NCAR UCAR

The quest for unified turbulence and convection parameterizations: Recent results from the EDMF CPT Project

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CGD Climate & Global Dynamics

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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.

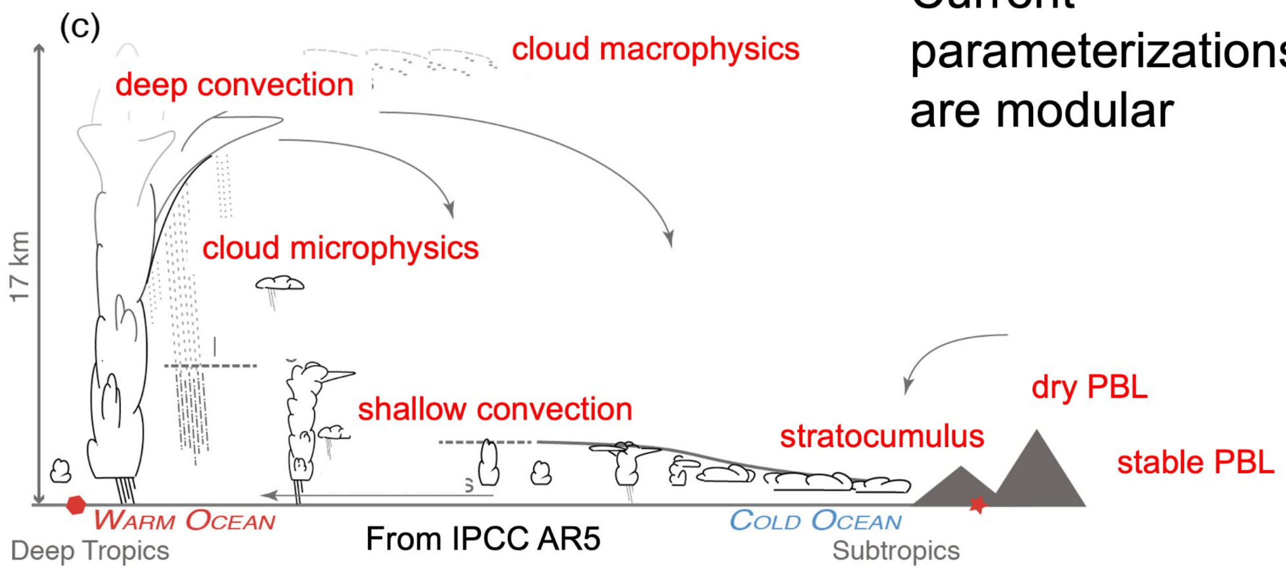
Implementing and evaluating unified PBL and convection multi-plume Eddy-Diffusivity/Mass-Flux (**EDMF**) parameterization.

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).

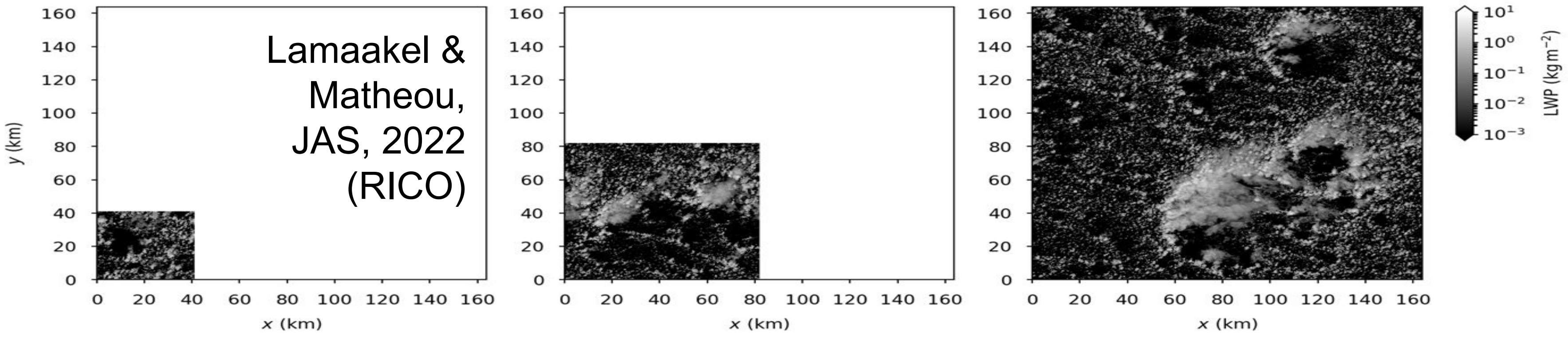
Fully Unified Mixing Parameterization



Current parameterizations are modular

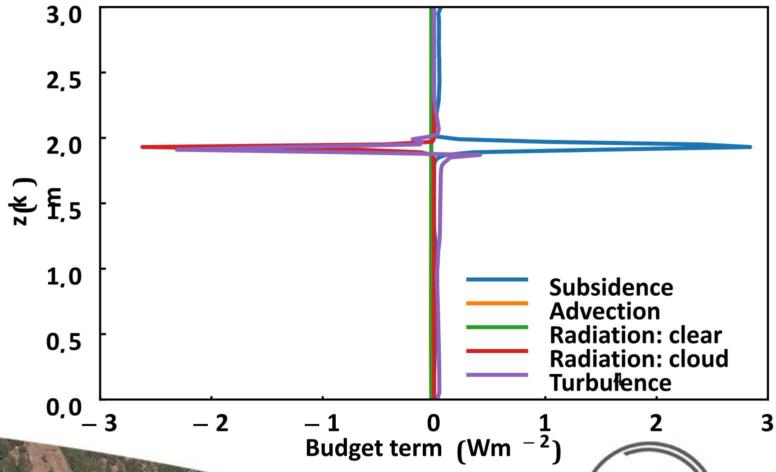
We will show results from a fully unified turbulence and convection parameterization:
From PBL to deep convection

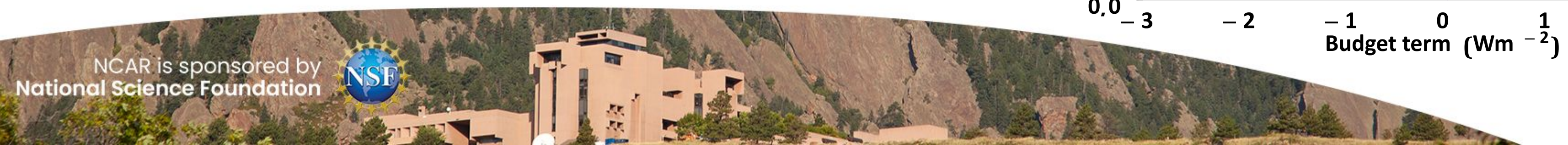
Large Eddy Simulation (LES)



Convection organization depends on LES domain size BUT mean profiles, scalar fluxes are not very sensitive to domain size

Recent high-resolution cloudy PBL simulations show tendencies are large in narrow region close to cloud top





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

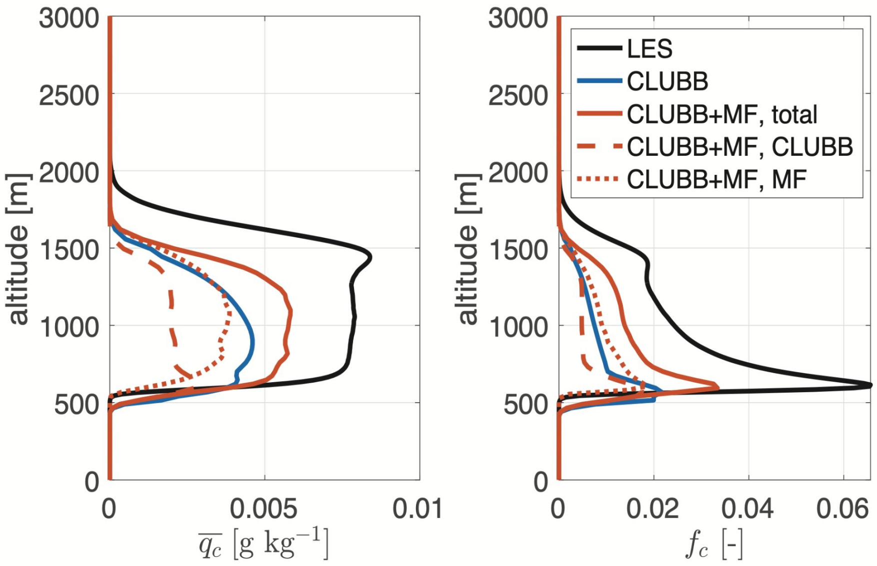
- MF plumes are coupled to CLUBB via 5-diagonal prognostic solver for mean fields and turbulent fluxes (solved simultaneously)

$$\frac{\bar{\varphi}_{t+\Delta t}}{\Delta t} + \frac{1}{\rho_s}\frac{\partial}{\partial z}\rho_s \overline{w'\varphi'}^{CLUBB}_{t+\Delta t} = \frac{\bar{\varphi}_t}{\Delta t} - \frac{1}{\rho_s}\frac{\partial}{\partial z}\left(\rho_s \sum a_i w_i \varphi'_i\right)^{MF}_t$$

CLUBB+MF: Shallow Convection

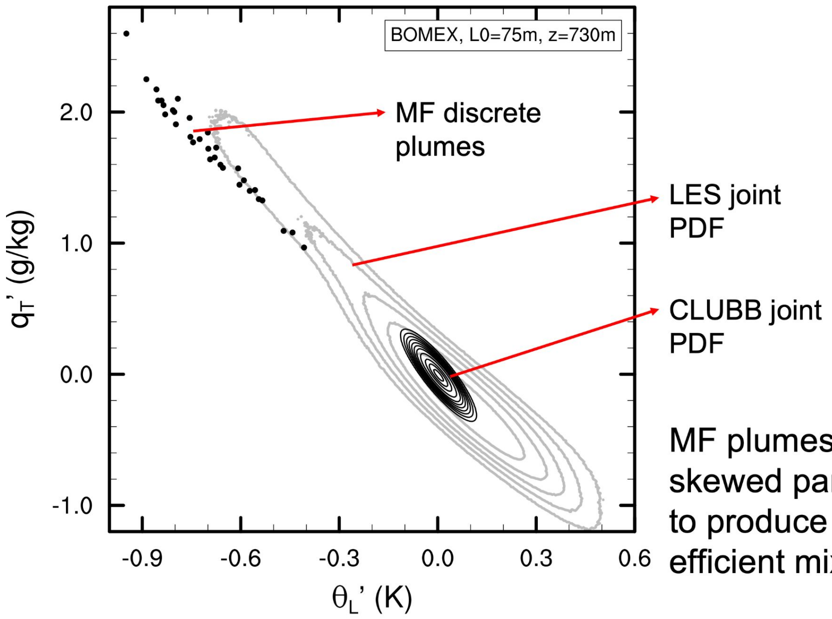
BOMEX Case

Witte et al., MWR, 2022



MF plumes provide additional vertical mixing to CLUBB

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

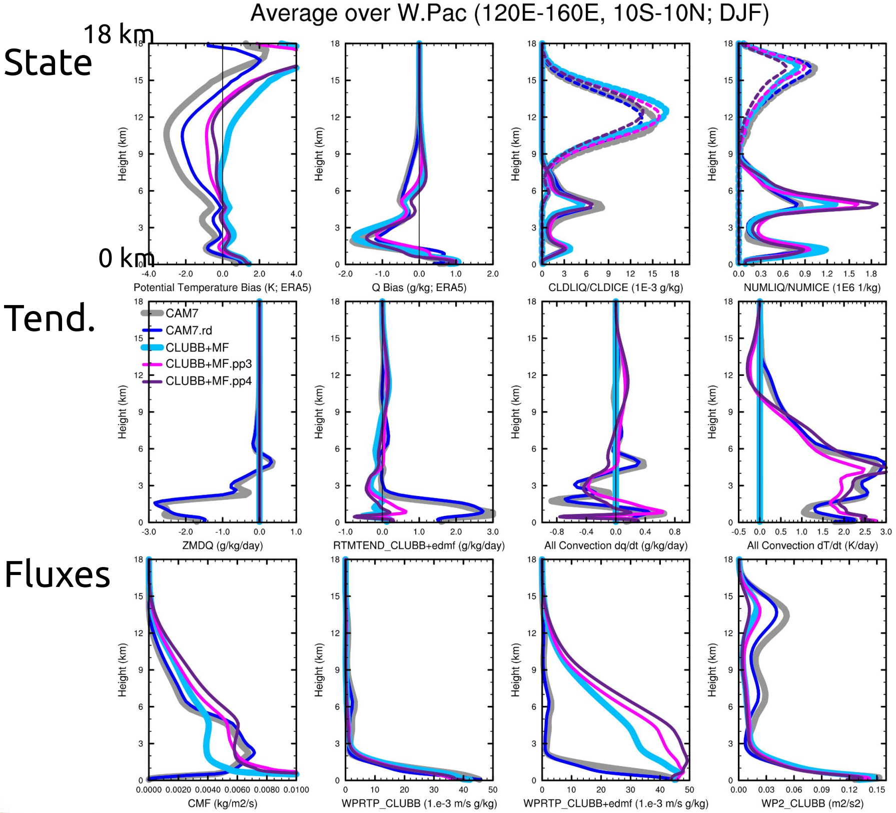


MF plumes populate skewed part of PDF to produce more efficient mixing

Deep Convection in CLUBB+MF

CLUBB+MF:

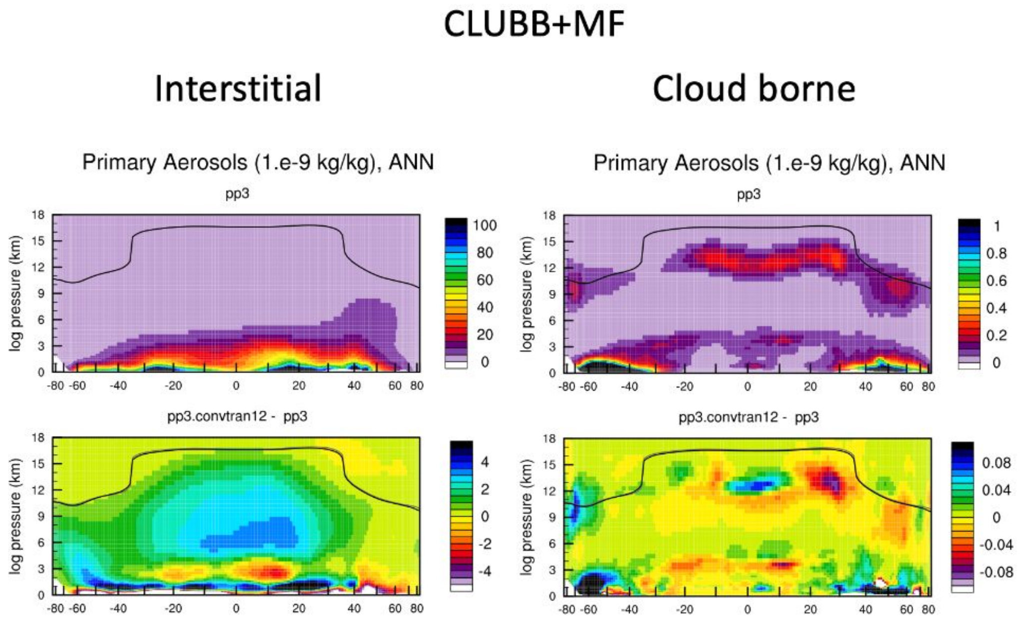
- Warms & moistens the Tropical Atmosphere compared to CAM7.
- Deep Cu is deeper; detrainment occurs much higher than in CAM7.
- Magnitude of Deep Cu mass fluxes similar to ZM.



Tracer Transport in CLUBB+MF

CLUBB - diffuses all tracers (water species, gases, aerosols).

MF - mass flux transport using ZM tracer transport scheme (convtran).



Impact of using Convtran to transport tracers (using the MF plume ensemble)

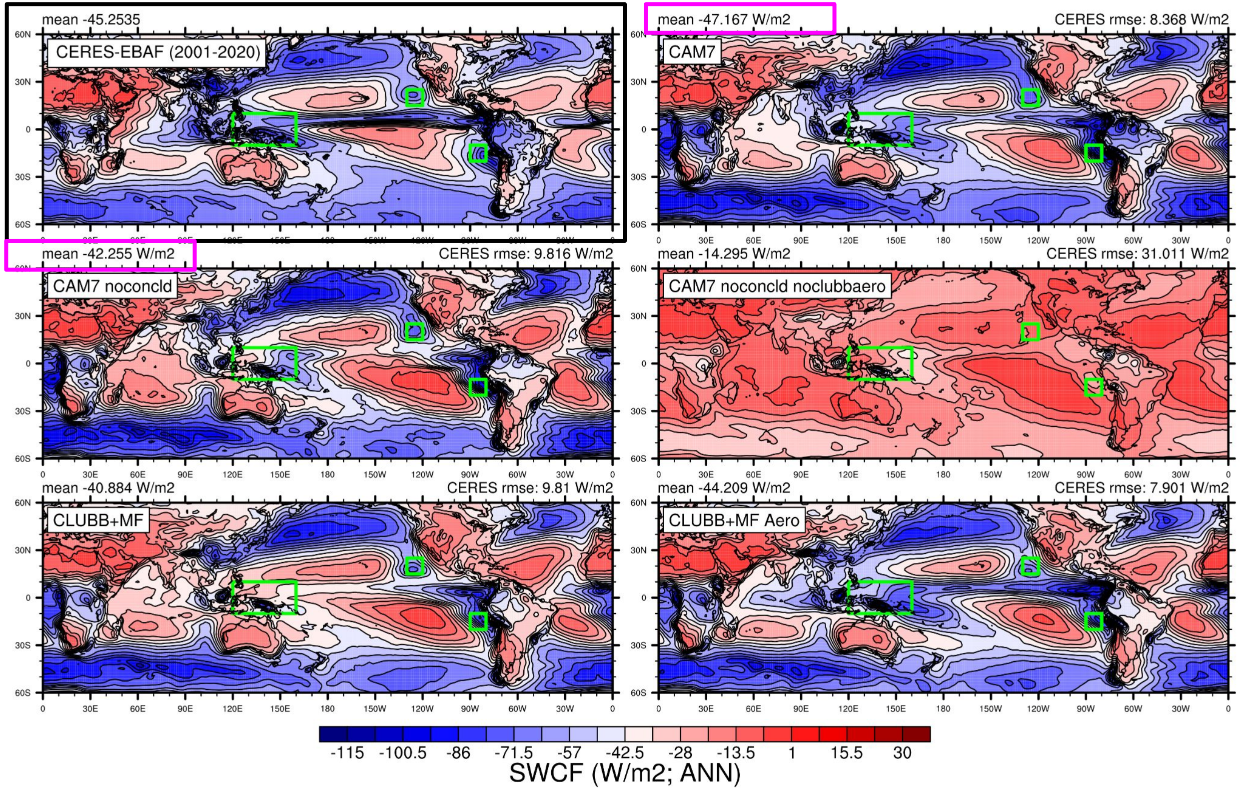
Cloud radiative forcing in CAM (shortwave)

Obs

CAM7 (alpha)

Impact of setting ZM cloud area = 0 (+5 W/m2)

Impact of turning off CLUBB aci (+ ZM cloud area=0)



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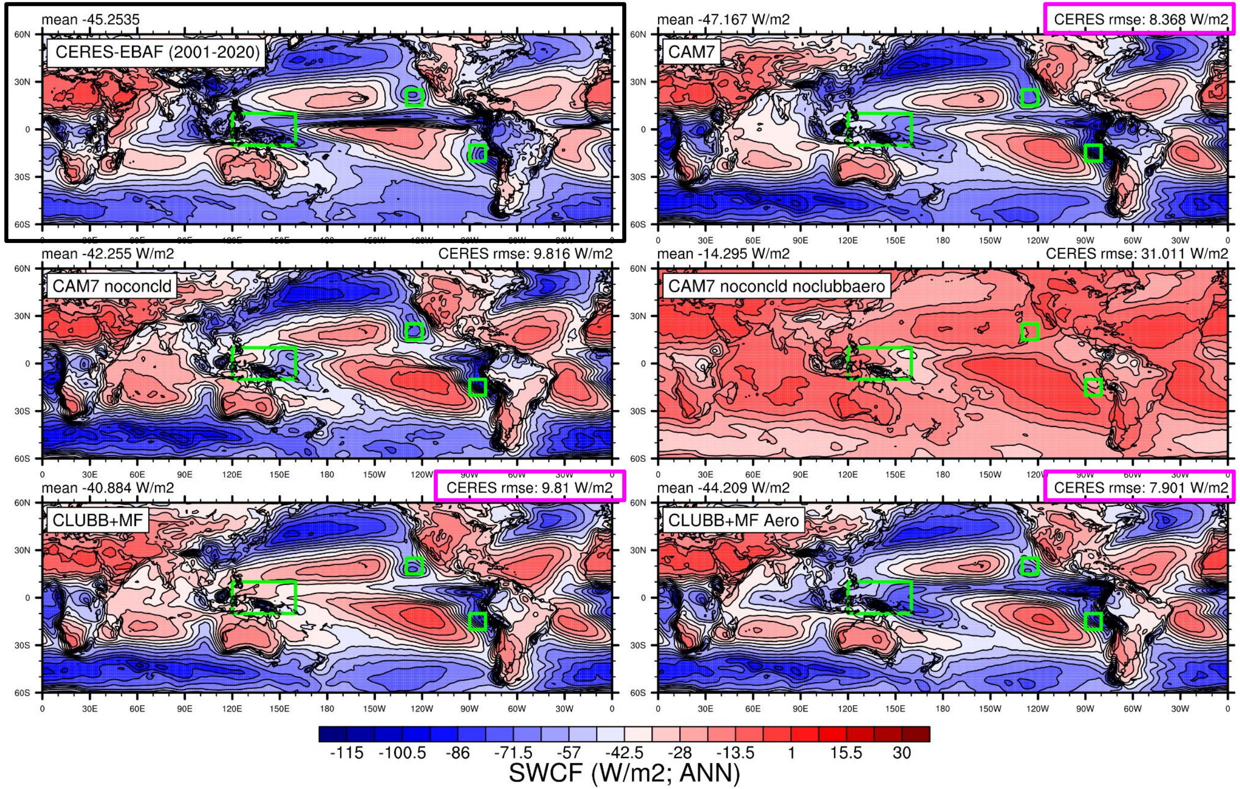
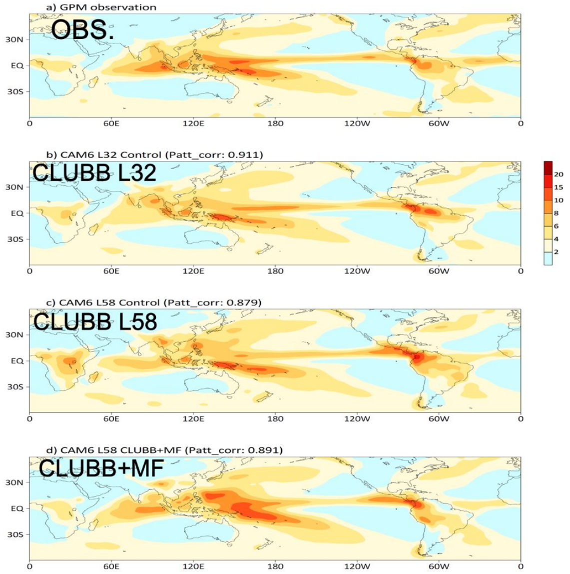


<u>CLUBB+MF</u>
No aerosol cloud interactions,
MF cloud area < ZM cloud area

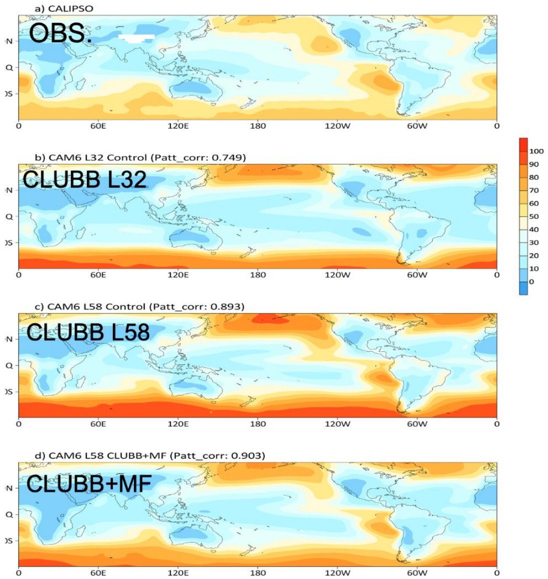
<u>CLUBB+MF Aero</u>
Aerosol activation and ice nucleation
Param. marginal conv. clouds

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

NCAR is sponsored by National Science Foundation

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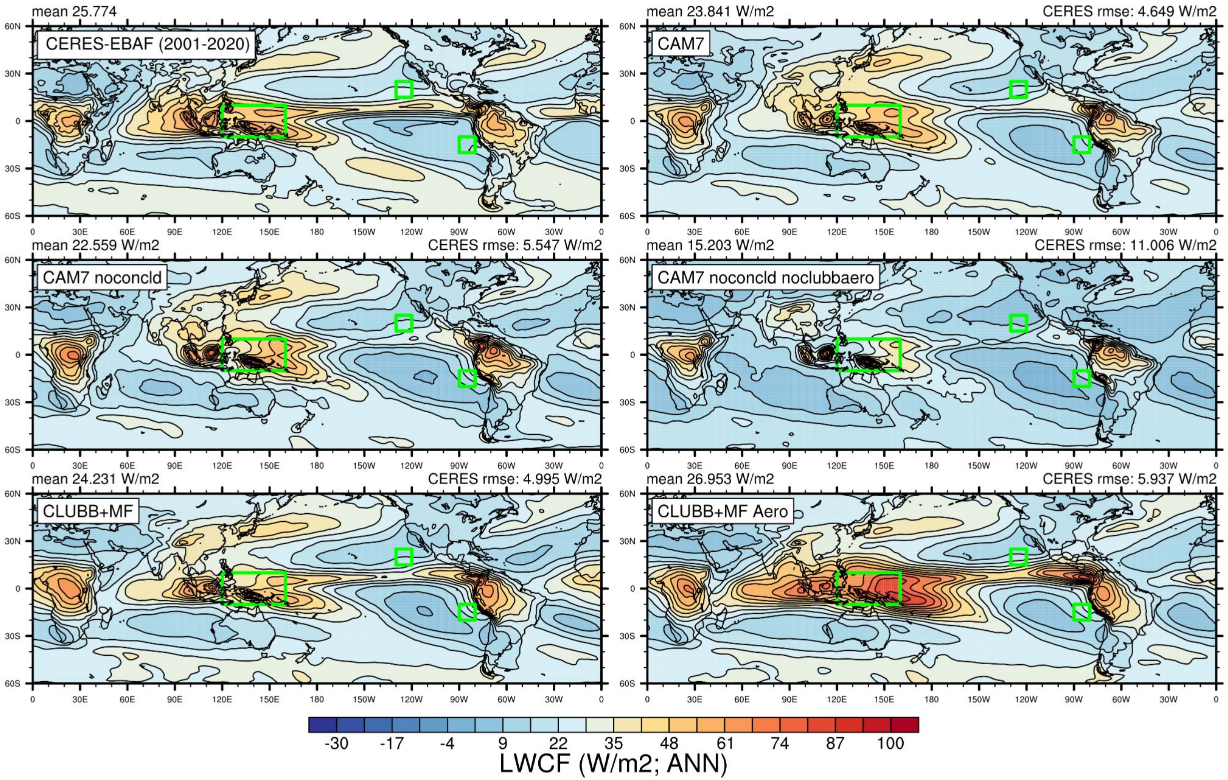
Summary

- 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) and produces realistic climatology of clouds, precipitation and TOA radiation
- **Fully unified (PBL+shallow+deep convection) CLUBB+MF parameterization implemented successfully in CAM**
- Clouds, precipitation, tropical variability competitive with CAM7 (AMIP/coupled?)
- Current focus - degraded diurnal cycle over land (collab. w/ GFDL partners)

Extra Slides

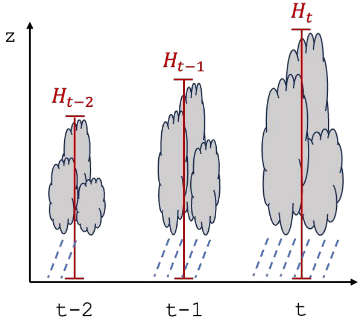
Cloud radiative forcing in CLUBB+MF (longwave)

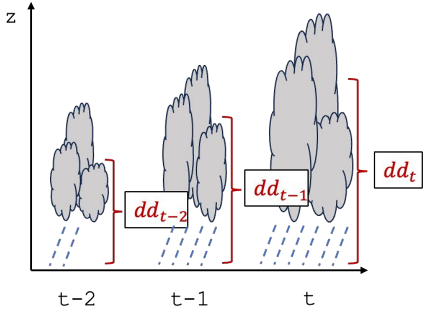


Convective Memory, Cold Pool Feedbacks

Ensemble of 'entraining' plumes:

- Stochastic entrain. - draw from a Poisson distribution determined by the mean entrain. L-scale (L_ε). (based on Romps and Kuang 2009)
- L_ε is determined by:
  - Height of the plume ensemble averaged over prior time-step(s) (e.g., H_{t-1}).
  - Cold pool strength averaged over prior time-step(s) (e.g., dd_{t-1}).
- Standard CLUBB+MF: same L_ε applied to entire ensemble.
- Per plume (pp): each plume computes its own unique L_ε.





Convective Memory, Cold Pool Feedbacks

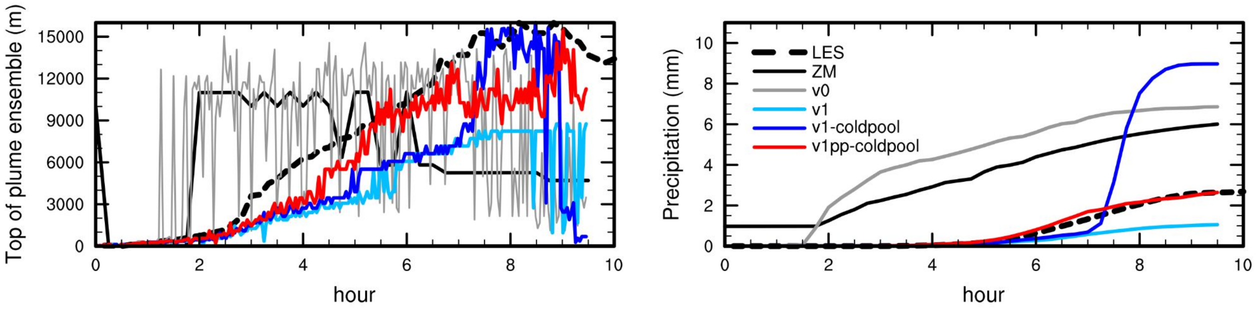
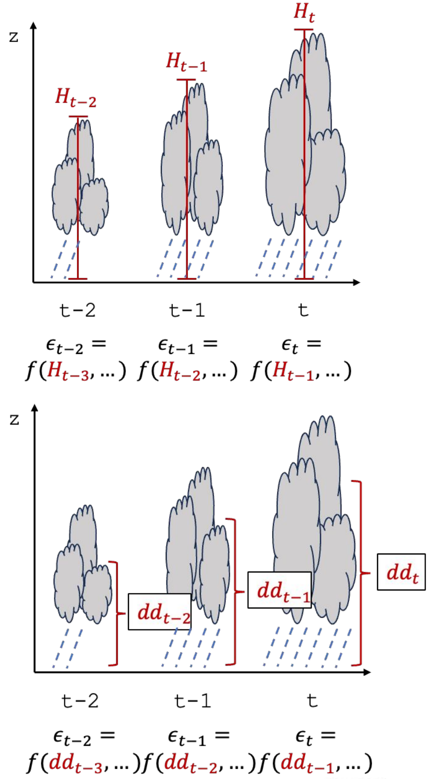


Figure 1. *CAM single column model experiments of the Large-Scale Biosphere-Atmosphere case (LBA), representing the diurnal cycle of moist convection over land. (Left) Top of the plume ensemble, and (right) cumulative precipitation rate. LES refers to large-eddy simulation reference, ZM refers to the operational deep convection scheme in CAM, whereas v0, v1, v1-coldpool and v1pp-coldpool refer to different configurations of CLUBB+MF discussed in the text.*



CAM7/CLUBB+MF MJO

- MJO propagation phase is ‘there’ in CAM7.
- AMIP has muted amplitudes in both the raw wave spectrum and hovmoller lagged regression coefficients.
- PP is competitive with CAM7.
- Missing processes - gusts, meso-scale heating and momentum transport.

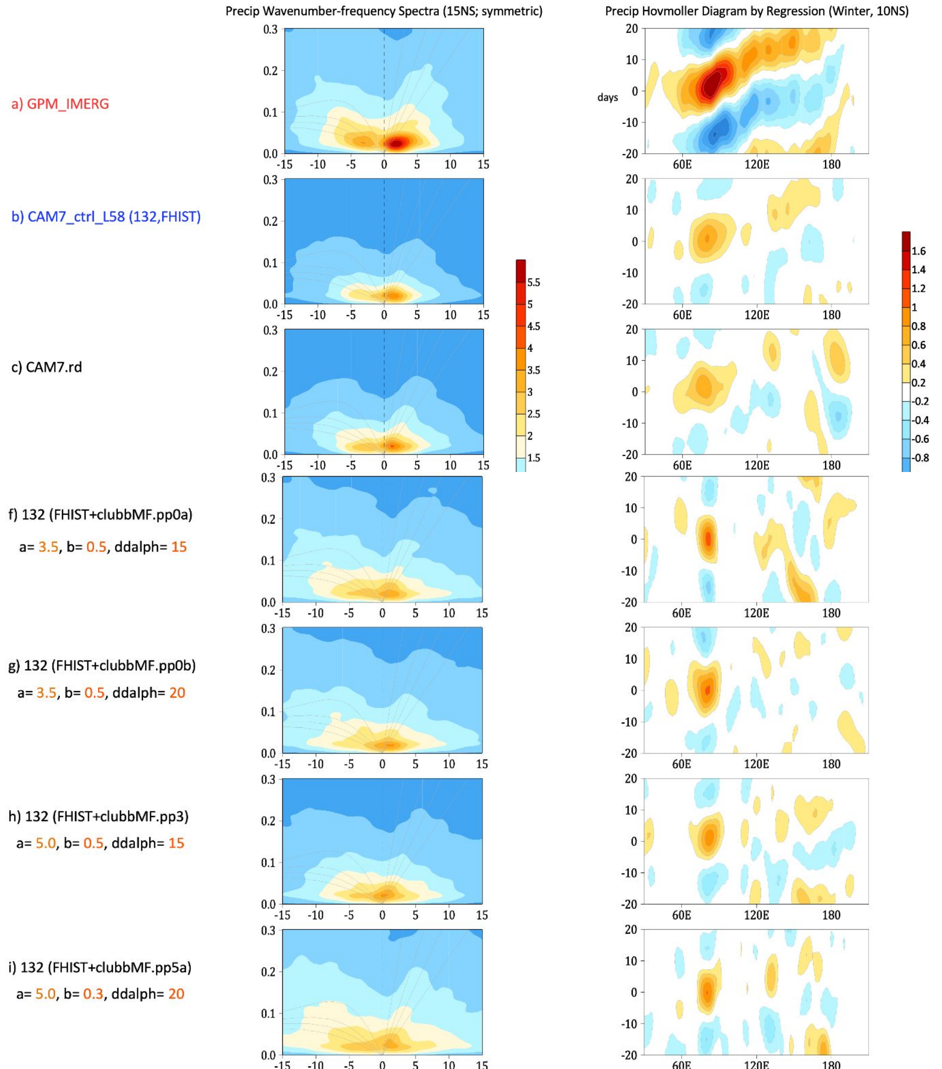


Figure courtesy Xianan Jiang