A Unified Convection Scheme : ‘UNICON’

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Sungsu Park

AMP. CGD. NESL. NCAR. Boulder. CO.

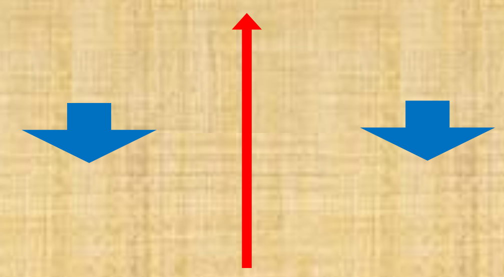
“ *The Unicorn is the only fabulous beast that does not seem to have been conceived out of human fears. He is fierce yet good , selfless yet solitary , but always mysteriously beautiful. He could be captured only by unfair means, and his single horn was said to neutralize poison* ”. From the ‘*The Unicorn and the Lake*’ by Marianna Mayer.

$$\frac{\partial \overline{A}}{\partial t} = -\vec{V} \cdot \nabla \overline{A} + \overline{Q}_A - \frac{\partial}{\partial z} \overline{w'A'}$$

Adiabatic Mixing by Turbulences

Symmetric Turbulence

(PBL Scheme ~ Symmetric Turbulence Scheme)



Asymmetric Turbulence

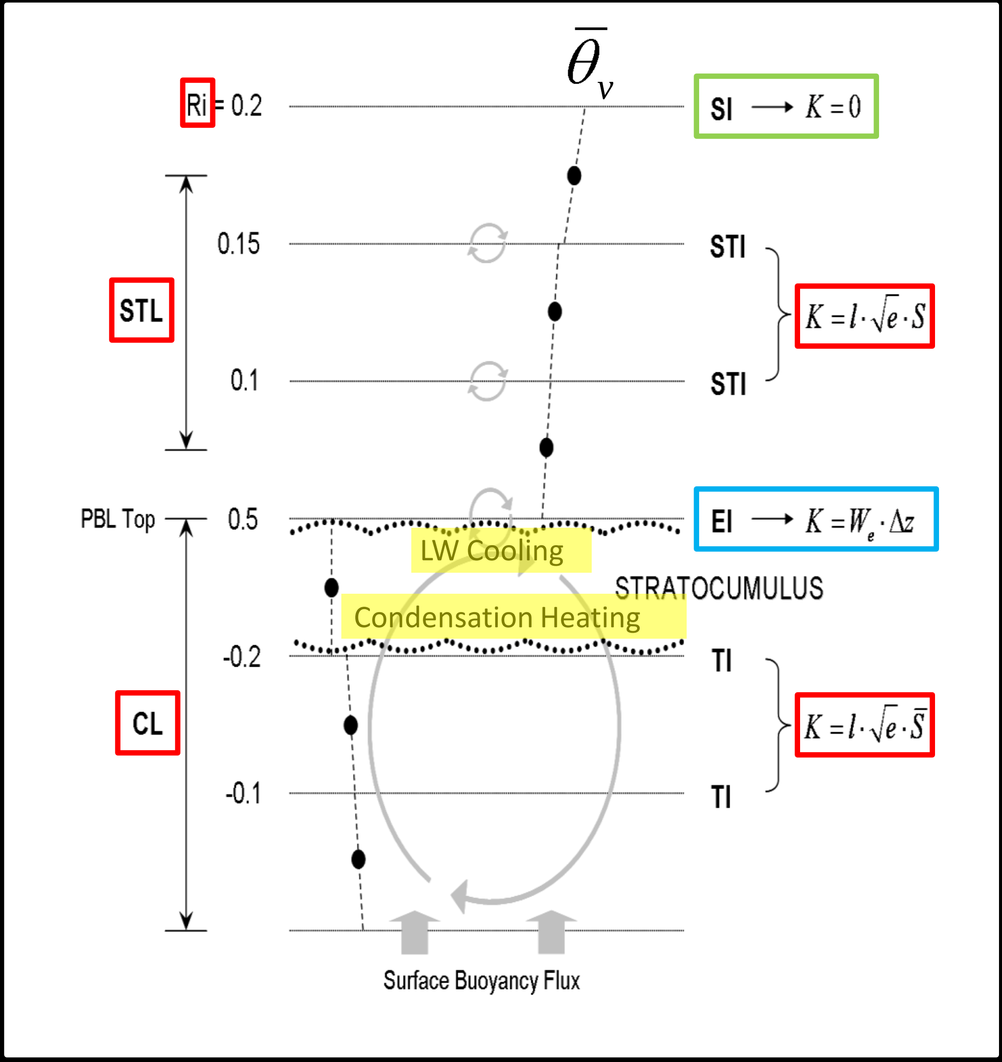
(Convection Scheme ~ Asymmetric Turbulence Scheme)

Evolutions of CAM-CESM1

Model	CCSM3 (2004)	CCSM3.5 (2007)	CCSM4 (Apr 2010)	CESM1 (Jun 2010)
Atmosphere	CAM3 (L26)	CAM3.5 (L26)	CAM4 (L26)	CAM5 (L30)
Boundary Layer Turbulence	Holtslag-Boville (93) Dry Turbulence	Holtslag-Boville	Holtslag-Boville	Bretherton-Park (09) UW Moist Turbulence
Shallow Convection	Hack (94)	Hack	Hack	Park-Bretherton (09) UW Shallow Convection
Deep Convection	Zhang-McFarlane (95)	Zhang-McFarlane Neale et al.(08) Richter-Rasch (08)	Zhang-McFarlane Neale et al.(08) Richter-Rasch (08)	Zhang-McFarlane Neale et al.(08) Richter-Rasch (08)
Cloud Macrophysics	Zhang et al. (03)	Zhang et al. with Park & Vavrus' mods.	Zhang et al. with Park & Vavrus' mods.	Park-Bretherton-Rasch (10) Revised Cloud Macrophysics
Stratiform Microphysics	Rasch-Kristjansson (98) *Single Moment*	Rasch-Kristian. *Single Moment*	Rasch-Kristian. *Single Moment*	Morrison and Gettelman (08) *Double Moment*
Radiation / Optics	CAMRT (01)	CAMRT	CAMRT	RRTMG Iacono et al.(08) / Mitchell (08)
Aerosols	Bulk Aerosol Model (BAM)	BAM	BAM	Modal Aerosol Model (MAM) Liu & Ghan (2009)
Dynamics	Spectral	Finite Volume (96,04)	Finite Volume	Finite Volume
Ocean	POP2 (L40)	POP2.1 (L60)	POP2.2 - *BGC*	POP2.2
Land	CLM3	CLM3.5	CLM4 - *CN*	CLM4
Sea Ice	CSIM4	CSIM4	CICE	CICE

MOIST TURBULENCE SCHEME in CAM5

C. Bretherton and S. Park. 2009



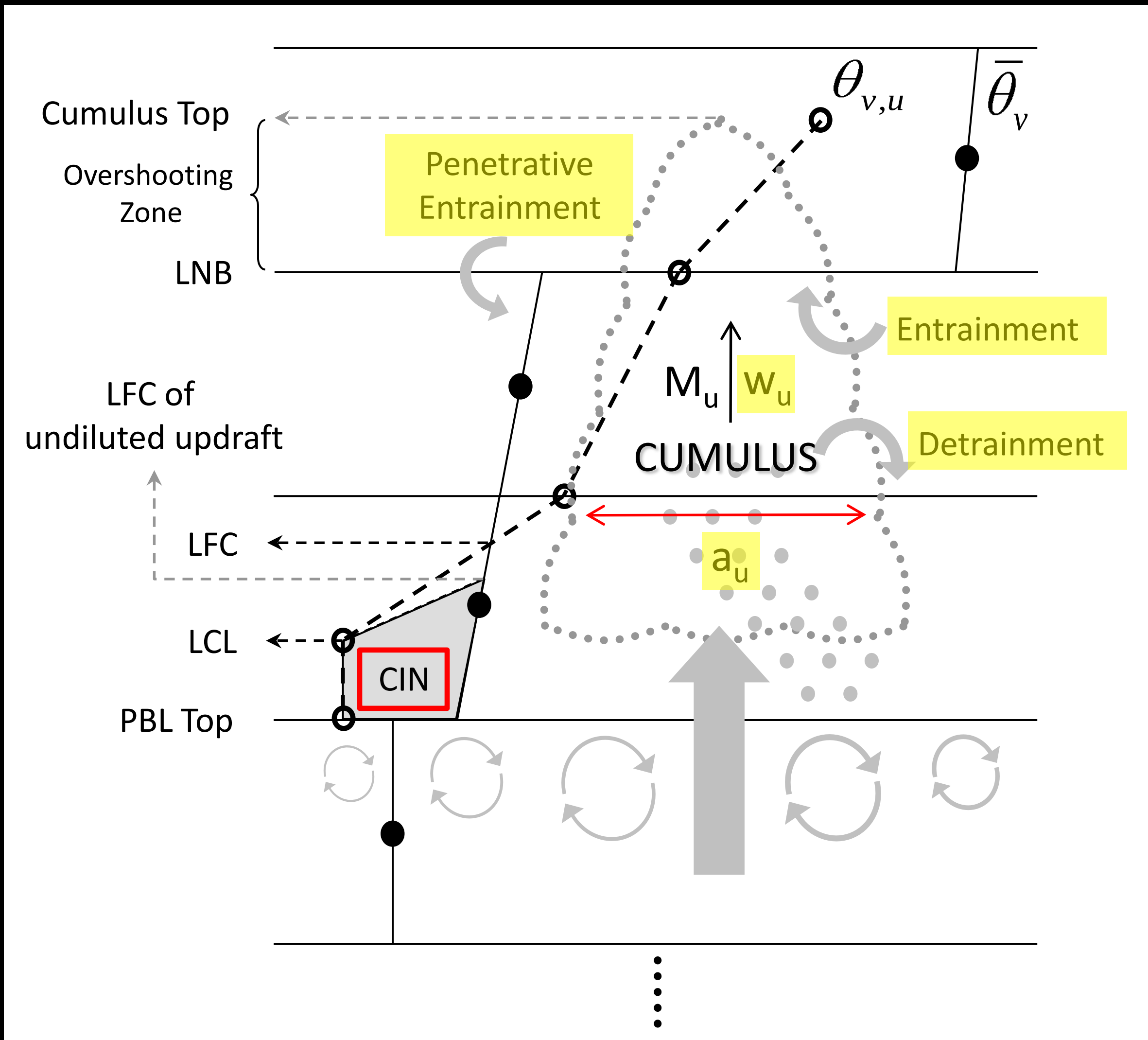
$$\frac{\partial \overline{A}}{\partial t} = -\frac{\partial}{\partial z}\overline{w'A'} = \frac{\partial}{\partial z}\left(K\frac{\partial \overline{A}}{\partial z}\right)$$

K : eddy diffusivity

Ri	: Moist Richardson Number
SI	: Stable Interface
STI	: Stably Turbulent Interface
EI	: Entrainment Interface
TI	: Turbulent Interface
STL	: Stably Turbulent Layer
CL	: Convective Layer
l	: Turbulent length scale
S	: Stability function (fcn of Ri)
e	: TKE
W_e	: Entrainment rate

SHALLOW CONVECTION SCHEME in CAM5

S. Park and C. Bretherton. 2009



$$\overline{w'A'} = \rho \cdot M_u \cdot (A_u - \overline{A})$$

M_u : updraft mass flux

A_u : updraft scalar

CIN	: Convective INhibition
LCL	: Lifting Condensation Level
LFC	: Level of Free Convection
LNB	: Level of Neutral Buoyancy
w_u	: Updraft vertical velocity
a_u	: Updraft fractional area

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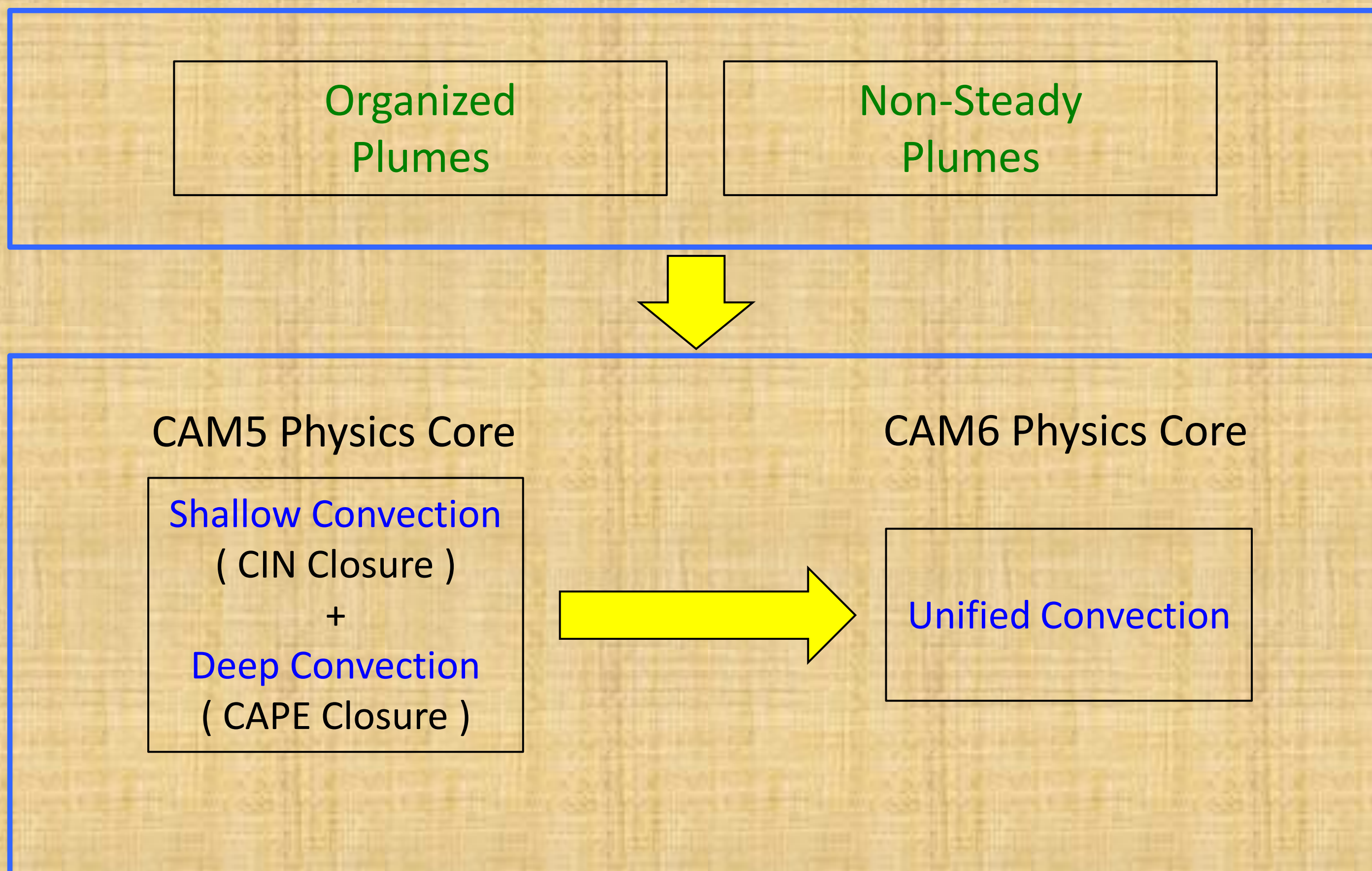
Sea Ice	CSIM4	CSIM4	CICE	CICE

A Strategic Plan for Next Generation CAM6



Overview of UNICON

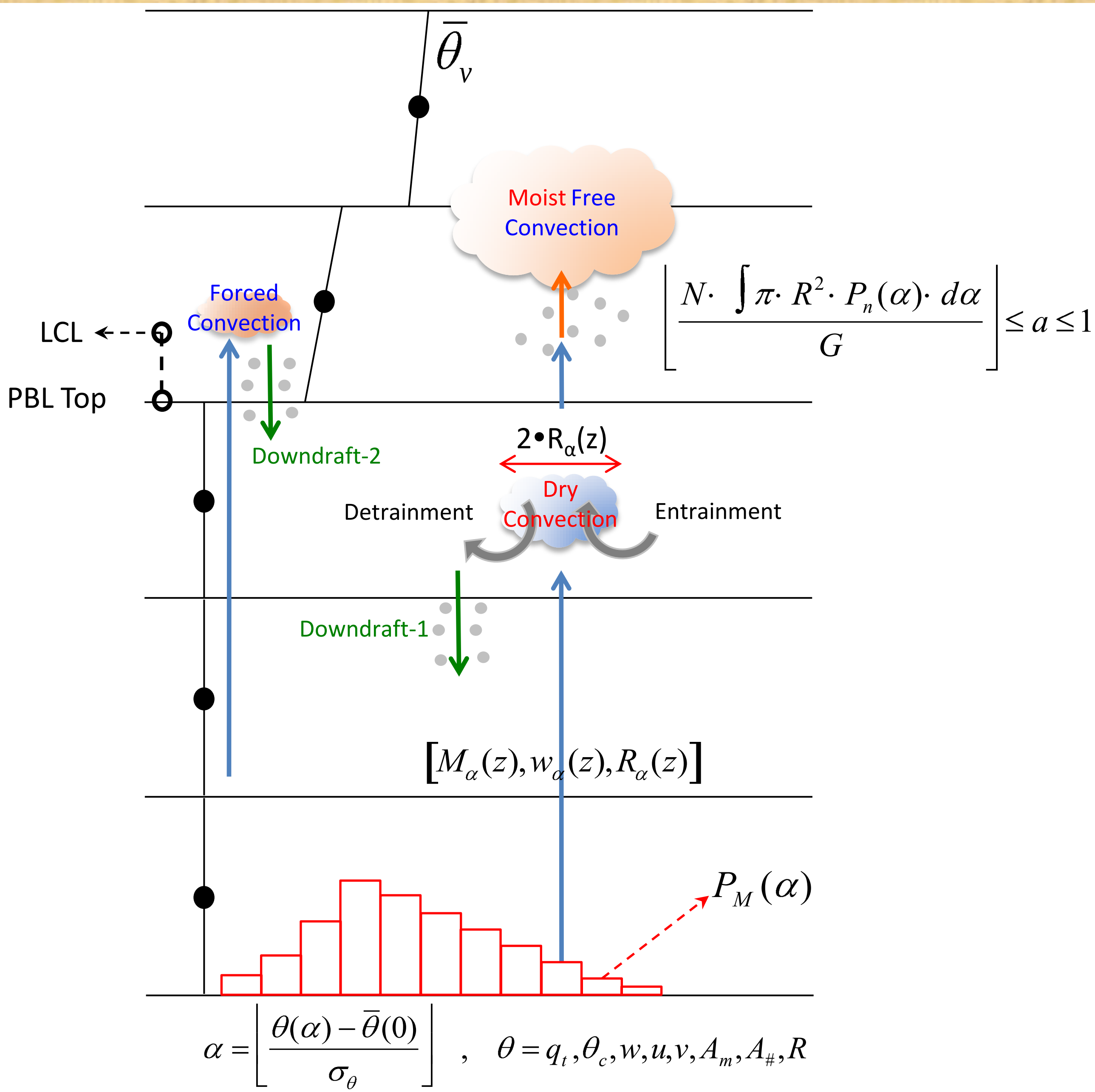
I. A completely new vertical transport scheme by asymmetric turbulences designed for addressing the major issues associated with the parameterization of convection :

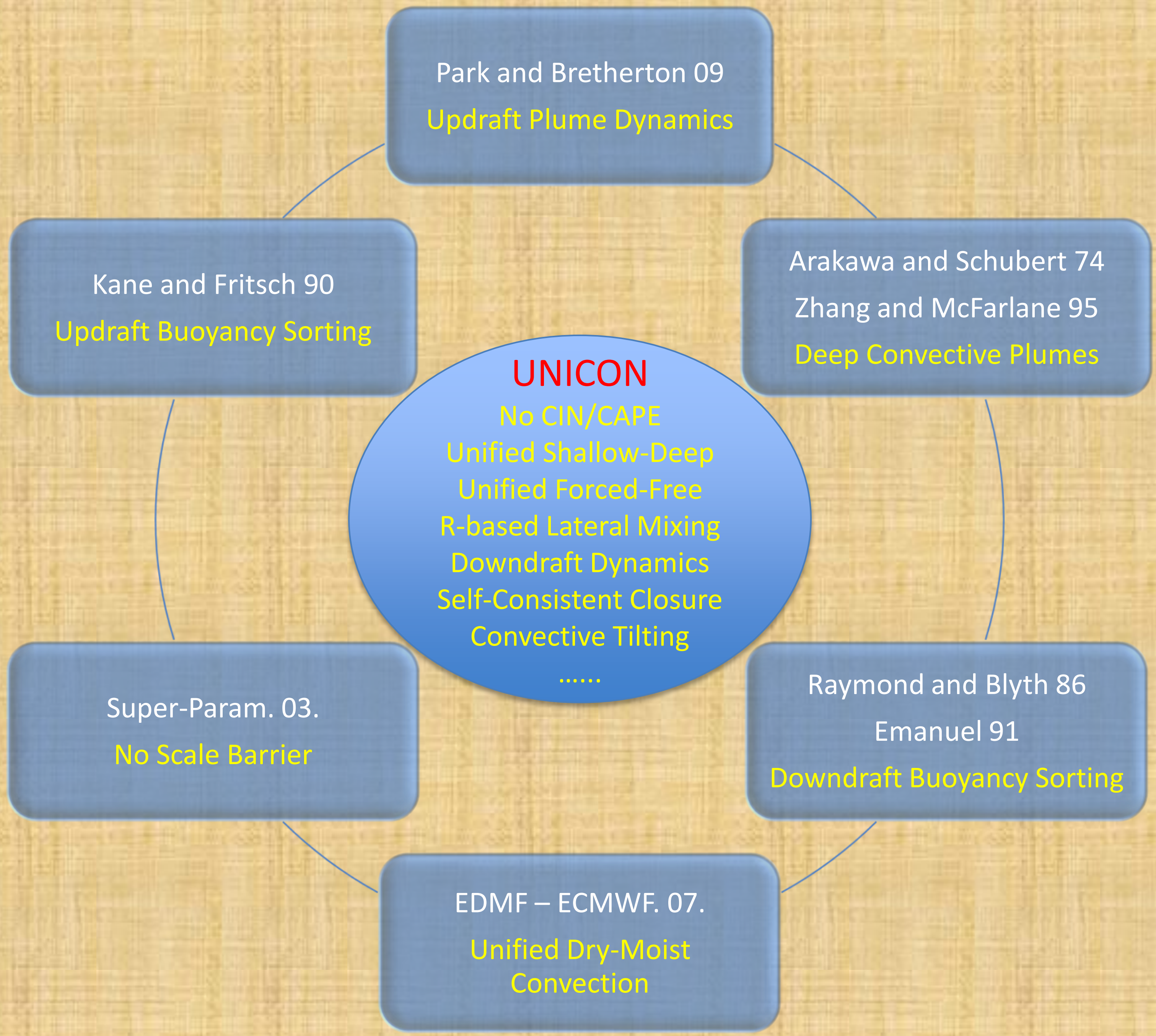
- Developing a conceptual framework : July. 2006 ~ Jan. 2009.
- Mathematical formulation and coding : Jan.2009 ~ Nov. 2009.
- Intensive debugging and *consistency check* : Nov. 2009 ~ Nov. 2010.
- Testing and *consistency check* : Nov.2010 ~ Present.
- Code : ~ 10,000 Lines, Computation time : ~ CAM5 shallow convection scheme when n=1.

II. Some of unique aspects of UNICON are

- Consistent closure for all scalars (q_t, θ_c, u, v, w, A_m, $A_\#$) controlled by the surface fluxes
- Updraft plume mixing rate as a function of plume radius R
- Launch correlated multiple plumes with different thermodynamic properties and R
- Generic treatments of 'convective downdraft' and 'detrainment'
- Treatment of vertical tilting of updraft plume : 'cumulus-precipitation overlap' and associated 'evaporation of convective precipitation'
- No CIN/CAPE closures : Fully dynamic plume model without any equilibrium assumptions
- Unified treatment of 'shallow/deep', 'dry/moist', and 'forced/free' convections
- Explicit treatment of convective organization
- Well-harmonized with the CAM5 symmetric turbulence scheme (i.e., moist PBL scheme)

UNICON (S. Park 2011)

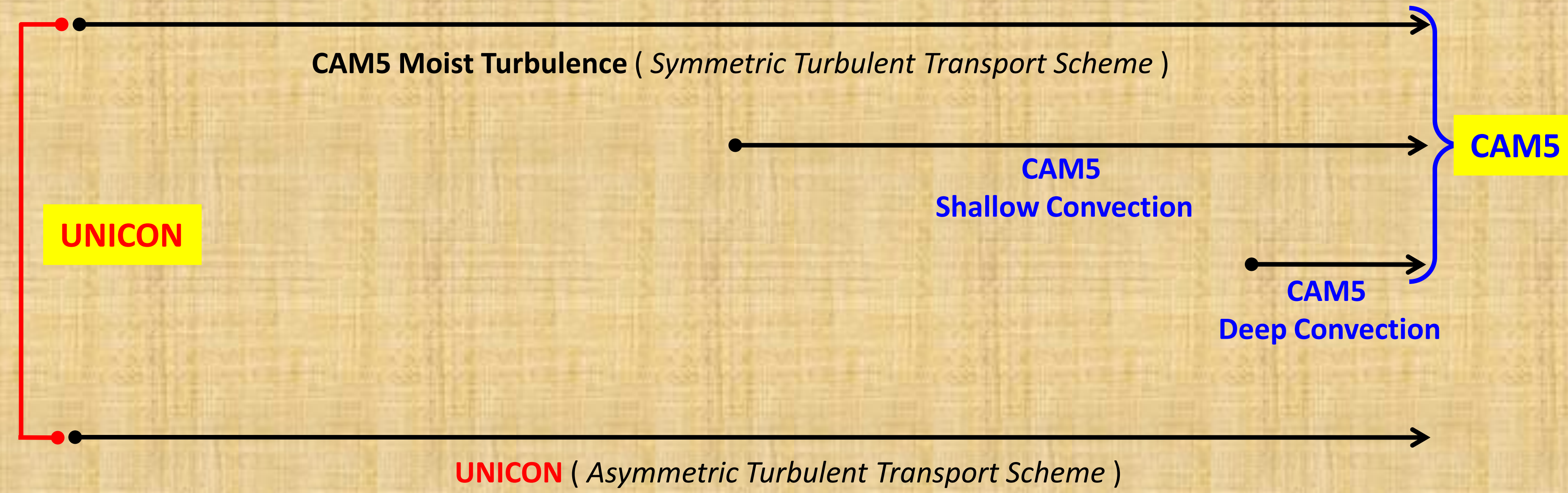



Park and Bretherton 09
Updraft Plume Dynamics
Kane and Fritsch 90
Updraft Buoyancy Sorting
Arakawa and Schubert 74
Zhang and McFarlane 95
Deep Convective Plumes
UNICON
No CIN/CAPE
Unified Shallow-Deep
Unified Forced-Free
R-based Lateral Mixing
Downdraft Dynamics
Self-Consistent Closure
Convective Tilting
……
Super-Param. 03.
No Scale Barrier
Raymond and Blyth 86
Emanuel 91
Downdraft Buoyancy Sorting
EDMF – ECMWF. 07.
Unified Dry-Moist Convection

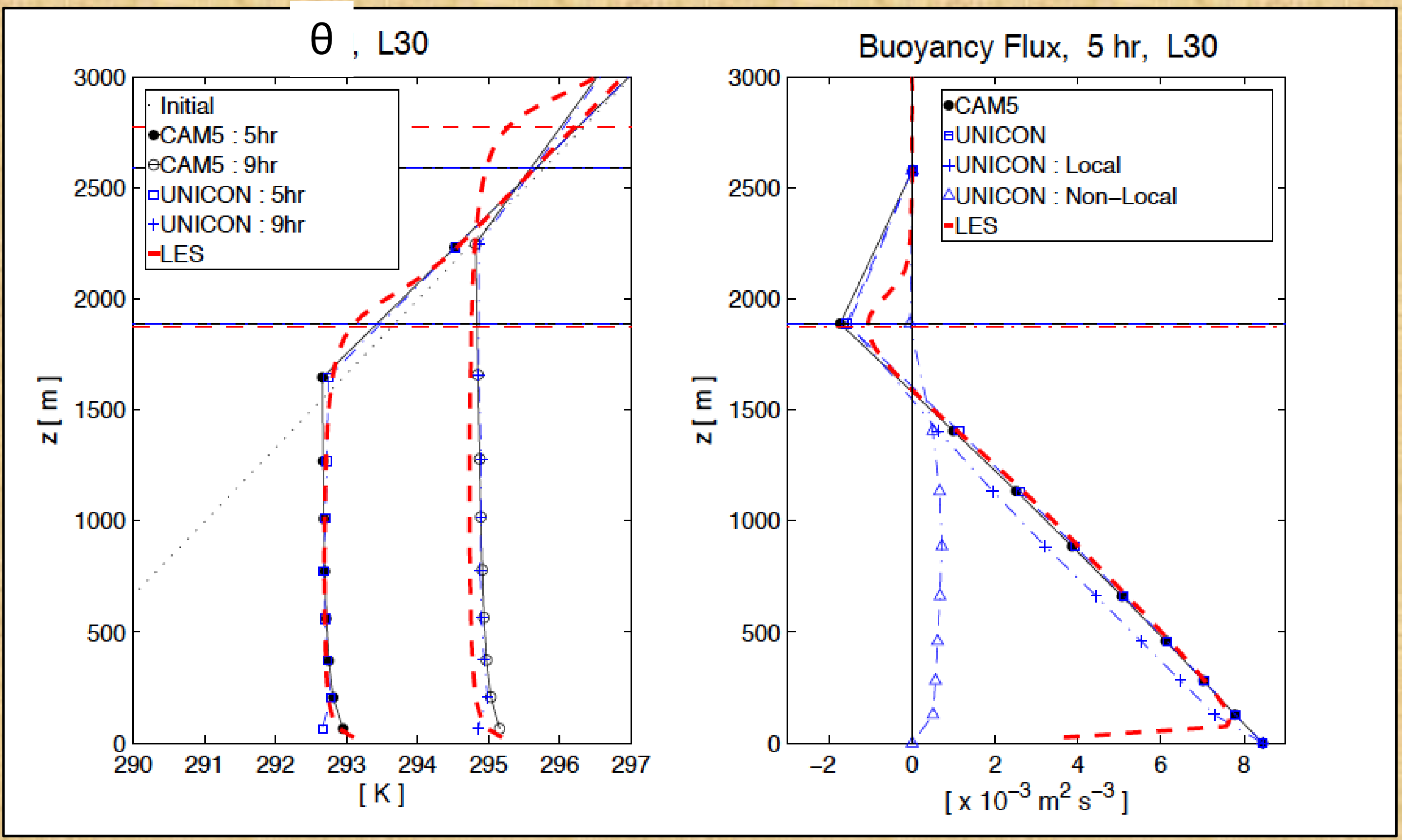
Single-Column CAM5 Simulation

DCBL | DYCOMS | STCU | BOMEX | ARM95, ARM97, GATEIII, TOGAII

Stable PBL ➔ Dry Conv. ➔ Sc. Conv. ➔ Sc to Shallow Cu ➔ Shallow Cu ➔ Deep Cu



Dry Convection Case. DCBL.



SCAM comparison of UNICON and CAM5

SKILL SCORE = rmse (UNICON,OBS) / rmse (CAM5,OBS)

(T, Q_v)

CASES	**SKILL SCORE** OF **UNICON** RELATIVE TO **CAM5**	
	L30. Δt = 1200 [sec]	**L80**. Δt = 300 [sec]
DCBL	0.89	1.01
DYCOMS	0.99	0.92
STCU	0.90	**0.39**
BOMEX	**0.50**	**0.50**
ARM95	0.98	**1.28**
ARM97	**0.62**	0.92
GATEIII	0.95	1.03
TOGAII	**0.71**	0.90
Average	0.82	0.87

Global CAM5 Simulation

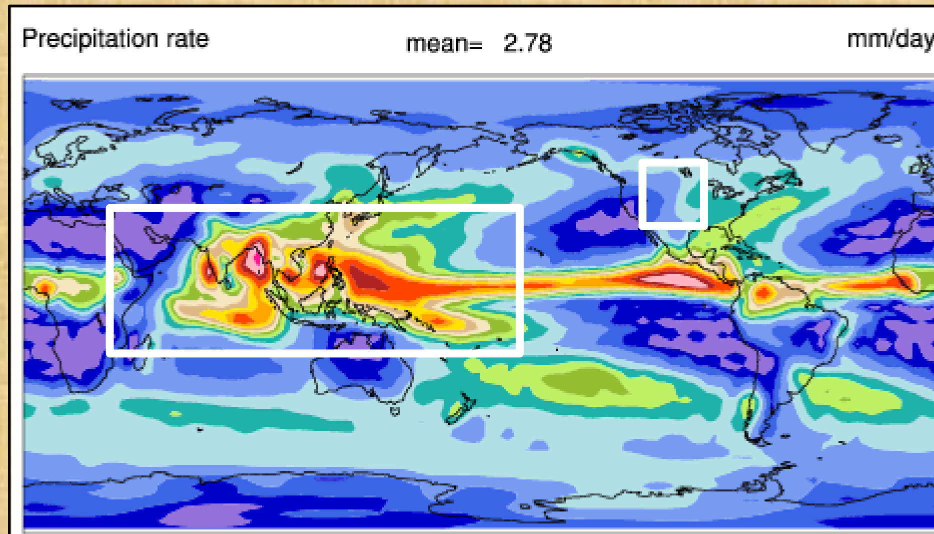
Precipitation Climatology

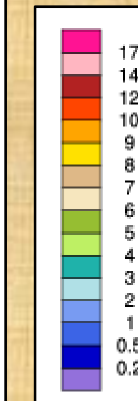
Diurnal Cycle of Precipitation

Madden-Julian Oscillation

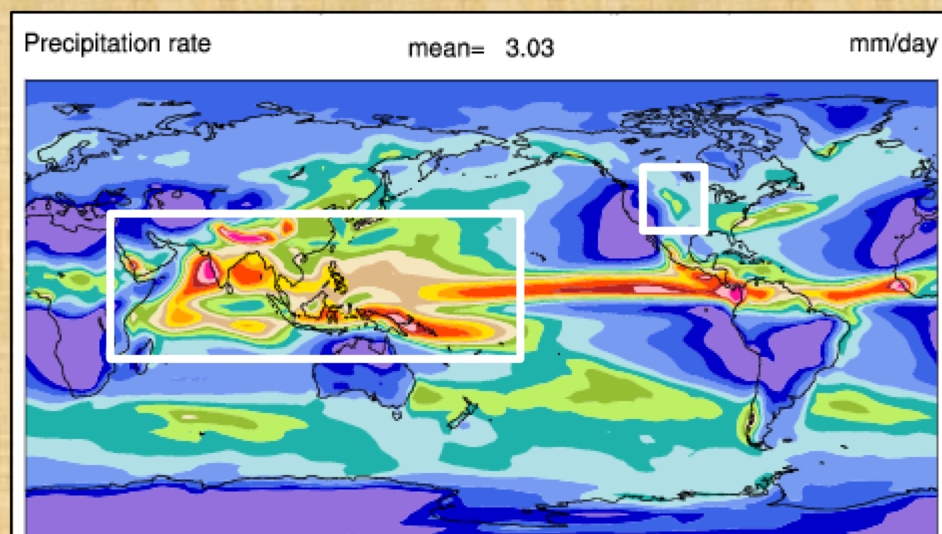
Precipitation Climatology. JJA.

OBSERVATION

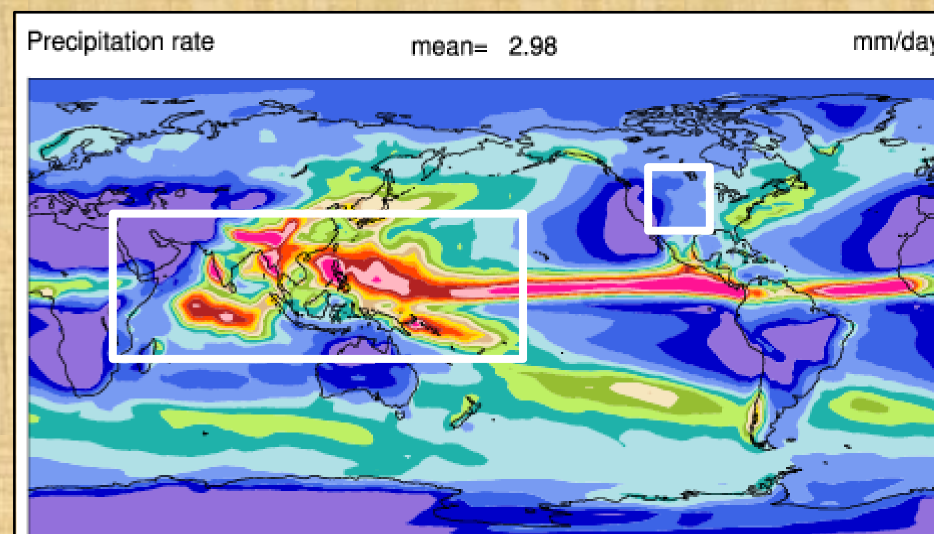




CAM5

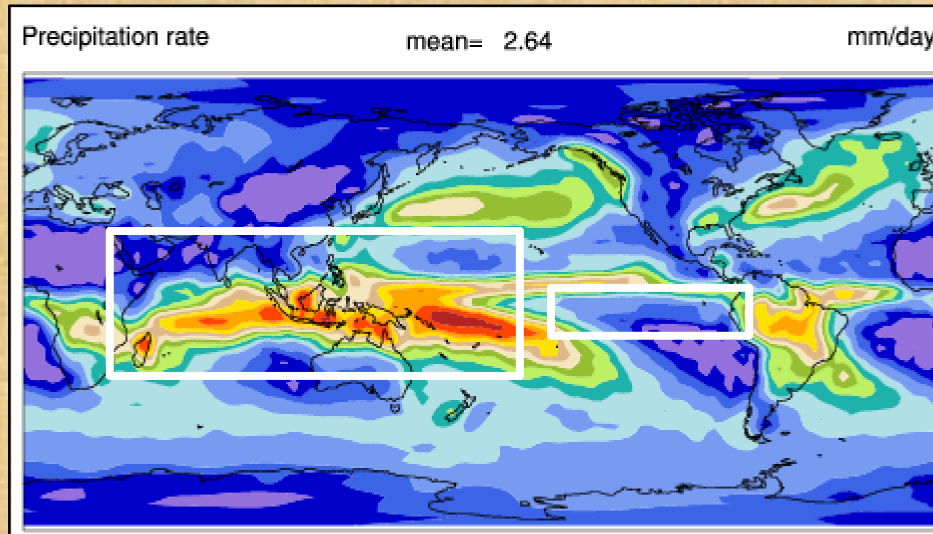


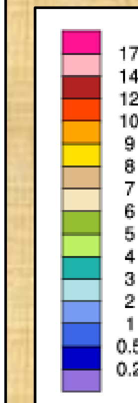
UNICON



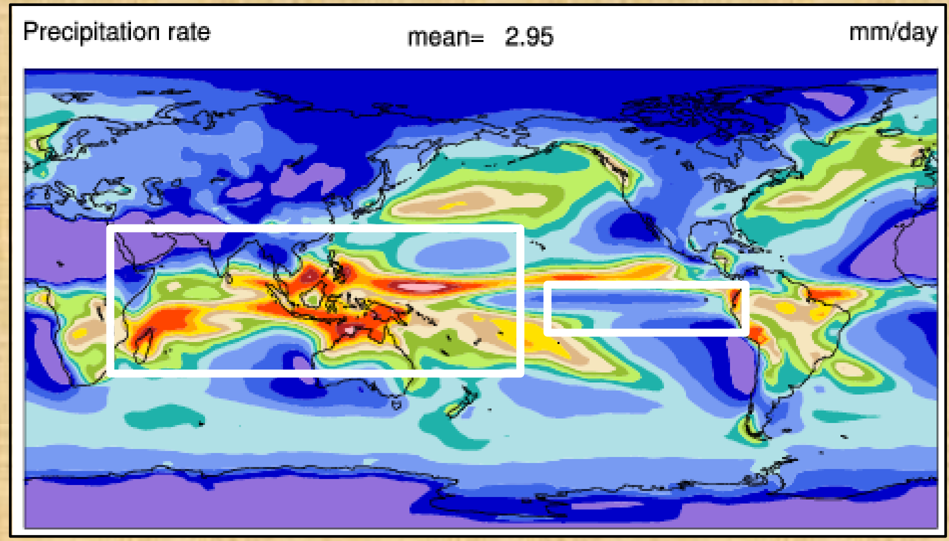
Precipitation Climatology. DJF.

OBSERVATION

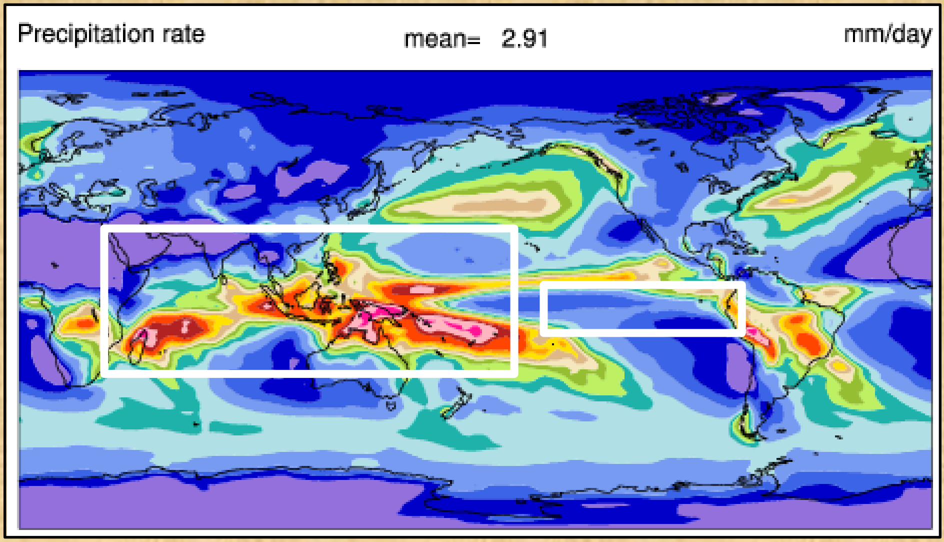




CAM5



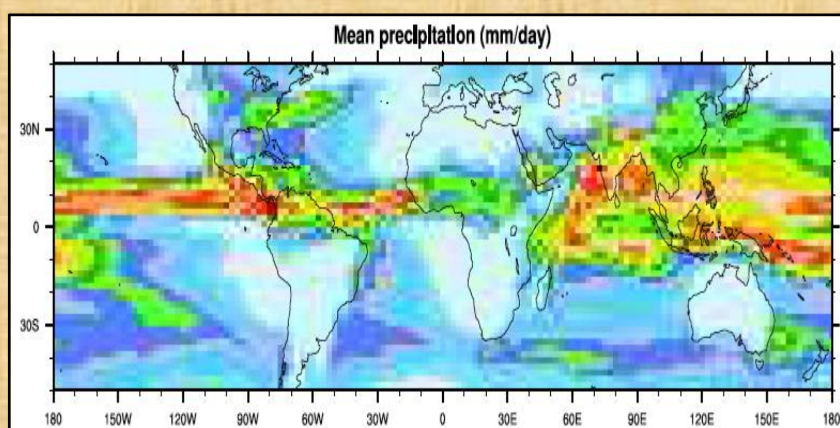
UNICON

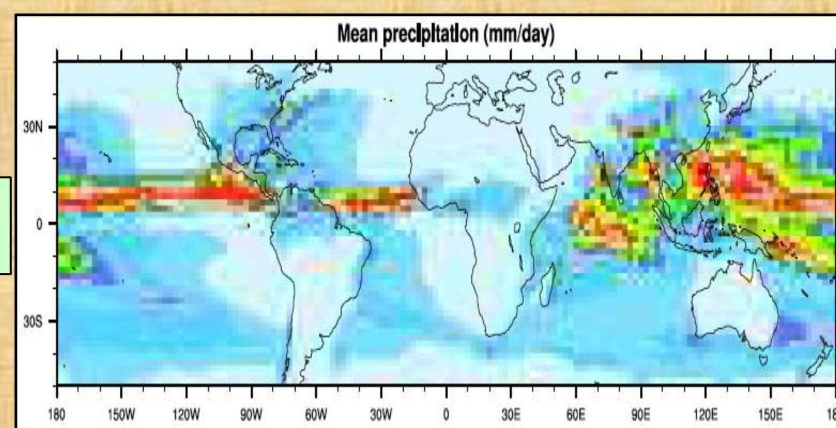


Convective (PRECC) vs Stratiform (PRECL) Precipitation. JJA.

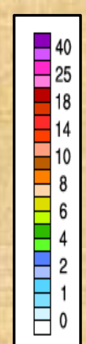
CAM5

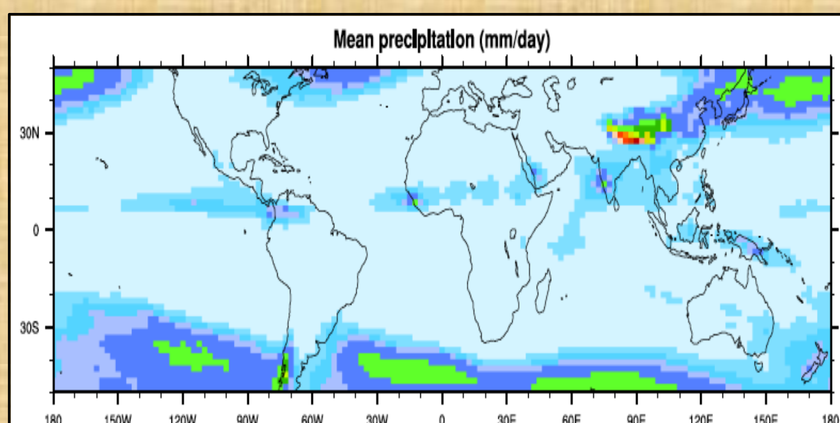
UNICON

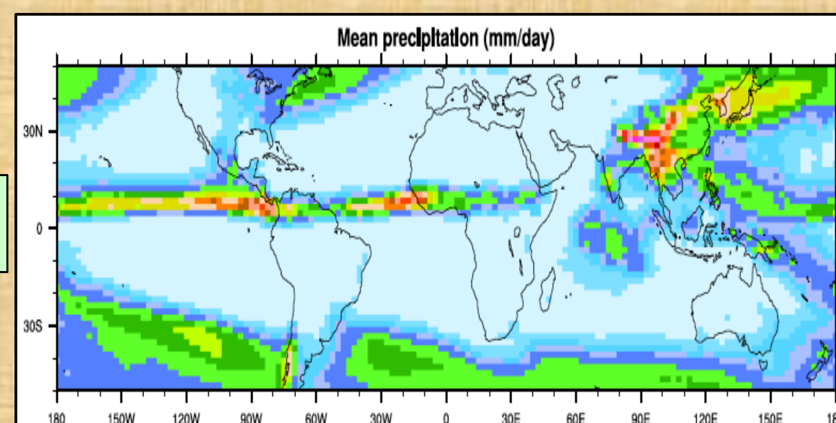




PRECC



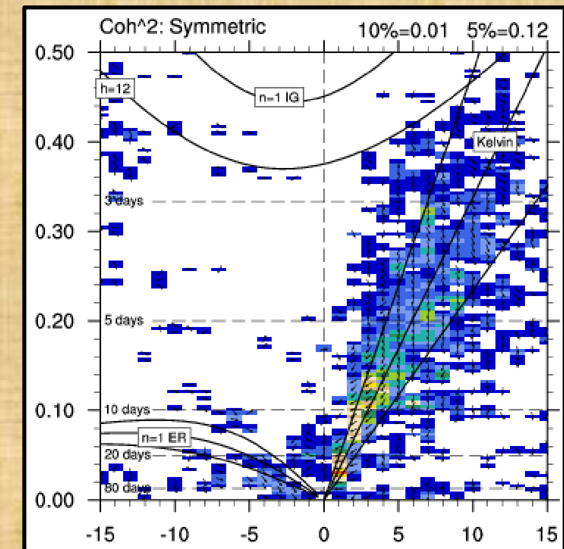




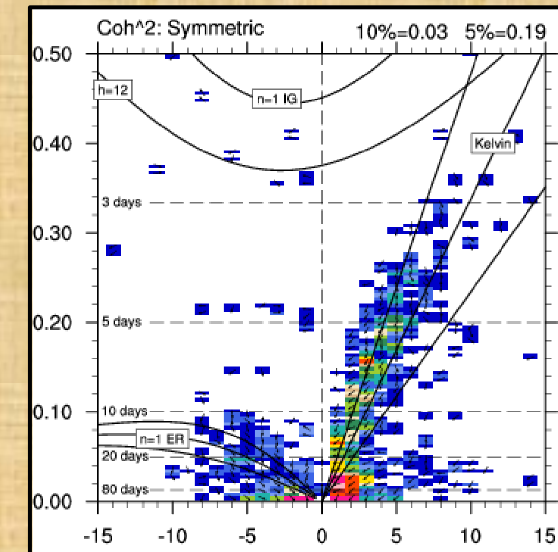
PRECL

Madden-Julian Oscillation

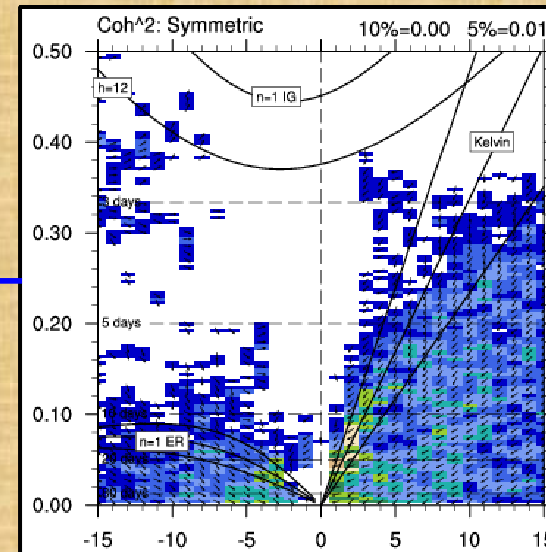
CAM5

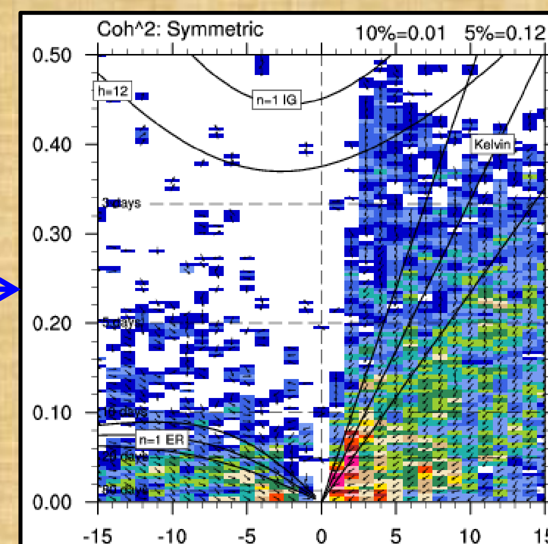


OBSERVATION

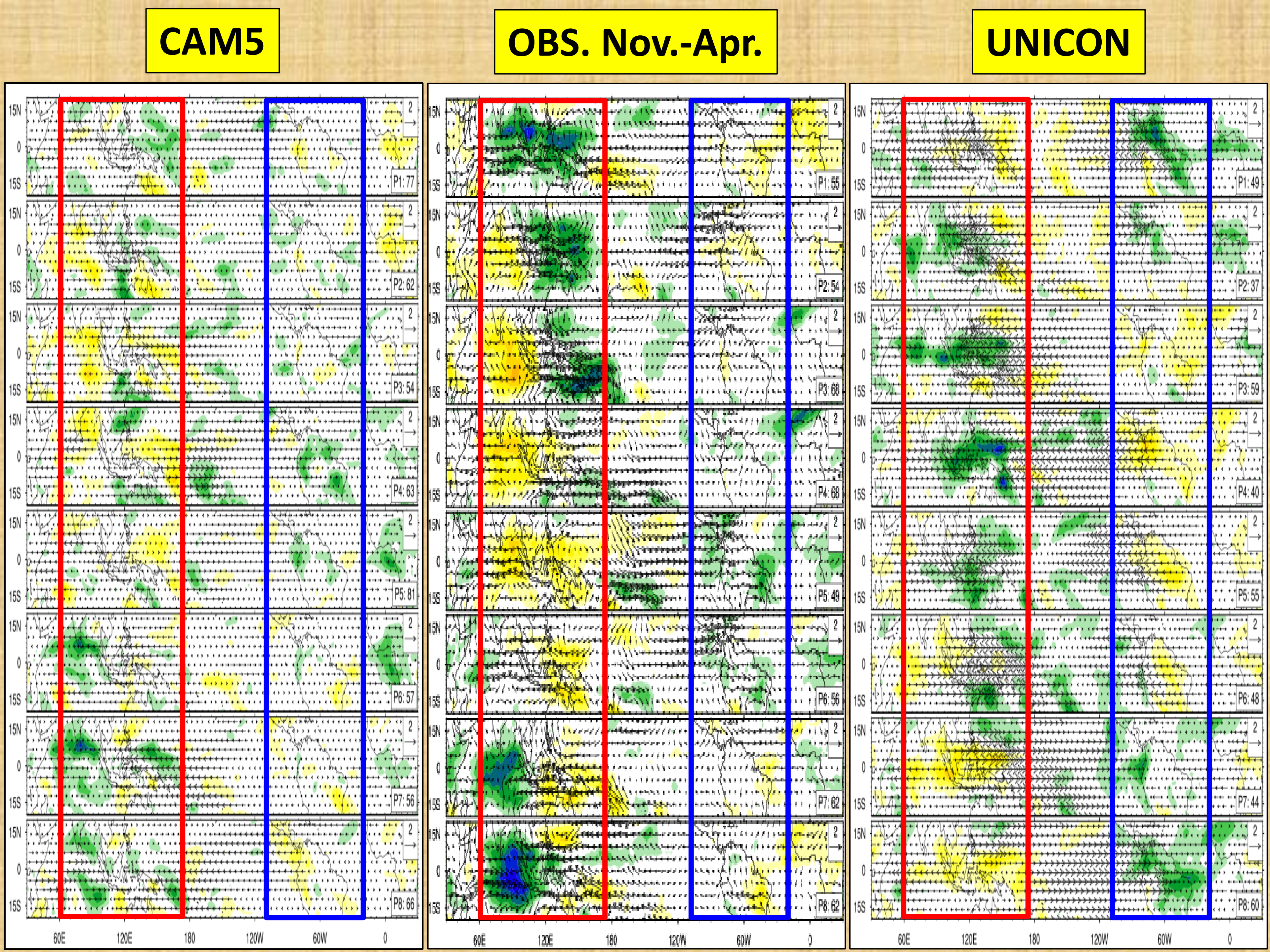


UNICON





Convection is forced to be weaker.


CAM5
OBS. Nov.-Apr.
UNICON
15N
0
15S
P1: 77
P2: 62
P3: 54
P4: 63
P5: 81
P6: 57
P7: 56
P8: 66
P1: 55
P2: 54
P3: 68
P4: 68
P5: 49
P6: 56
P7: 62
P8: 62
P1: 49
P2: 37
P3: 59
P4: 40
P5: 55
P6: 48
P7: 44
P8: 60
60E
120E
180
120W
60W
0

SUMMARY

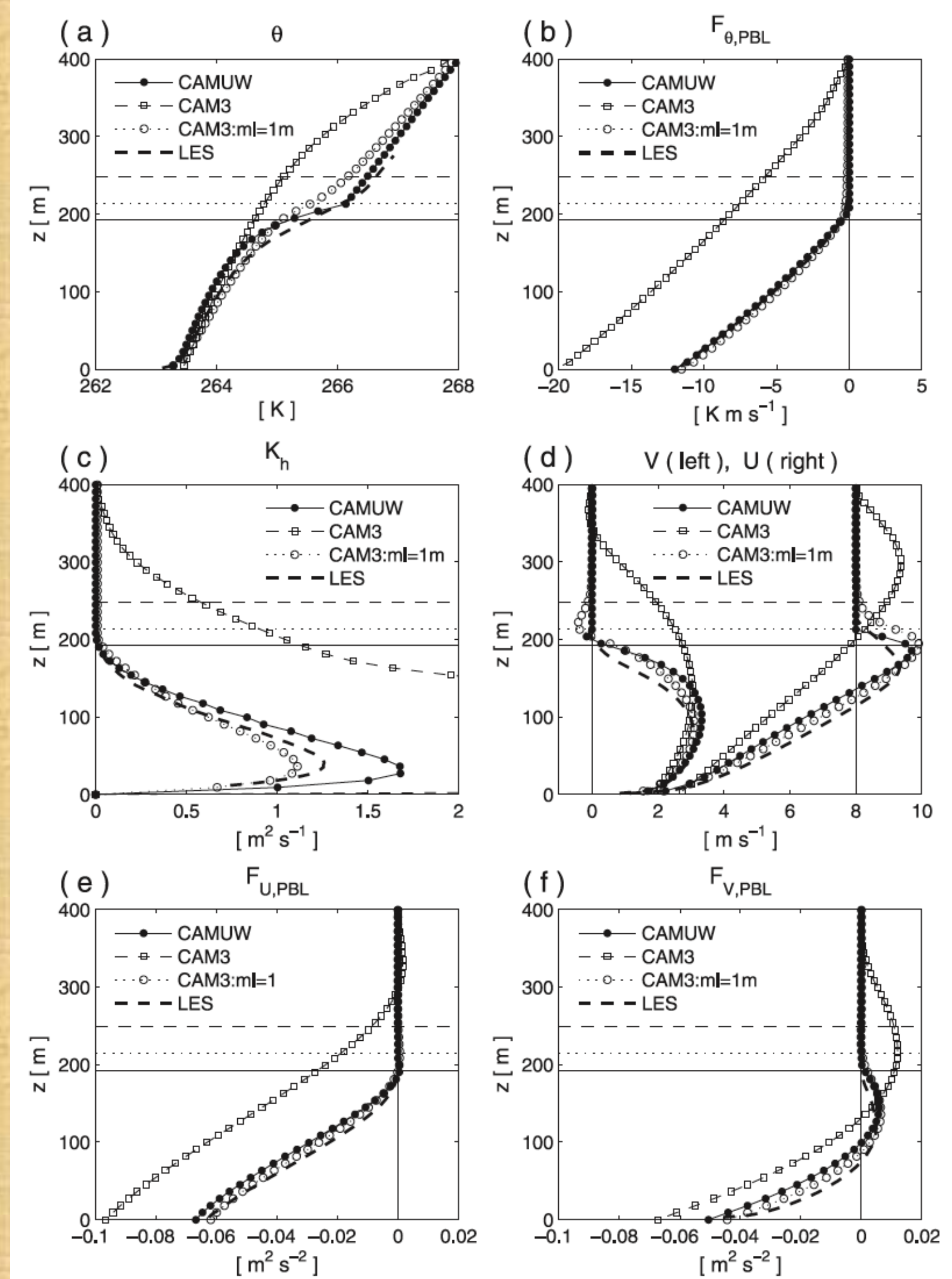
- UNICON (Unified Convection Scheme or more precisely, sub-grid vertical transport scheme by asymmetric turbulences) was finally found after 5 years of intensive search. With CAM5 sub-grid vertical transport scheme by symmetric turbulences (i.e., PBL scheme), UNICON can simulate all sub-grid vertical transports without any missing or double-counting. Similar to CAM5 symmetric turbulence transport scheme, UNICON can be seamlessly applied across any GCM grid size as long as GCM horizontal grid size is larger than the maximum plume radius assumed in the UNICON (~ 1 km).

- In most of the SCAM tests, UNICON showed improved performances both in L30 and L80 with less sensitivity to vertical resolution. Non-local transport and penetrative entrainment are generically simulated by UNICON.

- Global simulation shows that UNICON well captures observed precipitation climatology, MJO and Sc-to-Cu transition. But diurnal cycle of precipitation needs to be further improved. UNICON can be served as an excellent tool to understand the dynamics of MJO and diurnal cycle of convection.

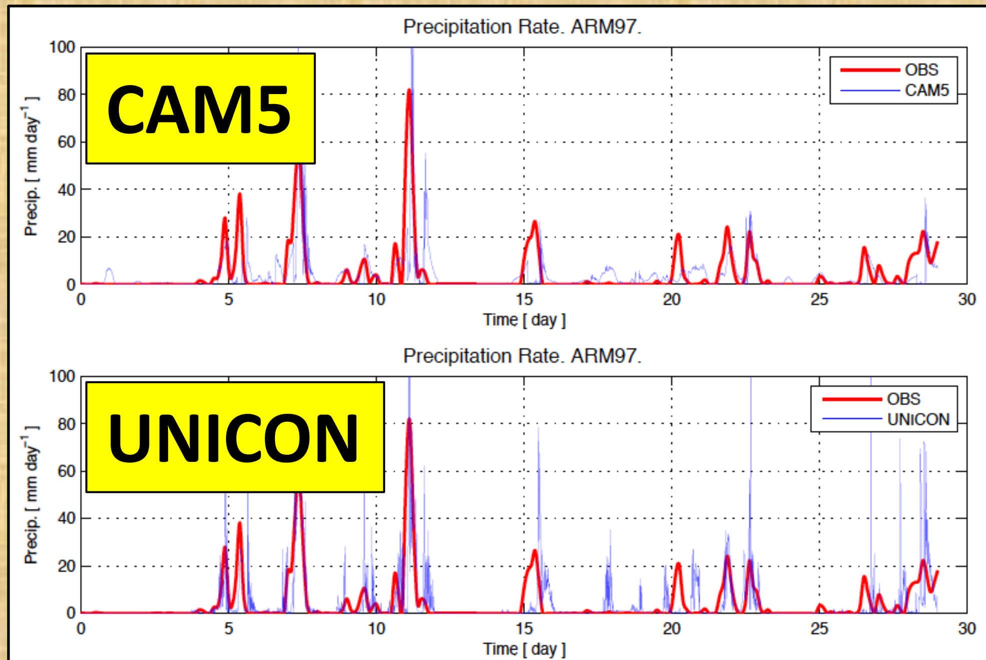
- UNICON is continuously growing. For mature UNICON, I need to provide the following ingredients : I. Objective and through training-tuning using reliable observation-LES test cases spanning a wide range of regimes and processes (e.g., diurnal cycle); II. implementation of detailed aerosol activation and convective microphysics.

Dry Stable PBL
: GABLS1

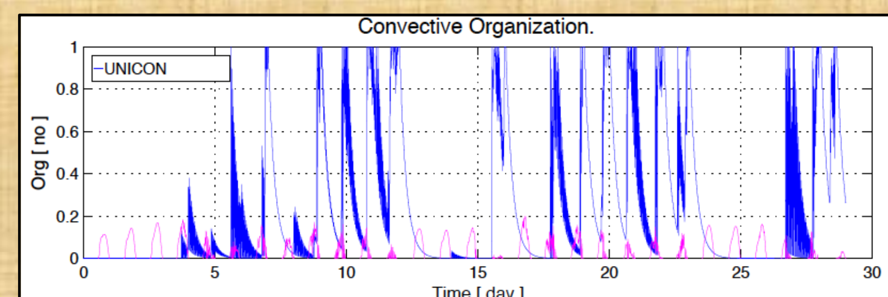


Deep Moist Convection. ARM97.

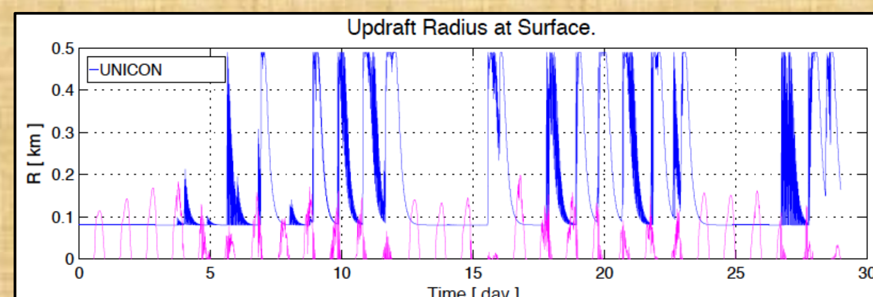
Precipitation Rate at Surface



Convective Organization. UNICON



Updraft Radius at Surface. UNICON



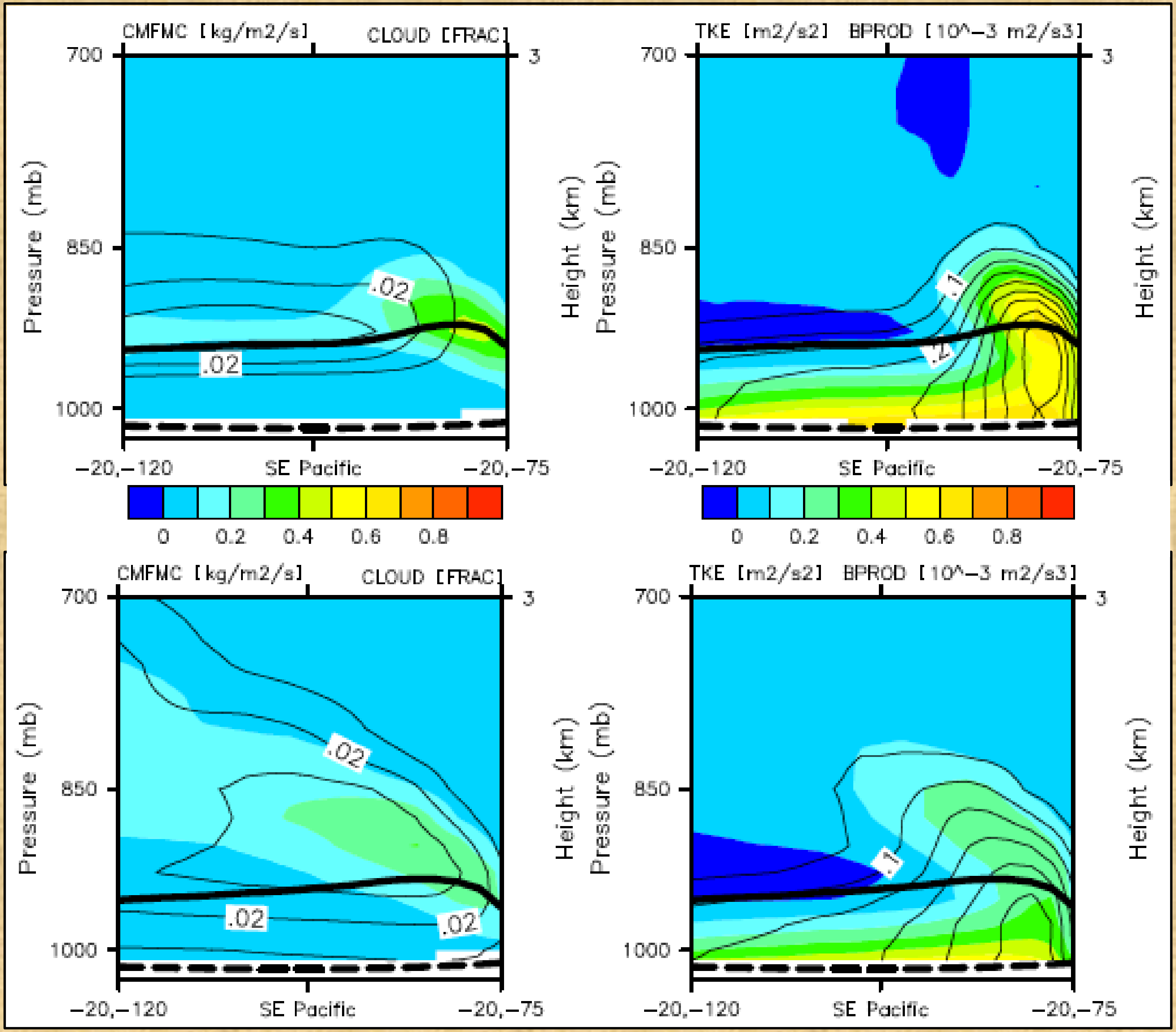
Stratocumulus to Cumulus Transition. SON.

CMFMC (Line), **CLOUD** (Color)

TKE (Line), **BPROD** (Color)

CAM5

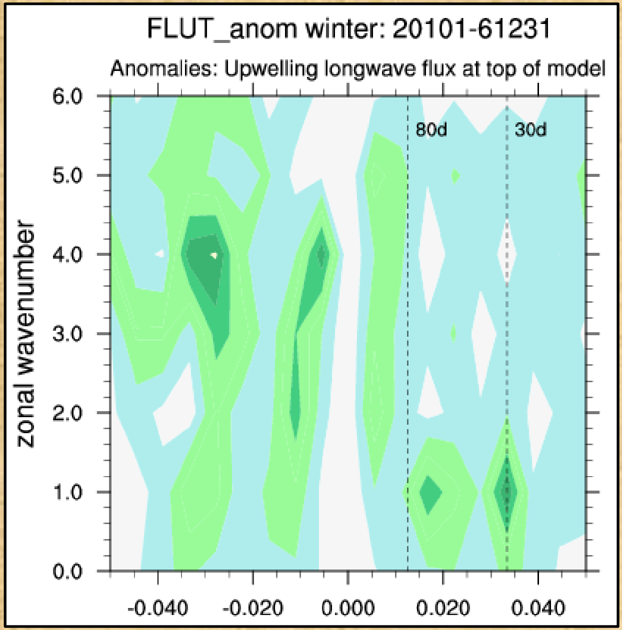
UNICON

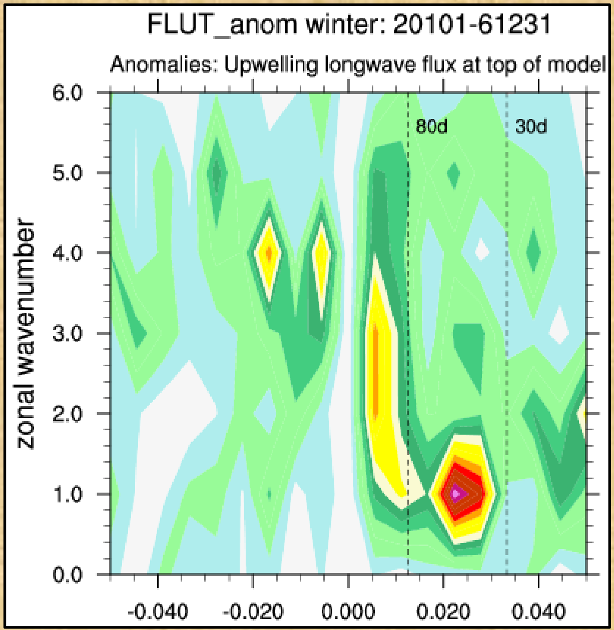


CAM5

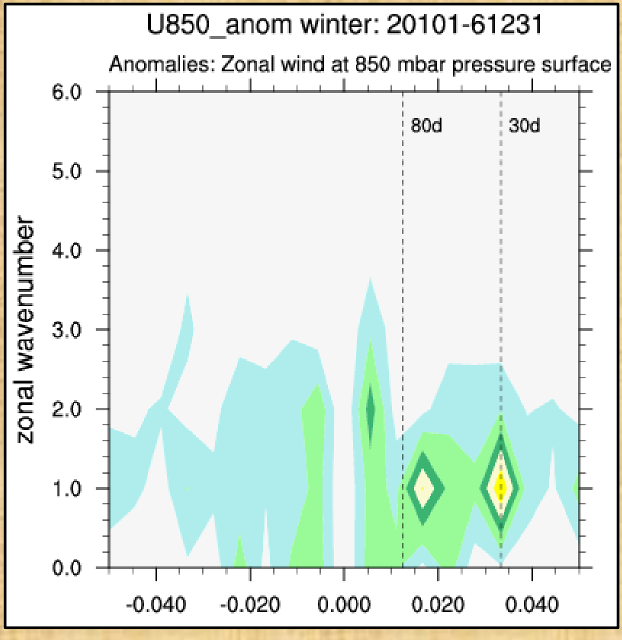
UNICON

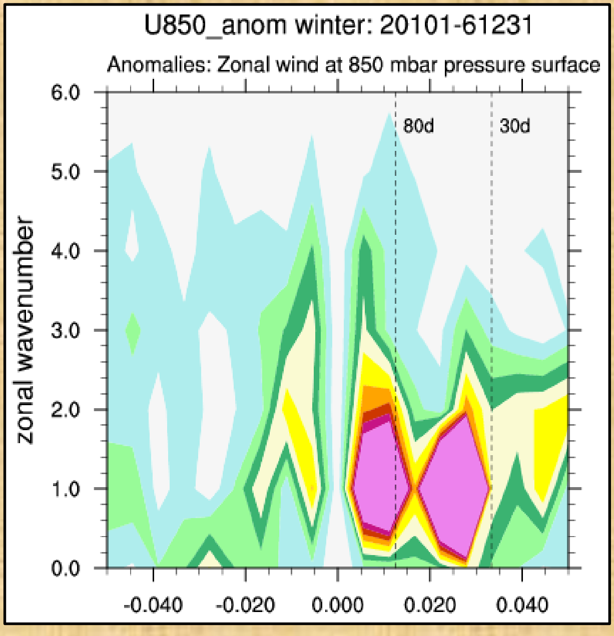
FLUT





U850





Major Remaining Issues in the Parameterization of Convection

I. Unified Treatment of *Shallow* and *Deep* Convection

II. Unified Treatment of *Dry* and *Moist* Convection

III. Unified Treatment of *Forced* and *Free* Convection

IV. Treatment of *Downdraft Dynamics*

I. Parameterization of *Lateral Mixing*

II. Formulation of *Self-Consistent Closure*

I. *Cloud Overlap* for Microphysics, Radiation, and Aerosol Wet Deposition

II. *Microphysics* interacting with *Aerosols*

III. Convection across the *Scale Barrier*

- Some important 'features' (possibly) associated with convection scheme
  - Precipitation Climatology : Double ITCZ, Monsoon, Precipitation over Land, Precipitation FQ, Ratio of Convective to Stratiform Precipitation
  - Lack or weak Diurnal Cycle of Precipitation
  - Lack or weak Madden-Julian Oscillation
  - Too rapid transition from stratocumulus to cumulus along the subtropical transect
  - ENSO characteristics
  - Climate sensitivity of marine stratocumulus and cirrus clouds
  - Global teleconnection
  - Biases of water vapor & clear sky LW radiation (?)
  - Too strong subtropical high in summer (?)
  - Too strong hydrological cycle (?)
  - Hurricane forecast
  - Many other features since 'convection' is the 'pump' of the atmospheric circulation

OUTLINE

I. Brief Description on the UNICON

II. SCAM5 Simulation :

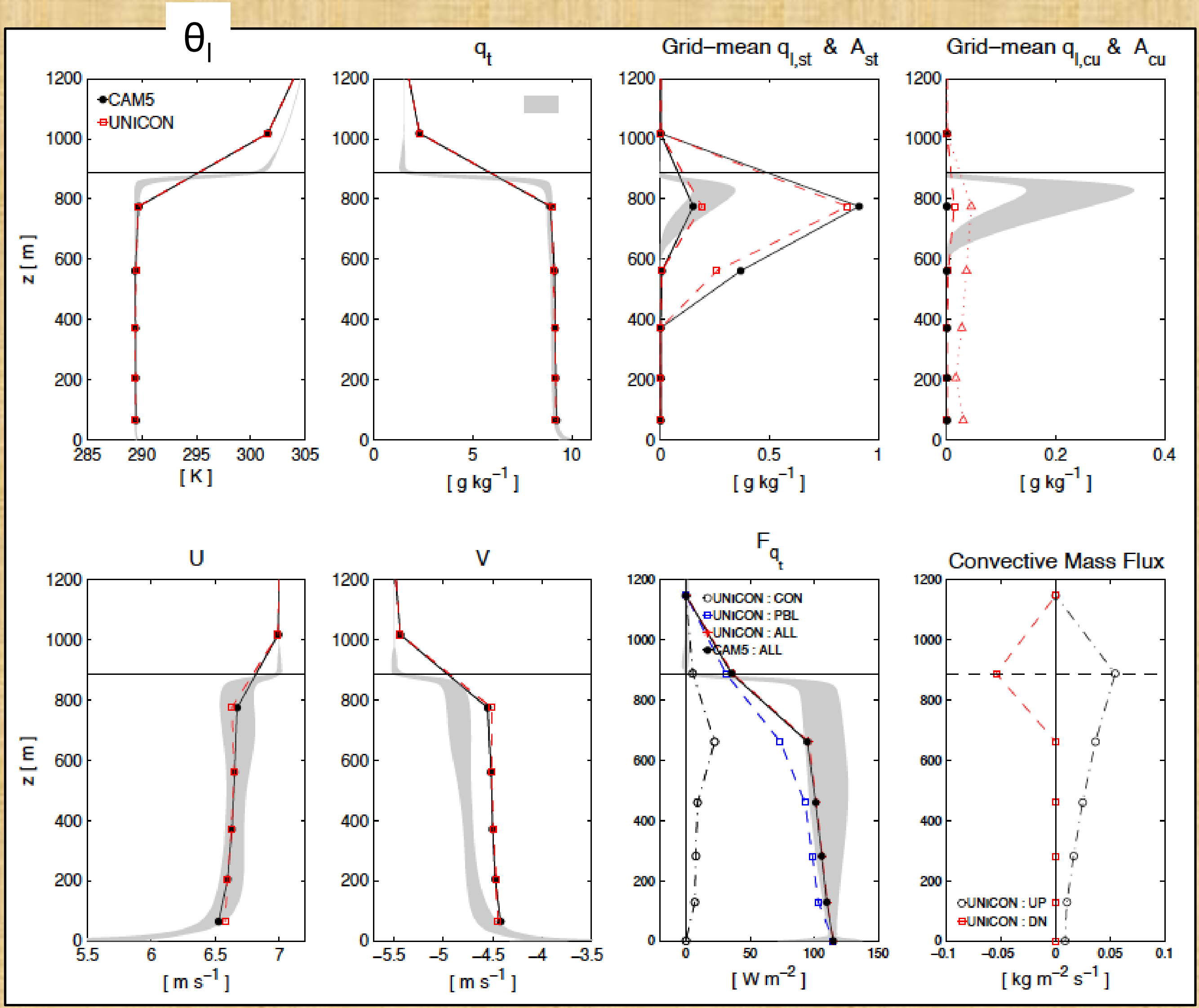
- Dry Convection (DCBL)
- Stratocumulus-Topped Convection (DYCOMS)
- Stratocumulus to Cumulus Transition (STCU)
- Shallow Convection (BOMEX)
- Deep Convection (ARM95, ARM97, GATEIII, TOGAII)

III. CAM5 Simulation

- Precipitation Climatology
- Diurnal Cycle of Precipitation
- Madden-Julian Oscillation
- Stratocumulus to Cumulus Transition

IV. SUMMARY

Stratocumulus-Topped Convection. DYCOMS.

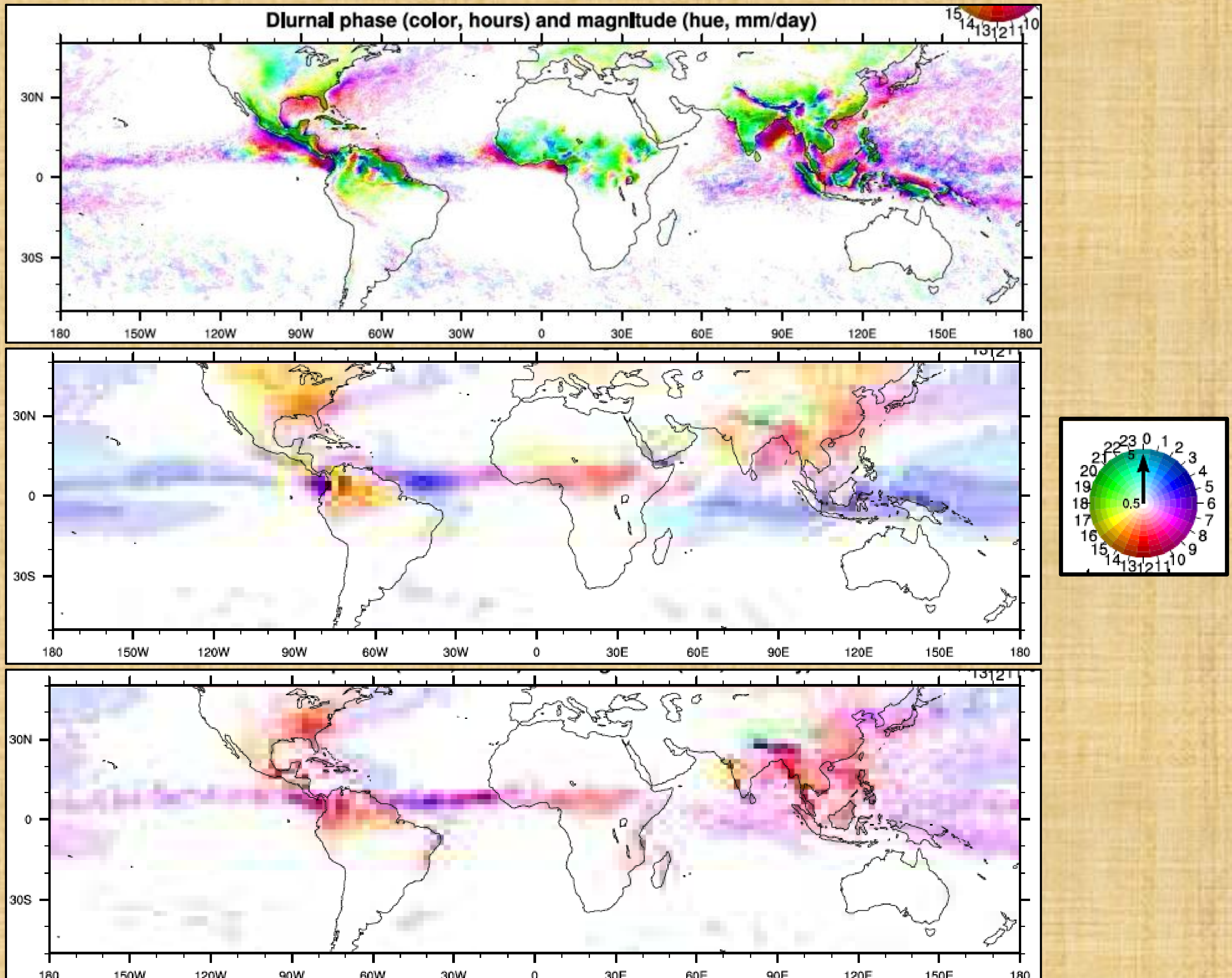


Diurnal Cycle of Precipitation. JJA.

OBS

CAM5

UNICON

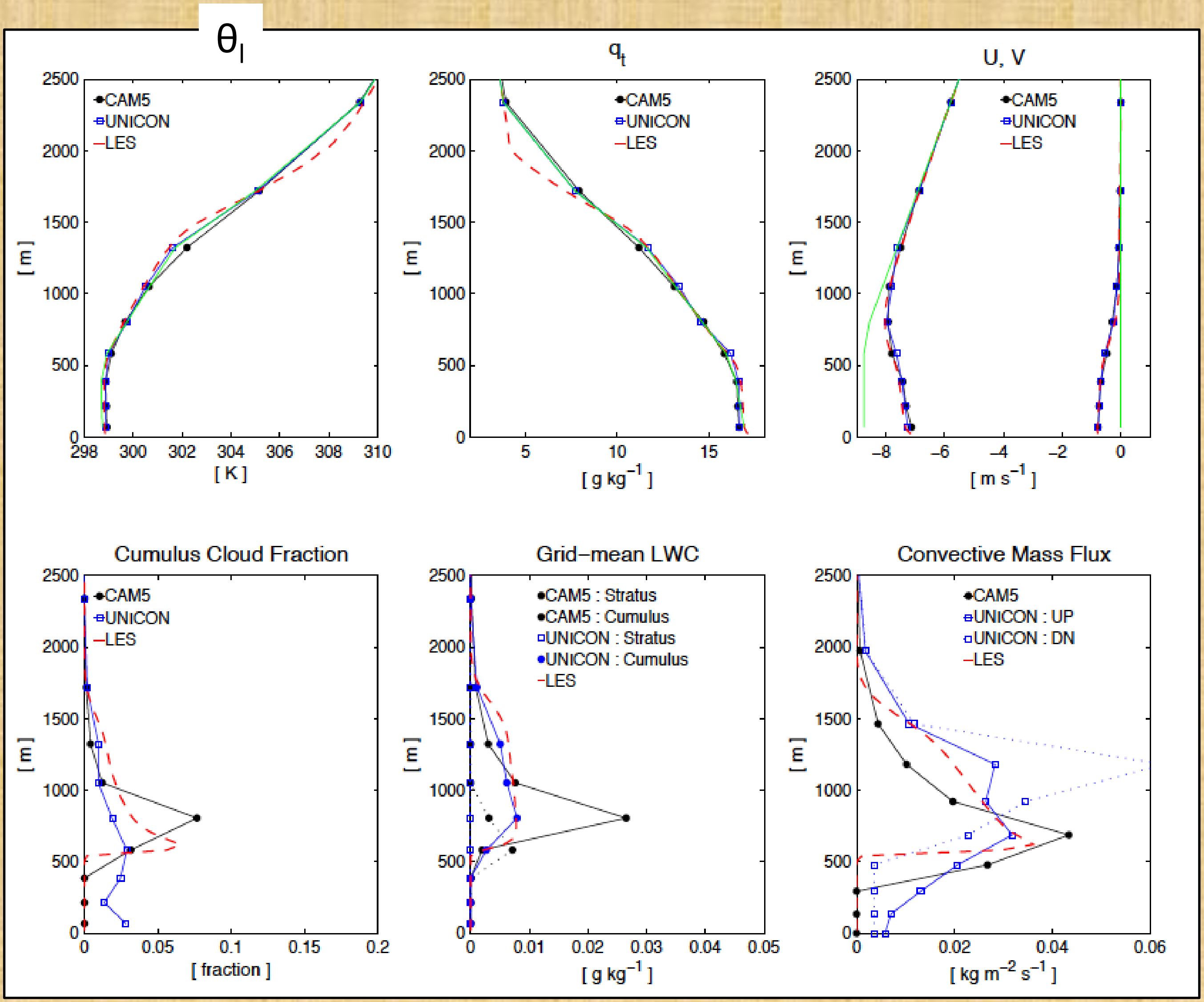


Moist Turbulence Scheme in CAM5

C. Bretherton and S. Park. 2009

- Diagnostic TKE-based 1.5st order K diffusion scheme with entrainment param.
  - Numerically stable, physically realistic, conceptually clear
  - TKE is fed into 'shallow convection' and 'cloud microphysics', and regulates the onset of cumulus updraft and cloud droplet activation
- Stratus-Top LW Cooling and In-Stratus Condensation Heating into TKE
  - Sensitive to 'cloud macro-microphysics' and 'radiation' schemes
  - Treatment of Stratus-Radiation-Turbulence Interactions
  - Now, stratus is a dynamic (as well as radiative) driver of the climate
  - Handling of the full 2nd aerosol indirect effects
  - Removal of the stability-based KH stratus fraction
- Activate in any layers above as well as within PBL
  - Simulate turbulences in the mid-level clouds
- Compared to CAM4 PBL scheme,
  - Much better performance in cloud-topped regime
  - Similar or superior performance in dry stable and convective regimes

Shallow Moist Convection. BOMEX.



Bias against Observation. ARM97.