Convective parameterization for improving Monsoon and MJO in NUIST CSM simulation

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Outline

1. Introduction of the NUIST model

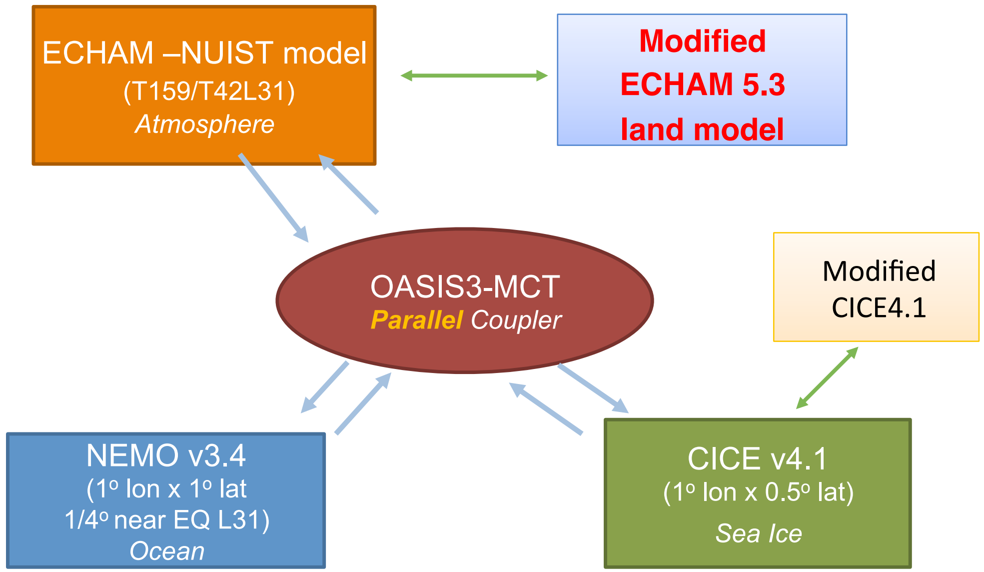
2. Problems with V1 in monsoon precipitation and MJO

3. Major Modifications of the cumulus parameterization scheme

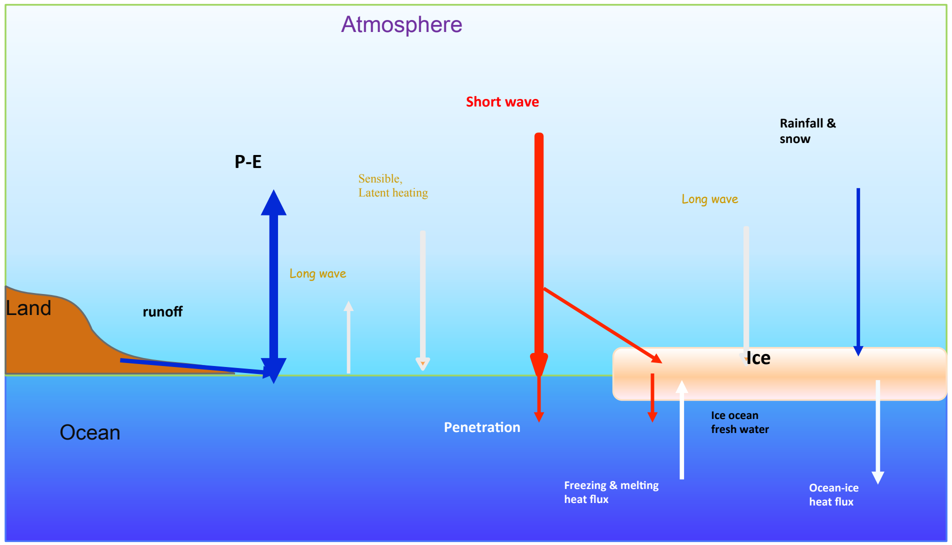
4. Impacts of the modifications on monsoon and MJO simulation

5. Conclusion

NUIST CSM V2 structure

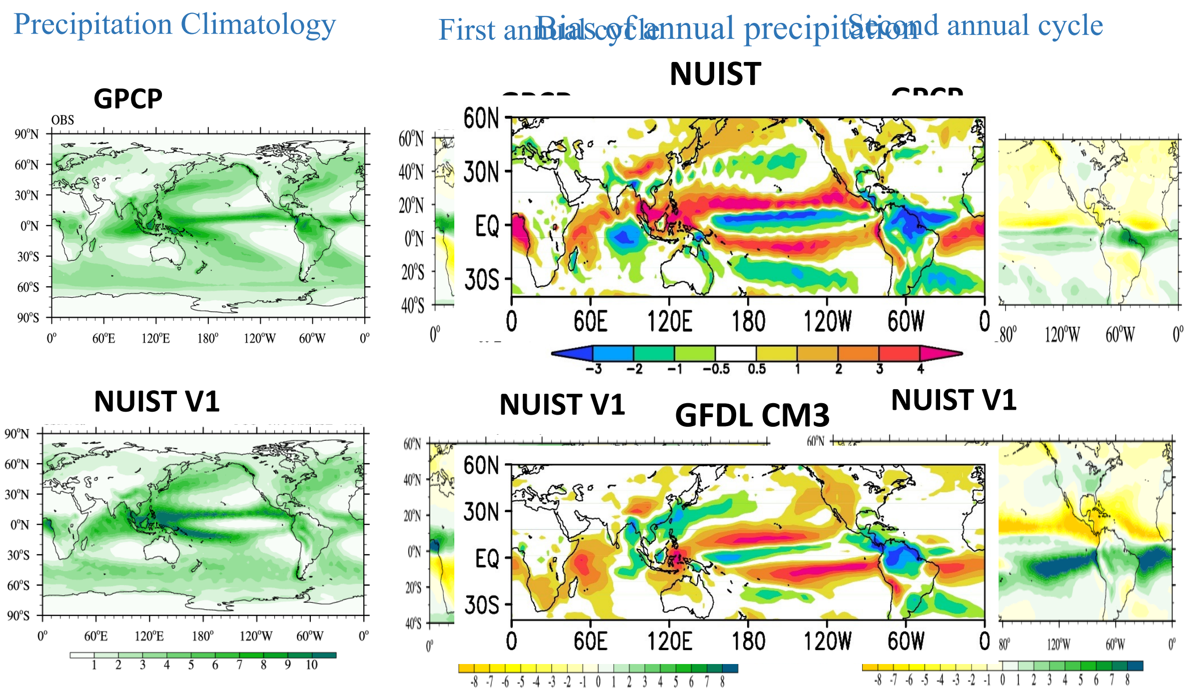


Coupling Processes



2. Major problems with NUIST V1 in simulated monsoon precipitation and MJO

Problems with NUIST v1 - Monsoon

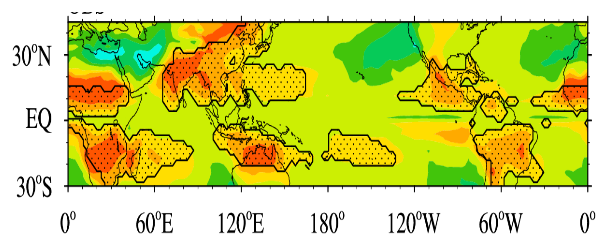


Precipitation amount is overestimated compared to observation

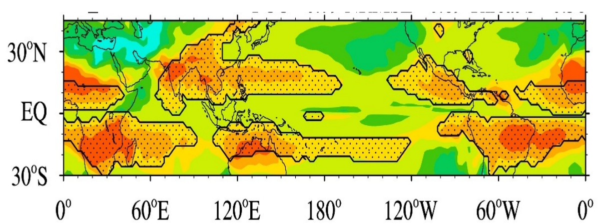
Problems with NUIST v1 - Monsoon

Global Monsoon Intensity and Domain

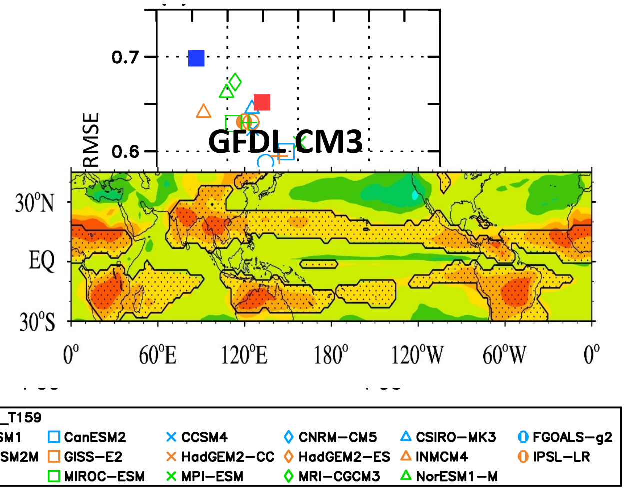
OBS



NUIST V1



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE of global monsoon intensity (30S-40N,0-360)

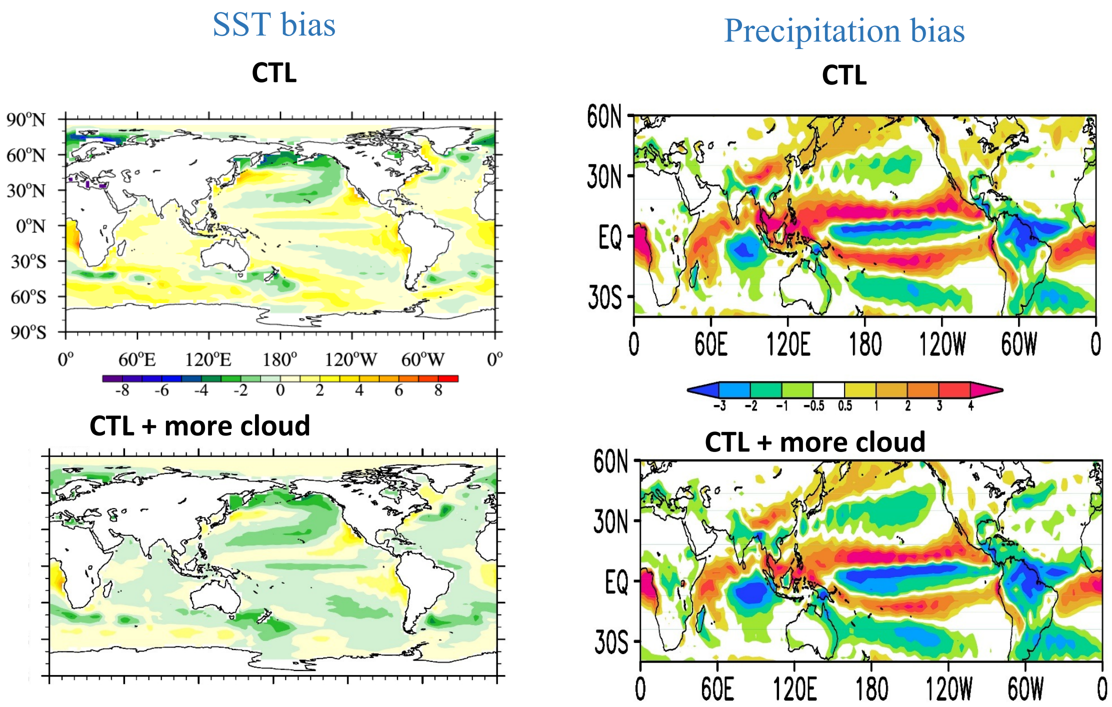


Shading : intensity
Dotted : domain

Possible reasons for the defects in V1 simulation

- **SST Bias**
  - Warmer SST can make more convection
- **convection parameterization needs improvements**
  - Mass flux closure/entrainment rate/trigger function
  - Convective tendency interacting with large scale circulation
- **shallow convection needs improvements**
  - A new shallow convection based on TKE
  - Enhanced shallow convection ahead of deep convection

Impact of SST bias on precipitation



Warm SST partly contributes to excessive precipitation

3. Major modification made to cumulus parametrization schemes

A. Entrainment rate based on relative humidity

B. Convective trigger function - Tokioka constraint

C. Enhanced convective downdraft heating

D. Shallow convection based on TKE

Mass Flux Convection Scheme

A. Cloud budget equation (cloud model)

$$\frac{\partial \sigma}{\partial t} = -D + E - g\frac{\partial M_c}{\partial p}$$

$$\frac{\partial \sigma s_c}{\partial t} = -Ds_c + E\bar{s} - g\frac{\partial M_c s_c}{\partial p} + LC_c$$

$$\frac{\partial \sigma q_c}{\partial t} = -Dq_c + E\bar{q} - g\frac{\partial M_c q_c}{\partial p} - C_c$$

Unknown: M_c, s_c, q_c

$D, E, C_c = f(s_c, \bar{s}, q_c, \bar{q})$

A. σ: cloud fraction
C. D: detrainment
D. E: entrainment

***Stationary assumption**

$$\frac{\partial \sigma}{\partial t} = \frac{\partial \sigma s_c}{\partial t} = \frac{\partial \sigma q_c}{\partial t} = 0$$

A. Cloud budget equation (cloud model)

$$0 = -D + E - g\frac{\partial M_c}{\partial p}$$

$$0 = -Ds_c + E\bar{s} - g\frac{\partial M_c s_c}{\partial p} + LC_c$$

$$0 = -Dq_c + E\bar{q} - g\frac{\partial M_c q_c}{\partial p} - C_c$$

A. Normalized equation (cloud model)

$$0 = M_c\left(-\delta + \varepsilon - g\frac{1}{\mu}\frac{\partial \mu}{\partial p}\right) \Rightarrow \frac{\partial \mu}{\partial z} = (\varepsilon - \delta)\mu$$

$$0 = M_c\left(-\delta s_c + \varepsilon\bar{s} - g\frac{1}{\mu}\frac{\partial \mu s_c}{\partial p} + Lc\right)$$

$$0 = M_c\left(-\delta q_c + \varepsilon\bar{q} - g\frac{1}{\mu}\frac{\partial \mu q_c}{\partial p} + Lc\right)$$

❖ **Determination of M_b ($M_c = M_b\mu$)**

closure of the convection scheme

Mass flux-type convection scheme

❖ **Normalized equation (cloud model)**

$$\frac{\partial \mu}{\partial z} = (\varepsilon - \delta)\mu$$

$$\frac{\partial S_c}{\partial z} = -\varepsilon(S_c - \bar{S}) + LC_c$$

$$\frac{\partial q_c}{\partial z} = -\varepsilon(q_c - \bar{q}) - C_c$$

$$\mu, S_c, q_c \;:\; f(\varepsilon, \delta, \bar{S}, \bar{q}),$$

$$\delta \;:\; f(\varepsilon)$$

❖ Variables to be parameterized

M_b : cloud base mass flux

ε : Entrainment

S_1 & q_1 : heat & moisture at cloud base (Trigger Function)

❖ convective tendency

1. Subsidence heating in the environment

$$\frac{\partial \bar{T}}{\partial t} = \frac{1}{\bar{\rho} c_p} M_c \frac{\partial \bar{S}}{\partial z} \qquad \frac{\partial \bar{q}}{\partial t} = \frac{1}{\bar{\rho}} M_c \frac{\partial \bar{q}}{\partial z}$$

2. Detrainment heating

$$\frac{\partial \bar{T}}{\partial t} = \frac{1}{\bar{\rho} c_p} D(S^t - \bar{S}) \qquad \frac{\partial \bar{q}}{\partial t} = \frac{1}{\bar{\rho}} D(q^t - \bar{q})$$

3. Downdraft heating &
   re-evaporation of precipitation

$$\frac{\partial \bar{T}}{\partial t} = \frac{1}{\bar{\rho} c_p} \frac{\partial M_d}{\partial z} (S^t - \bar{S}) \qquad \frac{\partial \bar{q}}{\partial t} = \frac{1}{\bar{\rho}} \frac{\partial M_d}{\partial z} (q^t - \bar{q})$$

Entrainment rate based on RH

❖ **Modified entrainment rate**

- **entrainment is related with buoyancy (b) and vertical velocity in cloud (w)**

$$\epsilon = \frac{b}{2\left(w_0^2 + \int_o^z b\,dz\right)} + \frac{1}{\overline{\rho}}\frac{\partial \overline{\rho}}{\partial z}$$ oeckner et al. (2003)

- **This formula does not consider moisture effect**
  (buoyancy and velocity are a function of temperature)

⇩

$$\epsilon_{new} = \epsilon_{old}\left(\frac{1}{\overline{RH}} - 1\right)$$ e.g. Kim & Kang (2012)

"Deep cloud develops
when RH is relatively large"

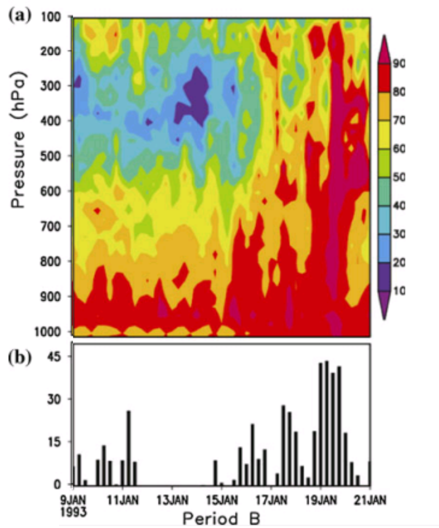


Fig. 1 **a** Relative humidity and **b** precipitation observed during selected period from total TOGA-COARE IFA period. *Left (right)* panels shows period A (**b**). Units for relative humidity and precipitation are % and mm day^{-1}, respectively
Kim & Kang (2012)

Entrainment rate modeling

RH vs Precipitation

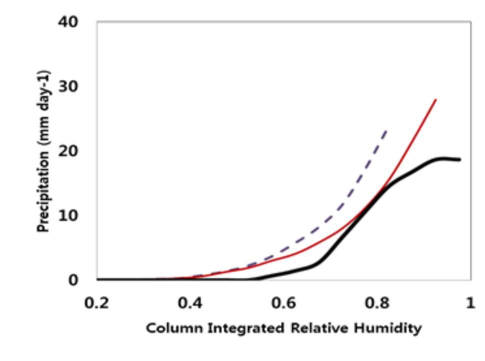
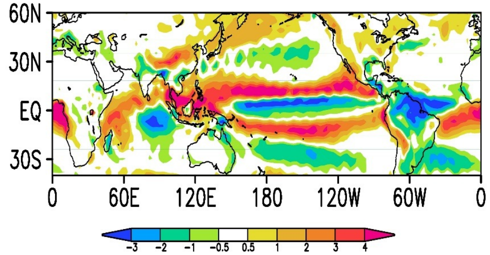


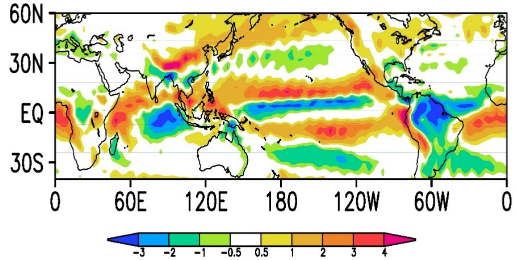
Fig. 10 Mean daily precipitation composited into 5% bins of column integrated saturation fraction for tropical ocean grid points in the west Pacific and Indian Ocean warm-pool region (15S–15N, 60–180E)

Bias of annual precipitation

CTL



Modified entrainment rate



Downdraft heating

❖ **Downdraft heating**

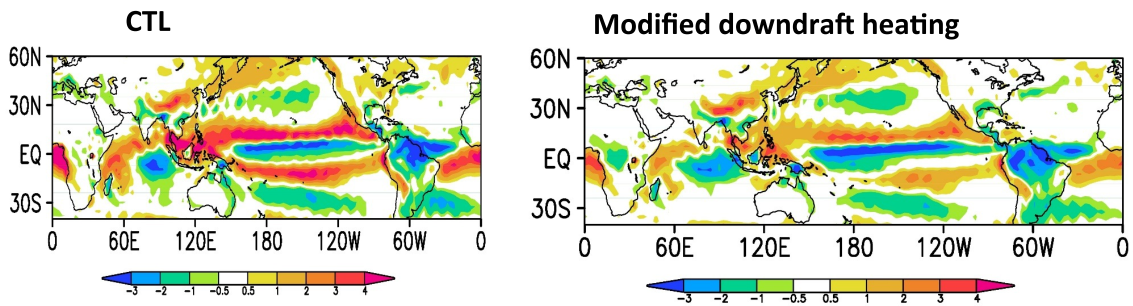
- **Downdraft heating : function of evaporation**
- **Evaporation makes lower level atmosphere cool and moist.**

  => convection is suppressed after deep convection develops

$$\frac{\partial \bar{T}}{\partial t} = \frac{1}{\bar{\rho} c_p} \frac{\partial M_d}{\partial z} (S^t - \bar{S}) \qquad \frac{\partial \bar{q}}{\partial t} = \frac{1}{\bar{\rho}} \frac{\partial M_d}{\partial z} (q^t - \bar{q})$$

$$\frac{\partial M_d}{\partial z} : f(Evap.)$$

Bias of annual precipitation



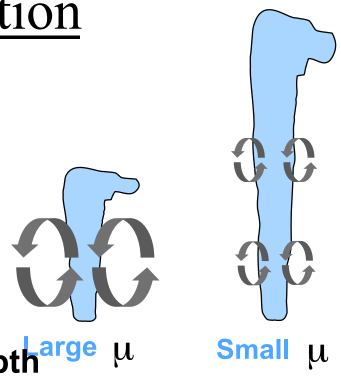
Triggering function for convection

Tokioka constraint

❖ **Minimum cumulus entrainment rate**

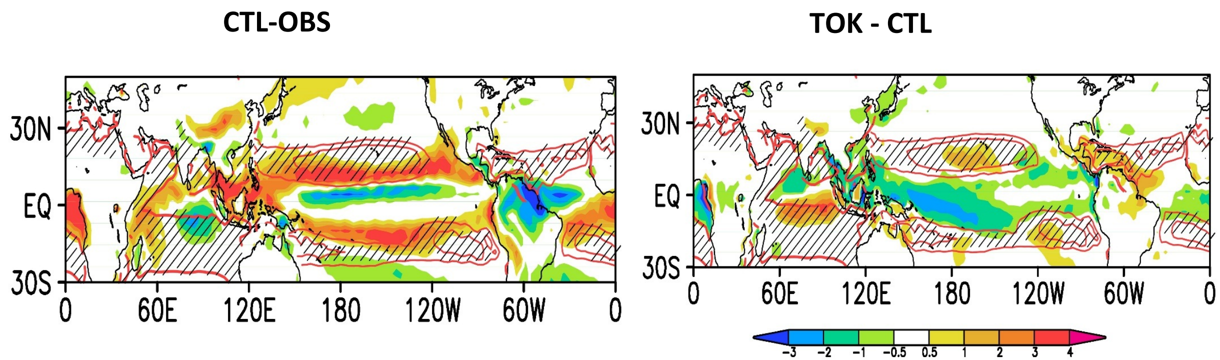
$$\mu_{min} = \frac{\alpha}{D}$$

D: PBL depth
: non-negative constant

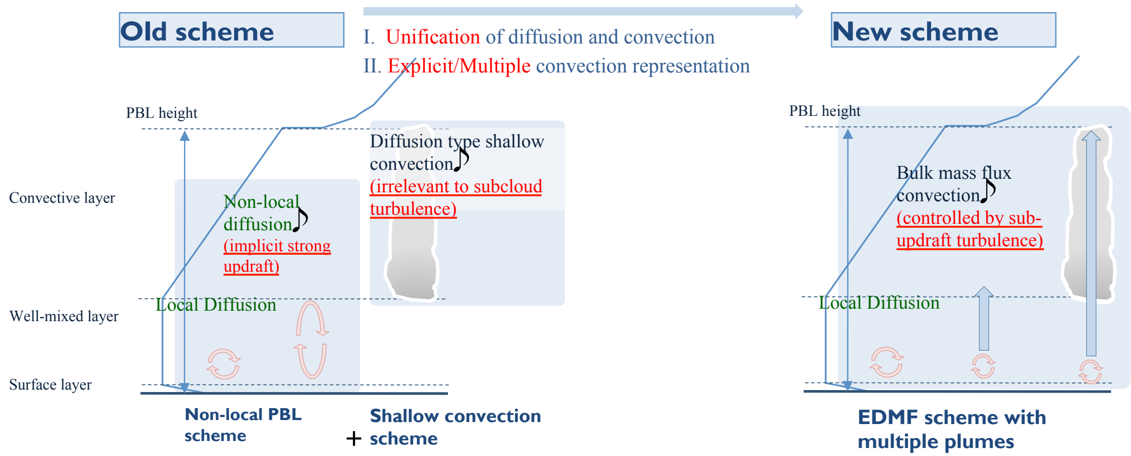


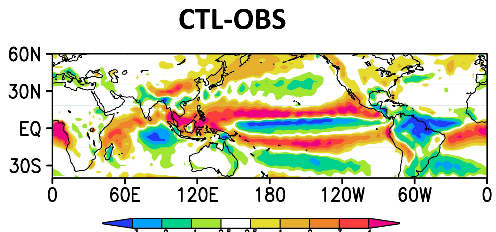
Convection can be occurred in case of deep PBL depth

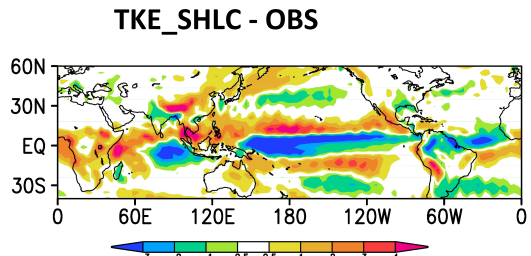
Bias of annual precipitation



Shallow convection based on TKE



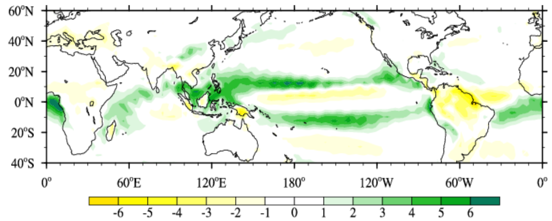




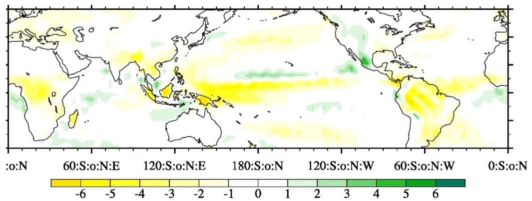
4. Impacts of the modifications on monsoon and MJO simulation

Annual Mean precipitation

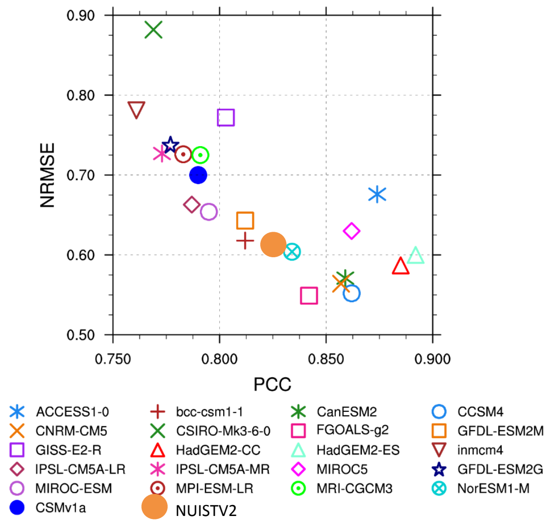
Bias (NUIST v1)



BIAS (NUISTV2)

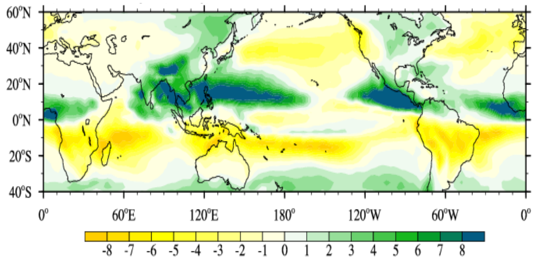


Comparison with CMIP5 Coupled models
in terms of the PCC skill and NRMSE (40S-60N)

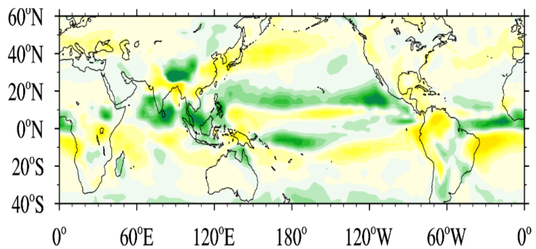


The First Annual Cycle (Solstice Mode) of precipitation

Bias (NUIST v1)



BIAS (NUISTV2)



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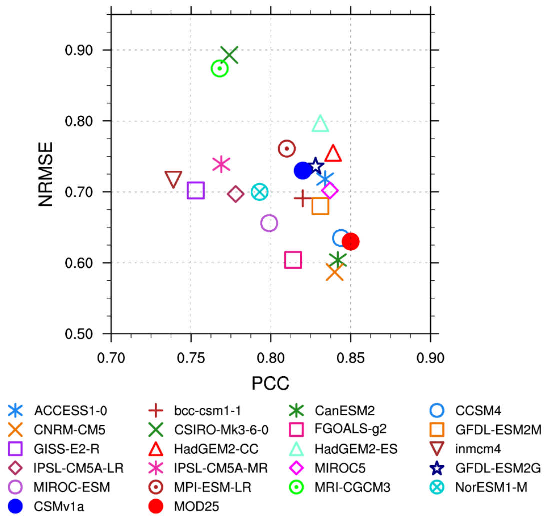
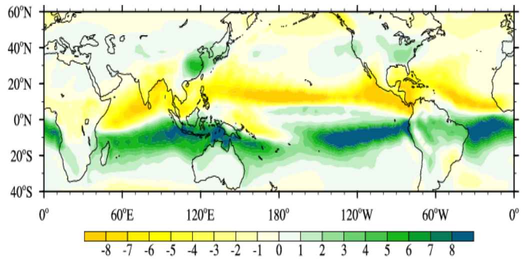
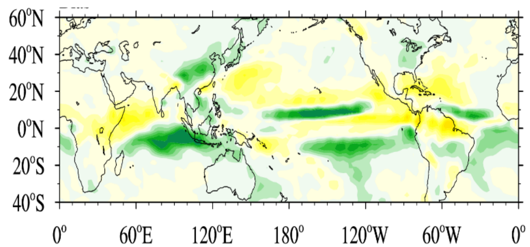


The Second Annual Cycle (Equinoctial Mode) of precipitation

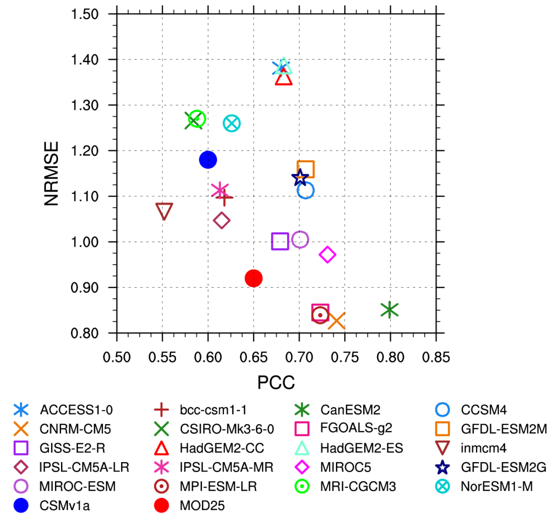
Bias (NUIST v1)



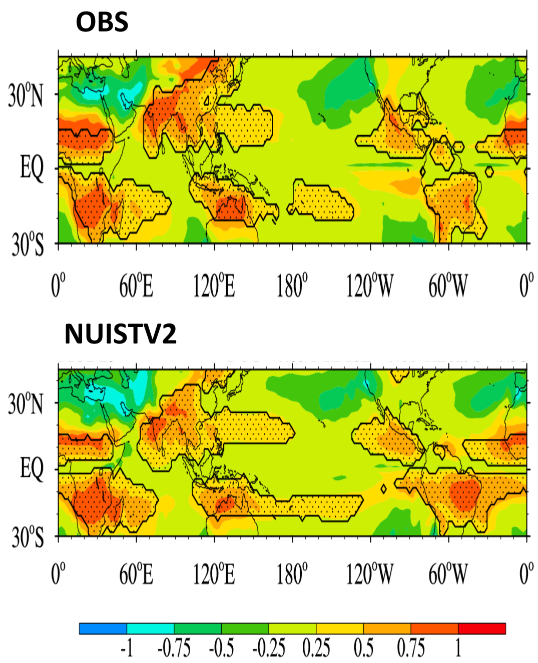
BIAS (NUISTV2)



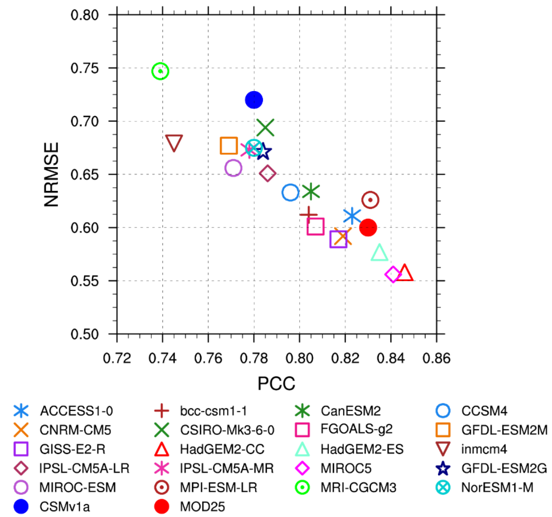
Comparison with CMIP5 Coupled models
in terms of the PCC skill and NRMSE (40S-60N)



Global Monsoon Intensity and Domain



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE of global monsoon intensity (30S-40N,0-360)

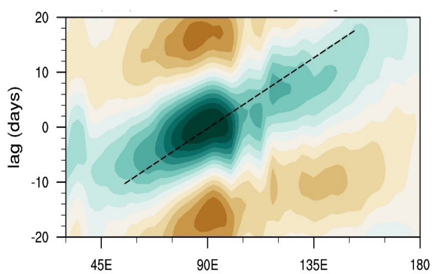


MJO simulation

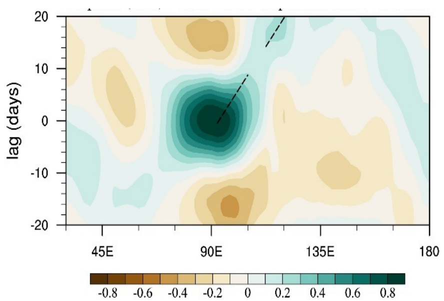
Problems with NUIST v1 - MJO

Lag correlation (precipitation)

OBS (5.4 m/s)

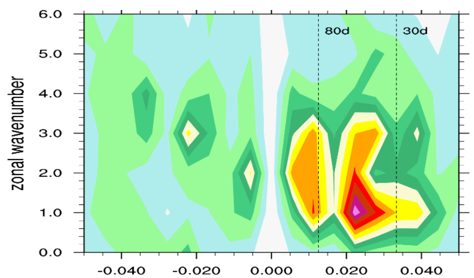


CTL (3.3 m/s)

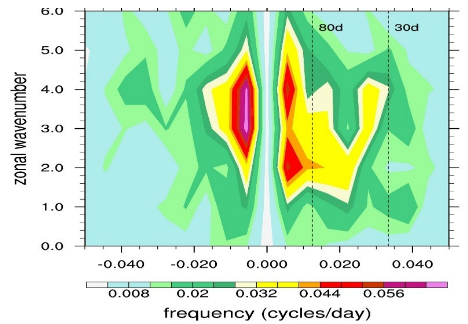


Space-time power spectra

OBS



CTL



What affects propagation of MJO?

- **Air-sea interaction (Emanuel 1987)**
  – Higher SST will produce deeper convection, which may cause slower propagation

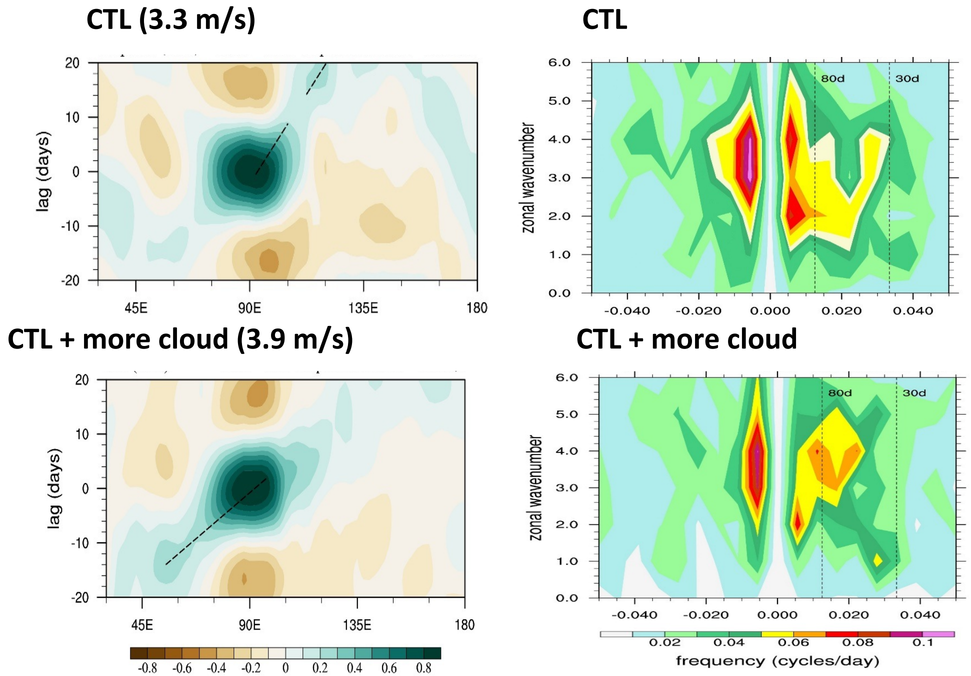
- **Frictional moisture convergence feedback (Wang 1988, Wang and Rui 1990):**
- **Enhanced interaction between shallow convection and BL convergence can enhance eastward propagation.**

- **Moisture feedback (Wang & Chen 2016)**
  – Moisture feedback slows down propagation of MJO by enhancing Rossby wave component

"Proper modification of convection scheme is needed for improving MJO propagation"

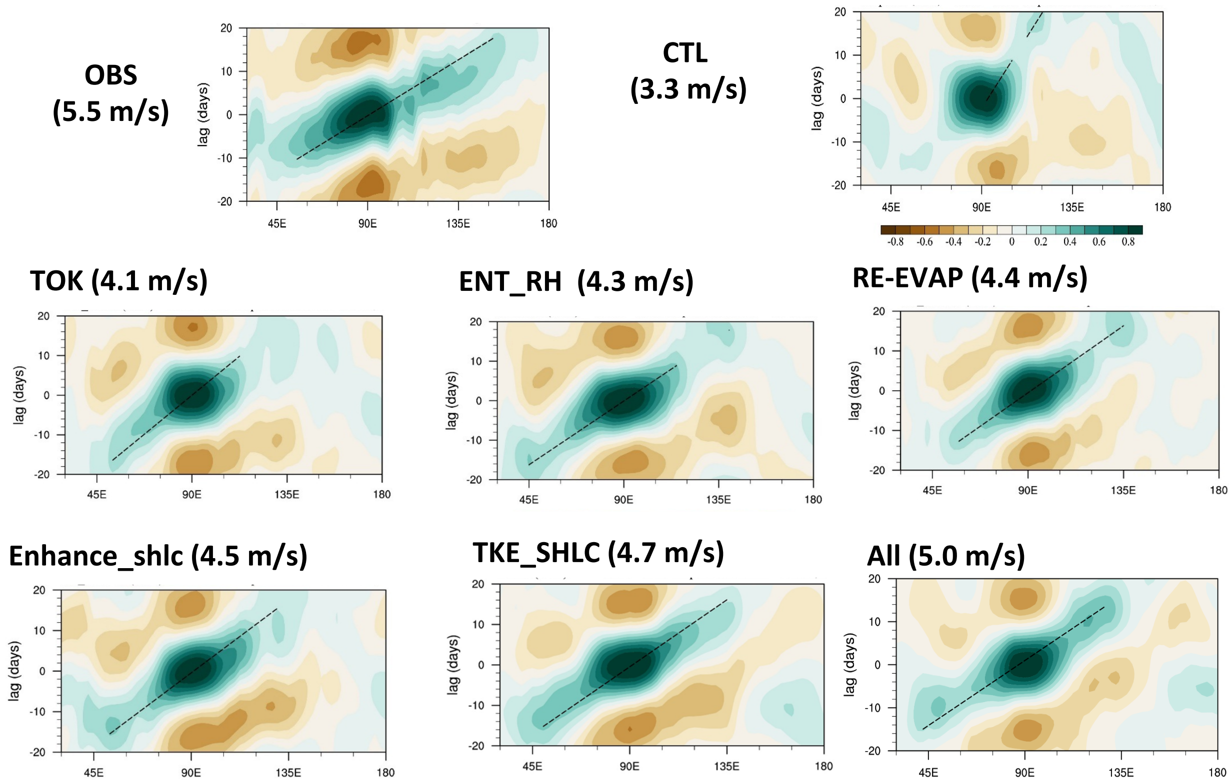
Impact of SST on MJO

Lag–longitude diagram | Wavenumber-Frequency Spectra

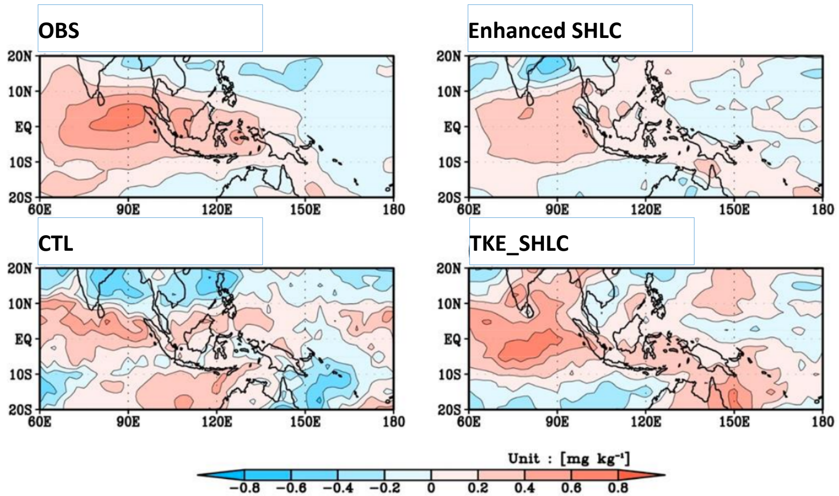


10N–10S-averaged intraseasonal precipitation anomalies correlated against precipitation anomalies averaged over the Equatorial Indian Ocean

Impact of Convective parameterization on MJO

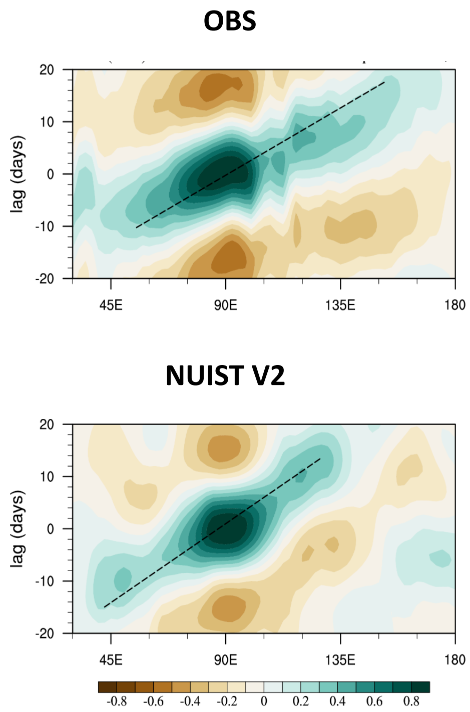


Role of shallow convection

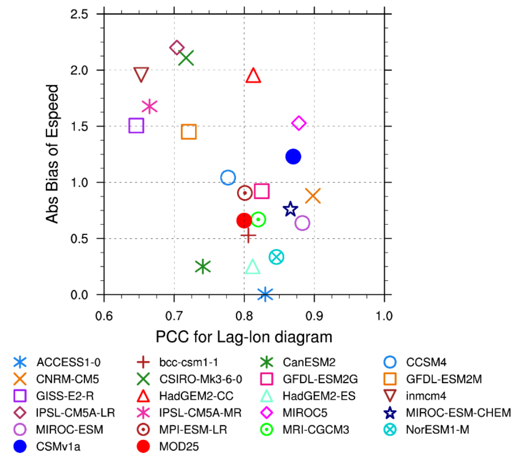


Composite map of 30-90 day filtered specific humidity averaged over low-level when 30-90 day filtered precipitation averaged over Indian Ocean is positive and larger than one standard deviation.

Performance of NUIST V2 (all modifications)



Comparison with CMIP5 Coupled models in terms of the PCC skill for *the* Lag–longitude diagram and Abs bias for eastward propagation speed



What causes slow propagation of MJO

- **Theoretical model** (2 & half layer model with moisture effect, Wang & Chen 2016)

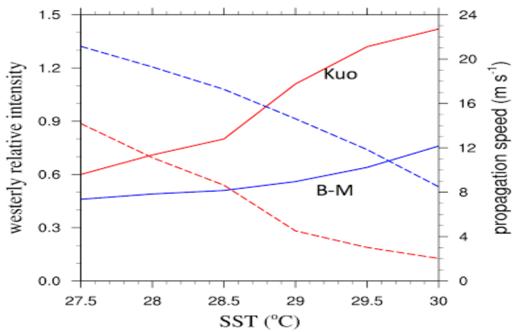
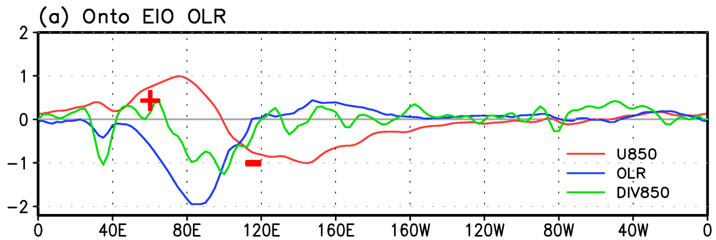


Fig. 11 Westerly relative intensity parameters as a function of SST in B-M simulation (red solid) and Kuo simulation (blue solid). The Westerly relative intensity parameter is defined as the ratio of the maximum MJO westerly vs. the maximum MJO easterly speed averaged between 5S and 5N. Also shown is the corresponding propagation speed for the B-M (red dash) and the Kuo (blue dash) simulations.

- **Relative strength of the Rossby wave vs. Kelvin wave (observation)**

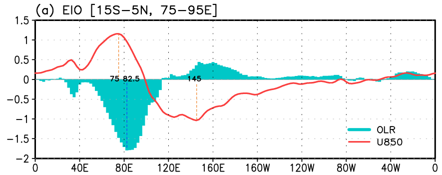


	Onto EIO –OLR
U850max	*0.99 (lon=75E)*
U850min	*-1.00 (lon=145E)*
γ=U850max /lU850minl	*0.99*

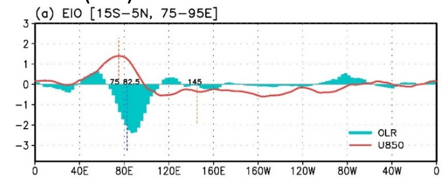
Fig. 4 Zonal variation of regressed OLR(*0.1), 850-hPa zonal wind, and 850-hPa divergence (*30) onto OLR*(-1) at three centers. 20-70 day filtered values were used.

Relative strength of the Rossby wave vs. Kelvin wave

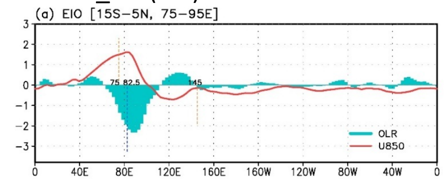
OBS (0.99)



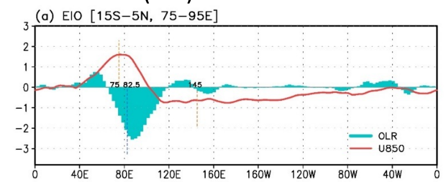
TOK (3.3)



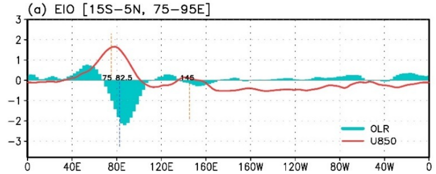
ENTR_RH (2.5)



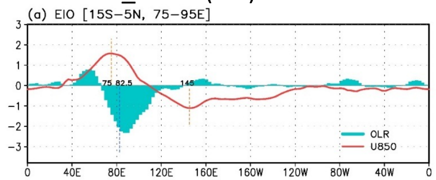
RE-EVAP(2.1)



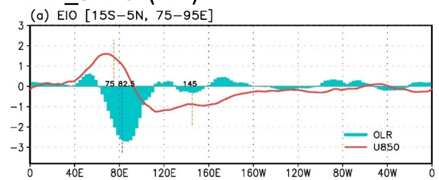
CTL (4.8)



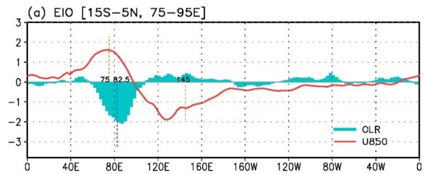
Enhance_SHLC (1.4)



TKE_SHLC (1.2)



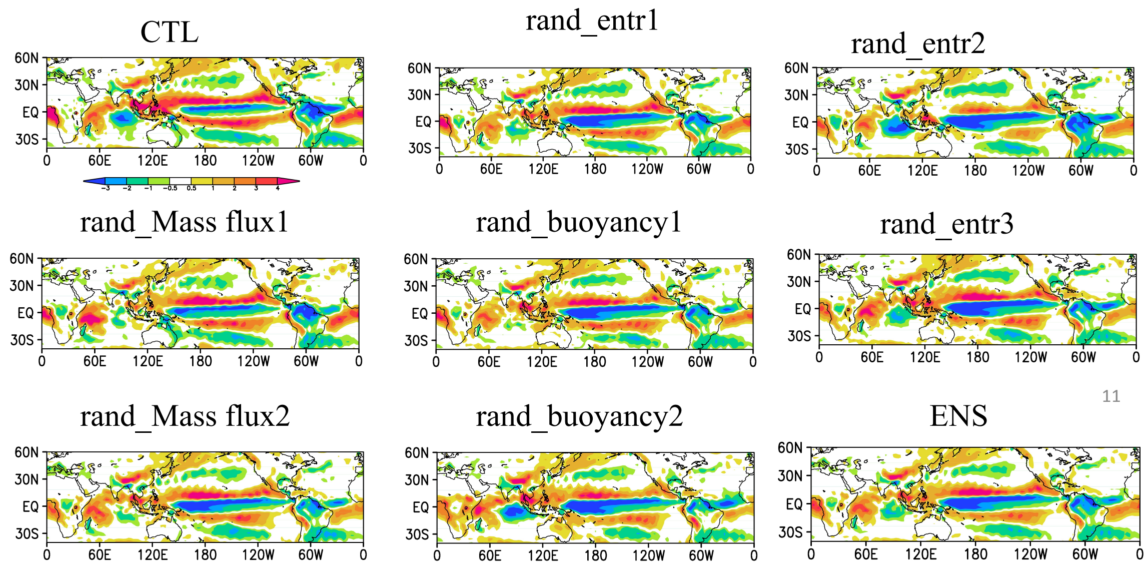
ALL (0.95)



- Stochastic Parameters
- Physical ensemble approach

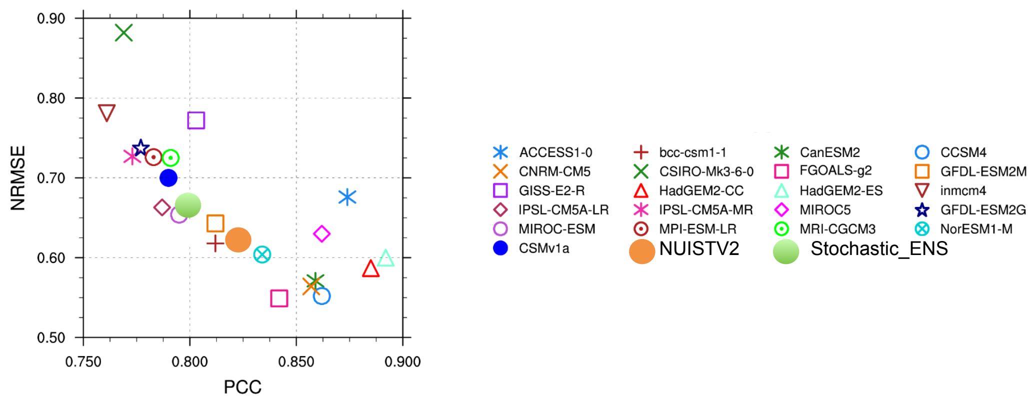
Stochastic Parameterization

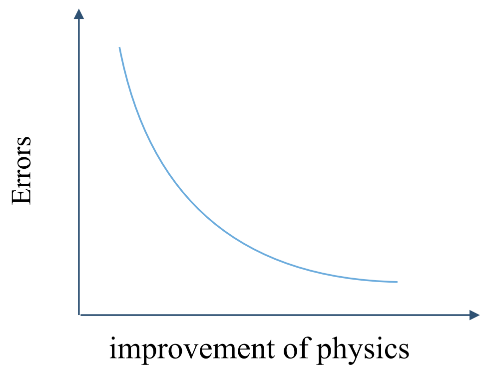
- Add random values to cloud-base mass flux, buoyancy and entrainment rate
- Random function : same probability density for all range
- Range of Random values : 1 ~3 standard deviation of average of each parameter

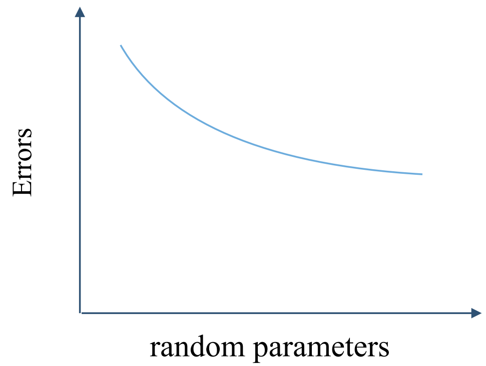


“NRMSE is slightly reduced but spatial pattern is not much changed”

Stochastic Parameterization

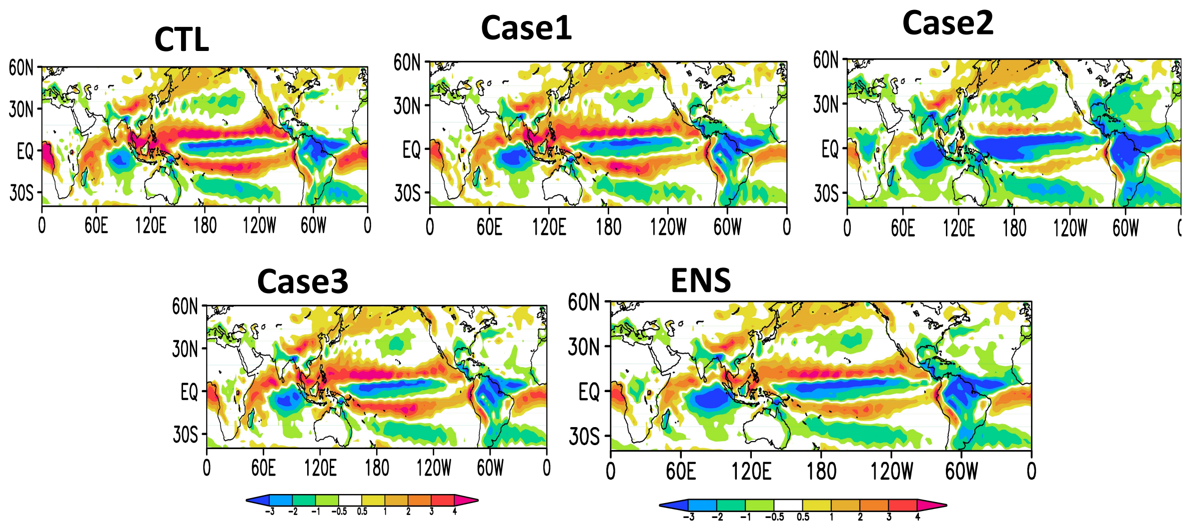






Physical ensemble simulation

- Two convective schemes - Tietke (1987) & RAS (1992) scheme
- **Various w**eighted average of tendency and precipitation of two schemes



“Physical ensembles does not always cancel model errors due to common problems”

Summary

- NUIST V1 overestimates precipitation intensity and poorly simulates MJO propagation with a slower speed.
- Proper suppression of convection by RH-dependent entrainment, convective trigger connected with PBL properties, enhanced shallow convection, and cold pool effect improves precipitation climatology and MJO simulation
- When convection is connected with PBL properties, simulated monsoon over Indian ocean can be further improved.
- Enhanced shallow convection contributes to faster MJO propagation by moistening lower atmosphere in front of the major convection.
- Changes in simulated monsoon induced by Stochastic parameter tends to be smaller than those induced by new physical parameterizations.

Thank you for your comments!