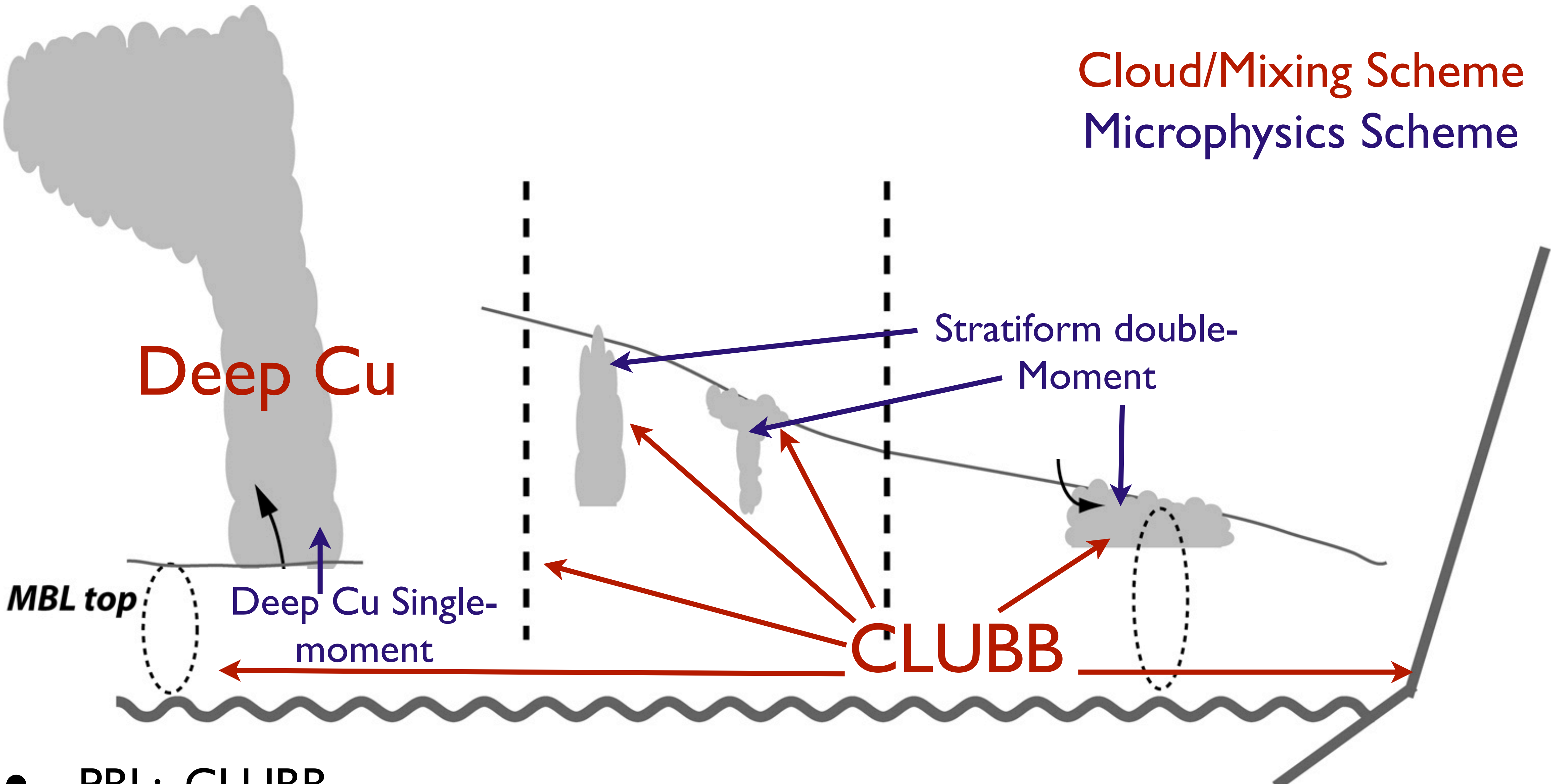
- Kay et al. (2012) shows that CAM5 improves cloud representation compared to CAM4 mostly due to new stratiform and shallow convection schemes
- However, stratocumulus to cumulus transition is still poorly represented...





Figs from Kay et al. (2012)

CAM-CLUBB



- PBL: CLUBB
- Cloud Macrophysics: CLUBB
- Shallow Cu: CLUBB
- Deep Cu: Zhang and McFarlane (1995)
- Microphysics: Morrison and Gettelman (2008)

Towards Unified Physics in GCMs

- Advantages of using a parameterization containing one equation set includes:
- Inconsistencies are avoided from calling separate parameterizations that may not be compatible with one another
- Atmospheric processes are often times not so distinct in nature (which scheme to call?)
    - Obvious example: Stratocumulus to cumulus transition
- Parameterizations (i.e. shallow and deep convection) often contain their own simplified treatments of microphysics
    - Unified cloud parameterizations can drive a single microphysics scheme (i.e. MG, double moment)
    - More consistent microphysics treatment as well as more consistent treatment of cloud-aerosol interactions

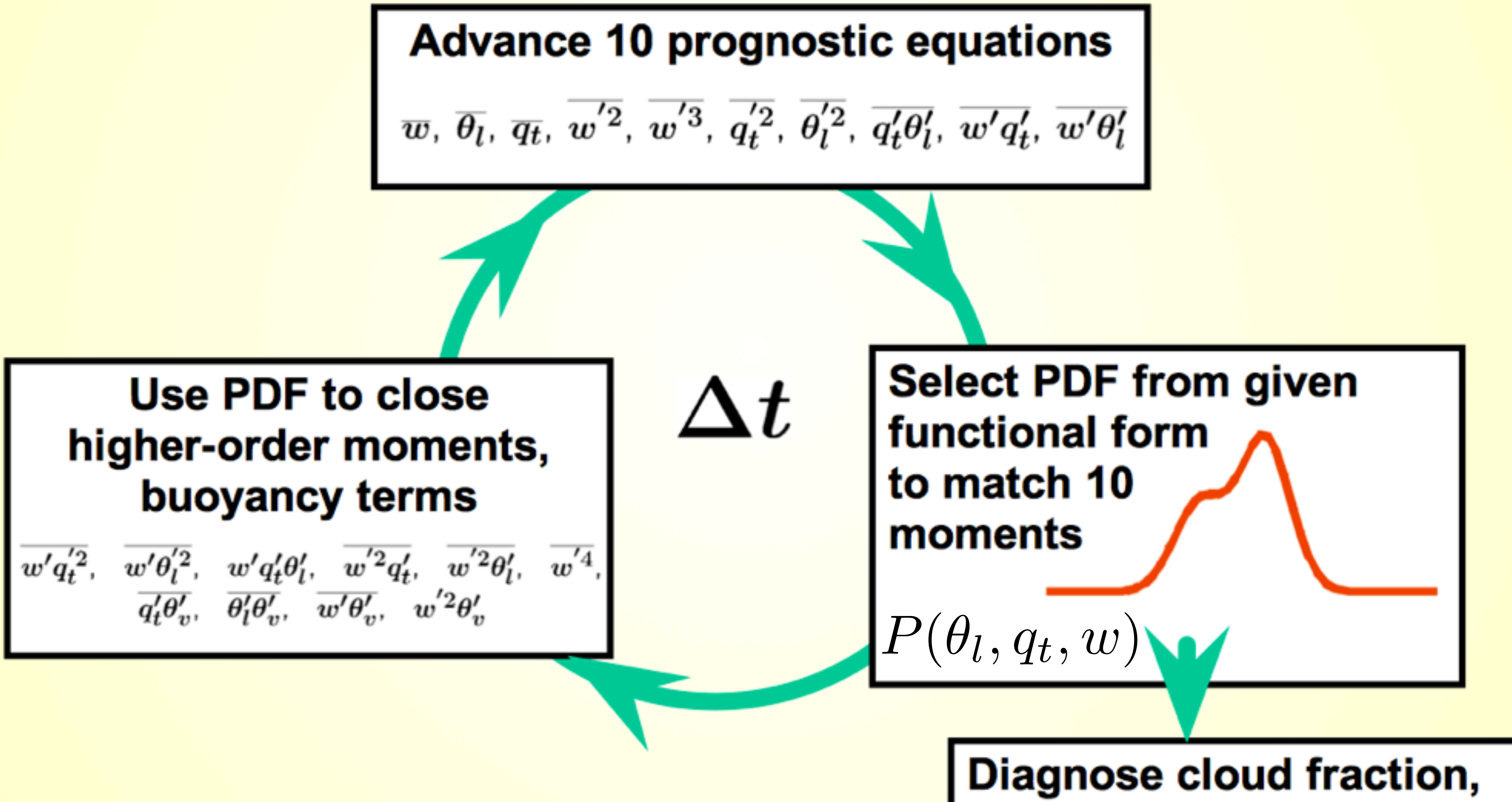
Outline

- CLUBB parameterization
- Coupling GCMs with this "Unified" parameterization
- Results
    - Successes ("it was the best of times...")
    - Challenges ("... it was the ...")
- Conclusions and future development: A sunny outlook

CLUBB

- CLUBB = Cloud Layers Unified By Binormals
- First developed by Golaz et al. (2002), maintained by University of Wisconsin Milwaukee (Vincent Larson's group)
- "Incomplete" third-order turbulence closure (predicting 9 second and third order moments), centered around a trivariate assumed double gaussian PDF
- Should provide a unified treatment of PBL and shallow convection, that drives a single microphysics scheme
- Based upon the so-called "assumed PDF" approach
  - Assumed double Gaussian PDF $P(\theta_l, q_t, w)$

Schematic of the Assumed PDF method



Golaz et al. (2002a)

Coupling CAM with CLUBB

Physics	CAM5	
Deep Convection	Zhang and McFarlane (1995)	
Boundary Layer	~~Bretherton and Park (2009)~~	
Shallow Convection	~~Park and Bretherton (2009)~~	
Cloud Macrophysics	~~Park (2012)~~	
Cloud Microphysics	Morrison and Gettelman (2008)	
Radiation	RRTMG (Iacono et al. 2008)	
Aerosols	Modal (Liu et al.2012)	

Coupling CAM with CLUBB

Physics	CAM5	CAM-CLUBB
Deep Convection	Zhang and McFarlane (1995)	Zhang and McFarlane (1995)
Boundary Layer	~~Bretherton and Park (2009)~~	CLUBB
Shallow Convection	~~Park and Bretherton (2009)~~	CLUBB
Cloud Macrophysics	~~Park (2012)~~	CLUBB
Cloud Microphysics	Morrison and Gettelman (2008)	Morrison and Gettelman (2008)
Radiation	RRTMG (Iacono et al. 2008)	RRTMG (Iacono et al. 2008)
Aerosols	Modal (Liu et al.2012)	Modal (Liu et al.2012)

The Details of CAM-CLUBB

- CLUBB called directly after deep convection, directly before microphysics
- CLUBB is currently only a warm cloud parameterization, therefore we still use the ice stratiform cloud fraction subroutine used in CAM5
- Timestep of CLUBB is 5 minutes, standard CAM timestep is 30 minutes
- Pass microphysics to CLUBB's predicted SGS vertical velocity variance for aerosol activation and CLUBB's diagnosed cloud water variance for autoconversion
- CAM-CLUBB only 10% more expensive than CAM5
- CAM-CLUBB of the future: provide deep convective tendencies

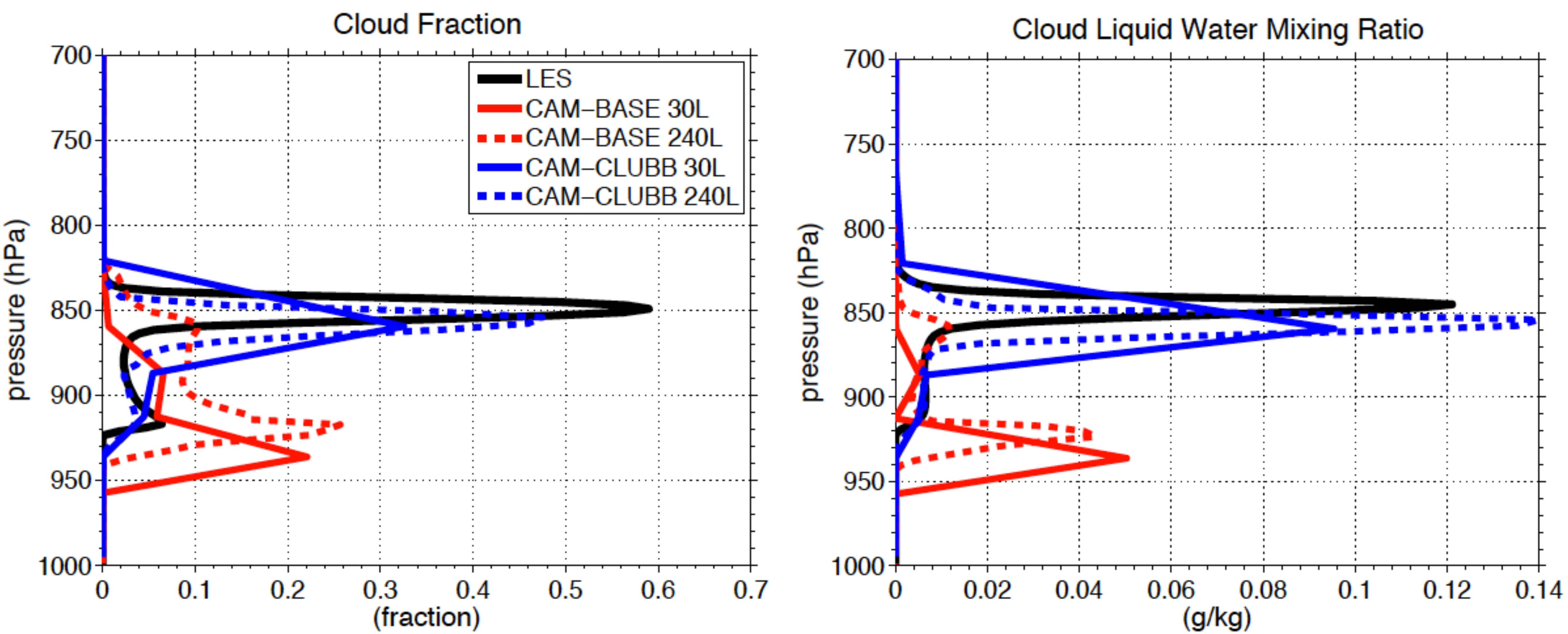
Results

- Successes in single-column world
  - SCM papers on AM3-CLUBB and CAM-CLUBB:
    - Guo et al. (2010) *(Geosci. Model Dev.)*
    - Guo et al. (2011) *(Geophysical Res. Letters)*
    - Bogenschutz et al. (2012) *(Geosci. Model Dev.)*
- Global results of AM3-CLUBB and CAM-CLUBB
  - Global GCM papers in prep. for both GCM versions of CLUBB

Single Column Testing

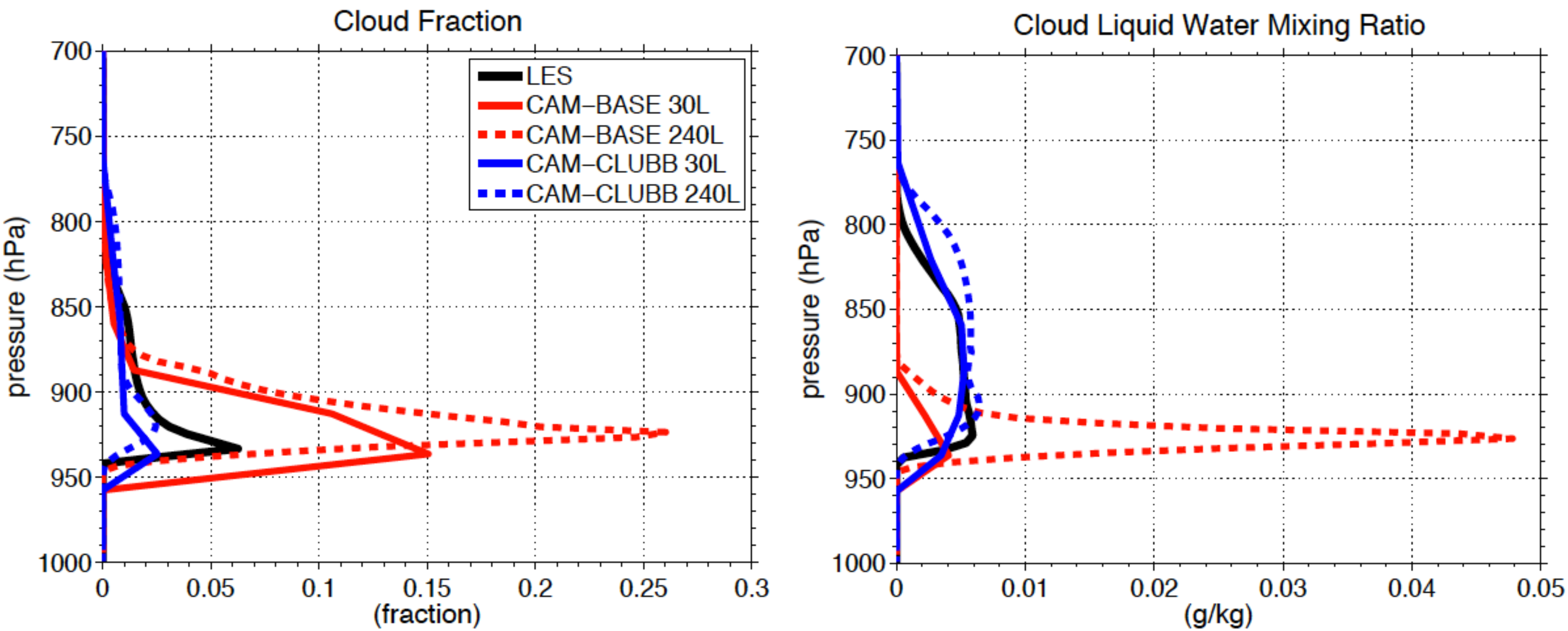
- SCAM-CLUBB tested on many boundary layer & deep convective regimes (Bogenschutz et al. 2012)
  - Cumulus: RICO, BOMEX, ARM_CC
  - Stratocumulus: DYCOMS2RF-01, DYCOMS2RF-02, ATEX
  - Deep convection: GATE, TOGA, ARM97
  - Mixed phase: MPACE
- Results show less sensitivity to vertical resolution and time step compared to CAM5.
- Improved simulation of transitional and shallow convective regimes (with comparable stratocumulus simulations relative to CAM5).

Cumulus Under a Strong Inversion (ATEX)



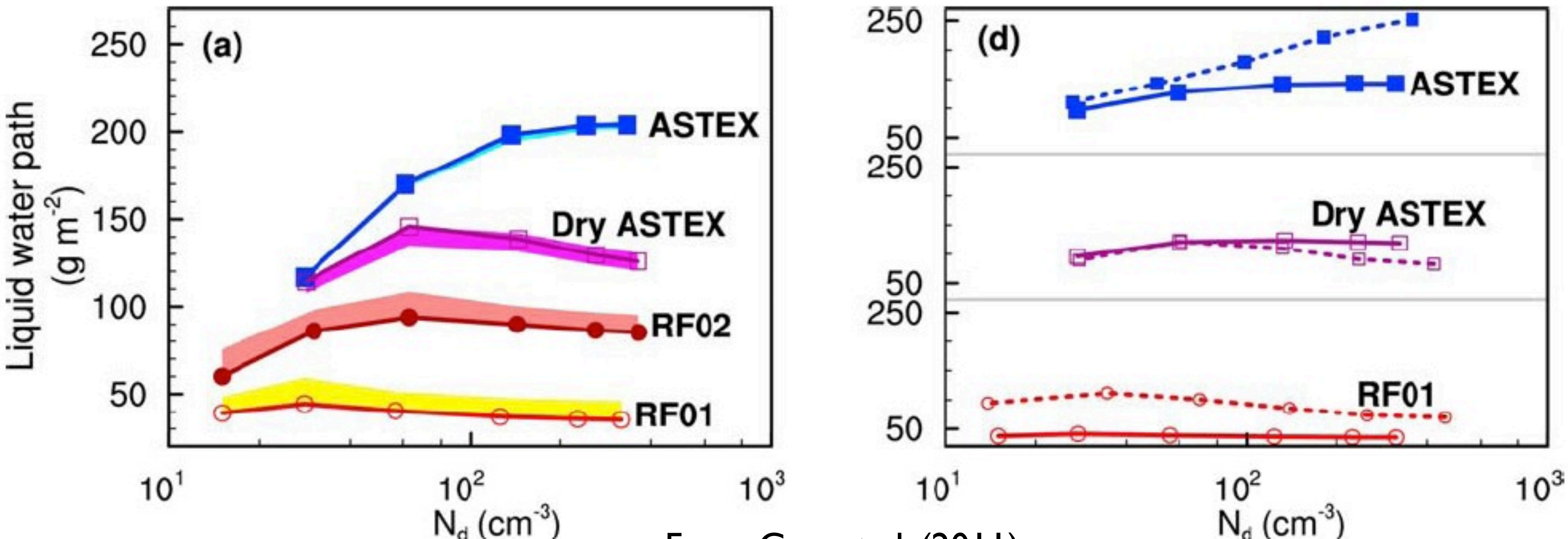
From Bogenschutz et al. (2012)

Trade-wind Cumulus (BOMEX)



From Bogenschutz et al. (2012)

AM3-CLUBB and Aerosol Effects



From Guo et al. (2011)

Solid curves: AM3-CLUBB

Dashed curves: LES

Global Results

- CAM-CLUBB results shown:
  - Five-year simulations using present day emissions
  - 1 degree horizontal resolution
  - Finite Volume dynamical core
  - Skill scores competitive with CAM5
  - Configuration has been preliminarily tested in CESM
- AM3-CLUBB results shown:
  - 1 degree horizontal resolution
  - FV dynamical core
  - 20-year simulations 1980-2000

22 possible endings!

21 are segmentation faults and core dumps

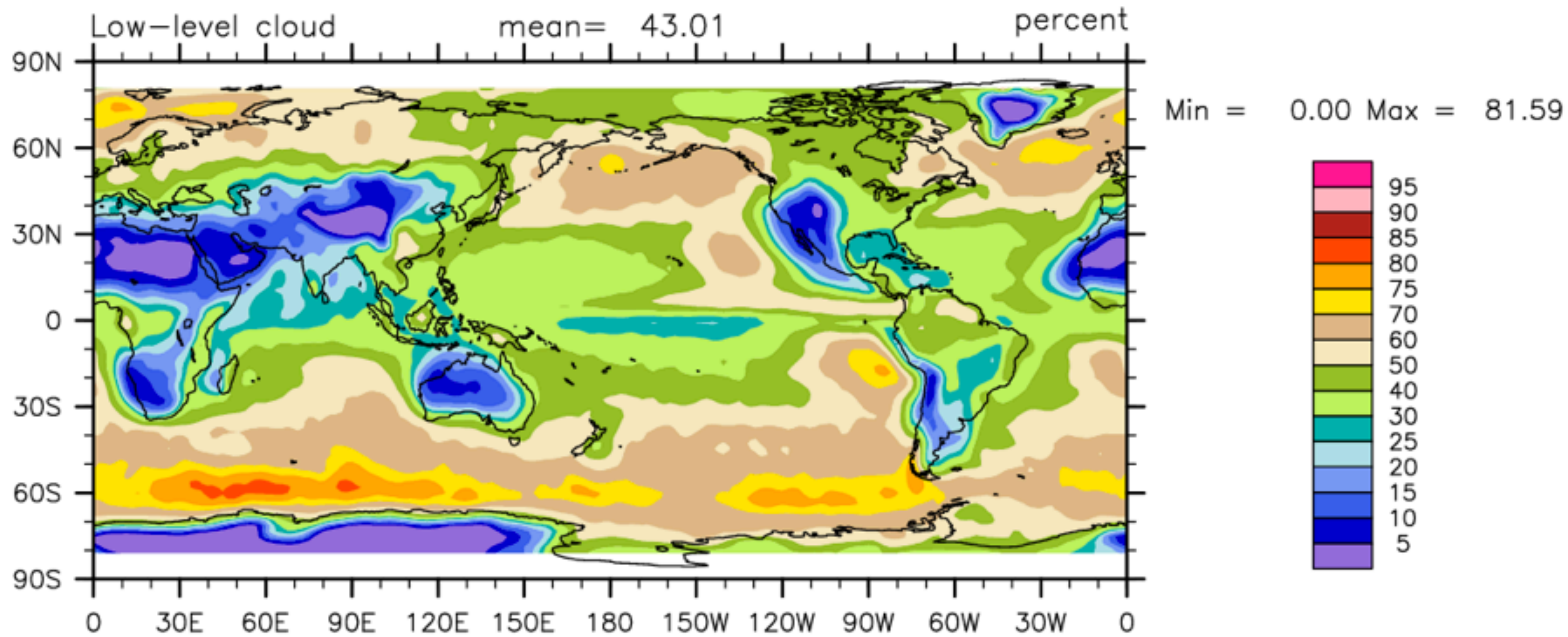
the other *may* give you a decent climate simulation

Bluefire

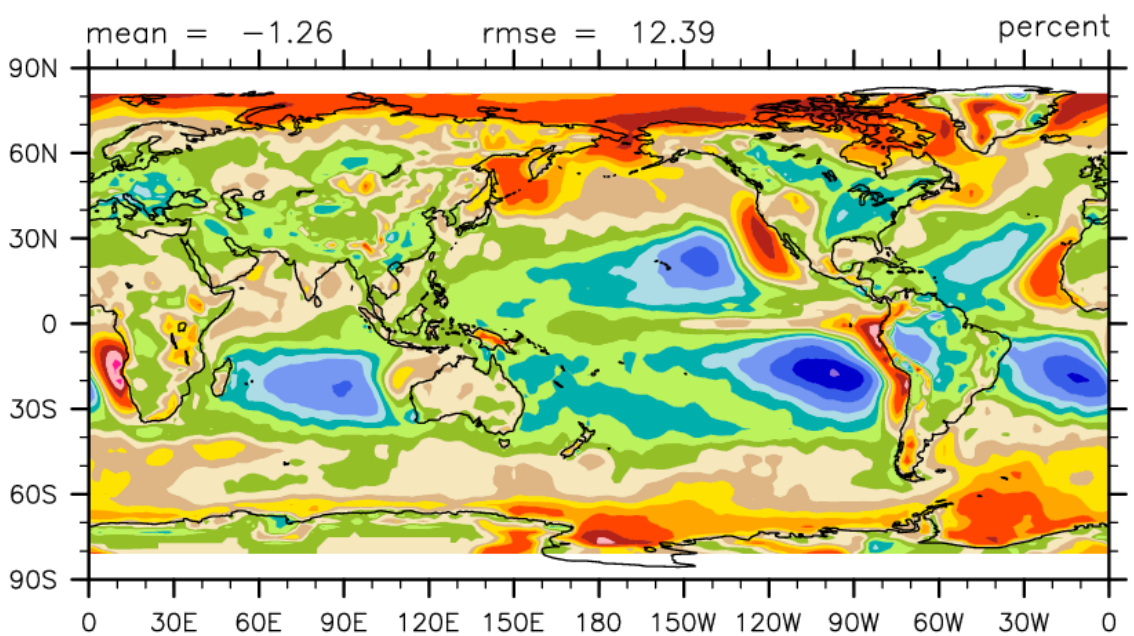
Huan and me

Low Cloud Amounts

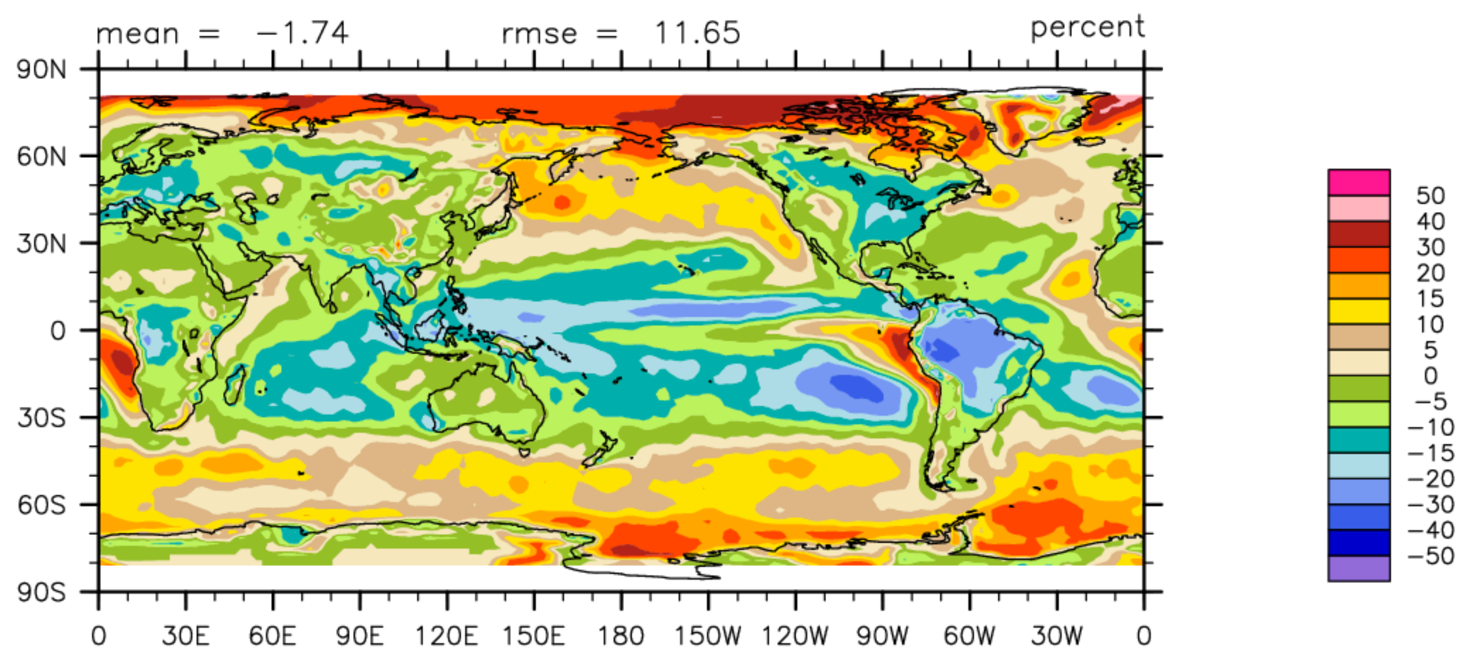
CLOUDSAT



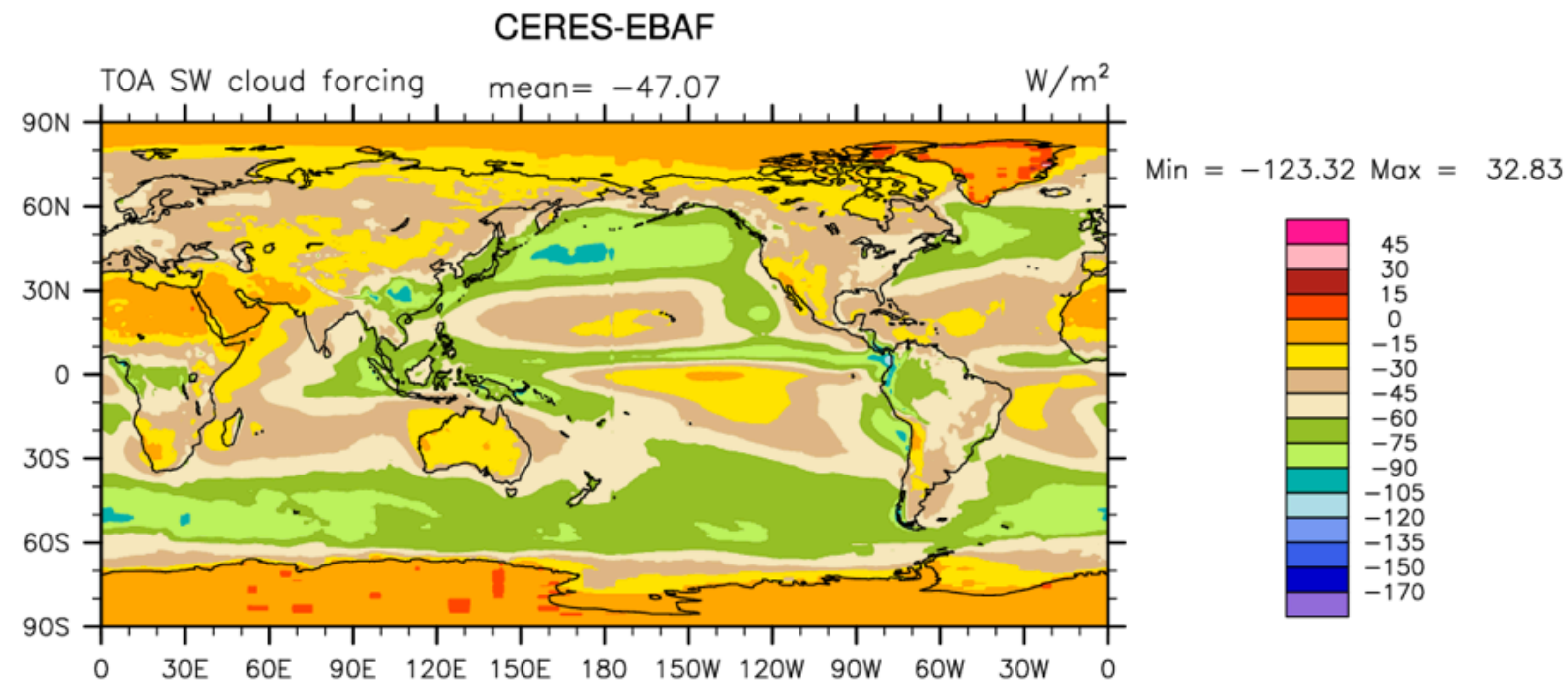
CAM5 - CLOUDSAT



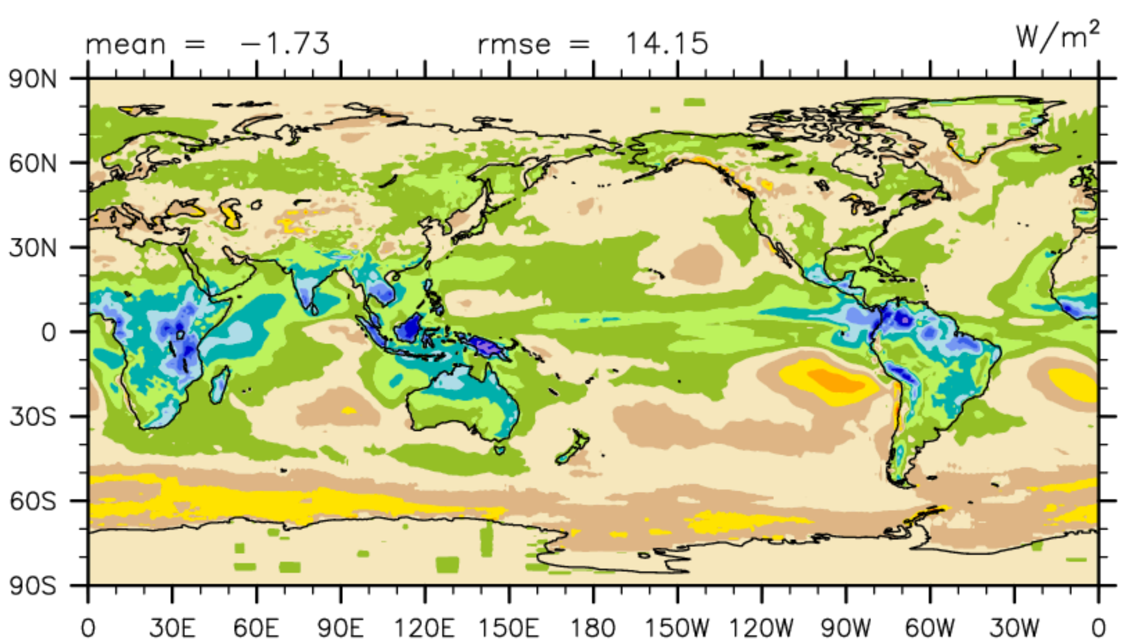
CAM-CLUBB - CLOUDSAT



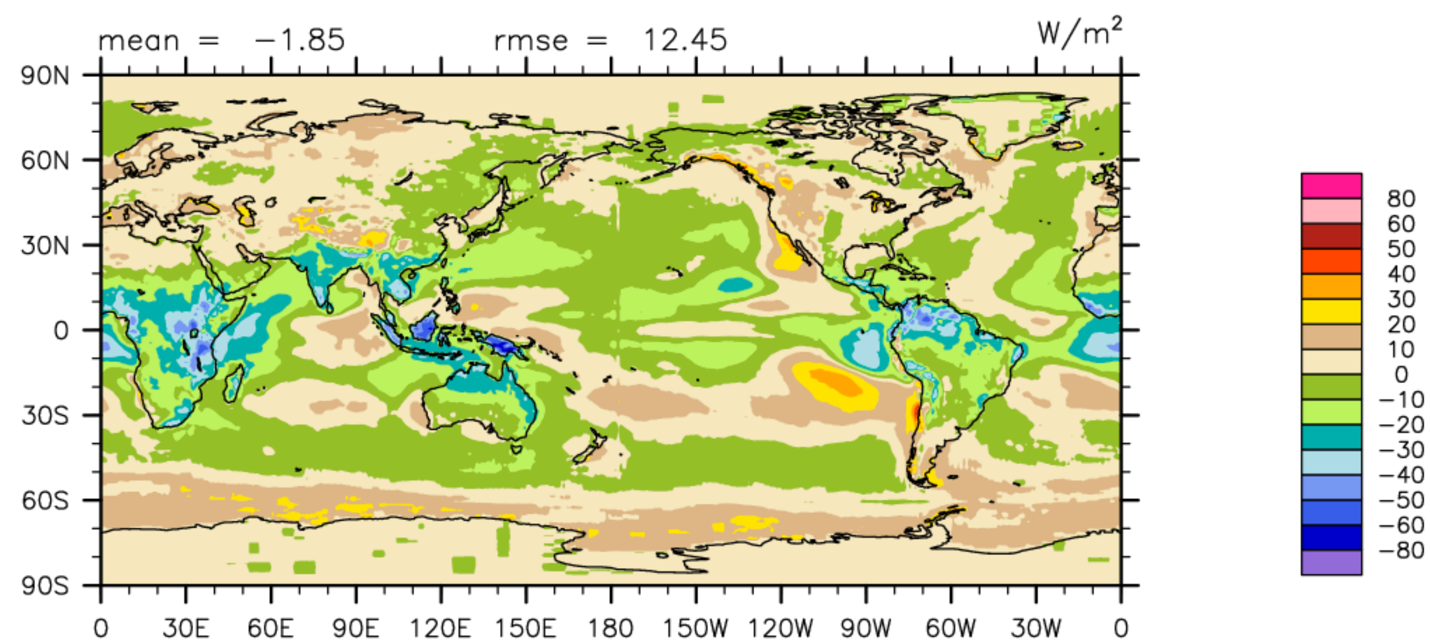
Shortwave Cloud Forcing



CAM5 - CERES-EBAF

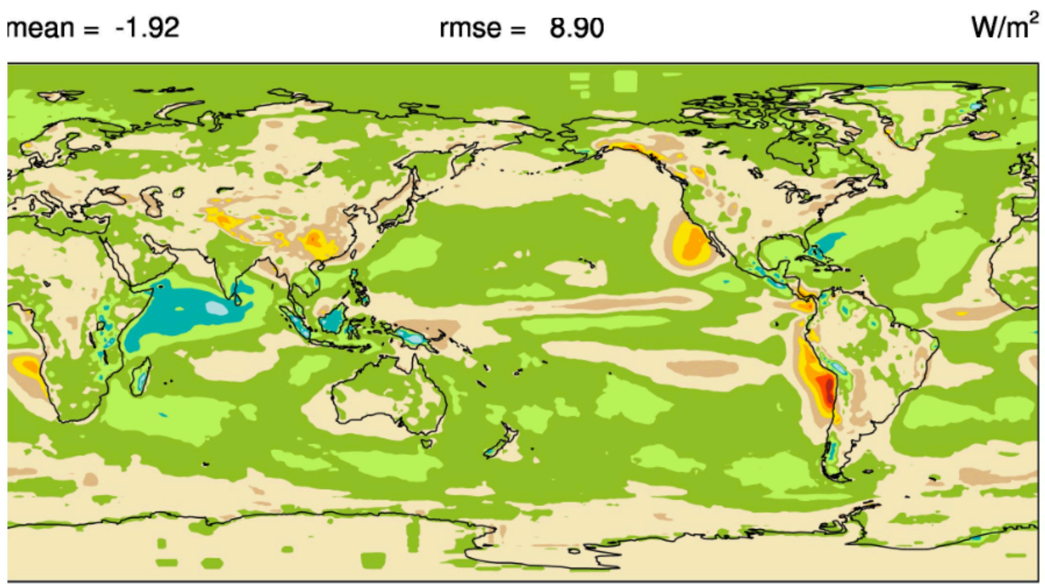


CAM-CLUBB - CERES-EBAF

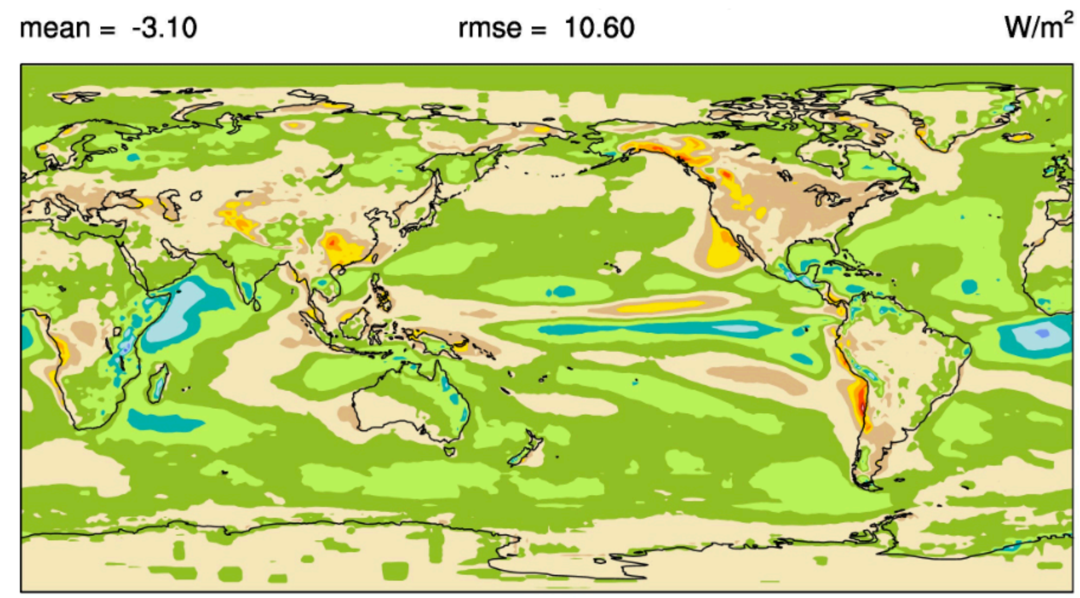


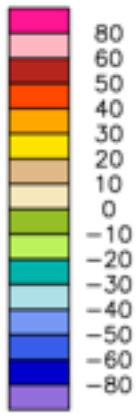
A Tale of Two Models... (SWCF biases)

AM3 - CERES-EBAF

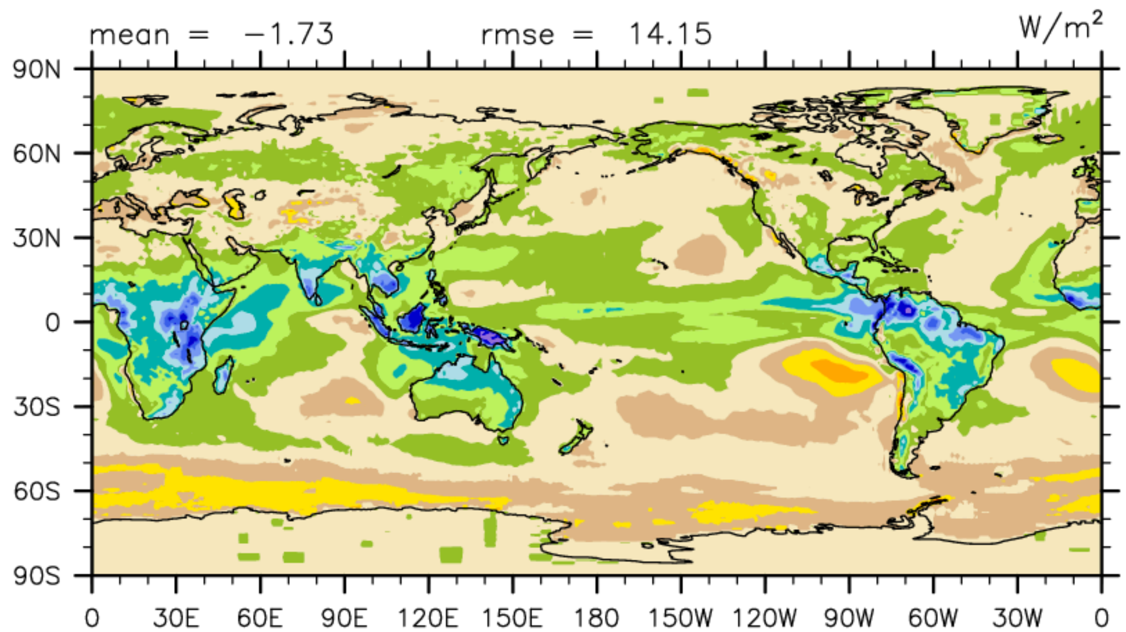


AM3-CLUBB - CERES-EBAF

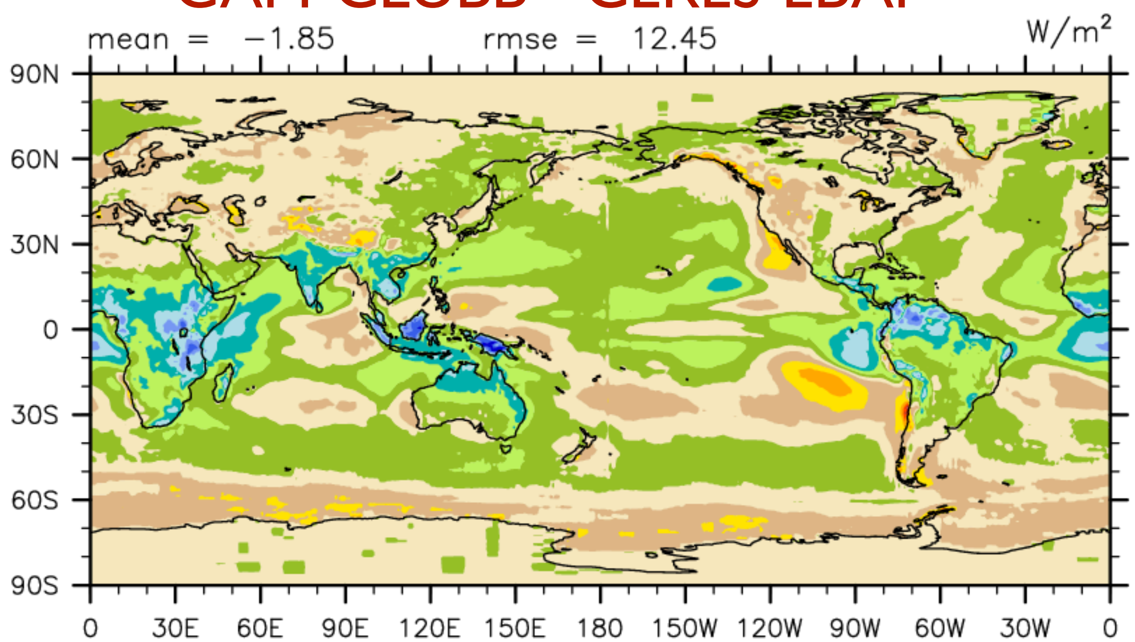




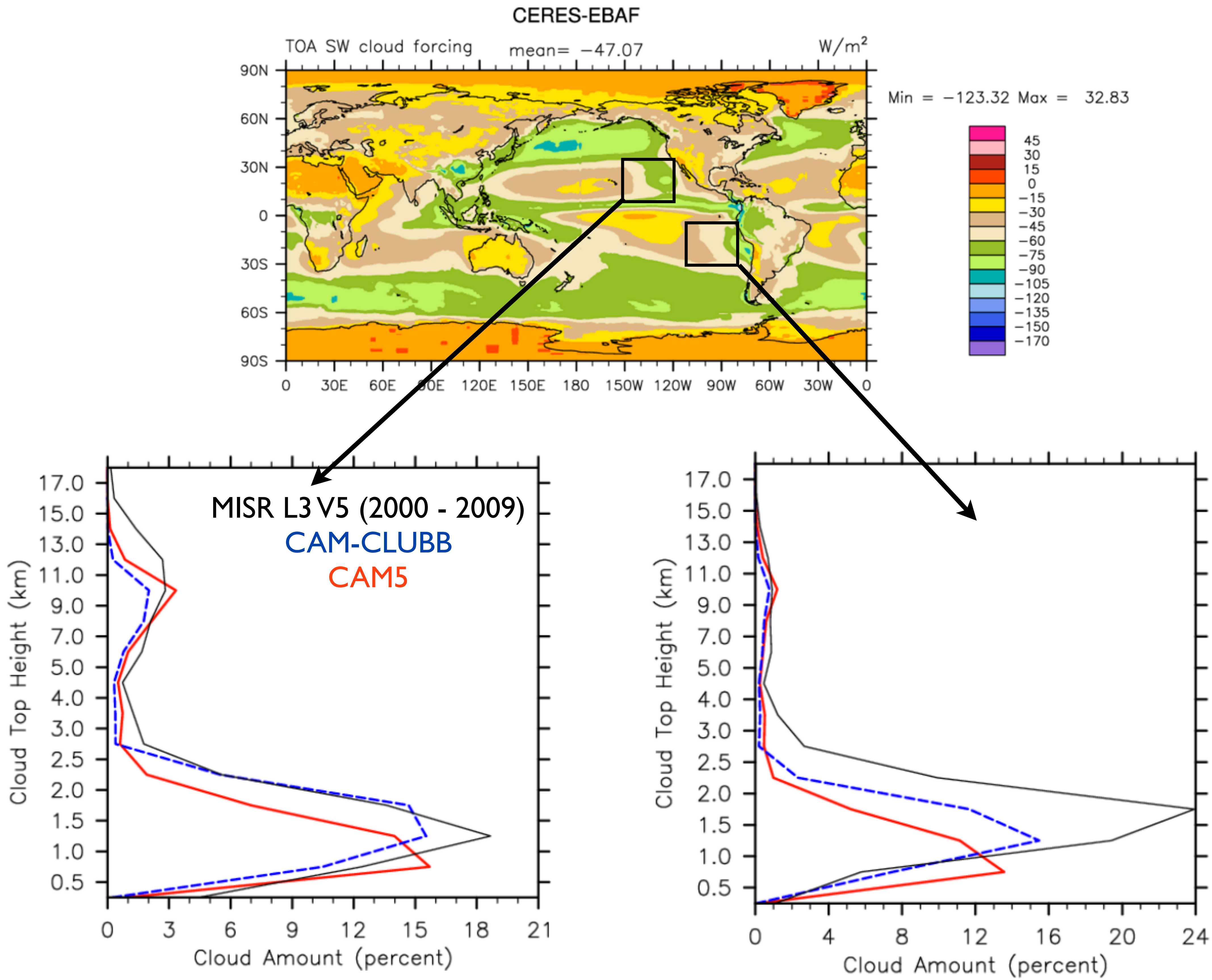
CAM5 - CERES-EBAF



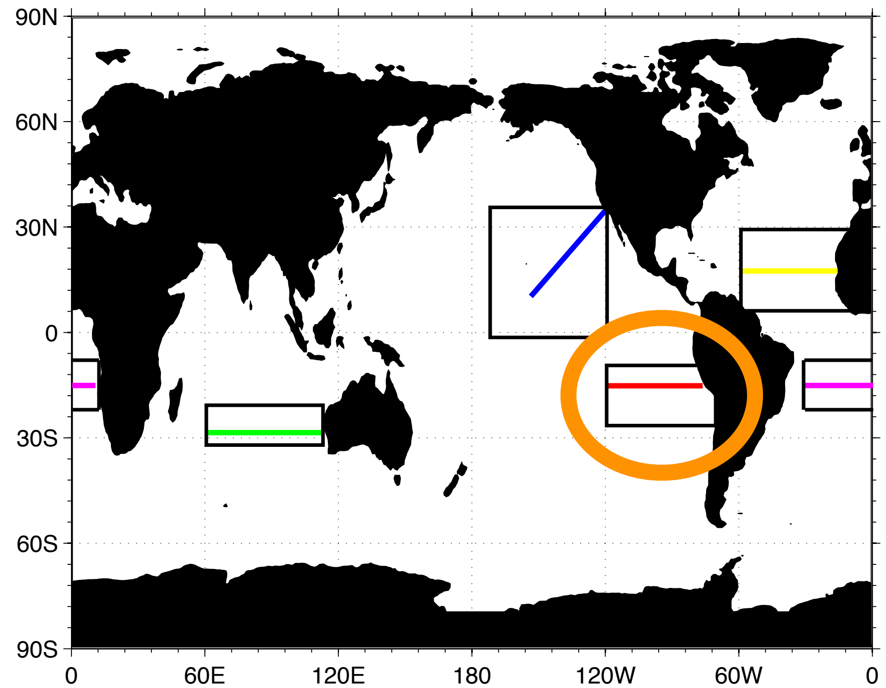
CAM-CLUBB - CERES-EBAF

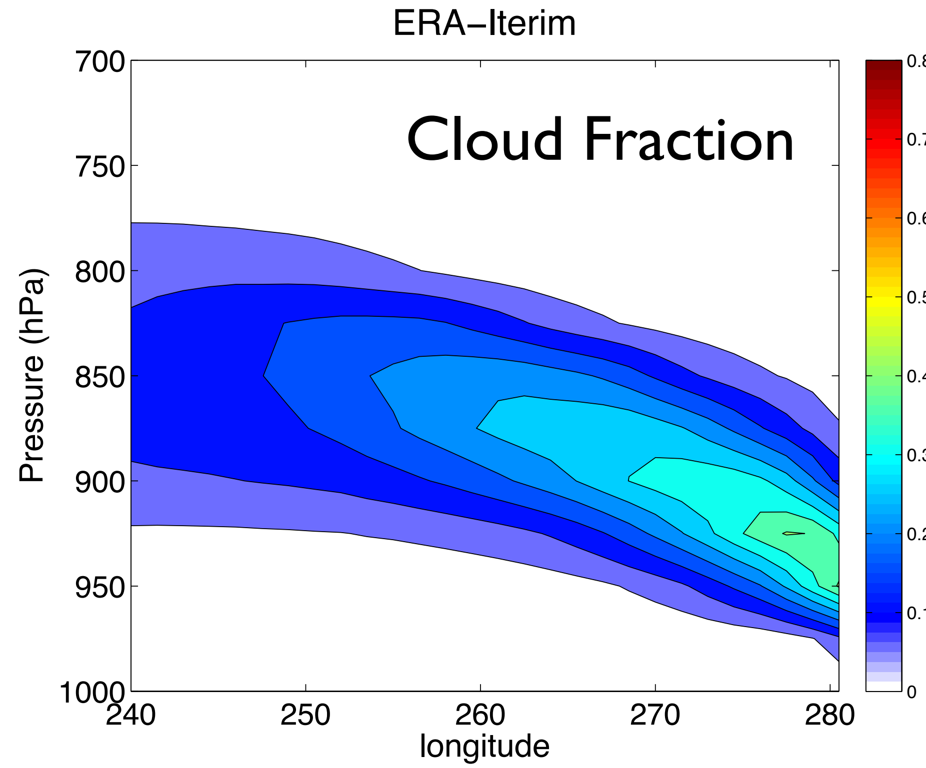


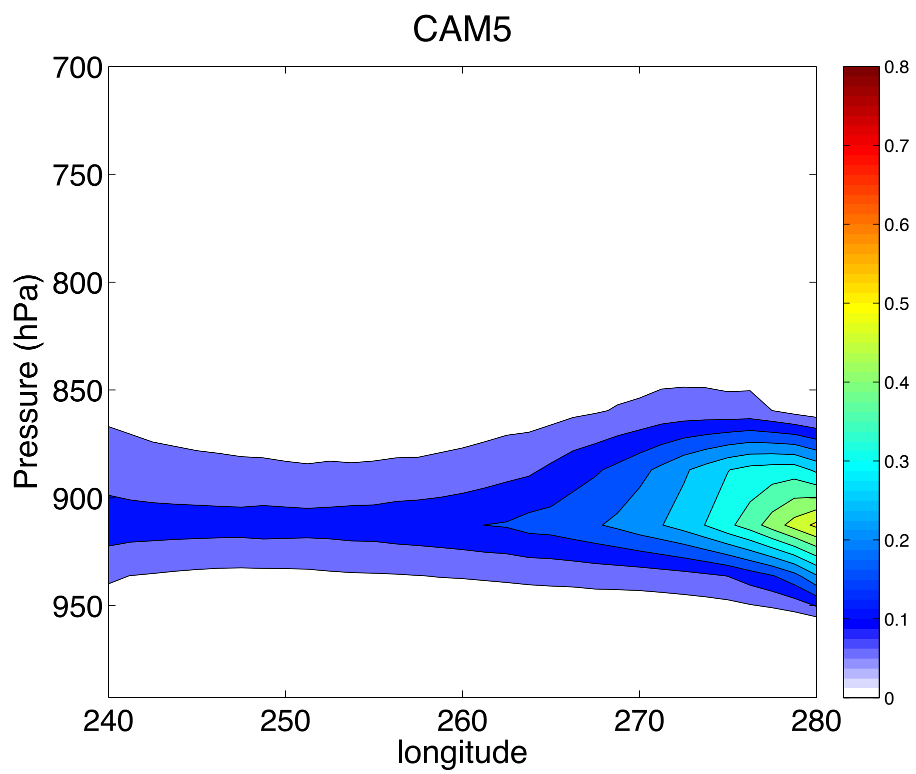
Differences in Boundary Layer Clouds

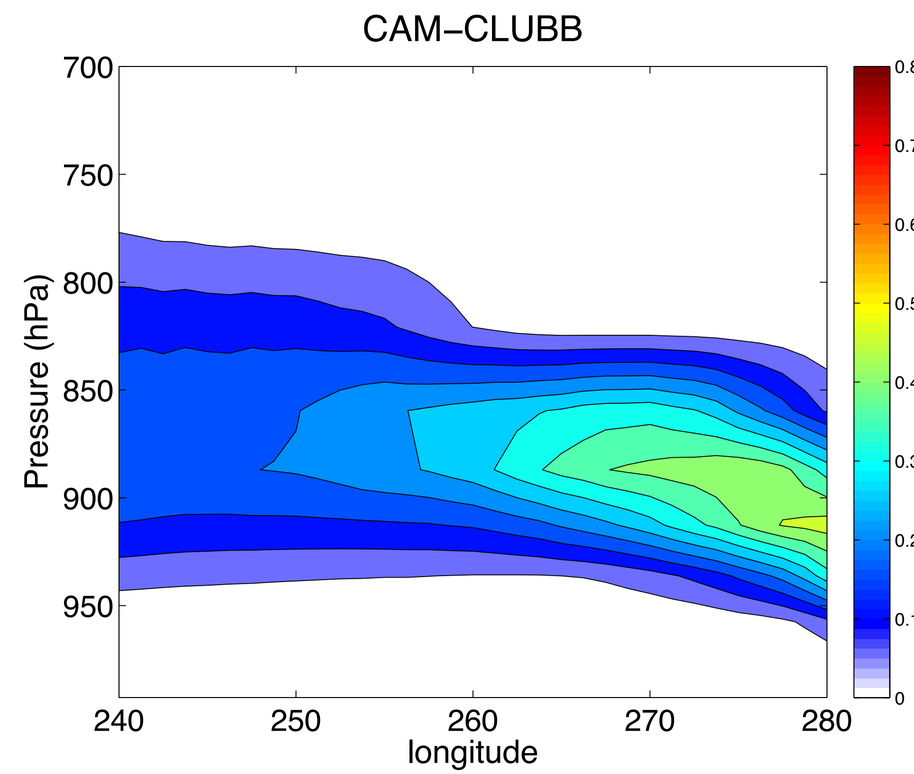


Transition Areas Appear to be Improved...



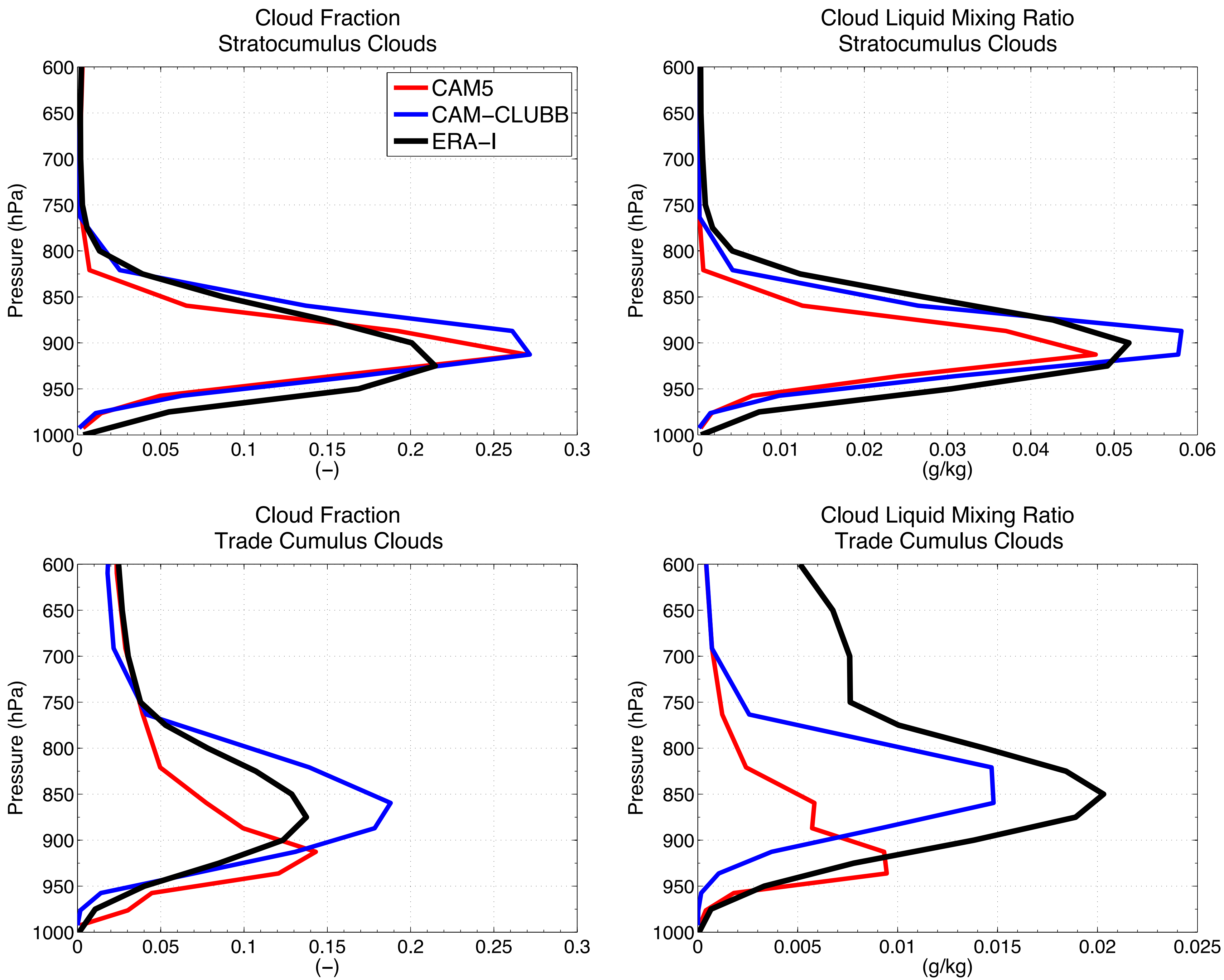






Stratocumulus and Cumulus

- Use LTS and dynamical conditional sampling as per Medeiros and Stevens (2011) to sample Sc and Cu (oceanic points between 35 S to 35 N)



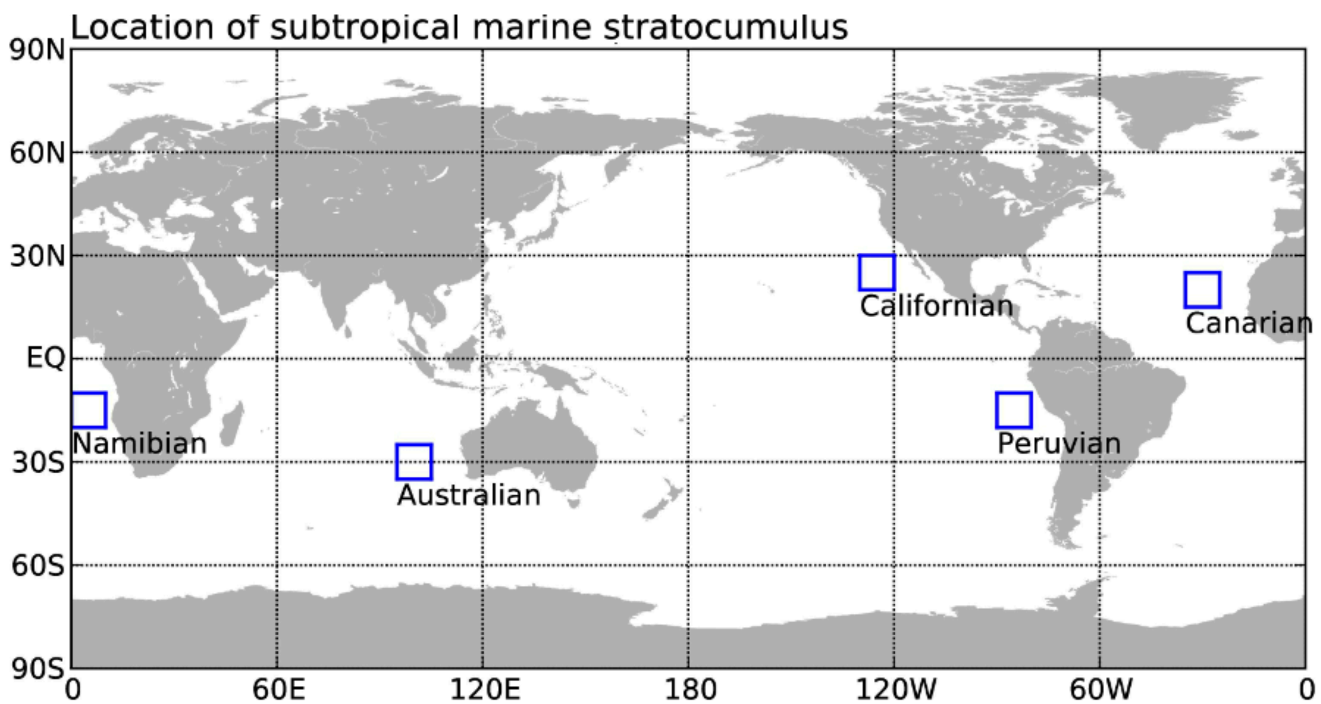
Sampling Criteria:
LTS > 18.5 K

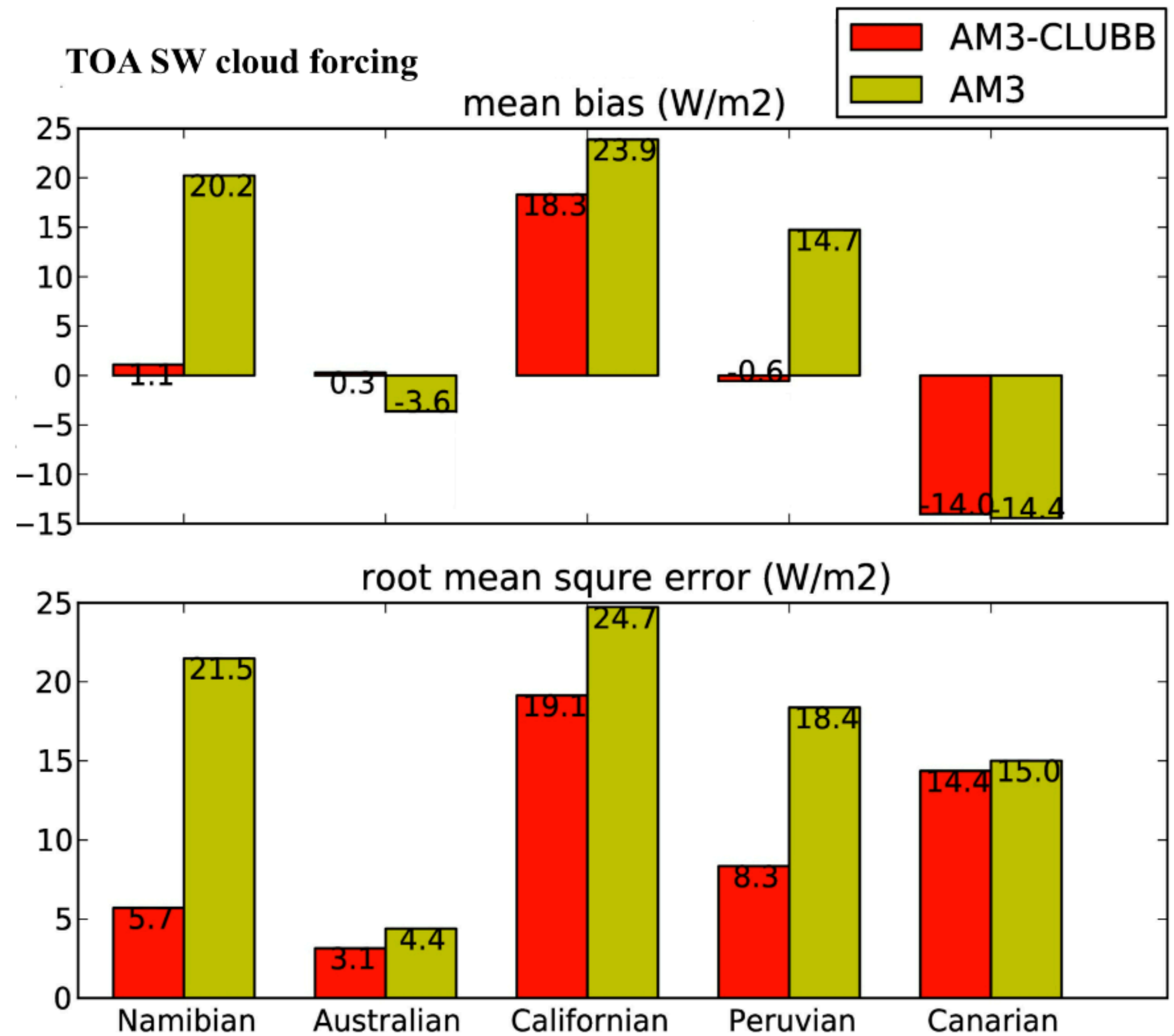
500 & 700 hPa omega > 10.0 hPa/d

Sampling Criteria:
15.3 > LTS > 11.3 K

500 & 700 hPa omega > 10.0 hPa/d

AM3-CLUBB improvements for Marine Sc

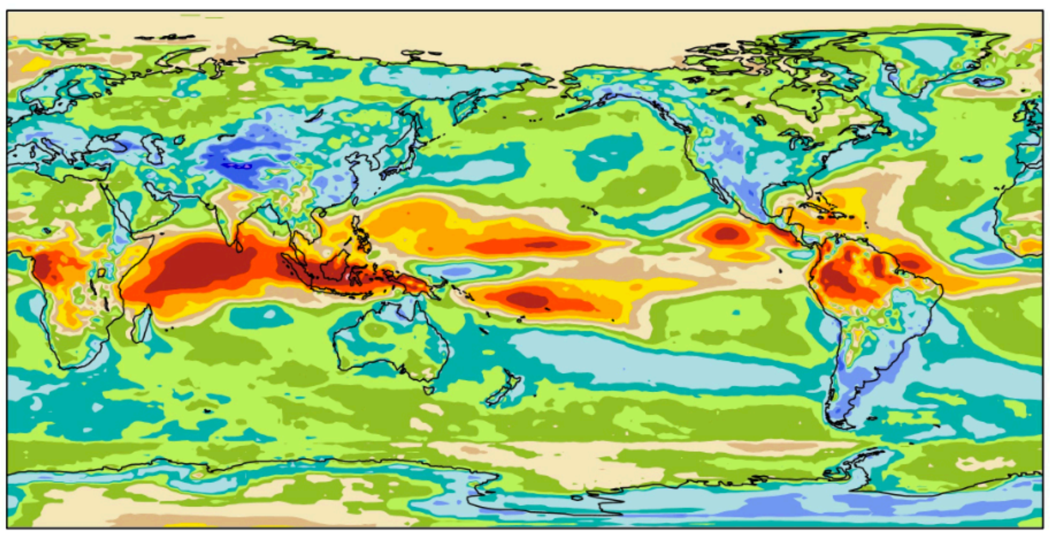




Biggest Challenge
(Longwave Cloud Forcing)

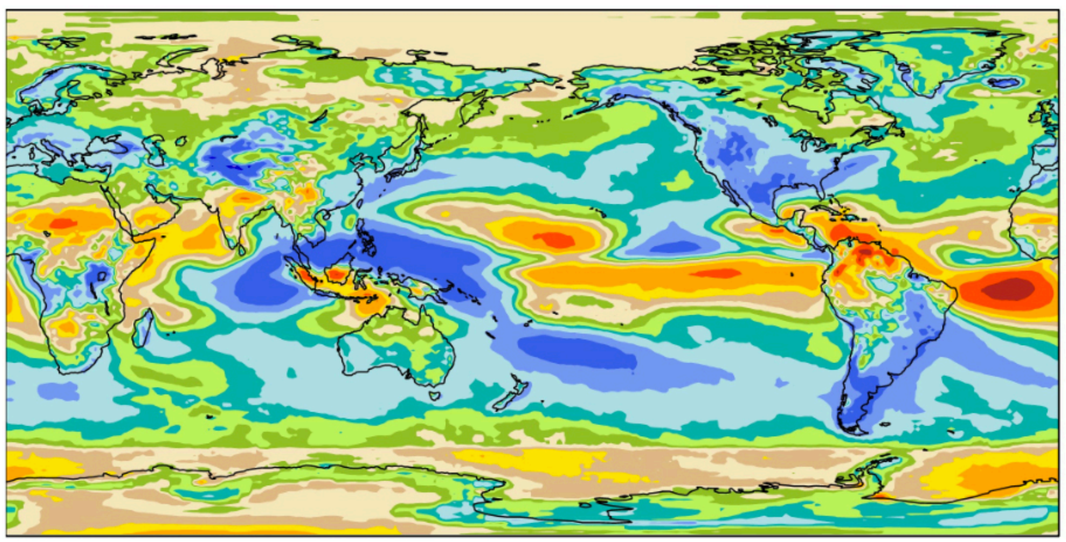
AM3 - CERES-EBAF

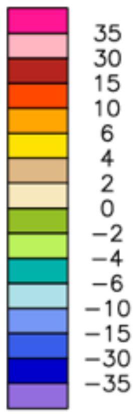
mean = -1.34 rmse = 6.05 W/m^2



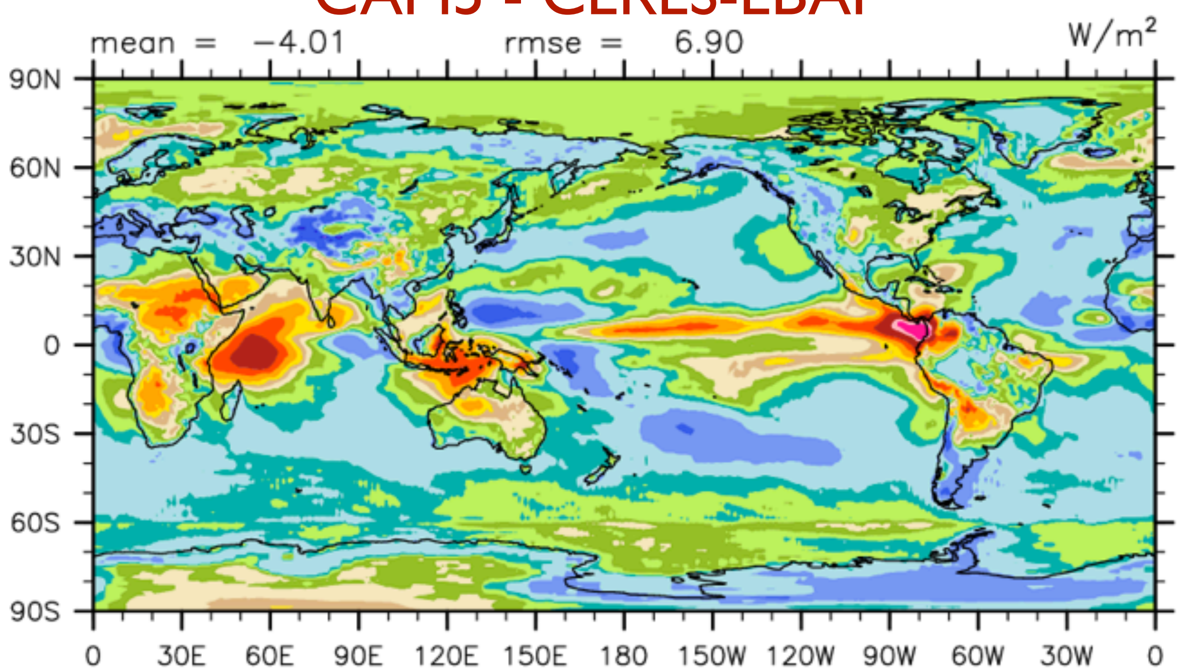
AM3-CLUBB - CERES-EBAF

mean = -3.56 rmse = 7.19 W/m^2

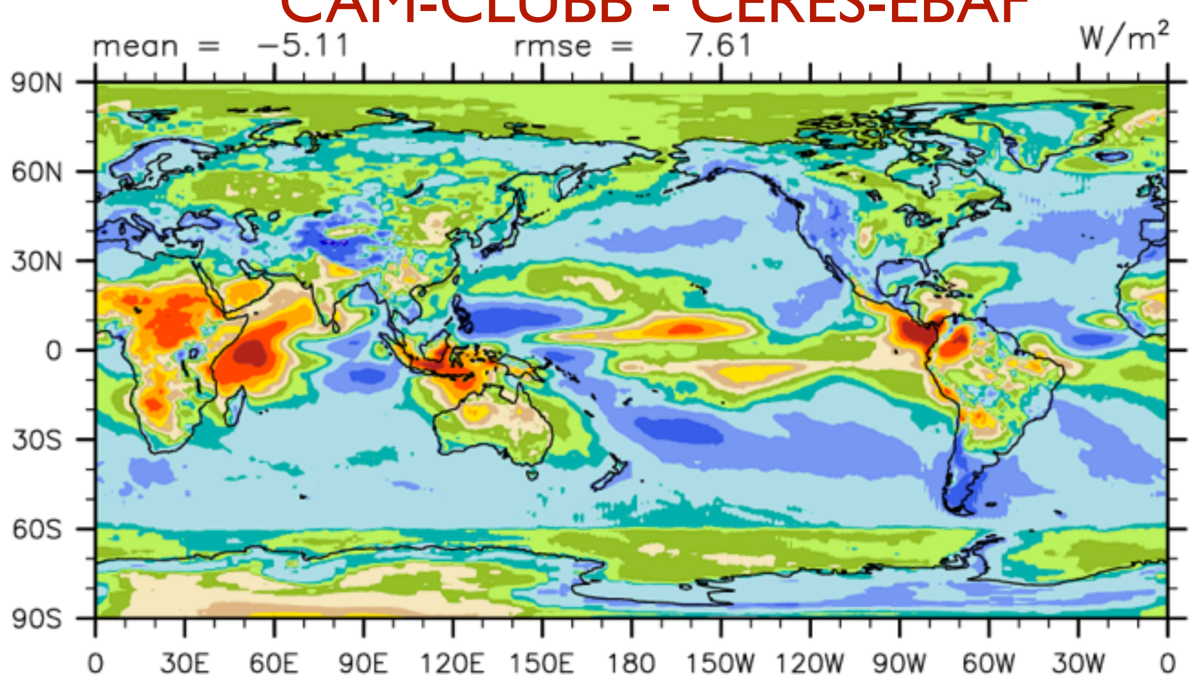




CAM5 - CERES-EBAF



CAM-CLUBB - CERES-EBAF



Summary

- CAM-CLUBB has been alive for almost two years (included in the last CESM release)
- Both GCM configurations with CLUBB represent a step forward towards unified conventional cloud parameterizations
- Successes are embedded in smoother transitions between cloud types traditionally handled by separate parameterizations and representation of boundary layer clouds
- Challenges are associated with tuning, compensating for host model biases, and shortcomings of the parameterization dealing with ice

Future Work

- CLUBB is a unique parameterization and yields many possible paths for future development in GCMs
  - Sub-step CLUBB and MG in concert
  - Integration over CLUBB's PDF to generate subcolumns for microphysics and radiation calculation
  - Have CLUBB provide deep convective tendencies
- Doing science with CAM-CLUBB
  - Aerosol indirect effects
  - Climate sensitivity