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From LES to CLUBB+MF: Recent results from the Unified EDMF CPT Project

J. Teixeira (1, 2), A. Herrington (3), X. Jiang (1), M. Witte (1, 6), J. Bacmeister (3), R. Fu (1), G. Matheou (5), L. Donner (4), O. Lamaakel (5), M. Kurowski (2), R. Storer (1), M. Chinita (1), 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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EDMF CPT (funded by NSF, NOAA)

Goal: to reduce key biases related to PBL clouds and deep convection in the NCAR and GFDL climate models.

Implementing and evaluating unified PBL and convection multi-plume Eddy-Diffusivity/Mass-Flux (**EDMF**) parameterization.

Focused on **PBL and transition to deep convection**:

(i) Spatial transition over ocean from stratocumulus to cumulus and to deep convection;

(ii) Temporal transition (diurnal cycle) over land from dry convection, to shallow convection and to deep convection.

Lead PI: J. Teixeira (UCLA/JPL)

PIs: J. Bacmeister (NCAR), L. Donner (GFDL), R. Fu (UCLA), G. Matheou (U. Conn.), M. Witte (UCLA, NPS).

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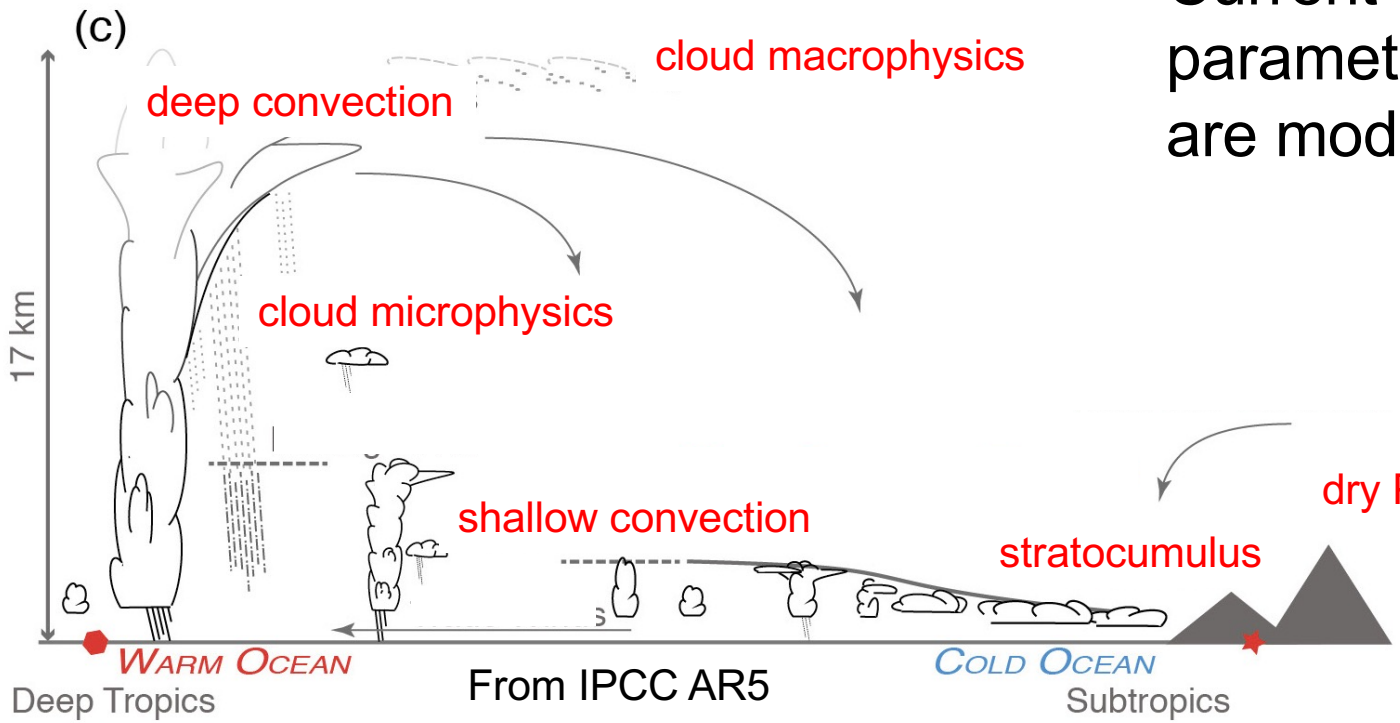
Fully Unified Mixing Parameterization

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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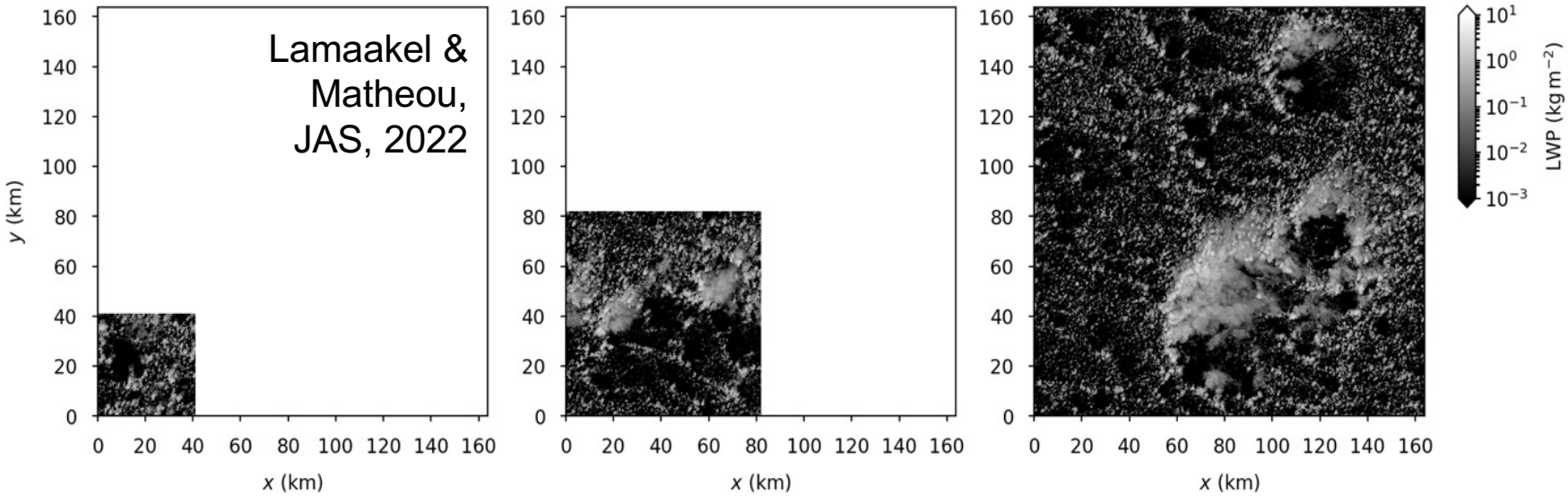
Large Eddy Simulation (LES): Shallow Convection and LES Domain Size

Convection organization depends on LES domain size



- Horizontal organization does not fundamentally modify local convective elements
- Mean profiles, vertical velocity variance, scalar fluxes are not particularly sensitive to domain size
- Partly explains why previous (small domain) LES and parameterizations have been somewhat successful
- Turbulent kinetic energy (TKE) depends on domain size

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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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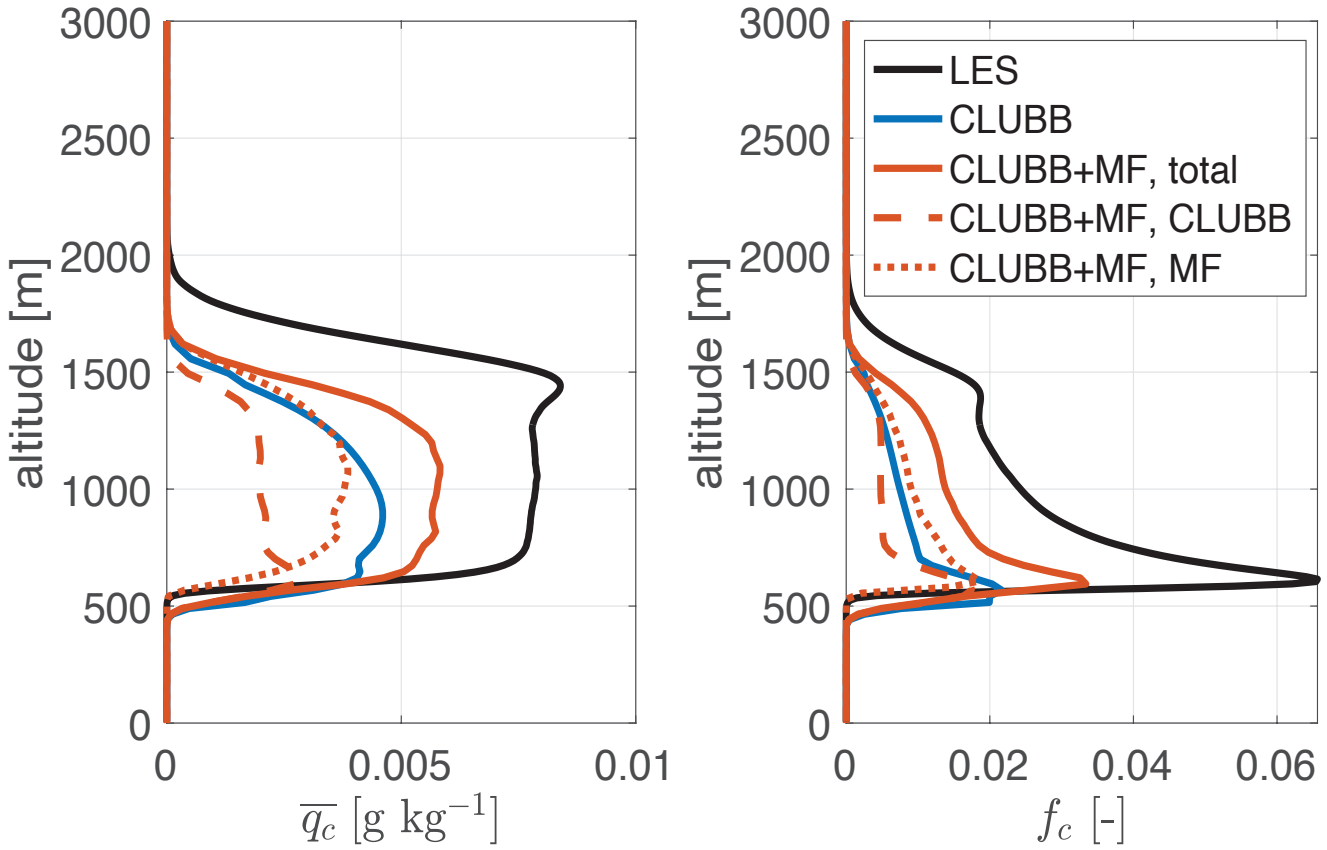
CLUBB+MF: Shallow Convection

BOMEX Case

Witte et al., MWR, 2022



MF plumes provide additional vertical mixing to CLUBB

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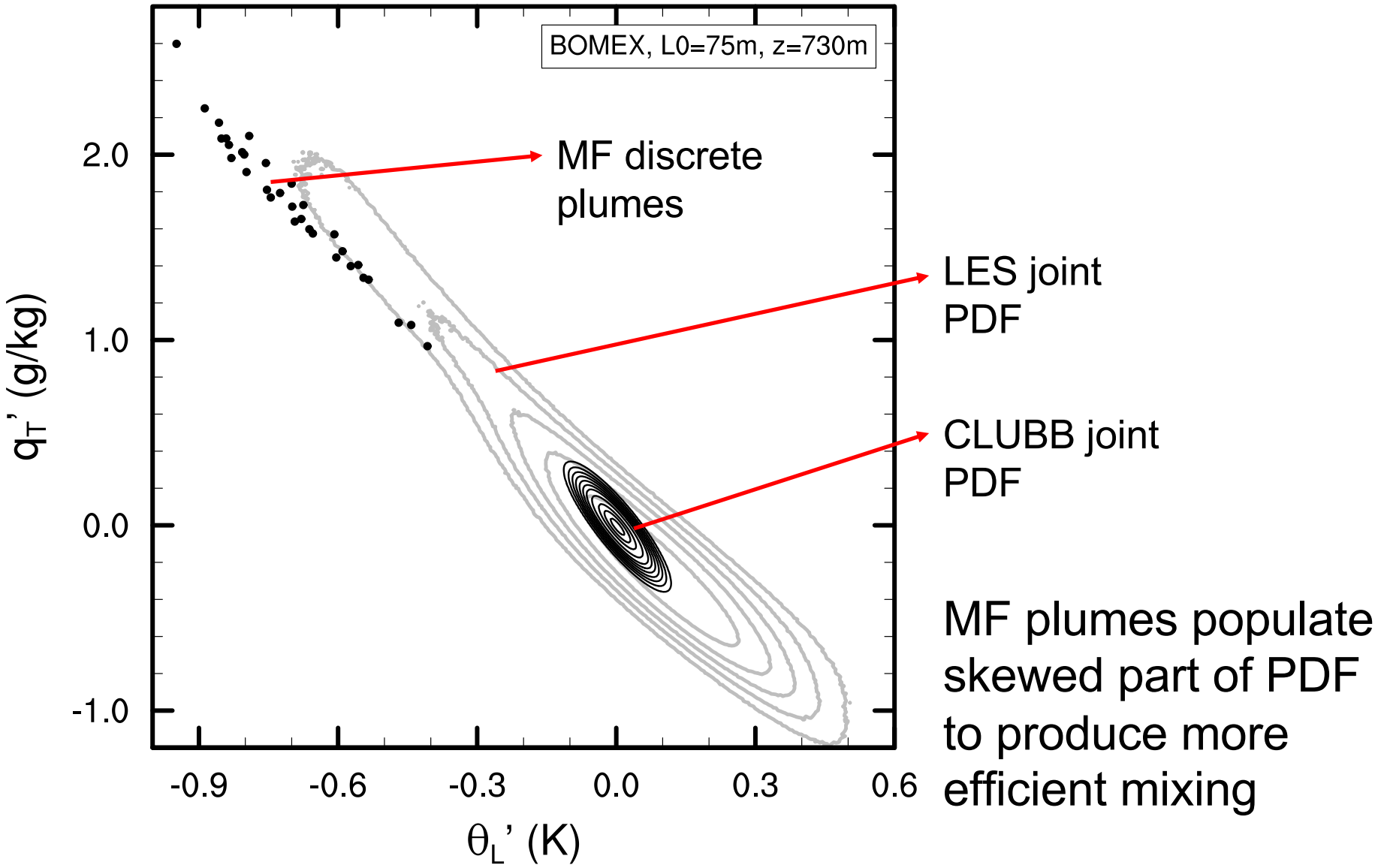
PDFs for LES, CLUBB and MF: the BOMEX Shallow Convection Case



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

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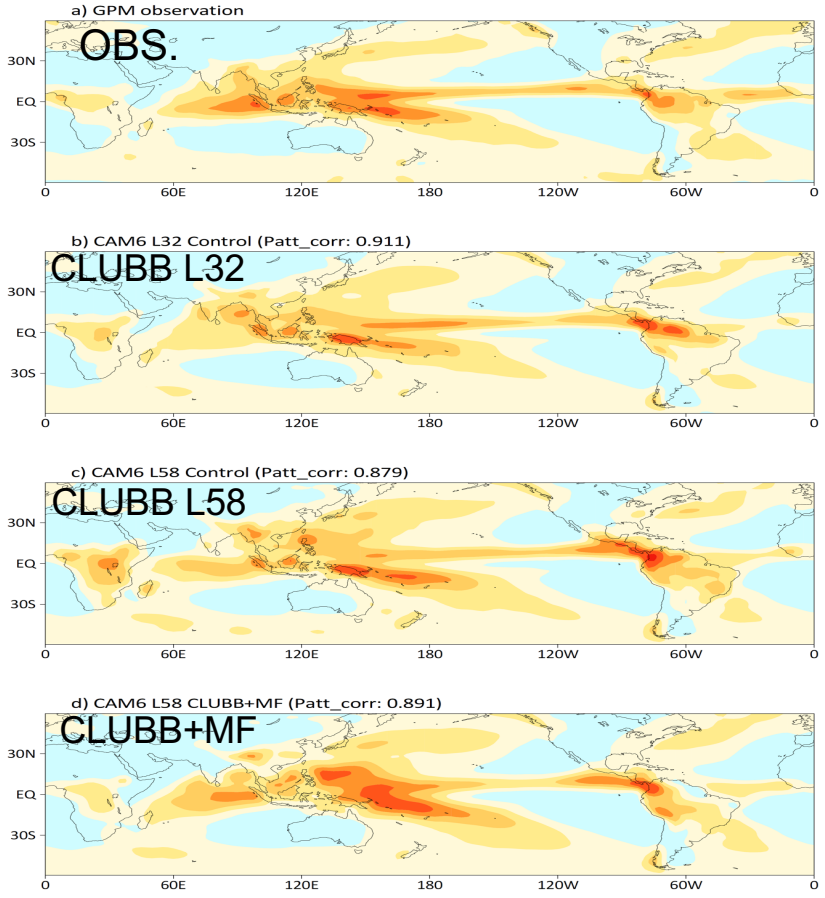
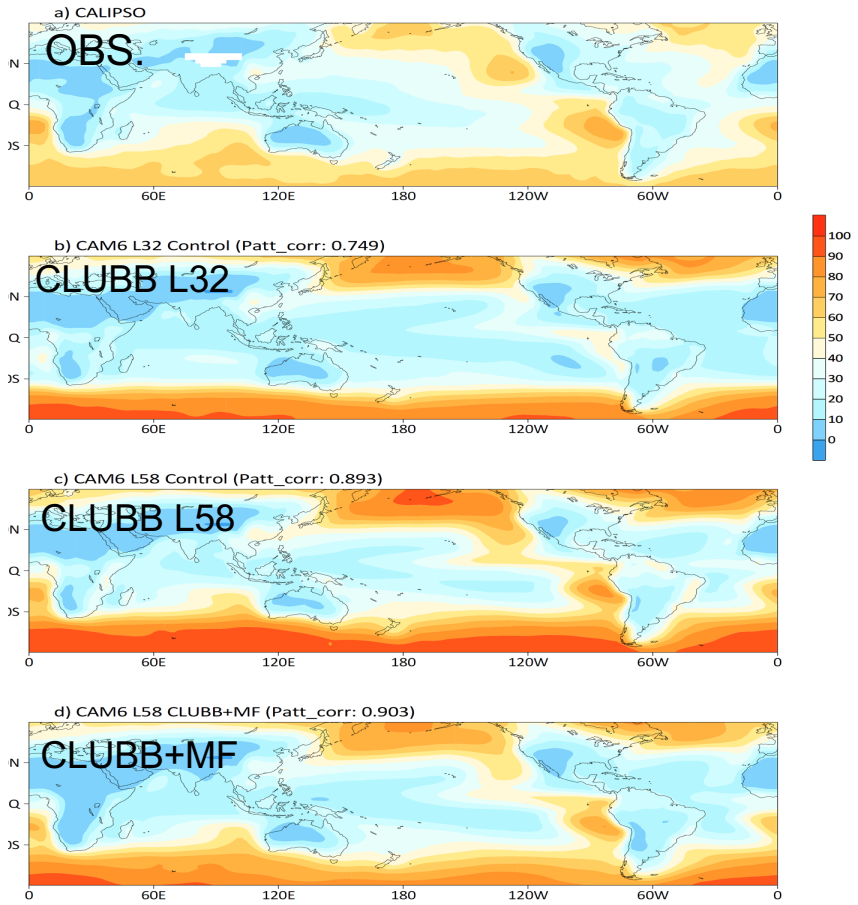
Unified CLUBB+MF: PBL+ Shallow+ Deep Convection

CLUBB+MF AMIP simulations without ZM convection parameterization: Realistic climatology of clouds, precipitation, TOA radiation



Annual mean precipitation (mm day^{-1}) for 1998-2017



Annual mean low-cloud cover (%) for 1998-2017

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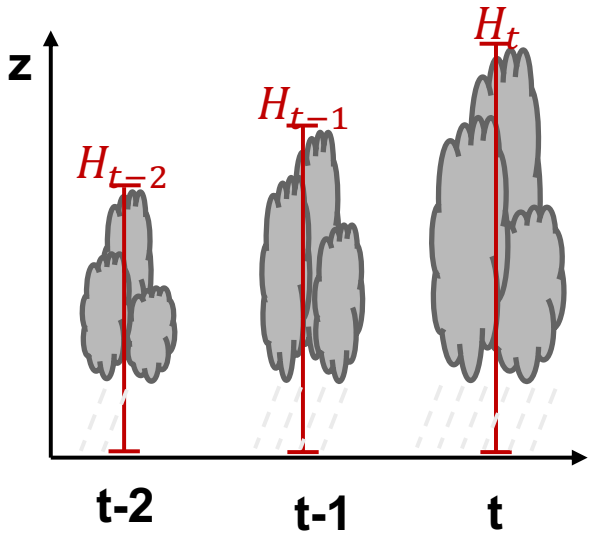
CLUBB+MF Recent Developments: Incorporating Convective Memory

- Take the properties of the plume ensemble over prior time-step(s) to inform the entrainment rate at the current time-step.
- Below are results setting the entrainment length-scale proportional to the depth of the plume ensemble, averaged over the prior 30 minutes.

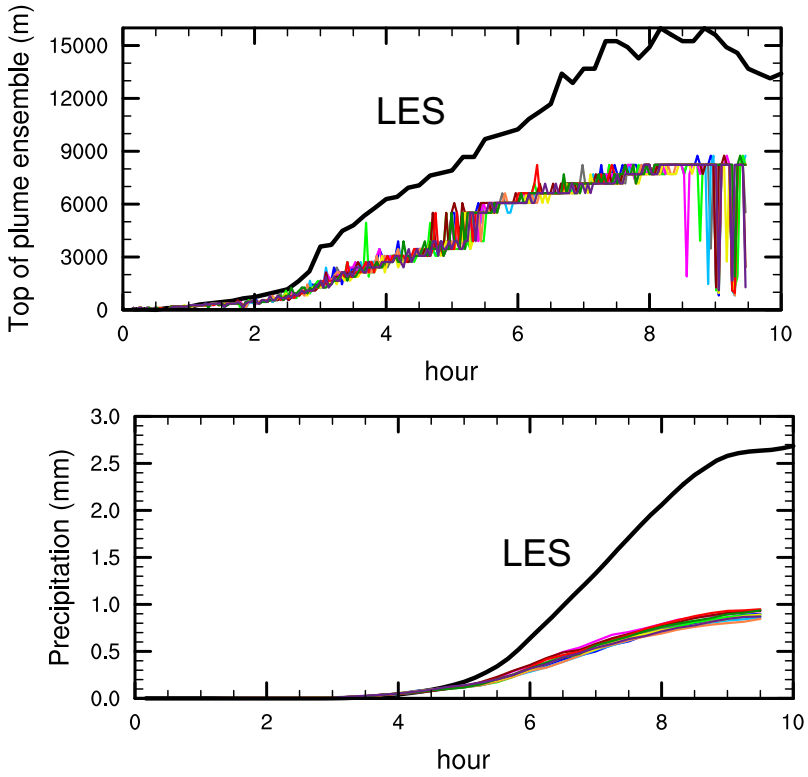


$$\epsilon_t = f(H_{t-1}, \dots)$$

$$\epsilon_{t-1} = f(H_{t-2}, \dots)$$

$$\epsilon_{t-2} = f(H_{t-3}, \dots)$$

Single Column Model (SCAM)
(LBA; 11 member ensemble)



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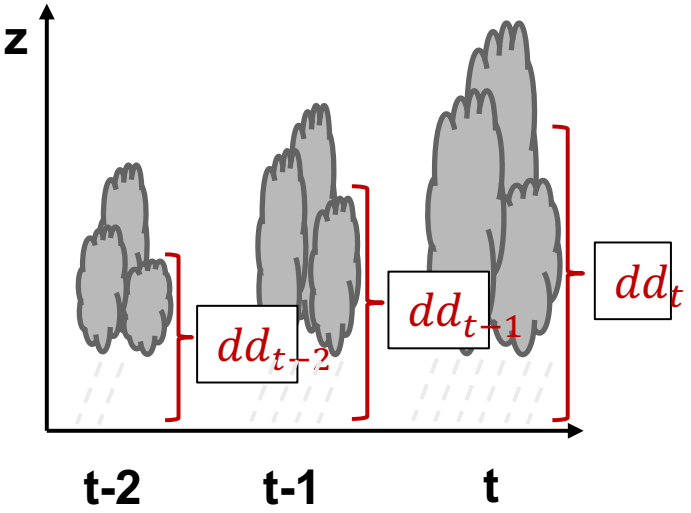
CLUBB+MF Recent Developments: Parameterizing Cold-Pool Effects

- Cold-pools facilitate new convection, organize convection.
- Ensemble mean downdraft speed (dd; m/s) of prior time-step(s) modifies the entrainment length-scale of the current time-step (Suselj et al. 2019).

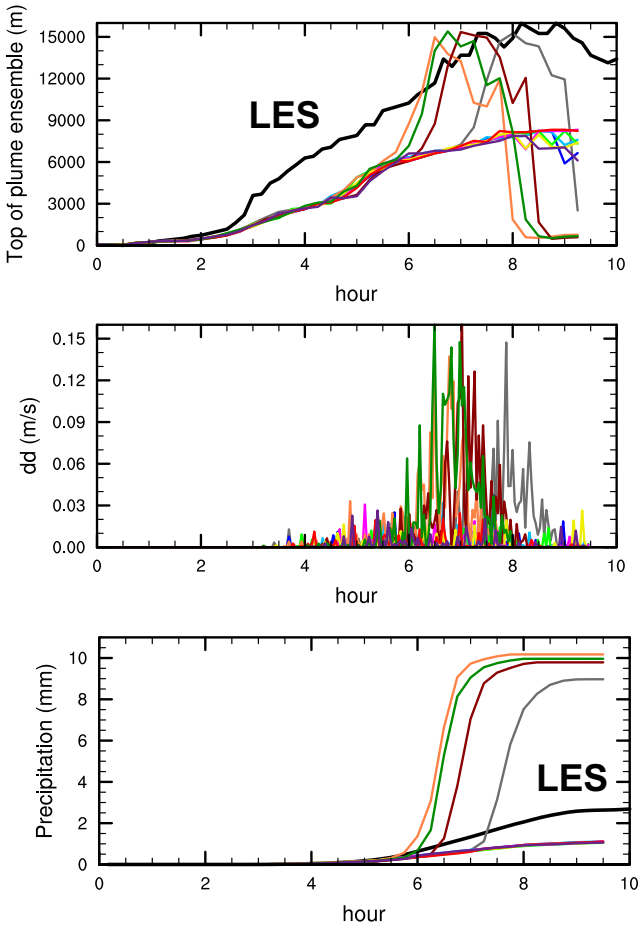


$$\epsilon_t = f(dd_{t-1}, \ldots)$$

$$\epsilon_{t-1} = f(dd_{t-2}, \ldots)$$

$$\epsilon_{t-2} = f(dd_{t-3}, \ldots)$$

Single Column Model (SCAM): (LBA; 11 member ensemble)



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Summary

- New fully unified (PBL+shallow+deep convection) parameterization: CLUBB combined with multi-plume mass-flux (MF)
- CLUBB+MF was tested in SCM and full 3D CAM (AMIP) without explicit deep convection parameterization (no ZM)
- CLUBB+MF produces realistic climatology of clouds, precipitation and TOA radiation

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

- Main development tracks: Entrainment formulation + plume initialization
- Parallel efforts: Convective momentum transport (Ben Stephens, NCAR) + plume initialization over sub-grid land patches (Meg Fowler, NCAR)