# Improved Diurnal Cycle of Precipitation in EAMv1 with a Modified Convective Triggering Mechanism

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E3SM Energy Exascale Earth System Model

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U.S. DEPARTMENT OF ENERGY

# Outline

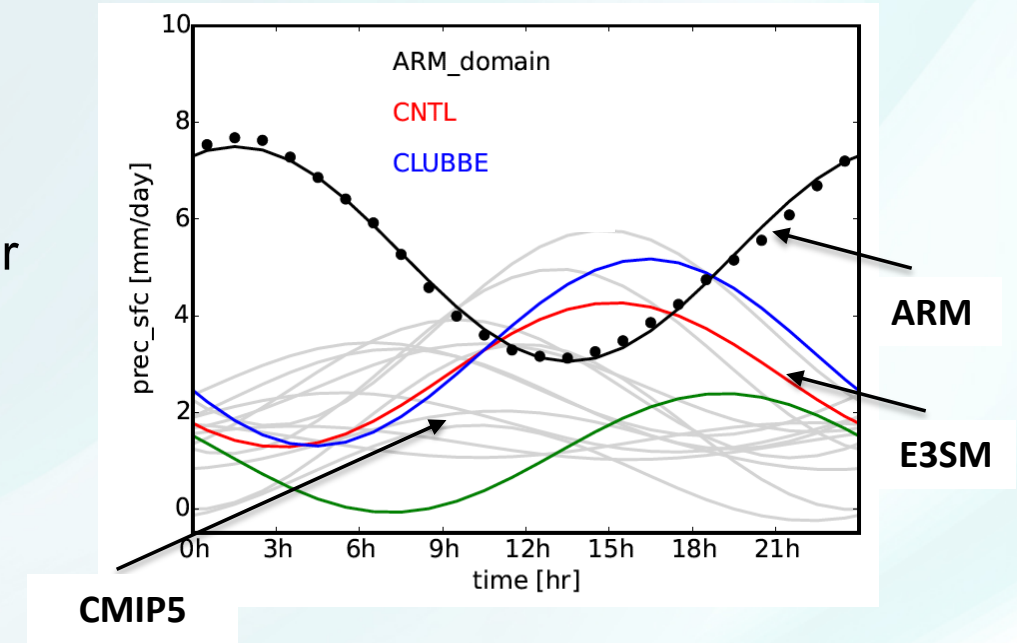
- Motivation
  - Issues with modeling the diurnal cycle of precipitation
  - Efforts in the field
- A modified convective trigger
  - Philosophy
  - Observational evidence
- Application to EAMv1
  - Mean precipitation
  - Diurnal cycle of precipitation
  - Propagation of meso-scale convective systems
- Summary

# Model Errors in Simulating Diurnal Cycle of Precipitation

Problems larger over land than over ocean

- Rainfall occurs too early after sunrise and "too frequent, too weak"
- Fail to capture the nocturnal peak over the central Great Plains
- No eastward propagation of MCSs from the Rocky Mountain to the central Great Plains.

**Summertime Diurnal Cycle of Precipitation at ARM SGP Site**




*No clear improvement with increasing model horizontal resolution*

**Black**: ARM observations
**Grey lines**: CMIP5 model results,
Colors for E3SM with different convection schemes

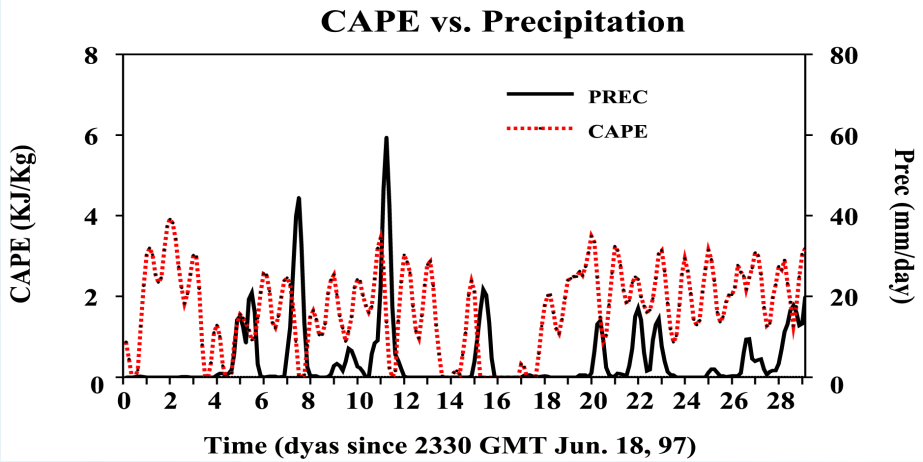
# Deficiencies in Model Convective Triggers

**CAPE-Based Trigger (e.g., ZM, CAPE>70 J/kg), *where CAPE is calculated from an air parcel originating from the PBL***

- Unrealistically strong coupling of convection to surface heating
- Lack of convection inhibition
- Lack of additional large-scale dynamic & thermodynamic controls (e.g., tropospheric moisture, low-level convergence)?
- Roles of cold pools?

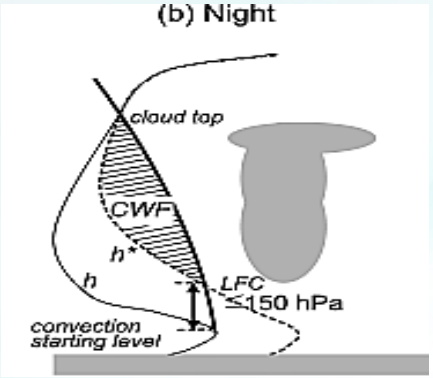
*Zhang 2003; Kain 2004; Bechtold et al. 2004, 2008; Lee et al. 2008; Han and Pan 2011, Neale et al. 2013; Wang etal. 2015*

**Problems with CAPE-based trigger**




==> Convection would be triggered too often over land during warm season

**Nocturnal Precipitation**




***Convection elevated***

***Surface decoupled***

*Lee et al. 2008*

# *How to Improve the Convective Trigger?*

Two key areas:

- *How to prevent convection from being triggered too frequently?*
- *How to capture elevated nocturnal convection, which occurs from moist conditionally unstable layers located above the boundary layer?*

# The DCAPE Trigger (*Xie and Zhang 2000*)

Xie and Zhang (2000) introduced a dynamic CAPE generation rate (**DCAPE**) to control the onset of deep convection, which was tested in CAM2 (Xie et al. 2004) and is being used in JMA's operational NWP model.

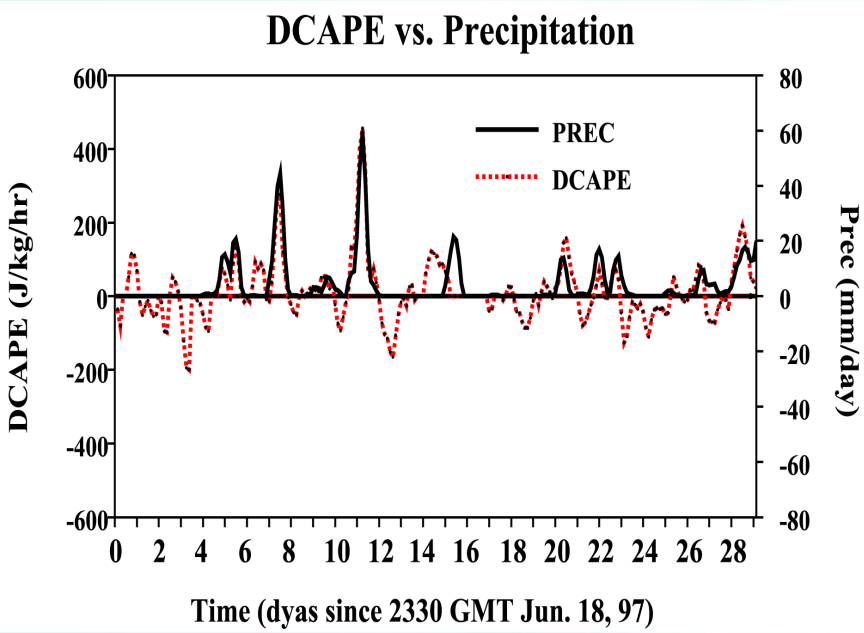
## Dynamical CAPE:

$$\mathrm{DCAPE} = [\mathrm{CAPE}(T^*,\ q^*) - \mathrm{CAPE}(T, q)]/\Delta t,$$

*Where*

$T^* = T + (\partial T/\partial t)_{adv} * \Delta t;$

$q^* = q + (\partial q/\partial t)_{adv} * \Delta t$

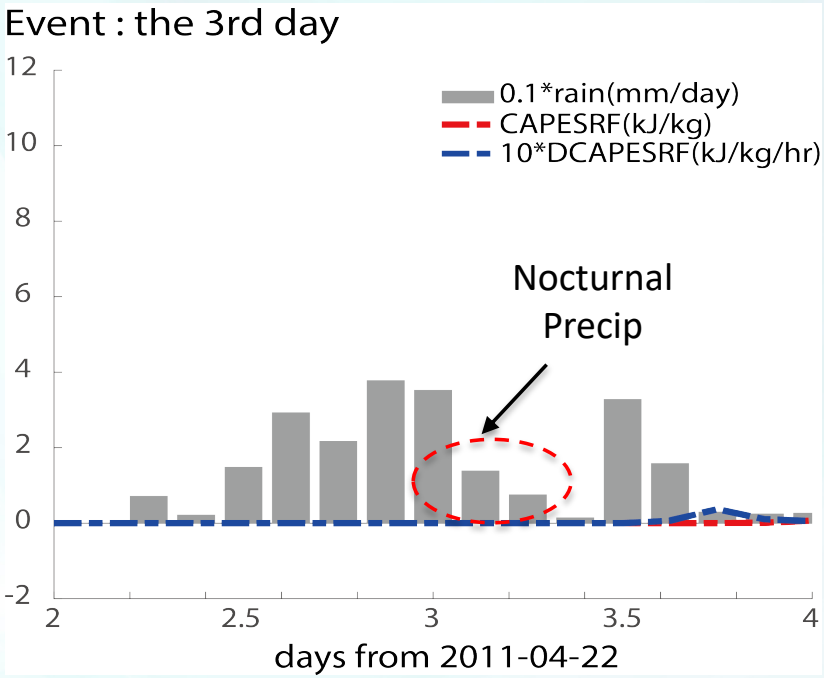



New Trigger: CAPE>0 & DCAPE>0

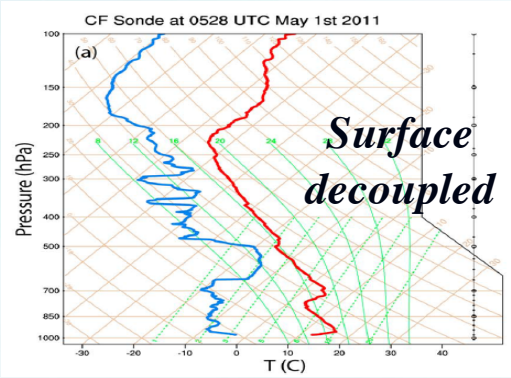
*Convection can only be triggered when the large-scale forcing is making a positive contribution to the existing CAPE. The DCAPE trigger links cumulus convection directly to the large-scale dynamic forcing, such as lower level convergence.*

# DCAPE may not work for some elevated nocturnal convection cases

## (CAPE, DCAPE) vs. Precipitation




An elevated nocturnal case selected from the ARM M3CE field campaign at SGP




*Xie et al. 2014*

Very stable PBL

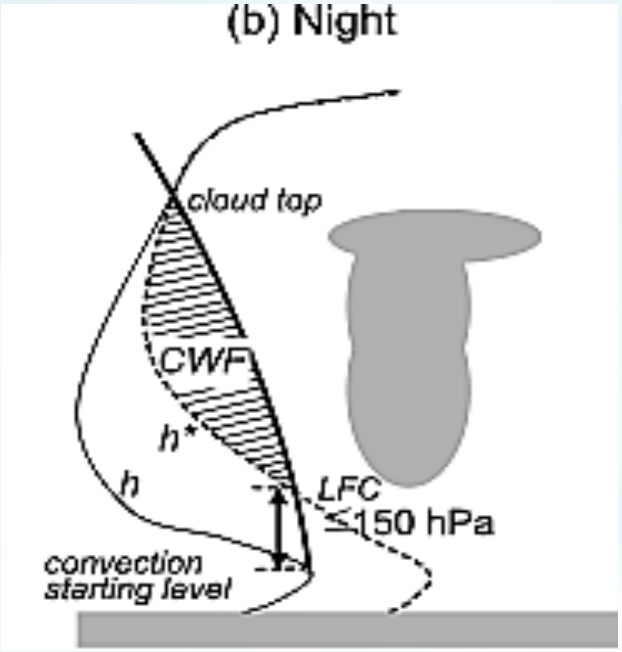
No CAPE and DCAPE are detected if the convection starting level is limited in the PBL, as assumed in several deep convection schemes including the ZM scheme

# Unrestricted Launch Level (ULL)
## *(Wang et al. 2015)*

### Unrestricted Launch Level (ULL):

The ULL method defines an air parcel launch level to be level where the maximum MSE is found below 600 hPa with searching from the surface.

- *Allows air parcel launching above PBL to capture elevated convection*



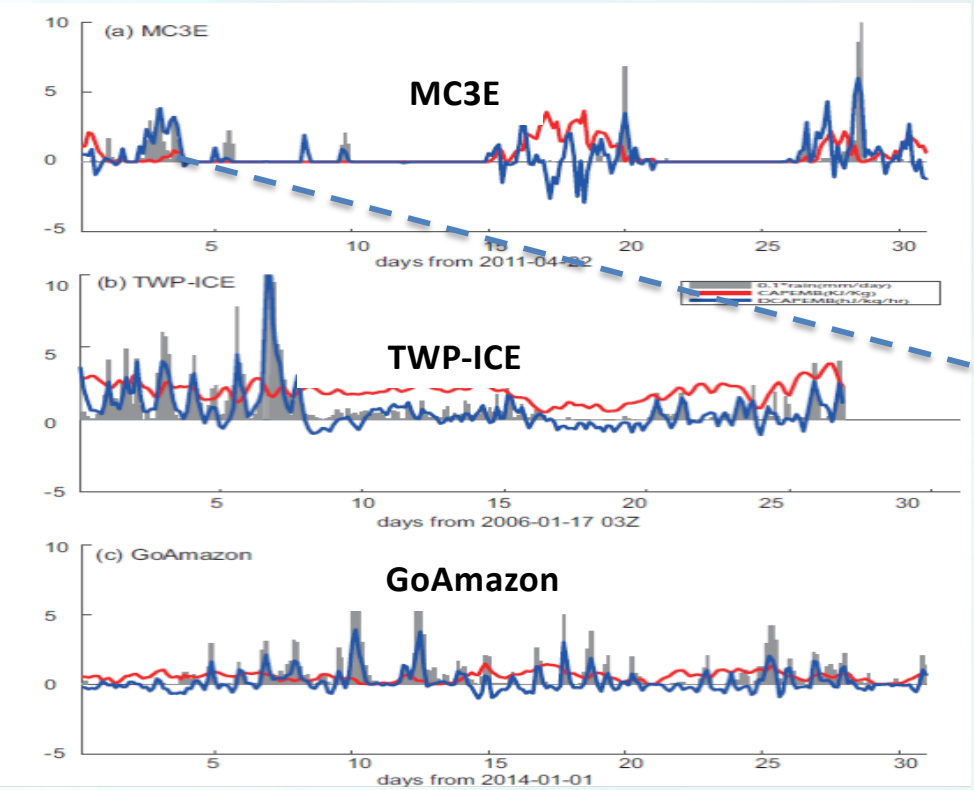

*Convection elevated*

*Lee et al. 2008*

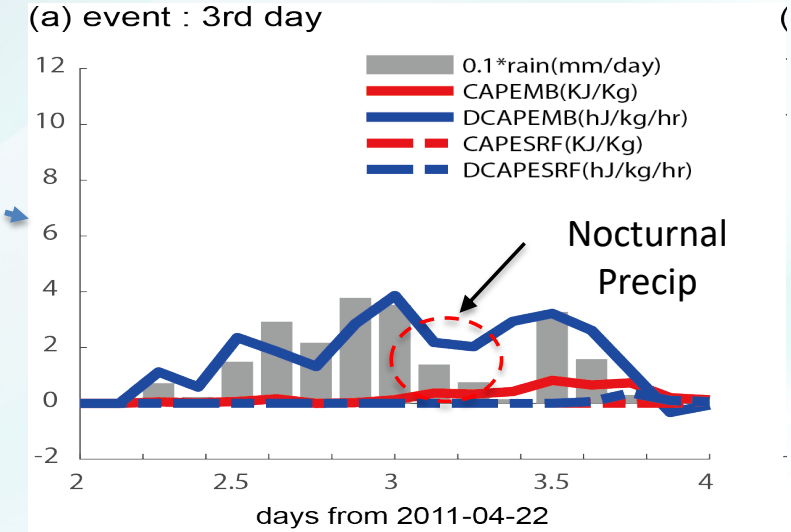
# A Modified Convective Trigger

- A modified trigger combined the DCAPE trigger with the ULL concept: **(CAPE> 0 & DCAPE > 0) + ULL**

(CAPE, DCAPE) vs. Precipitation over different climate regimes




Selected Nocturnal Precipitation Case

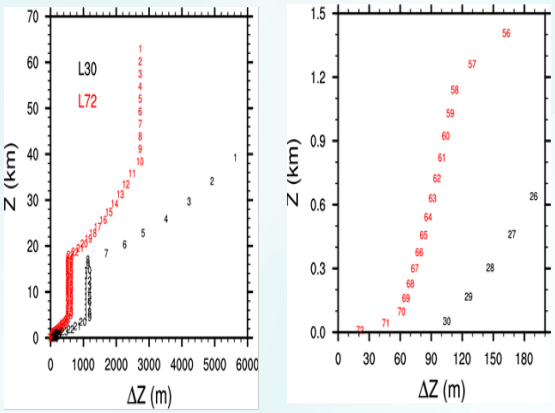


# Application to EAMv1

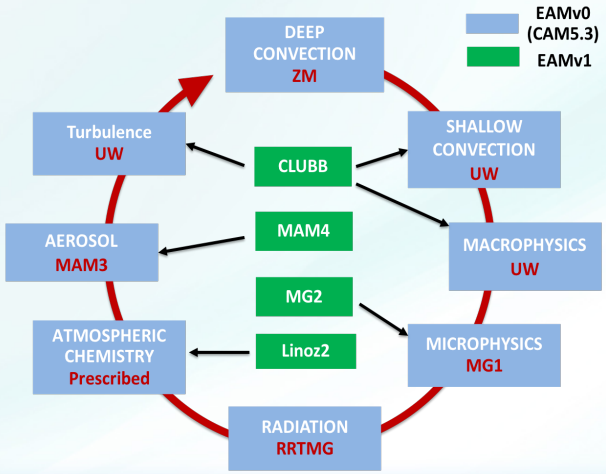
# EAMv1

EAMv1 starts from CAM5.3 + Spectral Element (SE) Dycore (**EAMv0**), but with increased horizontal and vertical resolution, as well as notable changes to its physical parameterizations, particularly in aerosols, clouds, and convection. Similar to CAM6

- **Resolution**
  - Standard version: $1^0$ in horizontal and 72 layers with top at ~ 60km, better resolved vertical structures
  - High-res version: $0.25^0$ in horizontal and 72 layers, better resolved both horizontal and vertical structures
- **Physics**
  - Zhang-McFarlane (1995) (ZM) for deep convection
  - CLUBB for a unified treatment of shallow convection/turbulence/macrophysics
  - MG2 for microphysics with improved ice micriophysics
  - MAM4 with Improvements in treating aerosols
  - Simple Ozone (linearized production and loss)




**Physics: EAMv0 → EAMv1**



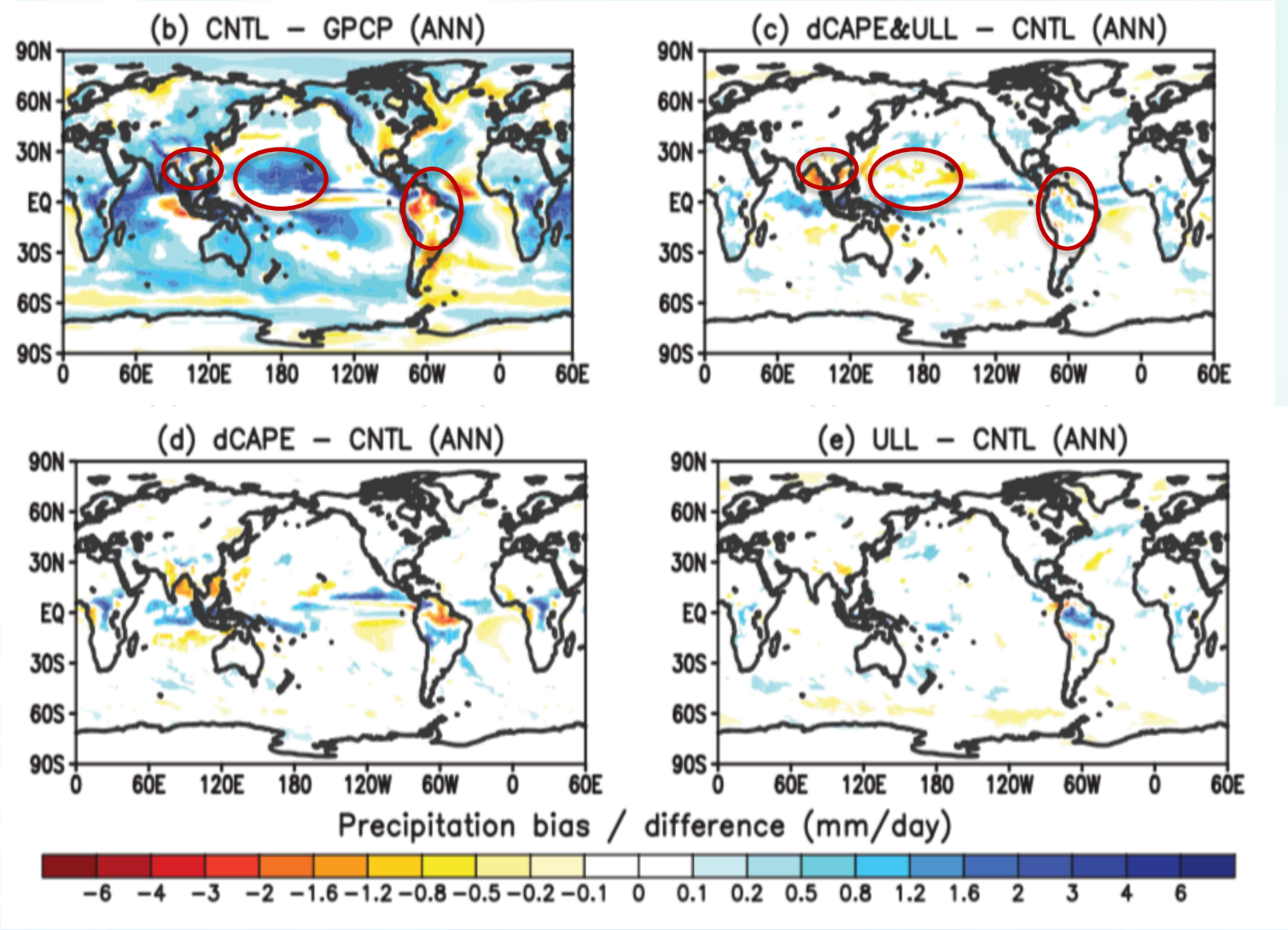
# Experiment Design

Model resolution is 1 deg and 72 levels. 11-yr AMIP run; 2-11 year simulations are analyzed

| Case | Description | Convective Trigger |
|---|---|---|
| Control | Default low-resolution ($1^0$) EAMv1 | CAPE > 70 J/kg |
| DCAPE+ULL | Control with the proposed new convective trigger | 1) DCAPE > 0 & CAPE>0<br>2) Allow unrestricted parcel launching level (ULL) below 600mb |
| DCAPE | Control with the DCAPE trigger only | DCAPE > 0 & CAPE>0 |
| ULL | EAMv1 with ULL only | Same as Control, but allow unrestricted parcel launching level (ULL) |

# Annual Mean Precipitation

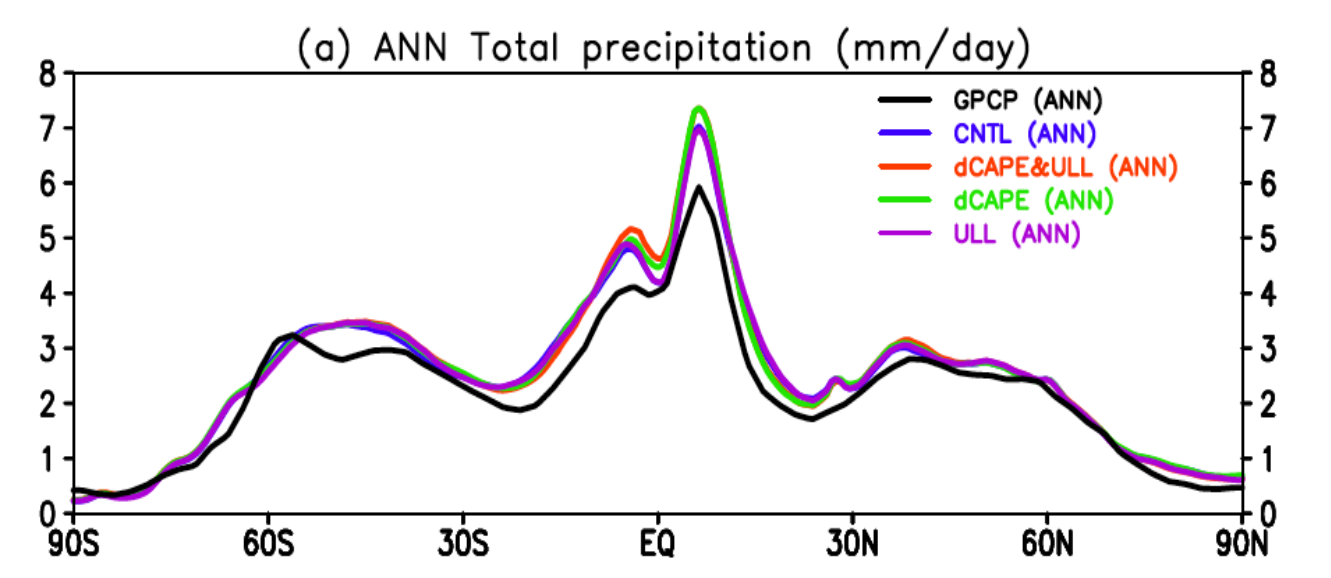
Only show the differences that are statistically significant



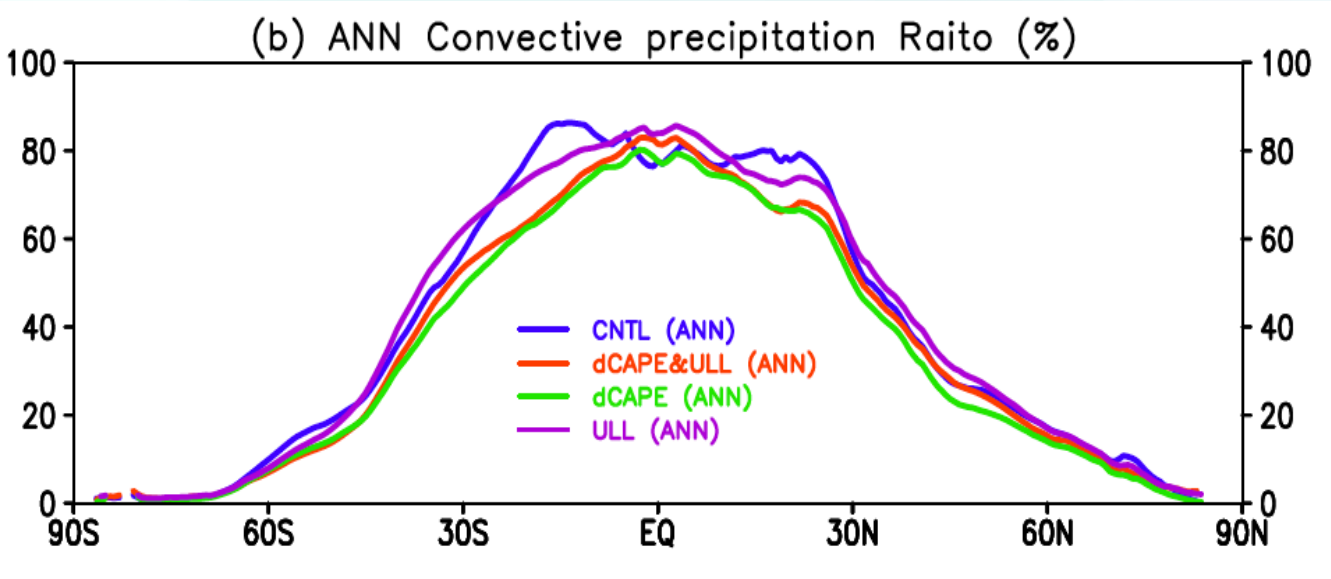

Overall impact on the mean state is minor

- Slight improvements over equatorial and subtropical Pacific and Atlantic, the Indian peninsula and surrounding oceans, South America
- A slight degradation is seen in the northern ITCZ in the eastern Pacific
- dCAPE plays a major role in changes seen in mean state

# Precipitation Partitioning

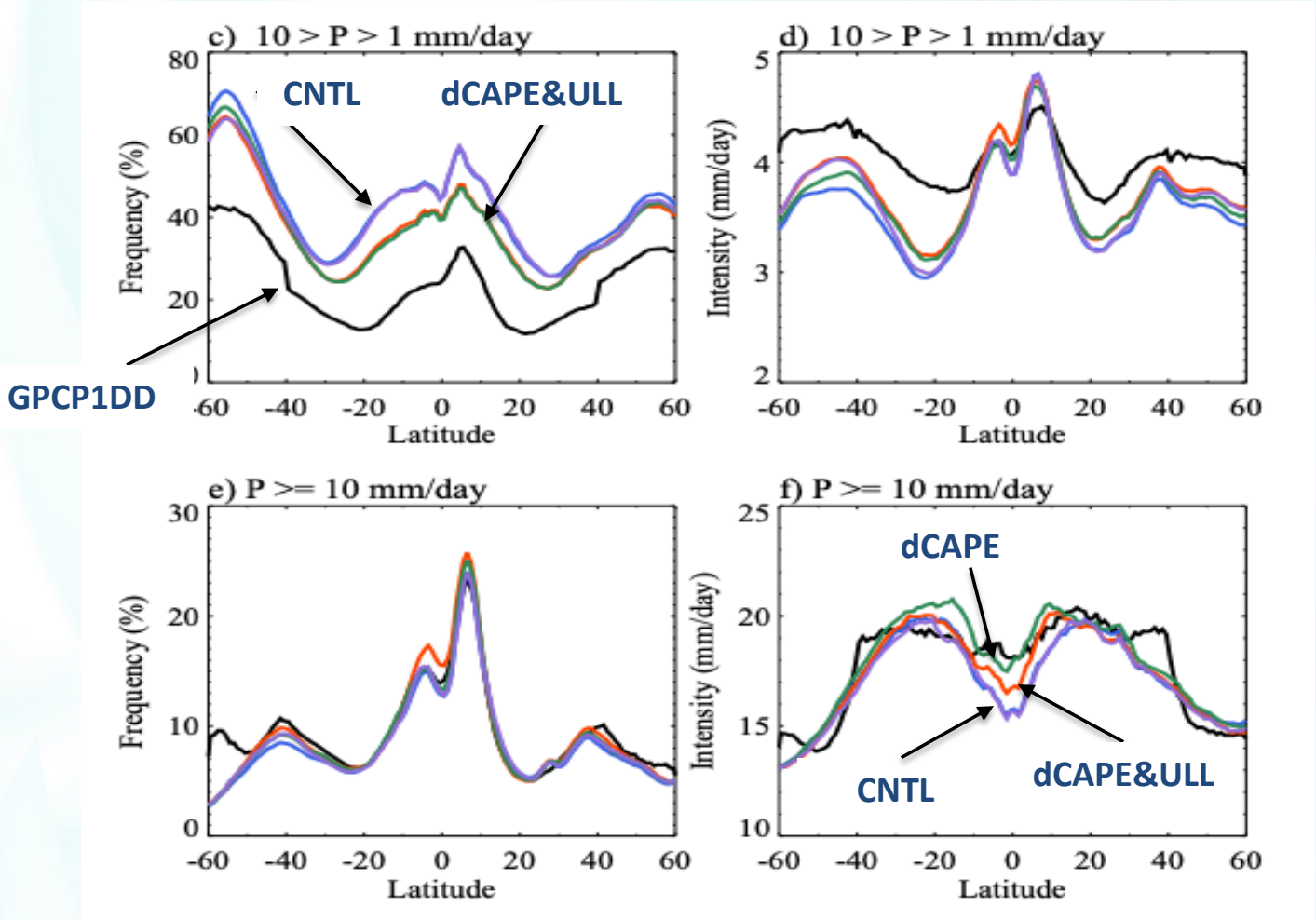


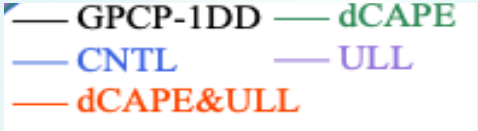

Changes in total precip are minor




Considerable reduction of convective precipitation fraction over the subtropical regions with the use of the **dCAPE** trigger.

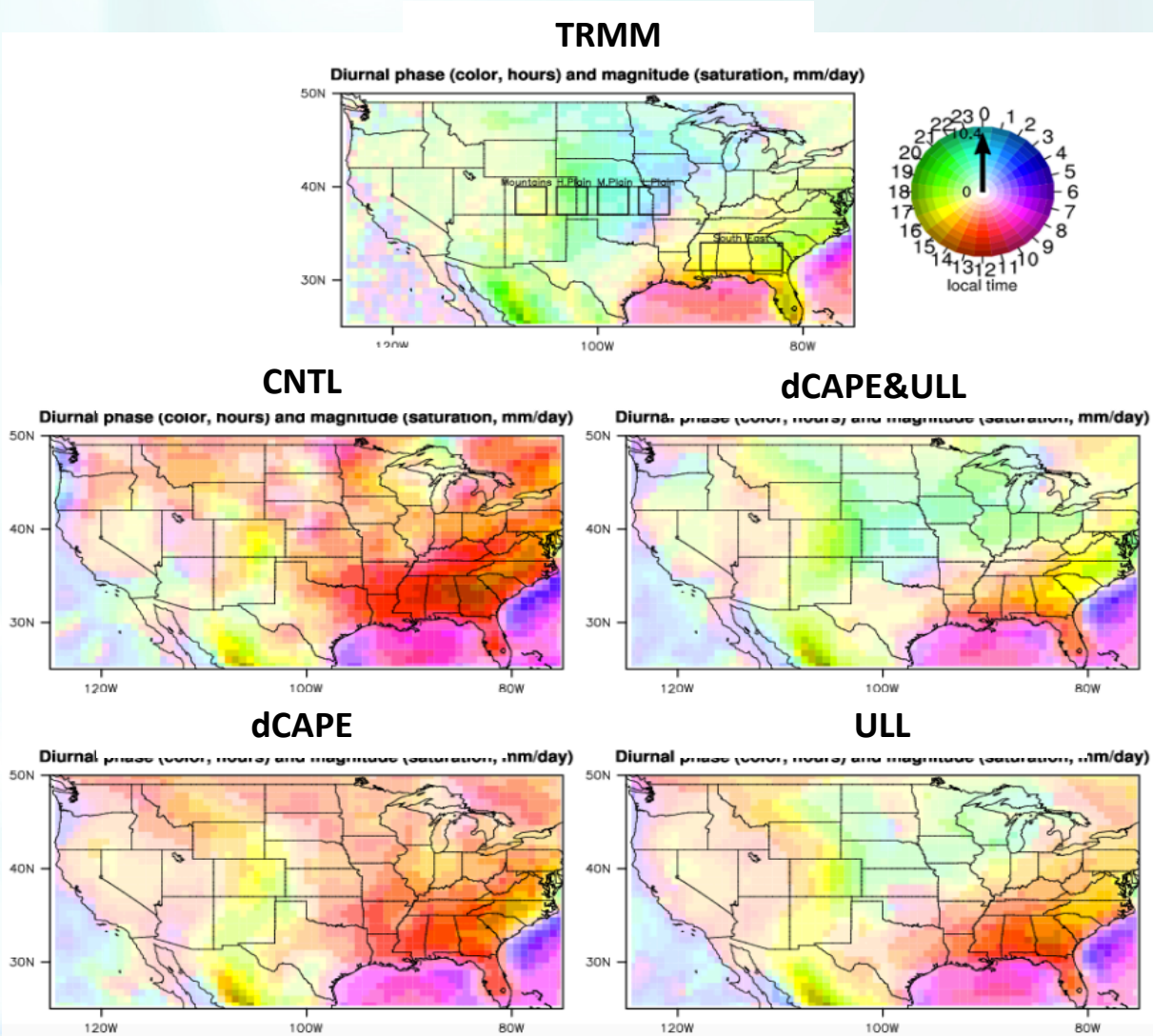
# Precipitation frequencies and intensities



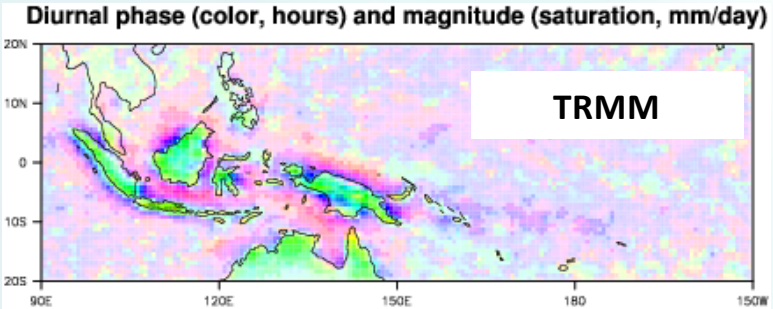

- EAMv1 "too frequent, too weak) for light-to-moderate precip
- EAMv1 does a decent job for the moderate-to-heavy precip in frequency, but largely underestimate the intensity in tropics
- The new trigger reduces the frequency of light-to-moderate precip and increase the intensity of moderate-to-heavy precipitation due to the use of dCAPE

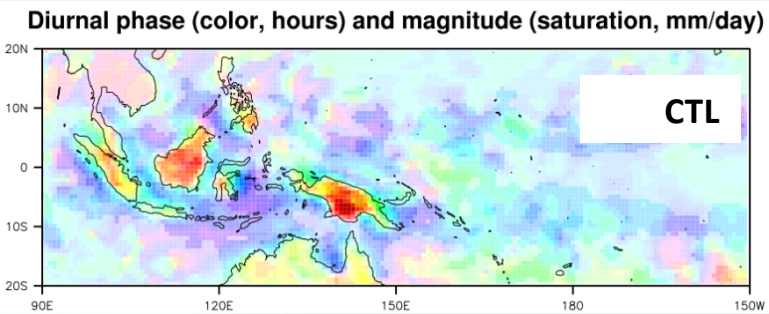
# Diurnal Cycle Precipitation over CONUS (JJA)

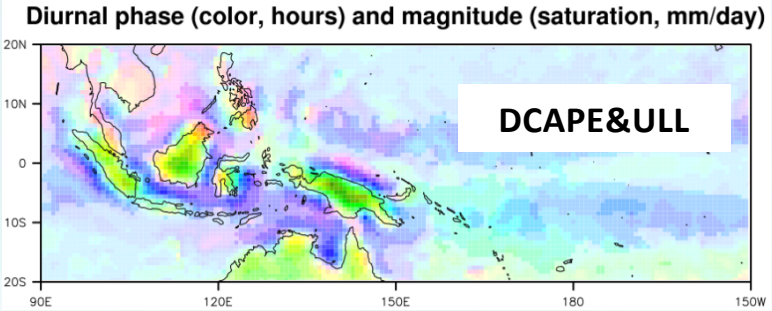


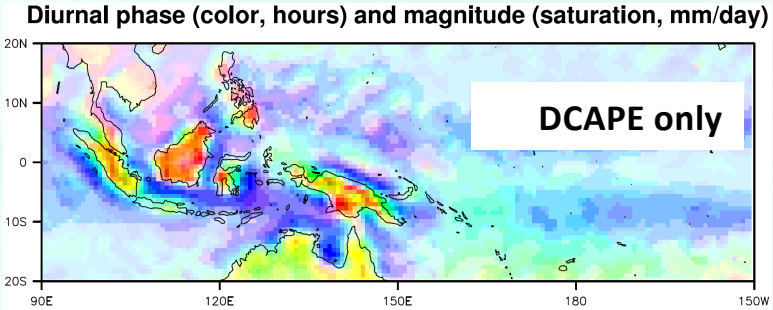

- EAMv1 peaks too early and fails to capture the notunal peak over the Great Plains
- The phase of diurnal cycle improved significantly with the new trigger
- The improvement is primarily due to ULL which helps to capture the nocturnal precip

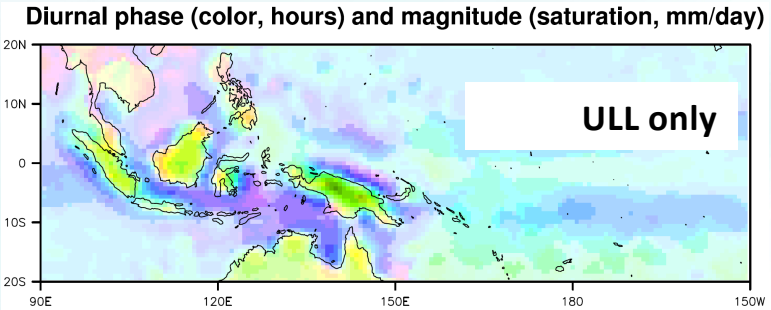
# Diurnal cycle of Precipitation over the Maritime Continent (DJF)

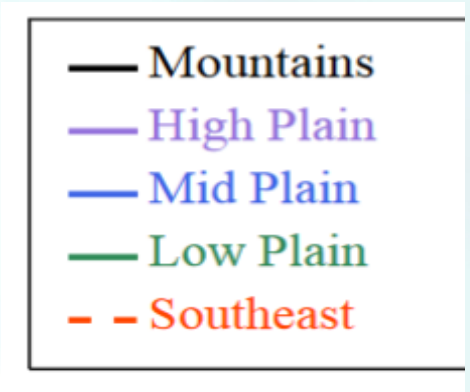



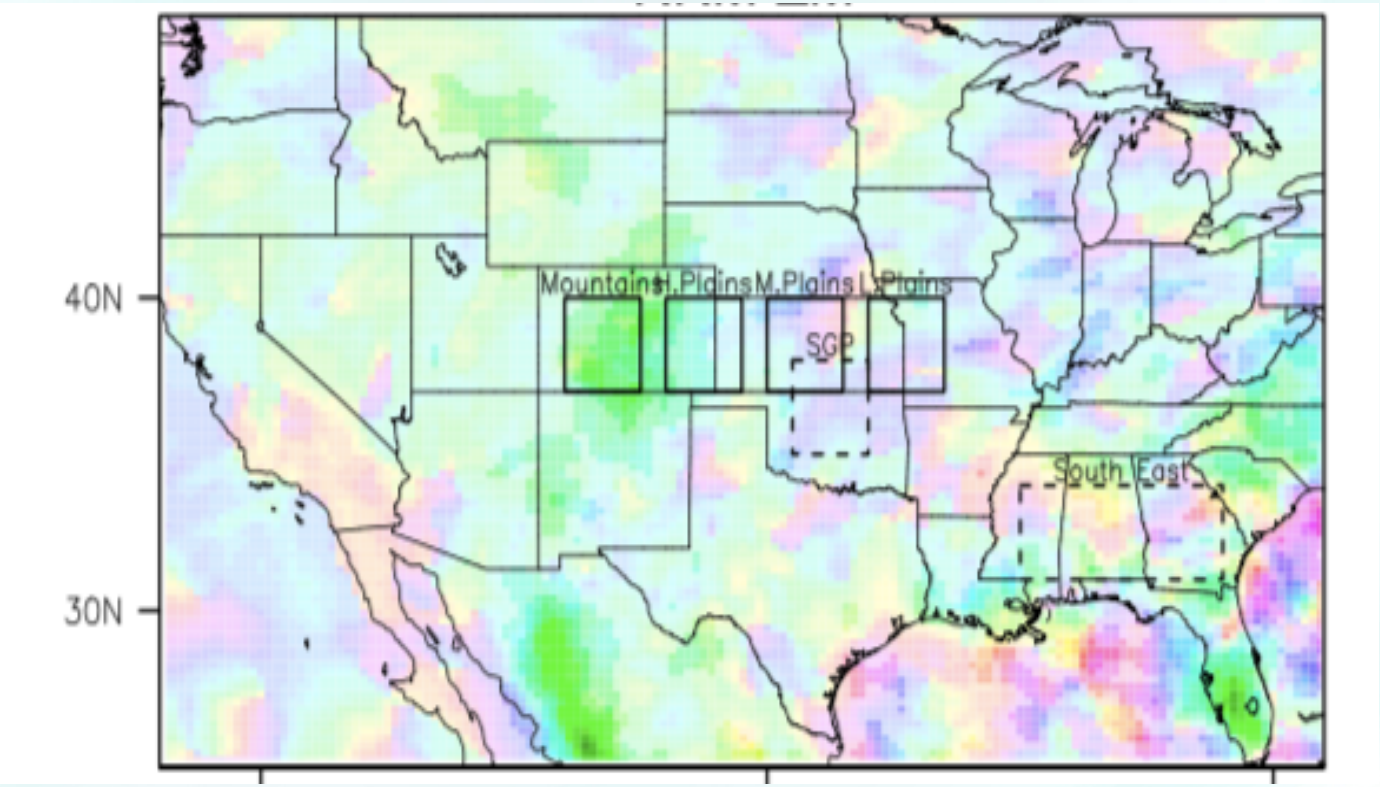



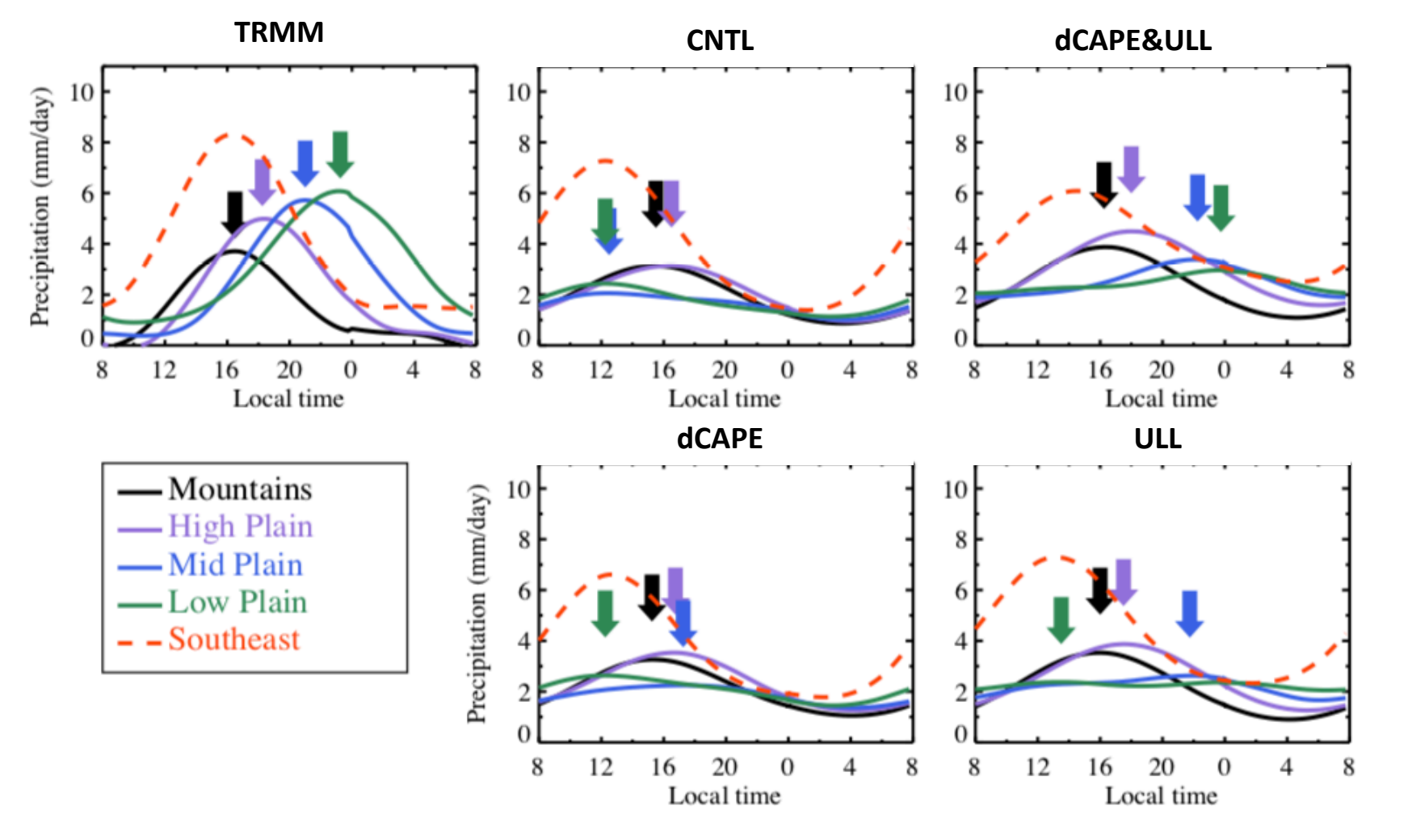



# Eastward propagation

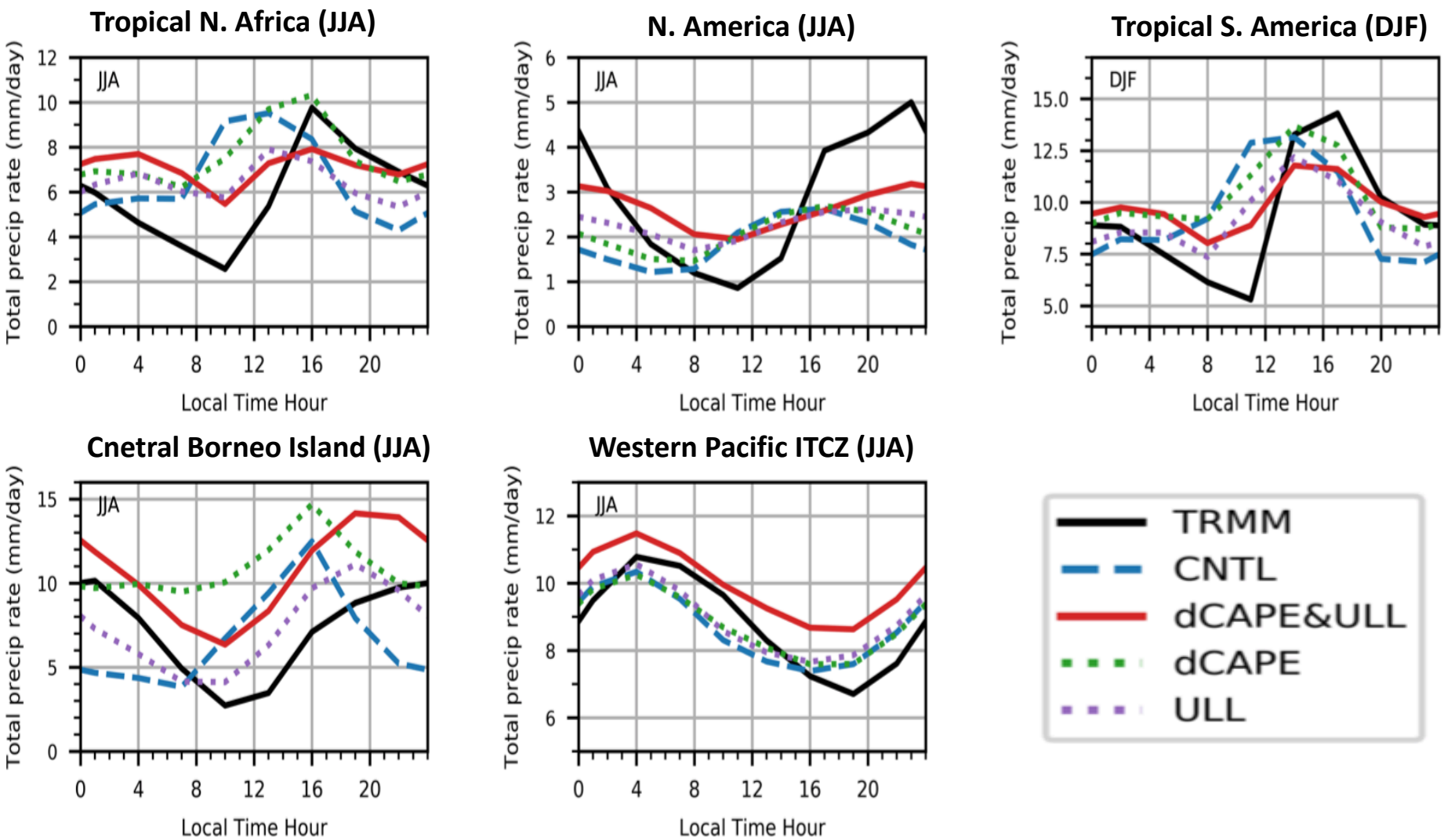


# Eastward propagation



# Diurnal cycle over selected regimes

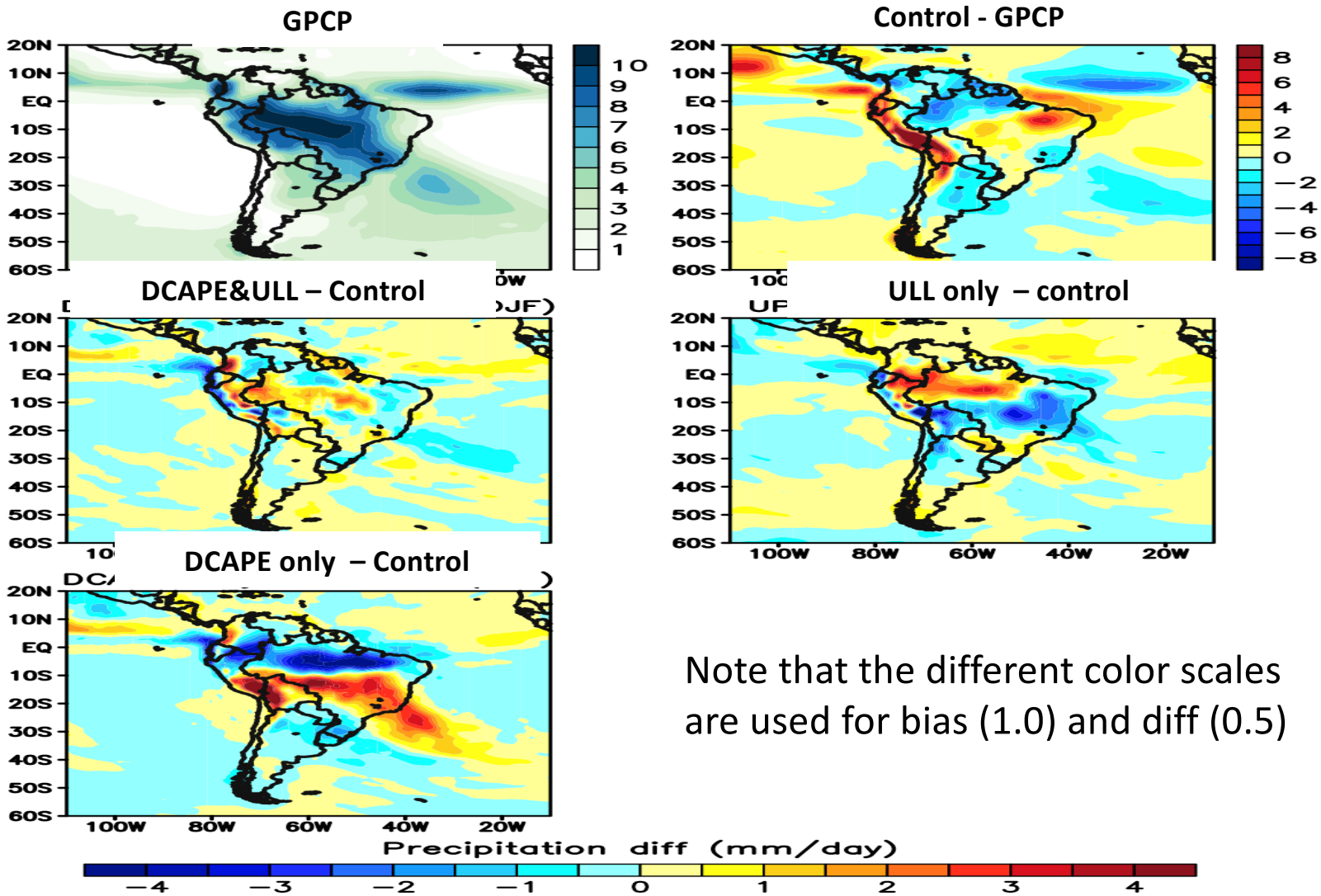


# Summary

- A new convective trigger (DCAPE+ULL) was tested with EAMv1.
  - dCAPE used to prevent CAPE being released spontaneously
  - ULL used to remove the restriction of having the air parcel launch level within PBL for elevated nocturnal convection
- The new trigger has minor impact on the mean state, but it leads to a substantial improvement in the phase of the diurnal cycle of precipitation although its amplitude is still too weak
- dCAPE suppresses daytime convection while the unrestricted launch level is key to capturing nocturnal elevated convection
- EAMv1 starts to show the eastward propagation of MCSs, but processes behind it needs to be better understood.
- Only minor changes seen in tropical waves

Xie, S., Wang, Y.-C., Lin, W., Ma, H.-Y., Tang, Q., Tang, S., et al (2019). Improved Diurnal Cycle of Precipitation in E3SM with a Revised Convective Triggering Function. Journal of Advances in Modeling Earth Systems. https://doi.org/10.1029/2019MS001702.

# DJF Precipitation over South America




Note that the different color scales are used for bias (1.0) and diff (0.5)

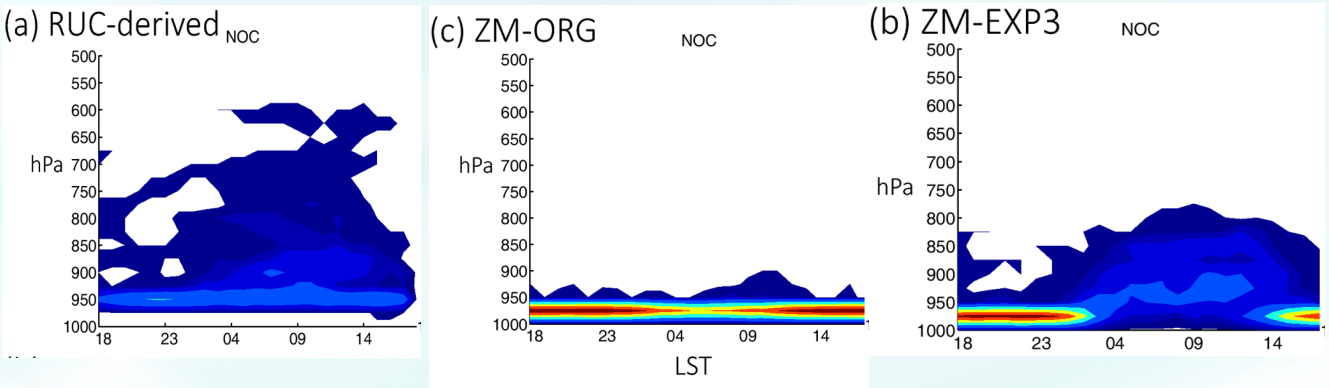
# Unrestricted Launch Level (ULL)
## *(Wang et al. 2015)*

### Unrestricted Launch Level (ULL):

The ULL method defines the air parcel launch level to be level where the maximum MSE is found below 600 hPa with searching from the surface.

- Allows air parcel launching above PBL to capture elevated convection

Launching level occurrence associated with nocturnal precipitation at SGP (JJA) (2002-2007)




(*Wang et al. 2015*)