Improving mean state and the intraseasonal variability of CFSv2 through super-parameterization and revised cloud-convection parameterization

P. Mukhopadhyay,

R. Phani Murali krishna[1], Bidyut B. Goswami[2], S. Abhik[3, 4], Malay Ganai[1], M. Mahakur[1], Marat Khairoutdinov[5] and Jimmy Dudhia[6]

1 Indian Institute of Tropical Meteorology, Pune-411008, India
2 Department of Mathematics and Statistics, University of Victoria, Canada
3 Monash University, Clayton, VIC, Australia
4 Bureau of Meteorology, Melbourne, Australia
5 Stony Brook University, New York, USA
6 NCAR, USA

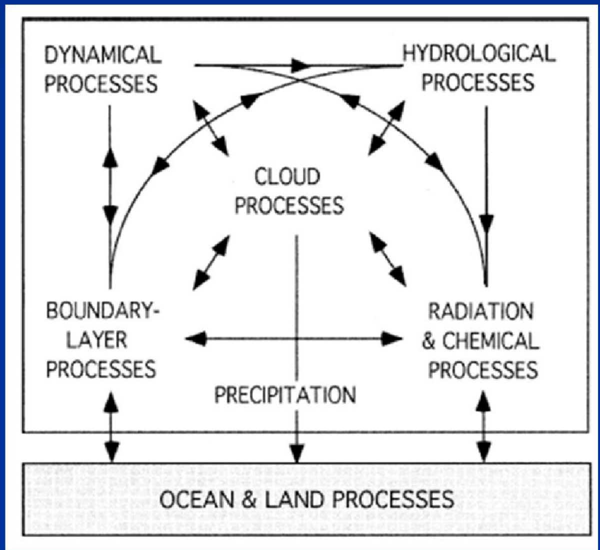
Outline

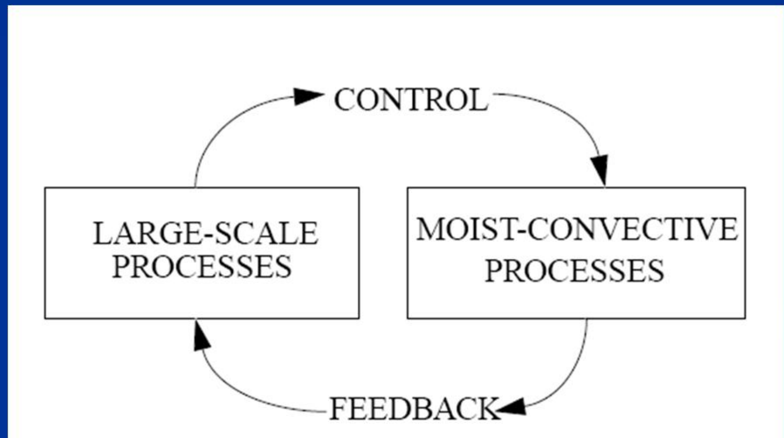
- Paradigm of Conventional Parameterization
- Issues of CFSv2 biases related to convection
- Recent New approaches in dealing convection parameterization in CFSv2
- Summary

Issues of cumulus Parameterization

The Cumulus Parameterization Problem: Past, Present, and Future
By Akio Arakawa, JOC, 2004, Arakawa et al. 2011, Arakawa and Wu 2013, Wu and Arakawa 2014

- "Major practical and conceptual problems in the conventional approach of cumulus parameterization, includes inappropriate separations of processes and scales".





$$\sum_{j=1}^{N} K_{ij} \cdot M_{Bj} + F_i = 0$$

K_{ij} = effect of cloud j on cloud i,

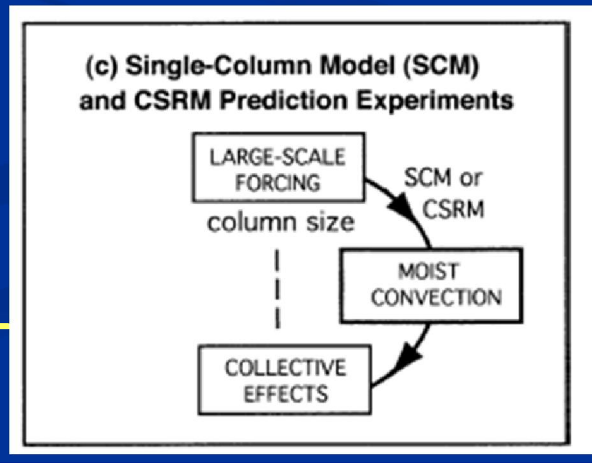
F_i = environmental forcing for cloud i

M_{Bj} = mass flux at base of cloud j

Task of Conv. Param

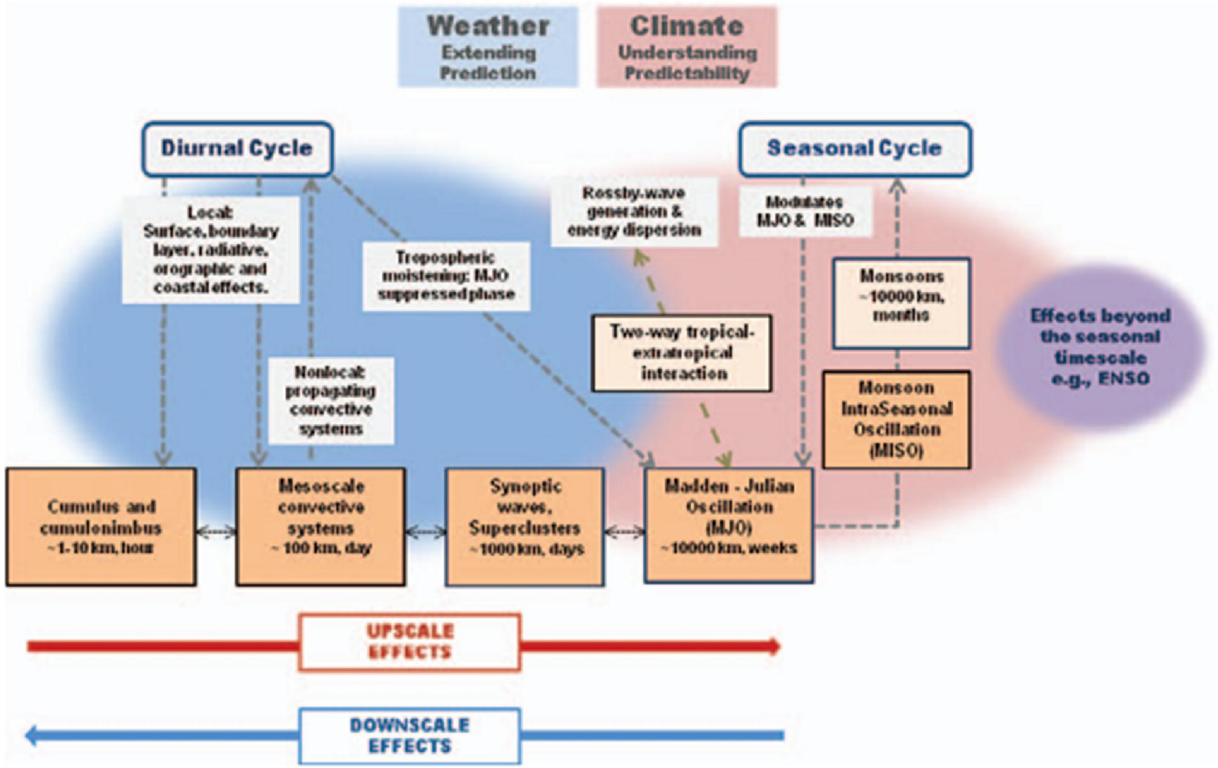
To calculate the collective effects of an ensemble of convective clouds in a model column

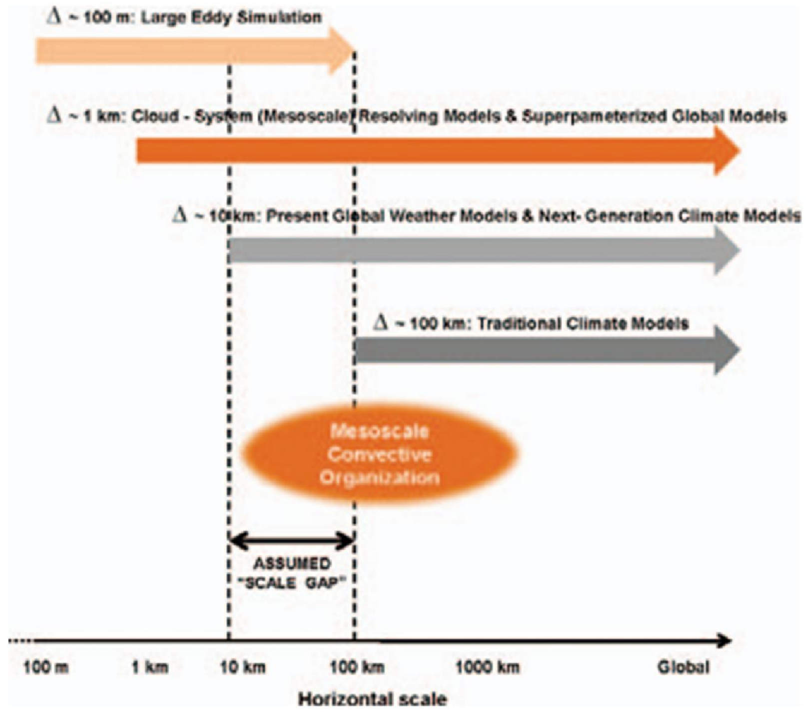
$$Q_{1C} \equiv Q_1 - Q_R \equiv L(\bar{c} - \bar{e}) - \frac{\partial \overline{\omega' s'}}{\partial p}$$



Moncrieff et al, 2012, BAMS

Scientific Basis of the study





The organized systems exhibit hierarchical coherence: (i) mesoscale systems consist of families of cumulonimbus; (ii) cumulonimbus and MCS are embedded in synoptic waves; and (iii) the MJO/MISO is an envelope of cumulonimbus, MCS, and superclusters.

The upscale effects of convective organization are not represented in traditional climate models.

The mean atmospheric state exerts a strong downscale control on convective structure, frequency, and variability. Mesoscale convective organization bridges the scale gap assumed in traditional convective parameterization.

- **(i) SCM/CRM resolves cumulus, cumulonimbus, mesoscale circulations, but the computational domain is small (~100 km) and simulations short (~1 day).**
- **(ii) Two-dimensional CSRMs in superparameterized global models permit MCS-type organization and mesoscale dynamics.**
- **(iii) High-resolution global numerical prediction models may crudely represent large MCS (superclusters). (iv) MCS, and other mesoscale dynamical systems, are absent from traditional climate models—organized convection is not parameterized.**

ISSUES

- CFSv2 T126 shows colder Tropospheric temperature bias and colder SST bias

- CFSv2 T382 shows warmer Tropospheric temperature and warmer SST bias

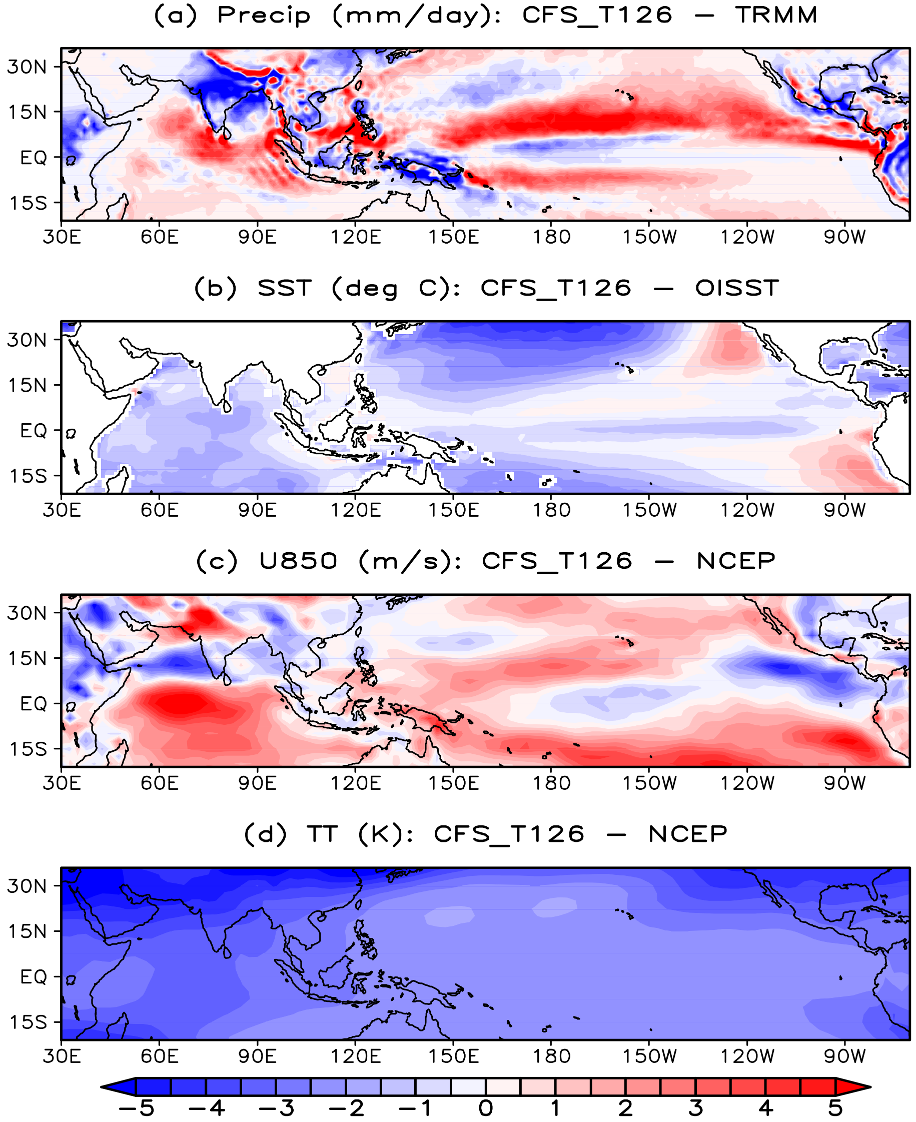
Inspite of contrasting bias, the rainfall bias in both the models are similar

- CFSv2T126 & CFSv2 T382 both produce too much frequency of lighter rainfall and shows dry bias over Indian land mass but northward propagation is reasonable in both.

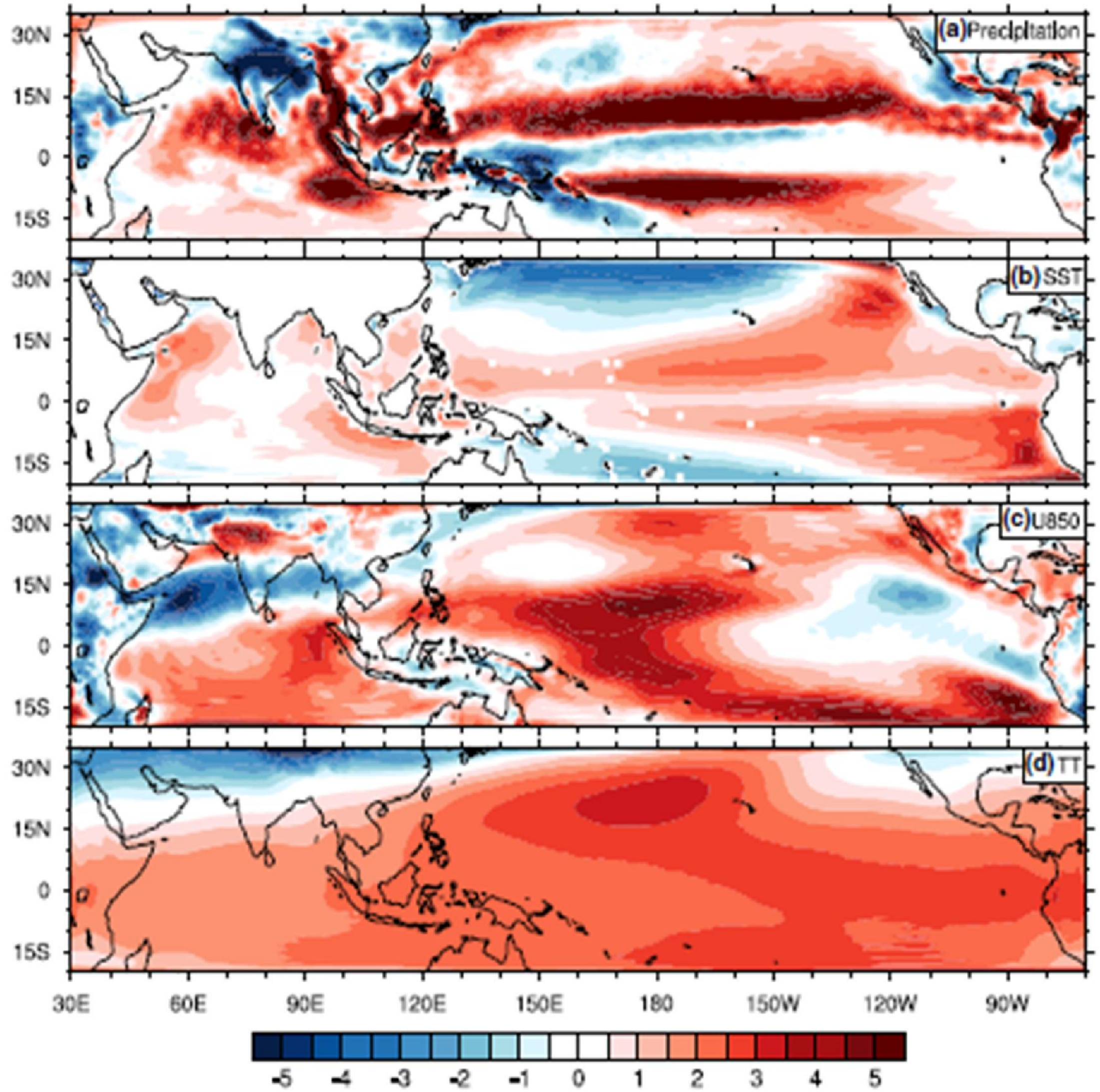
- CFSv2T126 & CFSv2 T382 both underestimates synoptic variance and overestimates ISO variance

- Diurnal Convective lifecycle is equally incorrect in CFSv2T126 & CFSv2 T382. (Deep convection is lacking)

CFSv2 T126 bias



CFSv2 T382 bias

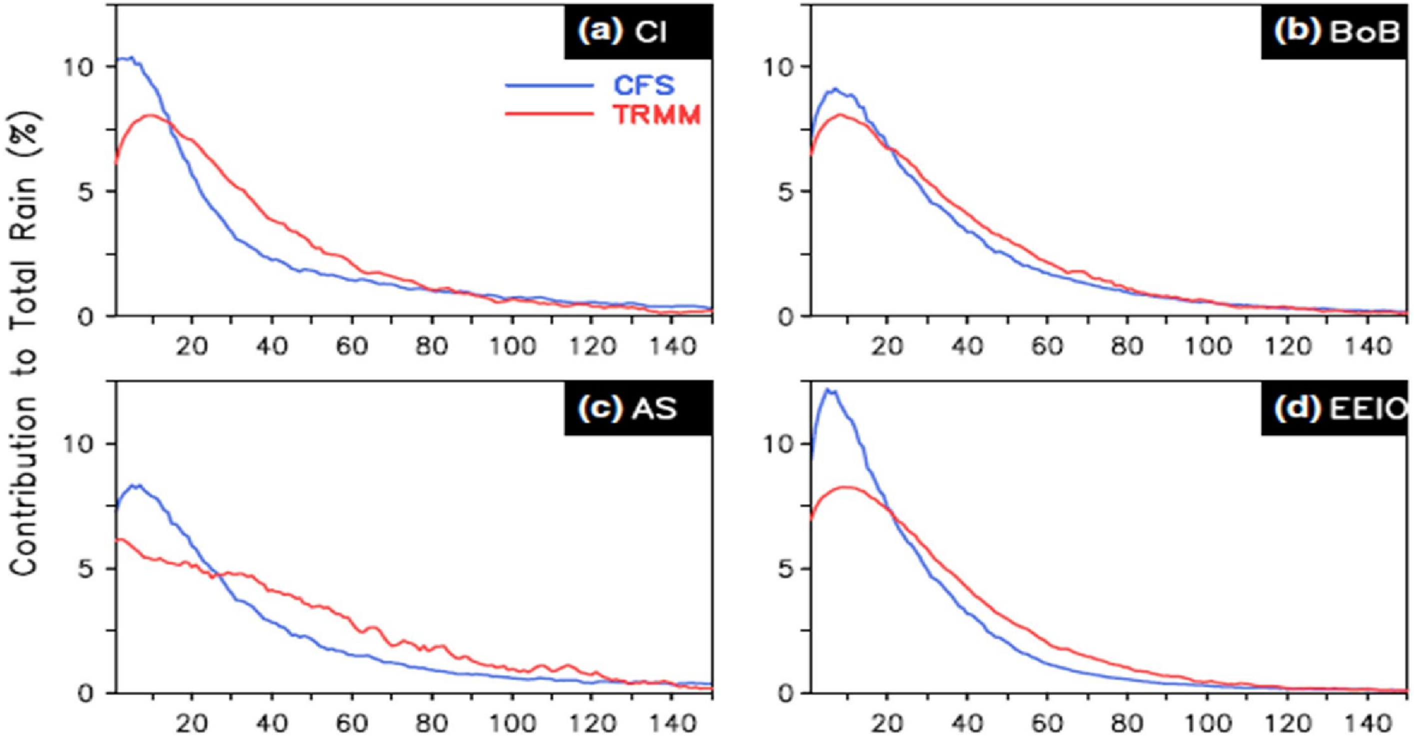


Seasonal mean bias in a) precipitation (mm day−1), b) SST (°C), c) zonal wind at 850 hPa (m s −1) and d) tropospheric temperature (TT, K) relative to TRMM, TMI and CFSR respectively

Abhik et al. Cli. Dyn. 2015, DOI 10.1007/s00382-015-2769-9

Fig. 4 Probability distribution function (PDF) of daily rainfall (mm day^{-1}) during all JJAS seasons with a bin width of 5 mm day^{-1} in percentage over **a** central India (CI), **b** Bay of Bengal (BoB), **c** Arabian Sea (AS) and eastern equatorial Indian Ocean (EEIO). The regions are marked by *white boxes* in Fig. 3b

CFSv2T382



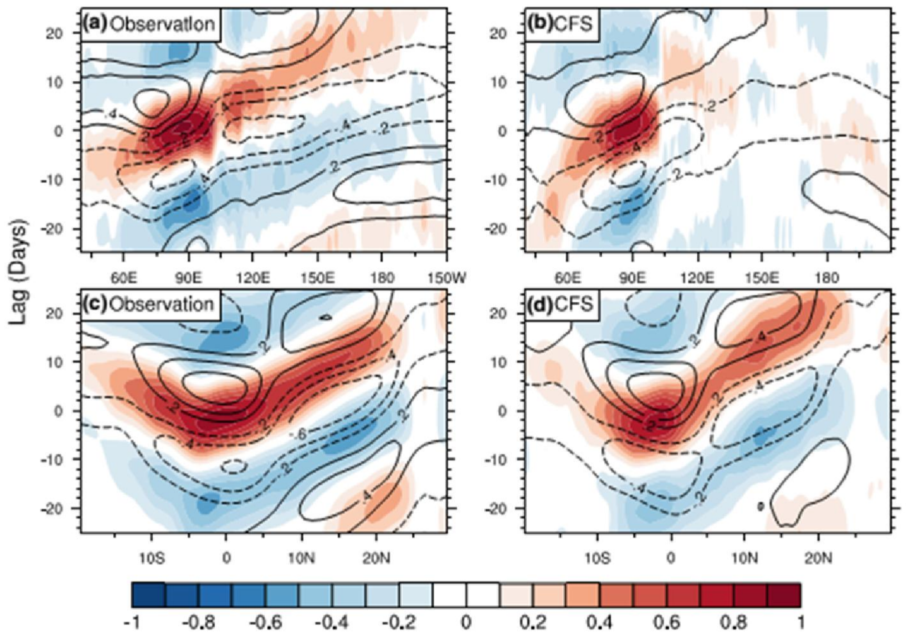
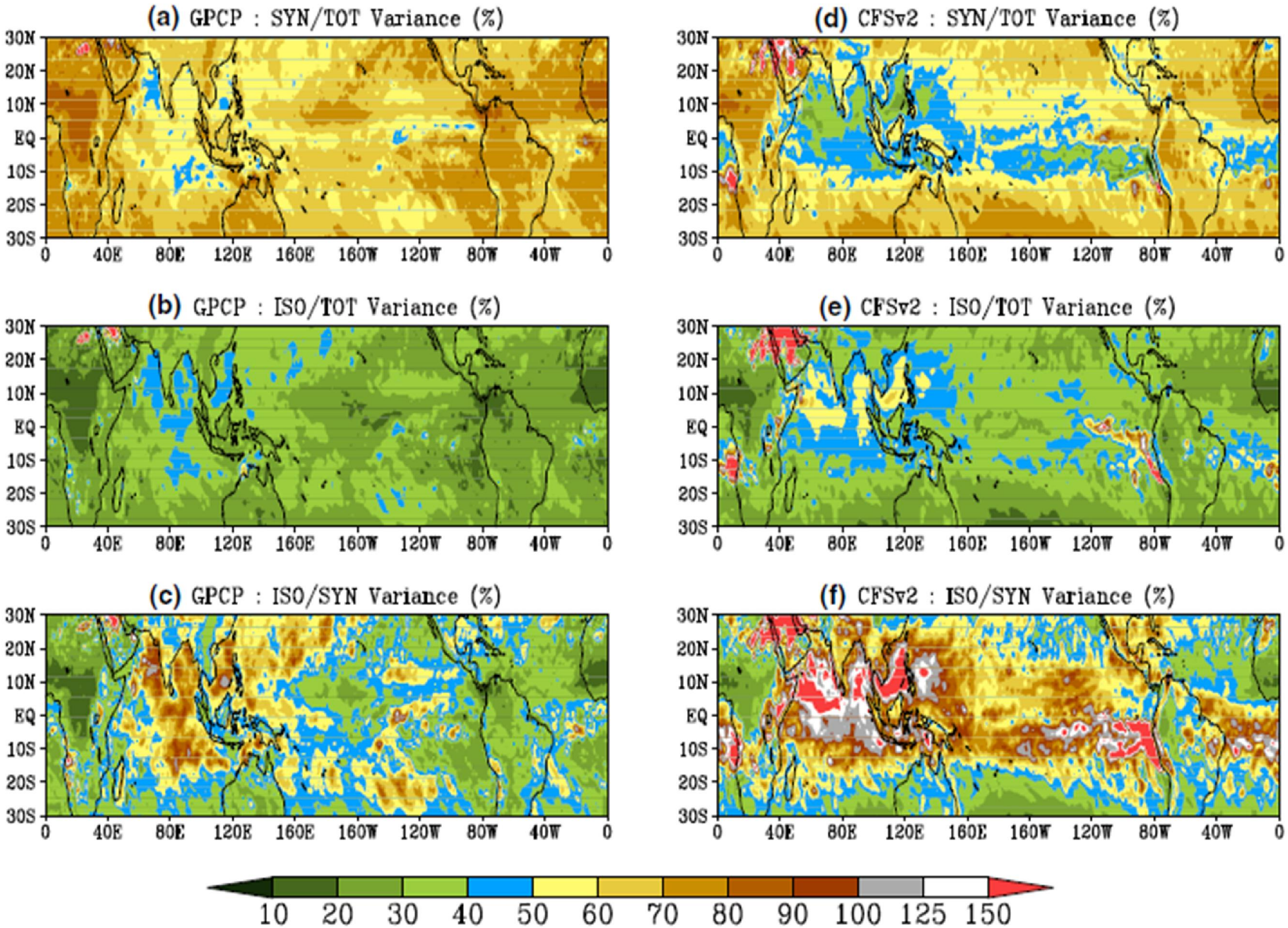


Fig. 8 **a**, **b** Longitude versus lag correlation and **c**, **d** latitude versus lag correlation of 20–100-day filtered precipitation (*shaded*) and U_{850} (*contour*) with base 20–100-day filtered precipitation time series over EEIO (10°S–5°N, 75°–100°E) for observation and CFS T382. For longitude-lag (latitude-lag) plot data are averaged between 70°E and 90°E (10°S and 10°N)

Abhik et al. 2015

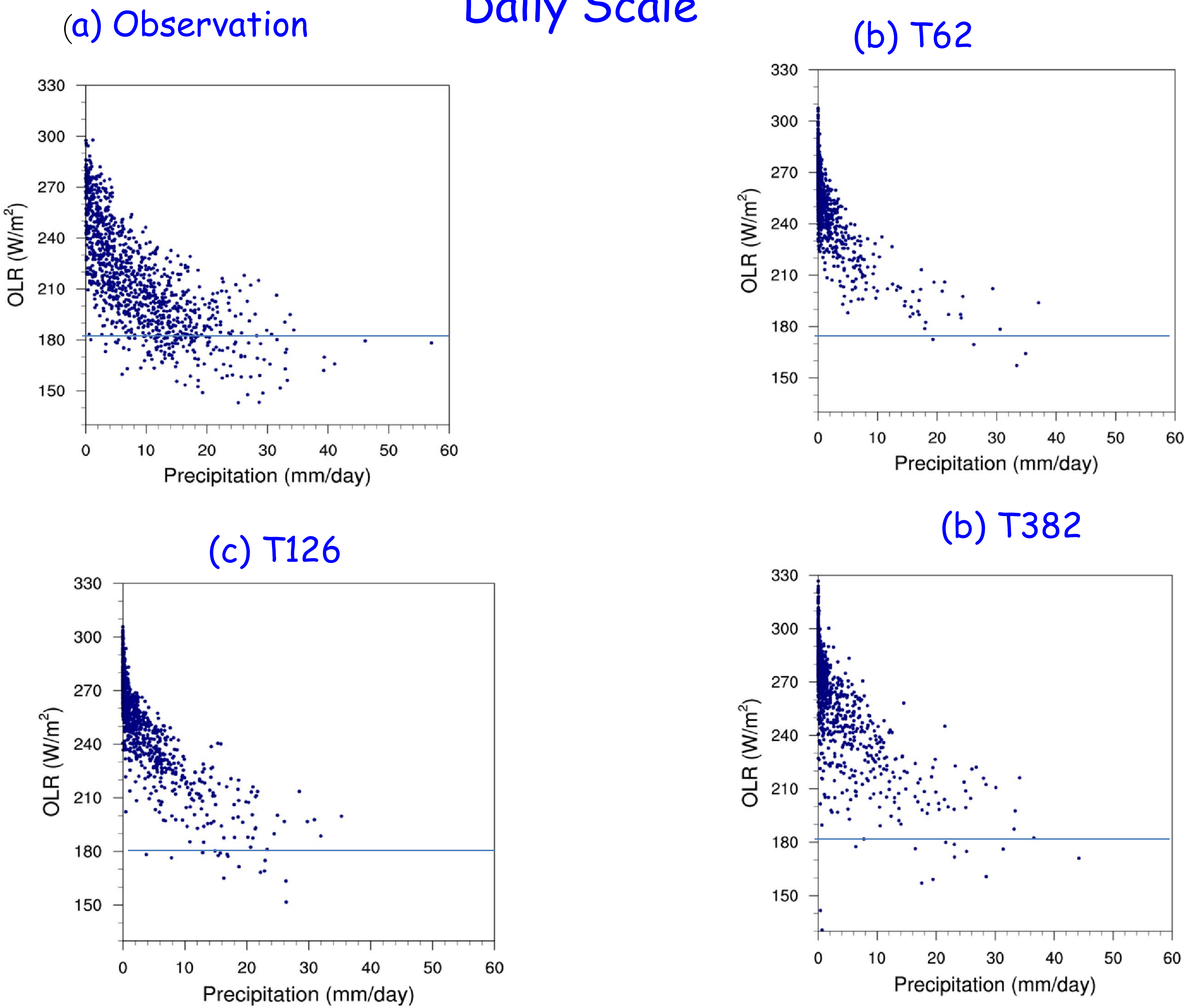


Goswami et al. 2014

CFSV2 T126: Less synoptic variance and more ISO variance

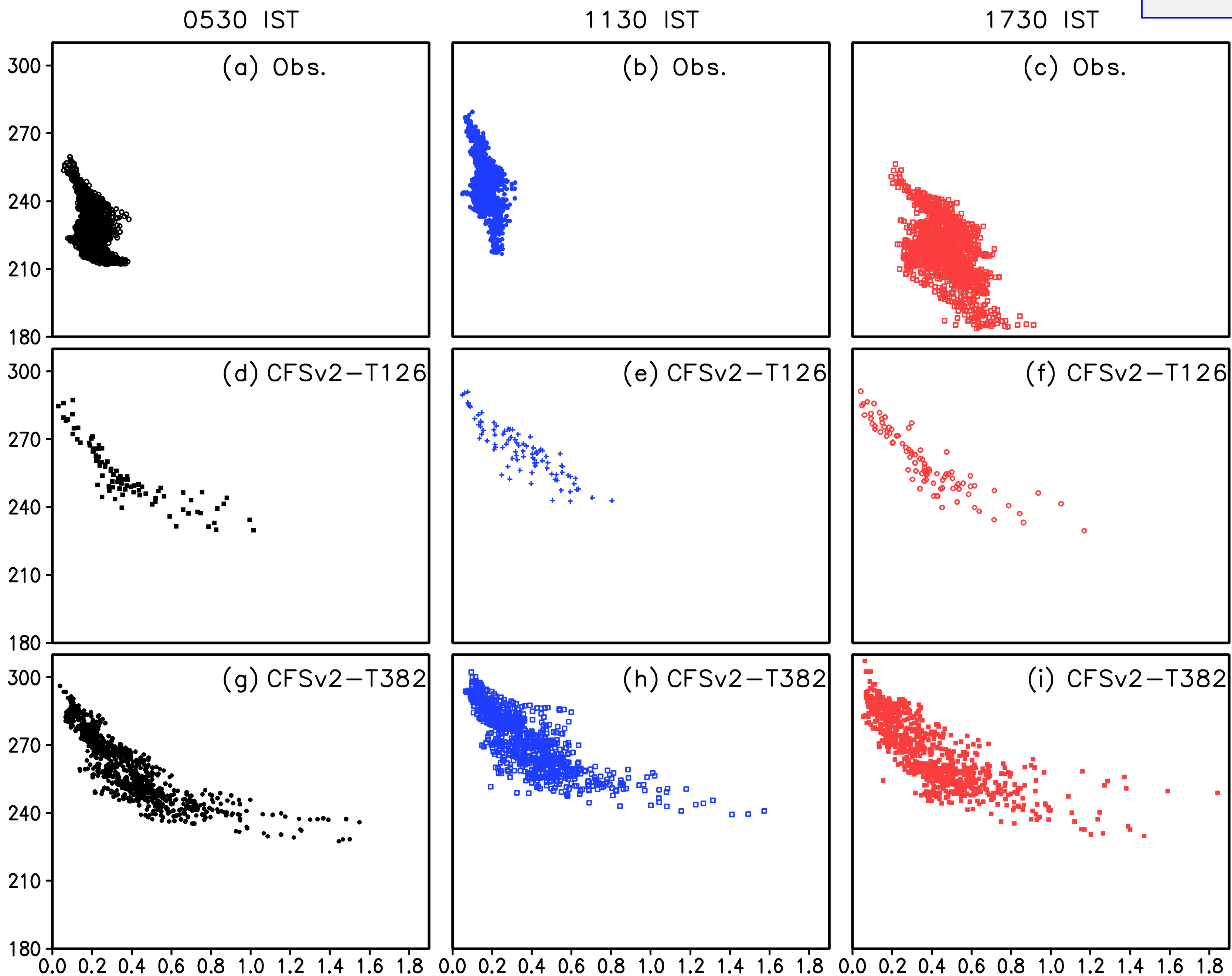
a) Ratio of synoptic scale (2–10 day bandpassed) variance to total variance in GPCP; b) ratio of ISO scale (10–90 day bandpassed) variance to total variance in GPCP; c) ratio of ISO scale variance to synoptic scale variance in GPCP; d) ratio of synoptic scale variance to total variance inCFSv2. e) Ratio of ISO scale variance to total variance in CFSv2; f) ratio of ISO scale variance to synoptic scale variance in CFSv2 (the values are given in percentage)

Daily Scale



Scatter plot of OLR vs Precipitation for JJAS monsoon zone India. OLR is taken from NOAA and precipitation from TRMM

Diurnal Issue



Scatter plot of OLR vs rainrate

Both the model produces shallow convection throughout the day consistent with too much of lighter precipitation

Ganai et al. 2015

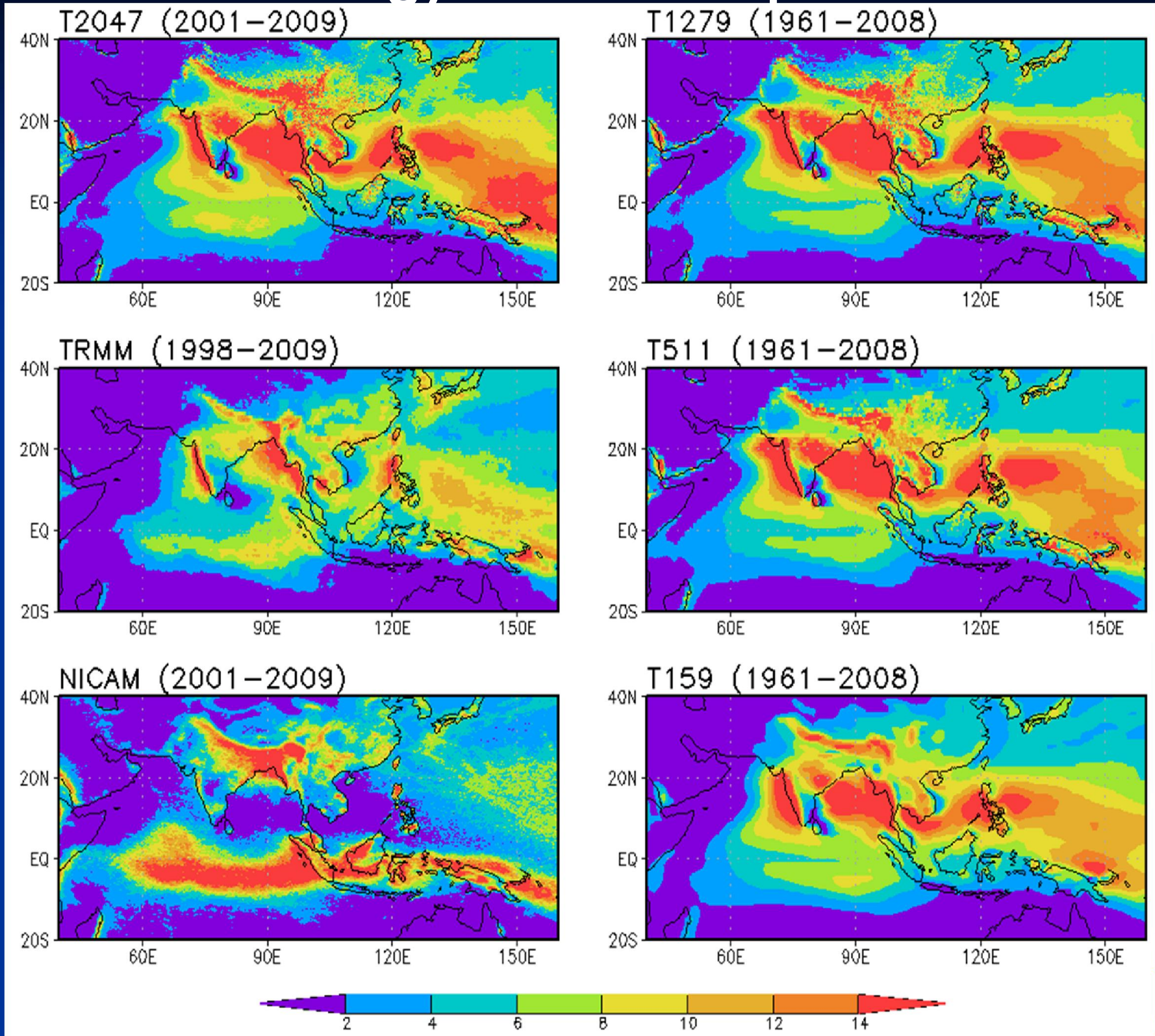
Kinter etal 2013

Climatology of JJA Precipitation

IFS T12047
10 km

TRMM
25km

NICAM
7 km



IFS T1279
15 km

IFS T1511
39km

IFS T1159
125 km

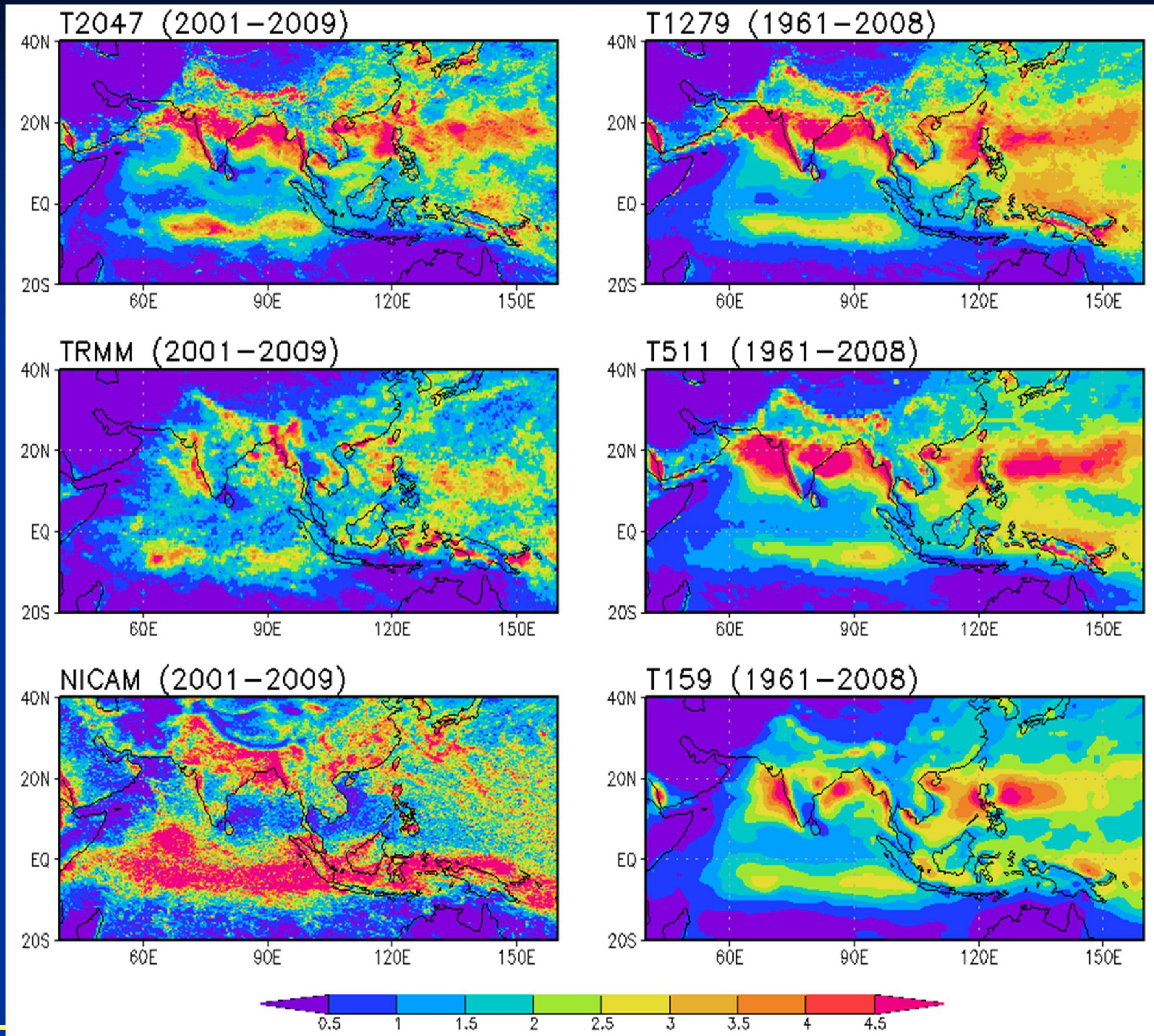
Adopted from Emilia Jin, Athena Workshop, ECMWF, 7-8 June 2010

Standard Deviation of JJA Precipitation Anomalies

IFS T12047
10 km

TRMM
25km

NICAM
7 km



IFS T1279
15 km

IFS T1511
39km

IFS T1159
125 km

Adopted from Emilia Jin, Athena Workshop, ECMWF, 7-8 June 2010

Arakawa and Wu, 2013

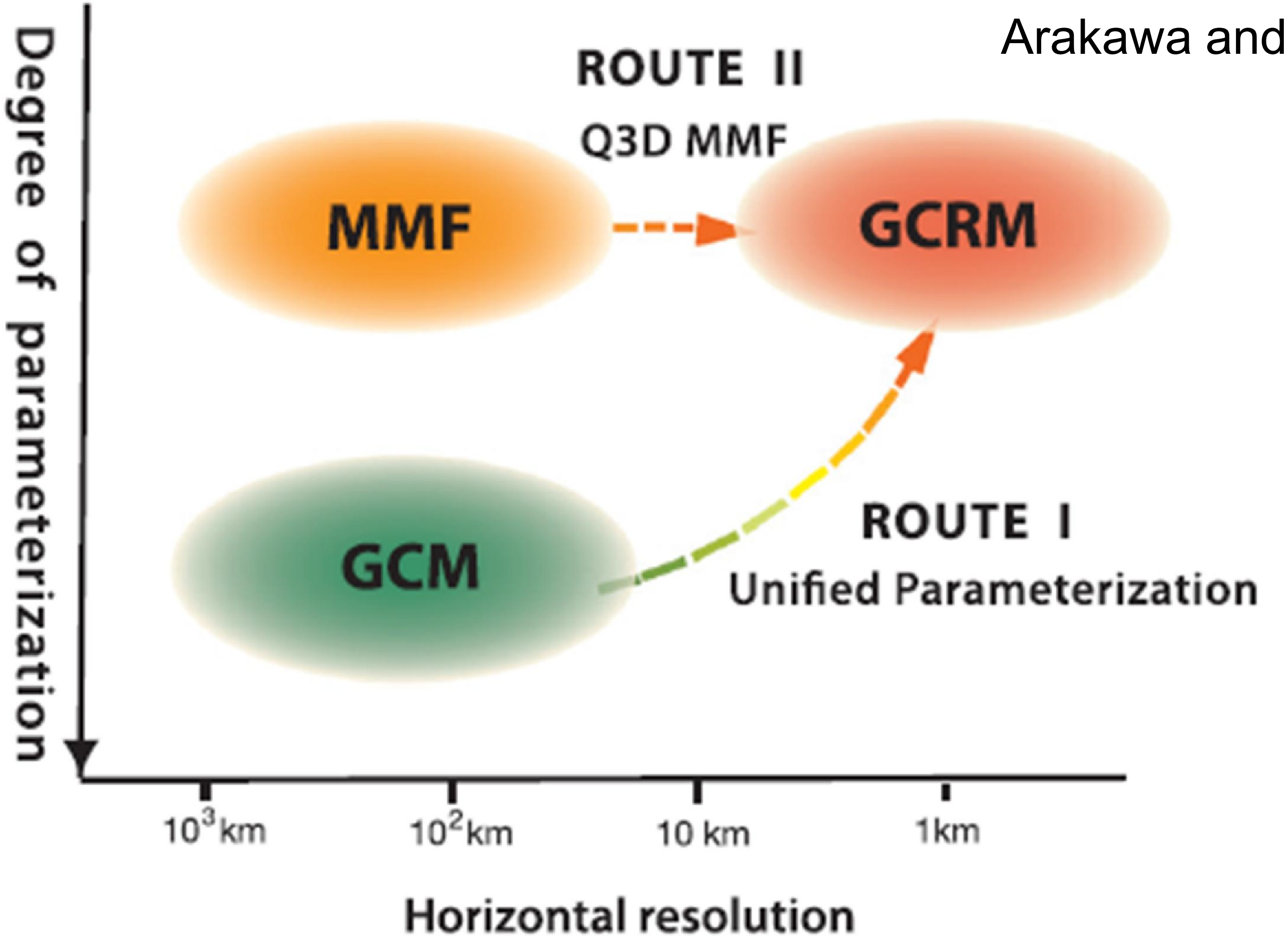


FIG. 3. Two routes for unifying the low- and high-resolution models.

Route II with 2D MMF: accomplished in IITM through development of SP-CFS

Attempts of Improving the biases of CFSv2 through Superparameterized CFS (SP-CFS)

Bidyut B. Goswami, R. P. M. Krishna, P. Mukhopadhyay, Marat Khairoutdinov, and B. N. Goswami, 2015: Simulation of the Indian Summer Monsoon in the Superparameterized Climate Forecast System Version 2: Preliminary Results. J. Climate, 28, 8988–9012

Early Online Releases

Journal of Climate

Current Issue
Available Issues
Early Online Releases
Author Index
Share this Article

Share |

Journal Information

Online ISSN: 1520-0442
Print ISSN: 0894-8755
Frequency: Semimonthly

< Previous Article Next Article >

Add to Favorites Email Download to Citation Manager Track Citations Glossary
Permissions

PDF

Journal of Climate 2015 ; e-View
doi: http://dx.doi.org/10.1175/JCLI-D-14-00607.1

Simulation of the Indian Summer Monsoon in the Superparameterized Climate Forecast System version 2: Preliminary Results

BIDYUT B. GOSWAMI,[1] R.P.M. KRISHNA,[2] P. MUKHOPADHYAY,[2] MARAT KHAIROUTDINOV,[3] and B. N. GOSWAMI[4]

[1] *Department of Mathematics and Statistics, University of Victoria, Canada*

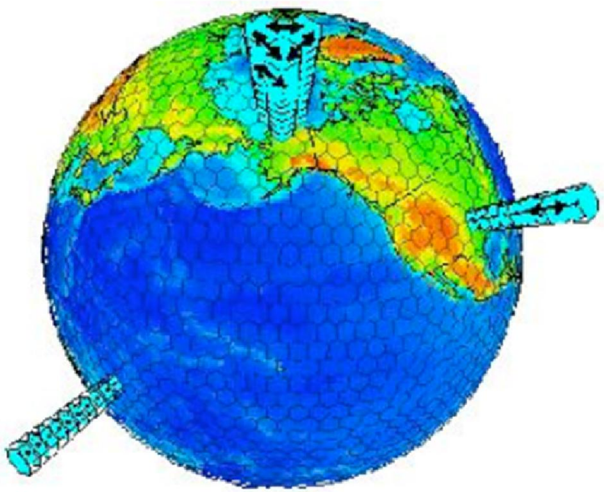
[2] *Indian Institute of Tropical Meteorology, Pune-411008, INDIA*

[3] *School of Marine and Atmospheric Sciences, New York University, Stony Brook, USA*

[4] *Pisharoty Chair Professor, MoES, Indian Institute of Science Education and Research, Pune-411008, INDIA*

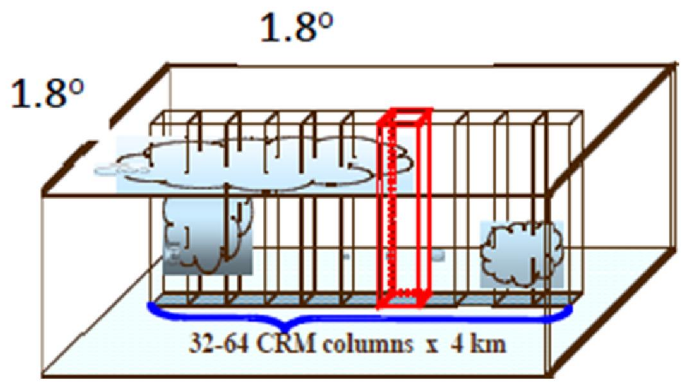
Super-parameterization-New Approach of treating cloud in GCM

Single-Column (of GCM) Modeling (SCM)

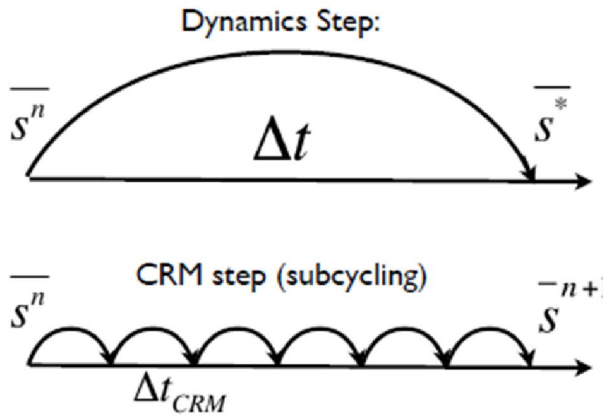


$$\frac{\partial \bar{s}}{\partial t} = \underbrace{-\overline{\nabla s V} - \frac{\partial \bar{s}\bar{\omega}}{\partial p}}_{LSForcing} + \underbrace{Q_1}_{Param's}$$

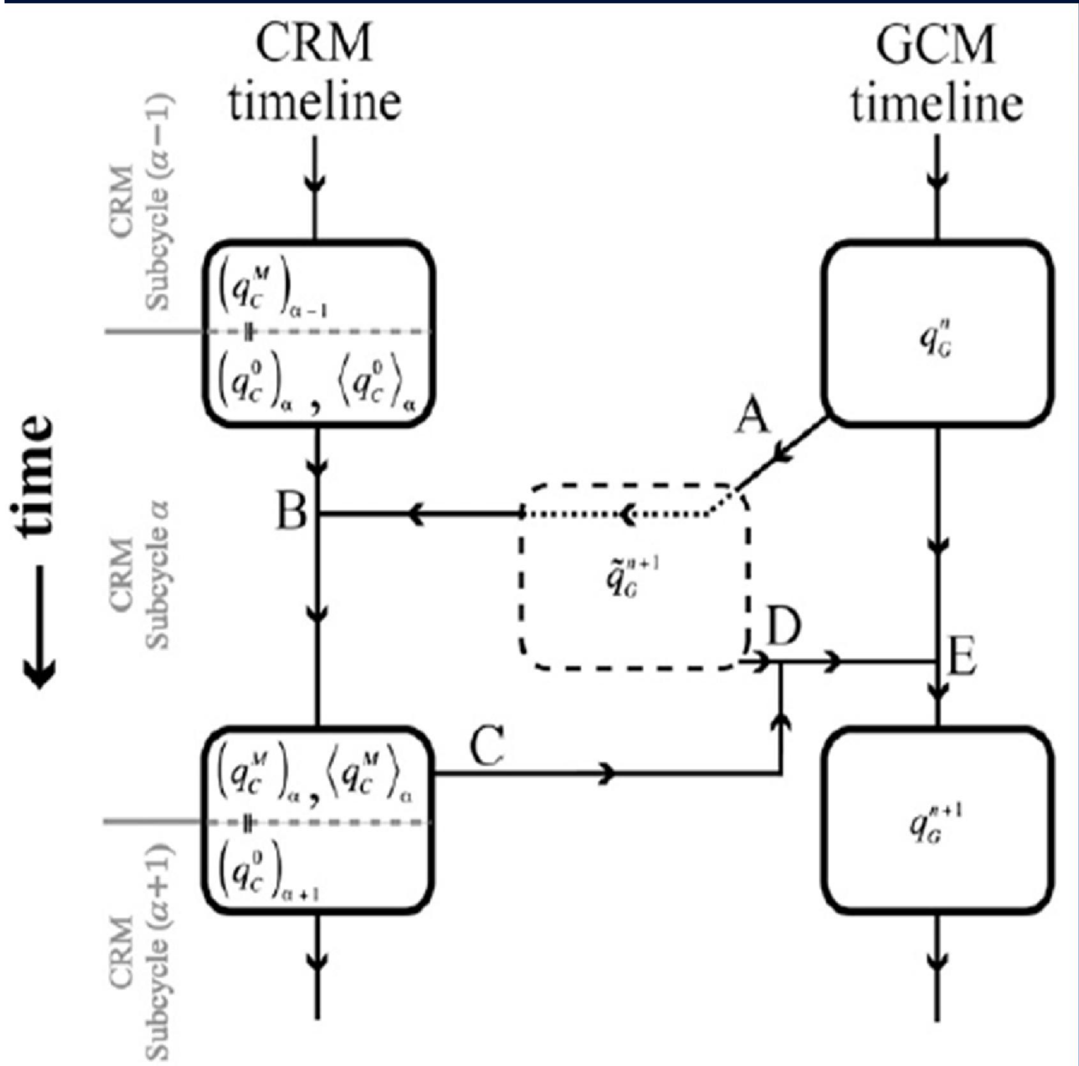
$$\frac{\partial \bar{q}}{\partial t} = \underbrace{-\overline{\nabla q V} - \frac{\partial \bar{q}\bar{\omega}}{\partial p}}_{LSForcing} - \underbrace{Q_2/L}_{Param's}$$



Traditionally, the large-scale forcing data would come from observations (GATE, TOGA, ARM, KWAJEX, etc.)



The Concept of Superparameterization



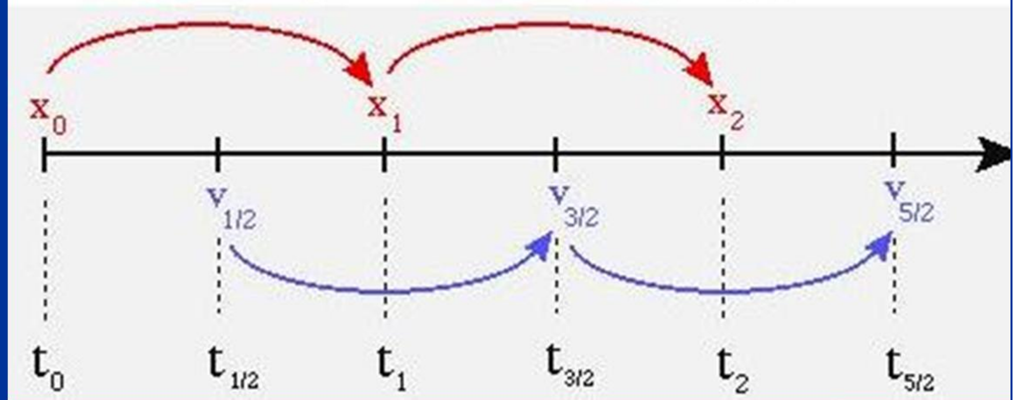
BENEDICT AND RANDALL, JAS 2009

Requirement for CFS for Leap-Frog

$$v_{x,n+\frac{1}{2}} = v_{x,n-\frac{1}{2}} + \Delta t\, a_x(x_n, y_n, t)$$

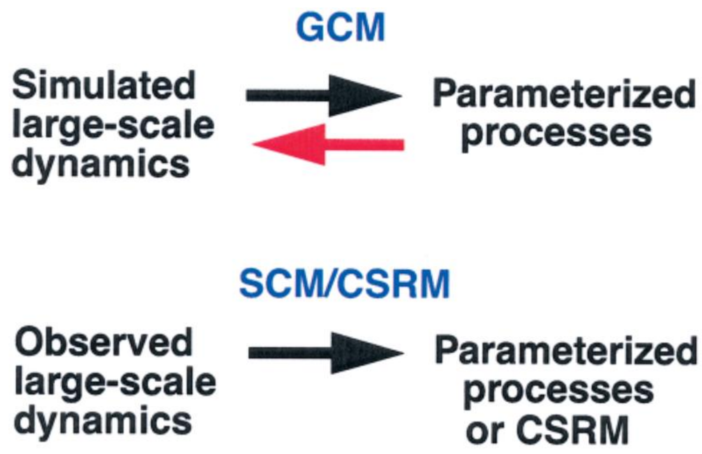
$$x_{n+1} = x_n + \Delta t\, v_{n+\frac{1}{2}}$$

$$v_{x,\frac{1}{2}} = v_0 + \frac{\Delta t}{2} a_x(x_0, y_0, 0) + \left(\frac{\Delta t}{2}\right)^2 \frac{\partial a_x}{\partial x}\Big|_{(x_0,y_0,0)}$$

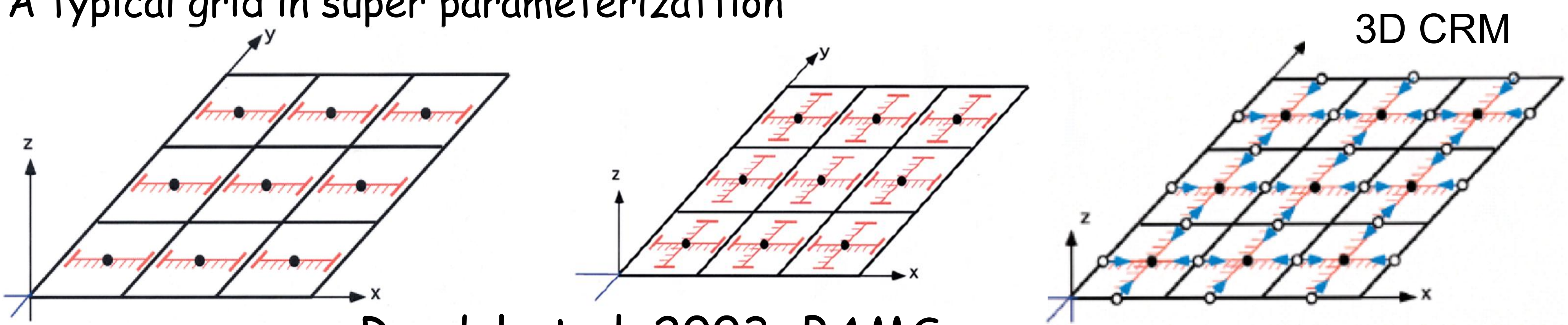


About Superparameterization

- The concept first put forward by Grabowski (2001, JAS) and Khaidrotdinov and Randal (2001, GRL). KR01 has coined the word 'Super parameterization'
- Randal et al (2003, BAMS)

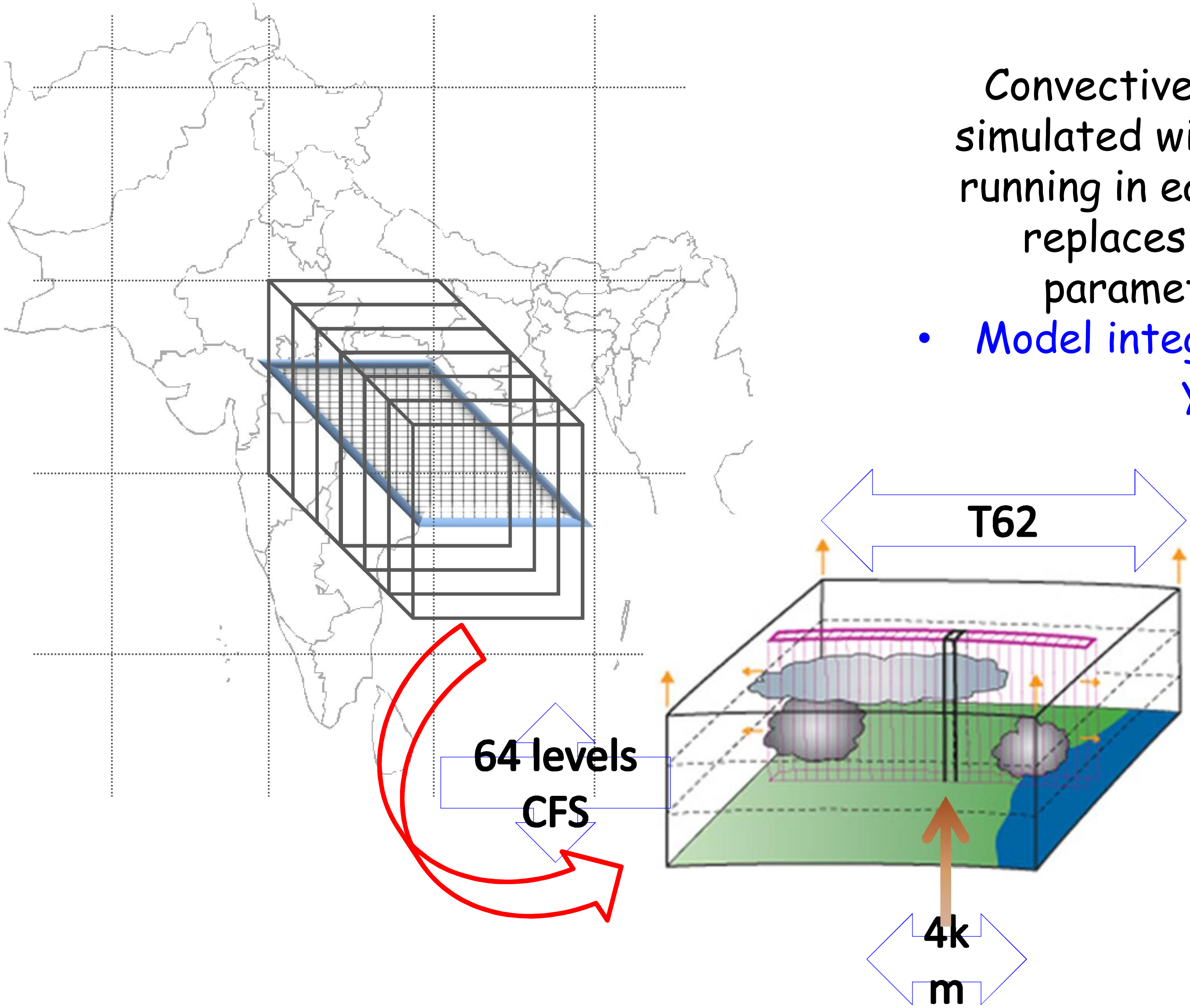


A typical grid in super parameterizattion



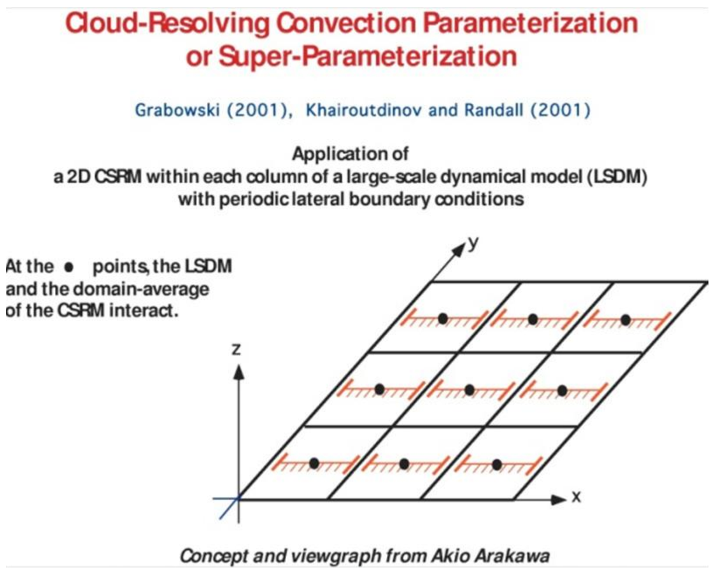
Randal et al. 2003, BAMS

Superparameterized CFSv2-T62 **(SPCFS) Analyses of 6.5 year free run**

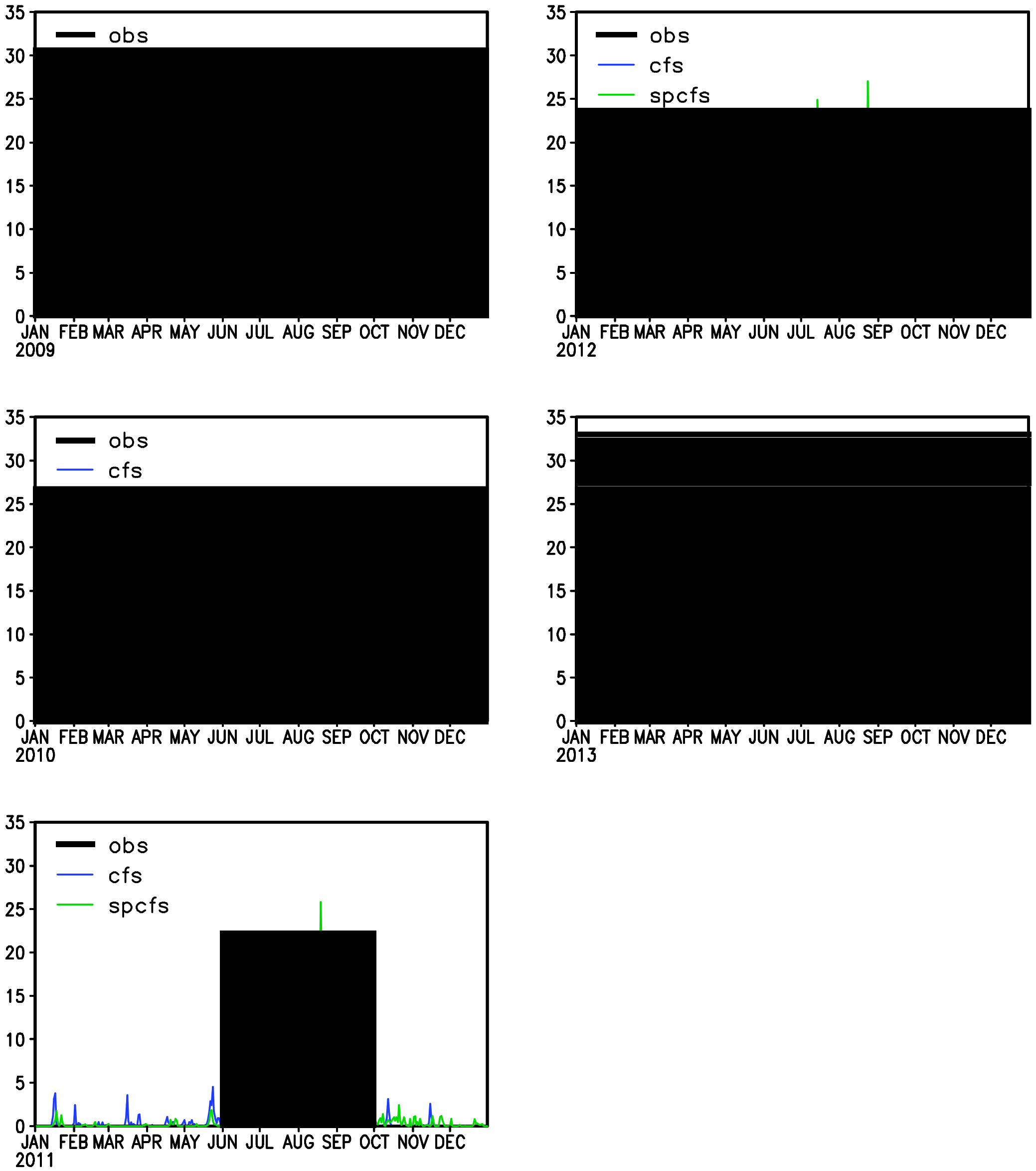


Convective tendencies are explicitly simulated with a **C**loud **R**esolving **M**odel running in each GCM grid column which replaces the traditional cumulus parameterization of the GCM.

- *Model integrated for 6.5 years and five years are analyzed*

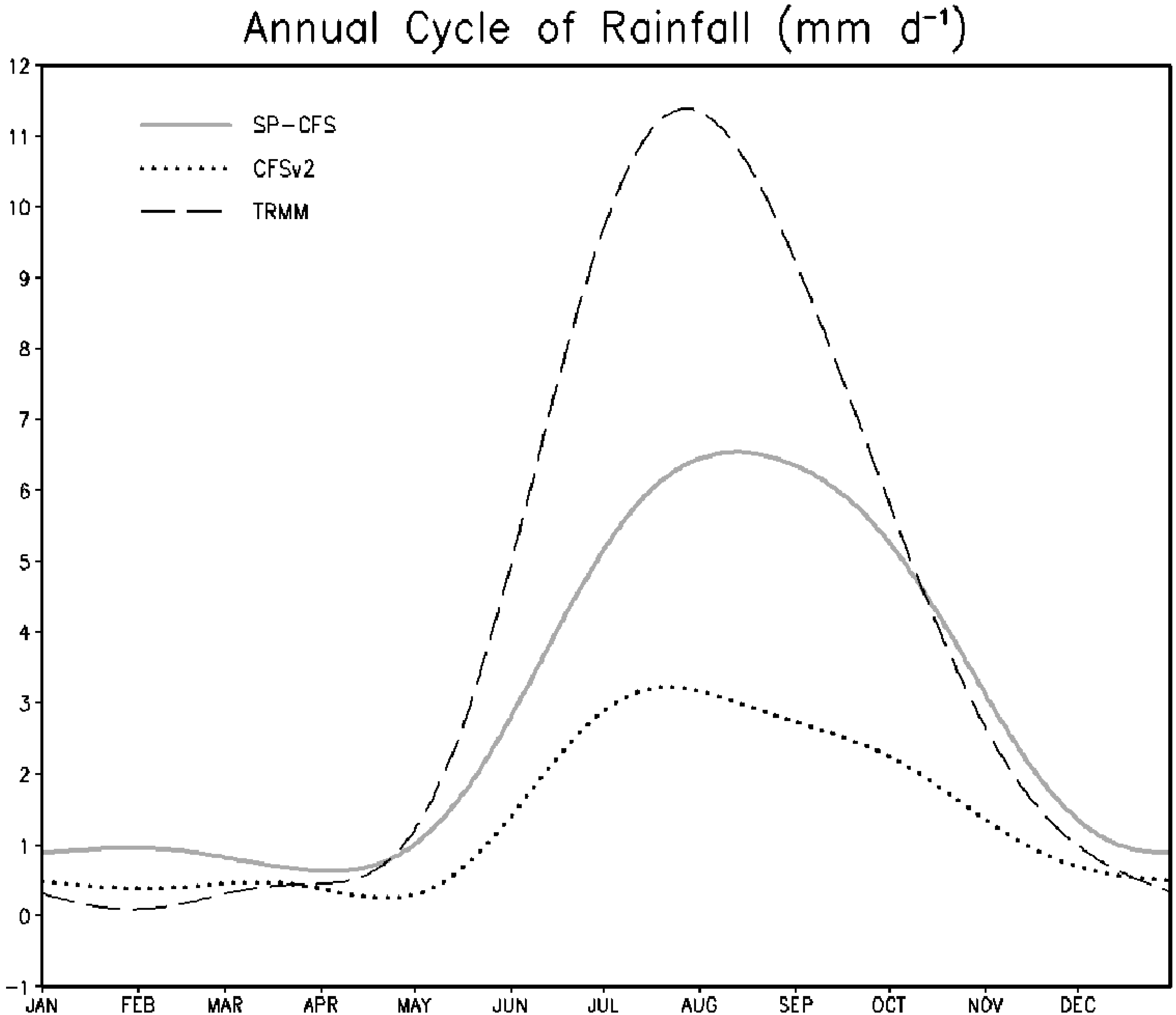


The rainfall is averaged over : 73-82E; 18-28N



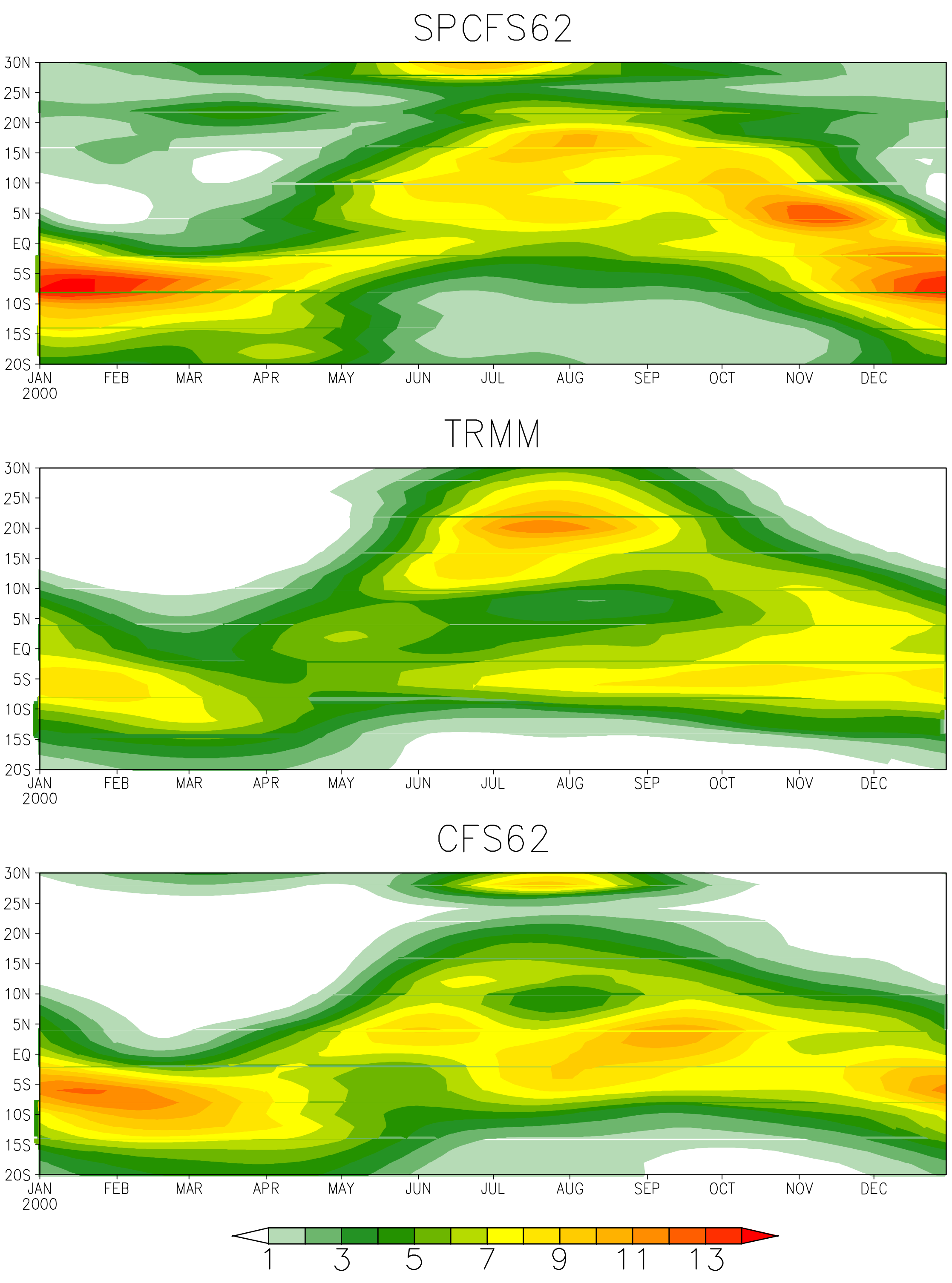
SP-CFS produces reasonable rain, CFS hardly rains

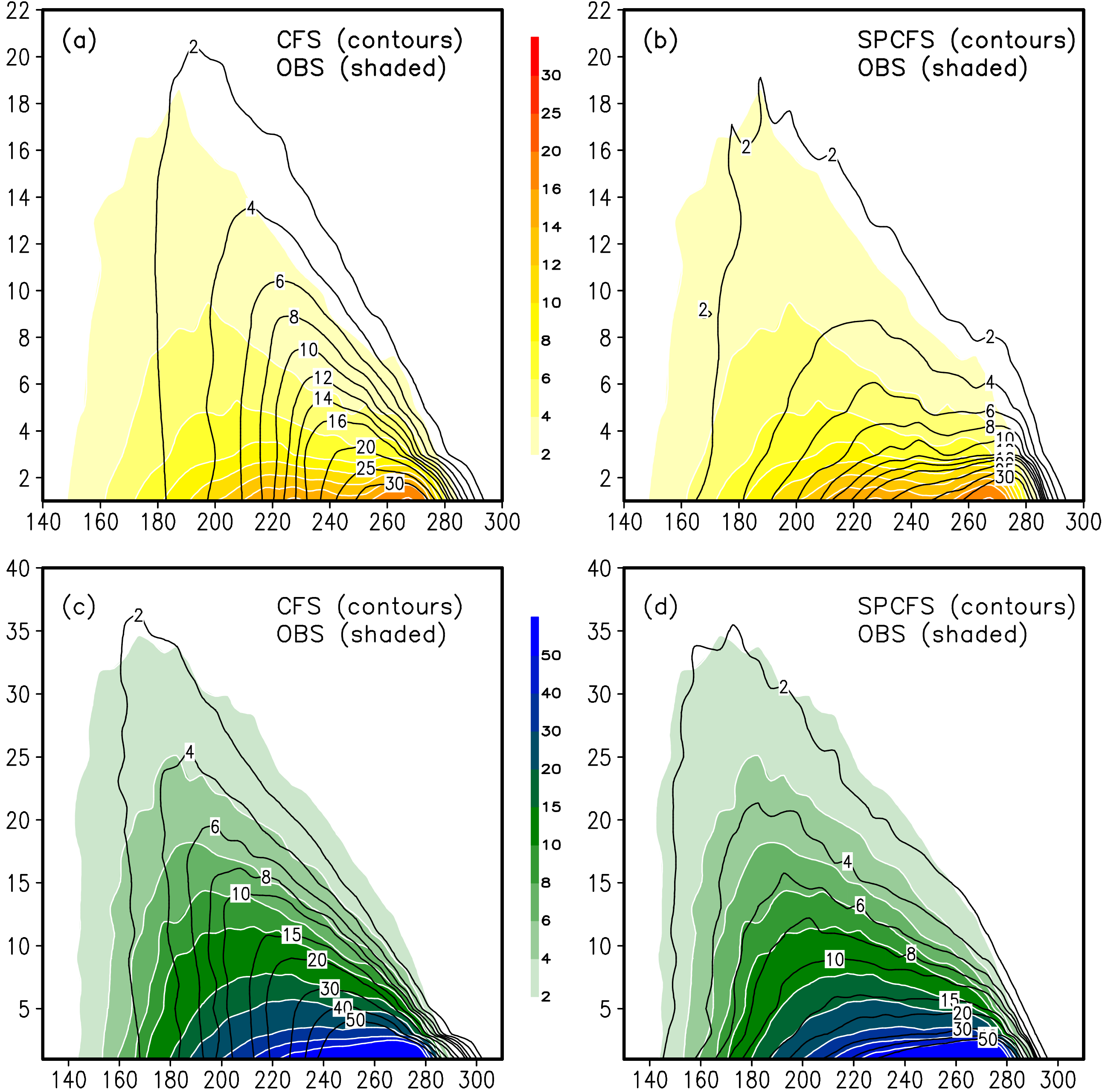
The Standard Dev for JJAS (5 years) :
IMD=5.01
SPCFS=4.33
CFS=1.8



Annual cycle of the climatological mean rainfall (mm day^{-1}) averaged over the area: 15°N-25°N; 75°E-90°E.

Northward migration of ITCZ is much better captured in SP-CFS

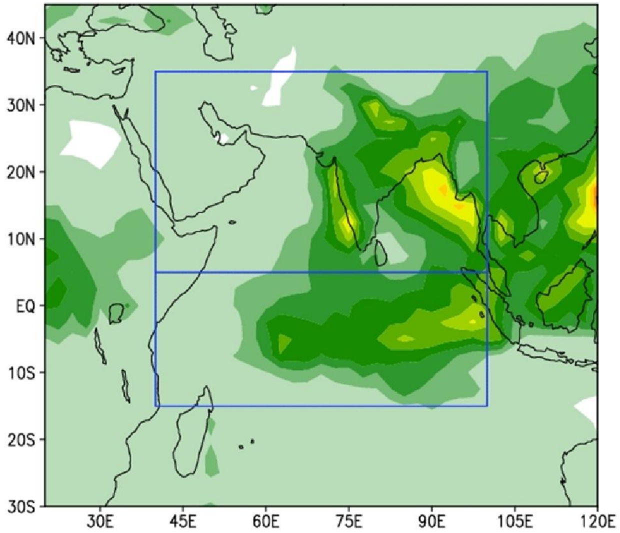


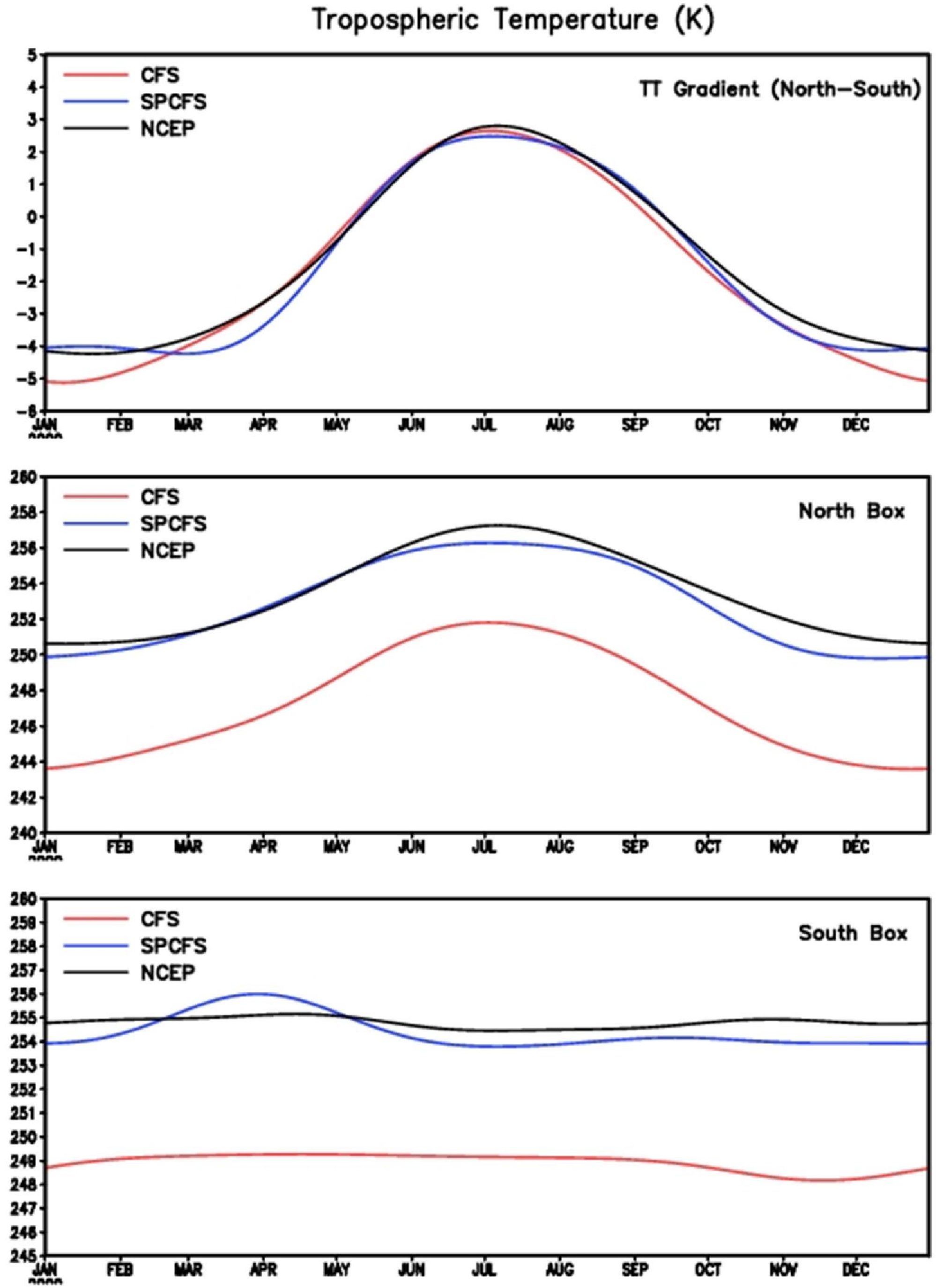


Joint distribution of rainfall (mm day^{-1}), along y-axis, and OLR (W m^{-2}), along x-axis, computed for each grid point, (a) & (b) over the monsoon domain bounded by 15°S-30°N and 50°E-110°E and (c) & (d) over the entire Tropics within 15°S-15°N, for the 5 boreal summers (JJAS). For observation we have taken TRMM rainfall and NOAA OLR. Model simulated values are contoured and overlaid on observation (in shading). The values are in multiples of 100.

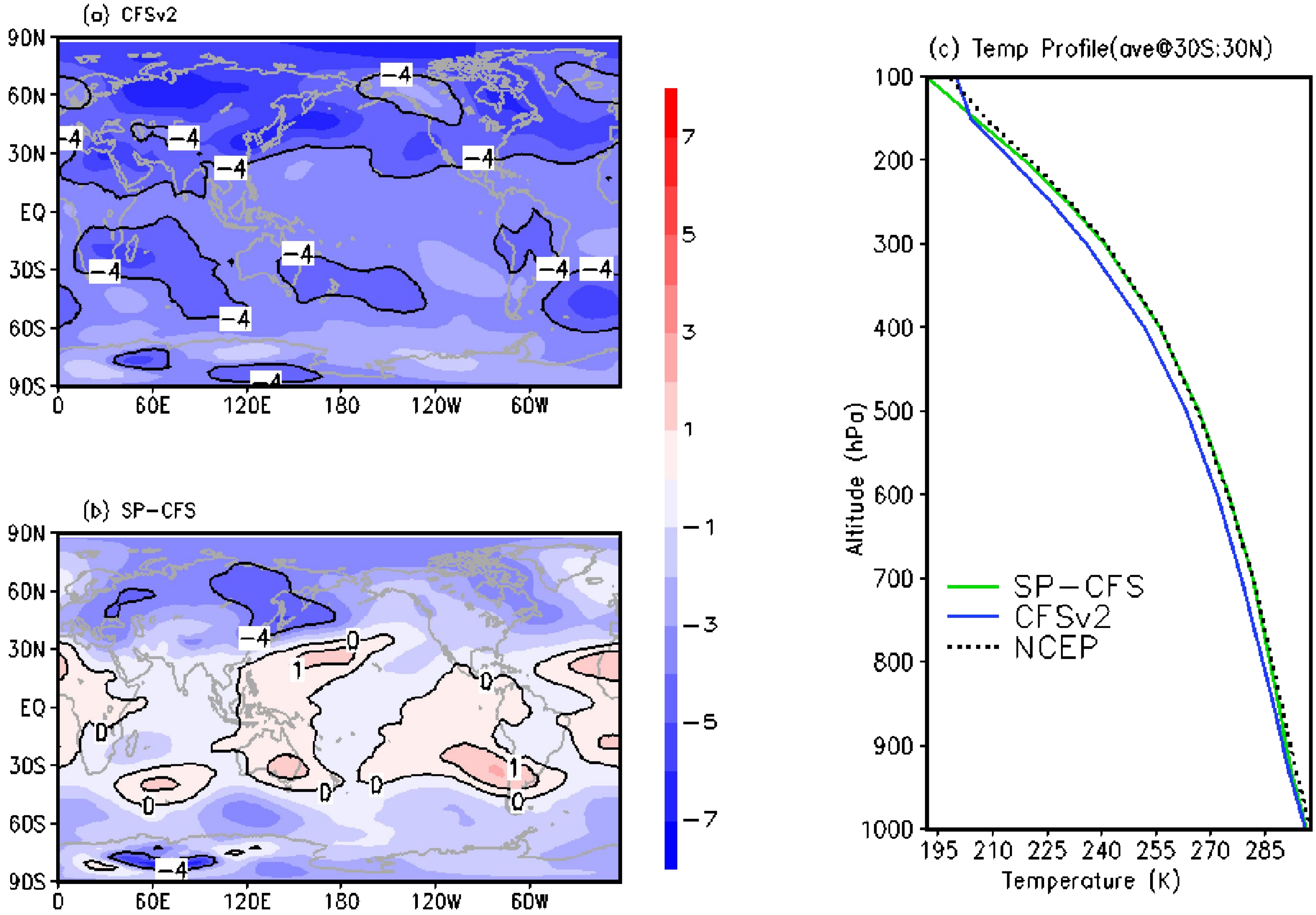
North box : 40-100E; 5-35N
South box : 40-100E;15S-5N
600-200hPa (Xavier et. al. 2007)

Right result due to wrong reason in CFSv2



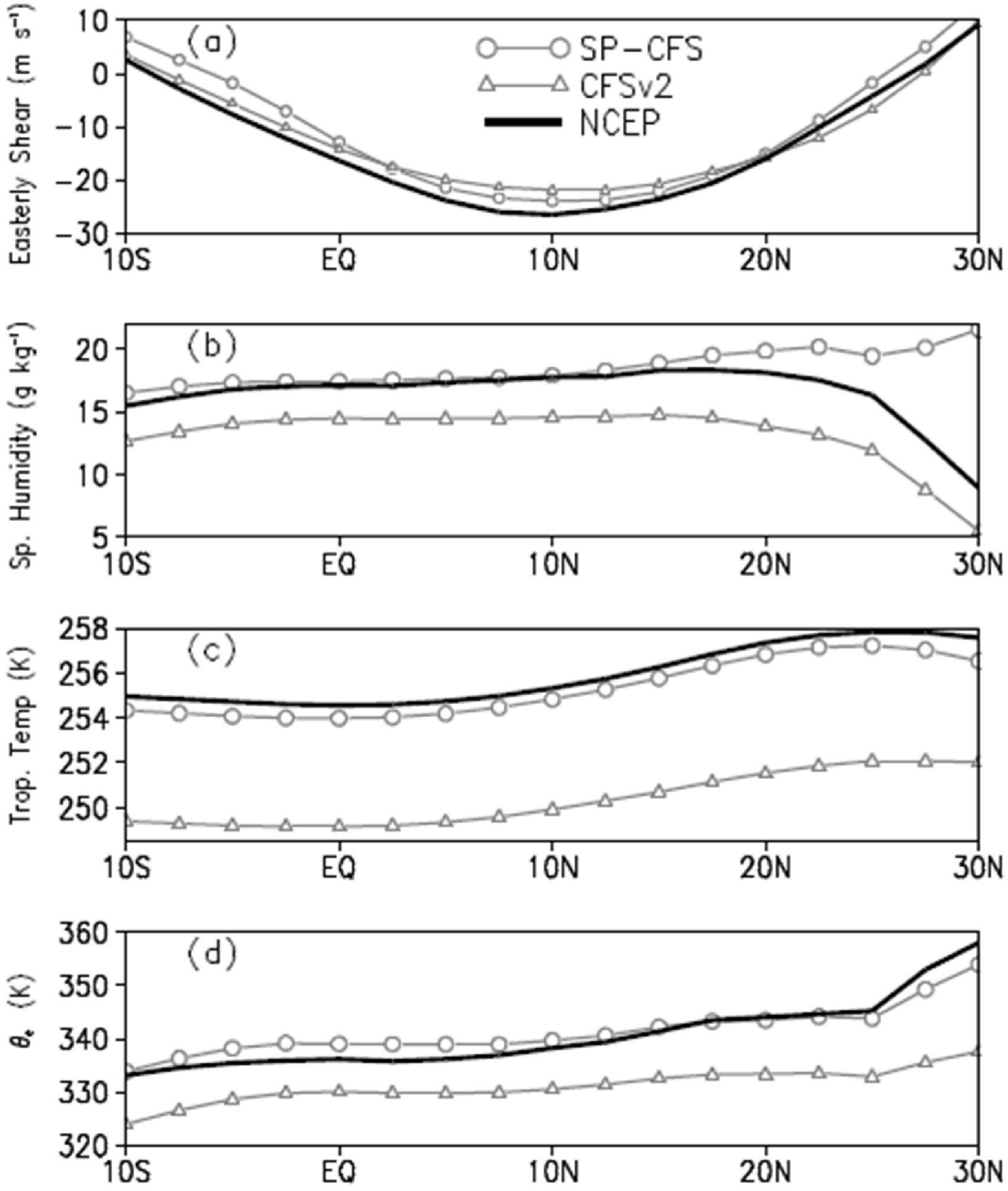


Improvement in tropospheric temperature bias is seen in TT gradient. Even though the Gradient looks reasonable in both CFS and SPCFS, but the bias is seen when we see the North and South boxes individually. The TT-gradient in a cooler background in CFS perhaps is consistent with reasonable circulation pattern (Fig-12 in manuscript) but deficient moisture (Fig-13b in manuscript) leading to dry monsoon.

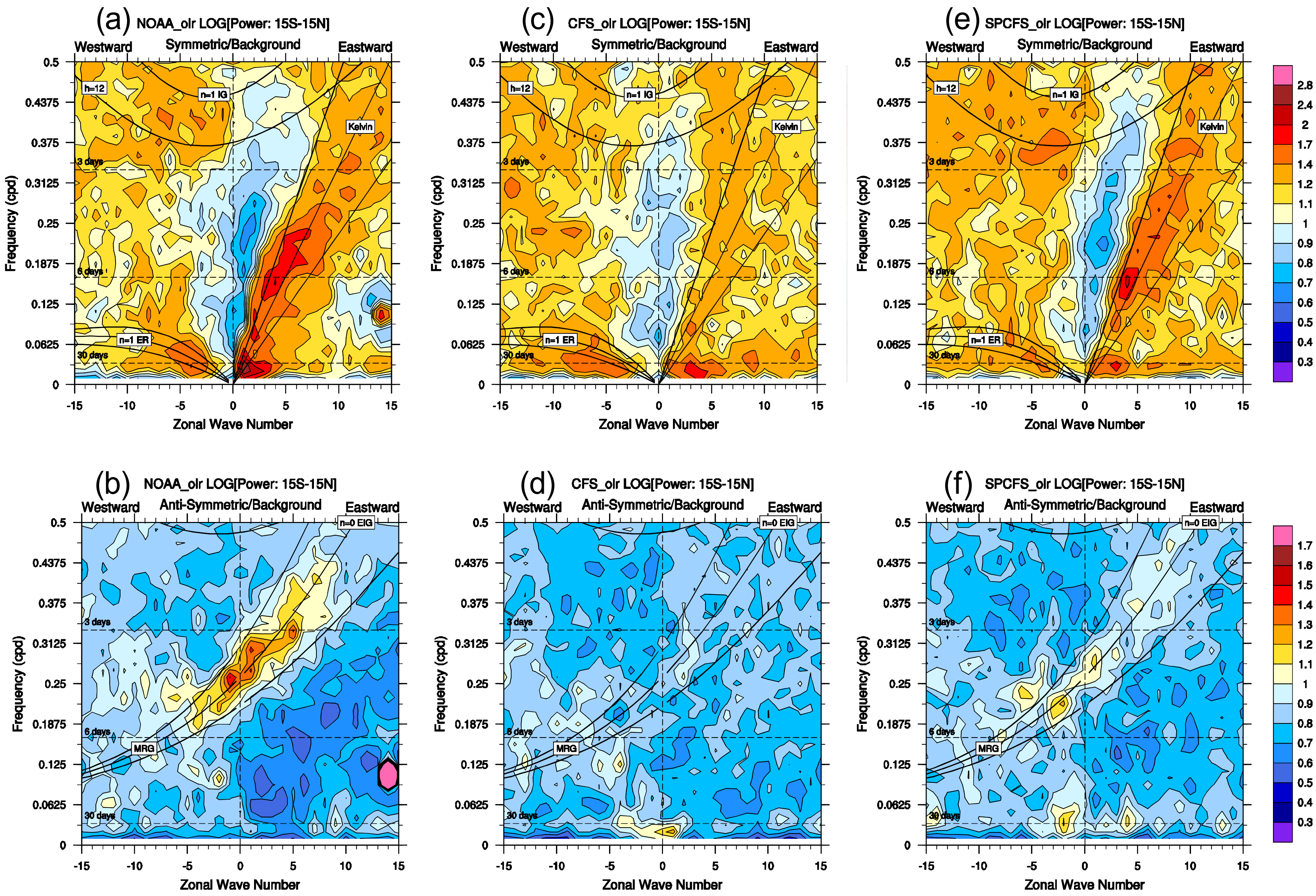


Boreal summer (JJAS) climatological Tropospheric temperature bias of (a) CFSv2 and (b) SP-CFS, relative to NCEP. (Averaged between 600hPa-300hPa). (c) Vertical profile of JJAS mean climatological temperature for tropics (30°S-30°N; 0°E-360°E).

Mean state in SP-CFS has improved due to improvement in moist instability and convective coupling as evident in the subsequent slides

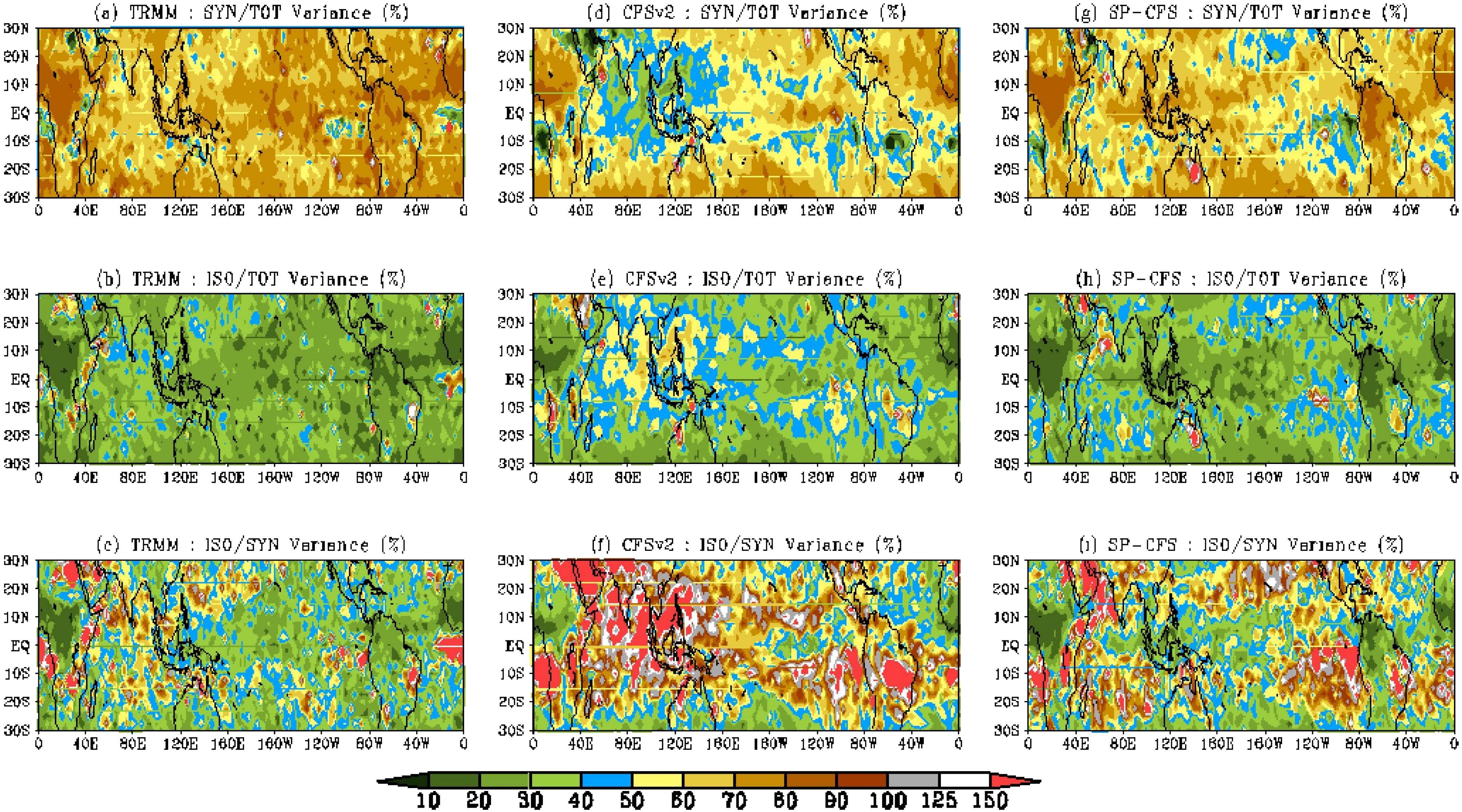


Climatological Seasonal mean meridional distribution of (a) easterly wind shear (U200–U850, m s-1), (b) surface level specific humidity (g kg-1), (c) tropospheric temperature (averaged between 200 and 600 hPa) and (d) equivalent potential temperature (averaged between 1000 to 850 hPa and 65° to 95°E.



Space-Time spectra (Wheeler-Kiladis diagram [Wheeler and Kiladis, 1999]) of OLR showing the symmetric component for (a) NOAA OLR, (c) CFSv2 and (e) SP-CFS and the anti-symmetric component for (b) NOAA OLR, (d) CFSv2 and (f) SP-CFS.

Ratio of Synoptic to ISO variance.



SP-CFS has improved the bias in synoptic and ISO variance

Super-parameterized GCMs

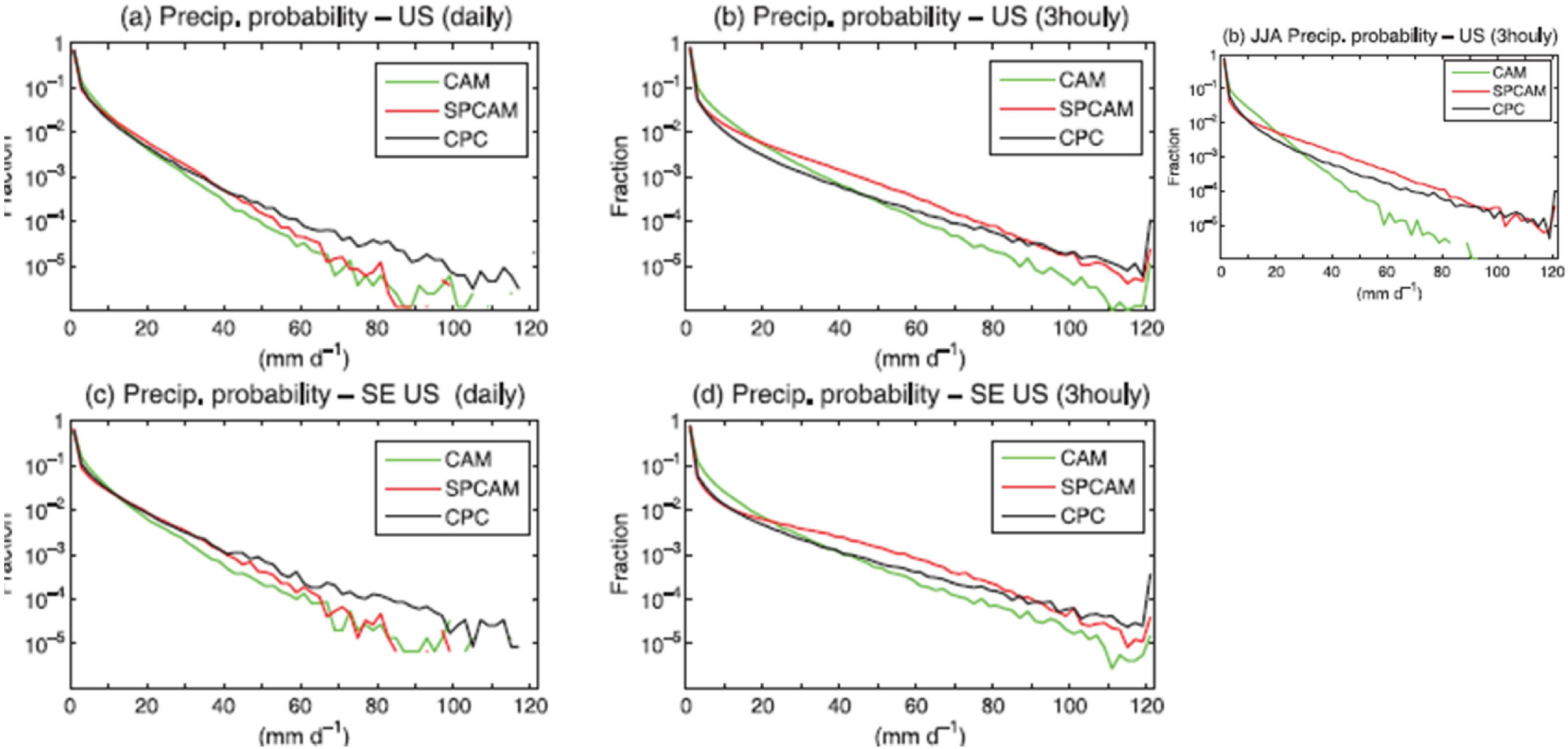
- **2001: SP-CAM**
- **2007: SP-fvGCM: NASA GSFC (Wei-Kuo Tao)**
- **2010: SP-WRF: (Stefan Tulich)**
- **2011: SP-CFS: Indian Institute of Tropical Meteorology**
- **2014: SP-IFS: ECMWF**

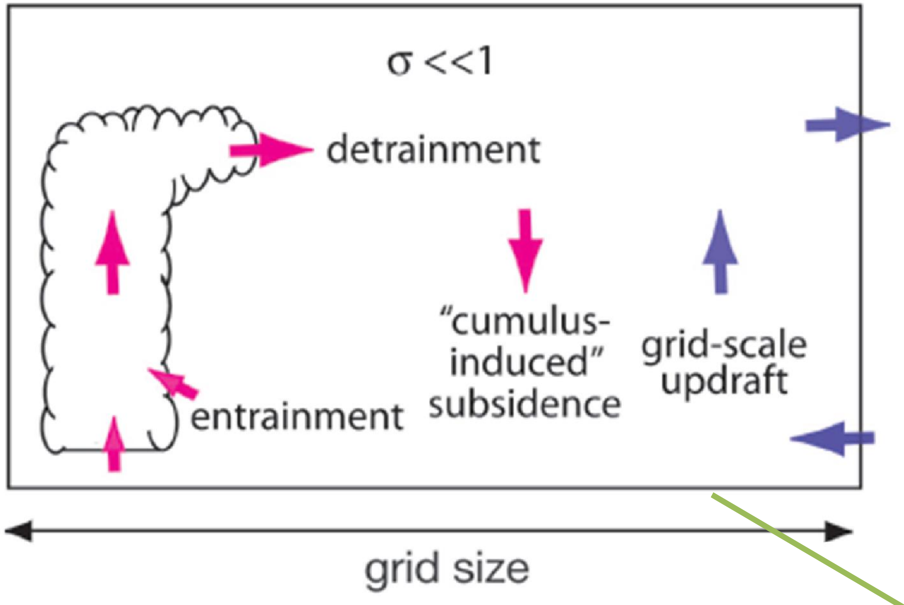
Slide Courtesy: Dr. Marat Khairoutdinov

Global status of Superparameterization

What is the use of SP framework apart from demonstrating the role of resolving the cloud processes in the GCM?

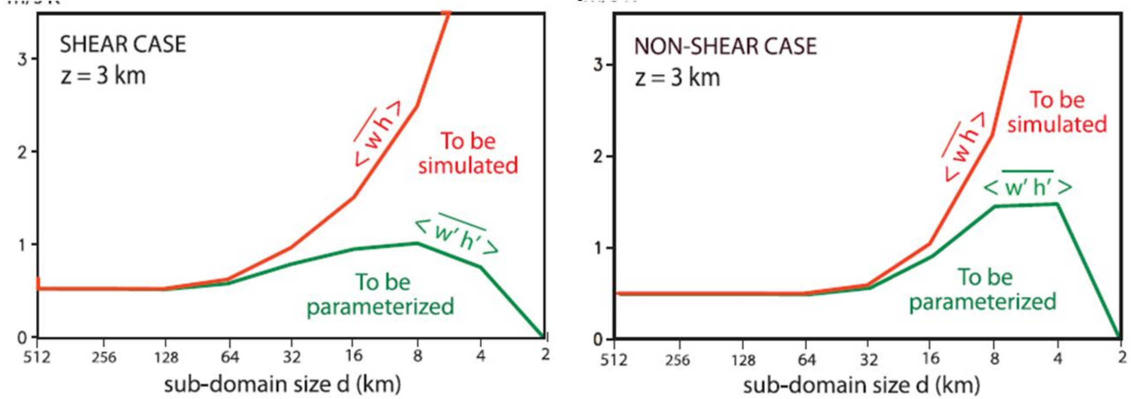
"Super-parameterization": A better way to simulate regional extreme precipitation?, by Li et al., JGR 2012





Arakawa et al. 2011, ACP

Arakawa and Wu, 2013



$\sigma \sim 1$

σ is the fractional area covered by all convective clouds in the grid cell

AS "Consider a horizontal area – large enough to contain an ensemble of cumulus clouds but small enough to cover a fraction of a large-scale disturbance. The existence of such an area is one of the basic assumptions of this paper." In reality, the GCM grid cells are not large enough and, at the same time, not small enough.

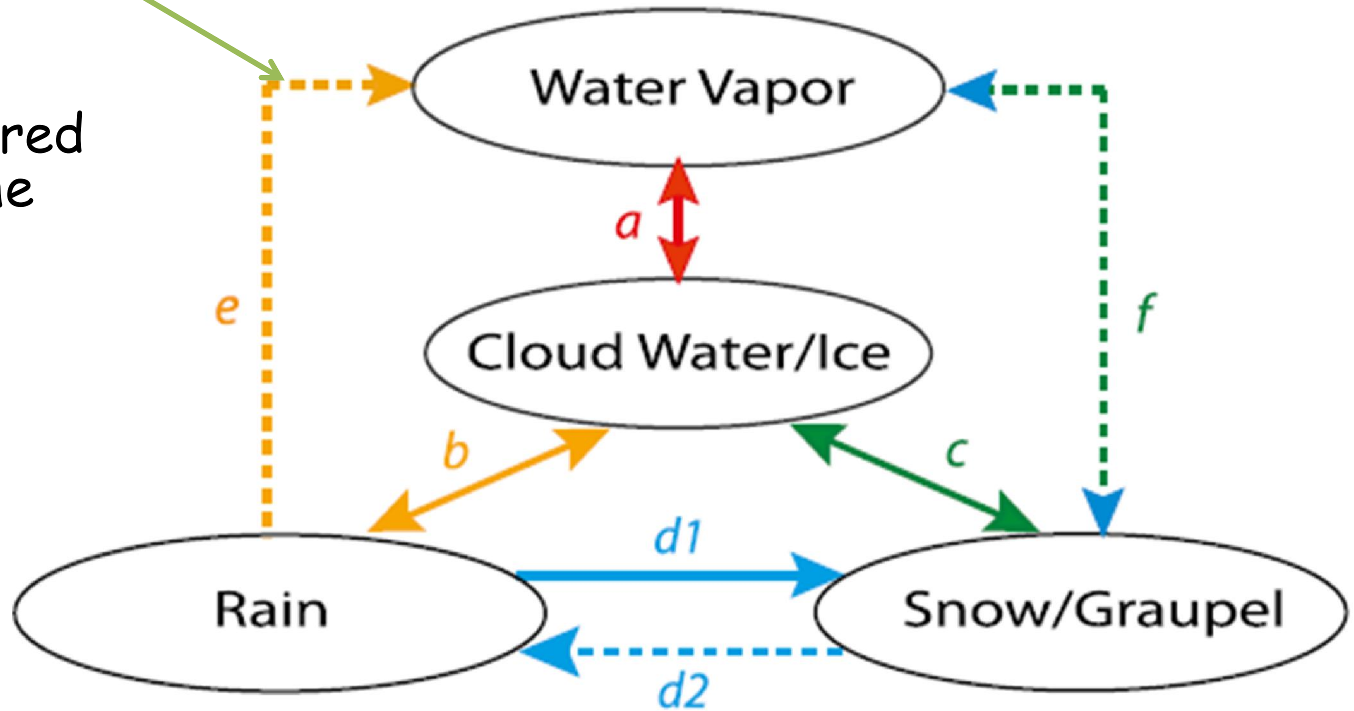


FIG. 9. A simplified view of the cloud microphysical conversions included in the CRM simulation used in this paper. See text for

Arakawa and Wu, 2014

Revised SAS

A revised version of SAS deep convection scheme following Han and Pan (2011) is tested and evaluated.

For deep convection, the scheme is revised to make cumulus convection stronger and deeper to deplete more instability in the atmospheric column.

Large eddy simulation (LES) studies by Siebesma and Cuijpers (1995) indicate that the fractional entrainment and detrainment rates are <u>one order of magnitude larger than the values used in most existing deep convection schemes</u>.

The GFS used in this test has 64 vertical sigma-pressure hybrid layers and T126 horizontal resolution (about 100 km at the equator). The CFS run was initialized at 0000 UTC 16 December 2002 and ran for 45 days. The CFS forecasts during the preceding 15 days (a spin up period) have been discarded from the analysis, and forecast results during the remaining 1-month period are presented. An evaluation using a longer CFS run would be desirable, but will be left for a future study.

	Default SAS	Revised SAS
	SAS suffers from underestimating the entrainment/detrainment rates by one order of magnitude.	Maximum allowable cloud base mass flux (M_{bmax}) is increased by defining a criteria proposed by Jacob and Siebesma (2003).
Entrainment	Entrainment is considered to take place at levels below the cloud base only	Entrainment is allowed above the cloud base also
Detrainment	from the cloud top only	for all the levels.
Entrainment rate	uniform below the cloud base	in sub-cloud layer is inversely proportional to the height

Han and Pan (2011), Pattnaik et al (2013), W. C. de Rooy et al. (2014),

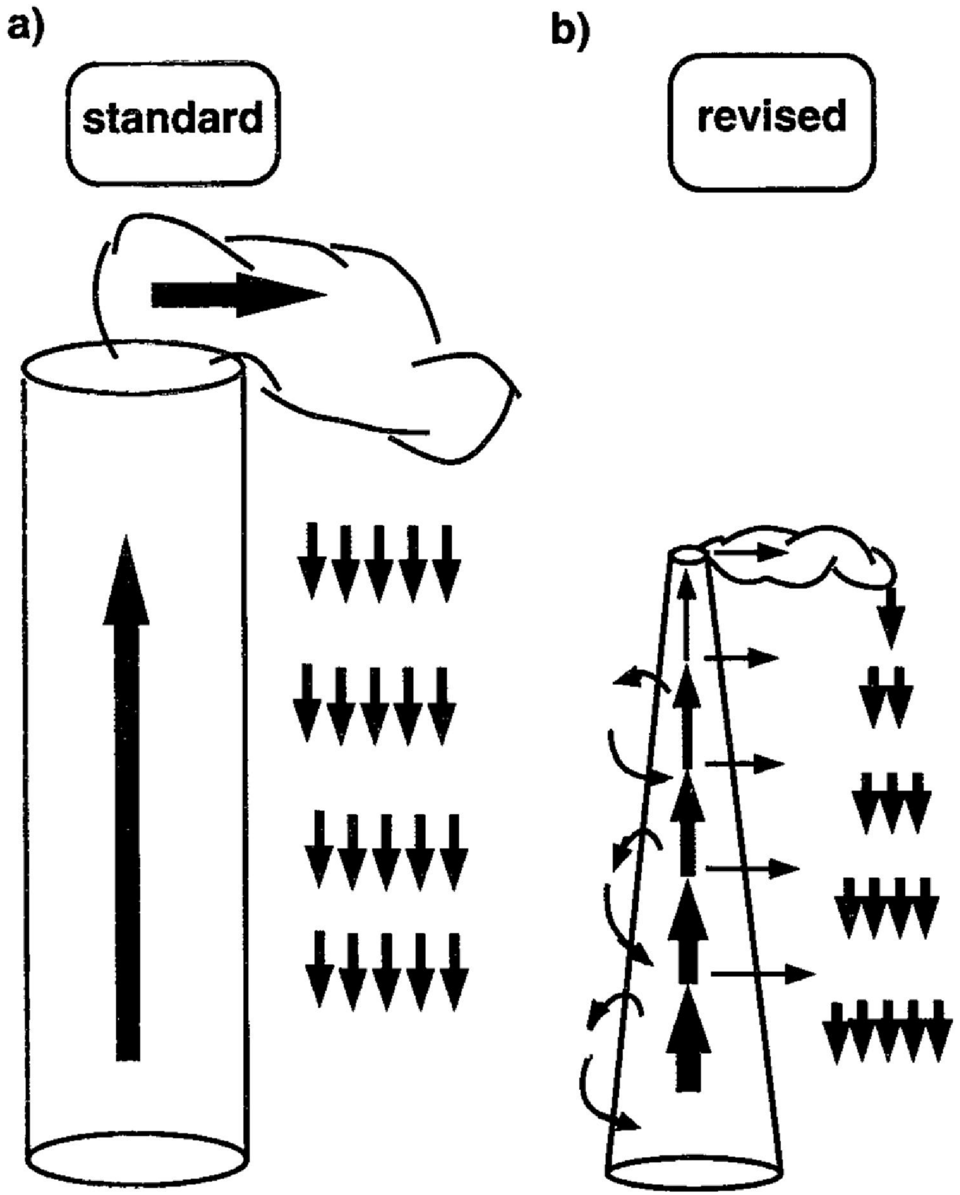


FIG. 7. Schematic picture of the turbulent mixing mechanism of a shallow cloud ensemble. In the case of the standard values of ϵ and δ, the scheme behaves approximately as a nonleaking funnel with massive detrainment at cloud top. When using the enhanced values of ϵ and δ, as suggested by the LES results, there is more intense lateral mixing and a decreasing mass flux with height due to the fact that $\delta > \epsilon$ and hence little massive detrainment at the top.

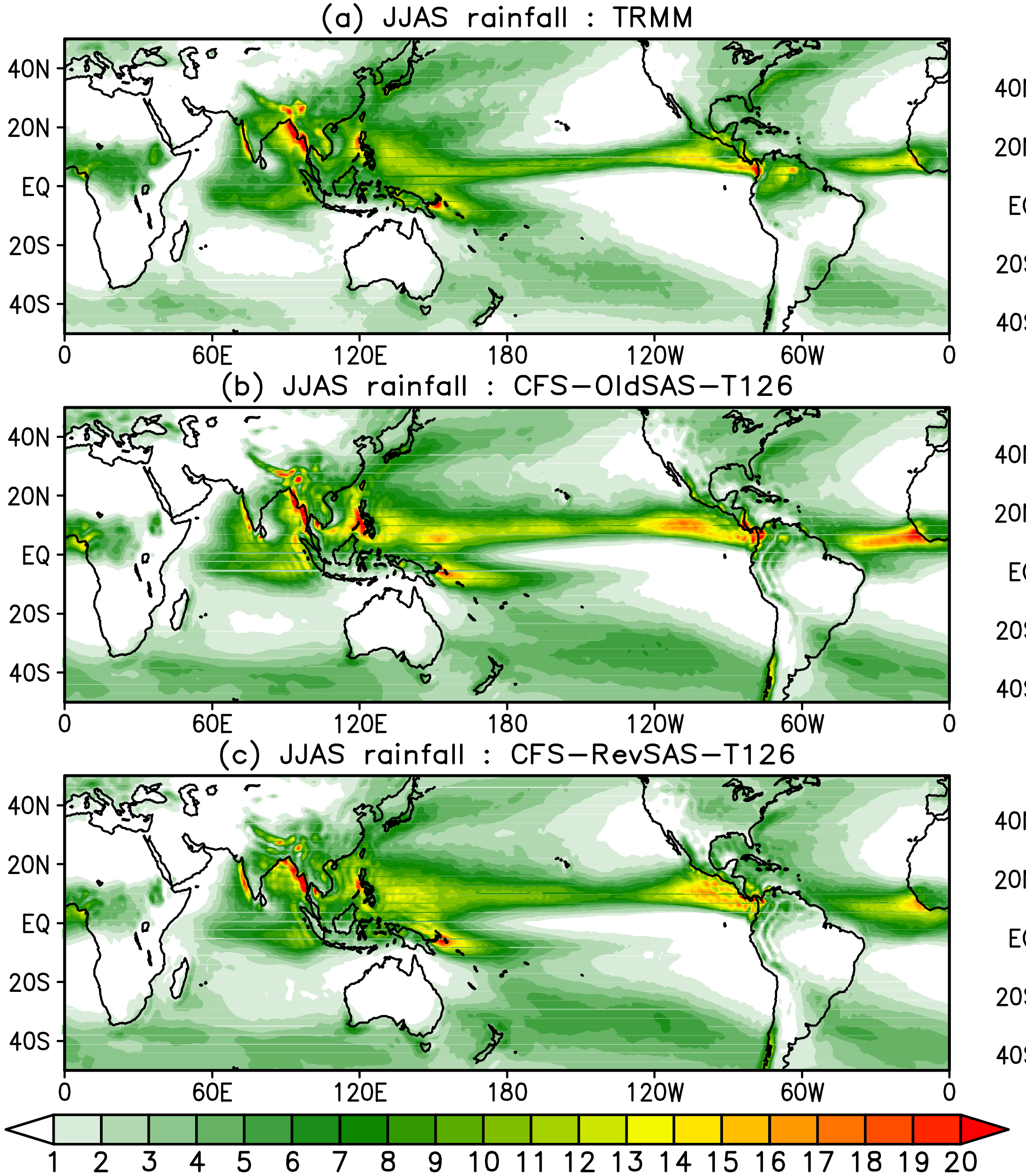
Model Impacts of Entrainment and Detrainment Rates in Shallow Cumulus Convection

A. P. SIEBESMA AND A. A. M. HOLTSLAG*

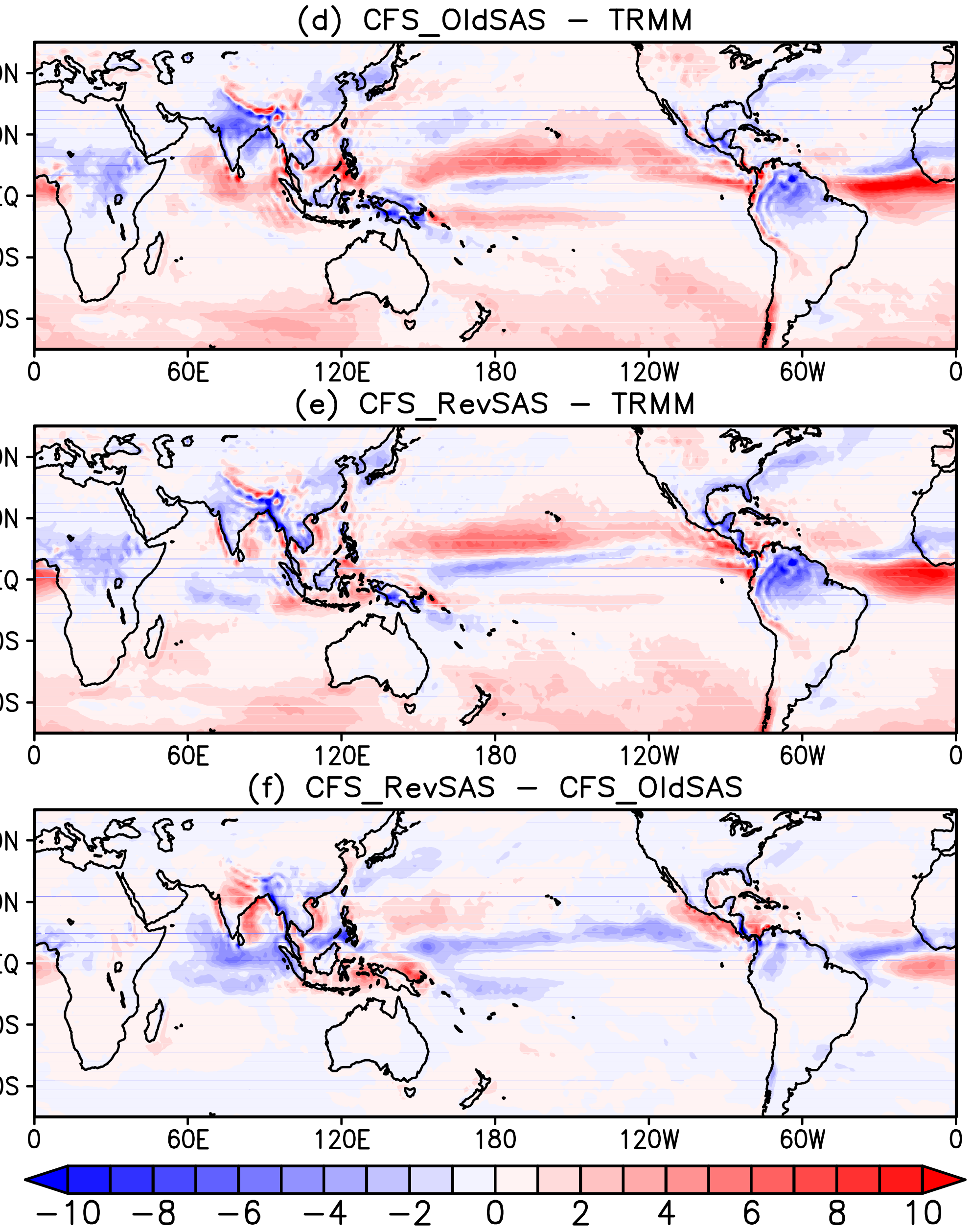
JAS, 1996

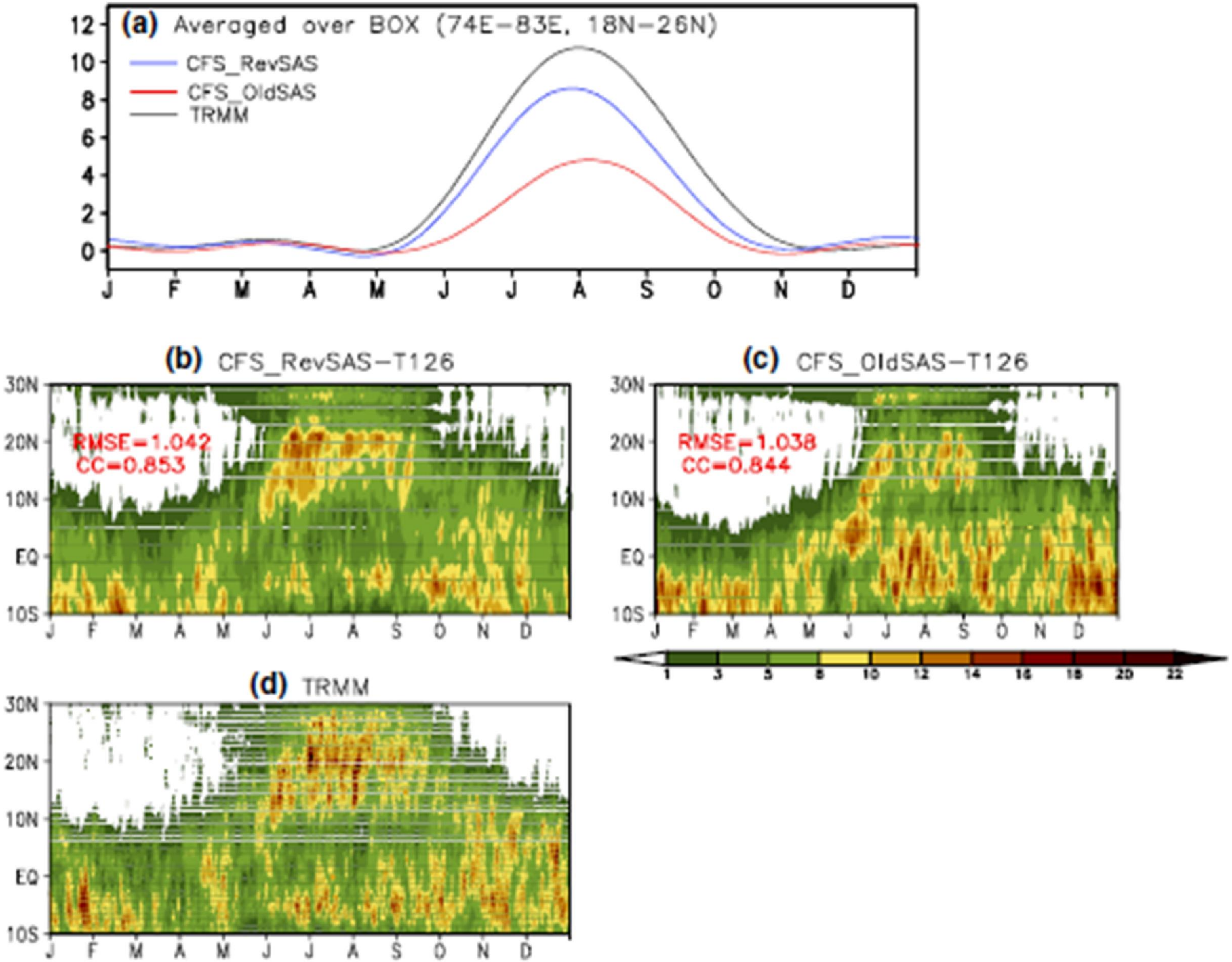
Impact of Revising Subgrid scale convection only RevSAS

JJAS Mean precip

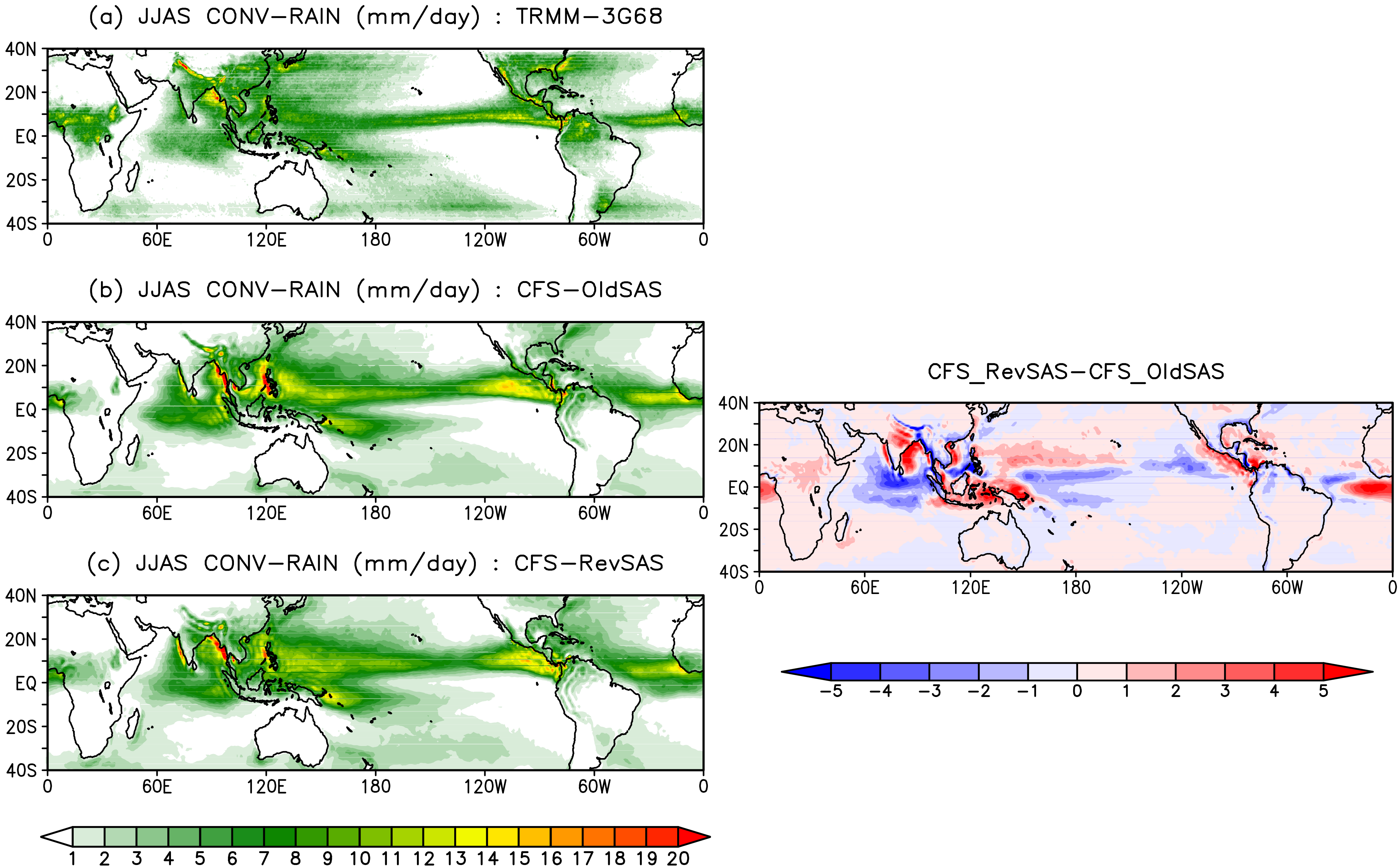


JJAS precip bias

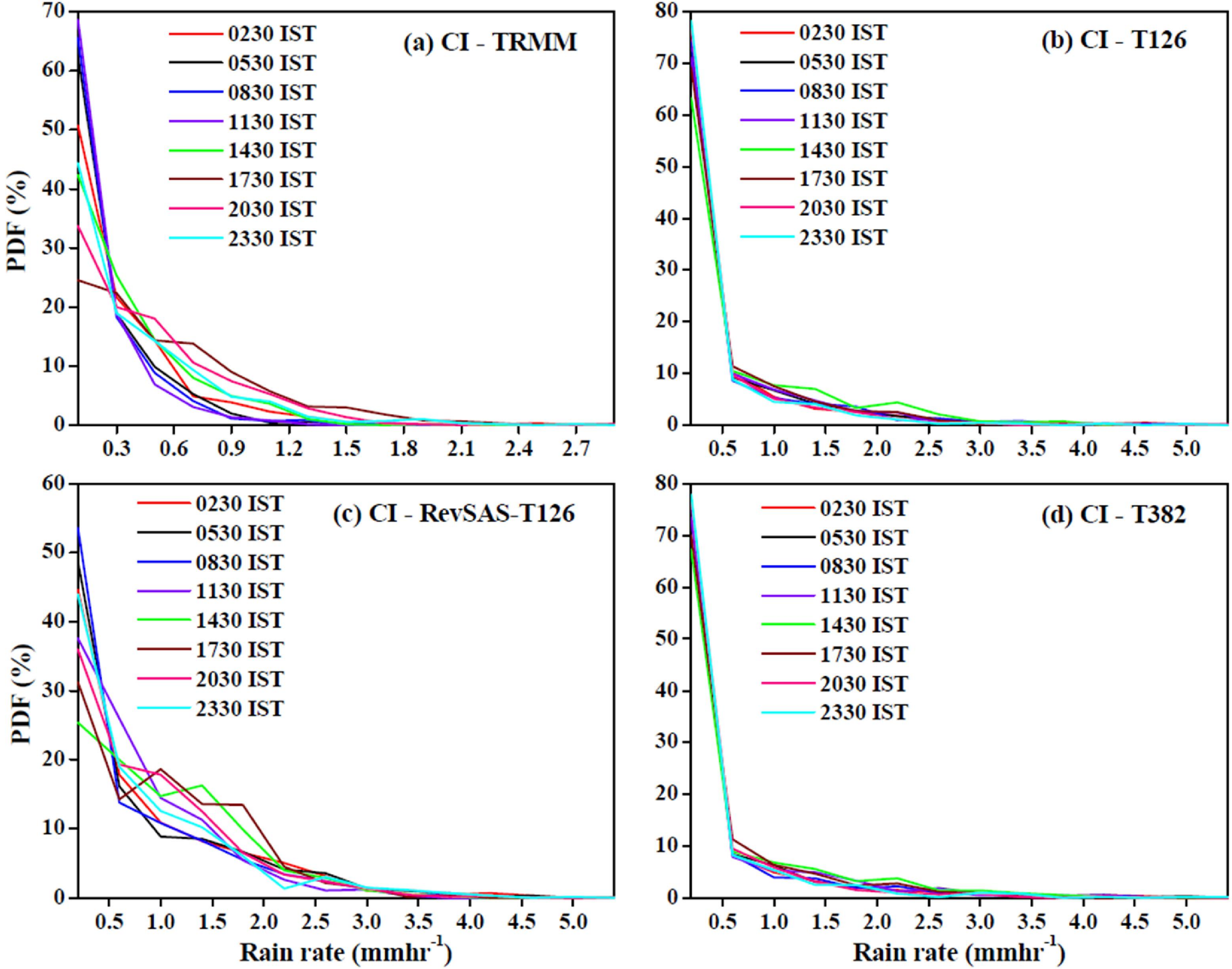




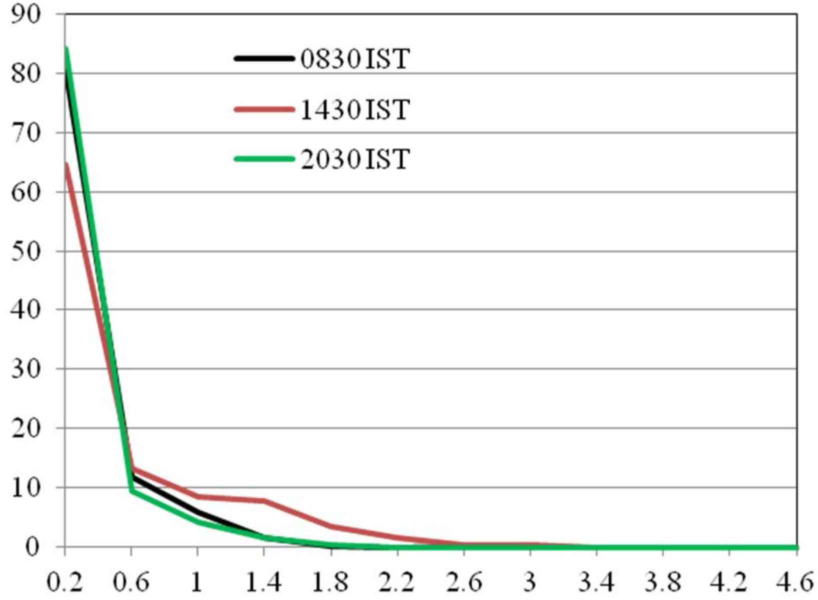
(a) The area averaged smoothed (first 3 harmonics plus mean) annual cycle of climatological rainfall (mm day−1) averaged over CI from TRMM (black line), CFSv2 with old SAS (red line) and revised SAS (blue line) scheme. Time-latitude section of rainfall (mm day−1) from b CFS2 with revised SAS, (c) CFSv2 with old SAS scheme and (d)TRMM averaged over 70°E–90°E. RMSE and pattern CC is calculated for revised SAS (b) and old SAS (c) with respect to TRMM



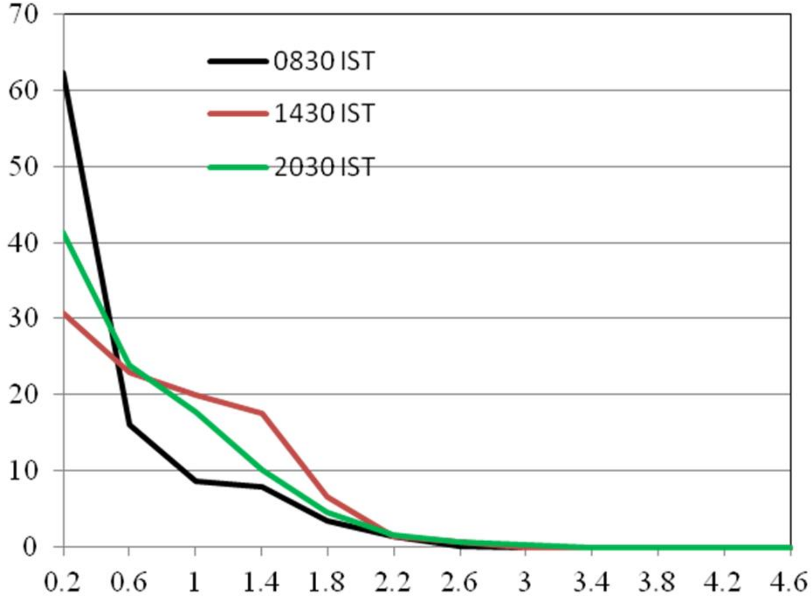
Convective Rain


(a) CI - TRMM
(b) CI - T126
(c) CI - RevSAS-T126
(d) CI - T382
0230 IST
0530 IST
0830 IST
1130 IST
1430 IST
1730 IST
2030 IST
2330 IST
PDF (%)
Rain rate (mmhr^{-1})

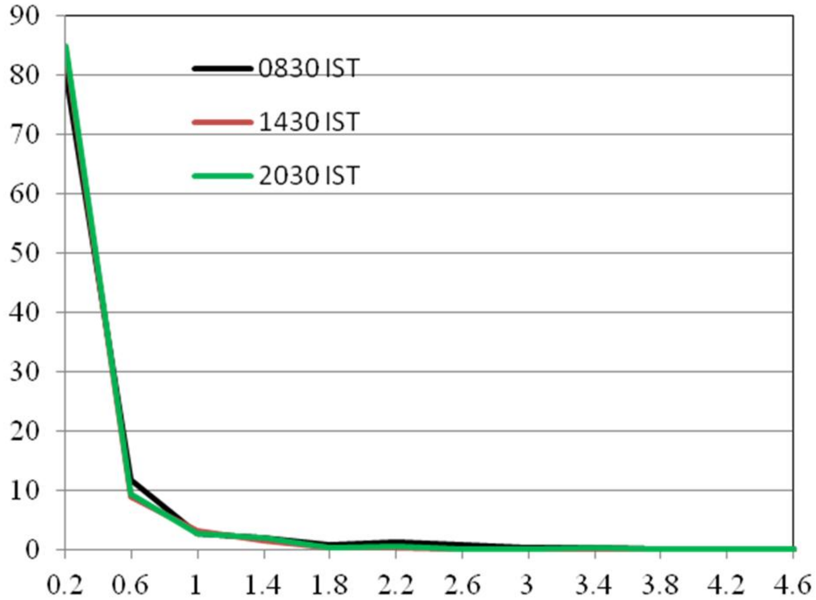
Convective-rain OldSAS



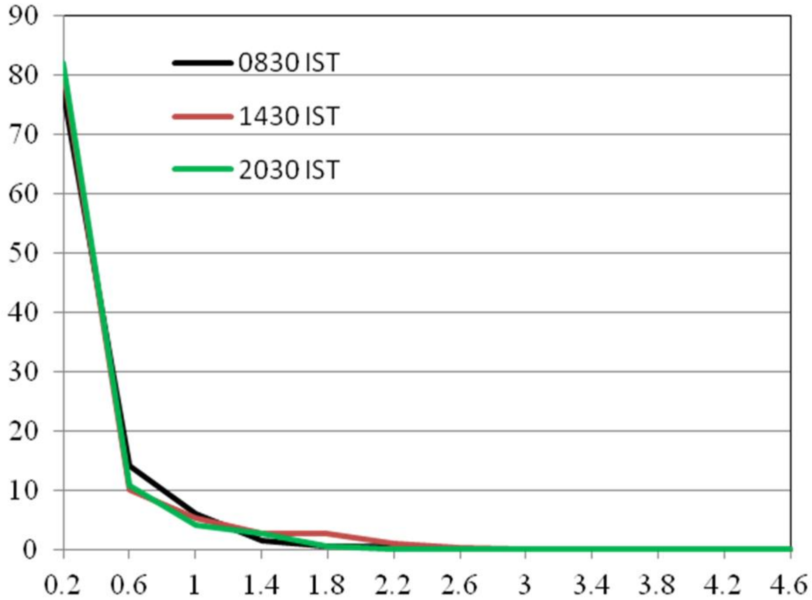
Convective-rain-RevSAS

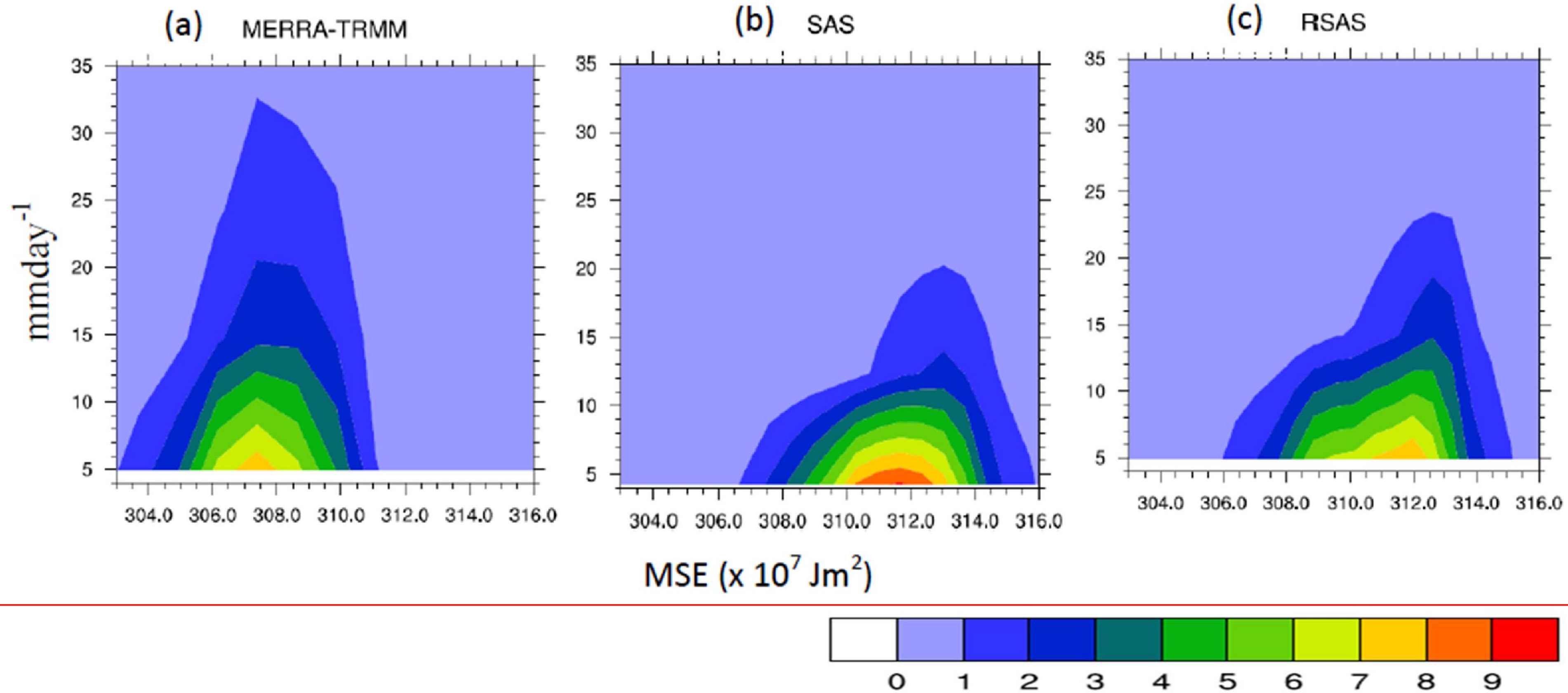


Stratiform-rain-OldSAS



Stratiform-rain RevSAS

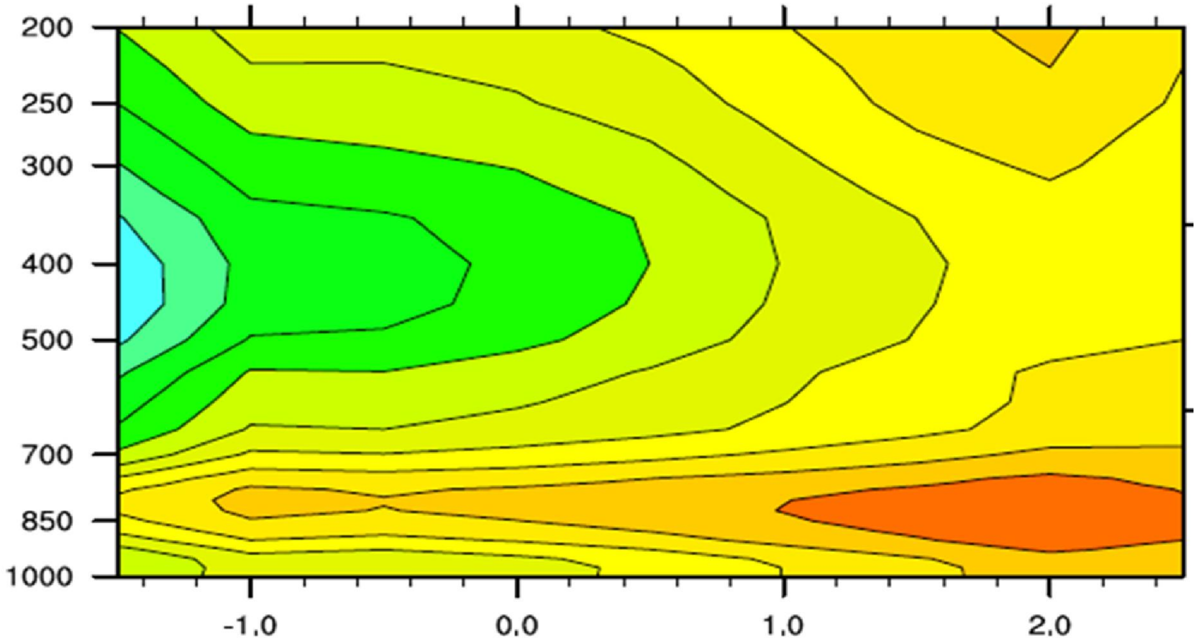


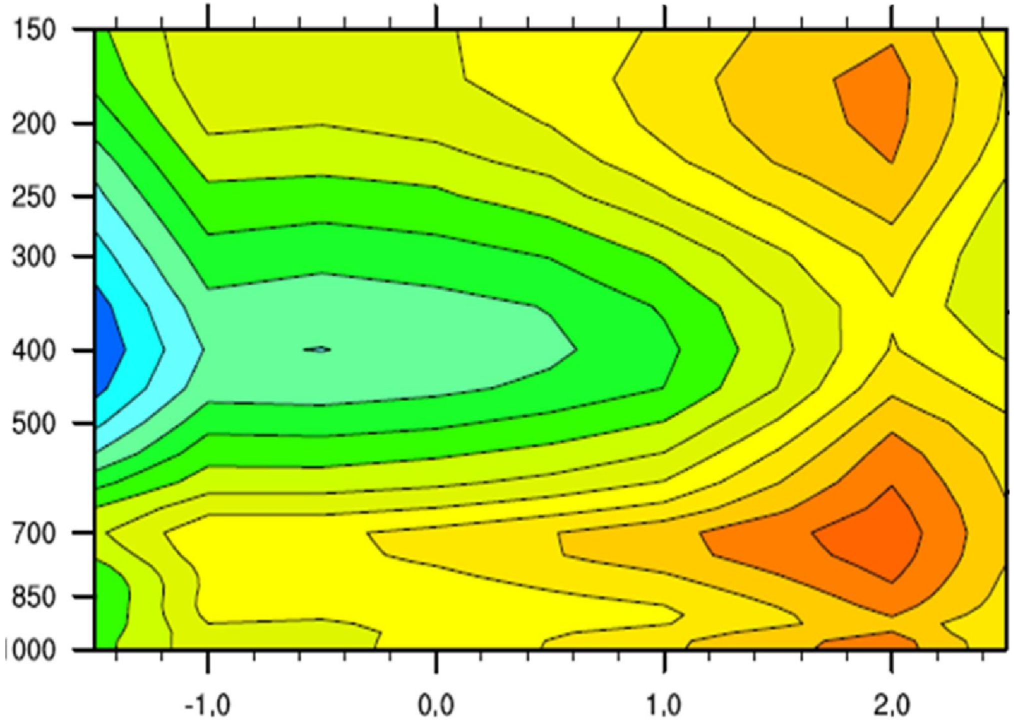


Joint probability distribution function of rainfall (mmday^{-1}), along the y axis, and column integrated (surface to 100 hPa) MSE (x 10^7 Jm^{-2}), along the x-axis, over CI region for (a) observation (TRMM and MERRA), CFSv2 with (b) SAS and (c) RSAS scheme during JJAS.

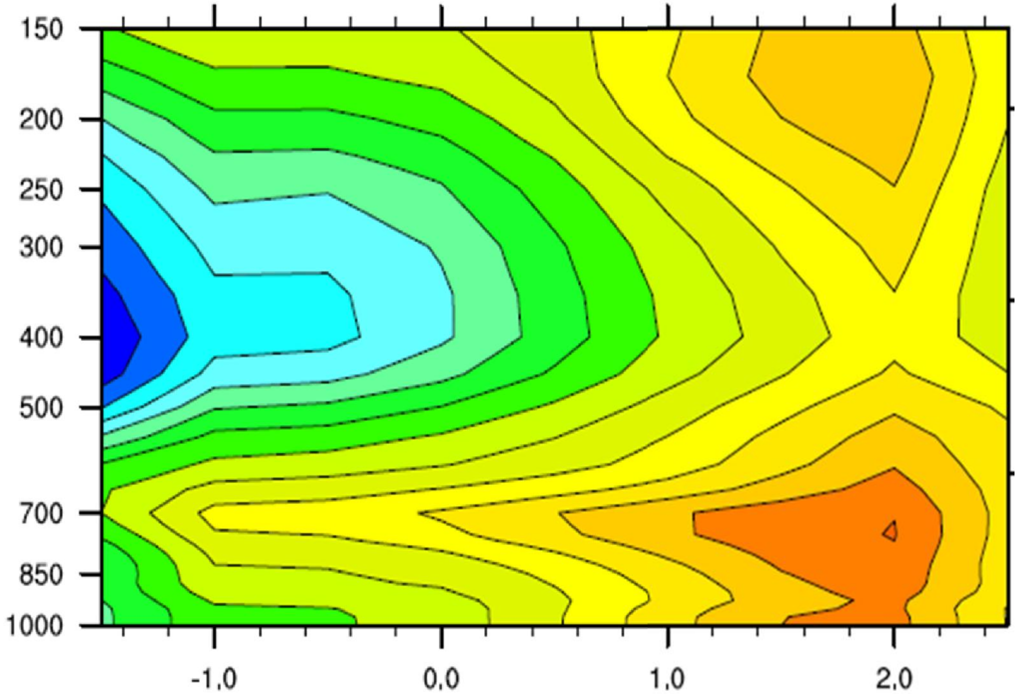
Log of RF (X-axis) along with vertical distribution of RH (Shaded)

ERA I vs TRMM

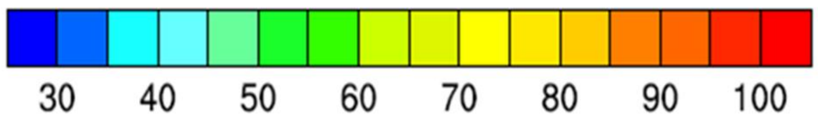




Revised SAS

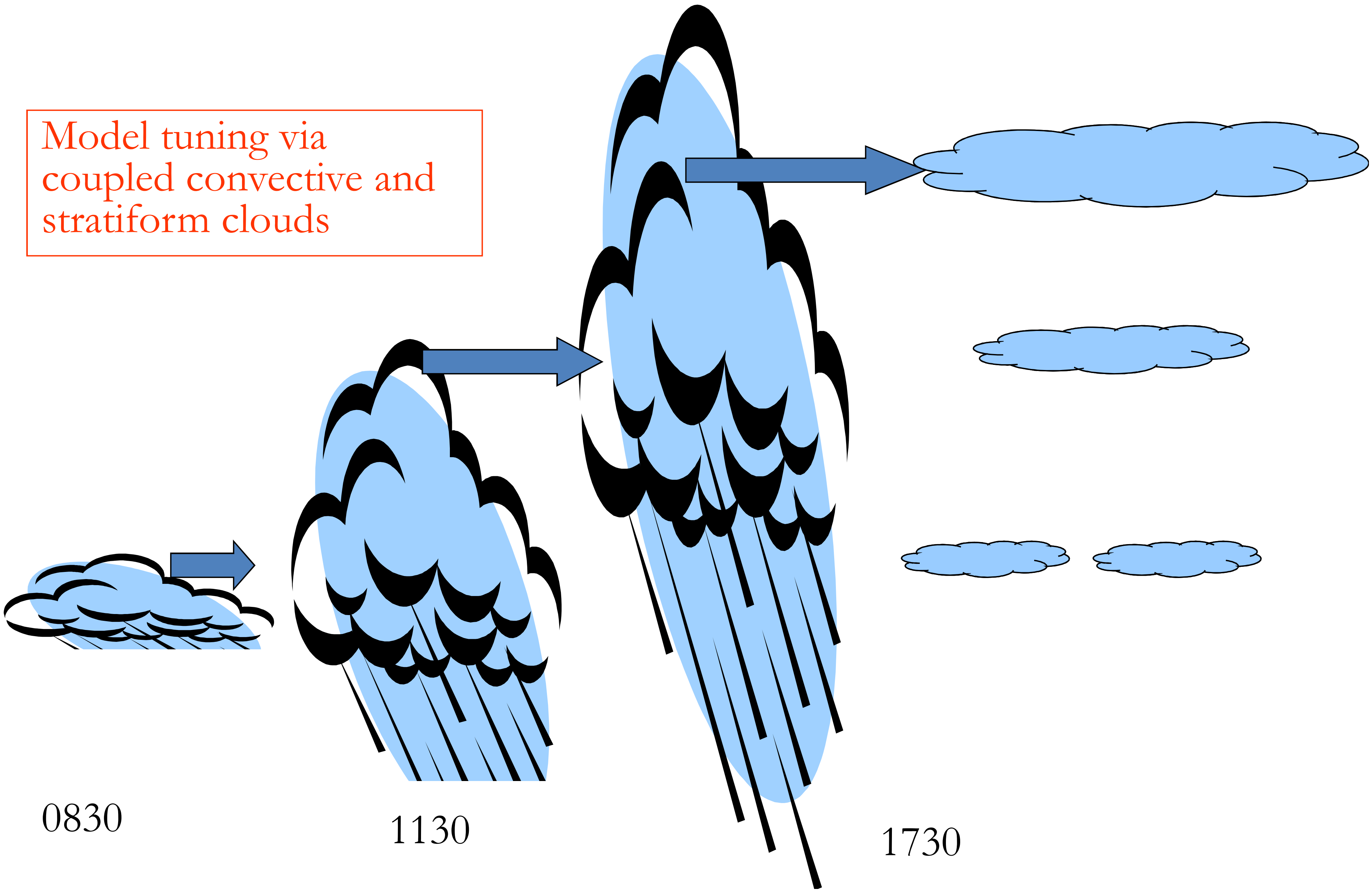


Default SAS

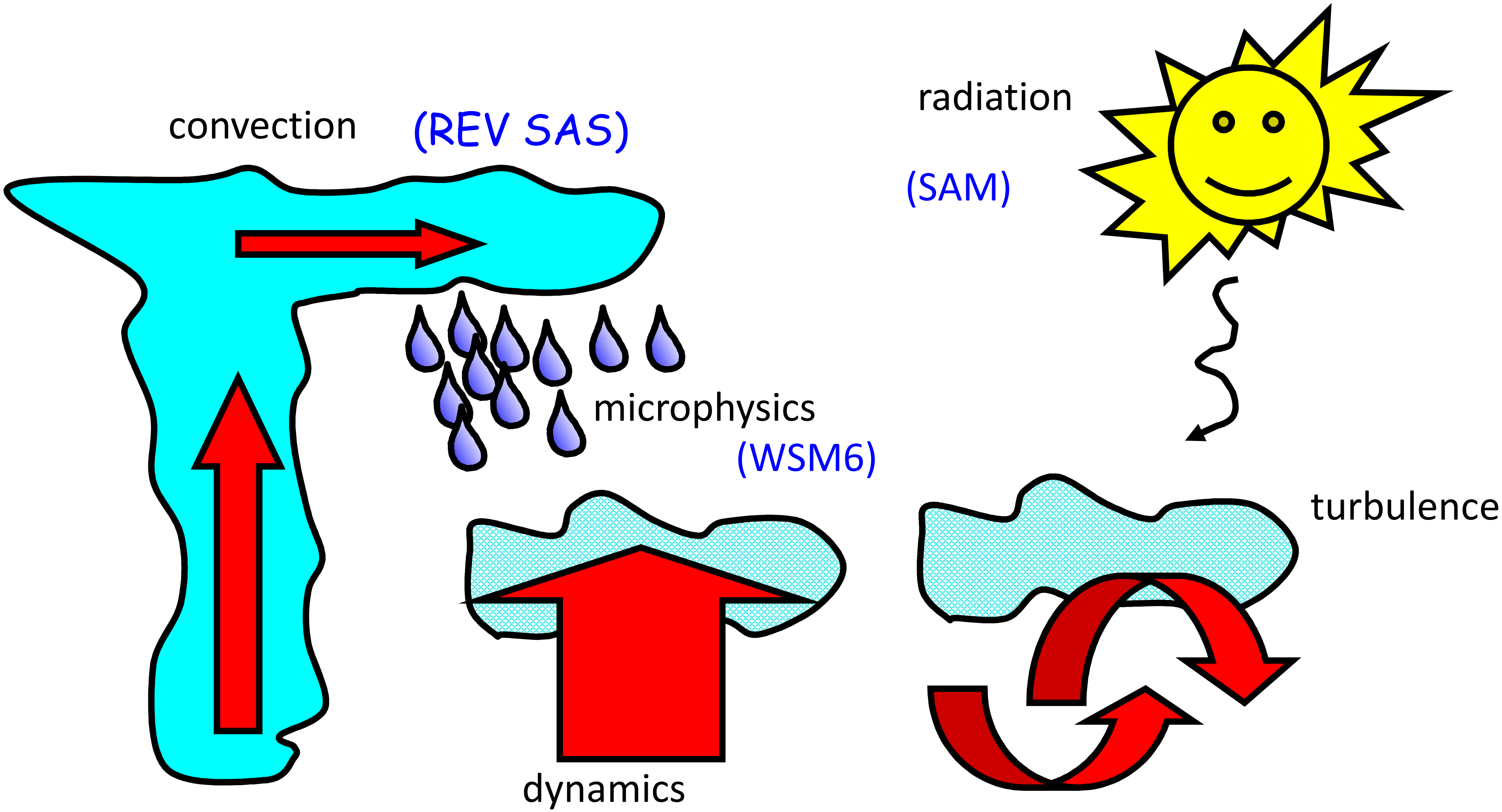


To simulate better stratiform clouds a spectrum of cumulus clouds is necessary.

Model tuning via coupled convective and stratiform clouds



Revised Cloud-Convective-Radiation in CFSv2 T126
(To enhance the grid scale variability)



Clouds are the result of complex interactions between a large number of processes

SAM: System of Atmospheric Model

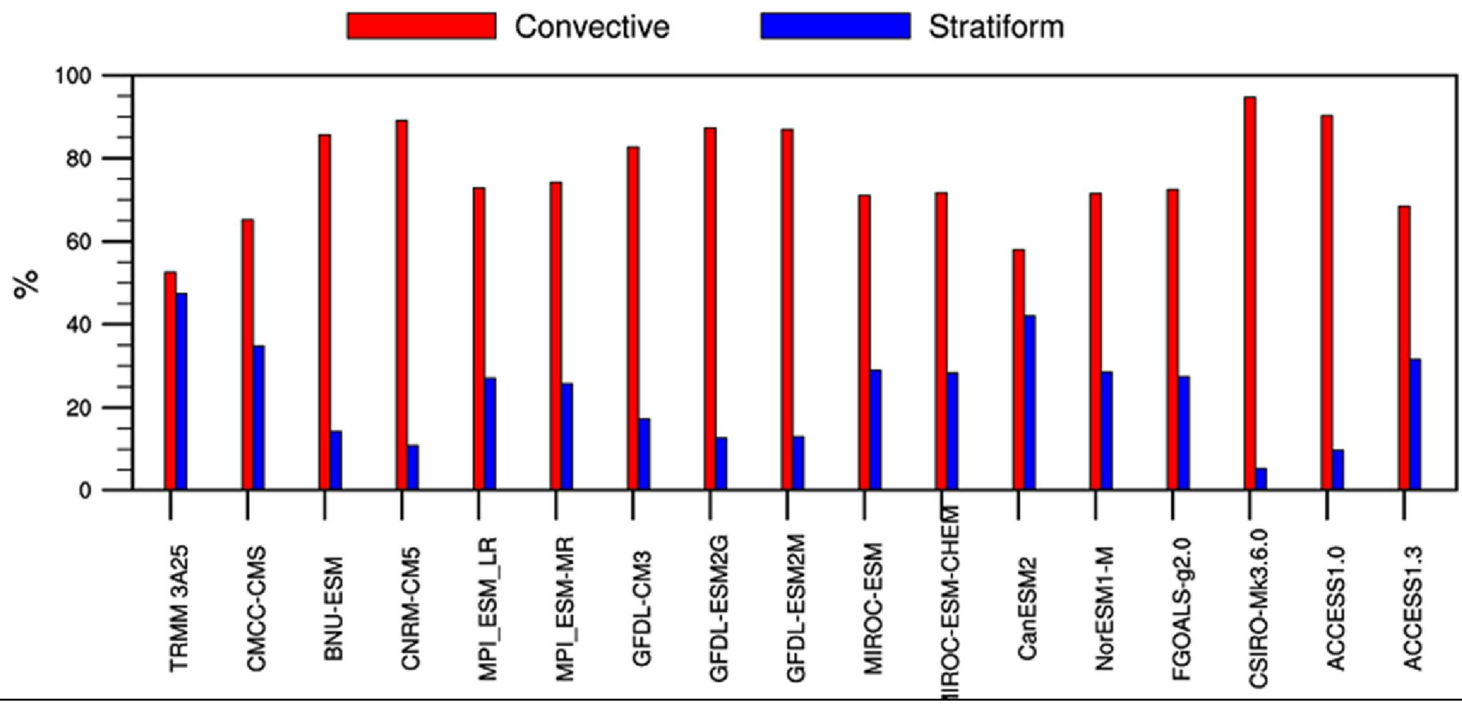


Fig. 8 Percentage of precipitation (averaged over SAM region, 10°N–30°N and 70°E–100°E) explained by convective (*red bars*) and stratiform (*blue bars*) types in the historical simulations of the 16 CMIP5 models along with that from observations (TRMM)

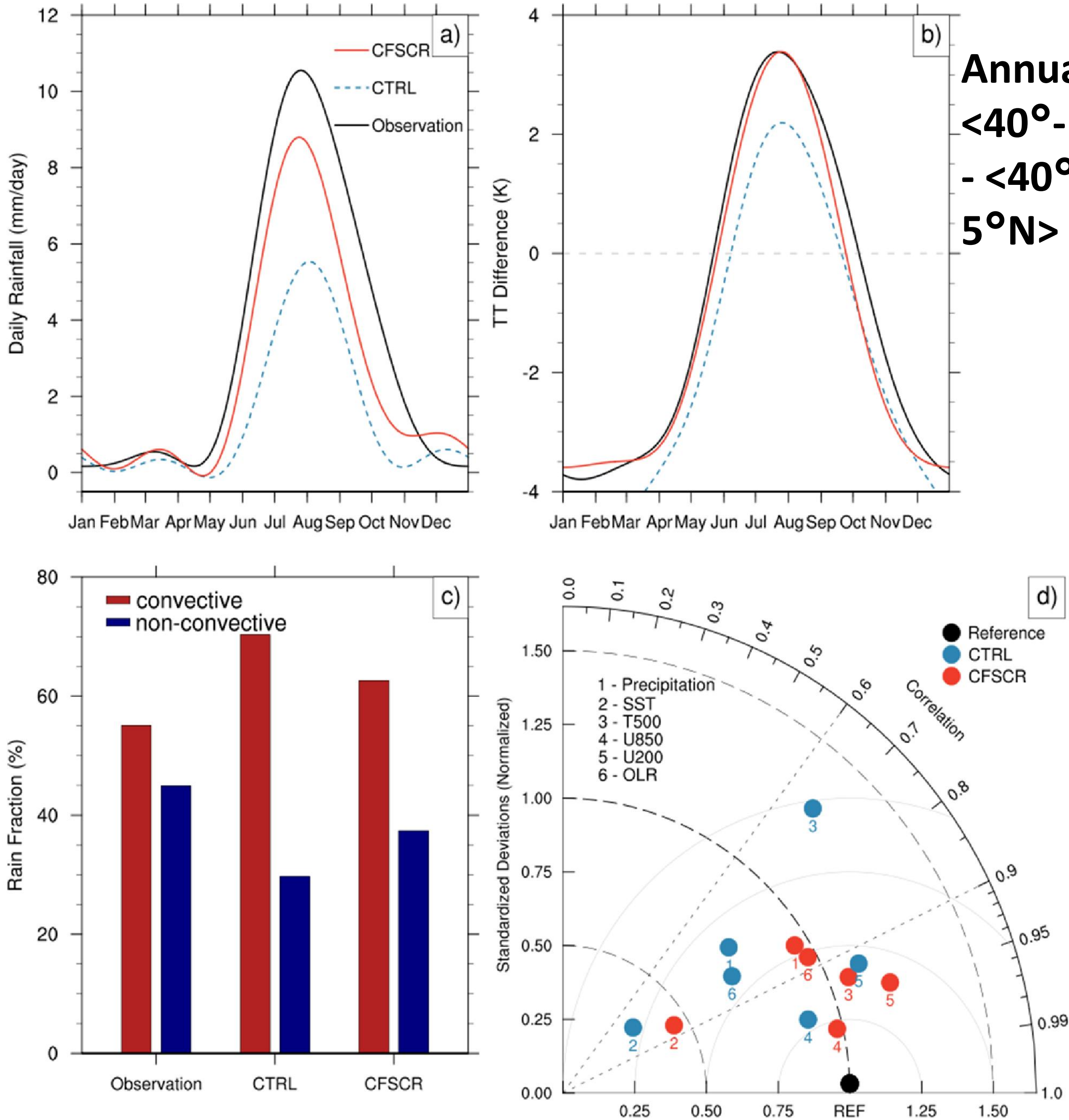
Why ensemble mean projection of south Asian monsoon rainfall by CMIP5 models is not reliable? C. T. Sabeerali · Suryachandra A. Rao · A. R. Dhakate ·K. Salunke · B. N. Goswami, Cli. Dyn. 2015

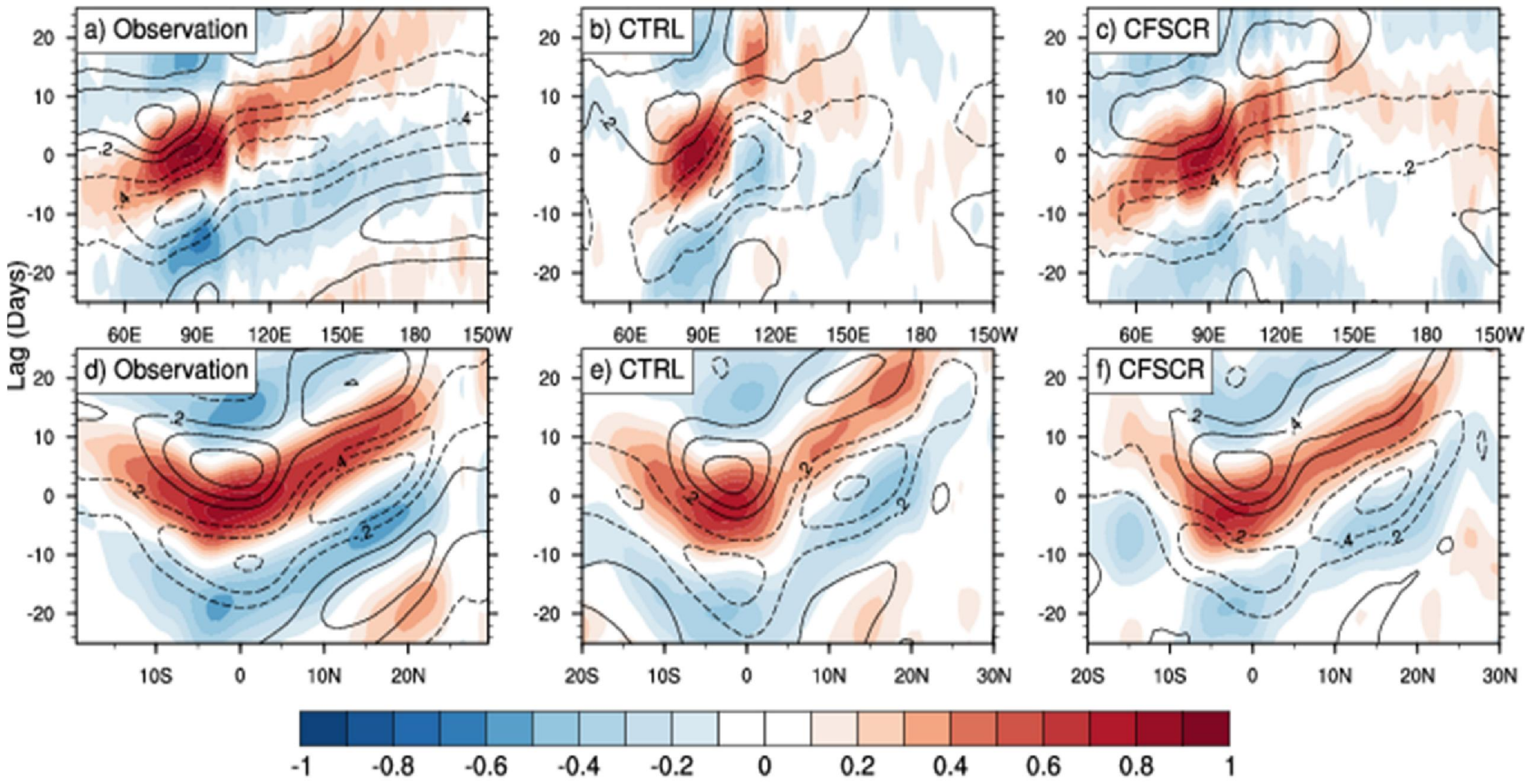
Revised convection, modified microphysics and radiation is able to improve the mean state and Intraseasonal variability of CFSv2T126

Annual Rainfall Cycle <73°-85°E,15°-25°N>

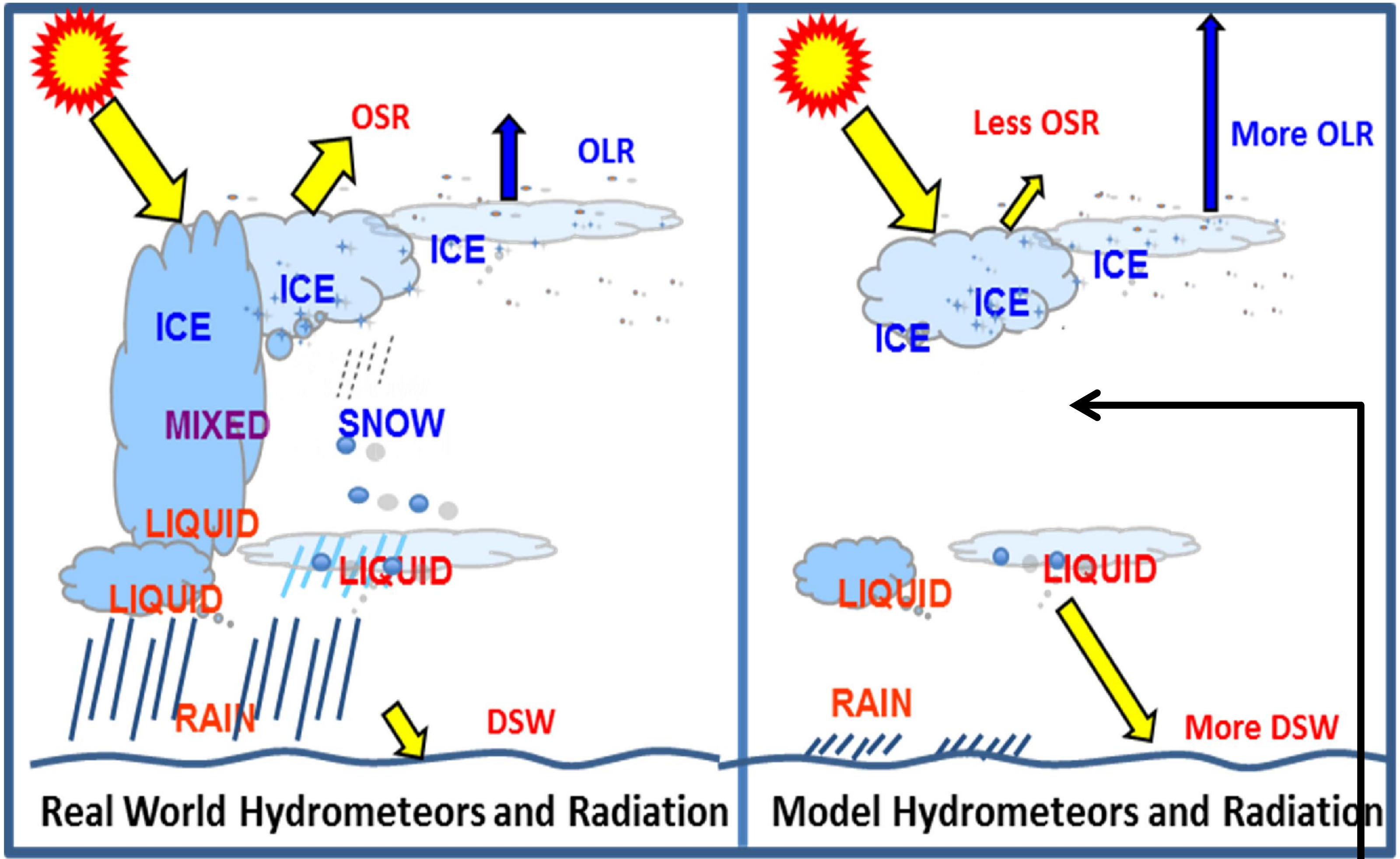
Annual TT Difference <40°-100°E,5°-35°N> - <40°-100°E,15°S-5°N>

<40°-120°E, 15°S-30°N>





Longitude (Latitude) vs lag correlation of 20–100-day filtered precipitation (shaded) and U_{850} (contour) with base 20-100-day filtered precipitation time series over EEIO (10°S–5°N, 75°–100°E).



Bridging the Gap in CFSv2 using modified Microphysics: WSM6

Summary

- Superparameterization is promising in improving grid scale variability and could be explored for high spatio-temporal ranfall variabiltiy.

- Improving the convective closures with better observational constraint.

- Robust microphysical schemes help improving the mean and intraseasonal variablity of the model.

References used:

Ganai et al. 2015, Climate Dynamics

Goswami et al. 2015, J. of Climate

Goswami et al. 2014, Climate Dynamics

Abhik et al., 2015, Climate Dynamics

Thank You !