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A Fully Unified Boundary Layer and Convection Parameterization in CAM: Recent Results from Three-Dimensional Simulations

J. Teixeira (1, 2), A. Herrington (3), X. Jiang (1), M. Witte (1, 6), J. Bacmeister (3), R. Fu (1), G. Matheou (5), M. Kurowski (2), R. Storer (1), M. Chinita (1), L. Donner (4) and K. Suselj (2)

(1) University of California Los Angeles, California
(2) JPL, California Institute of Technology, Pasadena, California
(3) NCAR, Boulder, Colorado
(4) GFDL, Princeton, New Jersey
(5) University of Connecticut, Storrs, Connecticut
6) Naval Postgraduate School, Monterey, California

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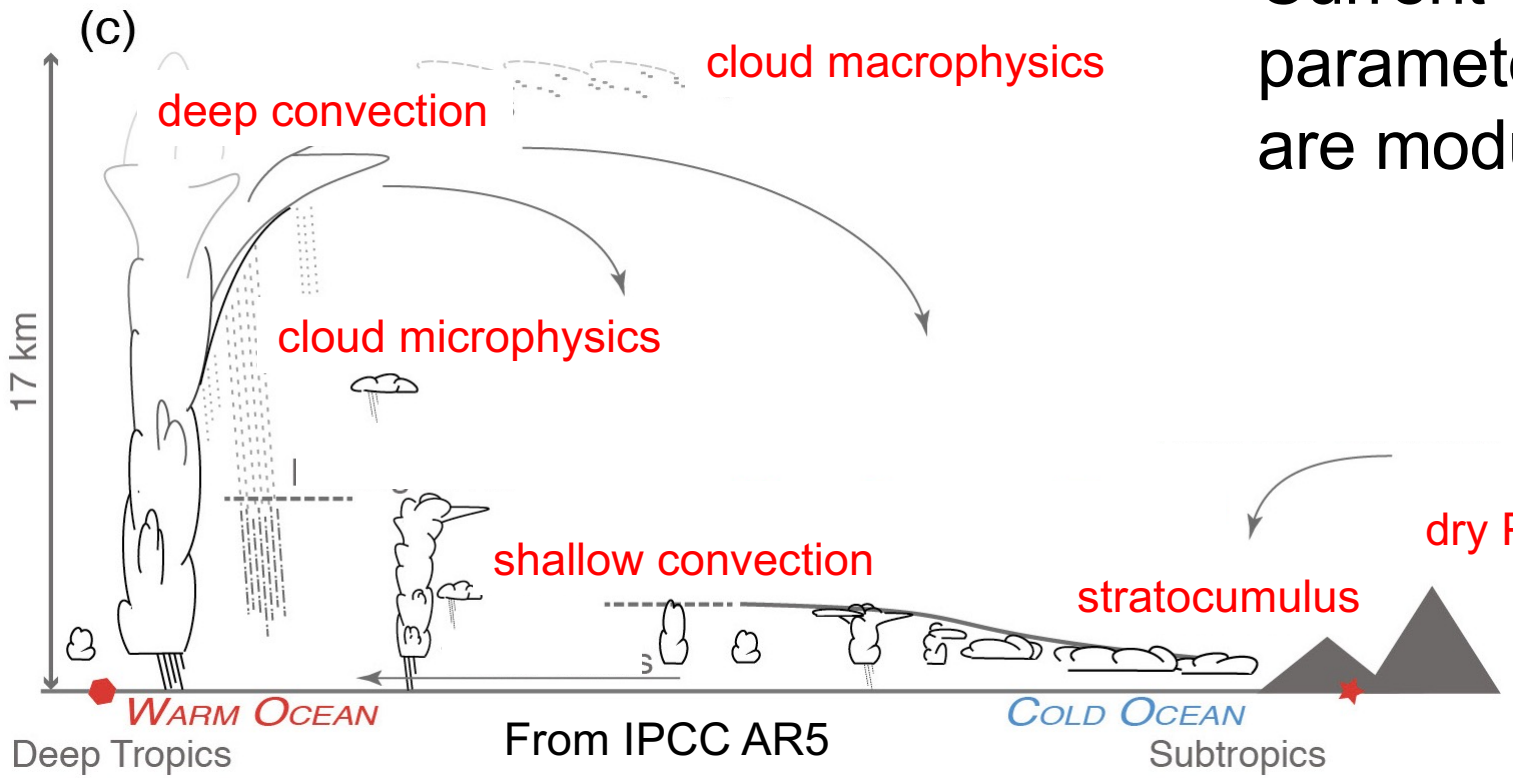
Fully Unified Mixing Parameterization



Current parameterizations are modular

We will show results from a fully unified turbulence and convection parameterization: From PBL to deep convection

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Merging Higher-Order Closure with Multi-plume Mass-Flux: CLUBB + MF

- **CLUBB represents double-gaussian mixing while MF plumes represent additional discrete skewness of the sub-grid PDF**

- Multi-plume MF: 1) Sampling from surface layer thermodynamic PDFs; 2) Stochastic lateral entrainment based on TKE

- MF plumes are coupled to CLUBB via 5-diagonal prognostic solver for mean fields and turbulent fluxes (solved simultaneously):

$$\frac{\bar{\varphi}^{t+\Delta t}}{\Delta t} + \frac{1}{\rho_s}\frac{\partial}{\partial z}\rho_s \overline{w'\varphi'}^{t+\Delta t}_{CLUBB}$$

$$= \frac{\bar{\varphi}^{t}}{\Delta t} - \frac{1}{\rho_s}\frac{\partial}{\partial z}\left(\rho_s \sum a_i w_i \varphi_i'\right)^{t}_{MF} + \left.\frac{\partial \bar{\varphi}}{\partial t}\right|_{forcing}$$

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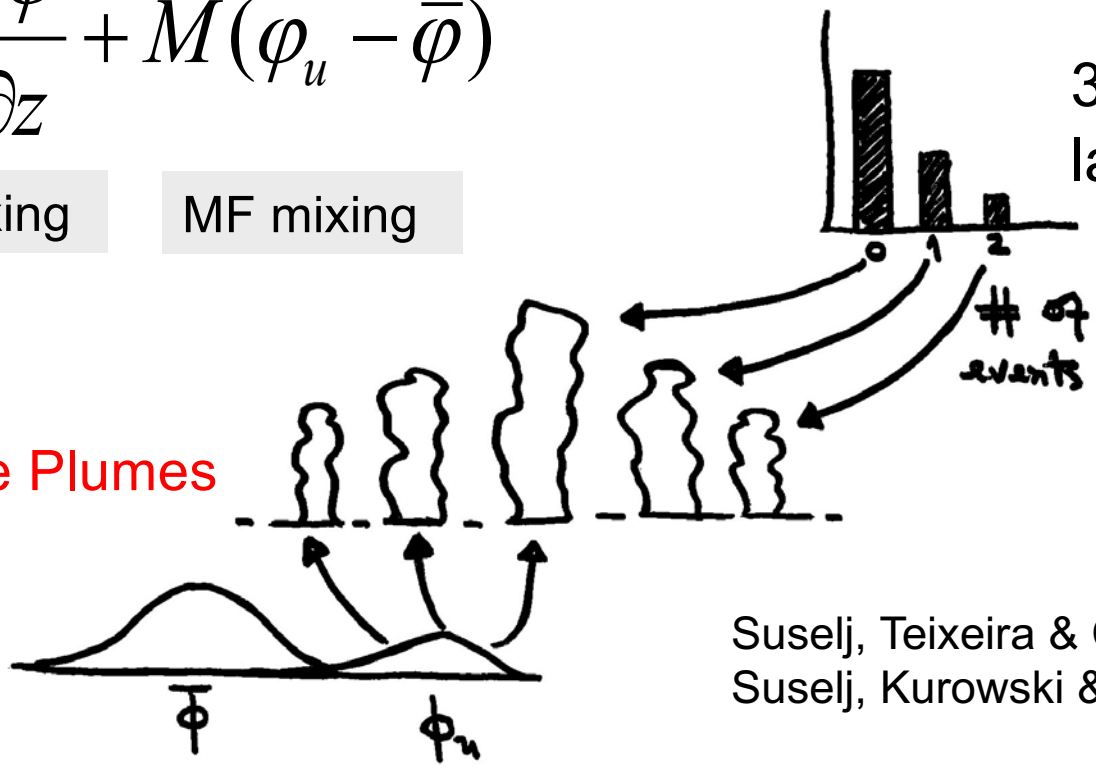
EDMF and moist convection: multiple plumes and stochastic entrainment

$$\overline{w'\varphi'} = -k\frac{\partial\bar{\varphi}}{\partial z} + M(\varphi_u - \bar{\varphi})$$

ED mixing

MF mixing



3) Stochastic lateral entrainment

Partly inspired by Romps & Kuang, JAS, 2010

Suselj, Teixeira & Chung, JAS, 2013
Suselj, Kurowski & Teixeira, JAS 2019a, b

1) Parameterization of PDF of surface layer thermodynamics
2) Sampling of PDF to produce multiple plumes

- Different types of convection coexist in the same model grid-box
- Total updraft area is just the sum of individual updraft areas

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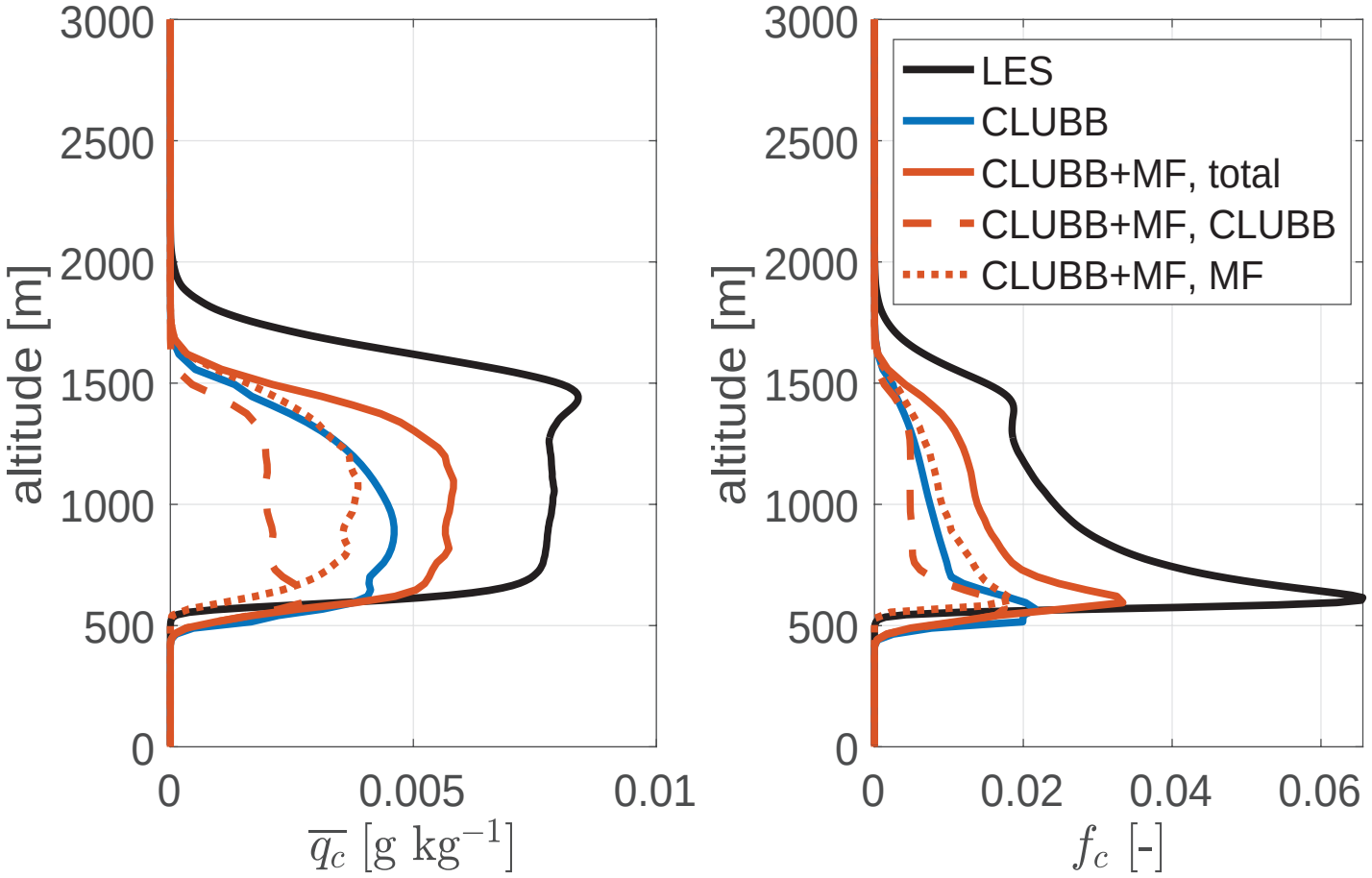
CLUBB+MF: Shallow Convection

BOMEX Case



Witte et al.,
MWR, 2022

MF plumes provide additional vertical mixing to CLUBB

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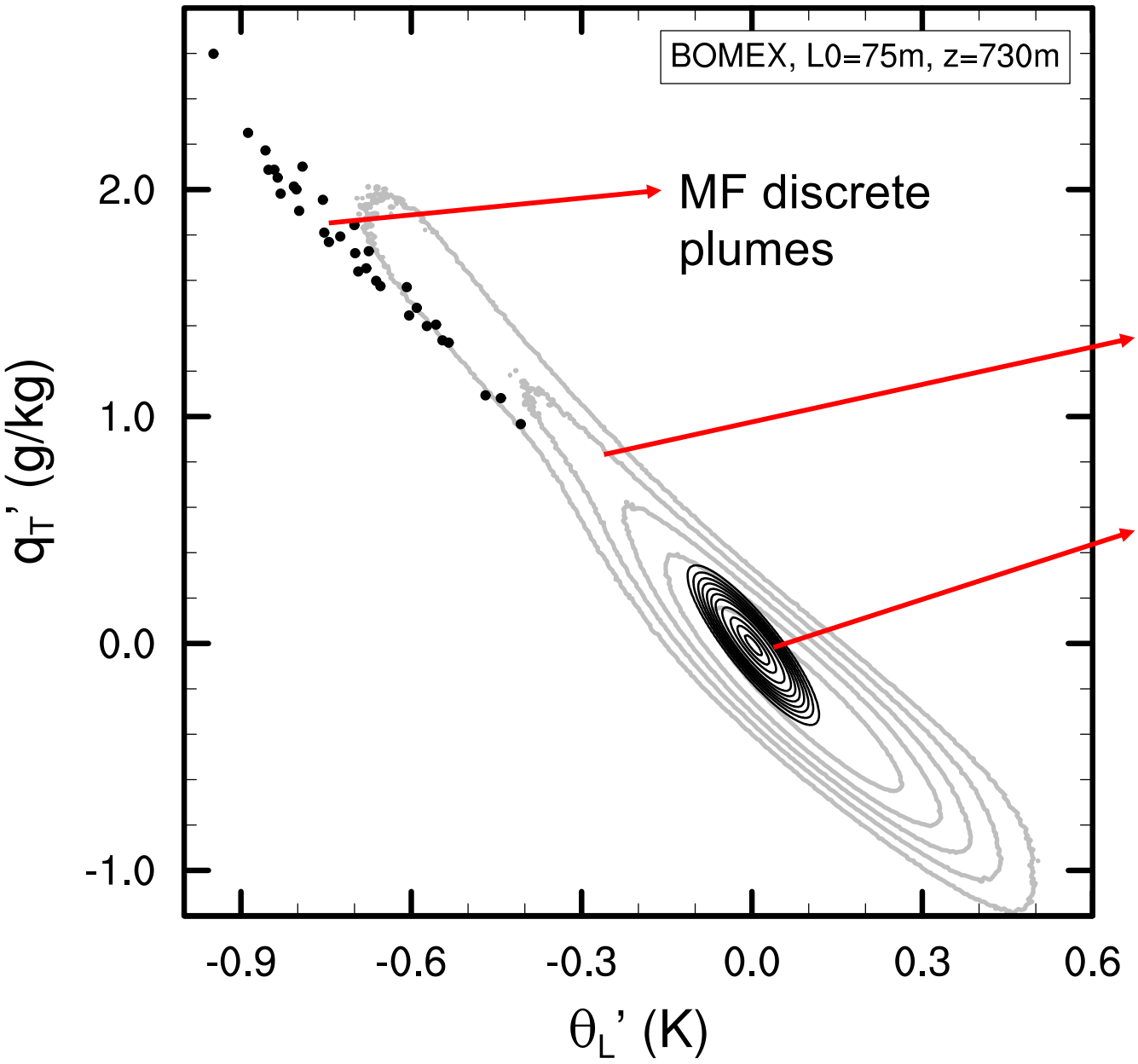
PDFs for LES, CLUBB and MF: the BOMEX Shallow Convection Case



MF plumes populate skewed part of PDF to produce more efficient mixing

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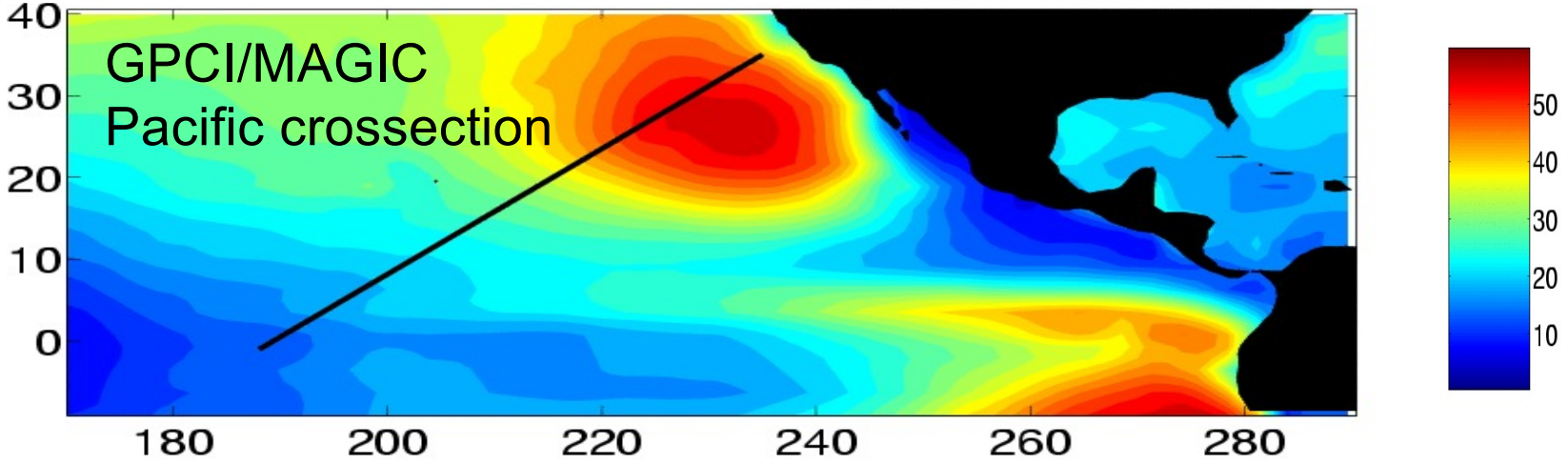
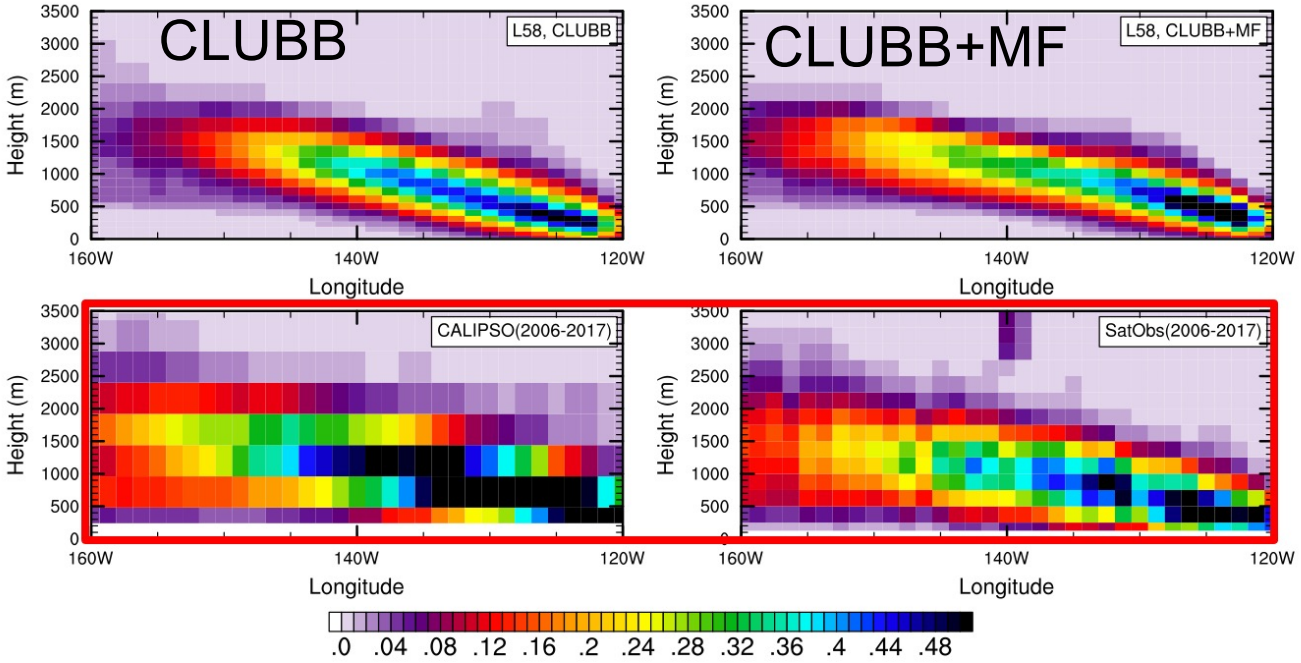
CLUBB+MF in 3D CAM: Sc to Cu



JJA Cloud Fraction



Satellite observations (courtesy of B. Medeiros, M. Smalley)

CLUBB+MF produces realistic Sc to Cu transition in 3D simulation

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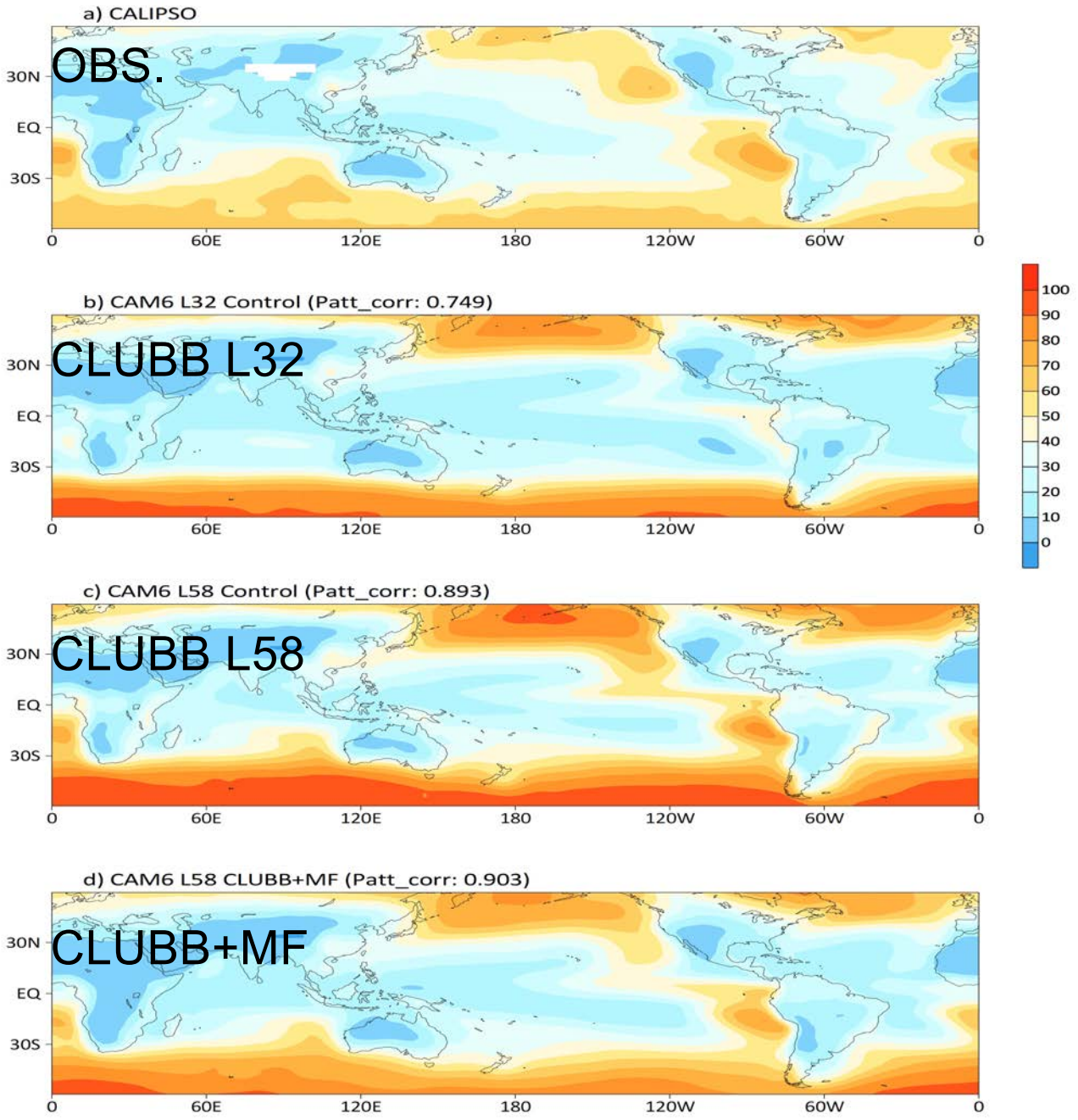
CLUBB+MF: Low Cloud Cover

Annual mean low-cloud cover (%) for 1998-2017: AMIP runs (no ZM) and observations

Realistic CLUBB+MF stratocumulus, Southern Ocean low clouds, N. Pacific and N. Atlantic low clouds



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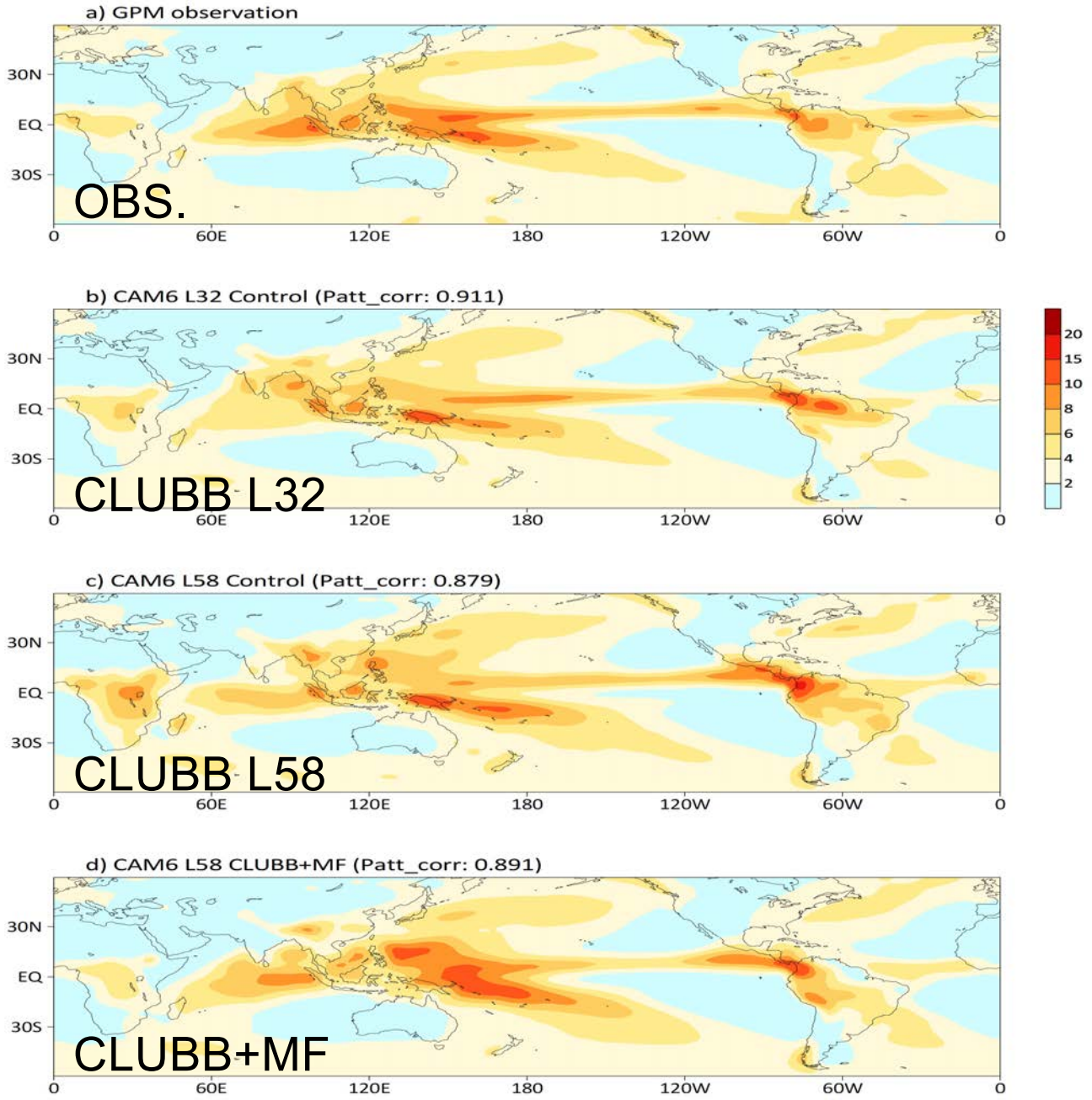
CLUBB+MF Climate: Precipitation

Annual mean precipitation (mm day^{-1}) for 1998-2017: AMIP runs (no ZM) and observations

Realistic CLUBB+MF precipitation climatology with some realistic key features



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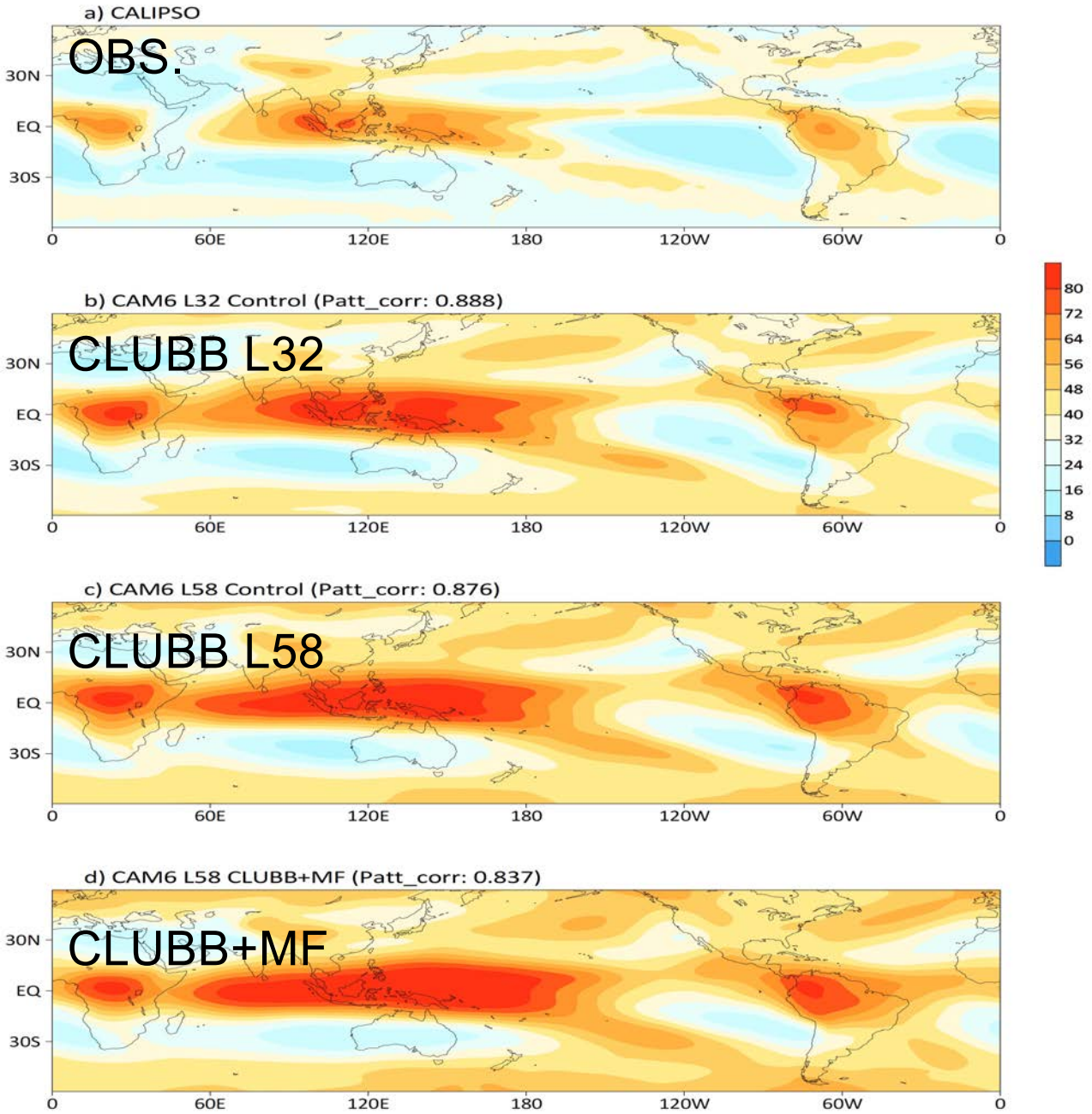
CLUBB+MF: High Cloud Cover

Annual mean high-cloud cover (%) for 1998-2017: AMIP runs (no ZM) and observations

High-cloud cover CLUBB+MF structure similar to control CLUBB



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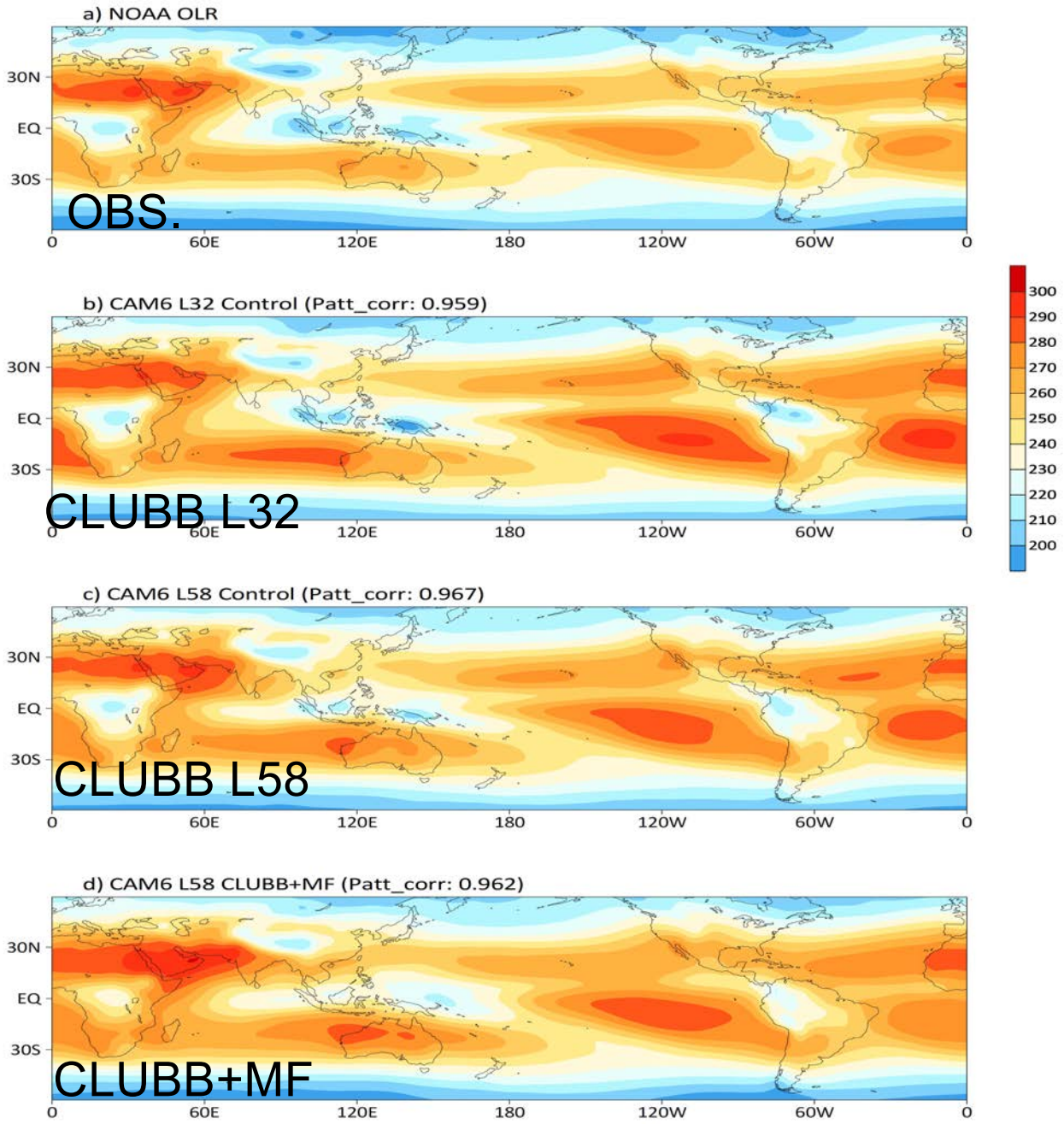
CLUBB+MF: Outgoing Longwave Radiation

Annual mean OLR (W m^{-2}) for 1998-2017: AMIP runs (no ZM) and observations

Realistic CLUBB+MF OLR: low OLR in deep convection regions, high OLR in shallow convection regions



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Summary

- New fully unified (PBL+shallow+deep convection) mixing parameterization was developed and implemented in CAM
- Based on combination of CLUBB with the multiple mass-flux (MF) approach from EDMF
- CLUBB+MF was tested in SCM and full 3D CAM (AMIP) without explicit deep convection parameterization (no ZM)
- CLUBB+MF produces realistic stratocumulus, shallow and deep convection
- Positive impact on global climatology of precipitation, low and high cloud cover, and OLR

Fully unified (PBL+shallow+deep) CLUBB+MF parameterization implemented successfully in CAM