Challenges of representing clouds in climate models

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International Workshop on Cloud Dynamics, Micro physics, and Small-Scale Simulation, IWCMS, 13-17 August 2018

Outline

- Issues of Representing clouds in climate models including NCEP CFSv2 (operational model in India)
- Recent New paradigms in dealing cloud and convection parameterization in climate model
- Summary

Scales of Motions

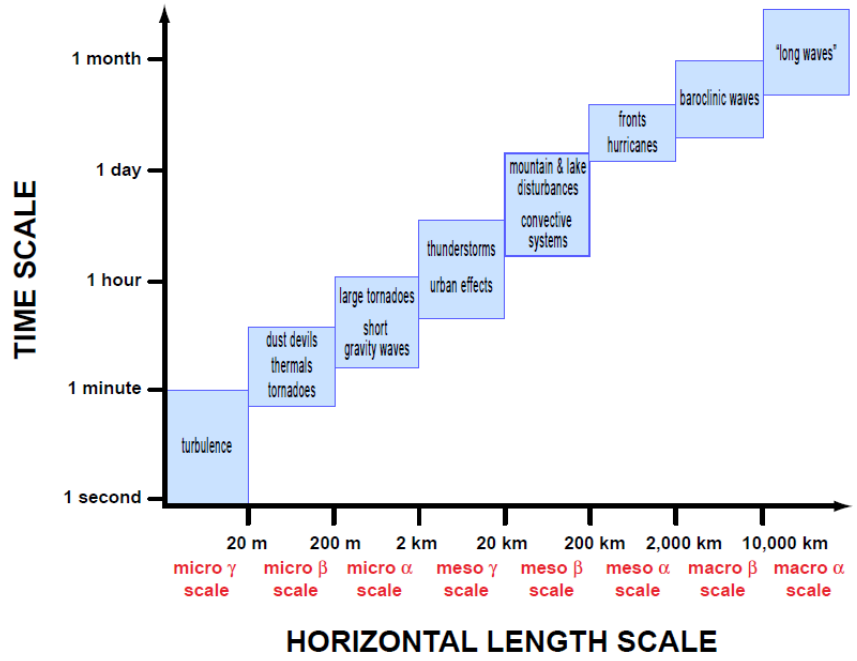


Figure 1.1. Scale definitions and the characteristic time and horizontal length scales of a variety of atmospheric processes. [Adapted from Orlanski (1975).]

Characteristic scales of atmospheric processes

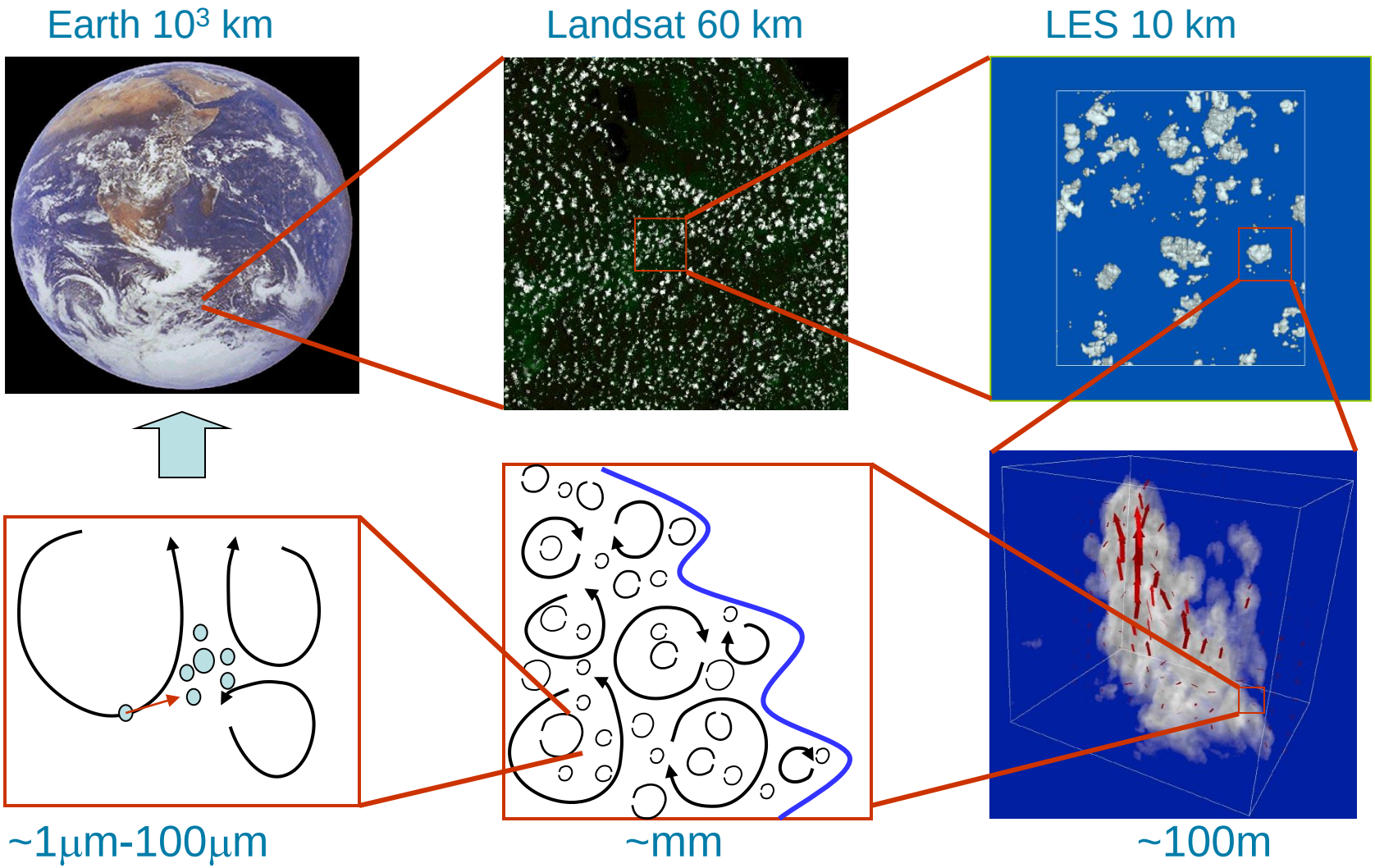
Atmospheric motions have different scales.

Climate model resolutions:
Regional: 50 km
Global: 100~200 km

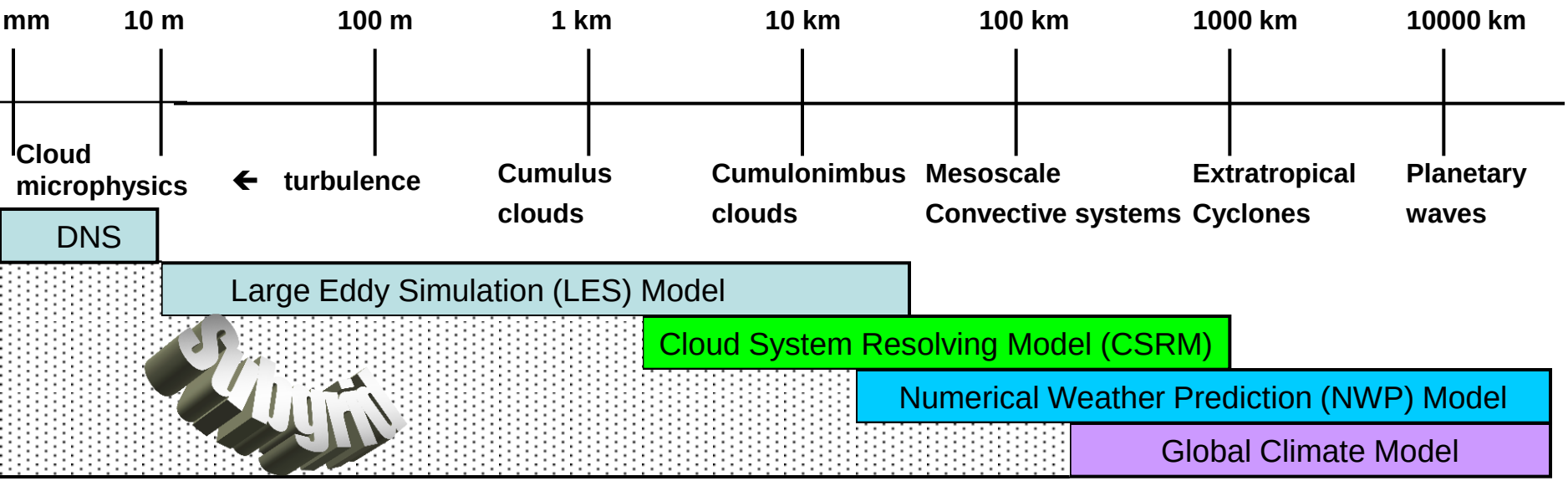
Sub-grid scale processes:
Atmospheric processes with scales can not be explicitly resolved by models.

Physical parameterization:
To represent the effect of sub-grid processes by using resolvable scale fields.

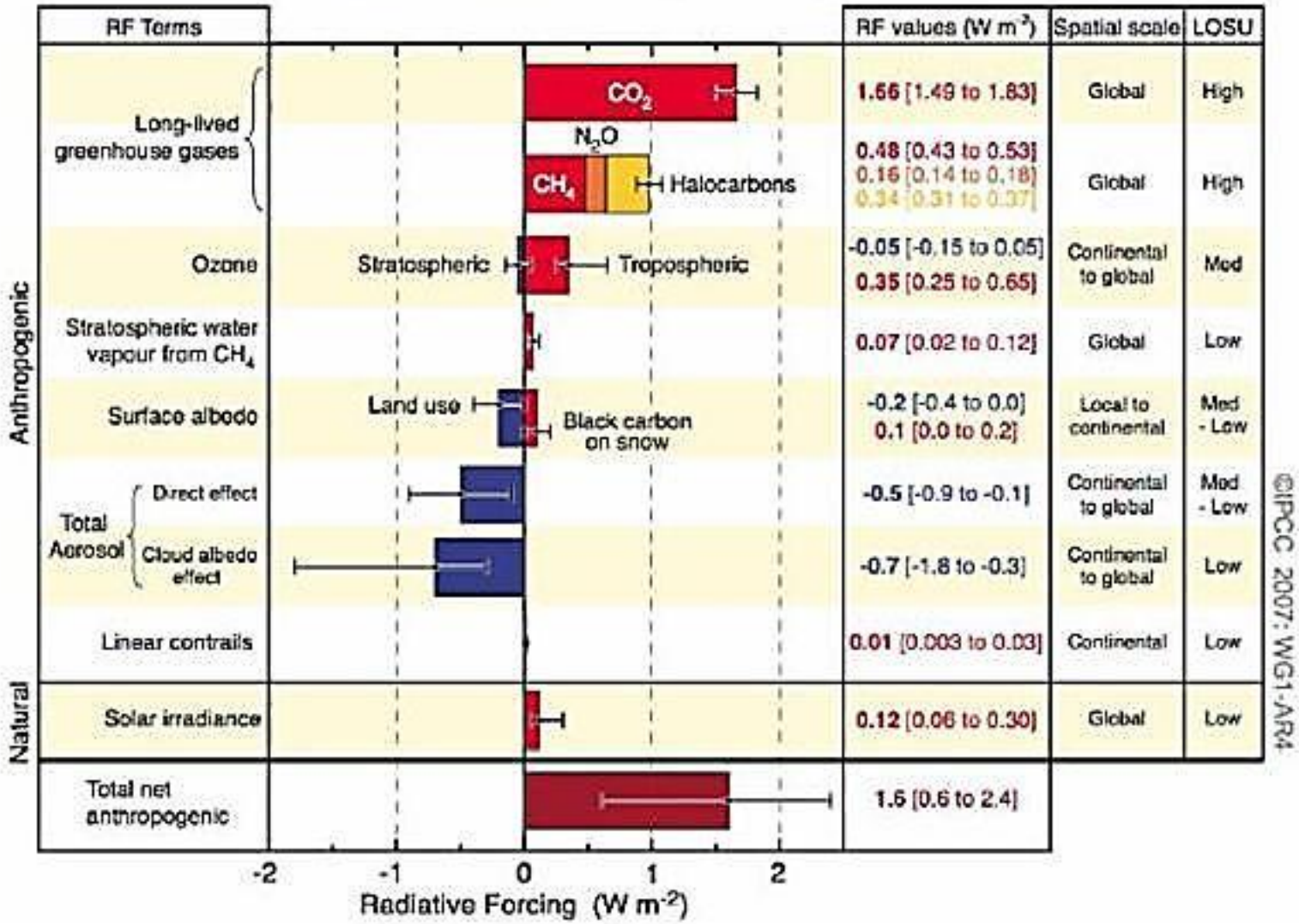
Length scales in the atmosphere



No single model can encompass all relevant processes

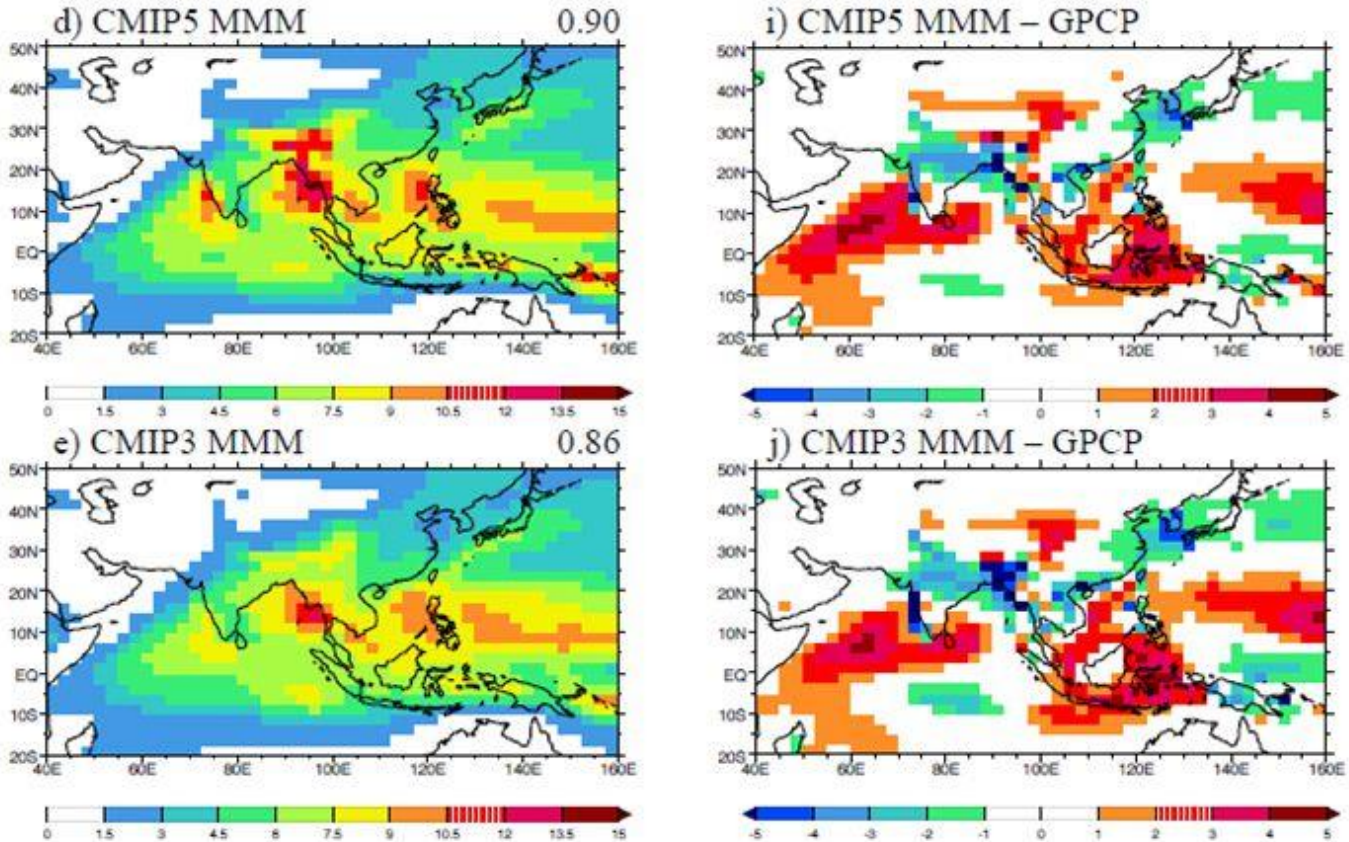


Radiative Forcing Components



CMIP3/CMIP5 precipitation biases

- CMIP3 and CMIP5 models show large dry biases over India but wet biases over the WEIO and Maritime Continent in boreal summer.



Sperber, Annamalai, Kang, Kitoh, Moise, **Turner**, Wang and Zhou (2012) *Climate Dynamics*.

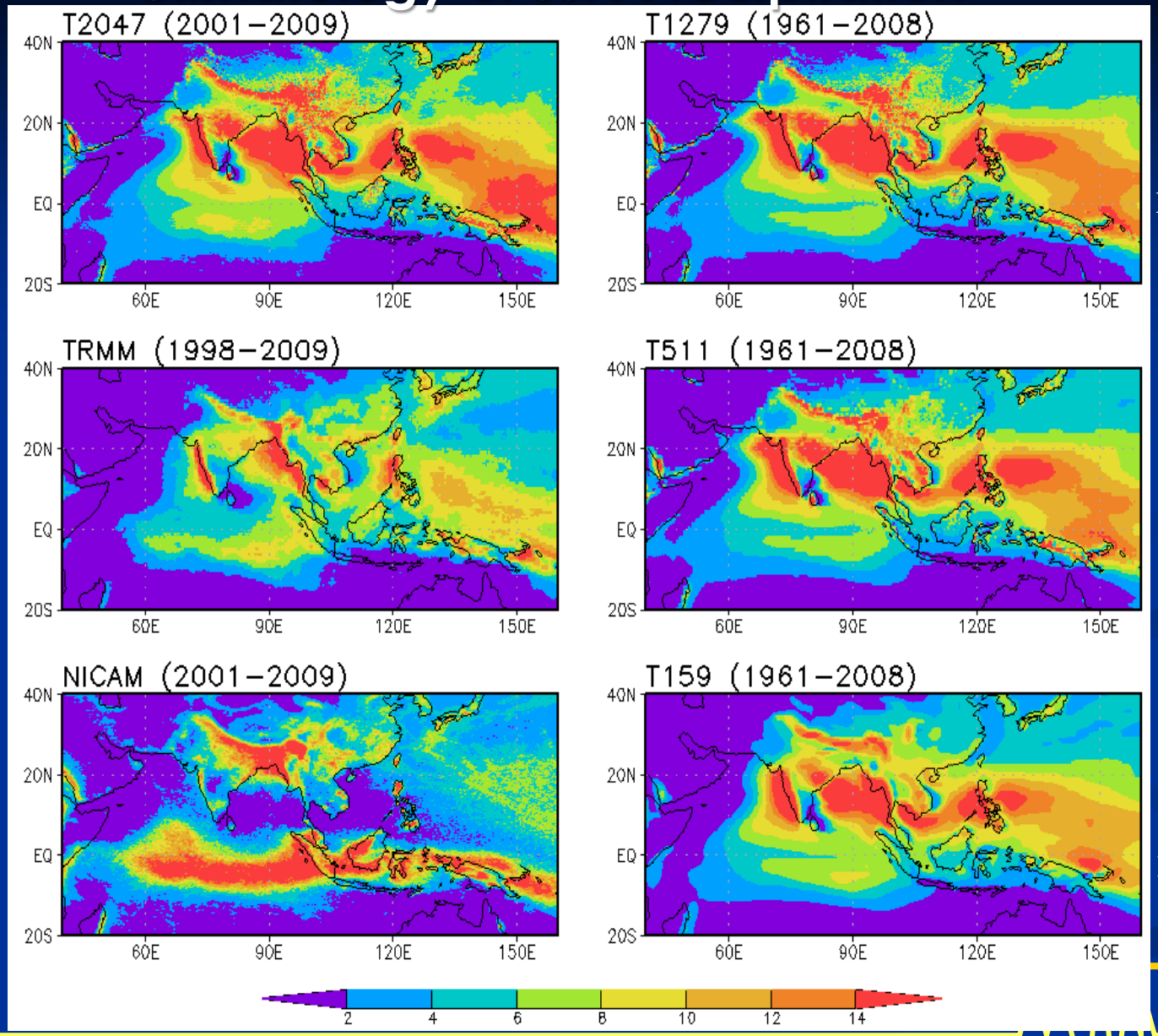
Climatology of JJA Precipitation

Kinter etal 2013

IFS T2047
10 km

TRMM
25km

NICAM
7 km



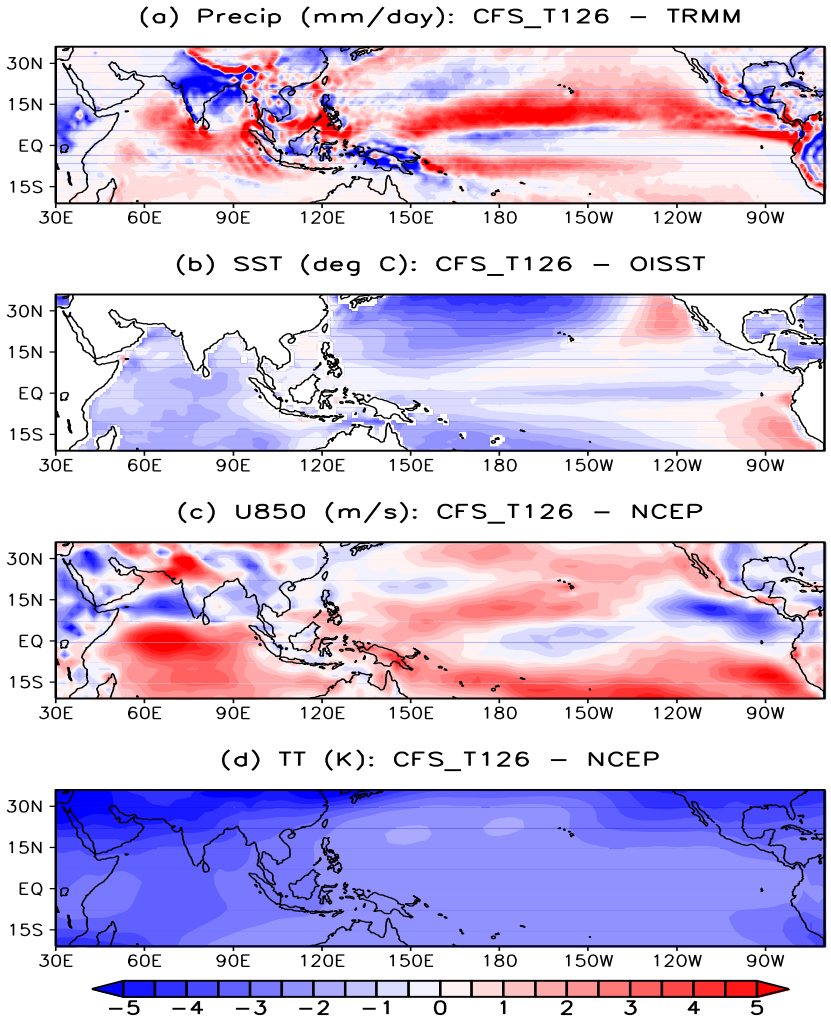
IFS T1279
15 km

IFS T1511
39km

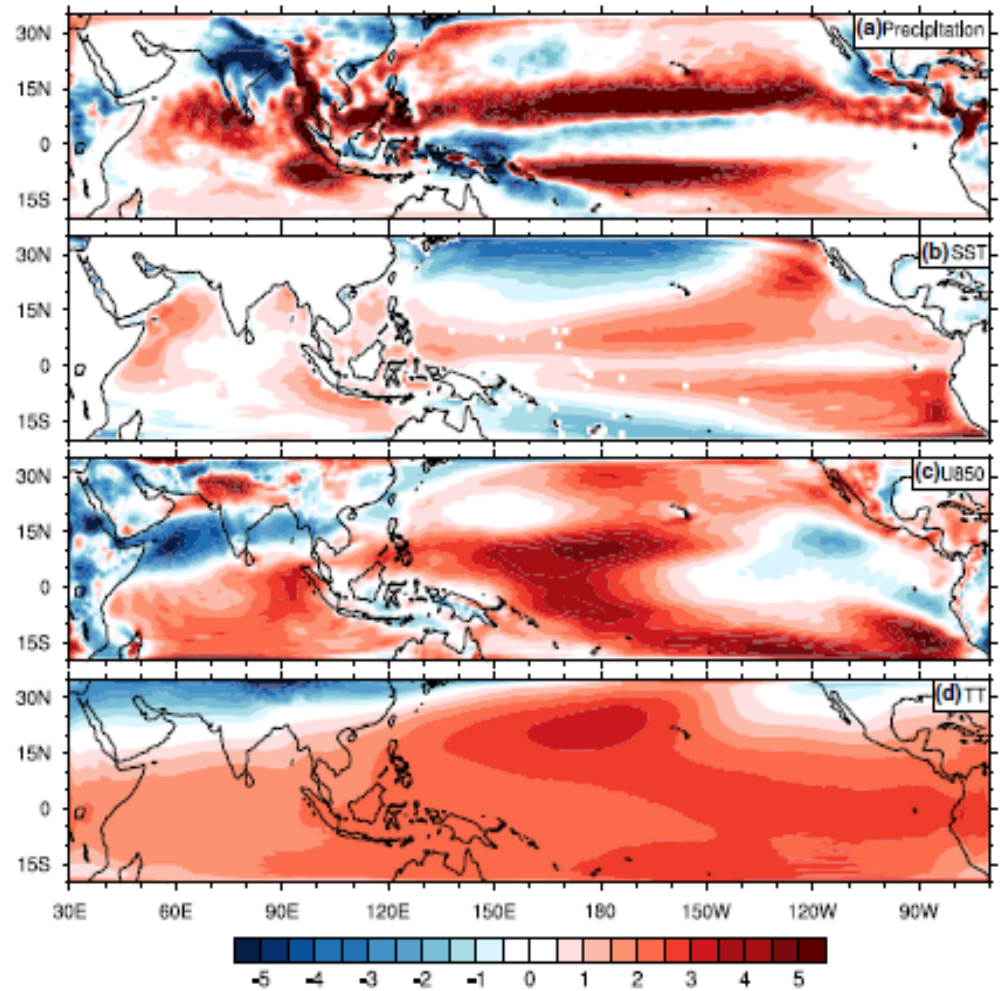
IFS T1159
125 km

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

CFSv2 T126 (~100km) bias

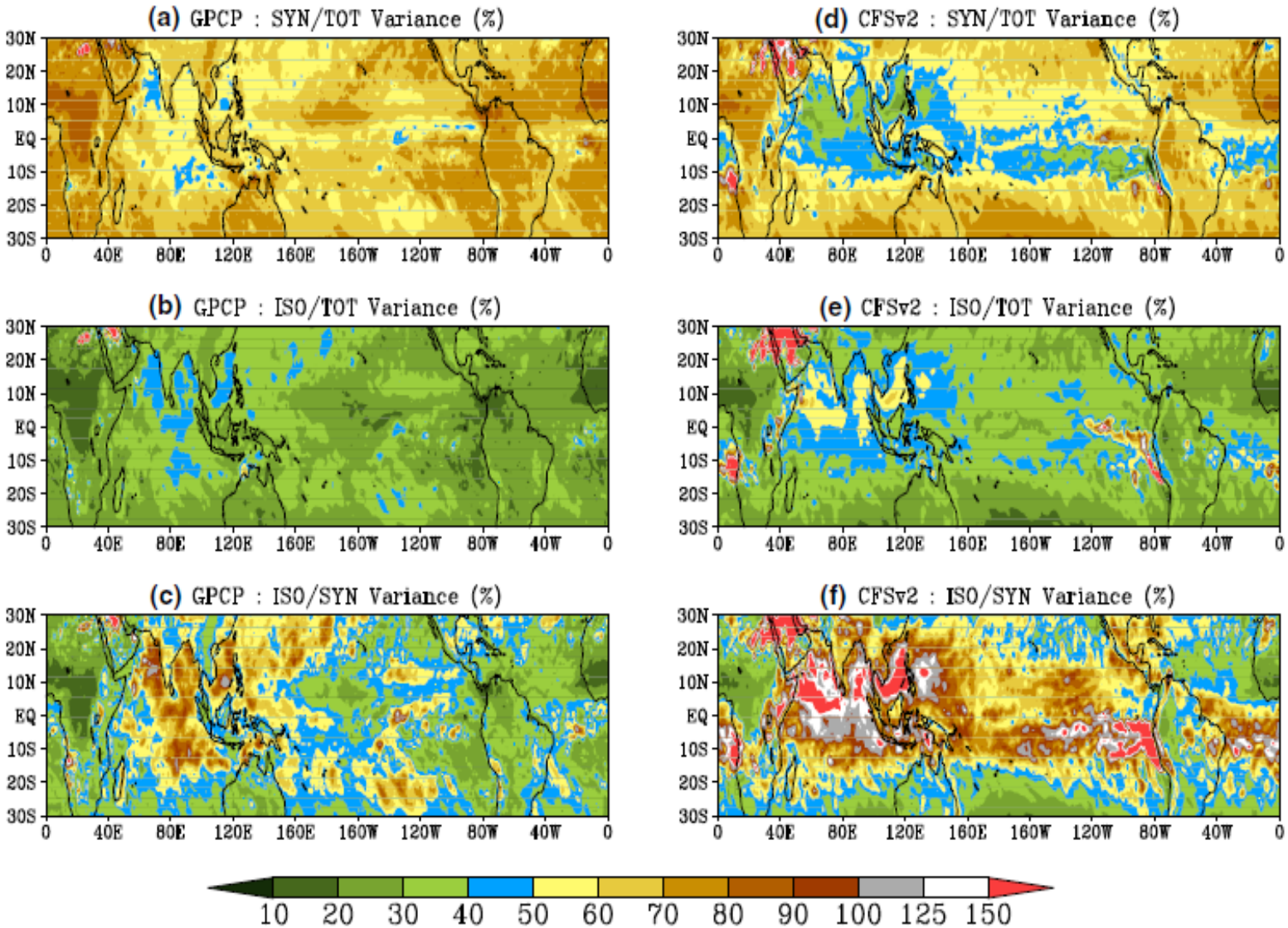


CFSv2 T382(~38km) bias



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



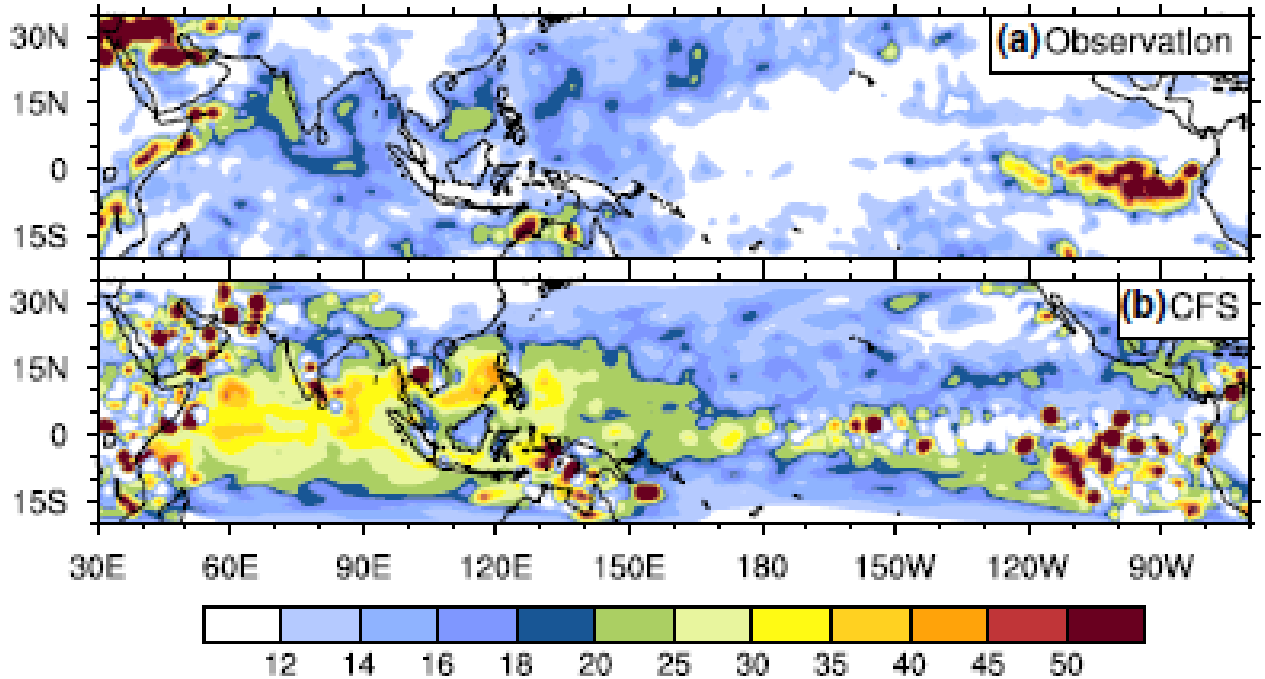
Bidyut Goswami et al. 2014

CFSV2: Less synoptic variance and more ISO variance

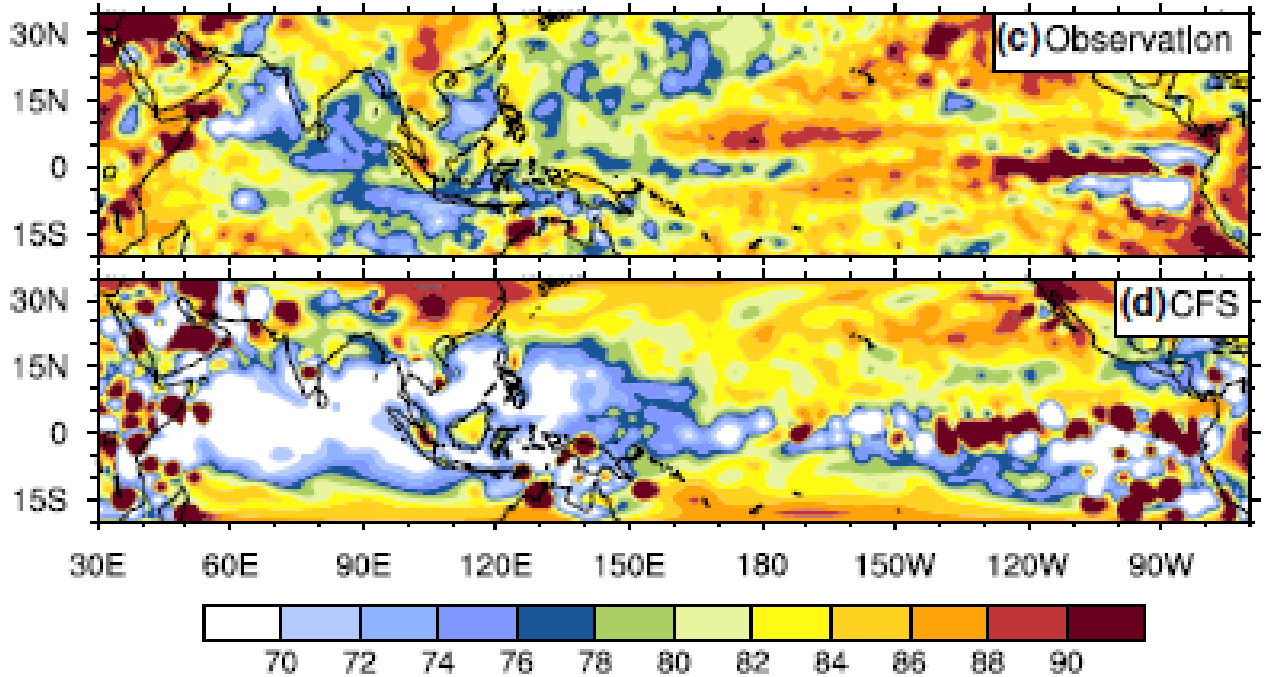
a) Ratio of synoptic scale (2-10 day bandpassed) variance to total variance in GPCP; b) ratio of ISO scale (10-90 day bandpassed) variance to total variance in GPCP; c) ratio of ISO scale variance to synoptic scale variance in GPCP; d) ratio of synoptic scale variance to total variance inCFSv2. e) Ratio 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)

Abhik et al. 2015

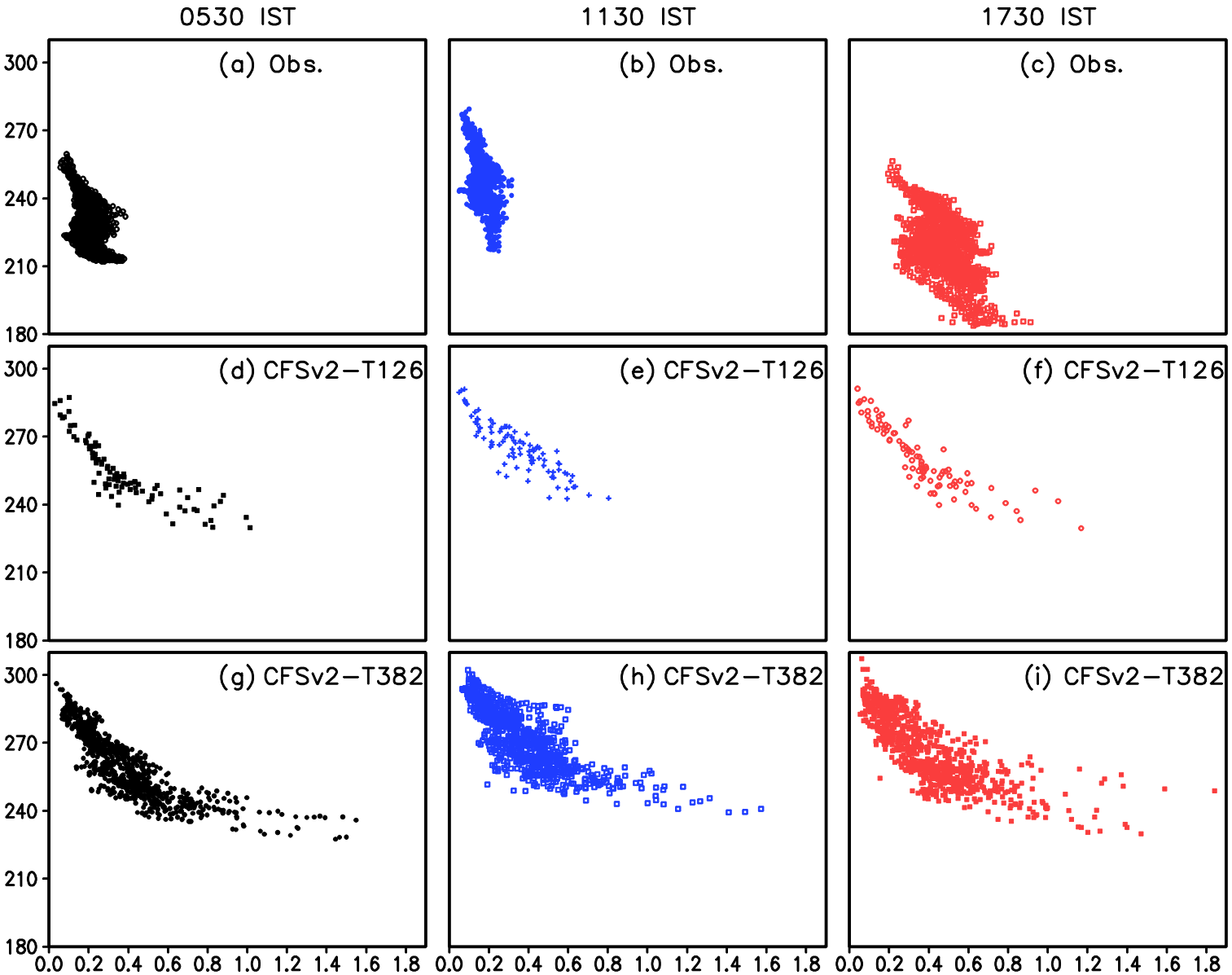
CFSv2 T382 ISO 10-90 days variance



CFSv2 T382 Synoptic variance (2-10 Days)



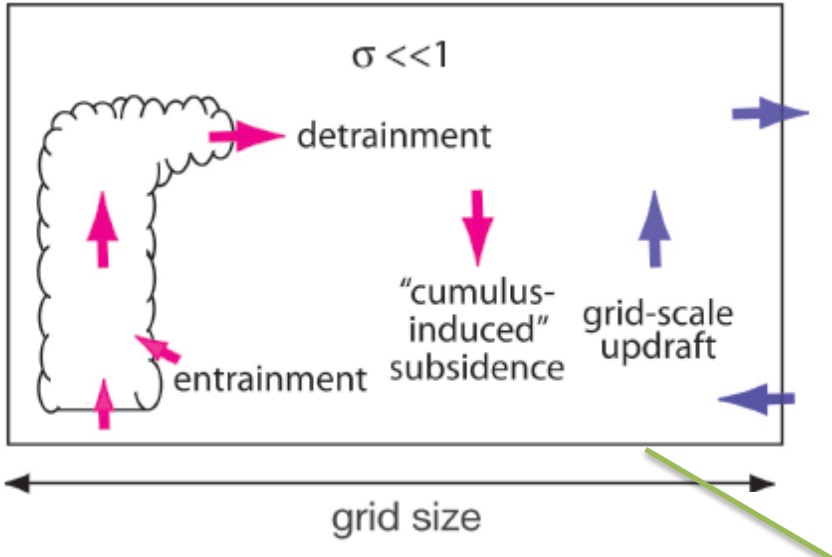
CFSv2 T382 overestimates ISO and underestimates Synoptic variance over tropics



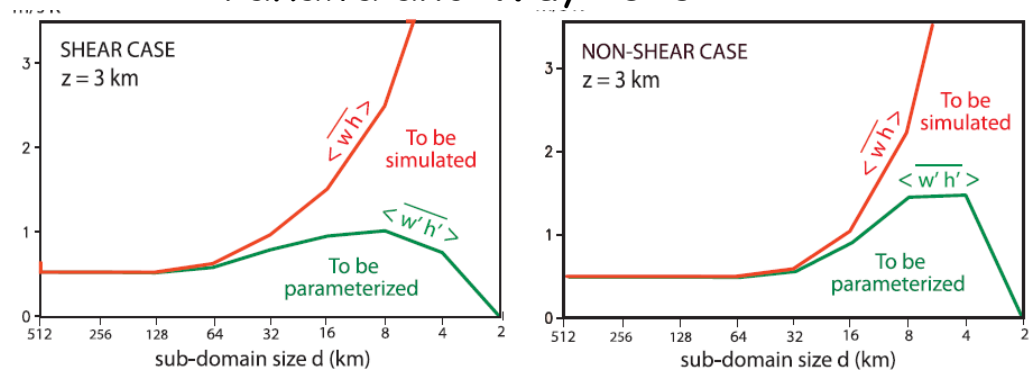
Scatter plot of OLR vs rainrate

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

Ganai et al. 2015



Arakawa and Wu, 2013



σ ~1

Arakawa et al. 2011, ACP

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.

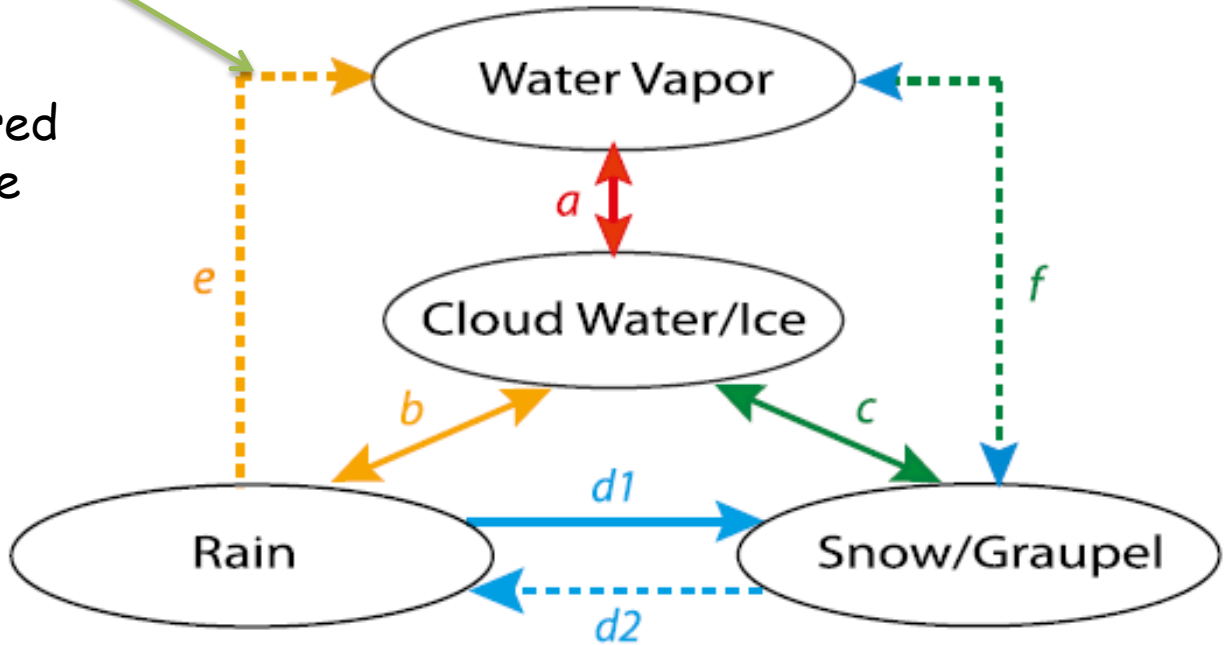


FIG. 9. A simplified view of the cloud microphysical conversions included in the CRM simulation used in this paper. See text for

Arakawa and Wu, 2014

Arakawa and Wu, 2013

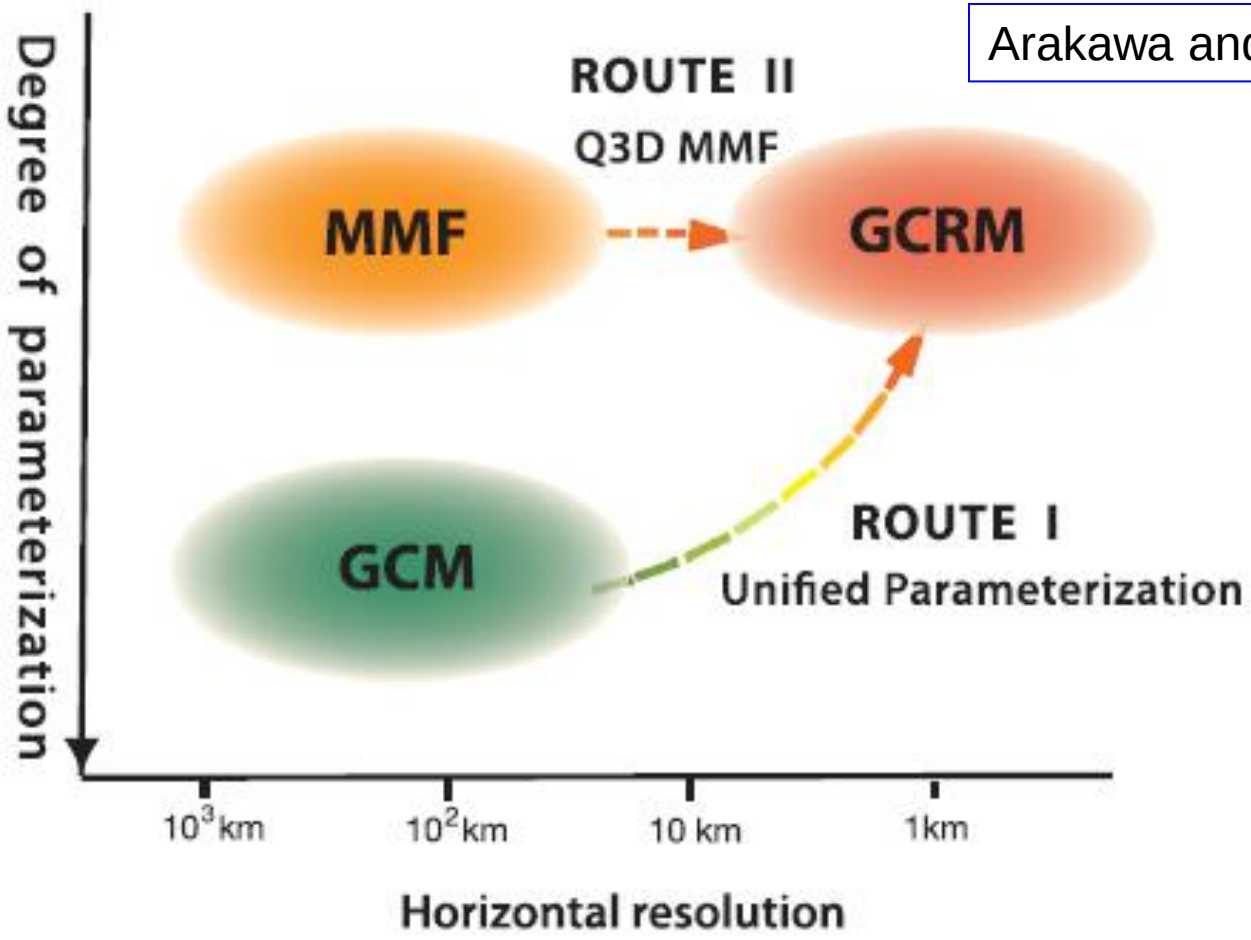
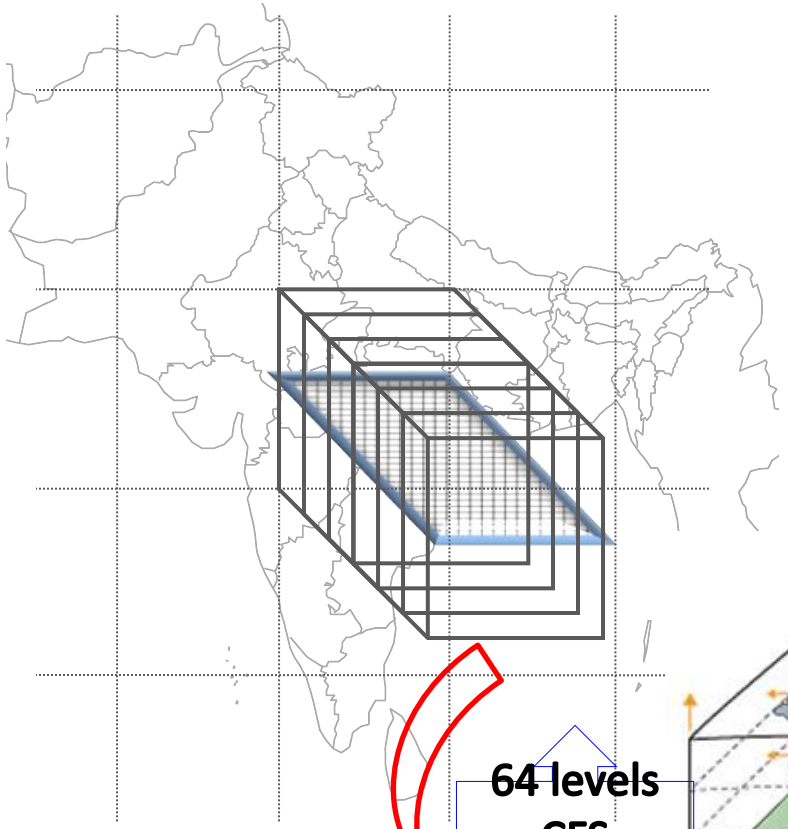


FIG. 3. Two routes for unifying the low- and high-resolution models.

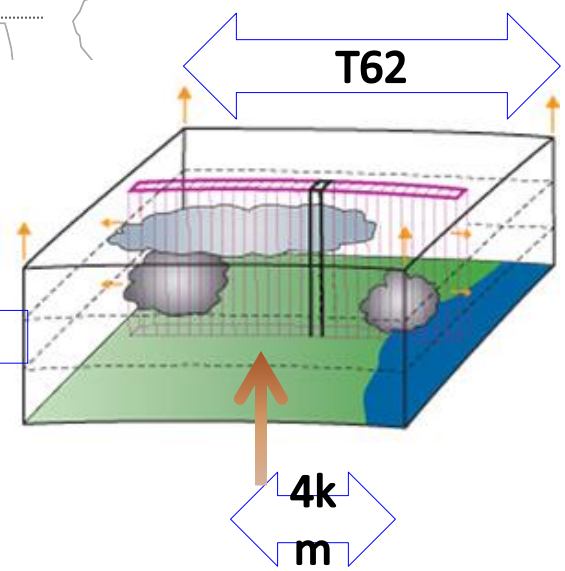
Route II with 2D MMF: accomplished in IITM through development of SP-CFS

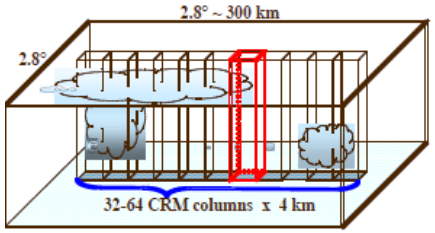
Superparameterized CFSv2-T62 (SPCFS) Analyses of 6.5 year free run

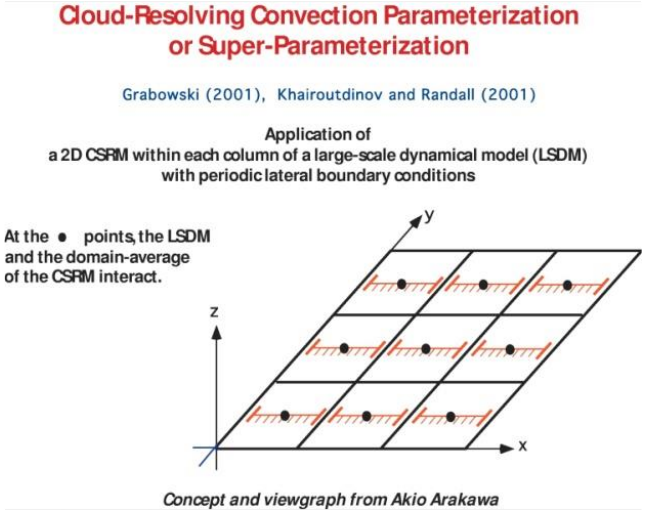


Convective tendencies are explicitly simulated with a **C**loud **R**esolving **M**odel running in each GCM grid column which replaces the traditional cumulus parameterization of the GCM.

- Model integrated for 6.5 years and five years are analyzed

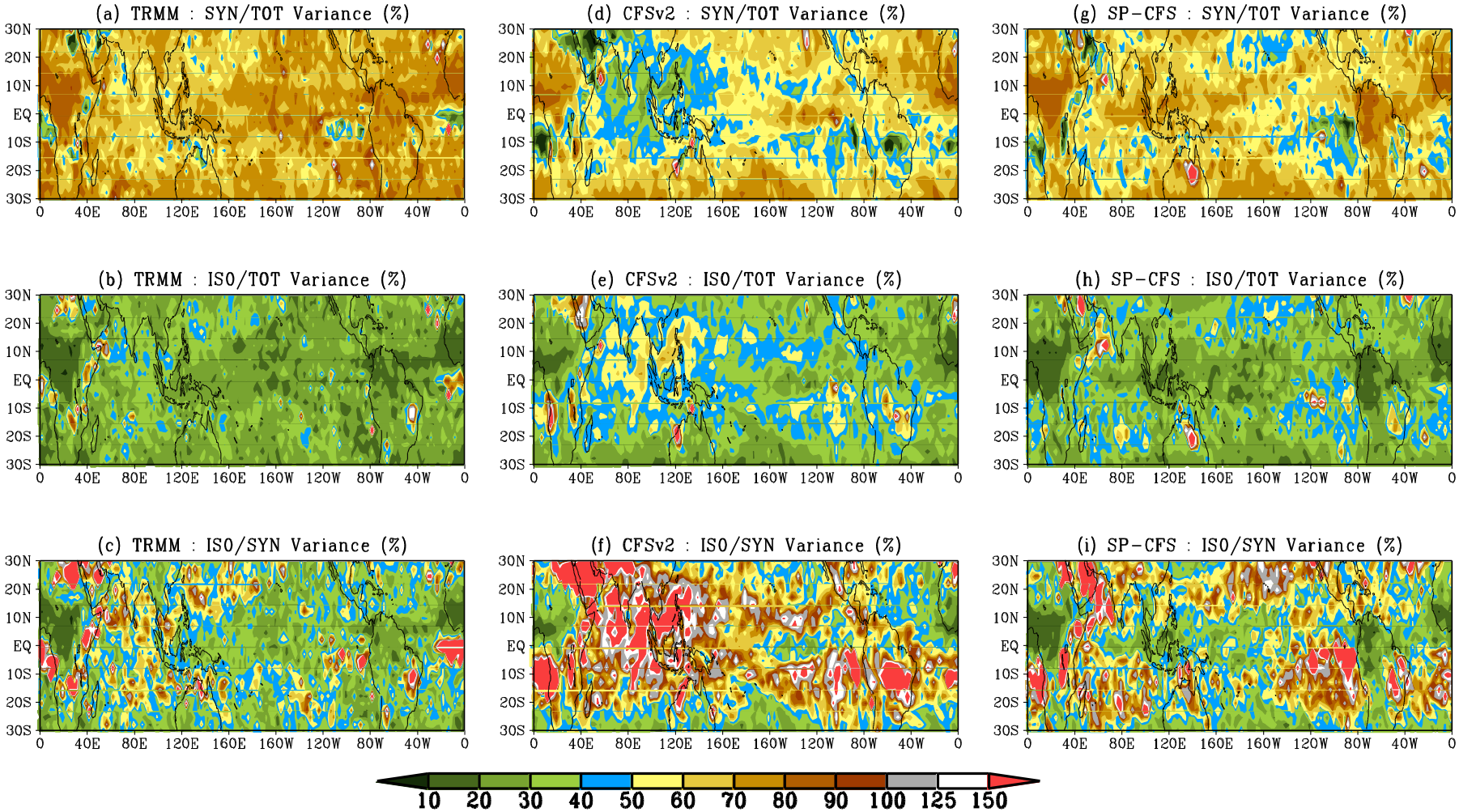






Bidyut B. Goswami, R. P. M. Krishna, P. Mukhopadhyay, Marat Khairoutdinov, and B. N. Goswami, 2015: Simulation of the Indian Summer Monsoon in the Superparameterized Climate Forecast System Version 2: Preliminary Results. J. Climate, 28, 8988–9012

Ratio of Synoptic to ISO variance.



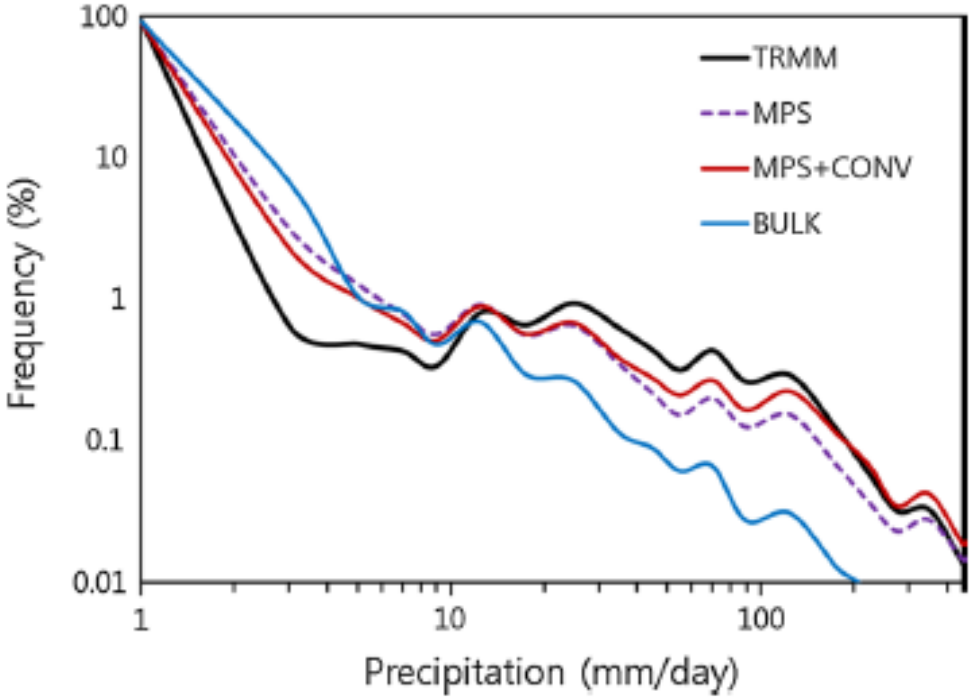
Bidyut Goswami et al., JOC, 2015

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

Clim Dyn
DOI 10.1007/s00382-014-2376-1

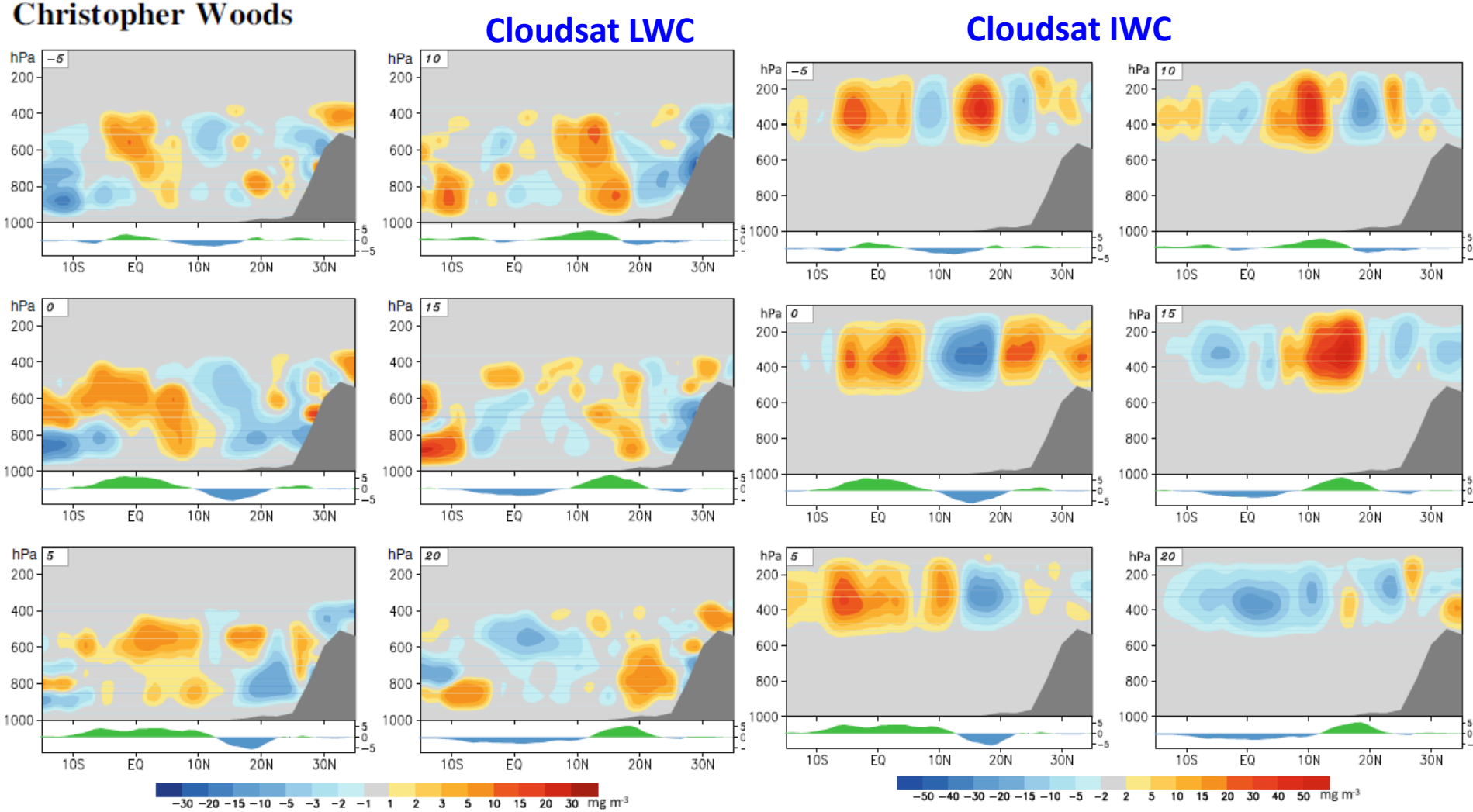
GCMs with implicit and explicit representation of cloud microphysics for simulation of extreme precipitation frequency

In-Sik Kang · Young-Min Yang · Wei-Kuo Tao

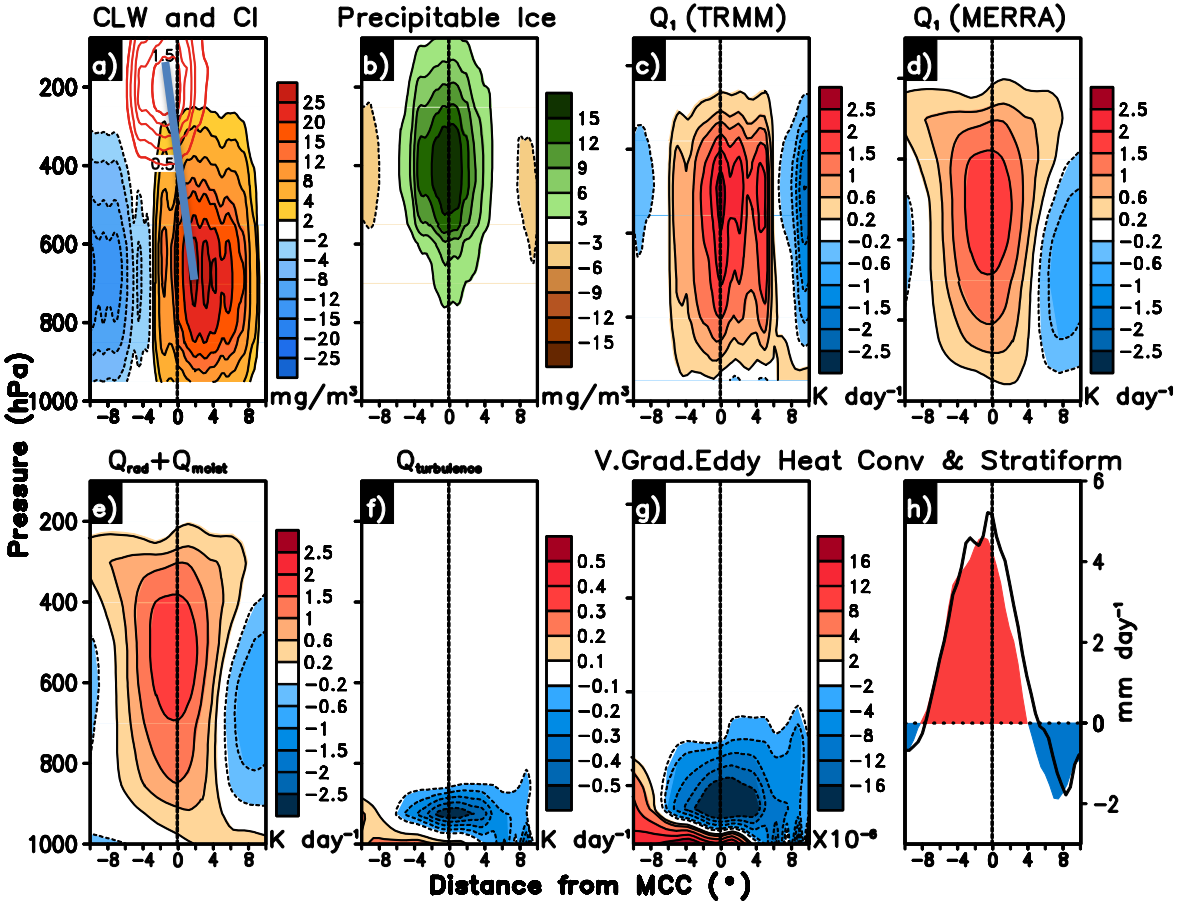


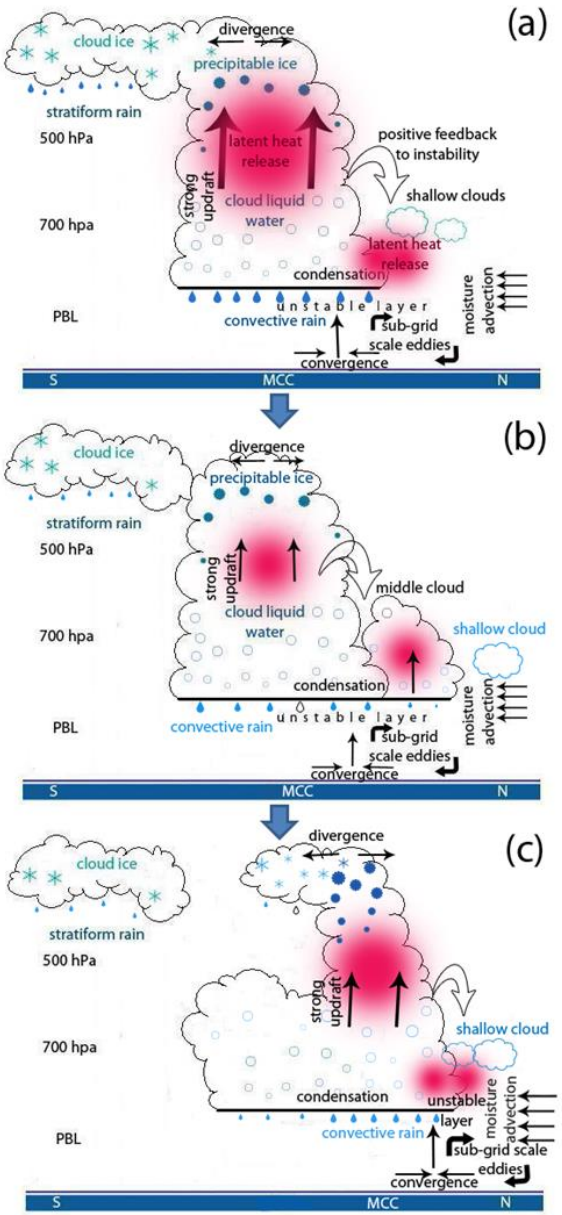
Vertical cloud structures of the boreal summer intraseasonal variability based on CloudSat observations and ERA-interim reanalysis

Xianan Jiang · Duane E. Waliser · Jui-Lin Li · Christopher Woods



Hypothesis based on observation for northward propagation BSISO (Abhik et al, 2013)





Our results are supplemented by few recent studies e. g.

Preconditioning Deep Convection with Cumulus Congestus by Hohenegger and Steven, 2013

A climatology of tropical congestus using CloudSat by Wall et al. 2013

TECHNICAL MEMORANDUM

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A new prognostic bulk microphysics scheme for the IFS

Richard M. Forbes[1], Adrian M. Tompkins[2] and Agathe Untch[1]

Research Department

[1]ECMWF [2]ICTP, Italy

September 2011

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen terme

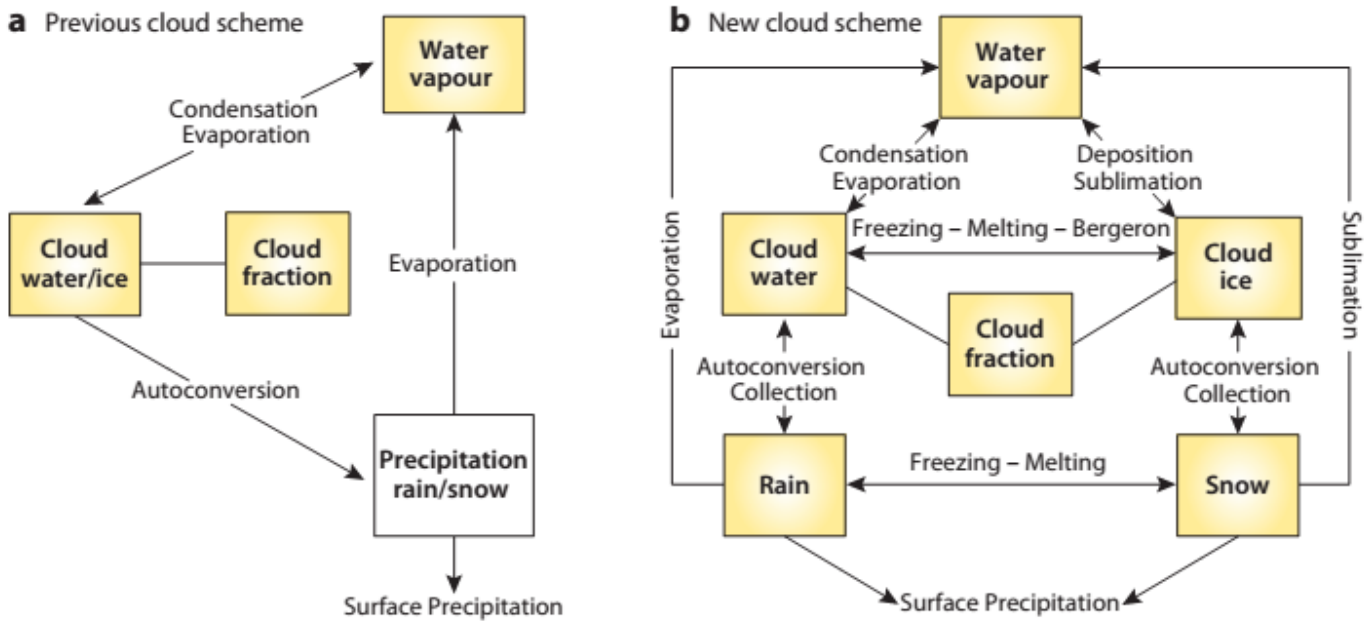


Figure 1: *Schematic of the IFS cloud scheme: (a) the Tiedtke scheme with three moisture related prognostic variables operational from 1995 to 2010 (before IFS Cy36r4) and (b) the new cloud scheme with six moisture related prognostic variables (Cy36r4 onwards). Yellow boxes indicate prognostic variables.*

2.2 Numerical framework

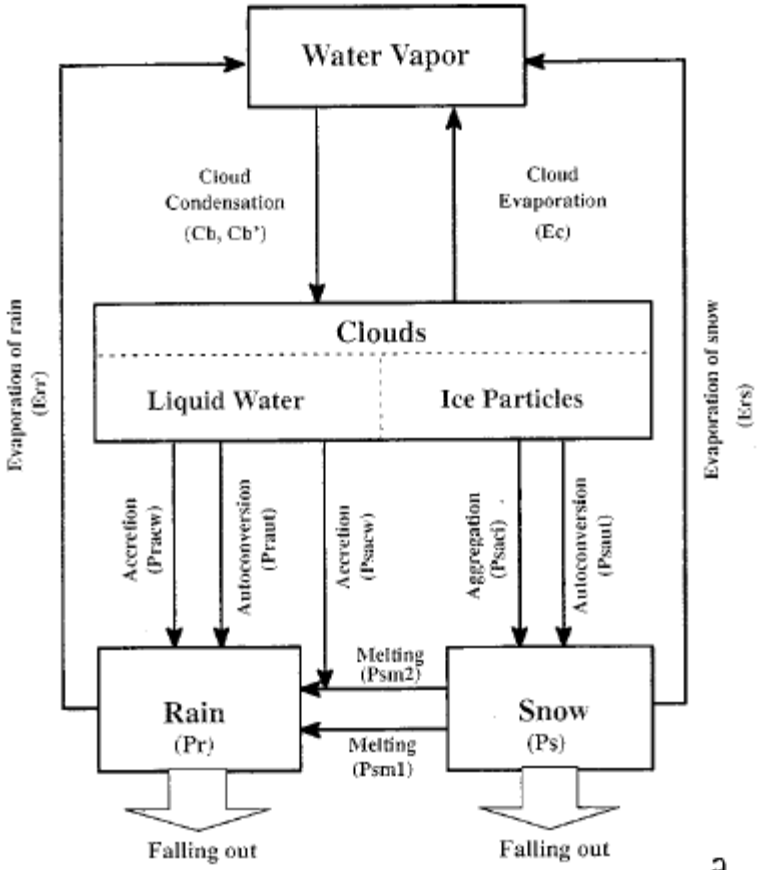
The new scheme is a multi-species prognostic microphysics scheme, with $m = 5$ prognostic equations for water vapour, cloud liquid water, rain, cloud ice and snow. The equation governing each prognostic cloud variable within the cloud scheme is

$$\frac{\partial q_x}{\partial t} = S_x + \frac{1}{\rho}\frac{\partial}{\partial z}(\rho V_x q_x), \tag{1}$$

where q_x is the specific water content for category x ($x = 1$ for cloud liquid droplets, $x = 2$ for rain, and so on), S_x is the net source or sink of q_x through microphysical processes, and the last term represents the sedimentation of q_x with fall speed V_x.

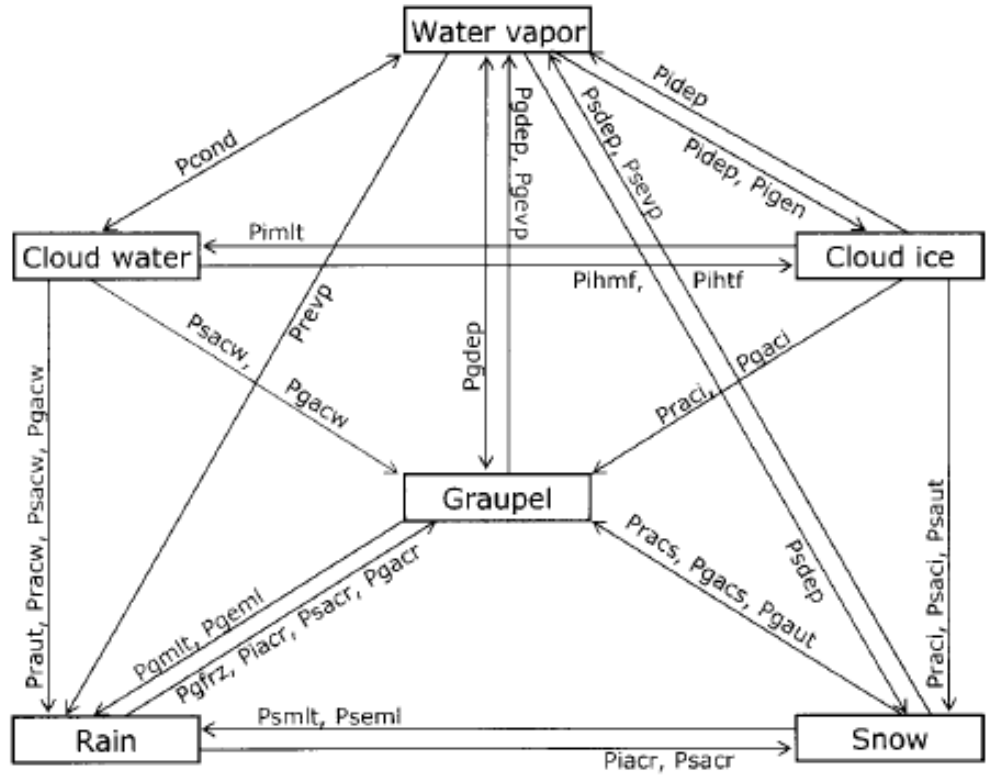
Zhao & Carr 1997

Default CFS Microphysics



Hong & Lim 2006

Modified WSM6 using aircraft campaign CAIPEEX



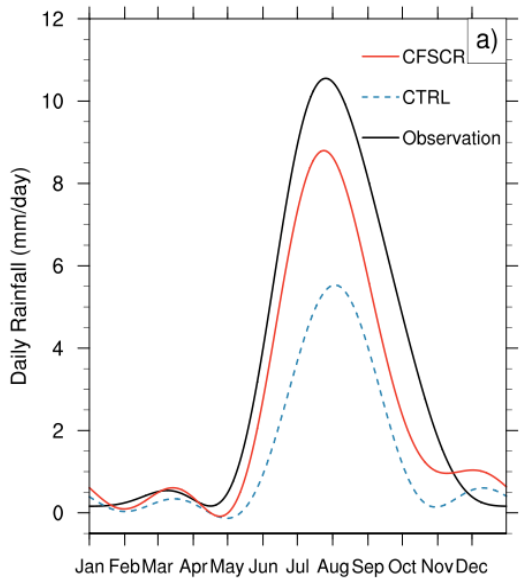
Tendencies

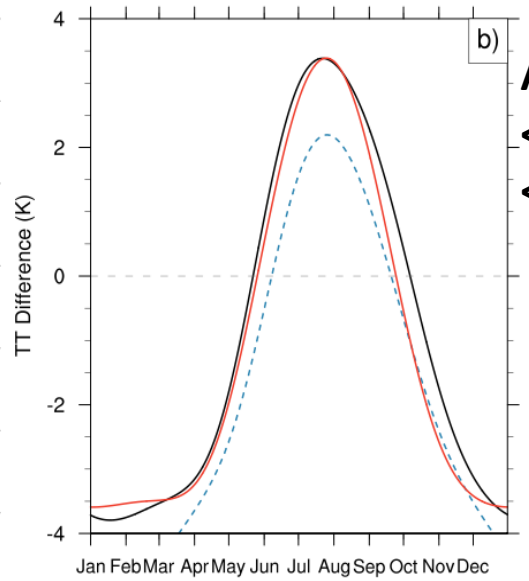
$$\frac{\partial}{\partial t}(n) = \mathrm{ADV}(n) + \mathrm{TURB}(n) + \mathrm{SEDIM}(n) + \mathrm{SOURCE}(n)$$

where n = *[n_r, n_i, n_s, n_{clw}, n_g, n_v] represents the concentration of rain, ice* crystals, snow, graupel, cloud water, water vap.

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

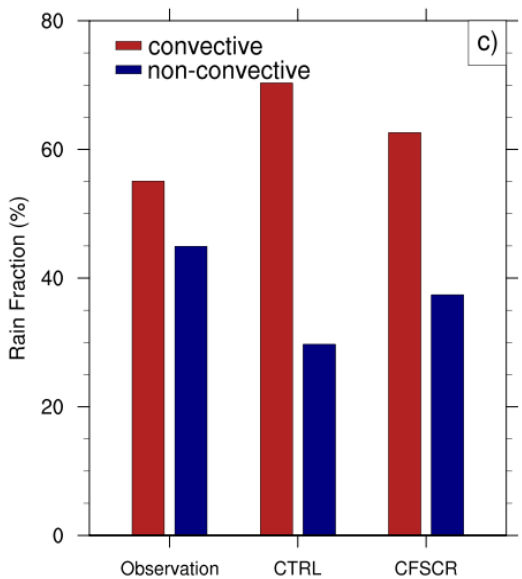
Annual Rainfall Cycle <73°-85°E,15°-25°N>

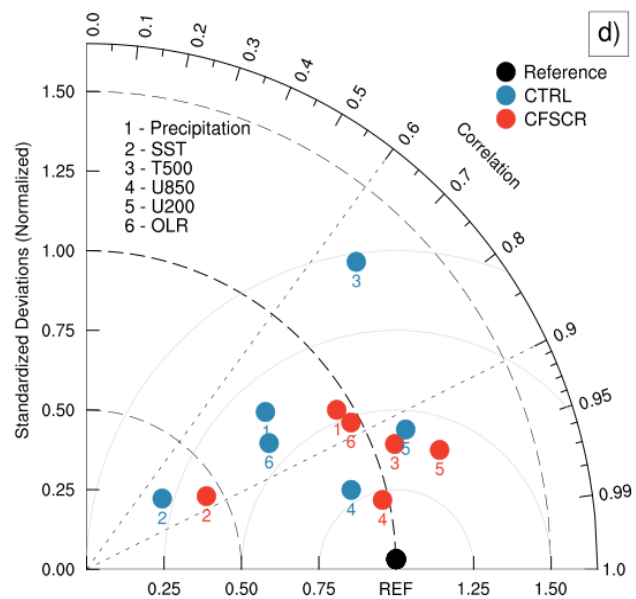




Annual TT Difference <40°-100°E,5°-35°N> - <40°-100°E,15°S-5°N>

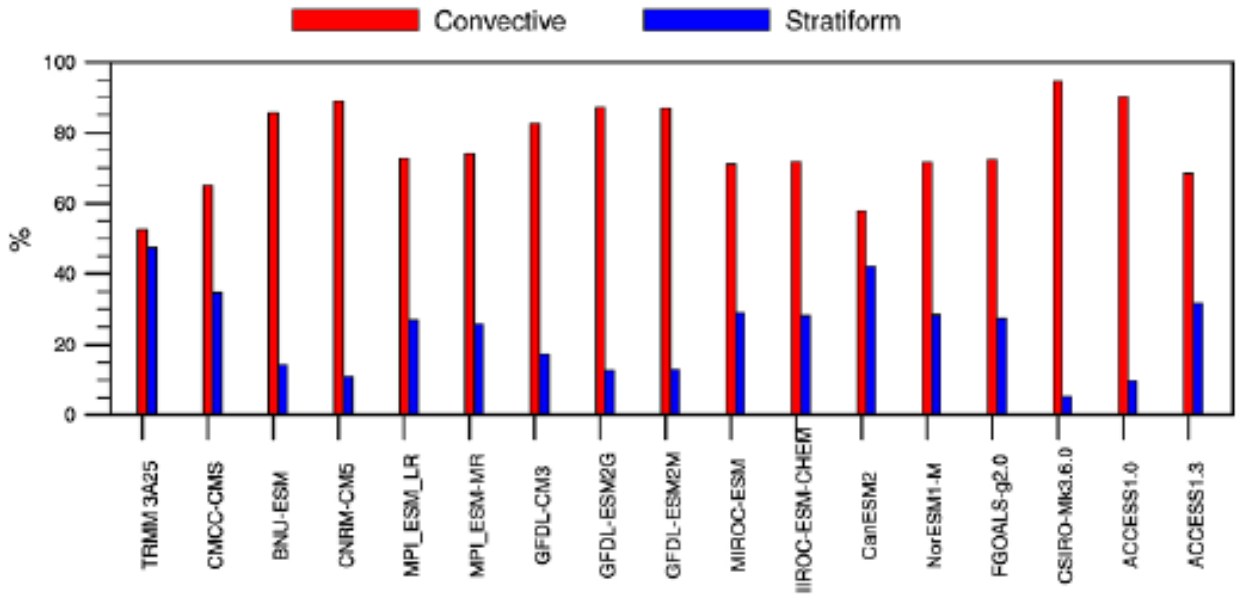
<40°-120°E, 15°S-30°N>





Abhik et al, JAMES

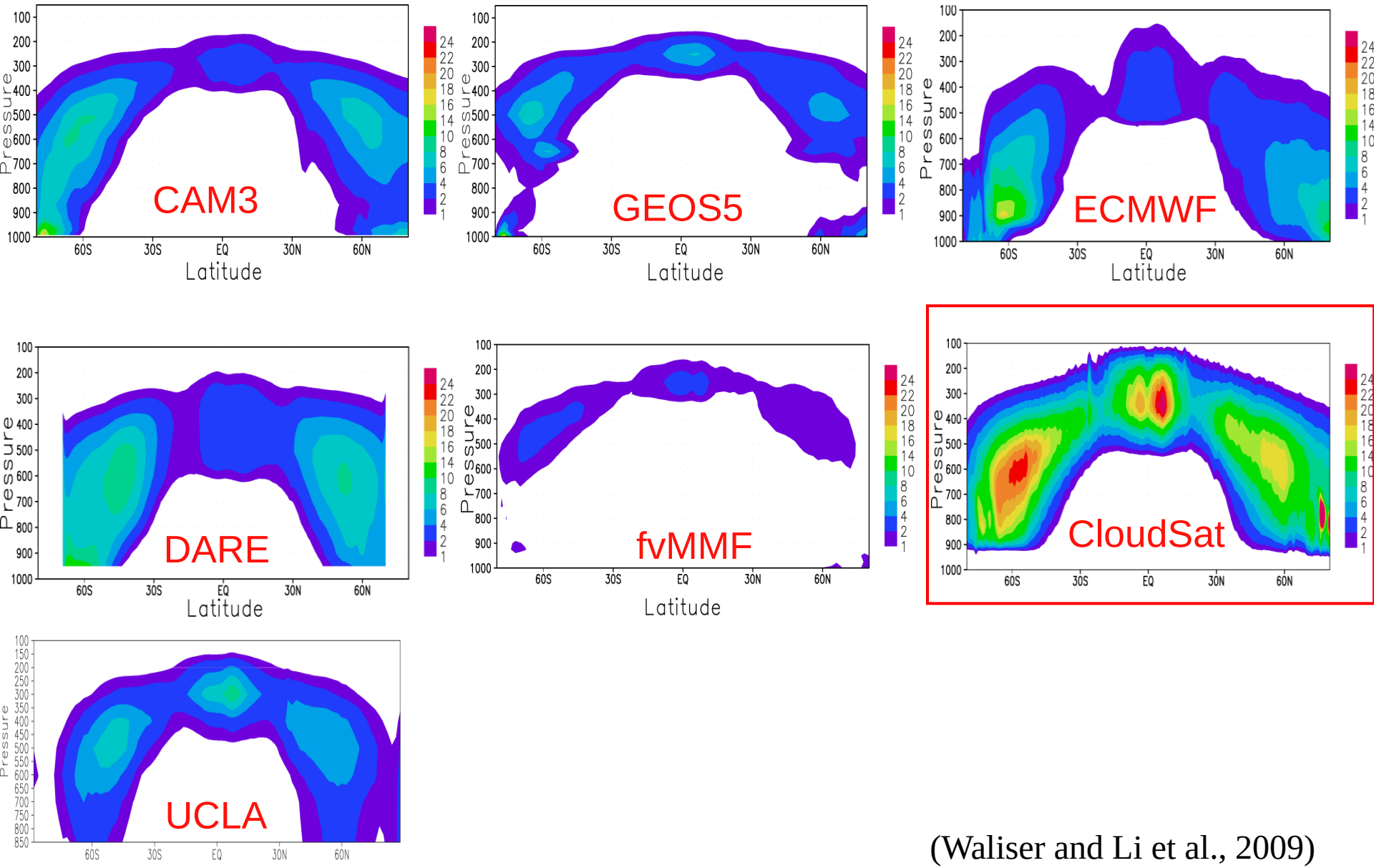
Fig. 8 Percentage of precipitation (averaged over SAM region, 10°N–30°N and 70°E–100°E) explained by convective (*red bars*) and stratiform (*blue bars*) types in the historical simulations of the 16 CMIP5 models along with that from observations (TRMM)



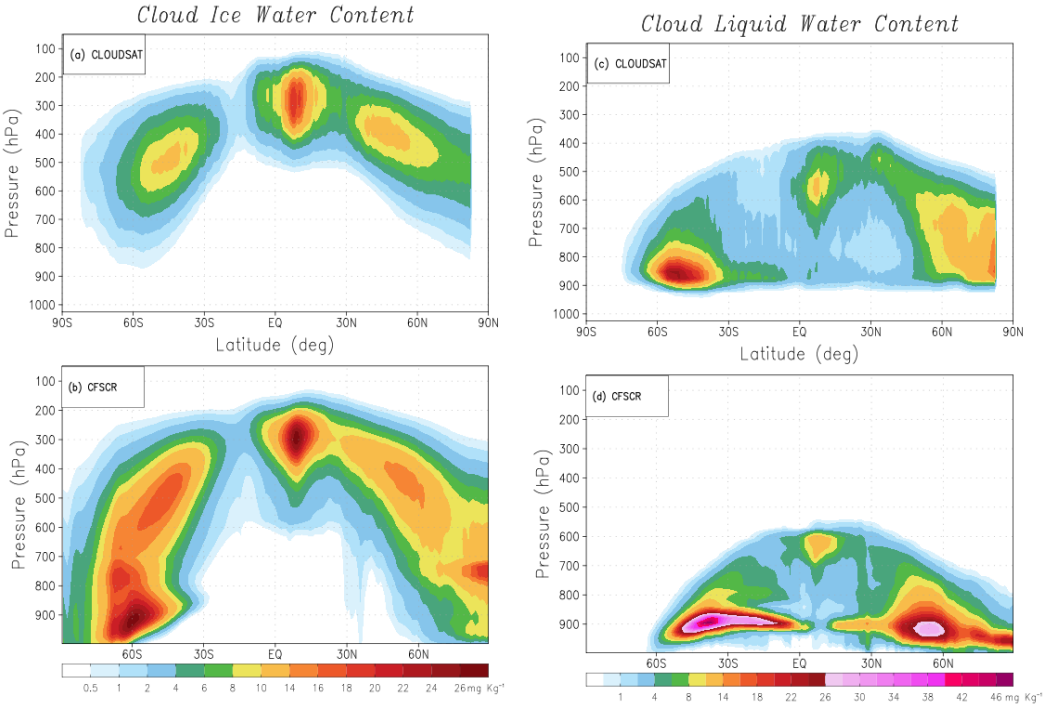
Why ensemble mean projection of south Asian monsoon rainfall by CMIP5 models is not reliable? C. T. Sabeerali · Suryachandra A. Rao · A. R. Dhakate · K. Salunke · B. N. Goswami, Cli. Dyn. 2015

GCM Cloud Ice Water Content (IWC)

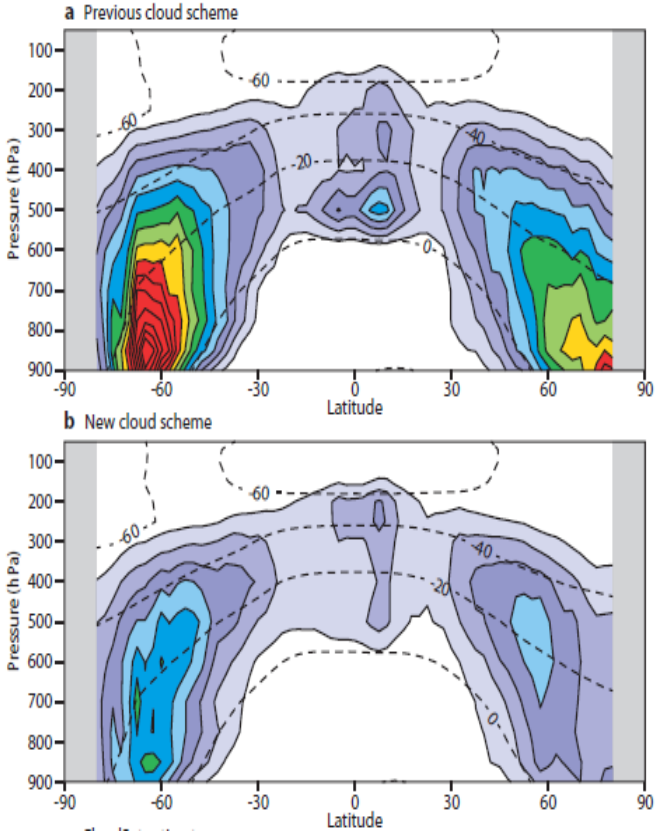
Annual Mean Values

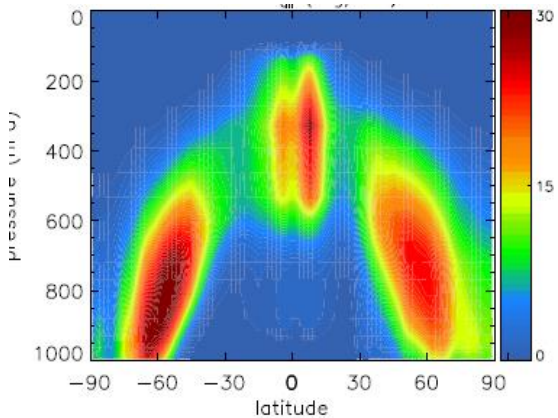


(Waliser and Li et al., 2009)



ECMWF IFS cloud ice
Betchold+Bulk (comp)

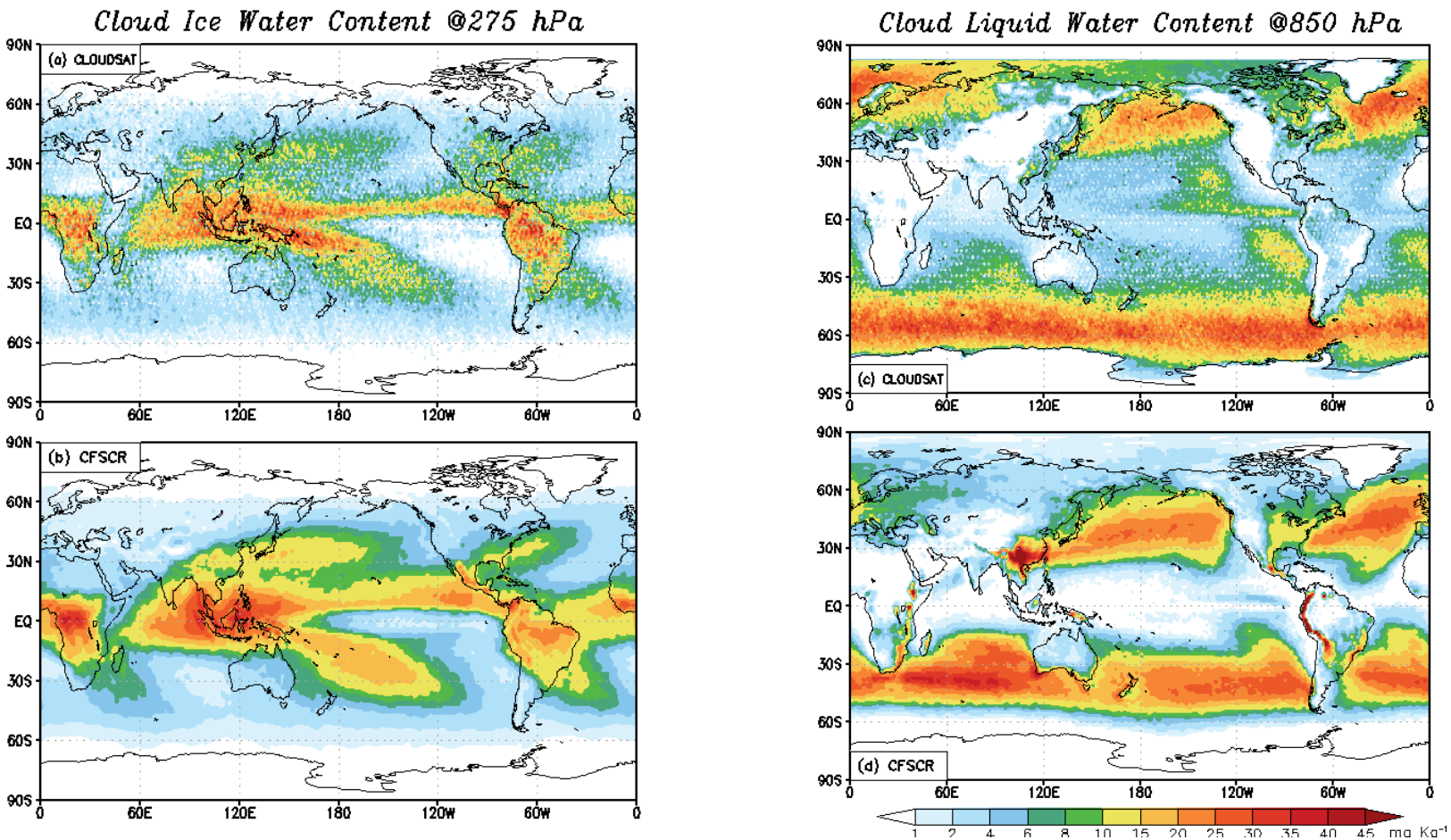




GFDL
AM3+Morrisson

Zonally averaged annual mean vertical distribution of cloud ice water content (mg kg^{-1}) obtained from (a) CFSCR; and cloud liquid water content (mg kg^{-1}) from (b) CFSCR model.

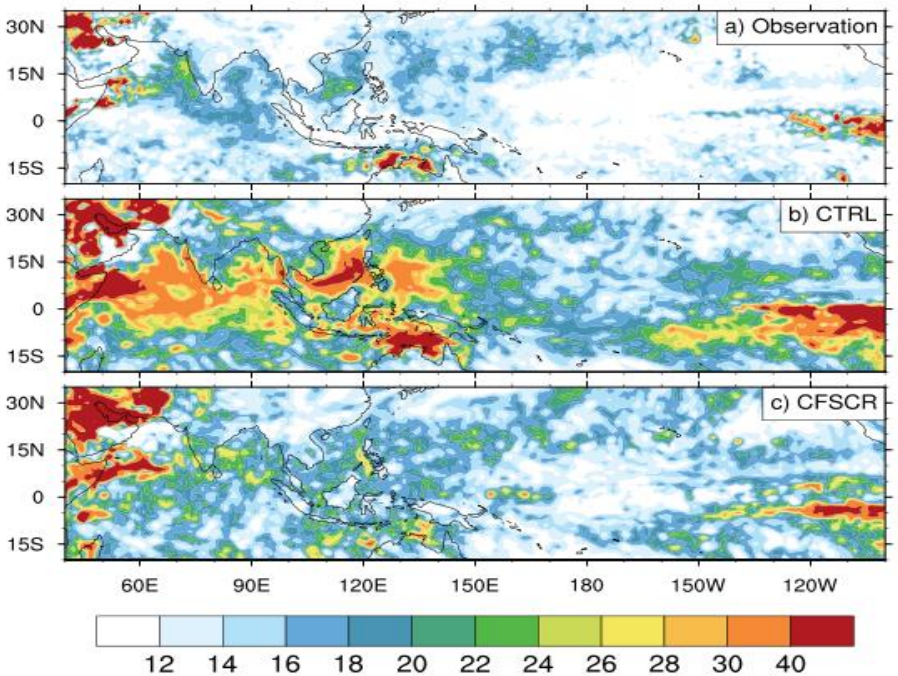
CFSCR: Modified CFSv2 with revised Cloud Microphysics, Convection and

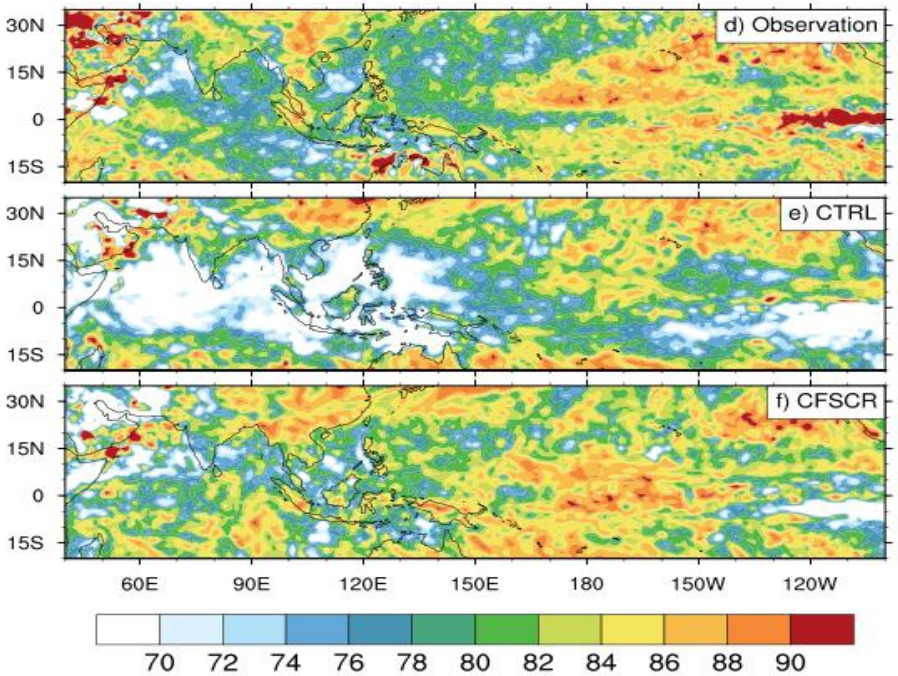


Annual mean isobaric distribution of cloud ice water content (mg kg^{-1}) obtained from (a) CloudSat 2B-CWC-RO, (b) CFSCR (at 271 hPa model level); and cloud liquid water content (mg kg^{-1}) from (c) CloudSat, (d) CFSCR (858 hPa).

Abhik et al. JAMES 2017

Spatial distribution of ISO scale (20–90 day bandpassed) variance for (a) TRMM,
(b) CTRL, and
(c) CFSCR;
Spatial distribution synoptic scale (2-20 day bandpassed) variance for (d) TRMM, (e) CTRL, and (f) CFSCR.
All of the variances are computed for JJAS daily rainfall anomalies (mm day^{-1}).





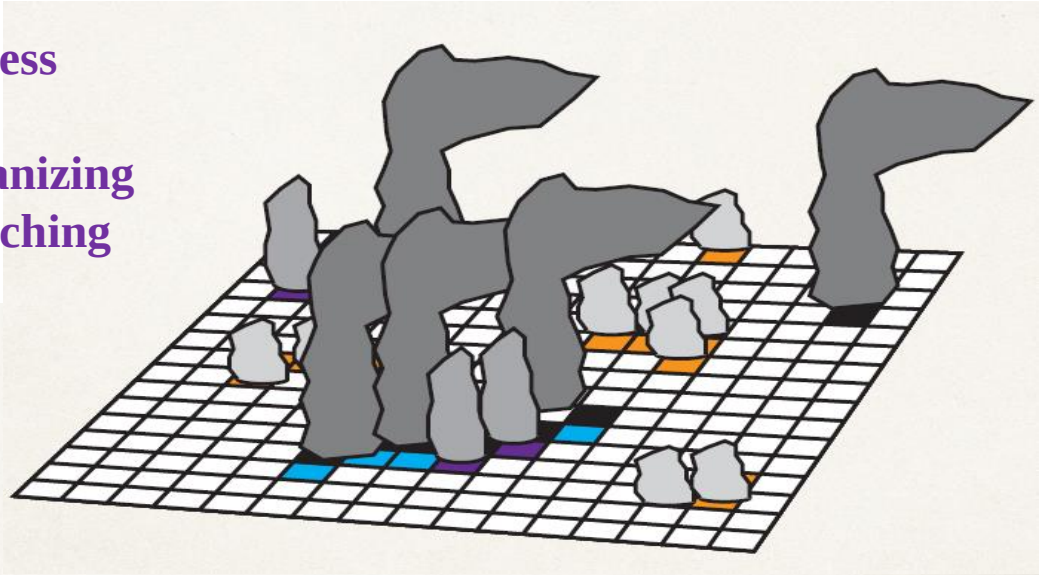
New Paradigm

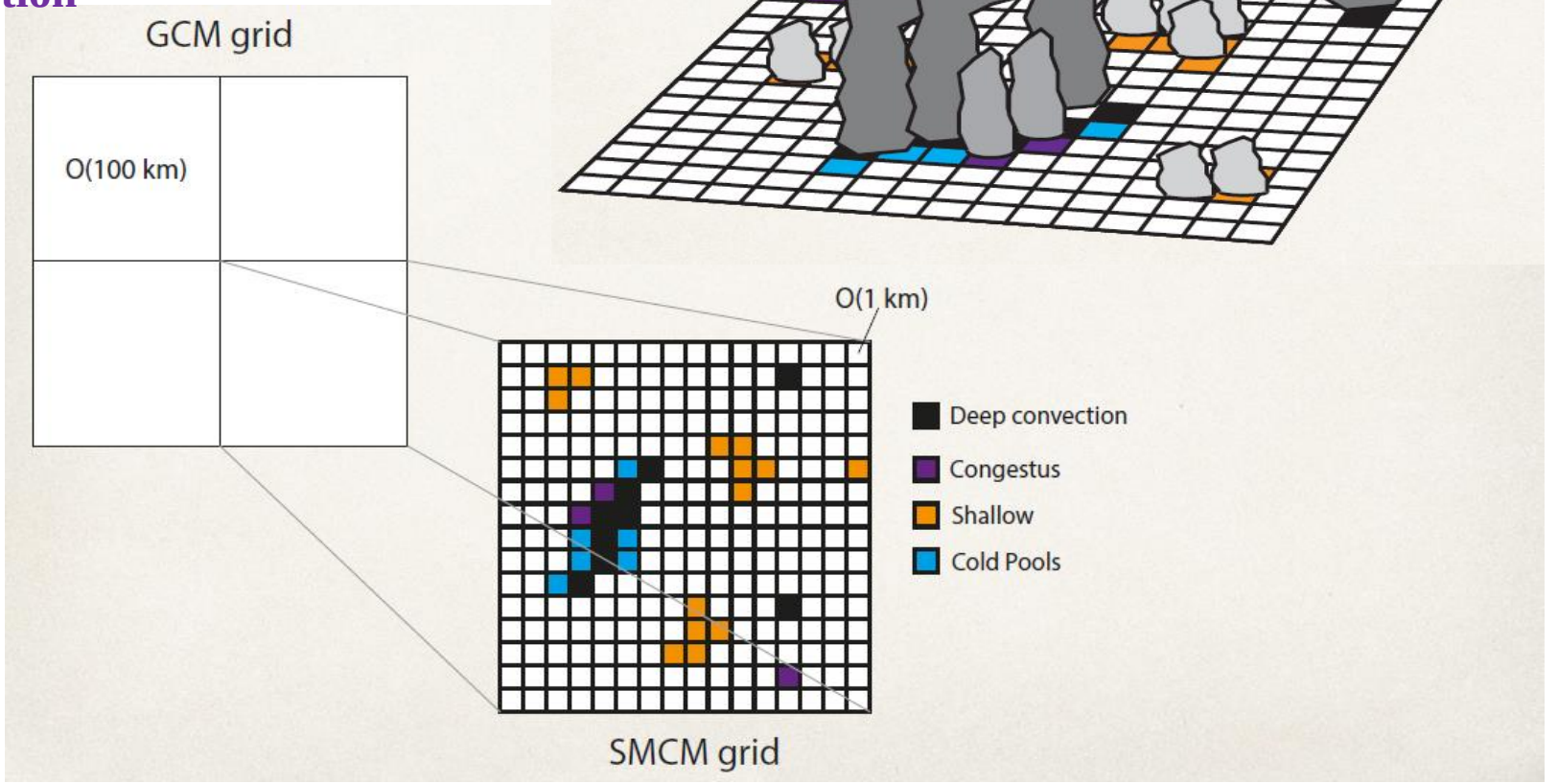
Stochastic modelling in Climate Forecast System (CFSsmcm) Model

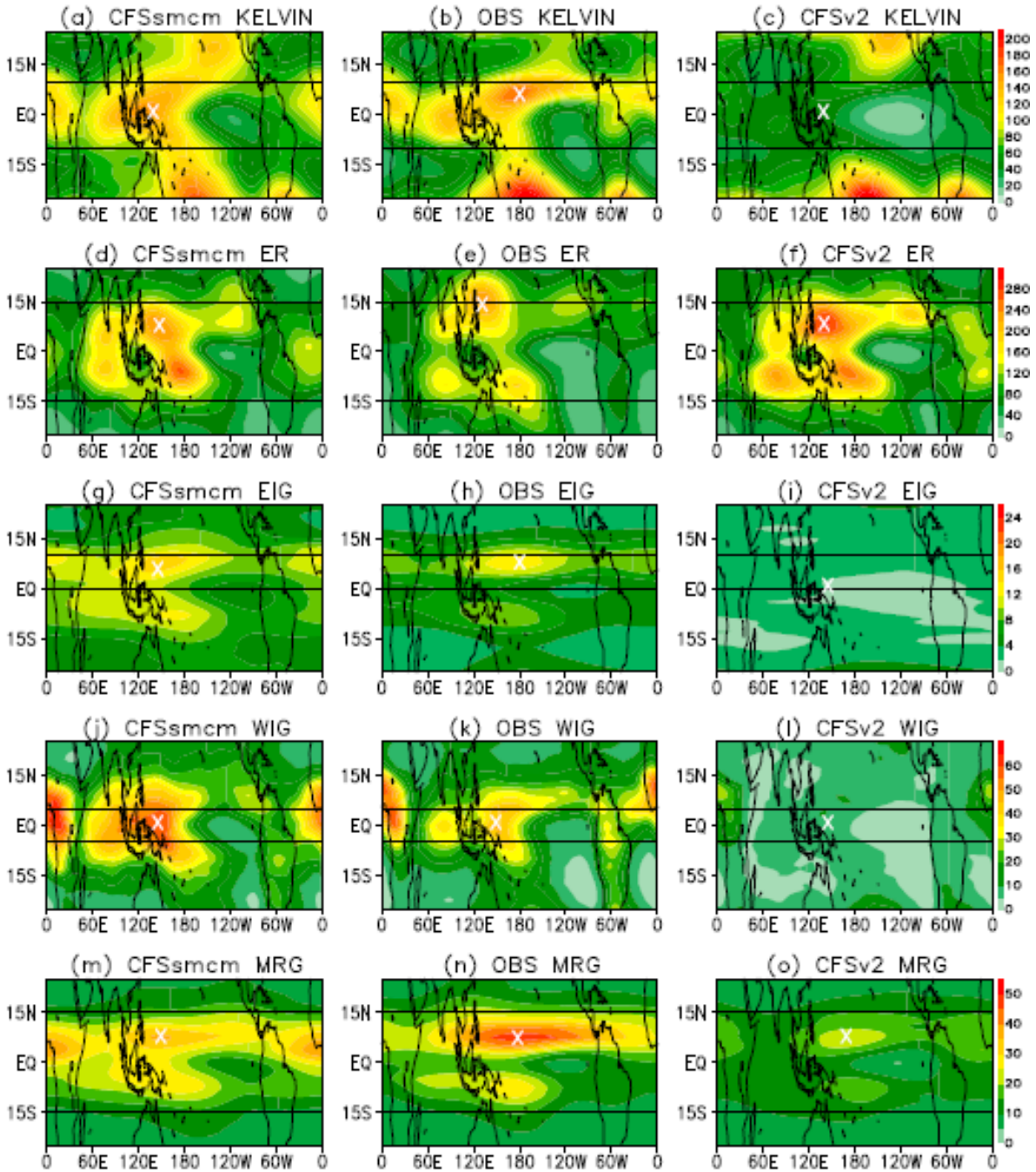
Convective tendencies are explicitly simulated in each GCM grid column which replaces the traditional cumulus parameterization of the GCM.

A Framework for the implementation of the Stochastic model in CFS

- **Stochastic nature in the convective process**
- **Existence of different clouds**
- **Distinguishing different clouds and organizing**
- **Resolution awareness and dynamic switching off in convection**







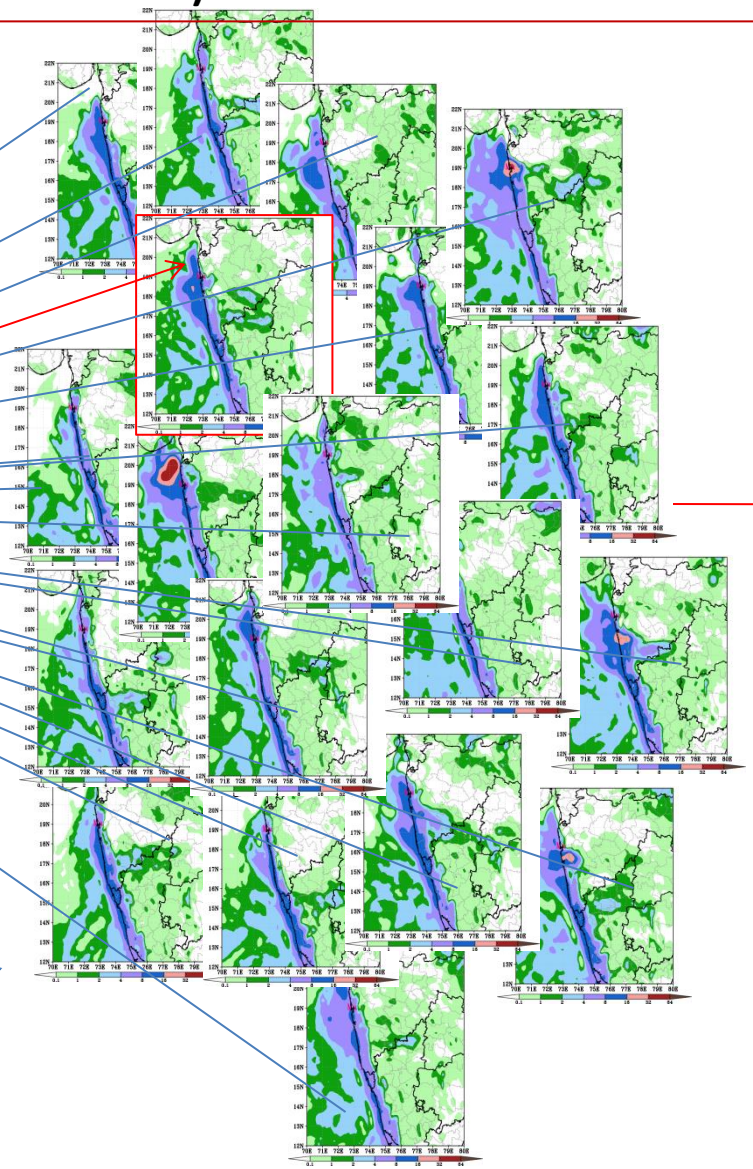
Goswami et al. JAS 2017

Global ensemble forecast system (at highest resolution 12km) : IC 7 June 2018 00Z: forecast valid for 10 June 2018 00Z (+72h forecast)

Control run showed as

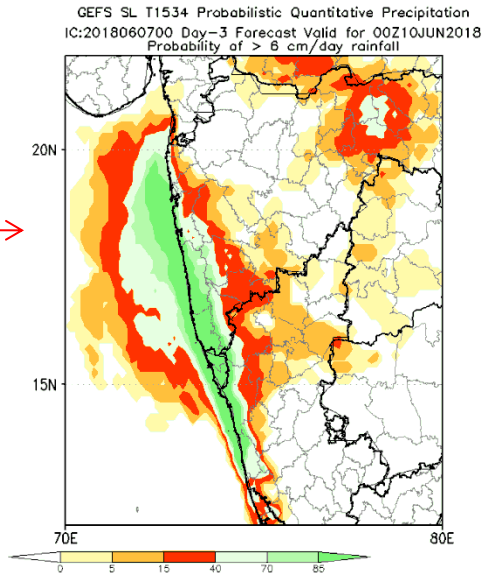
Initial Condition

Analysis

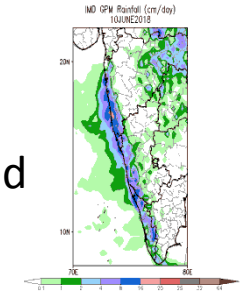


Forecast Uncertainty of 21 ensemble members

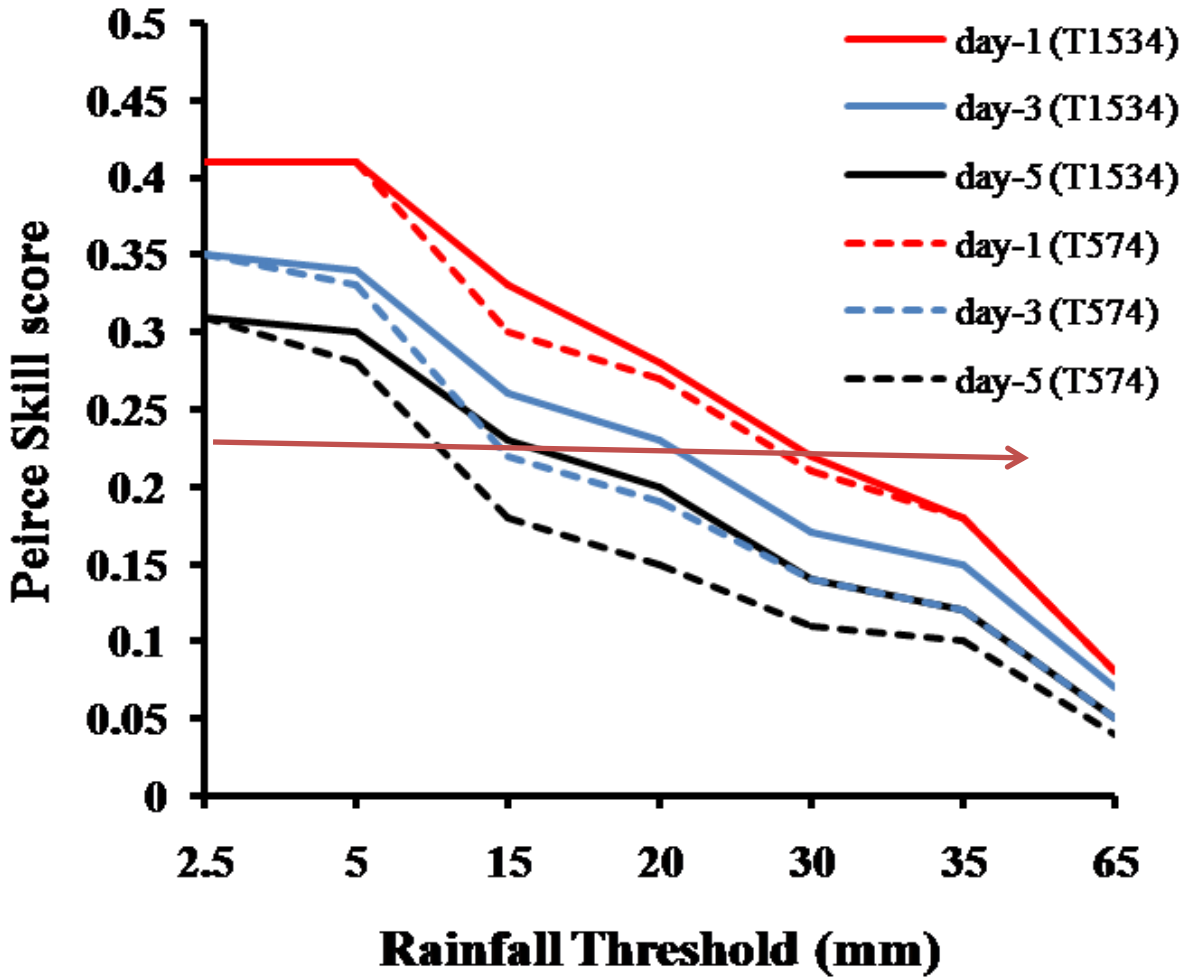
Probability of Rainfall > 6 cm/day



Observed Rainfall



High Resolution global 12.5 km model gives better skill (The skill of GFS T574 with 3 day lead is now extended to 5 days with T1534 ~12.5 km global GFS



Summary and Conclusion

- Improvement of cloud and convective parameterization has significantly reduced the systematic biases of the model
- Improved Cloud process parameterization has reduced the convective rainfall bias of model
- CFSCR has showed better synoptic scale variance and improved convectively coupled equatorial wave and propagations.
- Recent approach of stochastic multi cloud model approach has been able to improve the variance of tropical waves.
- All these physics improvement tested in coarser version of T126 will now be put in the high resolution GFS T1534 for improvement of Ensemble prediction system at 10 days time scale

Thank You !