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

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Lawrence Livermore National Laboratory

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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

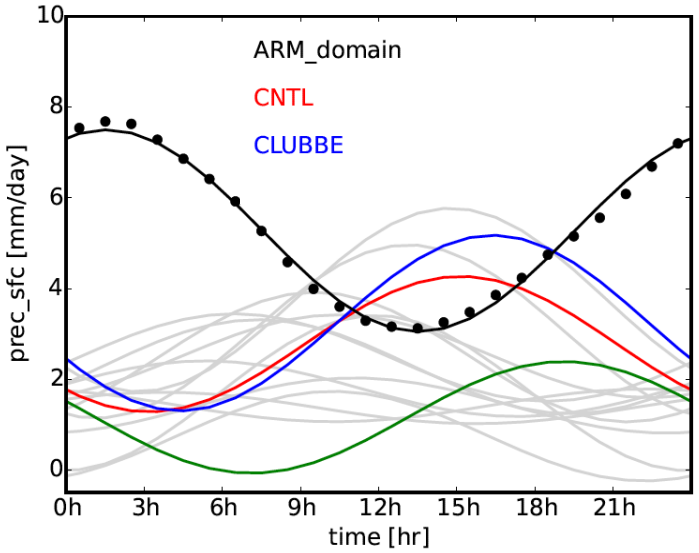
Model Errors in Simulating Diurnal Cycle of Precipitation

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.

No clear improvement with increasing model horizontal resolution

Summertime Diurnal Cycle of Precipitation at ARM SGP Site



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

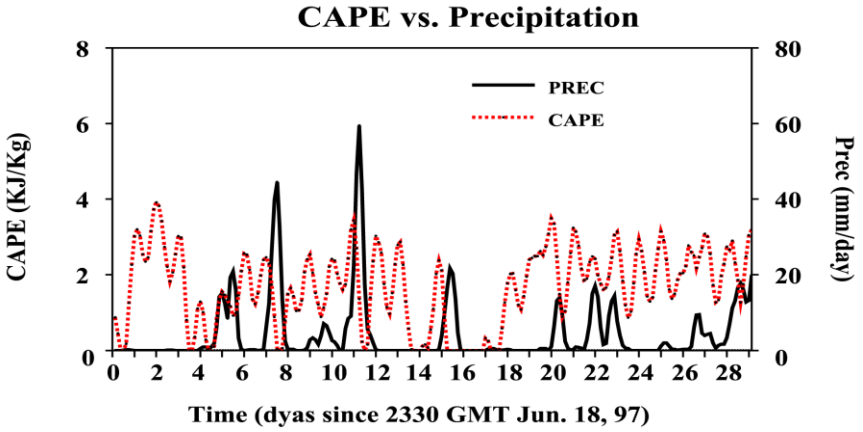
Deficiencies in Model Convective Triggers

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?

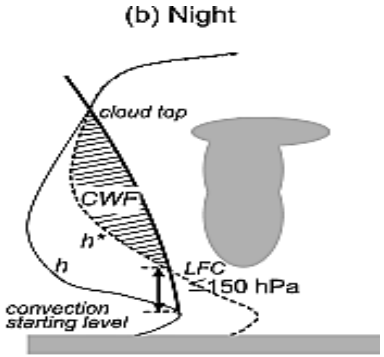
Zhang 2003; Kain 2004; Bechtold et al. 2004, 2008; Lee et al. 2008; Han and Pan 2011, Neale et al. 2013; Wang etal. 2015

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*)

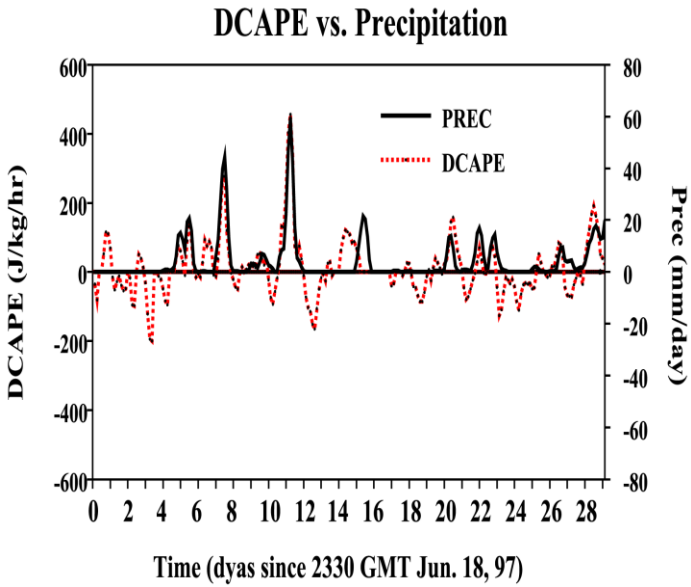
Xie and Zhang (2000) introduced a dynamic CAPE generation rate (**DCAPE**) to control the onset of deep convection (*tested in CAM2, Xie et al. 2004 and being used in JMA's operational NWP model*)

Dynamical CAPE:

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

Where

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

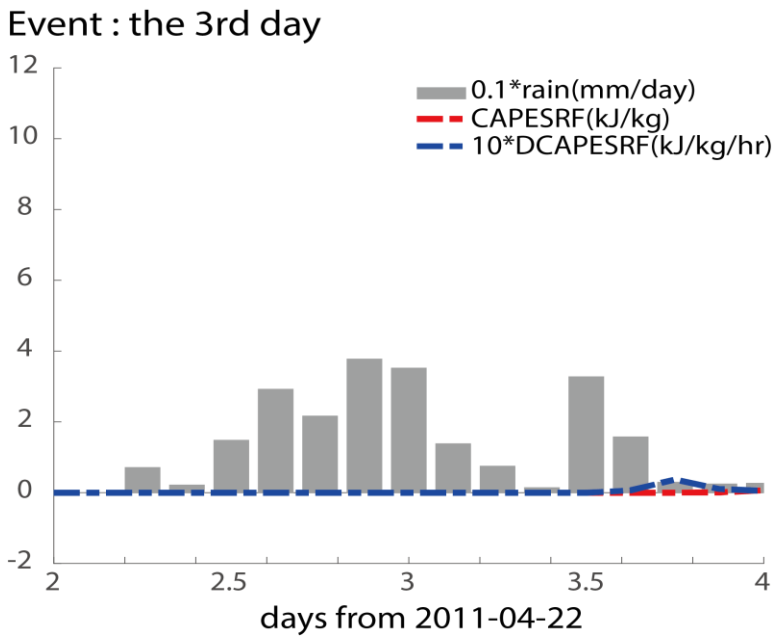


New Trigger: CAPE>0 & DCAPE>0

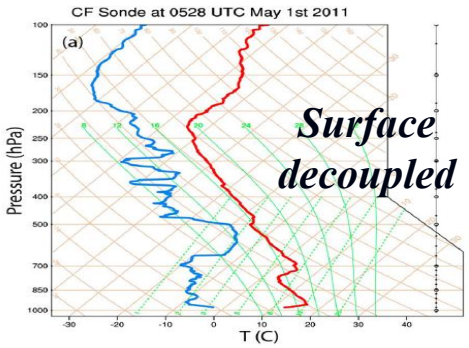
Convection can only be triggered when the large-scale forcing is making a positive contribution to the existing CAPE. Links convection directly to the large-scale dynamic forcing, such as lower level convergence.

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

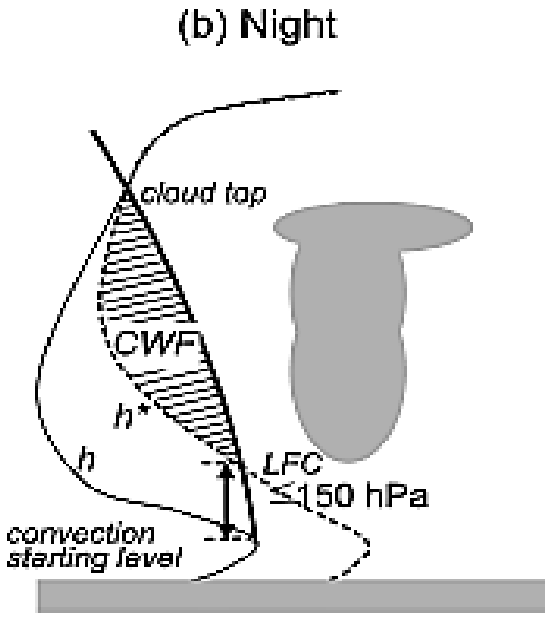
No CAPE and DCAPE are detected if the convection starting level is limited in the PBL, as assumed in several deep convection schemes including the ZM scheme

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*

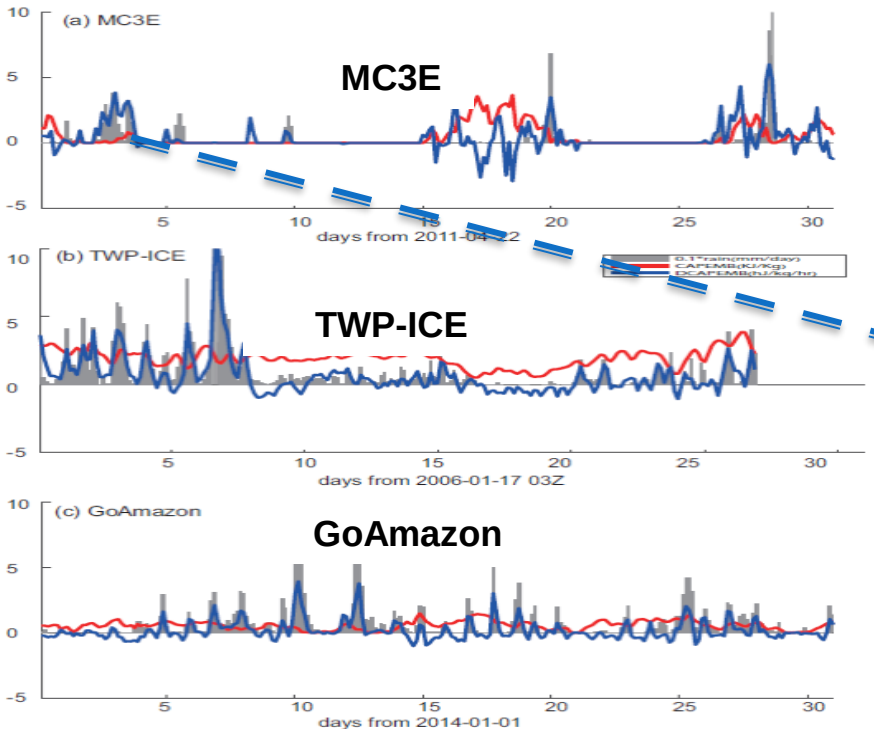


Lee et al. 2008

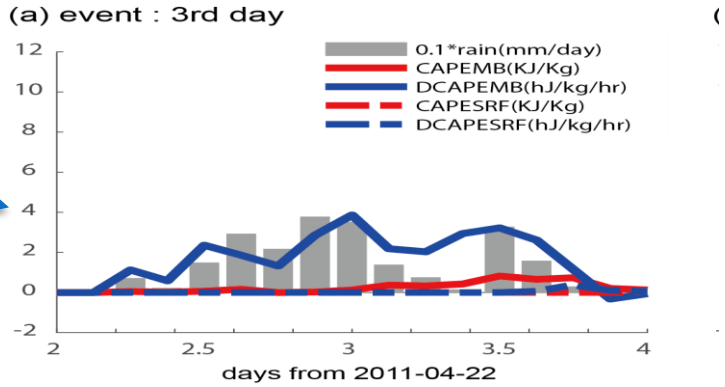
A Modified Convective Trigger

- 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

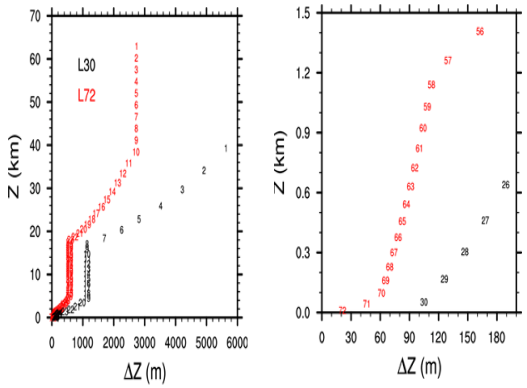


Application to EAMv1

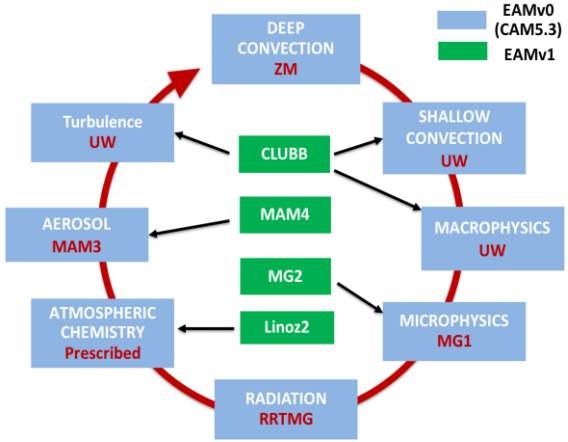
EAMv1

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

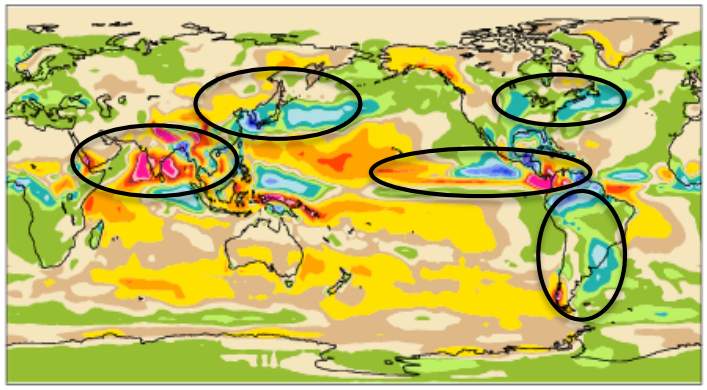
Model resolution is 1 deg and 72 levels. 11-yr AMIP run; 2-11 year simulations are analyzed

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 2) Allow unrestricted parcel launching level (ULL) below 600mb
DCAPE	Control with the DCAPE trigger only	DCAPE > 0
ULL	EAMv1 with ULL only	Same as Control, but allow unrestricted parcel launching level (ULL)

Annual Mean Precipitation

Control - GPCP

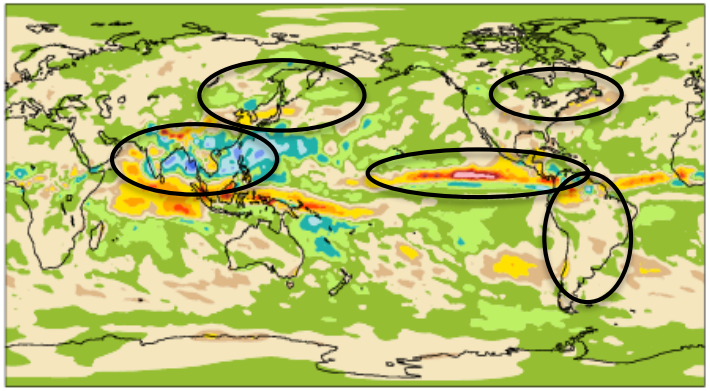
mean = 0.44 rmse = 1.44 mm/day



DCAPE&ULL – Control

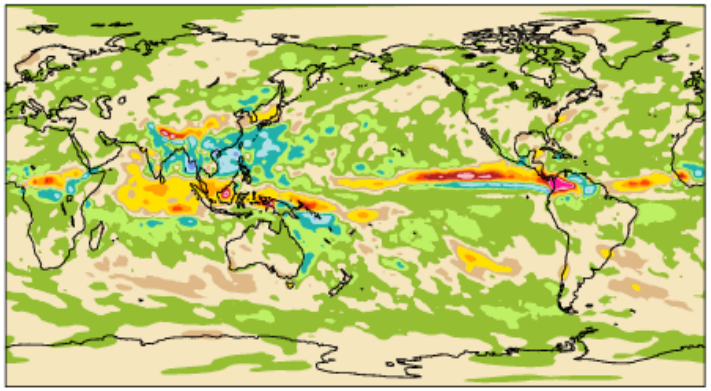
mean = 0.05 rmse = 0.75 mm/day

Min Min = −4.94 Max = 7.89



DCAPE only – Control

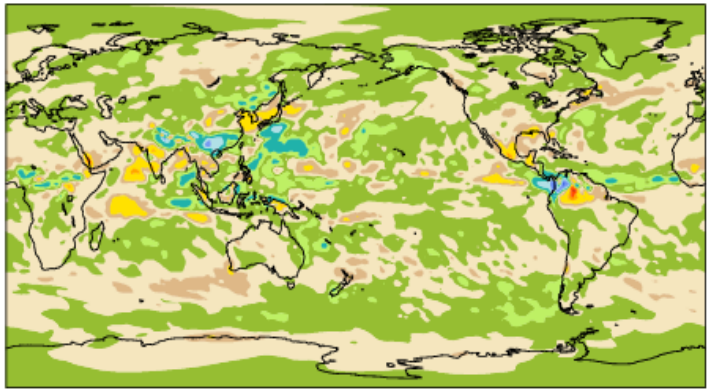
mean = 0.04 rmse = 0.82 mm/day



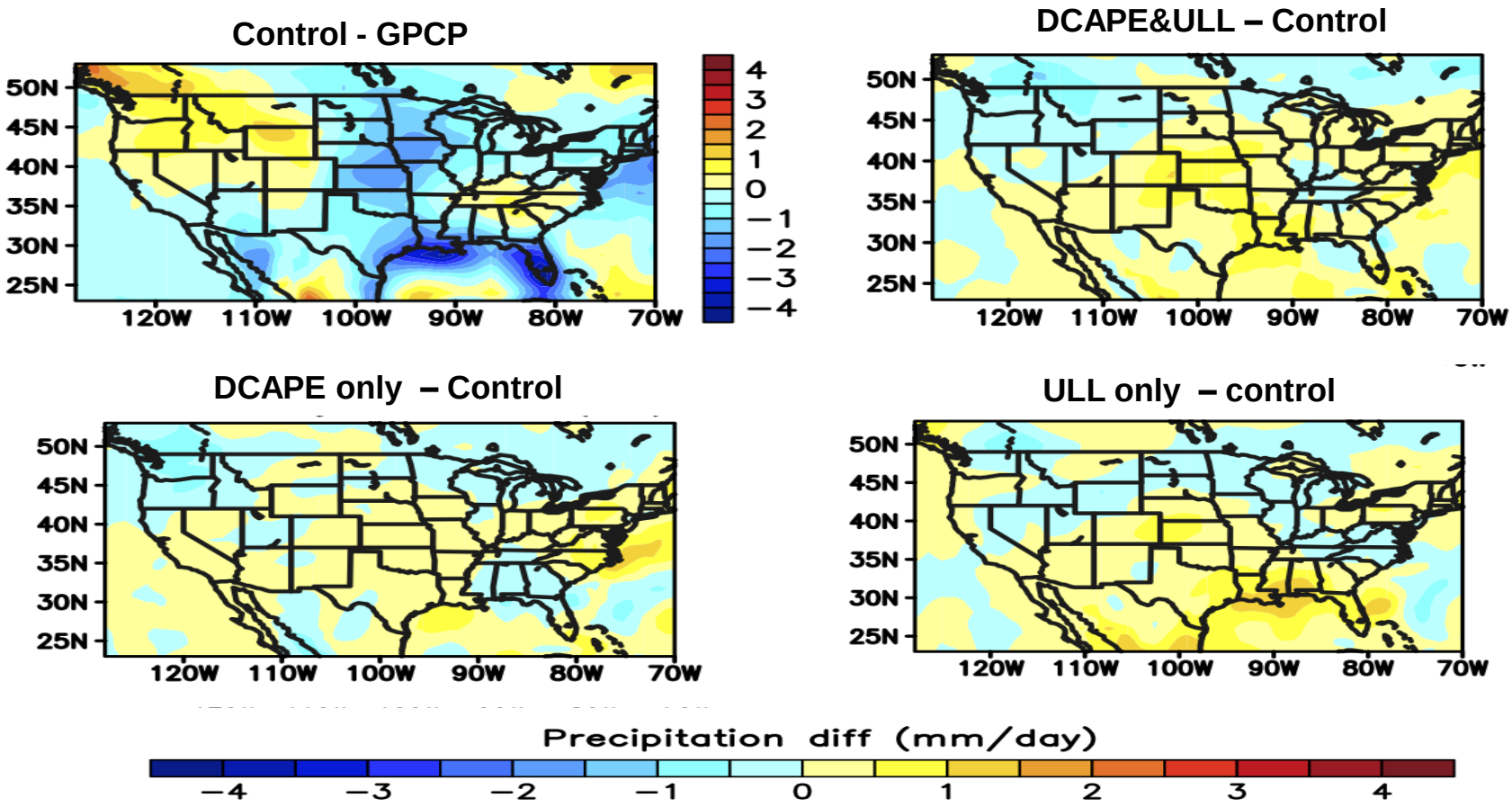
ULL only – control

mean = 0.01 rmse = 0.43 mm/day

Min Min = −5.19 Max = 4.04



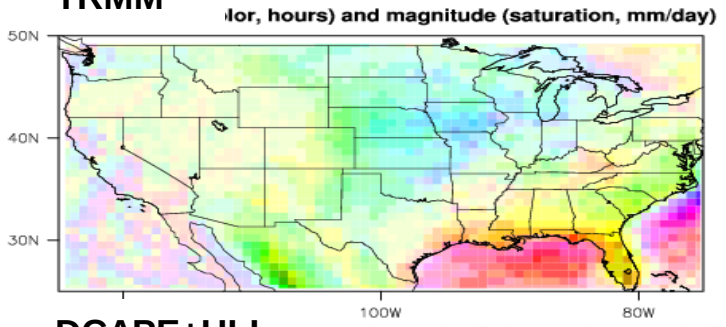
JJA Precipitation over CONUS



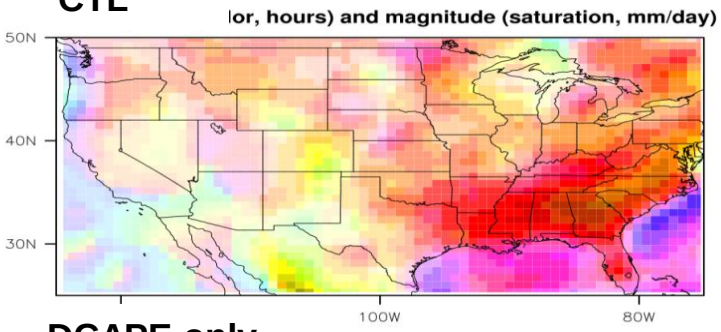
Note that the different color scales are used for bias (1.0) and diff (0.5)

Diurnal Cycle Precipitation over CONUS (JJA)

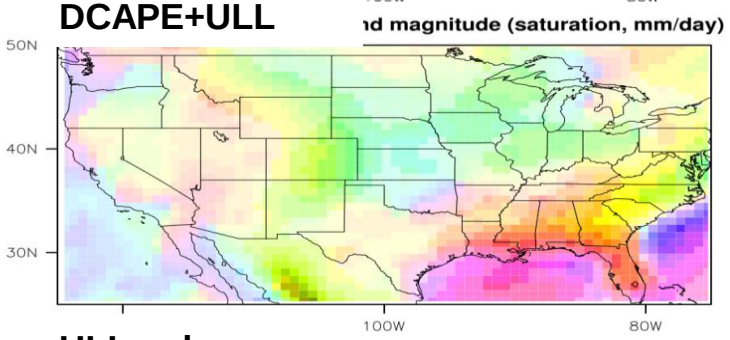
TRMM



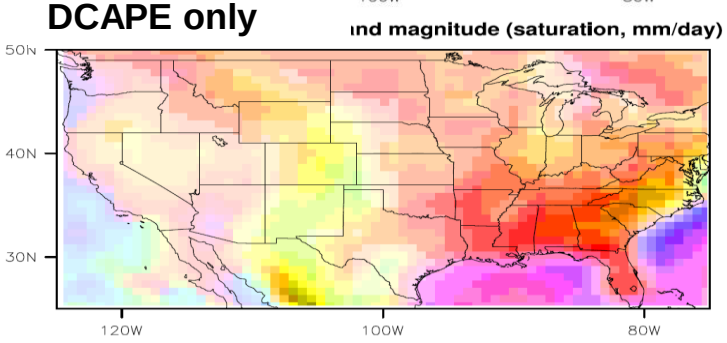
CTL



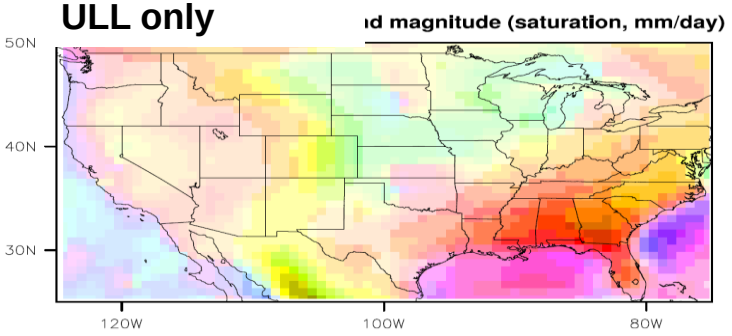
DCAPE+ULL



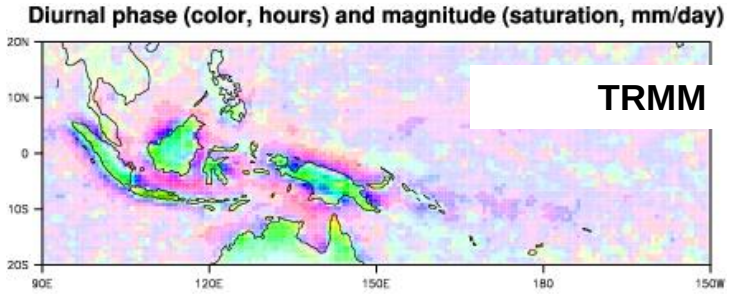
DCAPE only

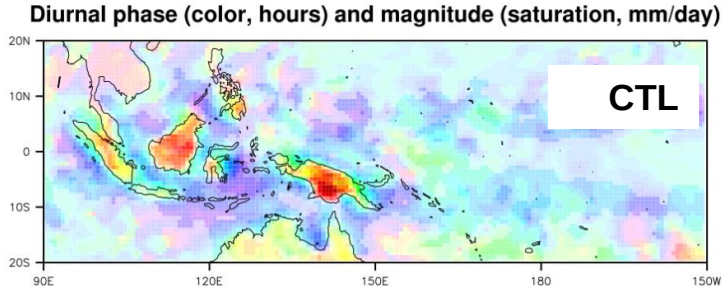


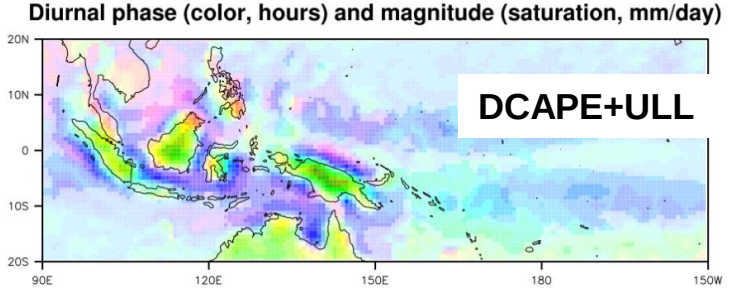
ULL only

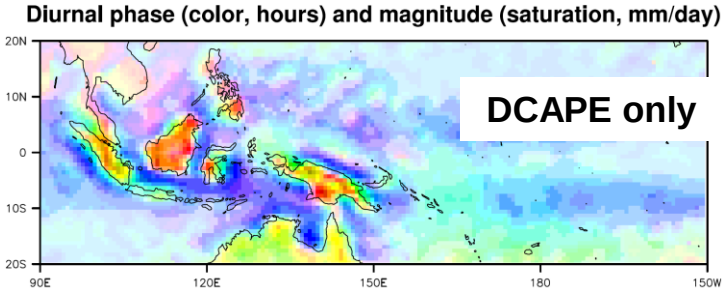


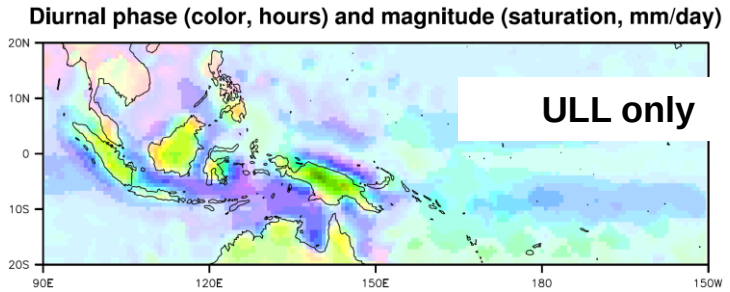
Diurnal cycle of Precipitation over the Maritime Continent (DJF)



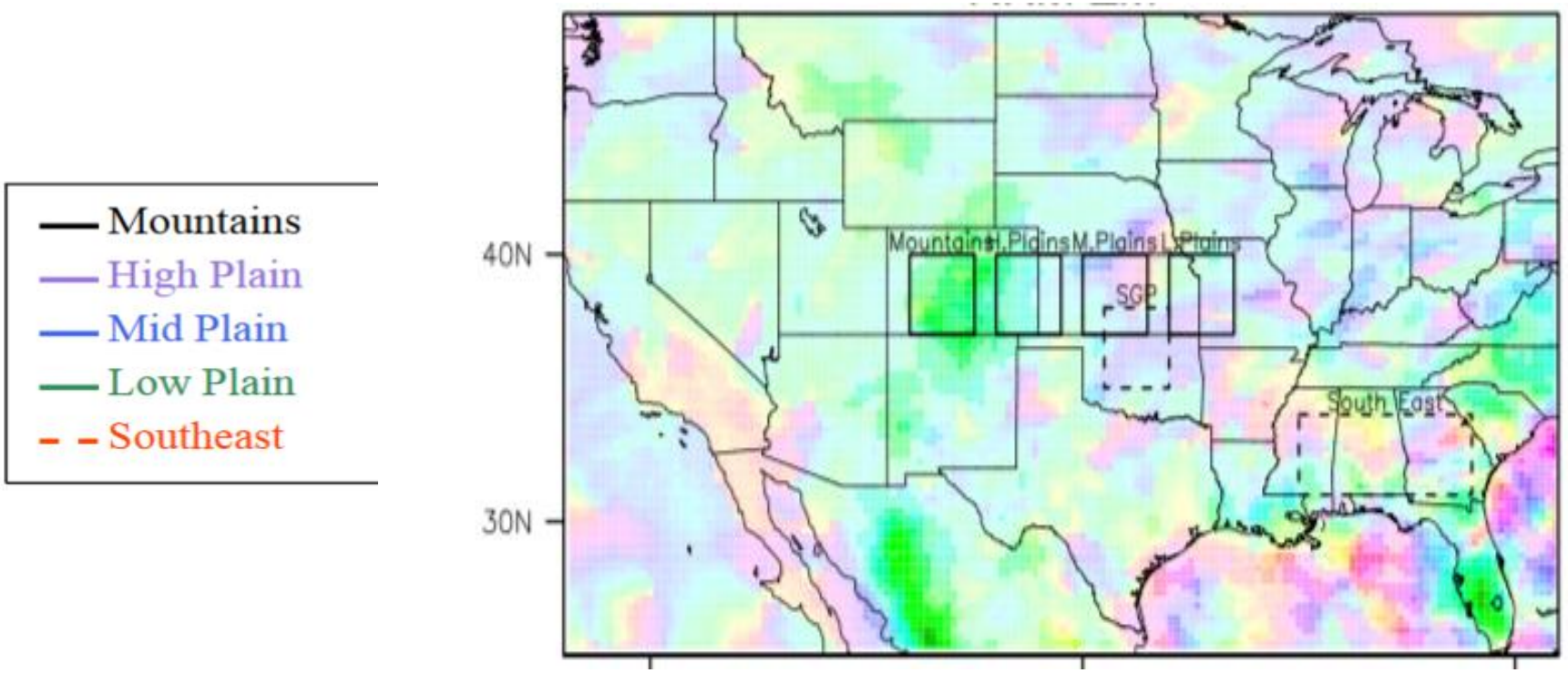




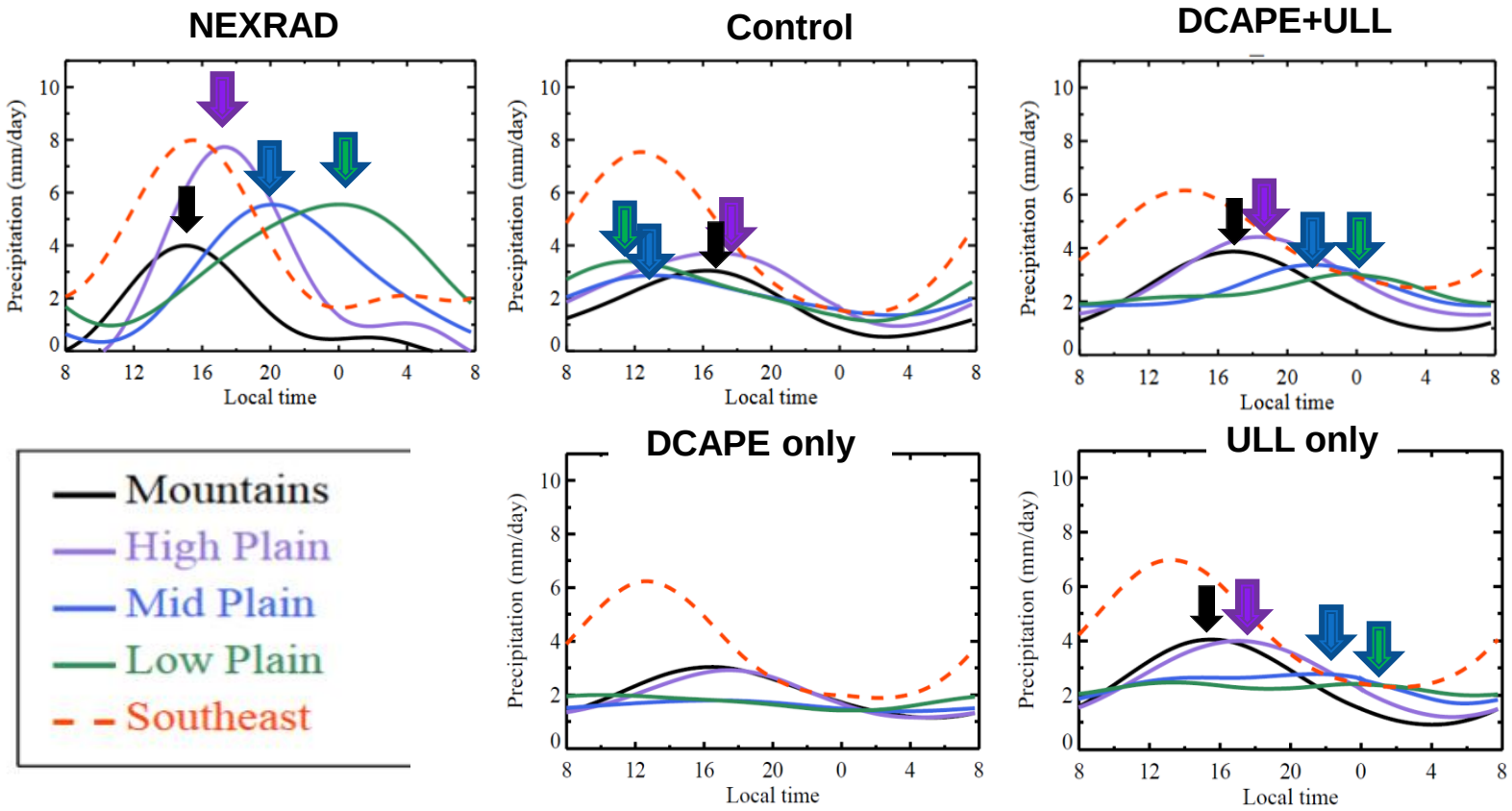




Eastward propagation



Eastward propagation



Summary

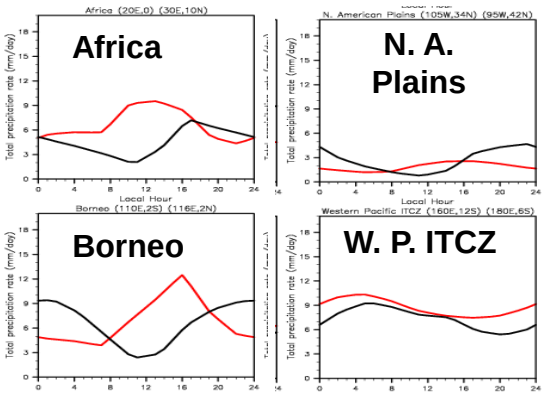
- A new convective trigger (DCAPE+ULL) was tested with EAMv1.
  - DCAPE used to prevent CAPE being released spontaneously
  - ULL used to remove the restriction of having the air parcel launch level within PBL for elevated nocturnal convection
- Mean state of precipitation is noticeably improved globably
  - Primarily due to the use of DCAPE
- The phase of the diurnal cycle of precipitation is substantially improved in EAMv1 over different climate regimes, but amplitude is still too weak
  - Primarily due to the use of ULL
- EAMv1 starts to show the eastward propagation of MCSs
- Only minor changes seen in tropical waves

Diurnal cycle of precipitation over selected climate regimes

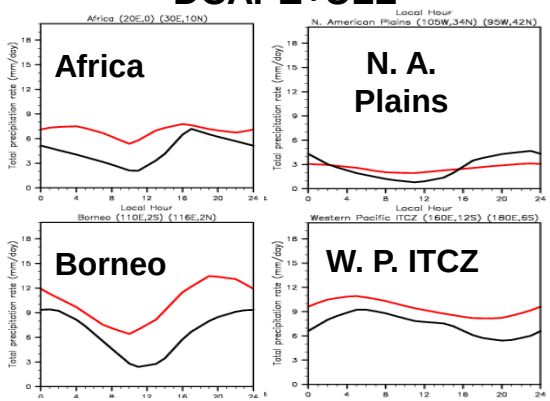
Black: TRMM
Red: Model

JJA

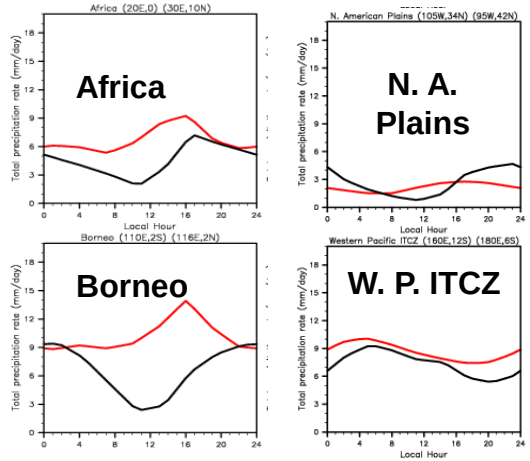
EAMv1



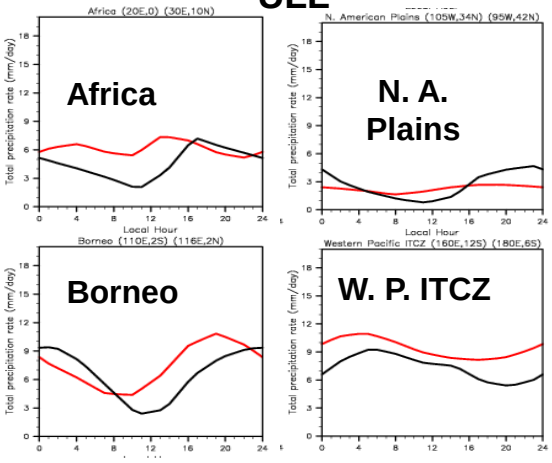
DCAPE+ULL



DCAPE

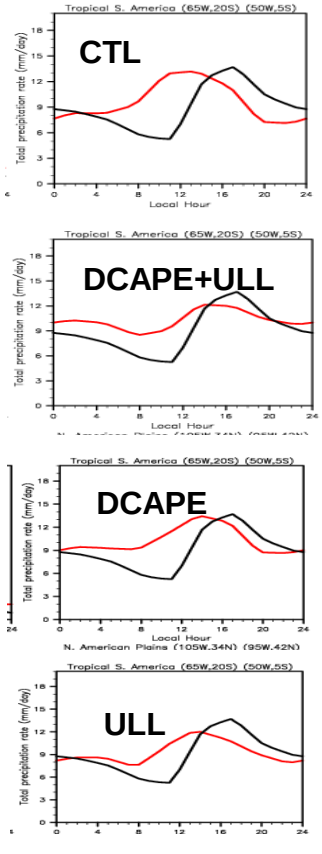


ULL

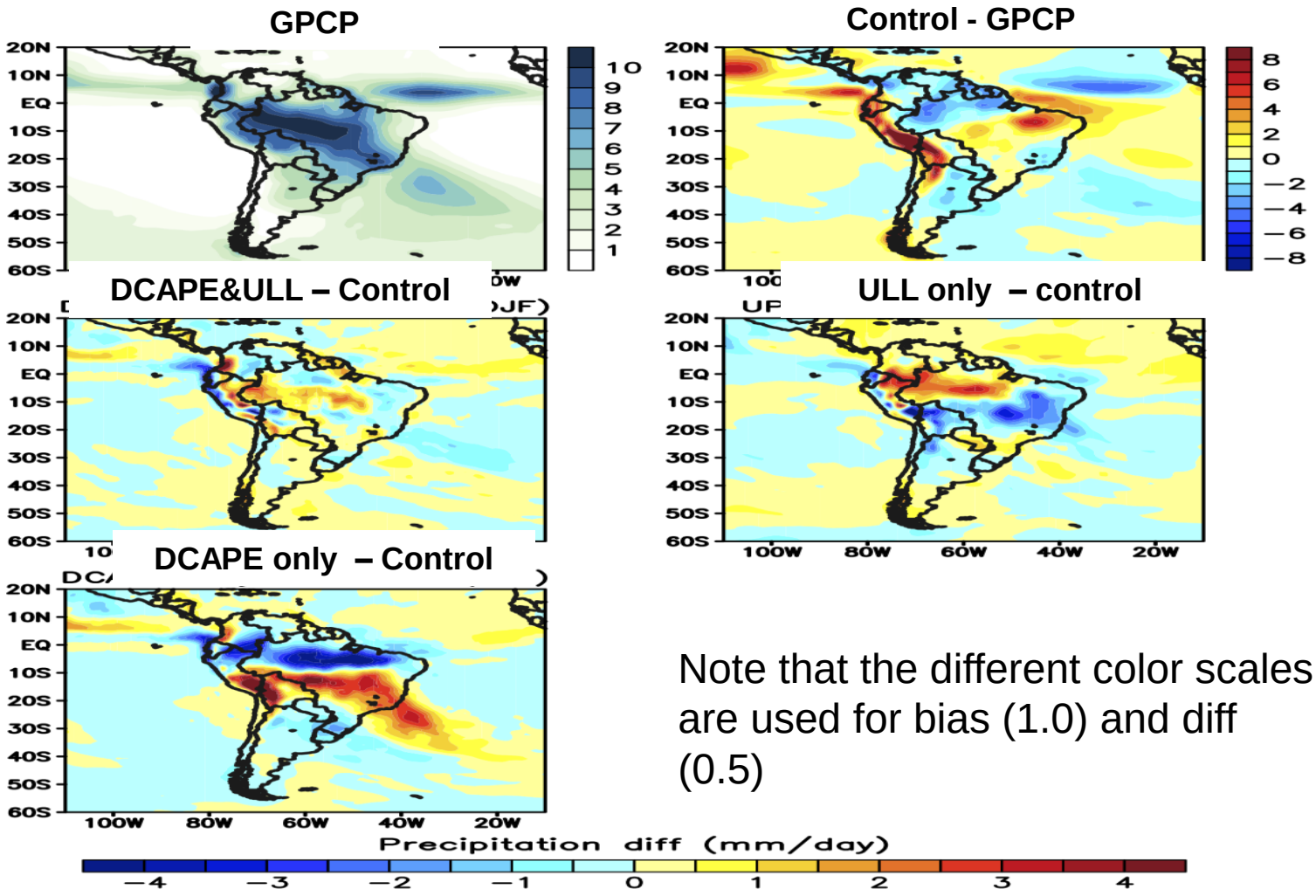


DJF

Tropical. S. A



DJF Precipitation over South America



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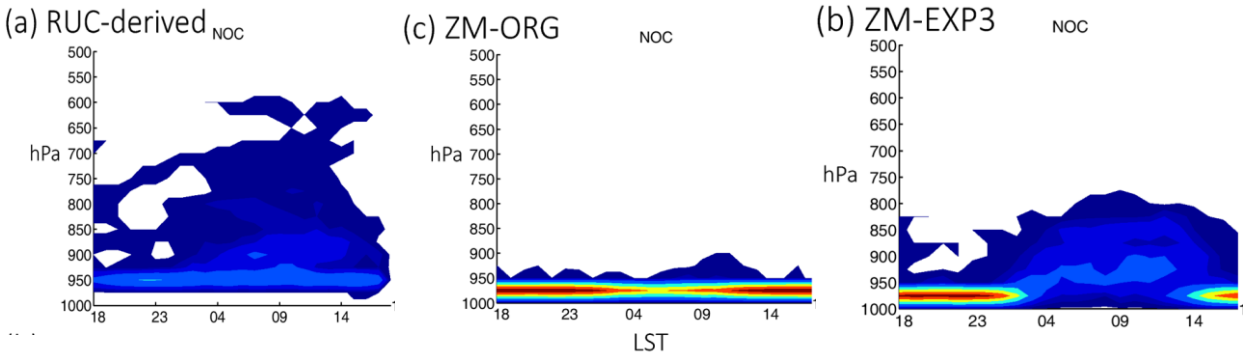
Unrestricted Launch Level (ULL) *(Wang et al. 2015)*

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*)