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Unified boundary layer and convection parameterization CPT project: Recent developments

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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.

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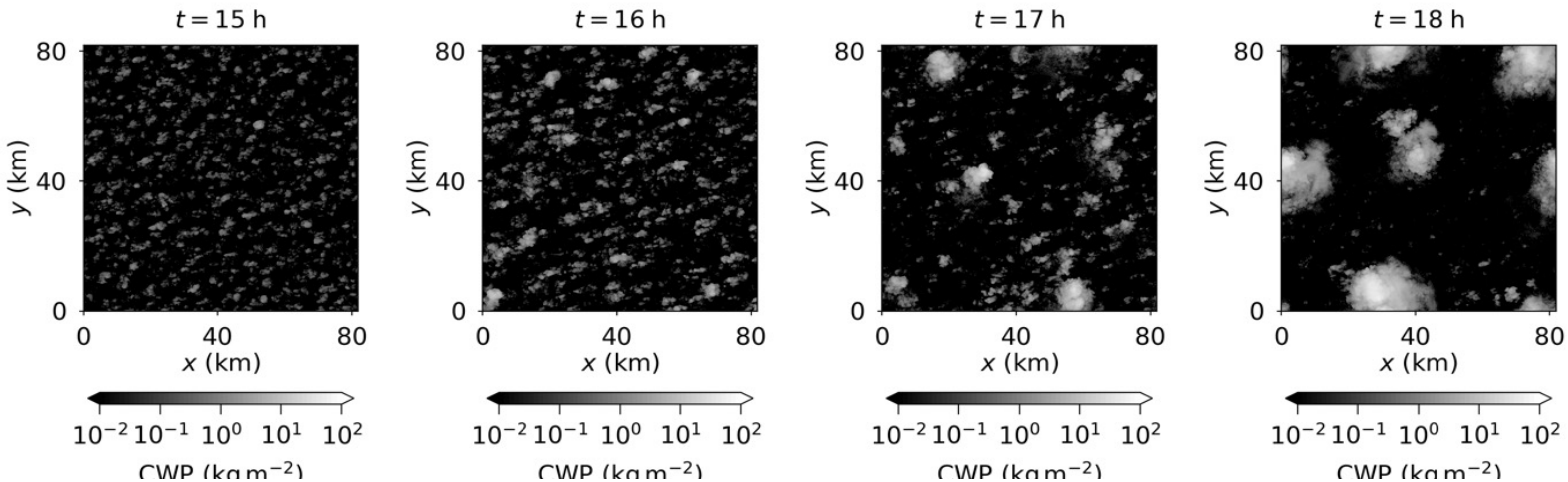
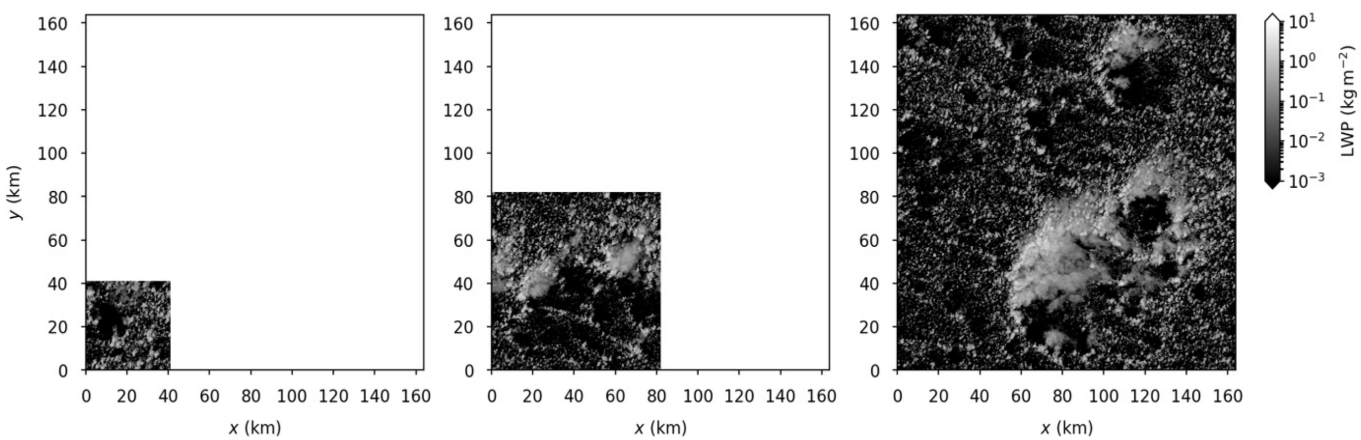
Large Eddy Simulation (LES)



Development of the cloud field as convection transitions from shallow to deep in the last four hours of the **UConn LES** of the AMMA case



Lamaakel & Matheou, JAS, 2022

Convection organization depends on LES domain size: potential significant impact on parameterization

Stratocumulus Diagnostic Studies at GFDL

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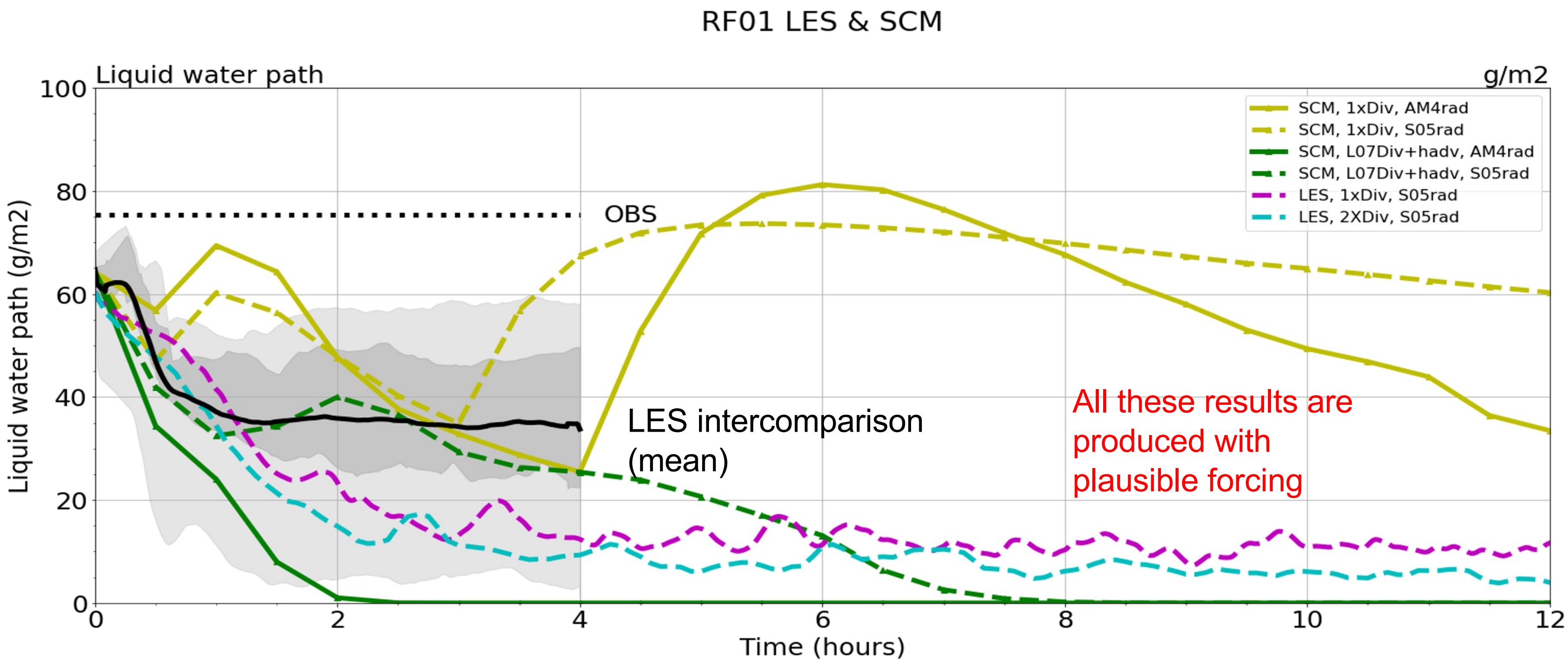
Stratocumulus DYCOMS RF01 case: LES and SCM experiments with different large-scale forcings



- Large-scale forcing estimates from obs., reanalysis and AMIP runs are different
- GFDL SCM shows significant sensitivity to large-scale forcing and radiation scheme
- LES appears less sensitive to large-scale forcing compared to SCM

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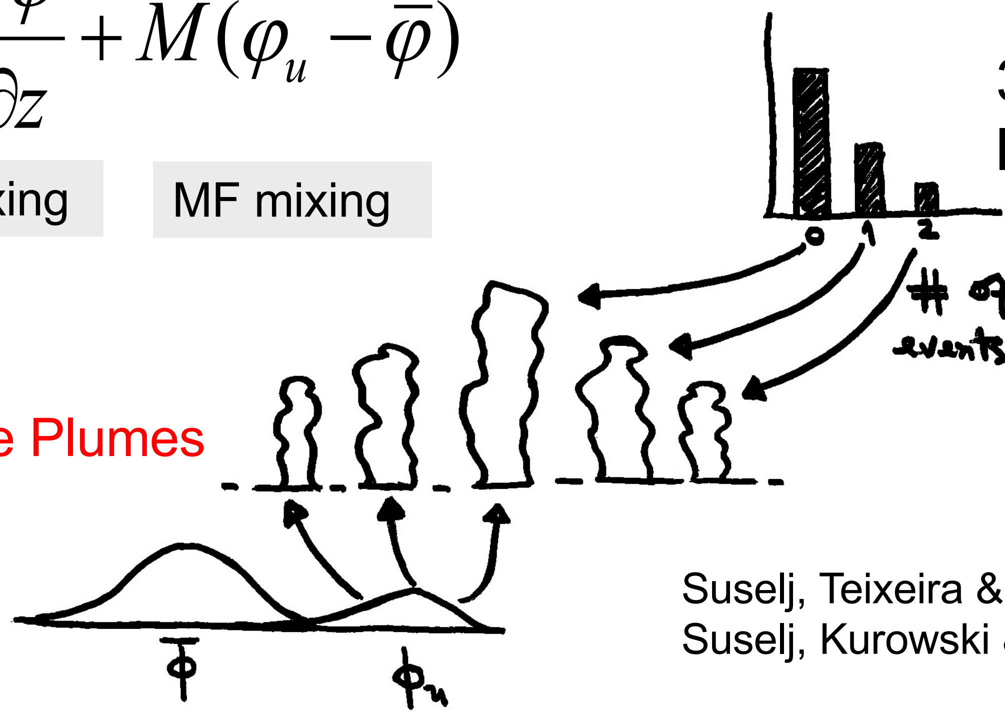
EDMF and moist convection: multiple plumes and stochastic entrainment

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

ED mixing

MF mixing



3) Stochastic lateral entrainment

Partly inspired by Romps & Kuang, JAS, 2010

Multiple Plumes

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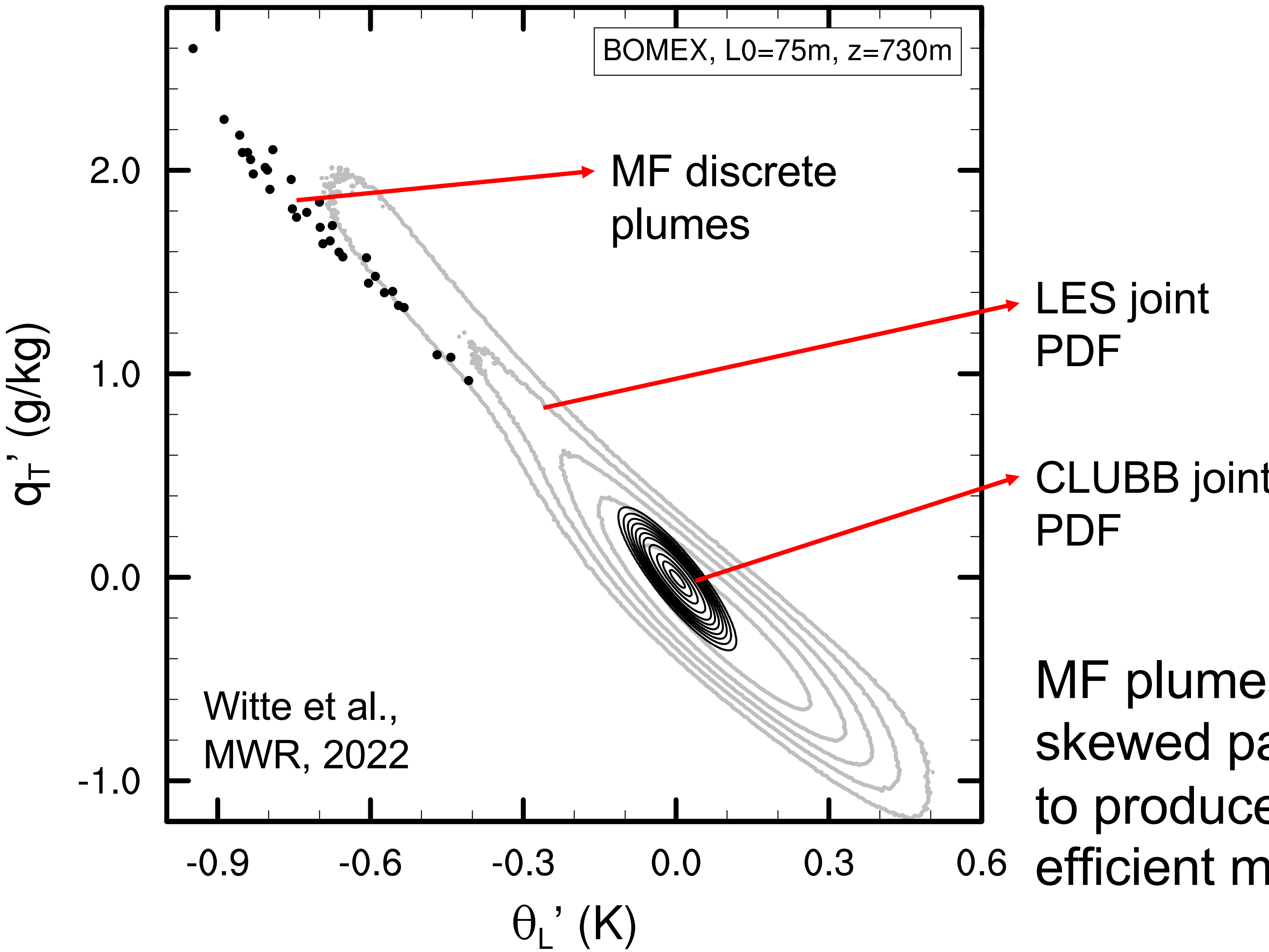
PDFs for LES, CLUBB and MF: the BOMEX Shallow Convection Case



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

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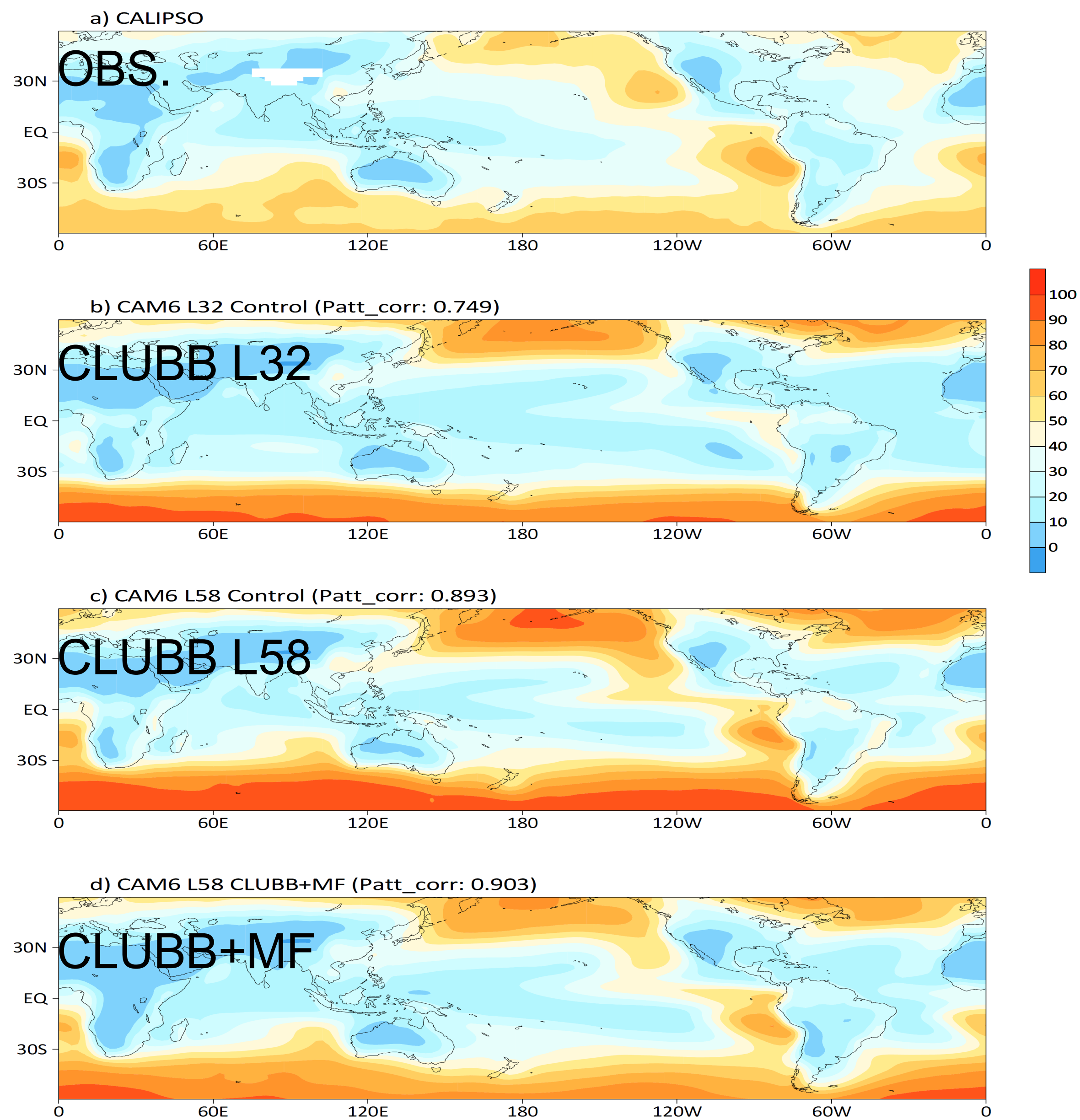
CLUBB+MF: Low Cloud Cover

Annual mean low-cloud cover (%) for 1998-2017: AMIP simulations and observations

Realistic CLUBB+MF (no ZM) stratocumulus, Southern Ocean low clouds, N. Pacific and N. Atlantic low clouds



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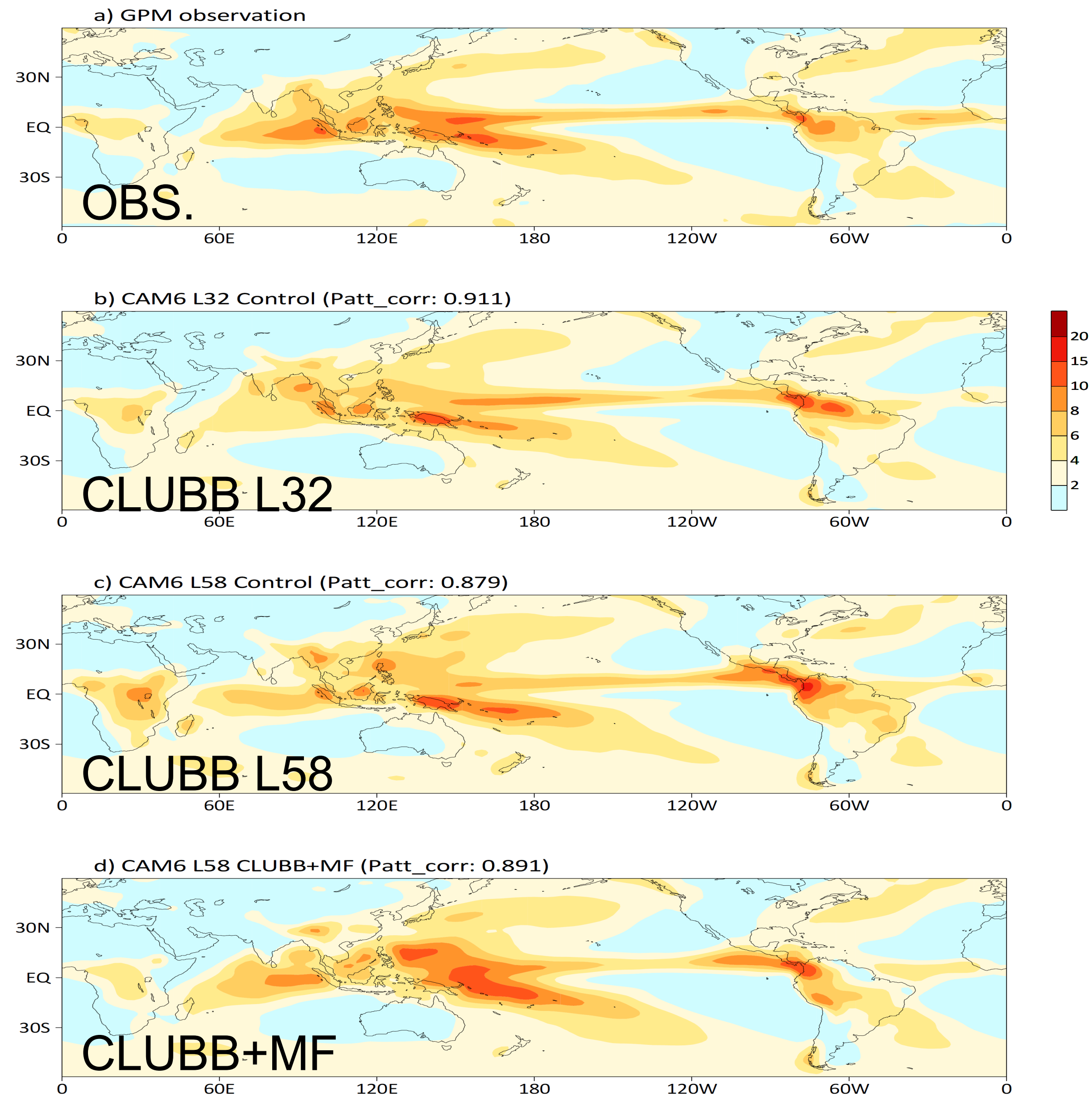
CLUBB+MF Climate: Precipitation

Annual mean precipitation (mm day^{-1}) for 1998-2017: AMIP simulations and observations

CLUBB+MF: No explicit deep convection parameterization (ZM)

Realistic CLUBB+MF precipitation climatology with some realistic key features



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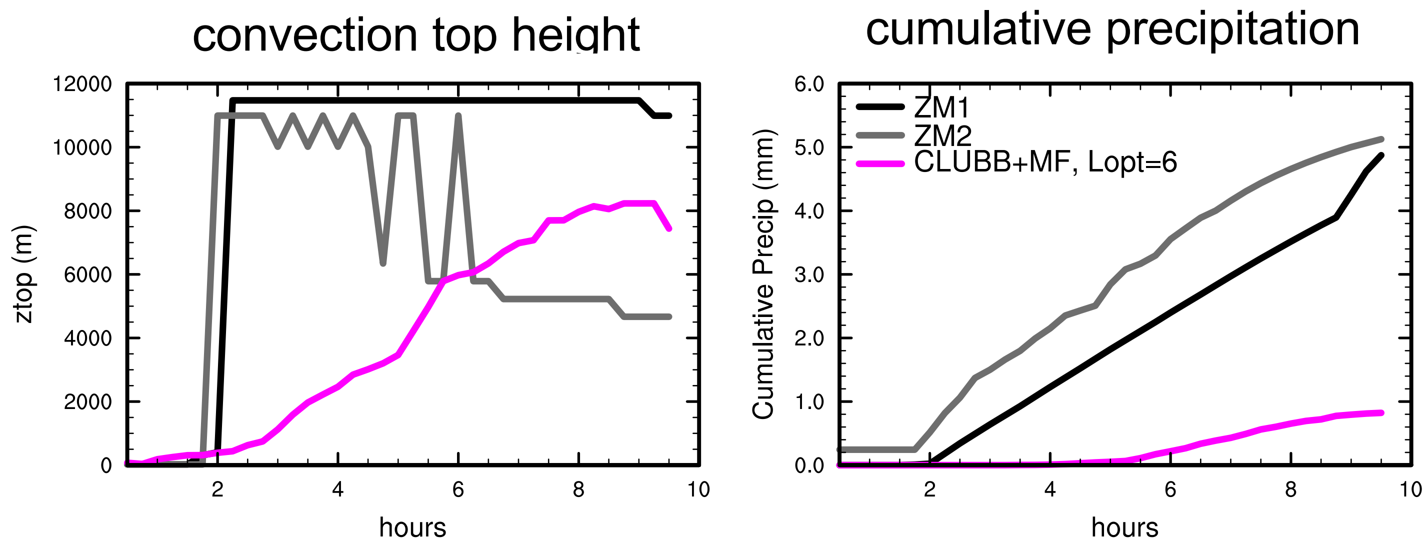
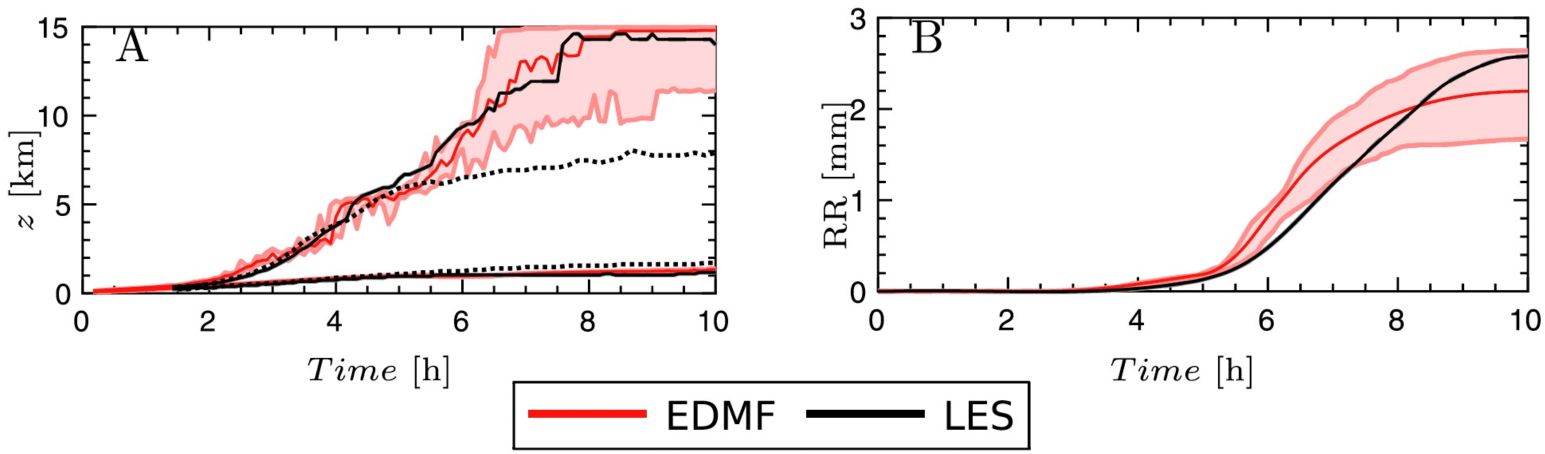
Diurnal Cycle of Convection and Precipitation over Amazon: LBA Case



SCAM results



SCAM LBA case: CLUBB+MF looks more realistic than ZM1 or ZM2

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Summary

- LES studies and GFDL model diagnostic investigations
- New fully unified (PBL+shallow+deep convection) mixing parameterization: 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, precipitation, OLR

- CLUBB+MF current research: Downdrafts, diurnal cycle of convection over land, lateral entrainment

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

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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