The Challenge of Predicting the South Asian Summer Monsoon : A Way Forward

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TTA Workshop on "***Challenge in Monsoon Prediction***"

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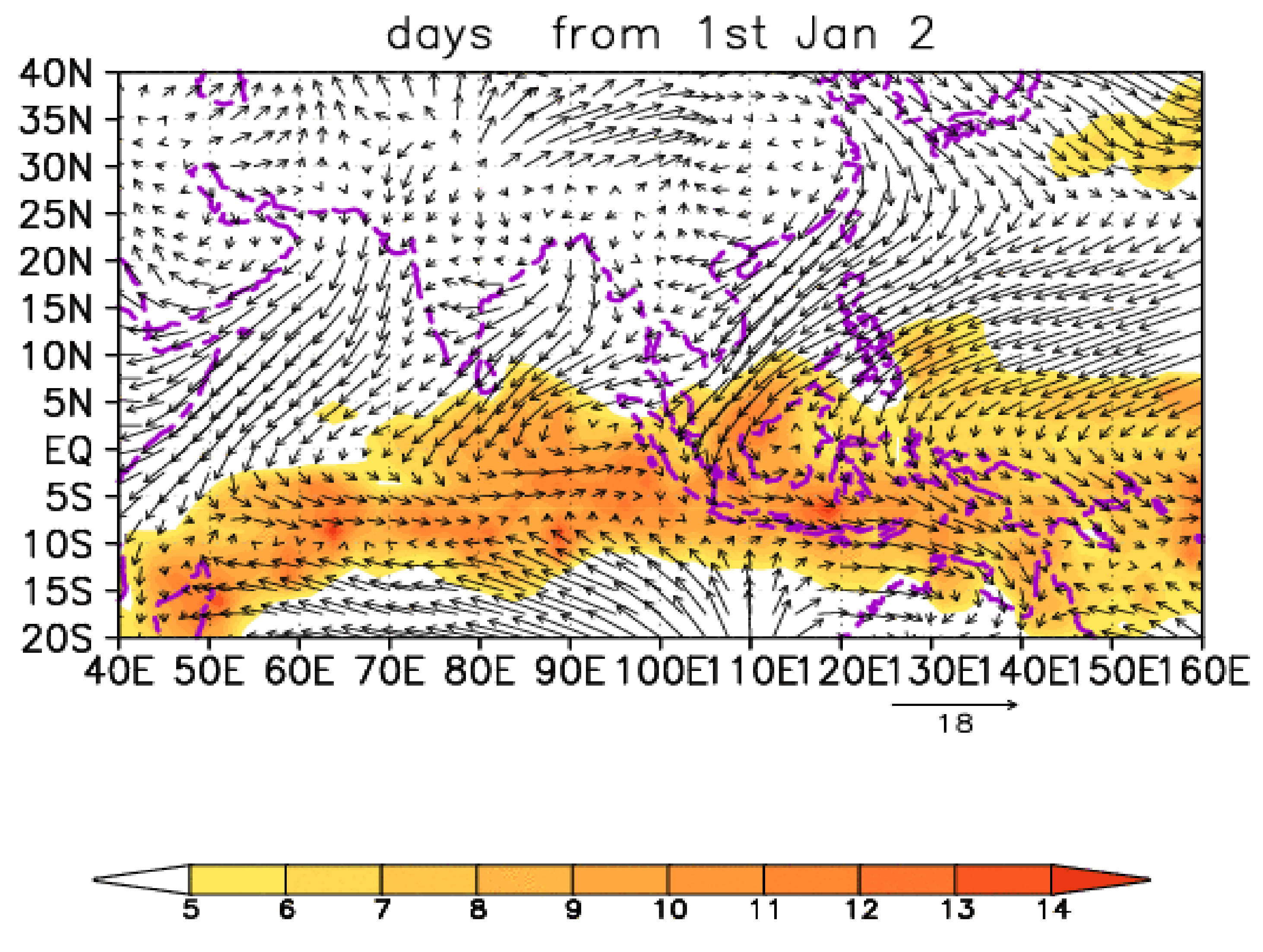
Outline

- ❖Why is predicting the ISM a Grand Challenge ?
- ❖Potential Predictability: Climate Noise- a Game spoiler
- ❖Origin of Climate Noise : Leading Role of Monsoon Intra-Seasonal Oscillations (MISO)
- ❖The Monsoon Mission : Attempt to scale the potential predictability barrier!
- ❖Some important model developments at IITM

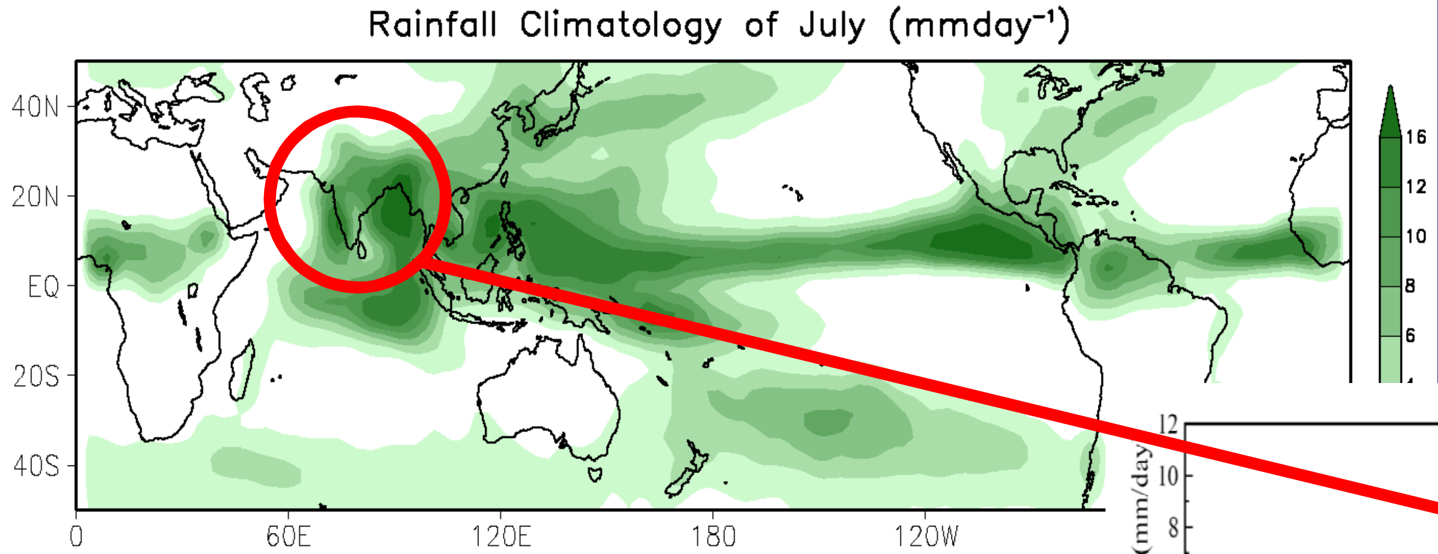
What is the Indian Summer Monsoon?

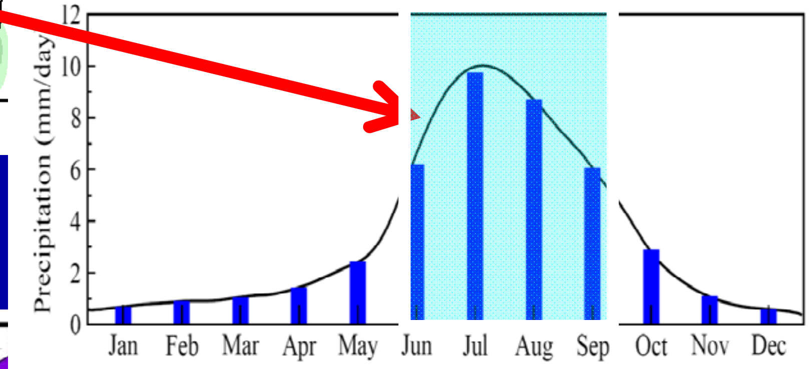
A manifestation of seasonal northward migration of the Rain Band or Tropical Convergence Zone (TCZ)



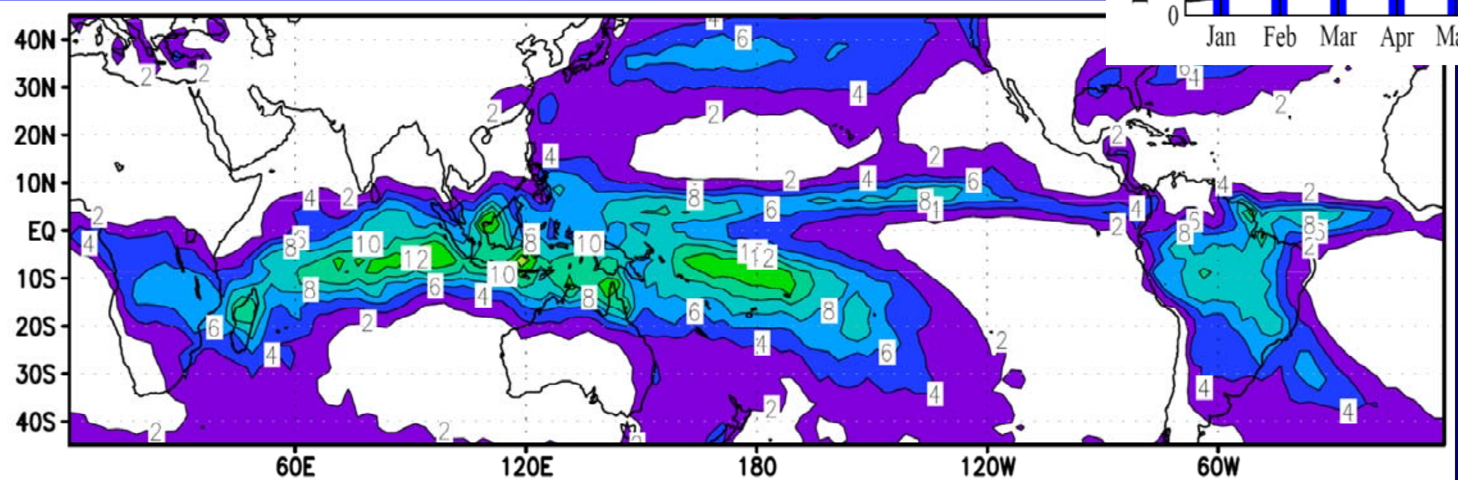
days from 1st Jan 2
40N
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
40E 50E 60E 70E 80E 90E 100E110E120E130E140E150E160E
18
5 6 7 8 9 10 11 12 13 14

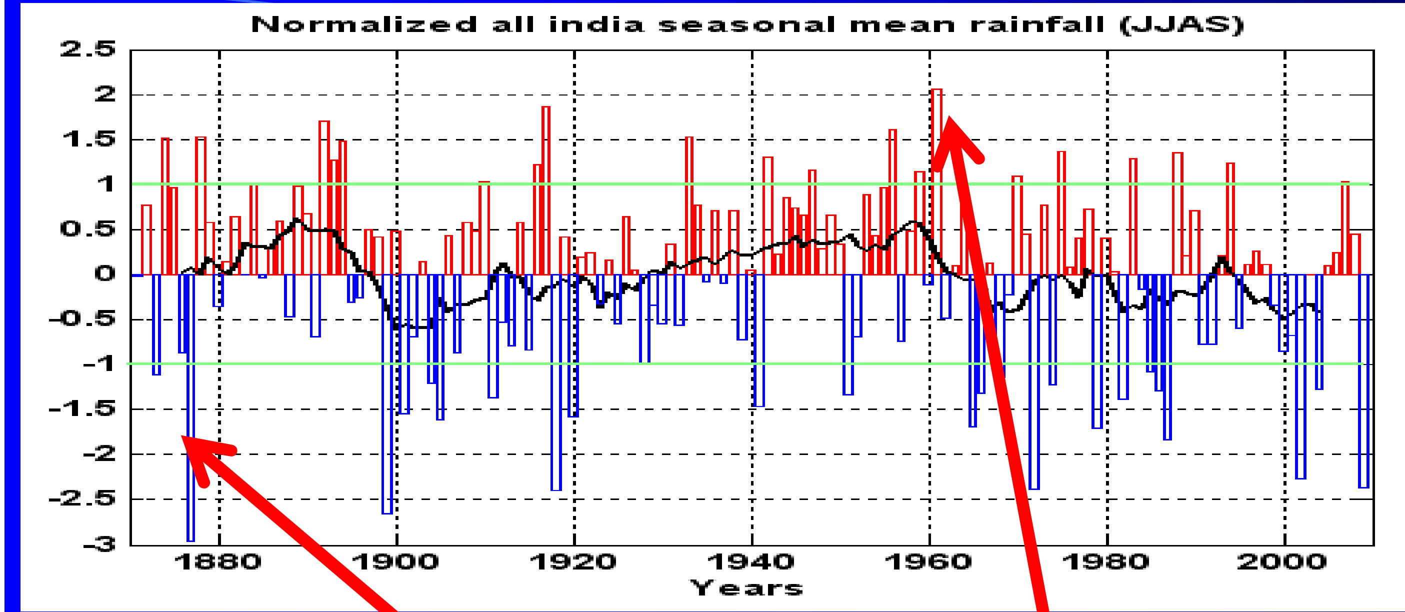
Indian Monsoon





Rainfall climatology of Jan (mm/day)





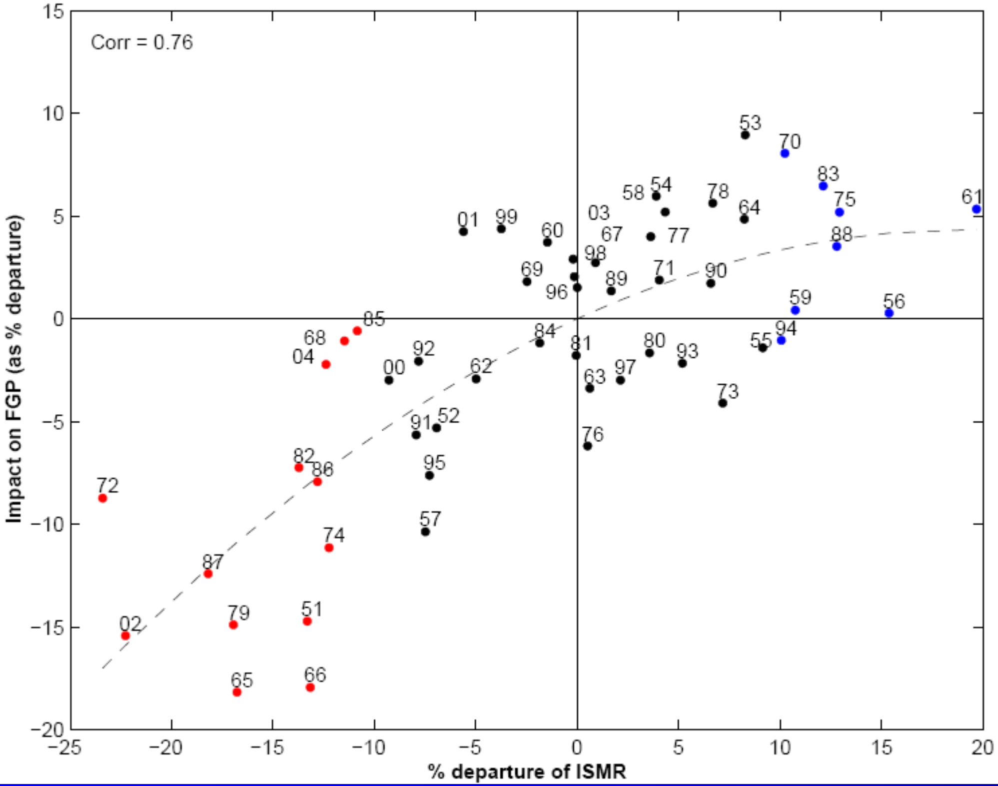
JJAS Mean ~ 90 cm

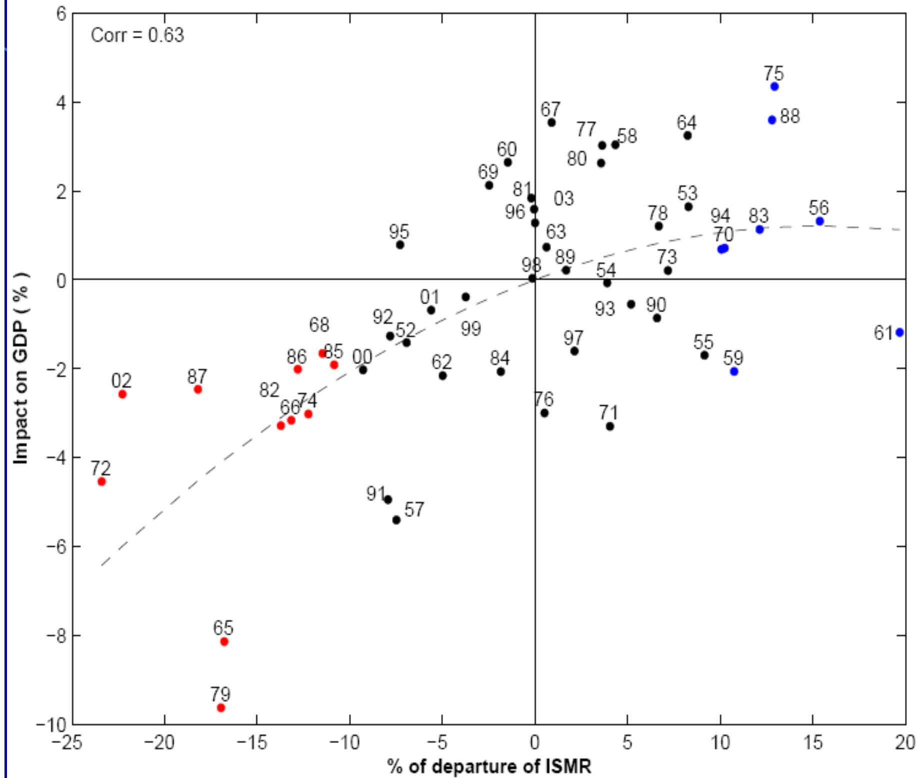
S.D. ~ 9 cm

Drought

Flood

Indian monsoon rainfall correlates strongly with food production & GDP





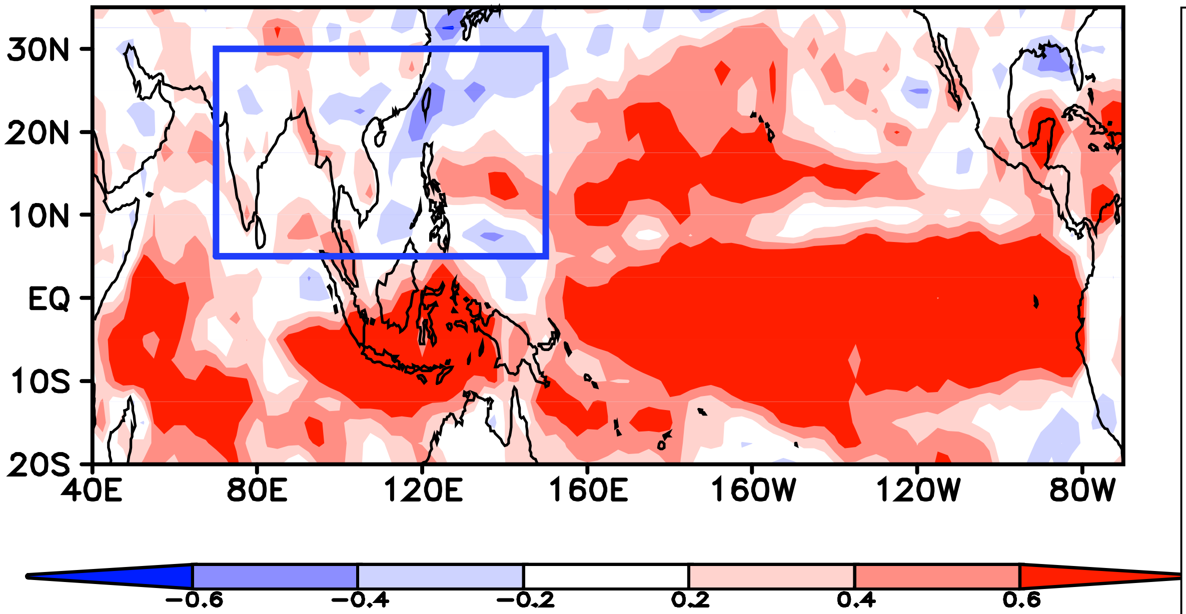
Variation of ISMR and its impact on food grain production ; drought and excess rainfall years are red and blue respectively.

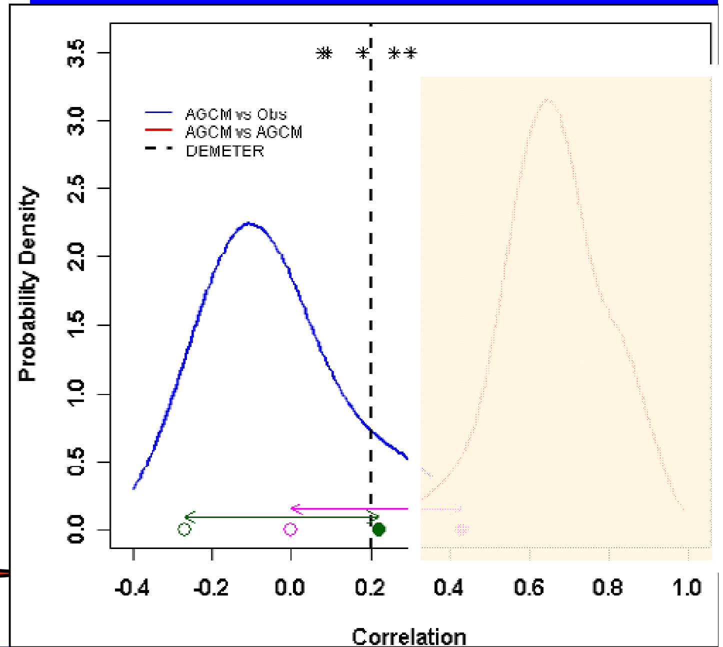
Variation of ISMR & its impact on GDP; drought and excess rainfall years are red and blue respectively.

Gadgil and Gadgil, Economic and Political Weekly, XLI, pp.4887–4895,2006.

The Problem!

While skill of prediction of seasonal mean rainfall by climate models have improved over Tropics, over the Asian Monsoon region has been poor.





Wang et al. (2005)

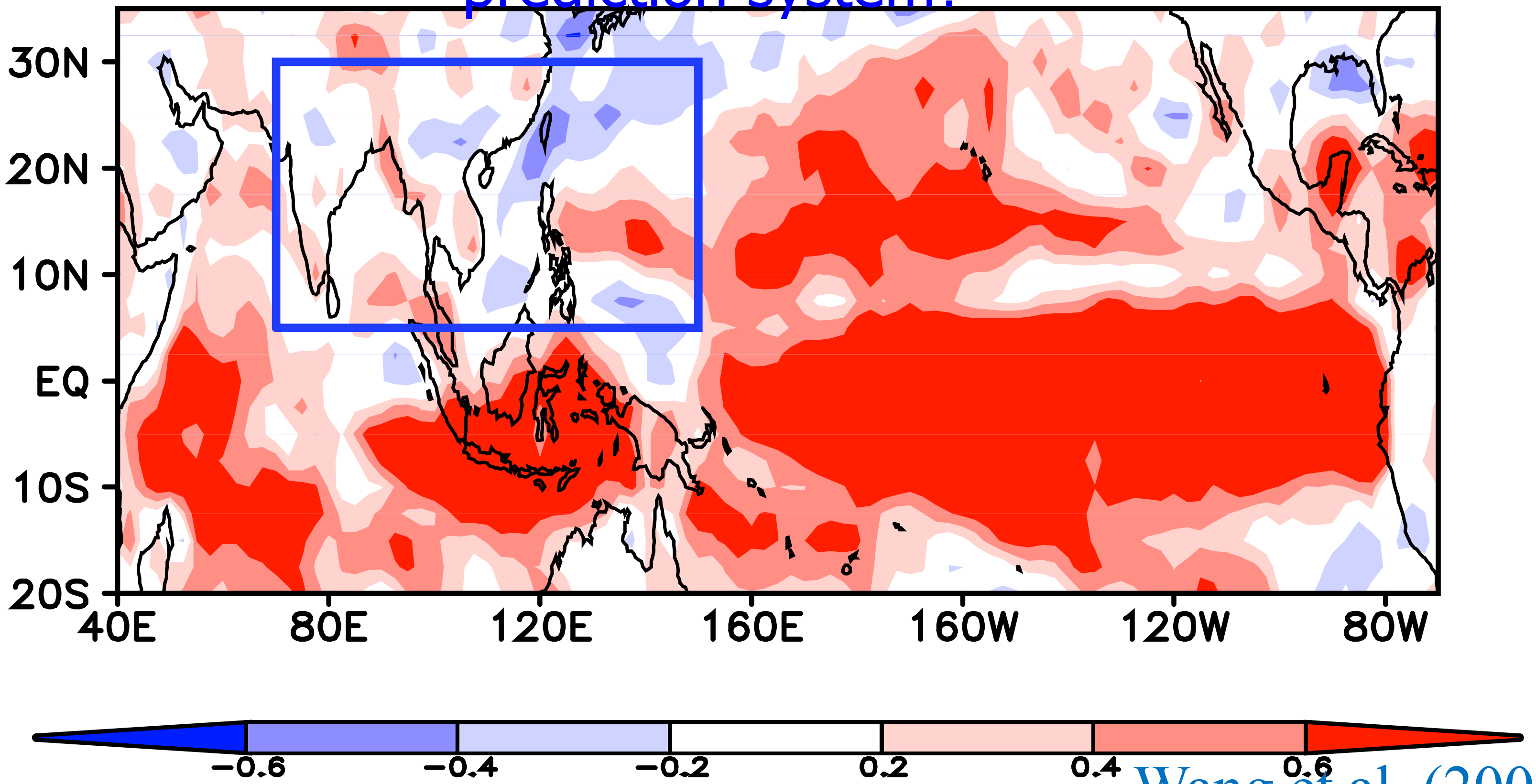
CC between the observed and MME hindcast of June-August precipitations (1979-1999)

Krishna Kumar et al., 2005, GRL

Why has the skill of Asian monsoon prediction remained poor while models are doing very well in other parts of tropics?

Is there a fundamental problem?

How far the skill could be pushed through improvement of prediction system?



Wang et al. (2005)

CC between the observed and MME hindcast June-August precipitations (1979-1999)

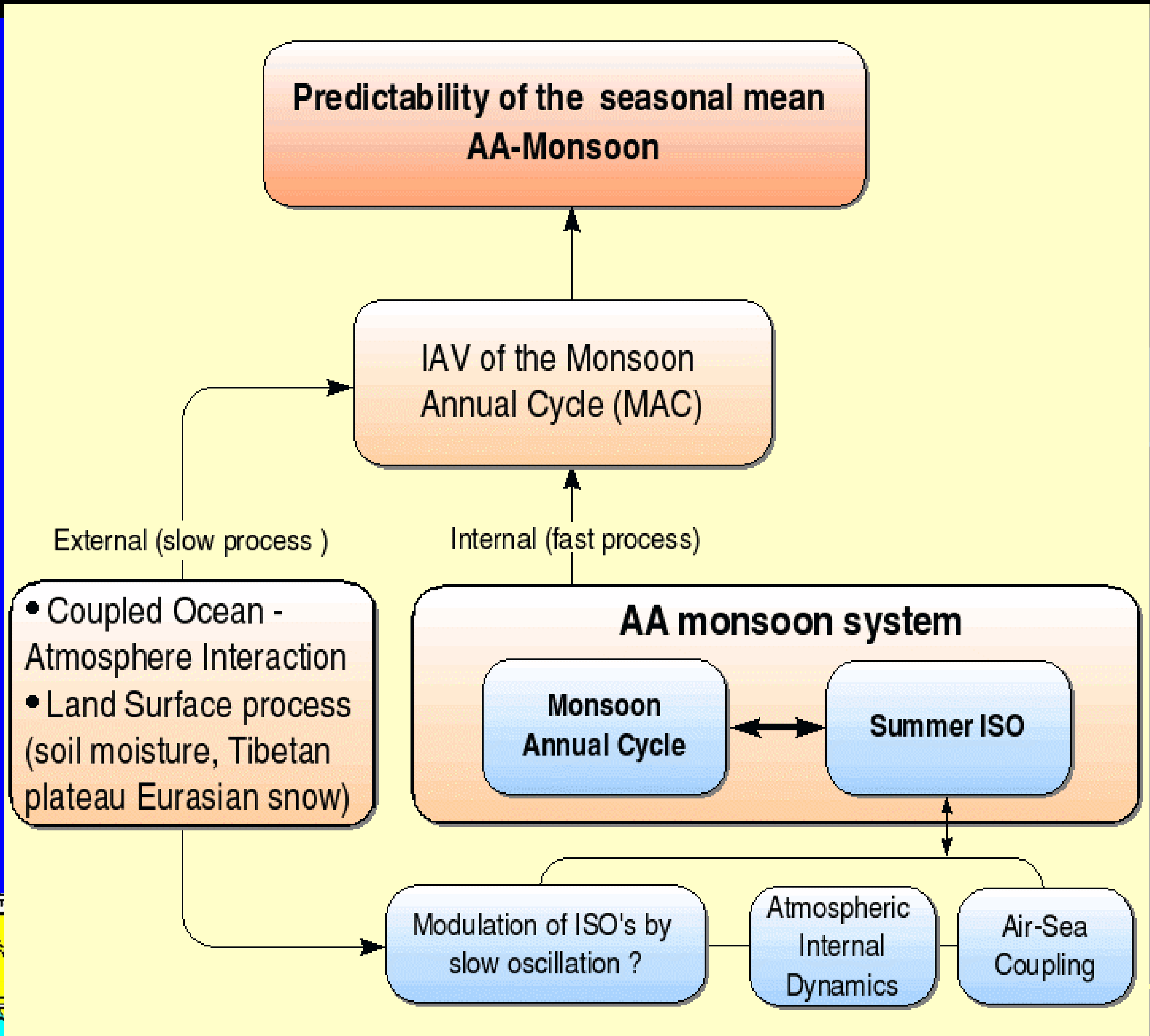
(Charney and Shukla, 1981; Shukla, 1981, 1988; Lau, 1985).

tropical climate is more predictable

than extra-tropics

Sperber and Palmer 1996, Sugi et.al.1997, Brankovic and Palmer 1997, Brankovic and Palmer 2000, Sperber et. al. 2001, Kang et. al. 2002

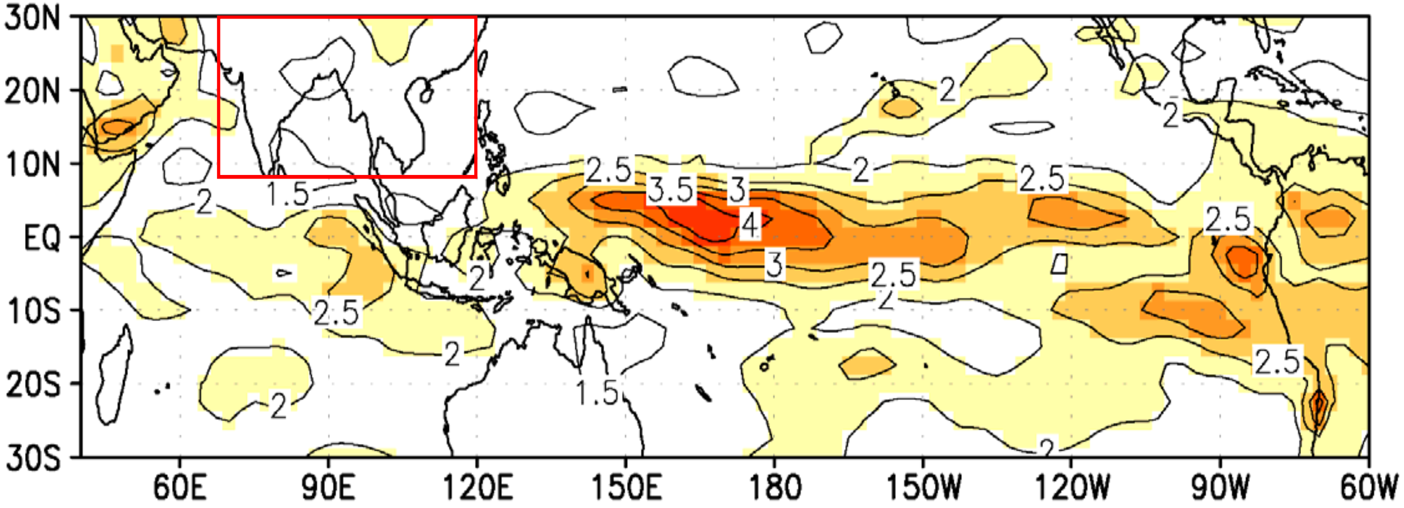
Limit on Potential Predictability of monsoon



Goswami, Wu and Yasunari, 2006, J. Climate

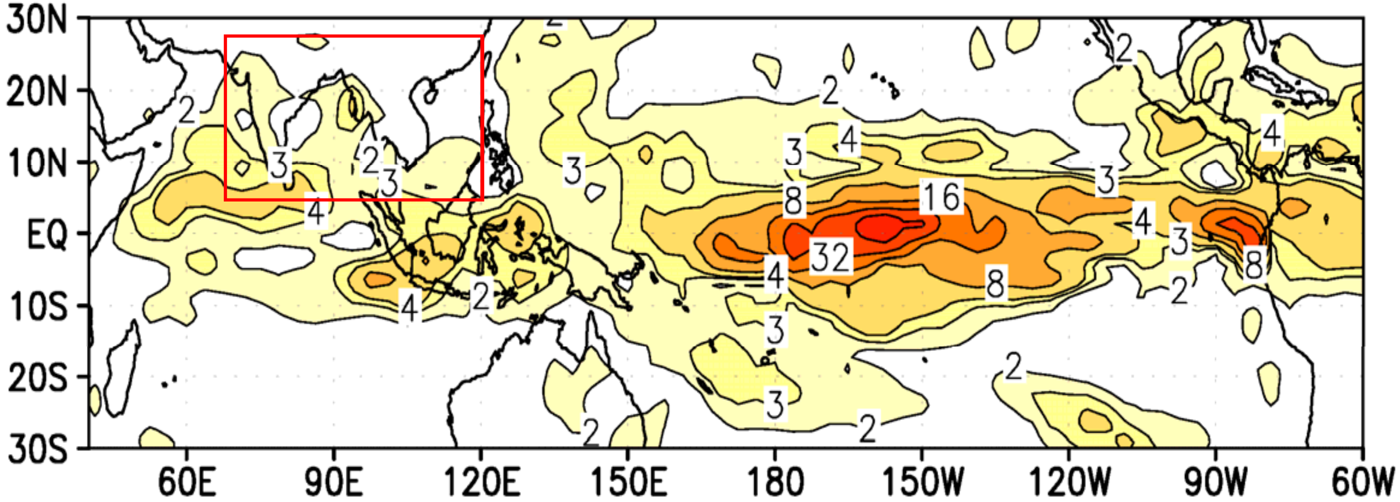
Estimates of potential predictability

F = 'total' /'internal' interannual variance



JJAS zonal winds at 850 hPa from NCEP reanalysis (Observation)

Goswami and Ajayamohan,2001



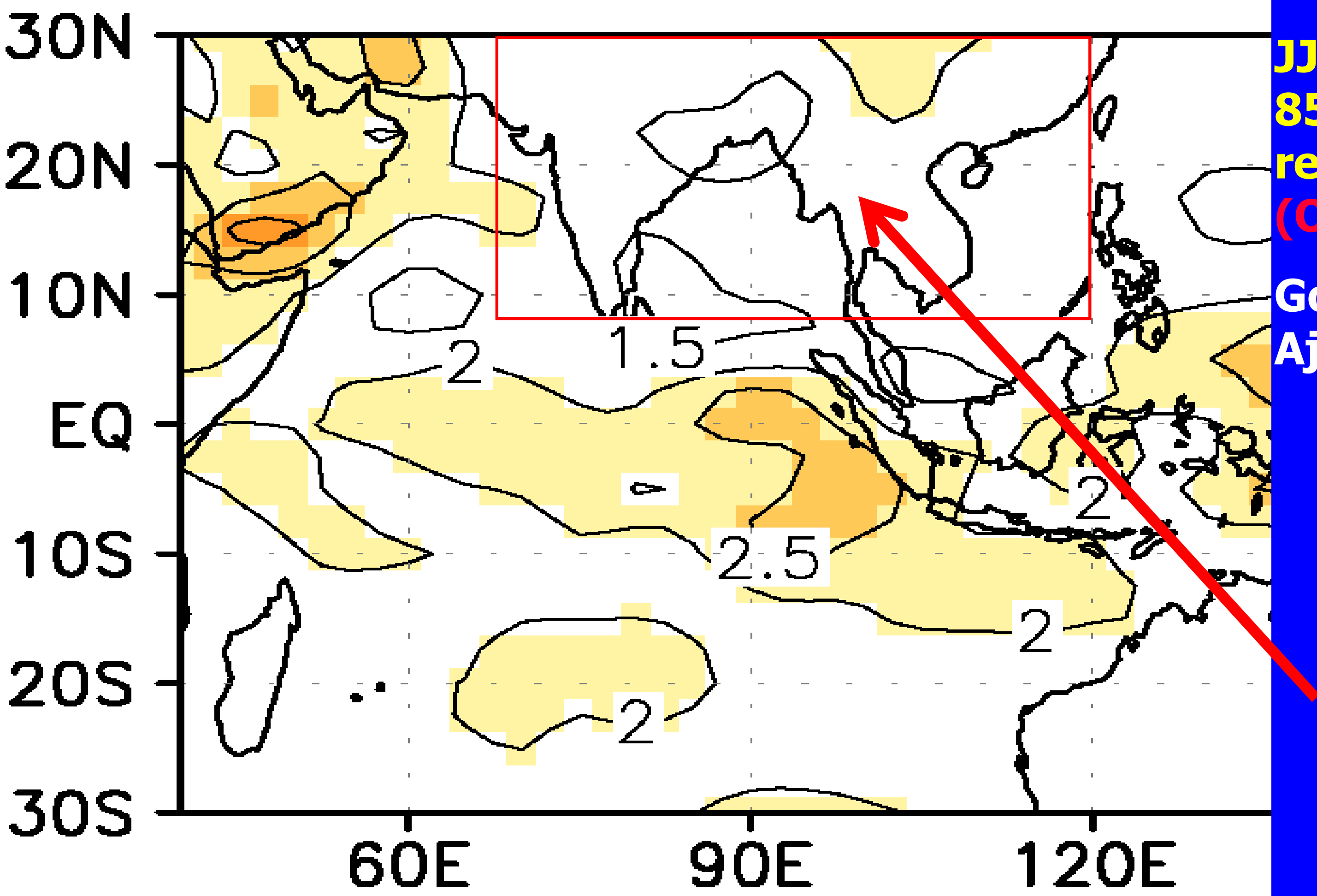
JJAS Precipitation from 5 ensemble simulations of 20 years by LMD model (another AGCM)

Goswami and Xavier, 2005

⇨ With F>>2 in large part of tropics, predictability high in tropics!

Estimates of potential predictability

F = 'total' /'internal' interannual variance



JJAS zonal winds at 850 hPa from NCEP reanalysis (Observation)

Goswami and Ajayamohan,2001

Over Asian Monson region

F ~ 2 ⟹ 50% or more of IAV is governed by Climate Noise!

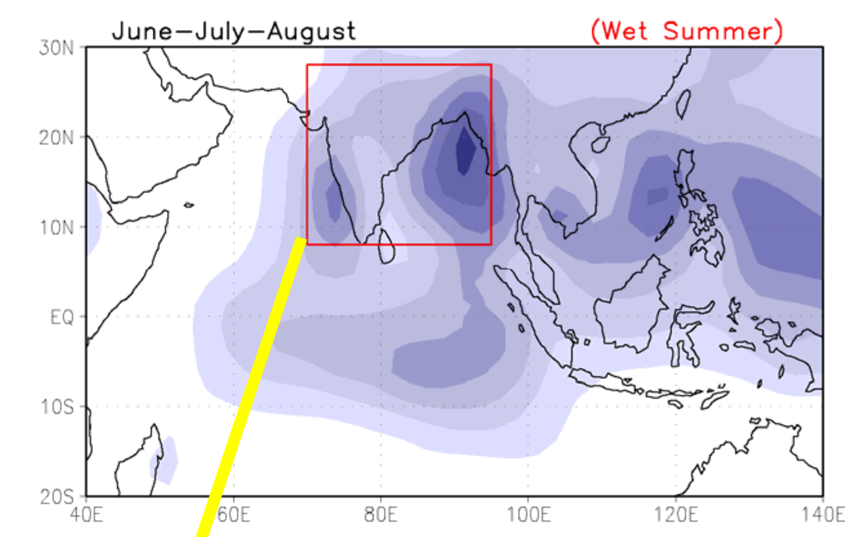
MONSOON

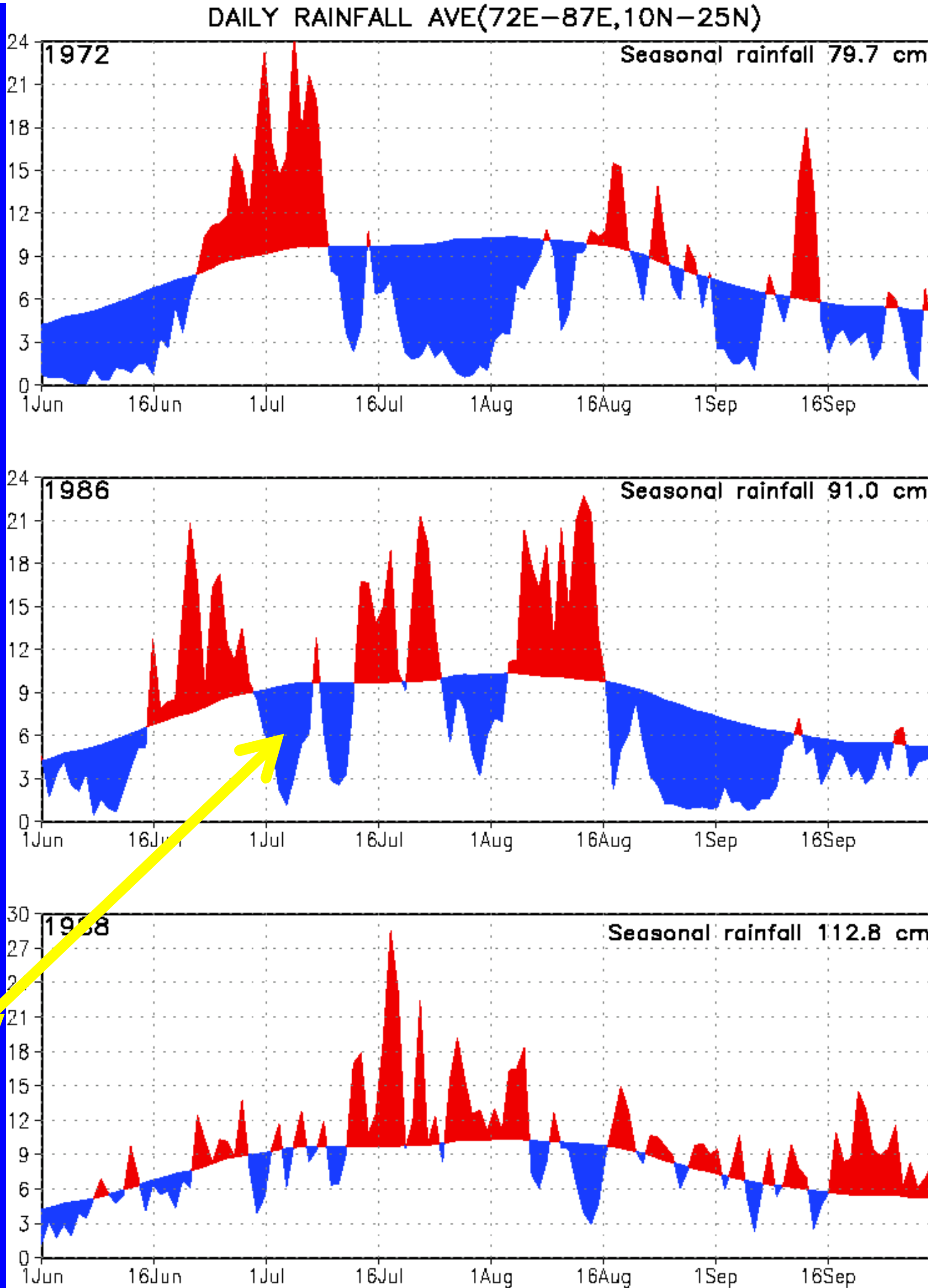
'External' Forcing

'Internal' Dynamics

(Goswami 1998; Ajaymohan and Goswami, 2001)

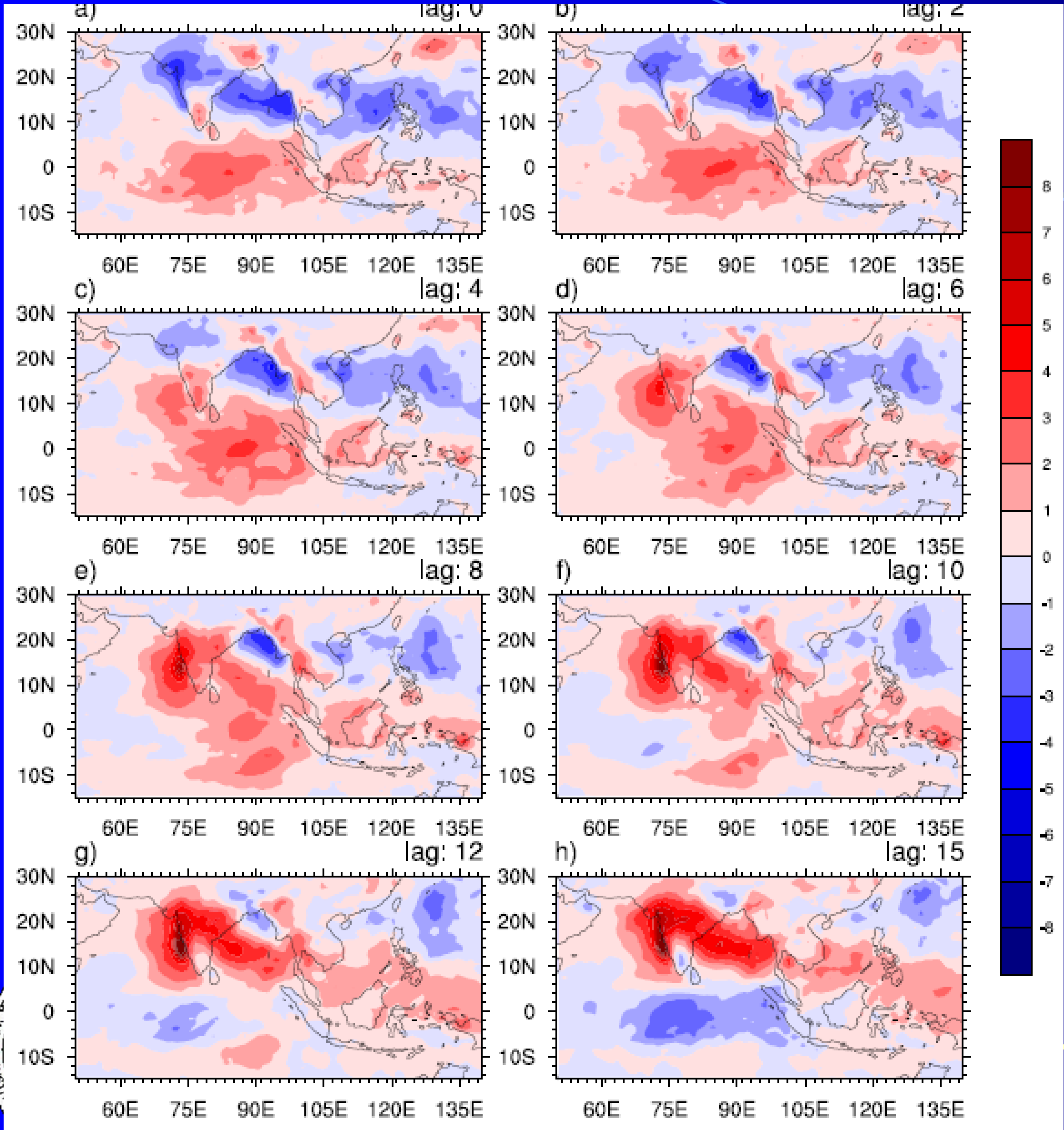
Where does the Climate Noise or 'Internal' IAV of the Monsoon arise from?





Indian monsoon is not steady but characterized by the large amplitude sub-seasonal oscillations, Active-break spells (cycles)

Lag composite of MISO: 25-90 day (GPCP JJAS)



MISO evolution one half cycle

- Large zonal scale
- Meridional dipole structure over the Indian monsoon region
- Northward propagation

And Convectively Coupled…

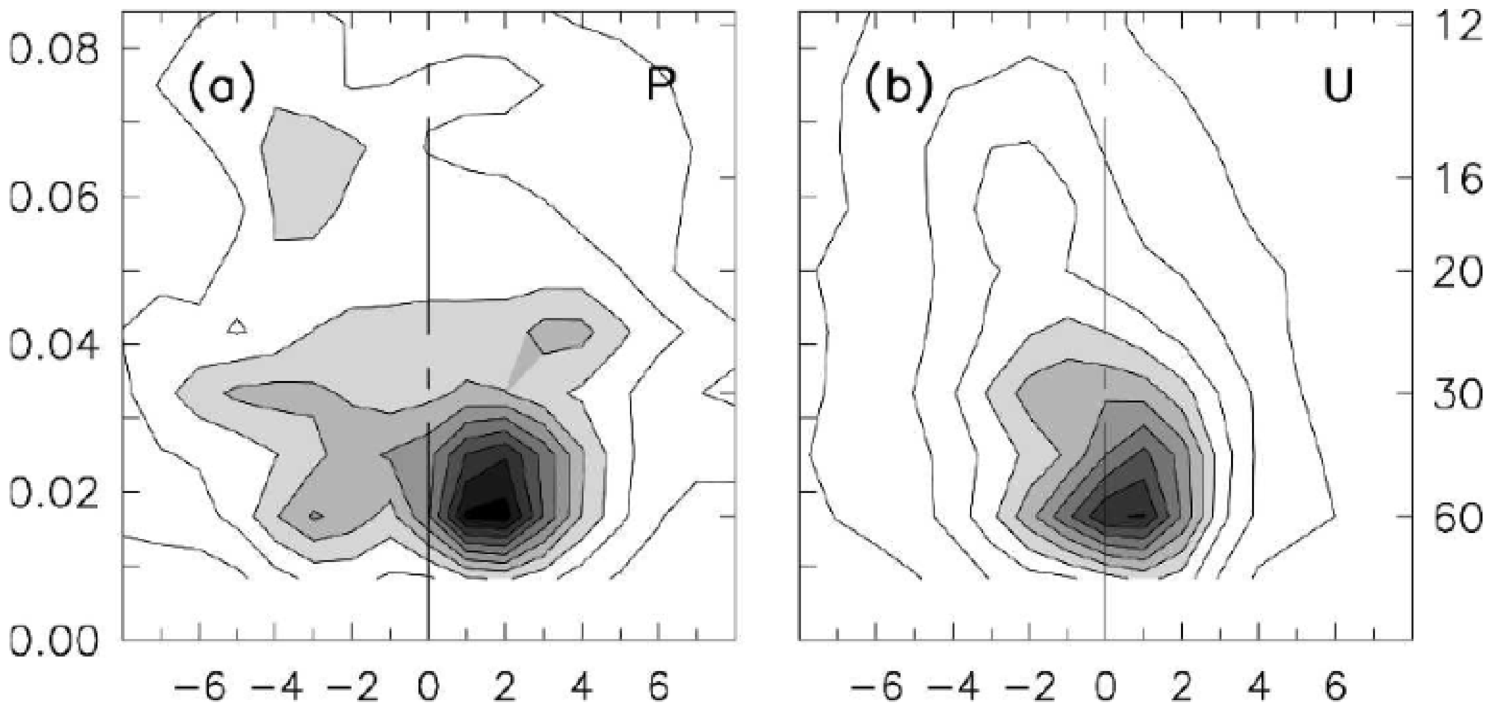
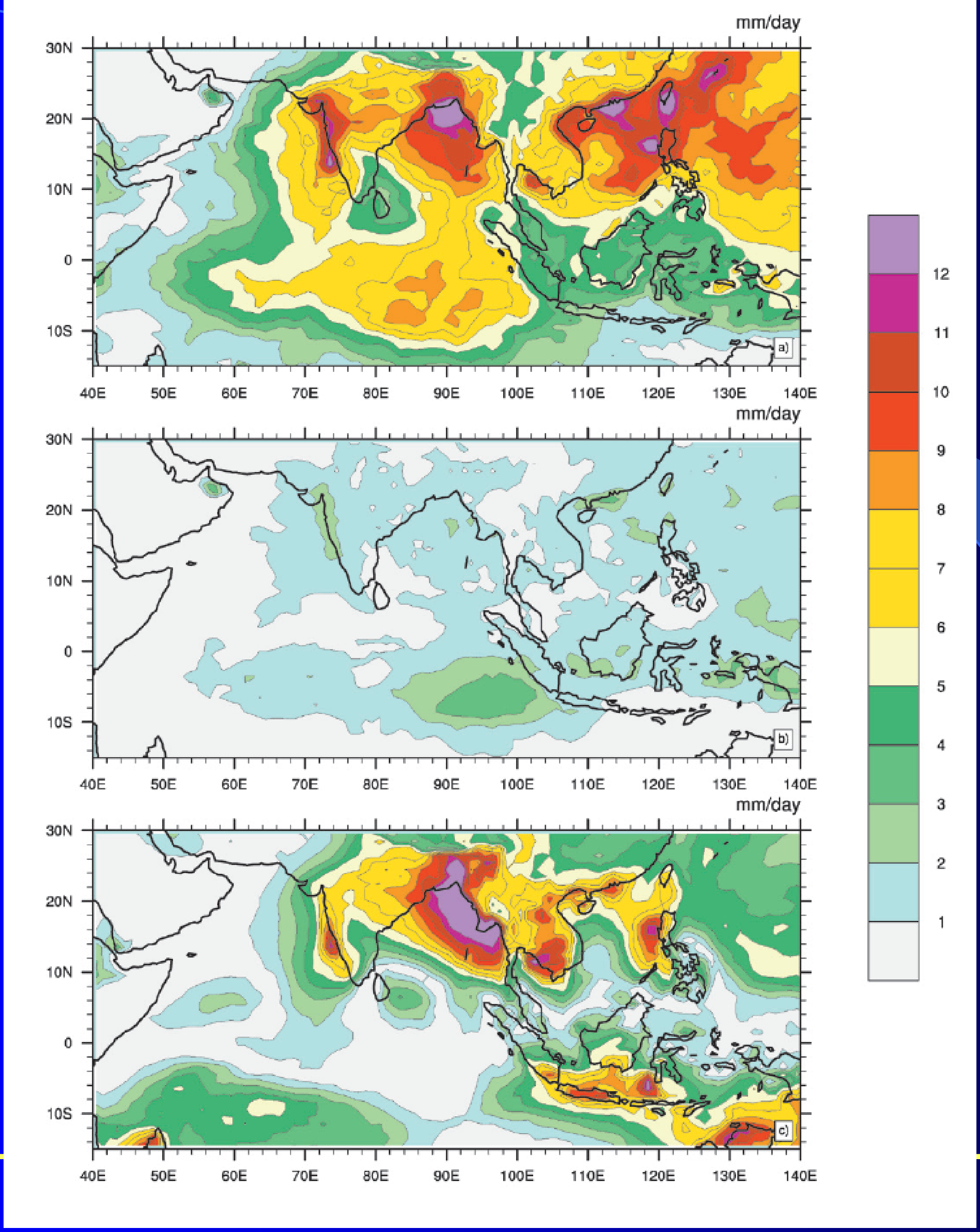


FIG. 2. Wavenumber–frequency spectral power of observed precipitation and 850-hPa zonal winds anomalies averaged over the latitude band 5°–25°N. The *y* axis left ordinate is frequency (in cycles per day, cpd) and right ordinate is period (days), while the *x* axis represents zonal wavenumber. The minimum contour and contour interval is 0.5; contours greater than 2.0 are shaded.

Amplitude of ISV

Amplitude of IAV of Seasonal Mean

Seasonal mean



Why MISO are important?

They represent a very large signal and hence potentially predictable!

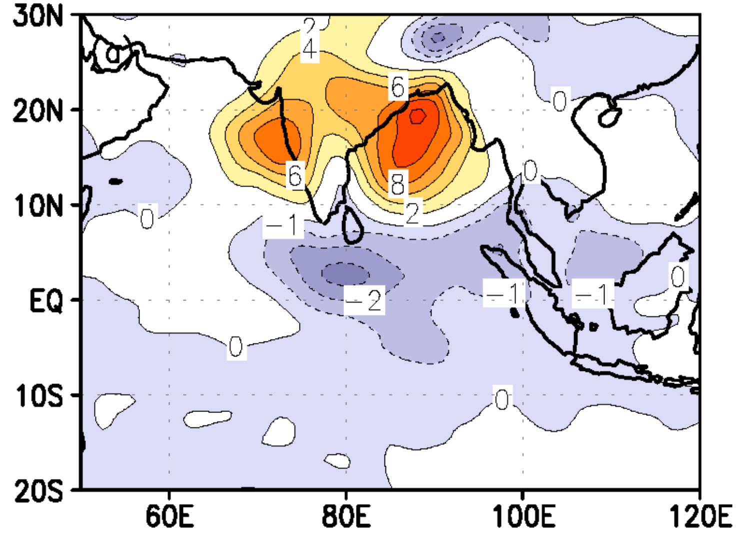
How does the MISO modulate the Seasonal Mean?

A common mode : Intraseasonal & interannual variability

Structure of dominant ISO mode

Active-Break composite of precipitation from NCEP

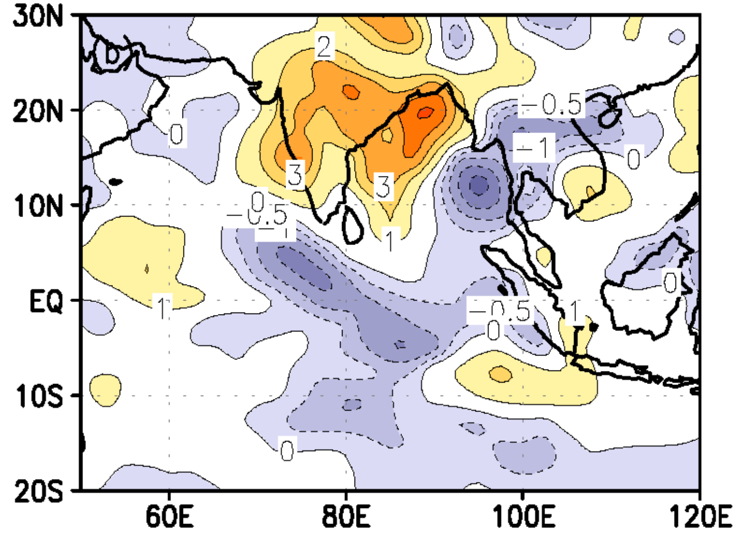
From 10-90 day filtered precip. Between 1 June-30 Sept., 1949-2002



Structure of dominant ISV mode

Strong-weak monsoon composite of precipitation from NCEP

From JJAS precip. Between 1949 and 2002, 6 strong and 4 weak monsoon years.

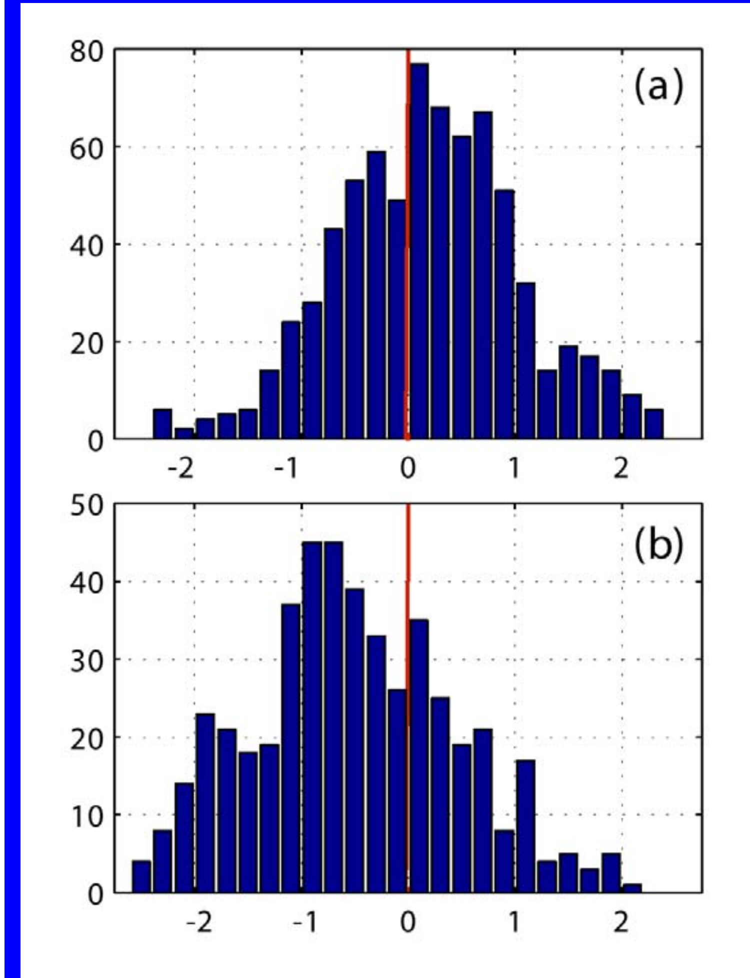


How does the ISOs influence the seasonal mean and IAV ?

- We have shown that the spatial structure of the summer ISOs have certain similarity with that of the summer seasonal mean. A common spatial mode of sub-seasonal and interannual variability.

- Seasonal mean of ISO anomaly can influence seasonal mean if frequency of occurrence of active and break phases are different.

Frequency distribution of ISO anomalies of P over 70E-90E, 10N-30N



‘strong’ Indian monsoon years

‘weak’ Indian monsoon years

Goswami ,Wu and Yasunari, 2006, J. Climate

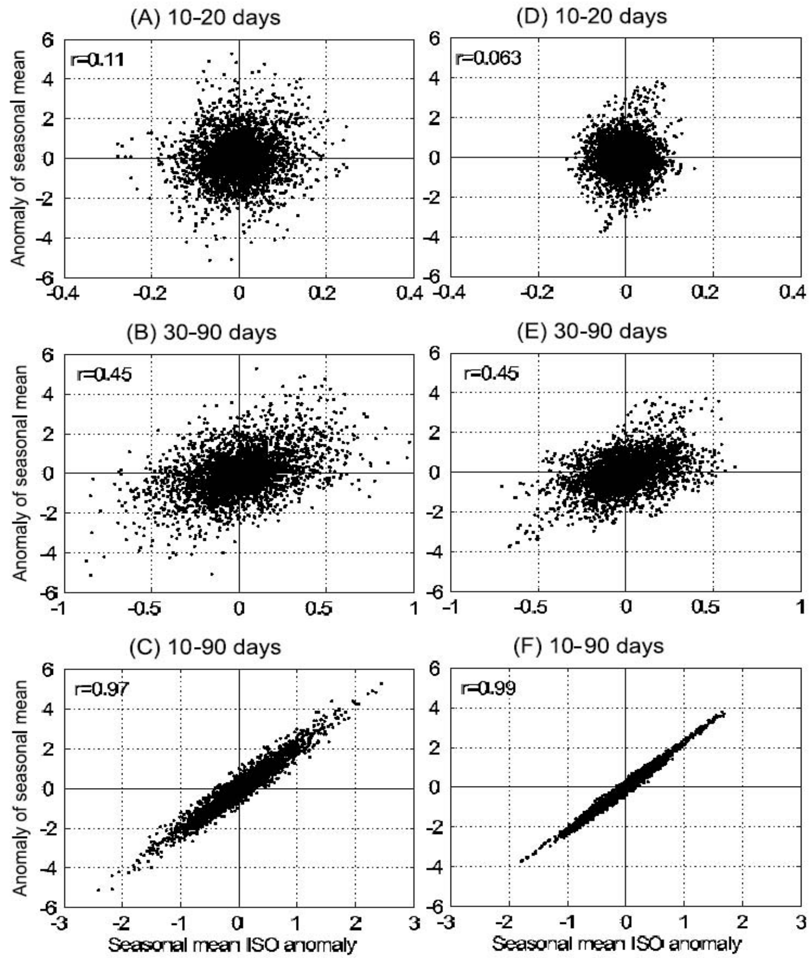


Figure 13. Scatter plot of interannual anomalies of seasonal mean versus seasonal mean of intraseasonal anomalies of precipitation (mm day^{-1}) from (a) 10–20 days band, (b) from 30–90 days band and (c) from 10–90 days band at all grid points in the domain 70°–100°E, 10°–30°N. (d, e, f) Similar to Figures 13a, 13b, and 13c, but for U850. Correlation values are given in the respective panels.

Goswami and Xavier, 2005, JGR

A Nonlinear Mechanism: Interaction between vigorous ISO's and the Annual Cycle gives rise to 'internal' interannual variability

A toy model for Atmospheric Fluctuations under an Annually varying forcing

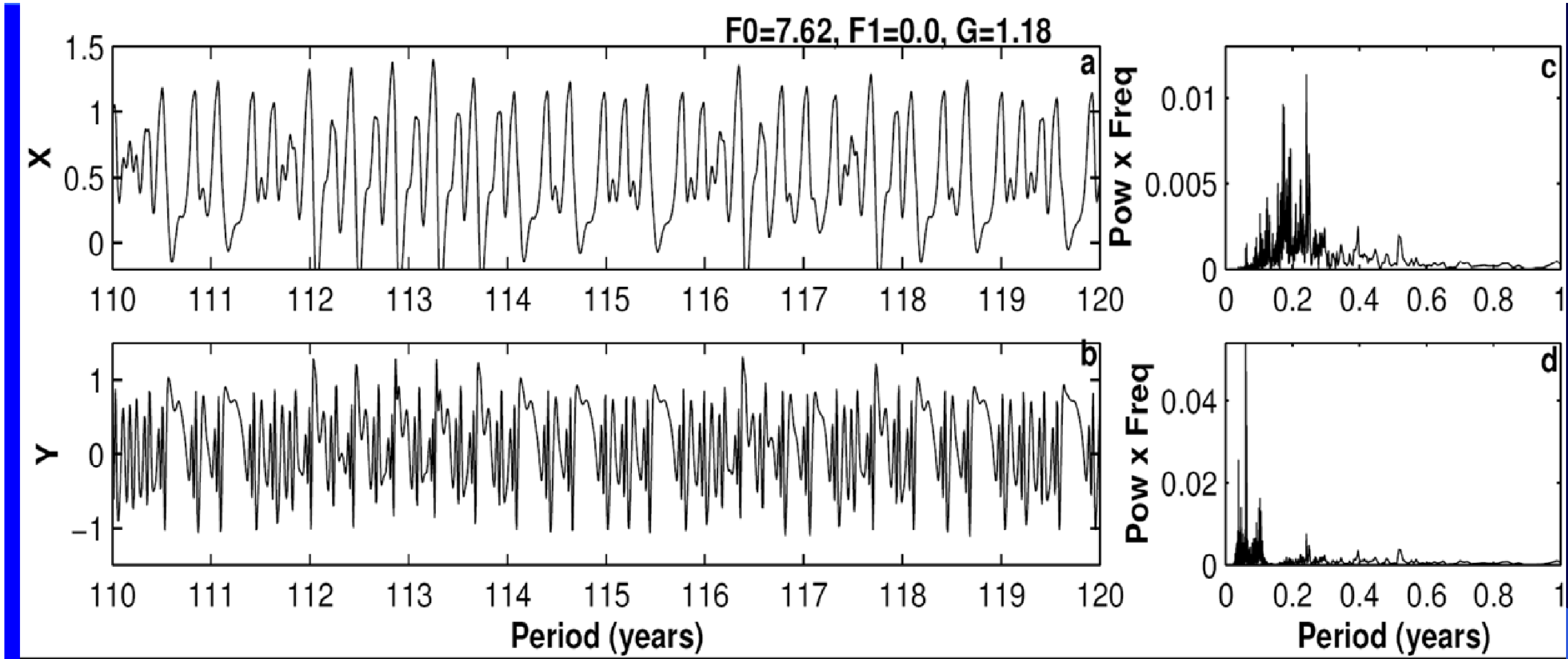
$$X = -Y^2 - Z^2 - aX + F$$ ← Solar forcing

$$\dot{Y} = XY - bXZ - cY + G$$ ← Land-ocean contrast

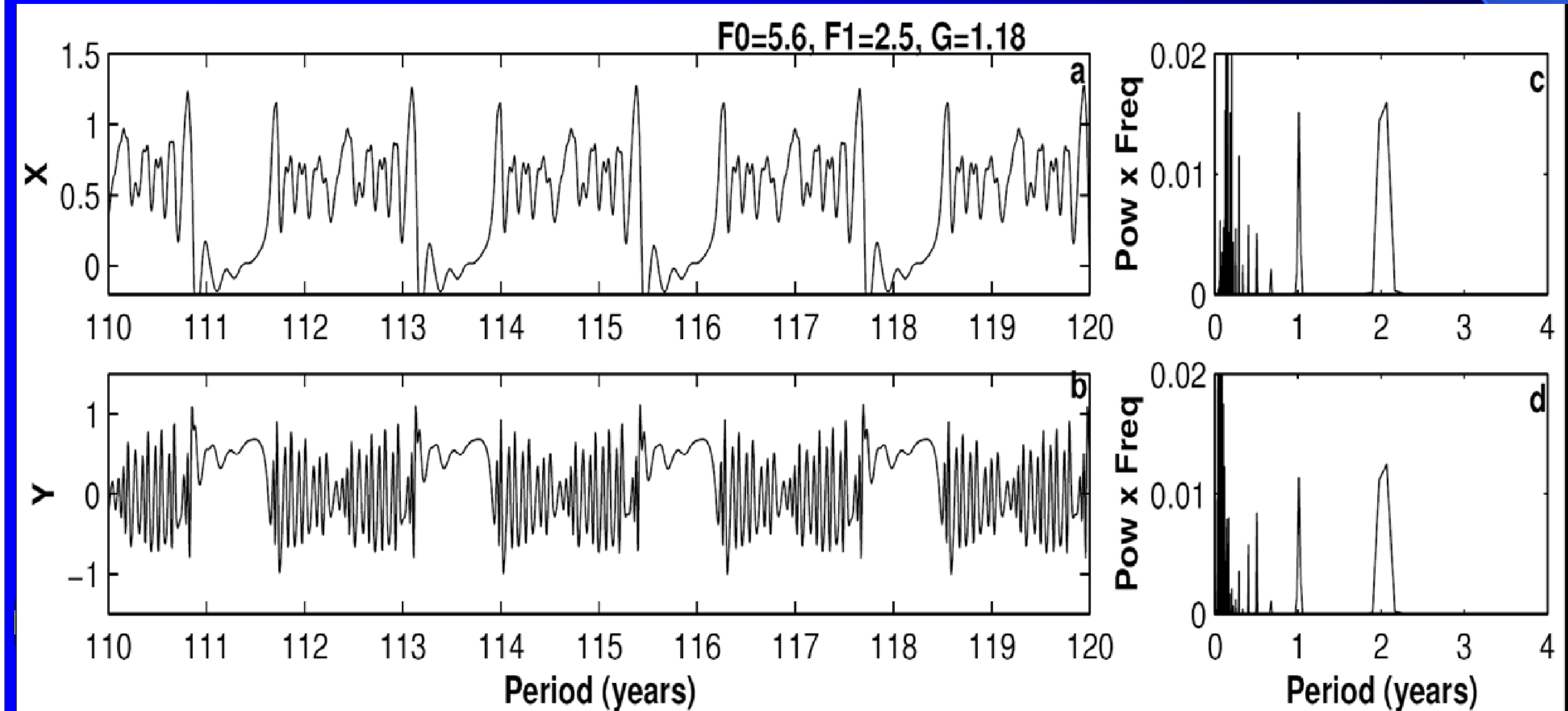
$$\dot{Z} = bXY + XZ - cZ$$

$$\dot{F} = F_0 + F_1 \cos(\pi t/\tau),$$

X-> Zonal mean , Y,Z-> wave component,a,c-> dissipation



F=const.



F=ann.cyl

Based on these research,

What is needed to improve South Asian Monsoon Prediction ?

- **The Asian monsoon Annual Cycle:**
  - Models must simulate mean monsoon climate with high fidelity
- **ENSO-Monsoon Teleconnection:**
  - Models must simulate the ENSO-Monsoon teleconnection correctly in phase and amplitude
- **Internal Dynamics:**
  - Models must also simulate the 'Internal Dynamics' contribution to seasonal mean correctly. This means that models must simulate the Monsoon ISO (MISOs) correctly in amplitude and northward propagation !

A way forward!

The Monsoon Mission:

A mission mode project to deliver quantifiable improved forecast of Seasonal mean monsoon rainfall

Of

The Ministry of Earth Sciences, Govt. of India

To be led and coordinated by IITM

The Context

- Any deterministic chaotic system like the Indian monsoon climate (seasonal mean) has a Theoretical Limit on Predictability

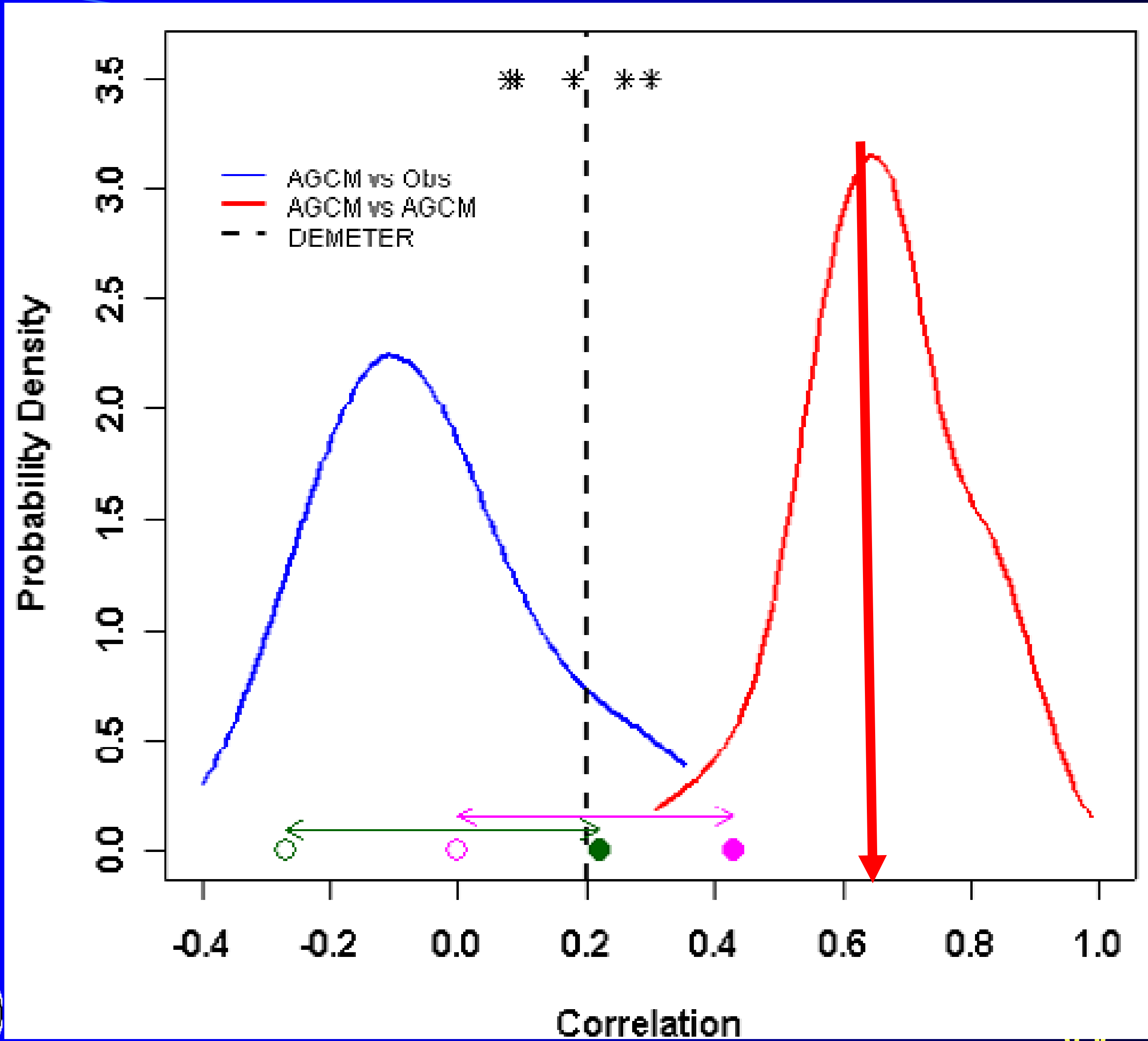
- The skill of a Prediction System, with a prediction model and data assimilation is generally lower than the theoretical limit but strives to reach it!

- The Monsoon Mission dreams of pushing the present skill of models to reach the limit of predictability!

Basis for Optimism for improvement of seasonal prediction of monsoon!

- Current skill of models fall far short of the limit on potential predictability.
- And there is indication that the skill of dynamical models are improving!
- How can we push the skill to reach close to limit?

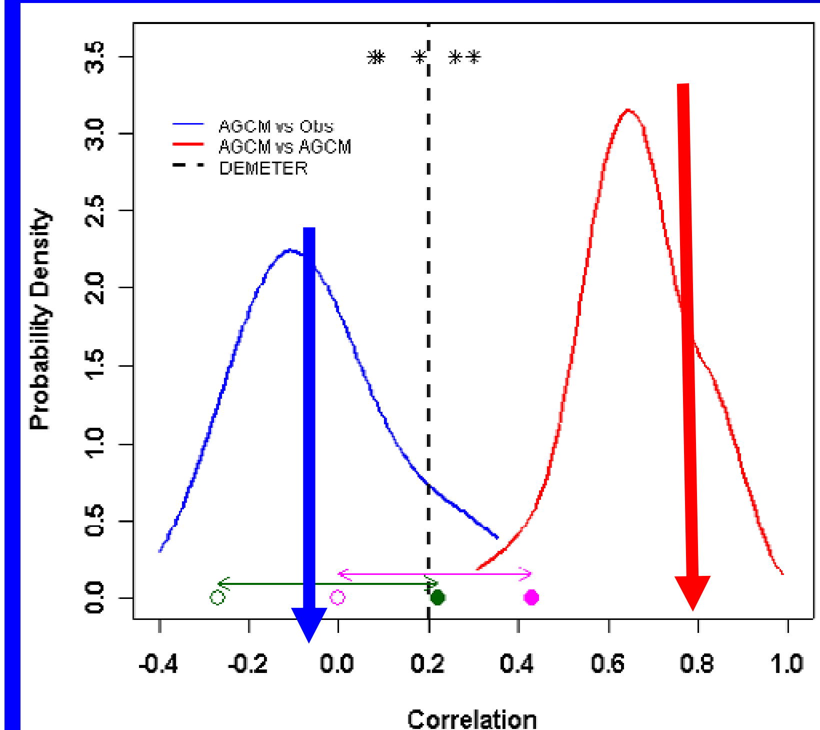
⇨ Goal of Monsoon Mission



Krishna Kumar et al., 2005, GRL

Krishna Kumar et al , 2005, GRL

Skill of ISMR prediction by ENSEMBLES models



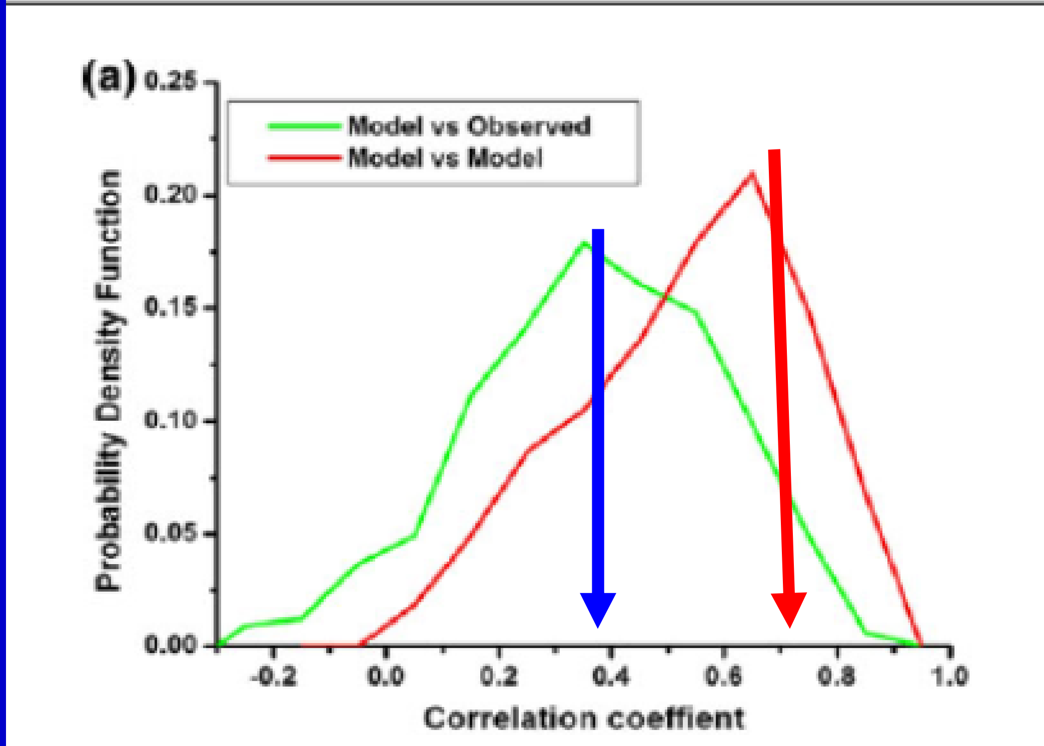


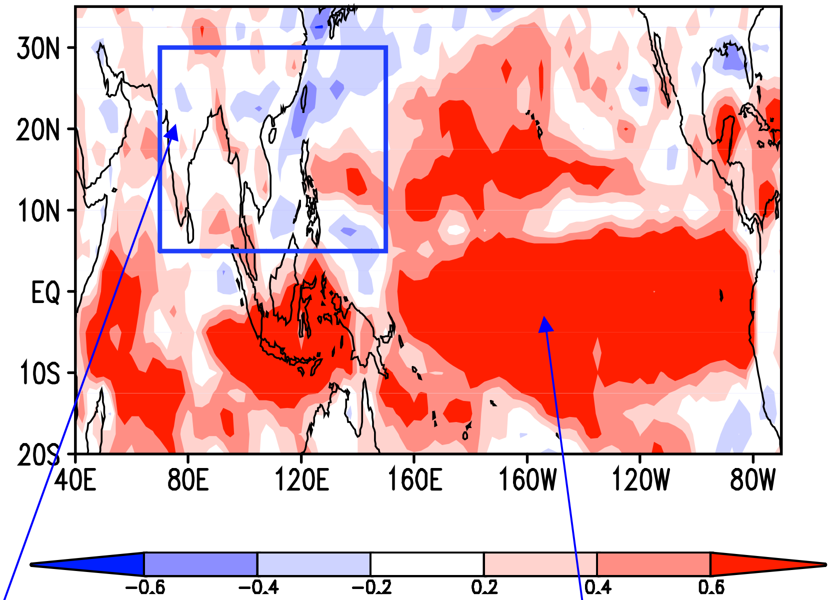
Fig. 13 PDFs of the correlation skill of ISMR based on a theoretical "perfect model" analysis (*red curve*) and based on the actual skill compared to the observed ISMR (*black curve*). **a** for the period 1960–1979 and **b** 1980–2005

Rajeevan et al. 2011, Climate Dynamics

Correlation Coefficients between the observation and prediction of precipitation using Multi models

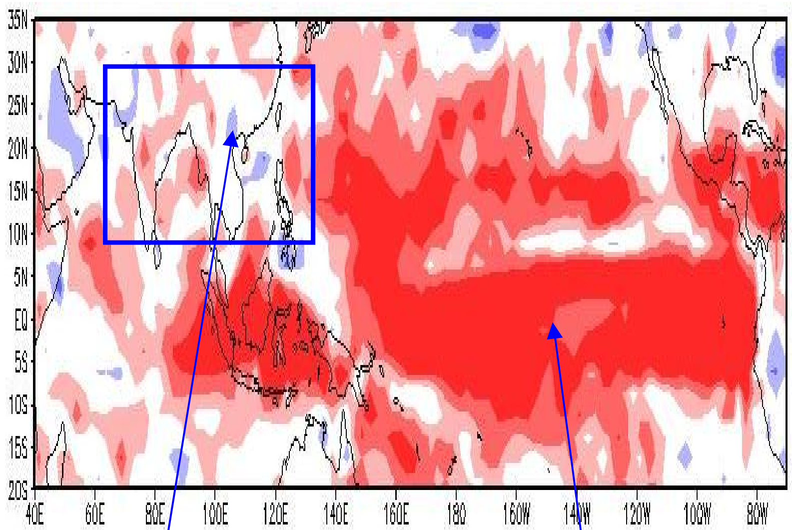
Earlier version models

1979-1999



Latest models (ENSEMBLES)

1979-1999



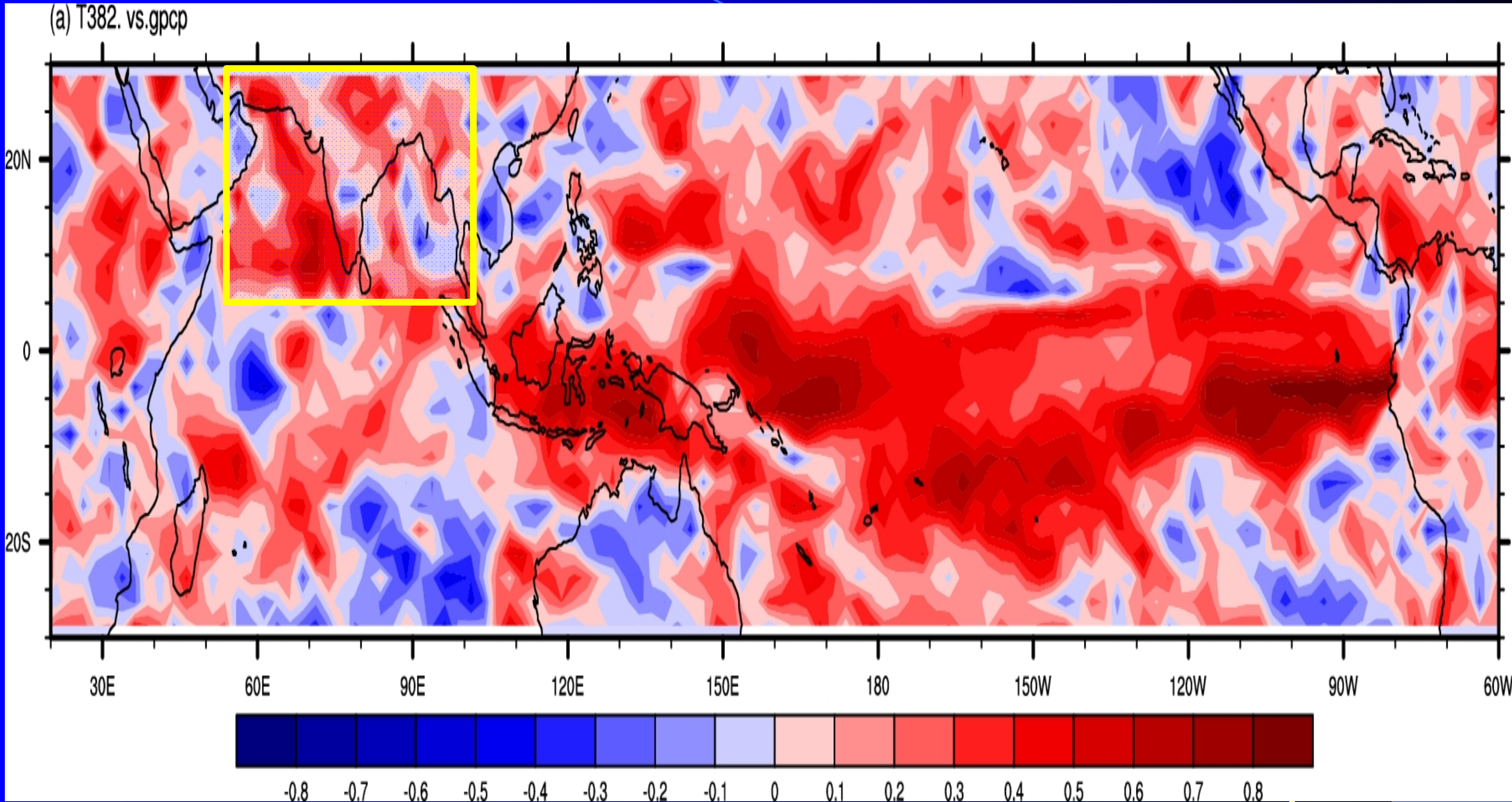
Poor skill

High skill

Improved skill

High skill

T382L64 Skill of Rainfall



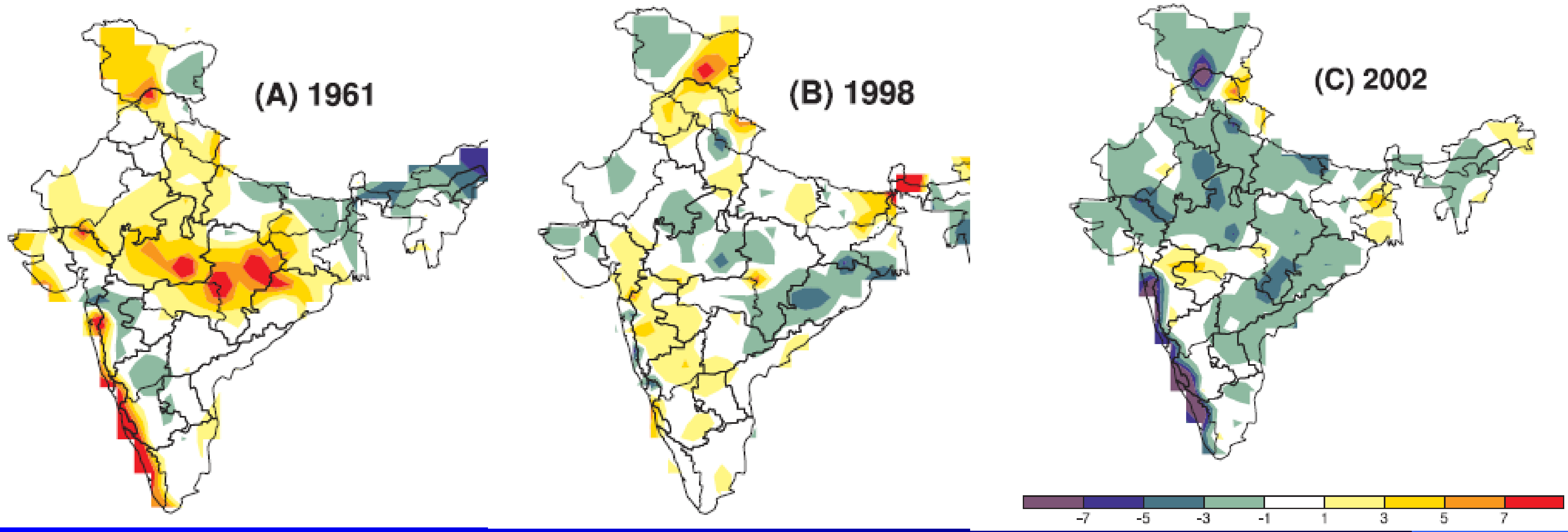
GPCP VS CFSv.2 T382, latest model at IITM

Fine Tuning the Mission Objectives..

- On seasonal time scale, only large scale like All Indian Summer Monsoon Rainfall (ISMR) is predictable and is useful for policy makers as a severe drought still influences the GDP by 2-5%
- However, ISMR is not useful for hydrological purposes and for farmers as seasonal mean rainfall is highly spatially inhomogeneous except in extreme cases!
- Hence, in addition to prediction of ISMR, prediction of something more useful to farmers is required!

Extreme Years : Seasonal mean anomaly homogeneous

Normal Years : Seasonal mean anomaly inhomogeneous



Anomalies of summer mean rainfall for 1961 (a), 1998 (b) and 2002 (c).

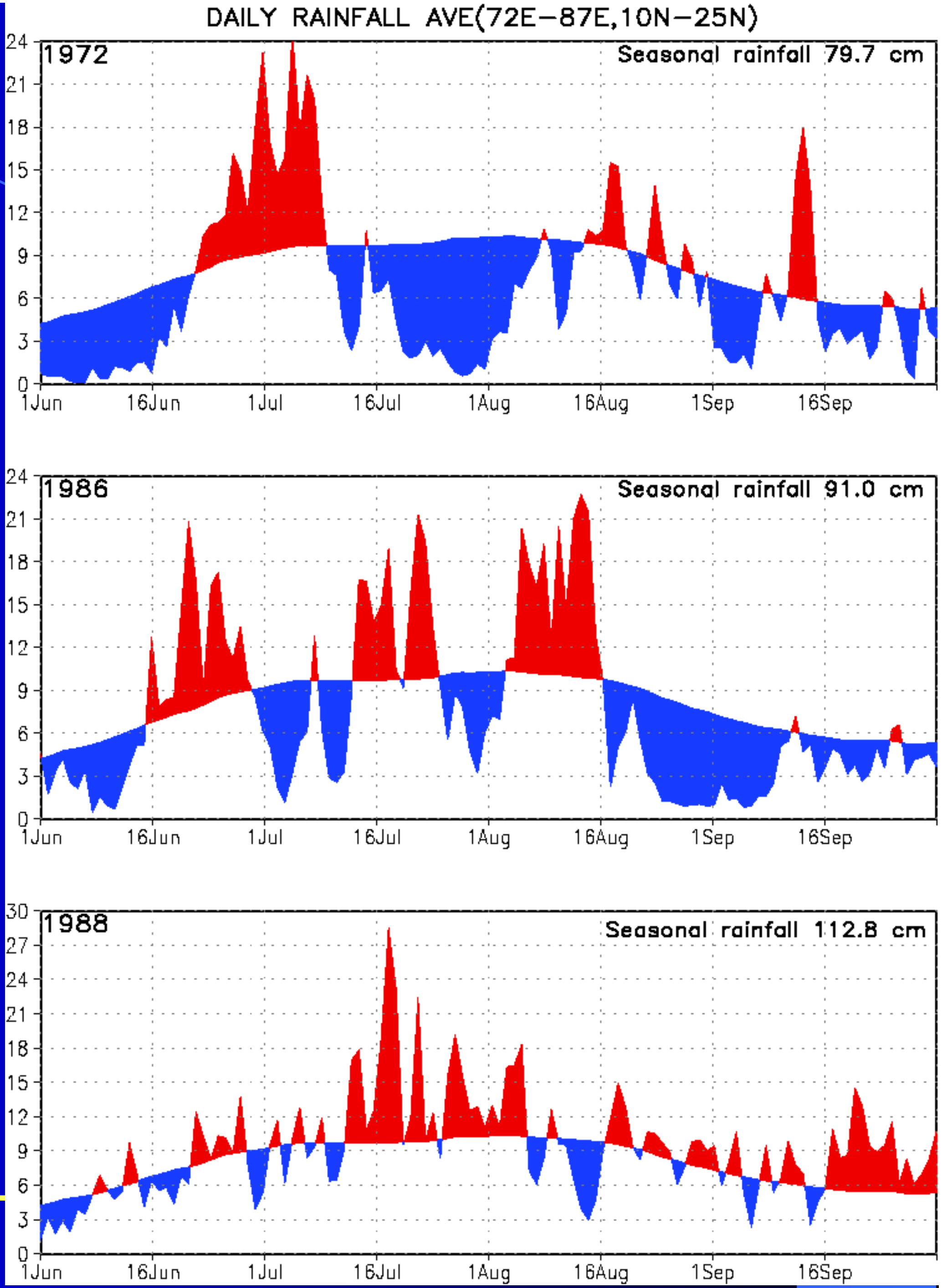
Indian monsoon is characterized by the

Active-break spells (cycles)

Daily rainfall (mm/day) over central India for three years, 1972, 1986 and 1988

The smooth curve shows long term mean.

Red shows above normal or wet spells while blue shows below normal or dry spells



Potential Predictability of MISO

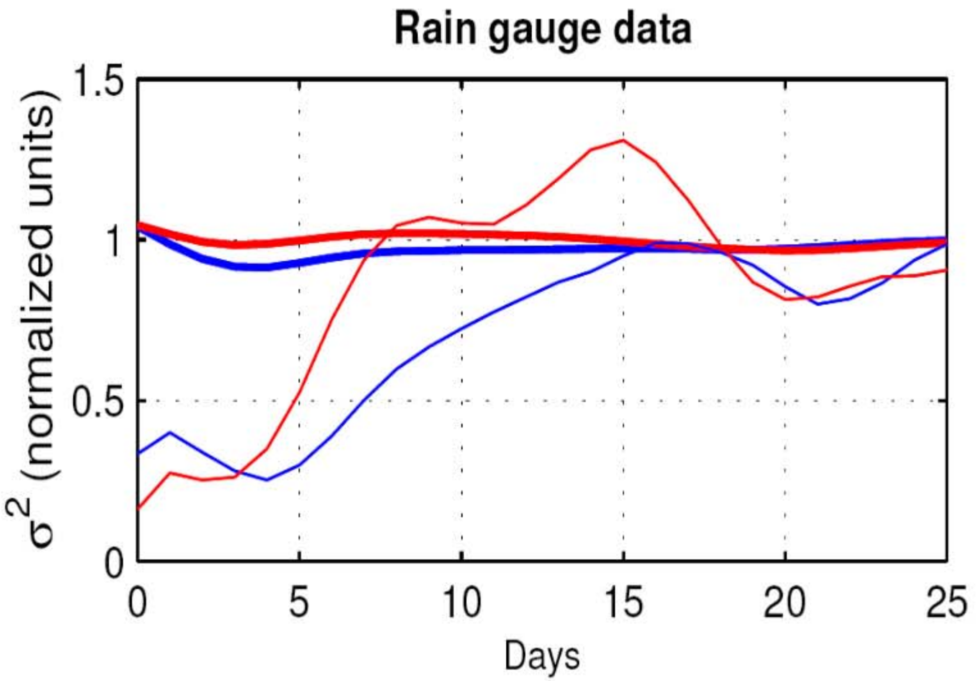


FIGURE 6.4: Same as Fig.6.3A, but for high resolution gridded daily rain gauge data (Rajeevan et al., 2006) for the JJAS season of 1951-2003, averaged over 70°-90°E, 18°-30°N.

Goswami and Xavier, 2003, GRL

Therefore, the Goal of the Monsoon Mission….

➢To set up and improve a Dynamical Seasonal Prediction System in India as well as to set up and improve a System of Dynamical Extended Range prediction of the Active-Break spells of MISO

Target

➢**To achieve correlation between observed and predicted ISMR of 0.7!**

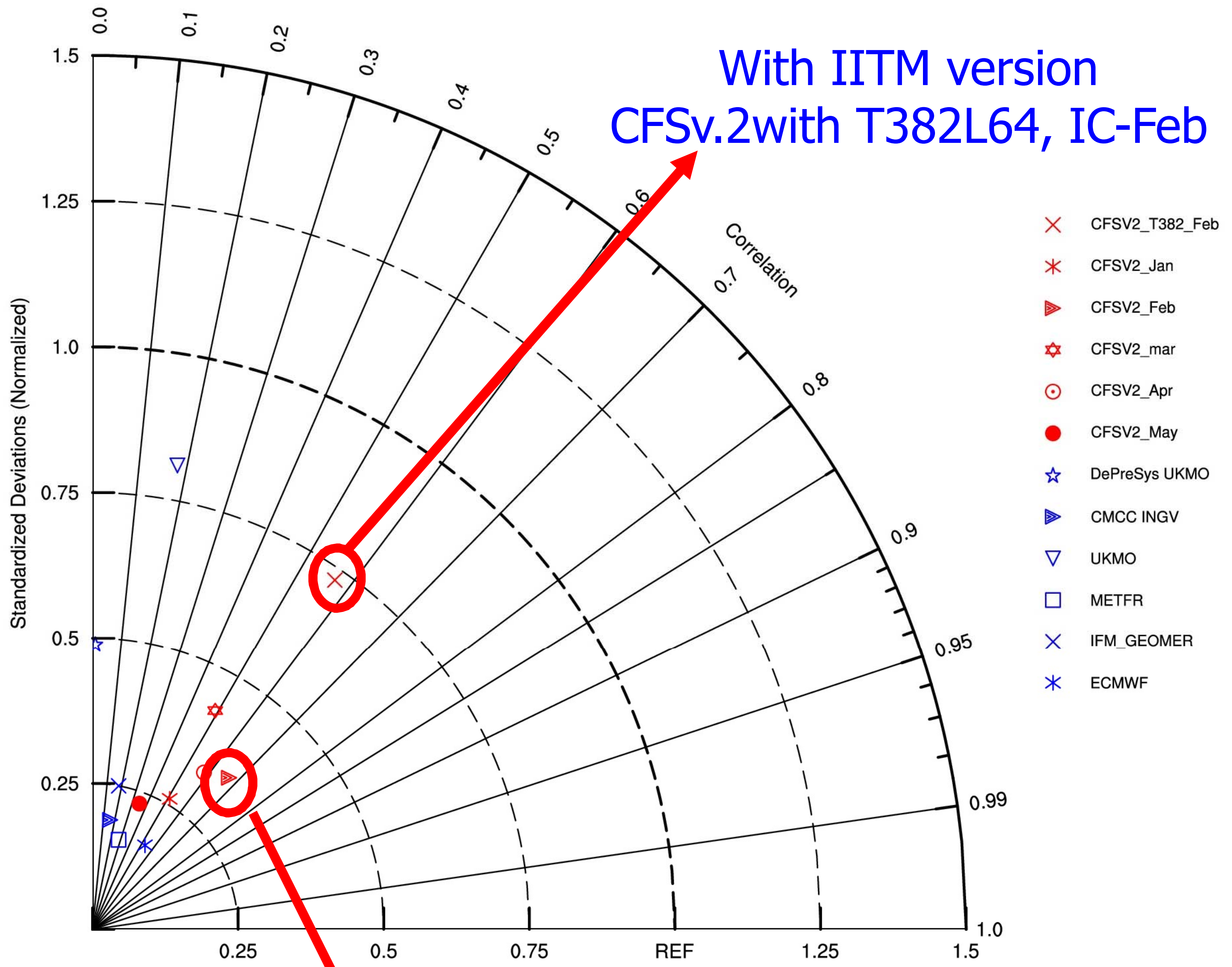
➢**To achieve lead time of 25 days for 0.6 correlation between observed and predicted MISO index!**

Seasonal and Extended Range Prediction Model Selection

- Through the NOAA-MoES MoU Institutional support from NCEP will be available.
- For predicting monsoon rainfall, skill of no coupled model is good. However, amongst the existing model systems, skill of CFS seems to be on the better side. It also has a reasonable monsoon climatology
- Appears to be a system upon which future developments could be built

Hindcast skill of Indian Land Rainfall

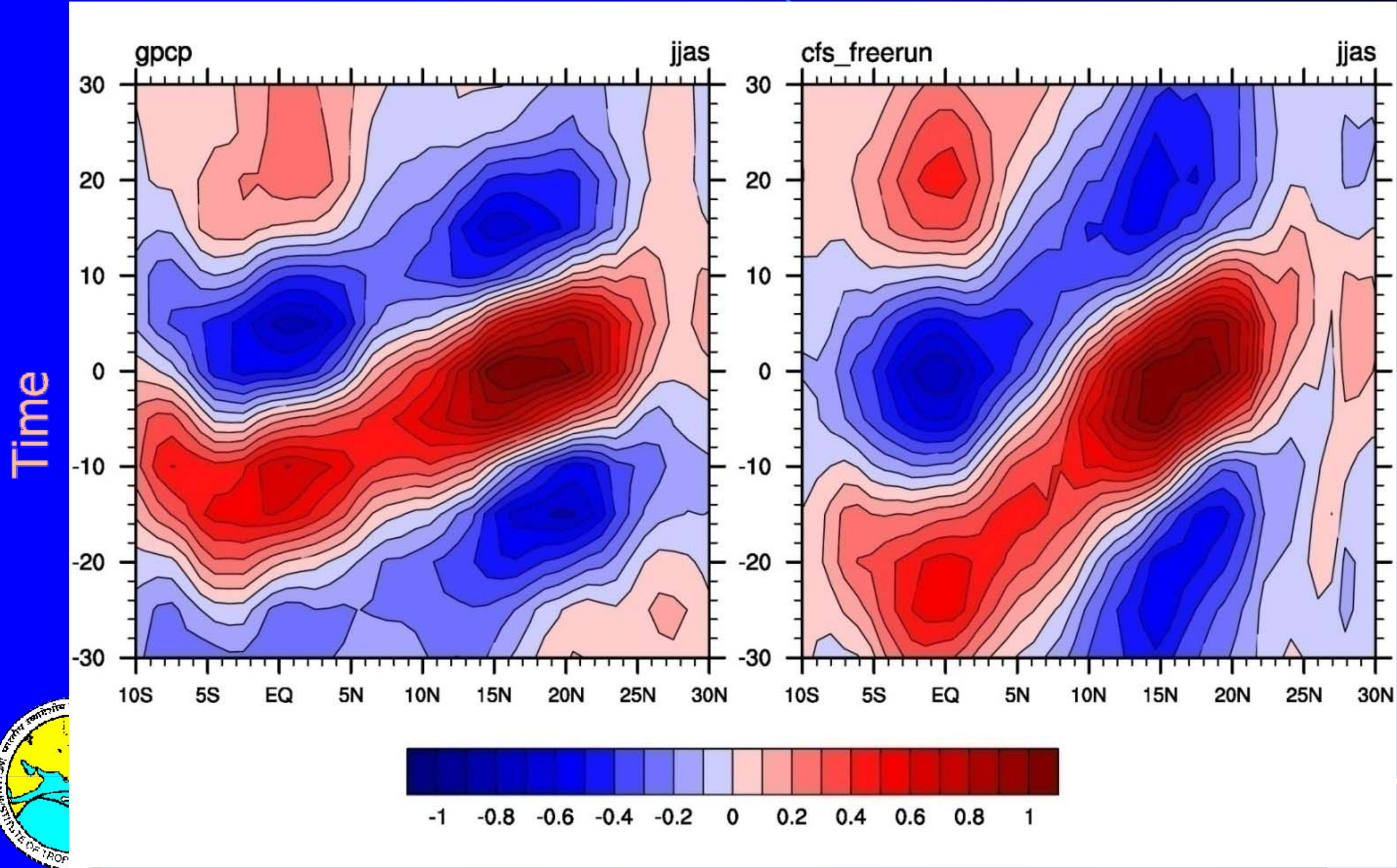
With IITM version
CFSv.2with T382L64, IC-Feb



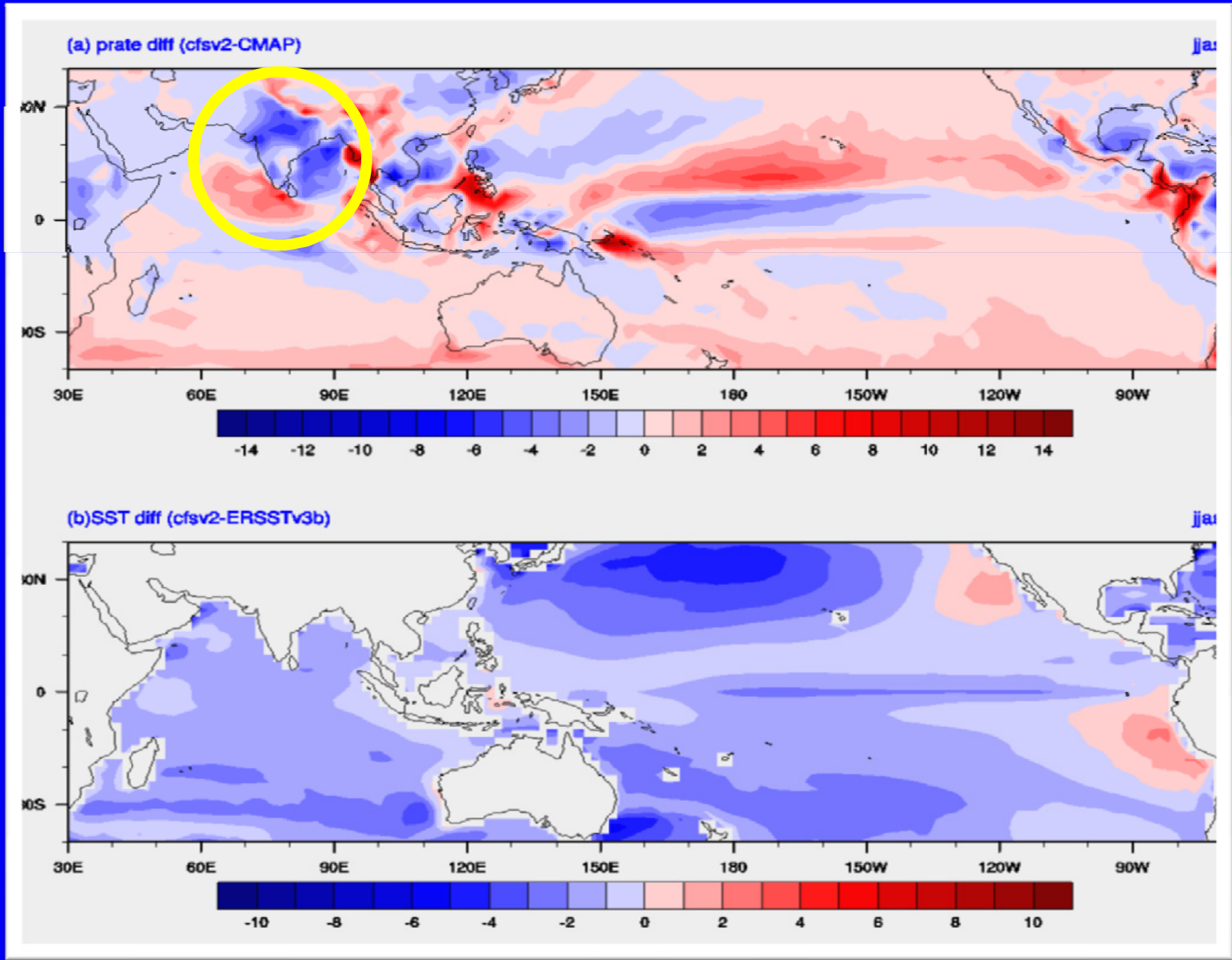
with standard version of CFSv.2, I.C- Feb

Good simulation of MISO by CFSv.2

Lead lag correlation plot: Ref. series: 70-90E,12N-22N

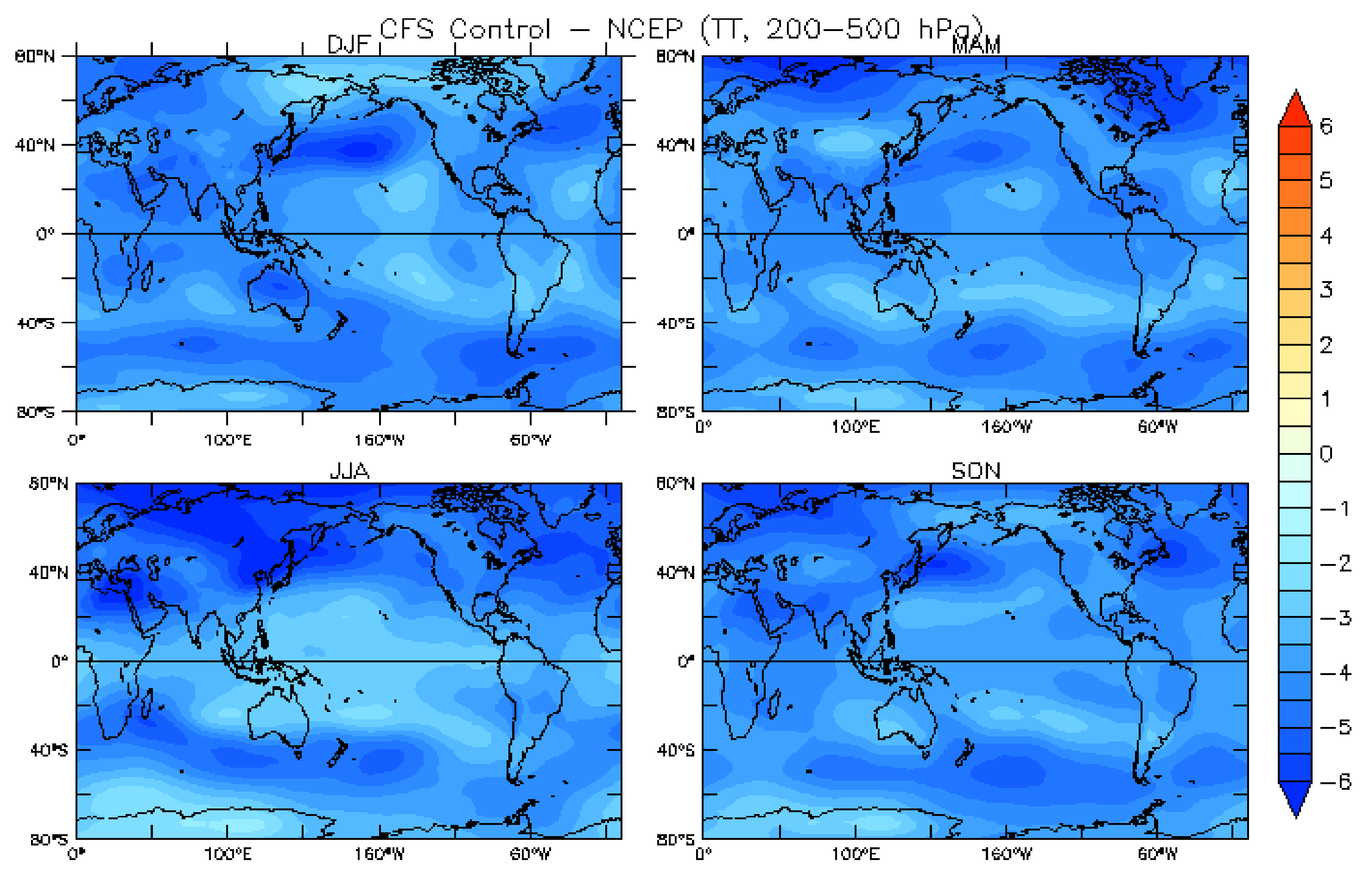


However, the model has significant dry bias over Indian land mass and cold SST bias!



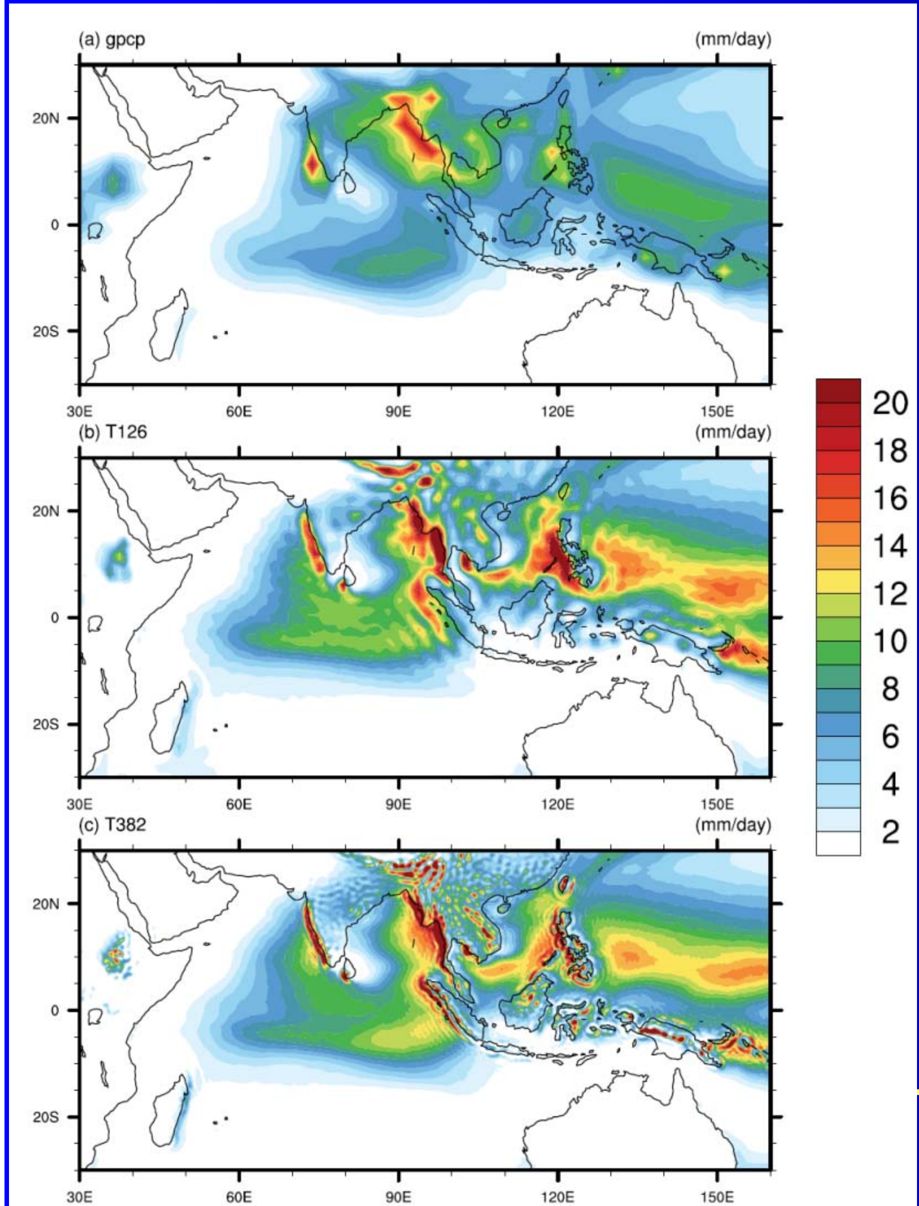
Last 20 years JJAS climatology difference between CFSv2 and Observation

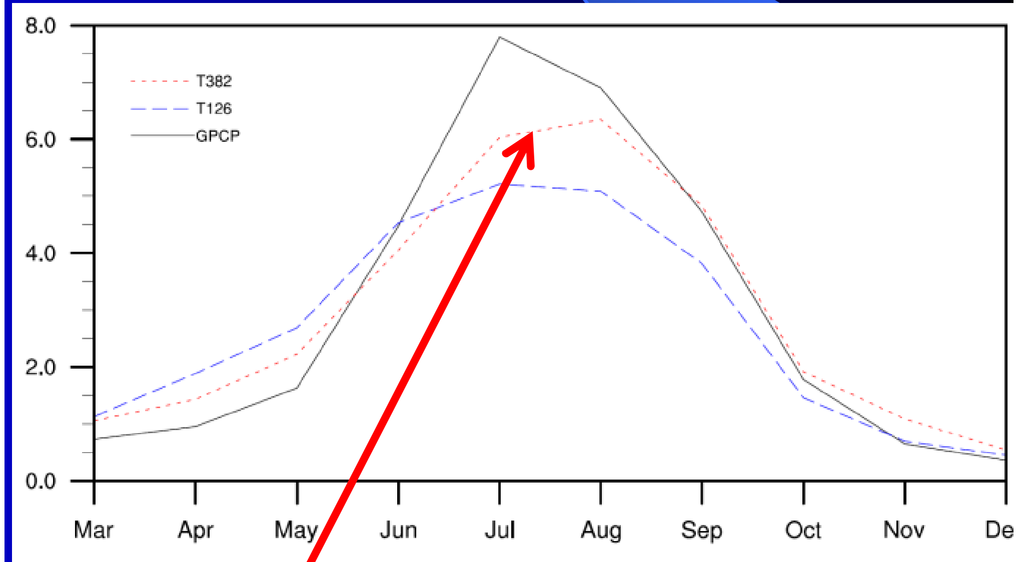
Difference in Tropospheric Temperature between model simulations and observations



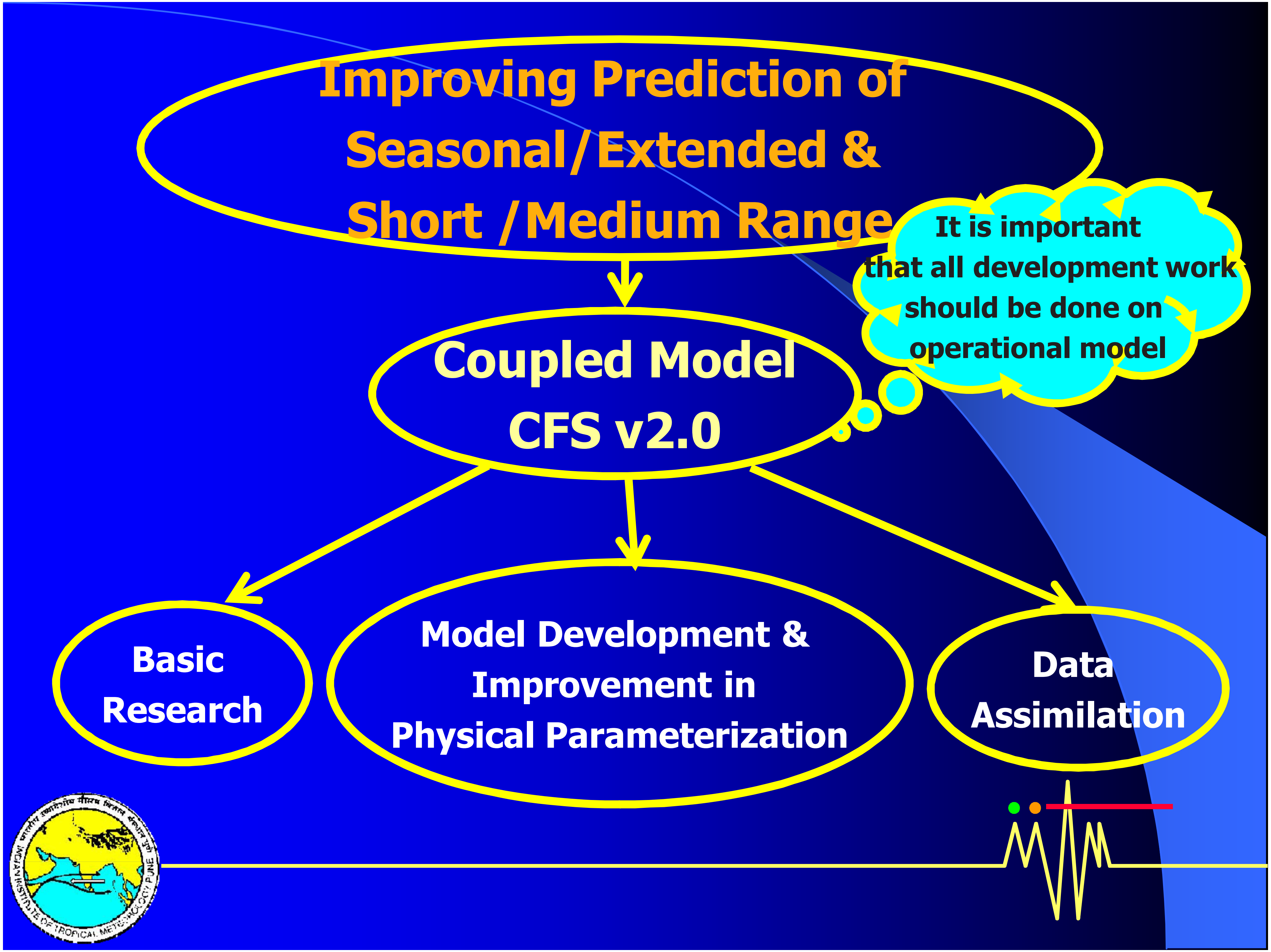
Cold bias throughout the troposphere!

High Resolution CFSv.2 improves cold bias over India substantially!.





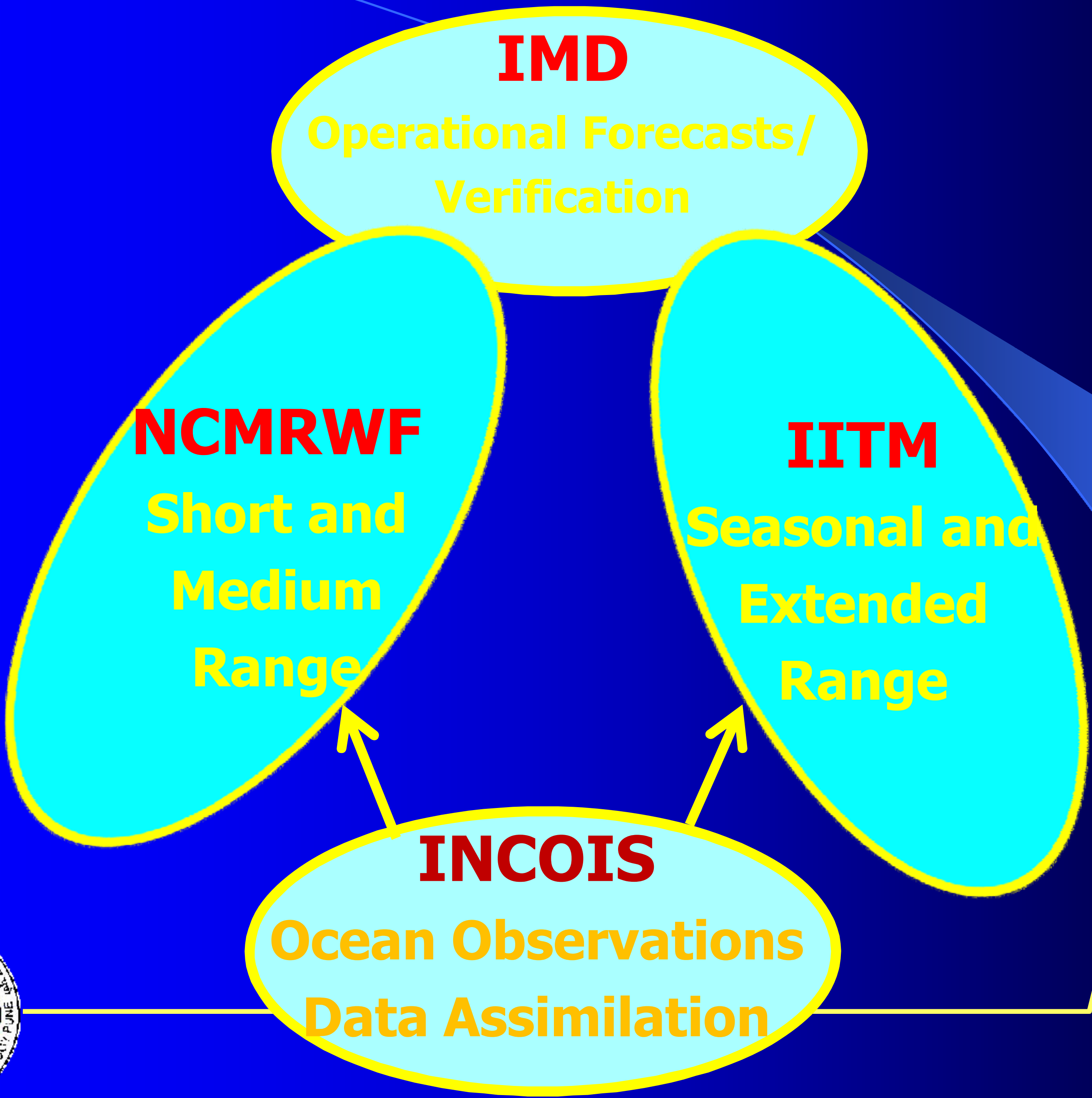
CFSv.2 T382


Improving Prediction of
Seasonal/Extended &
Short /Medium Range
It is important
that all development work
should be done on
operational model
Coupled Model
CFS v2.0
Basic
Research
Model Development &
Improvement in
Physical Parameterization
Data
Assimilation

Implementation Strategy

- To forge an working relationship with the Academic Community and engage the Community on improving the Operational Forecast System through an **Open Call for funding Research Proposals** to
  - **Reduce the biases of the CFS model**
  - **To improve skill of prediction of seasonal mean monsoon as well as MISO**
  - **To carry out some basic research for improving physical processes in the Forecast model**

Implementation Framework

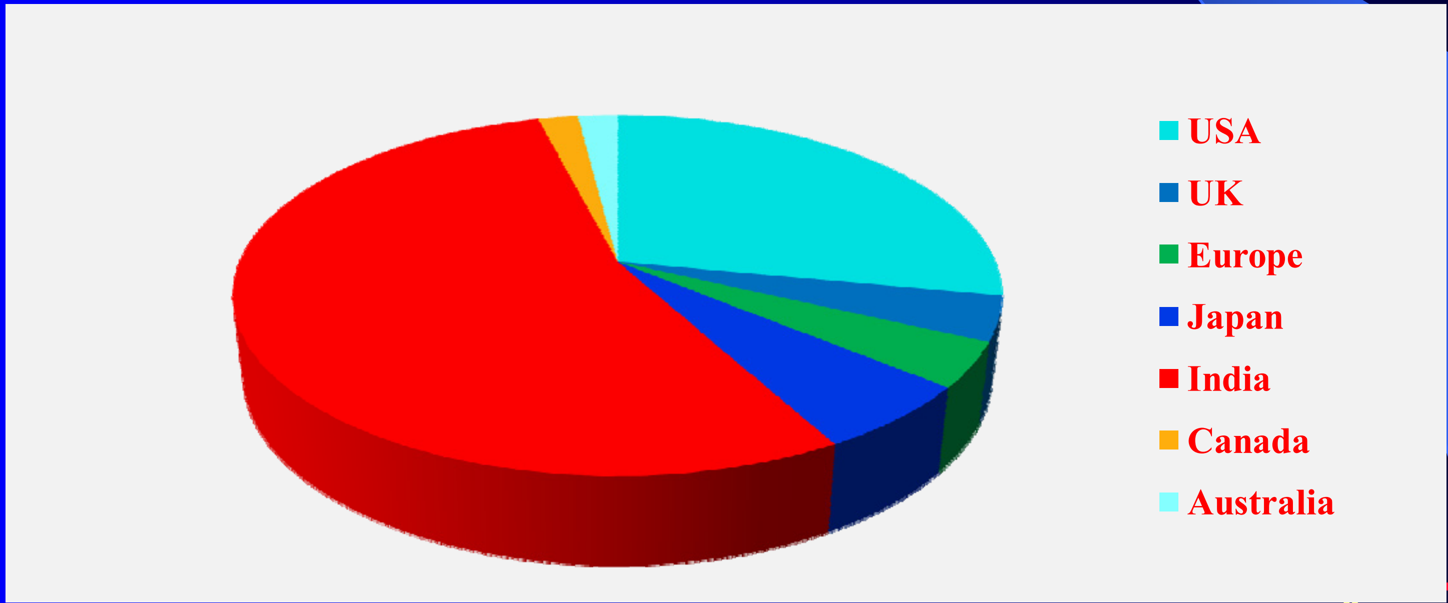


Deliverables

- **An Indian Model with improved skill for**
  - **Seasonal and Extended Range Prediction**
  - **Short and Medium Range Prediction**
- **To train a substantial group of young Indian scientists on Model Building.**

Support of Proposals

- Proposals Submitted: 50
- Proposals rejected: 16
- Proposals funded: 25



Major areas of support

- ❖ Data assimilation (EnKF):1
- ❖ Model Development (LSM, Ocean, AGCM): 10
- ❖ Cloud Parametrization: 3
- ❖ Model Diagnostics: 5
- ❖ Regional Downscaling: 3
- ❖ Applications (Hydrology): 1
- ❖ Model Code development: 2

First time in the country, we shall have Petafloop computing capacity at MoES!

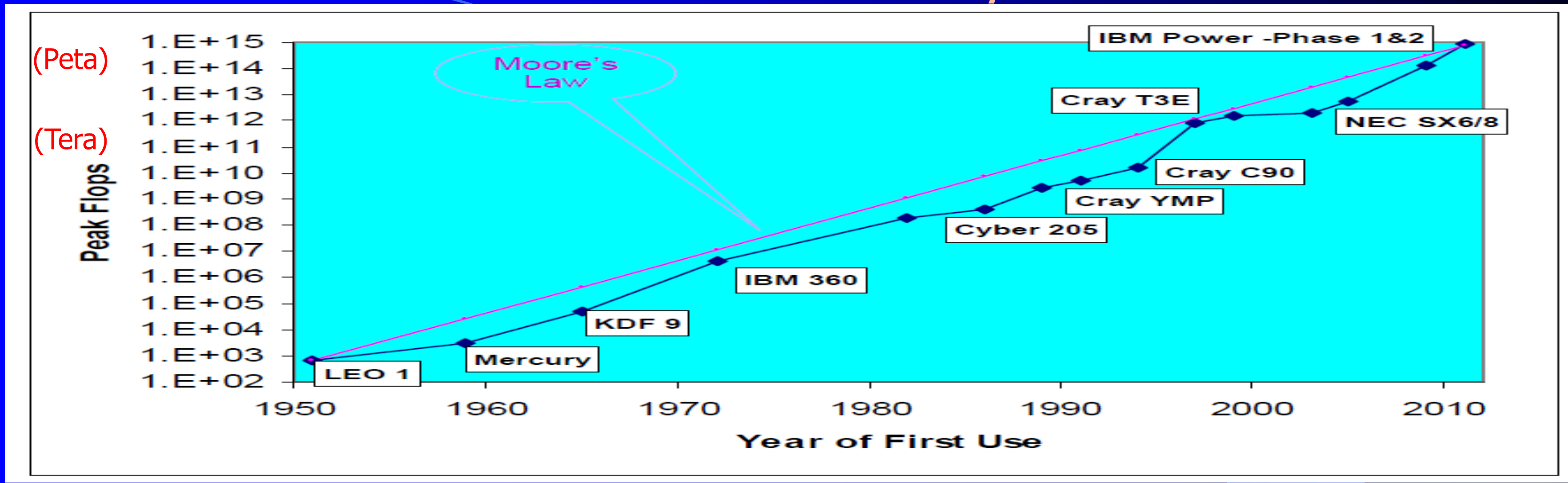
350 (20) TF
at
NCMRWF,Noida

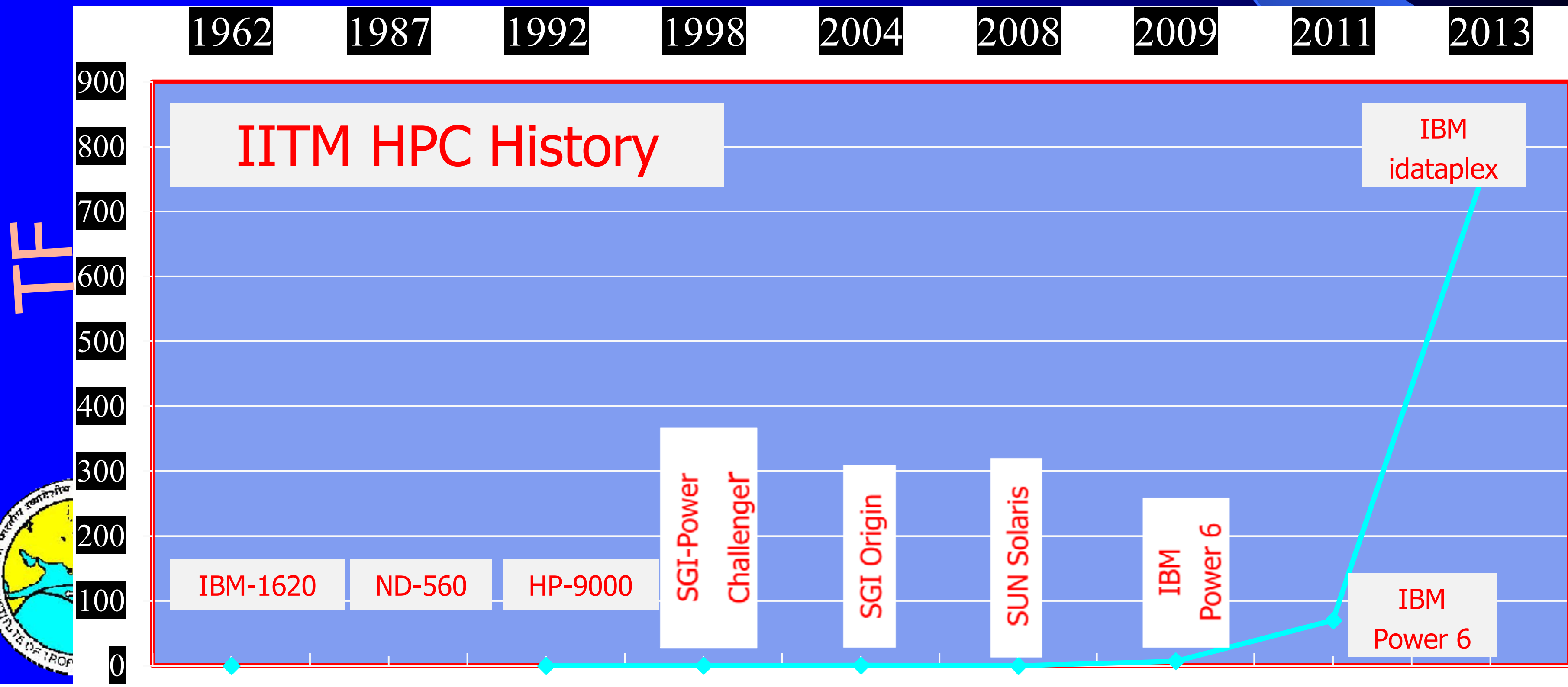
N
K
N

790 (70) TF at
IITM, Pune
100TF –INCOIS
100TF- IMD

Combined capacity of MoES >1PF

UKMO HPC History

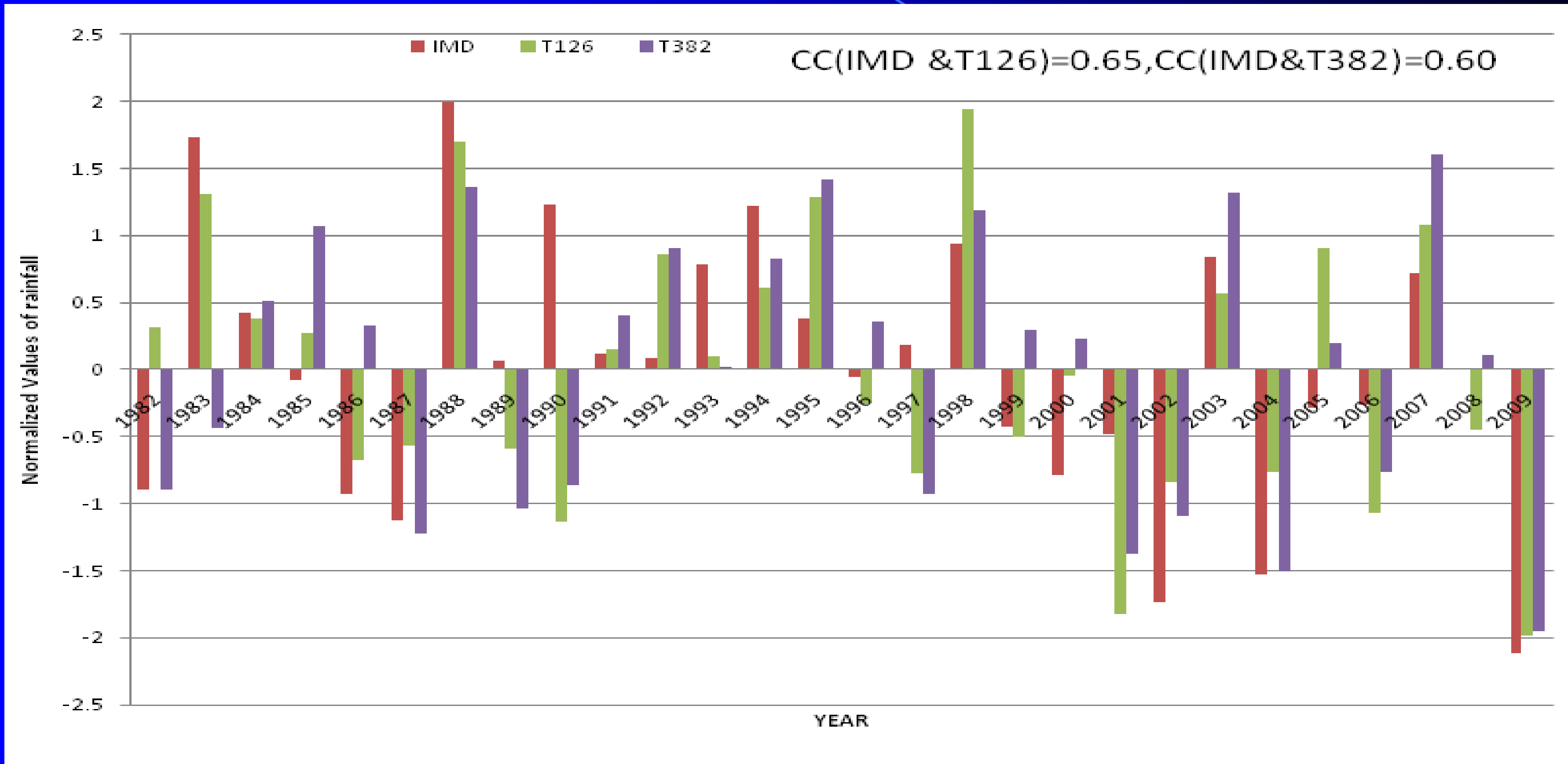




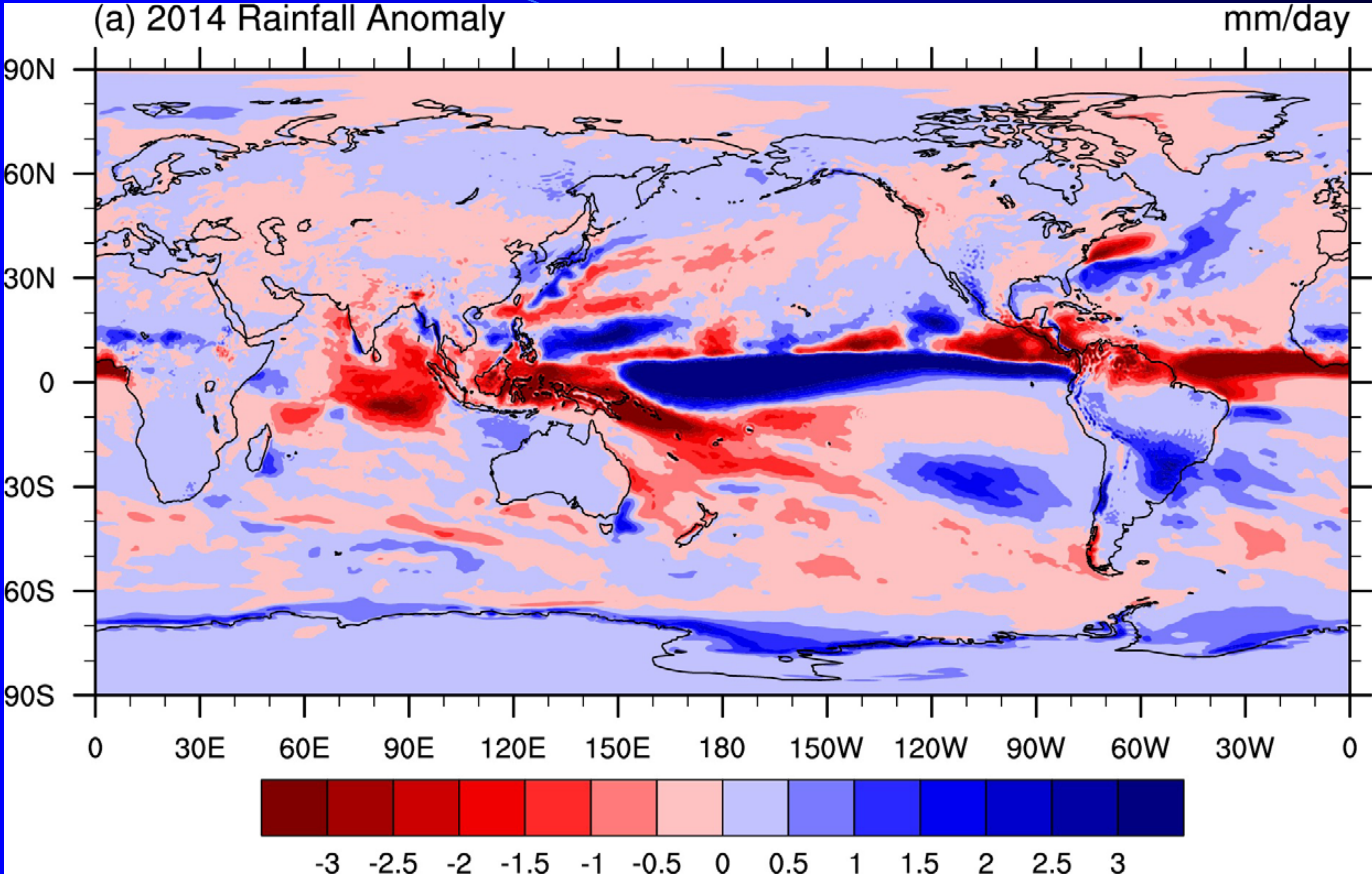
Time lines of the Monsoon Mission

2010-2011	Setting up nodal point at IITM Setup CFS V 2.0 model at IITM
2011-2012	Identify the strengths and weakness of the model and define the problems for further investigation. Invite the project Proposals and distribute the work
2012-2015	Carryout research on identified problems together with national/ international partners and review the progress made by external experts committee
2012-2015	Implement the experts suggestions in the proposal and carryout the model development activities and test the model's skill
2015-2016	Expected to have an intermediate model, whose skill will be better than model adopted at the initial stages.
2017	Review the progress made by the national mission A New Indian Model and Prediction System

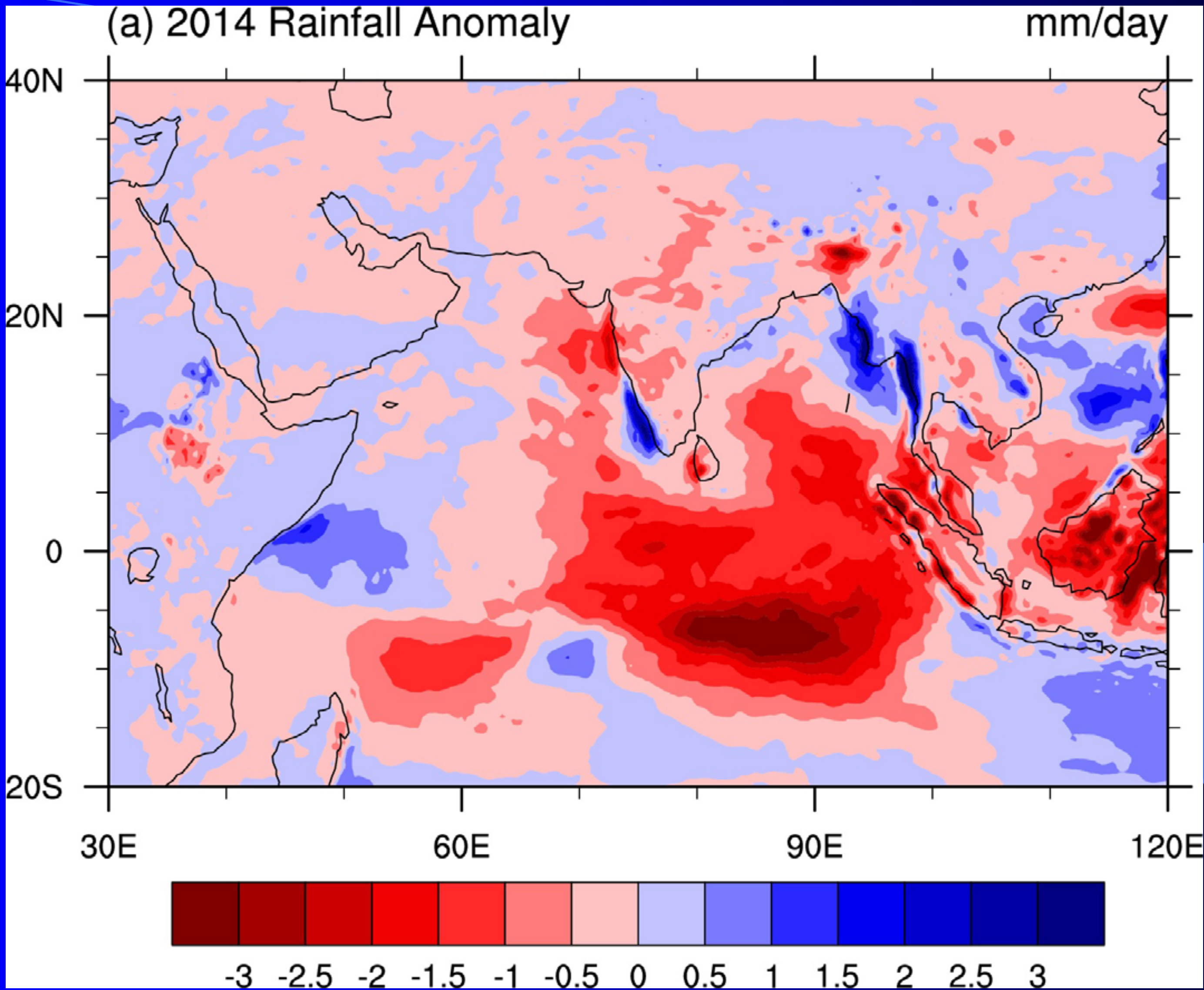
Real time Seasonal Forecasts by the IITM Model



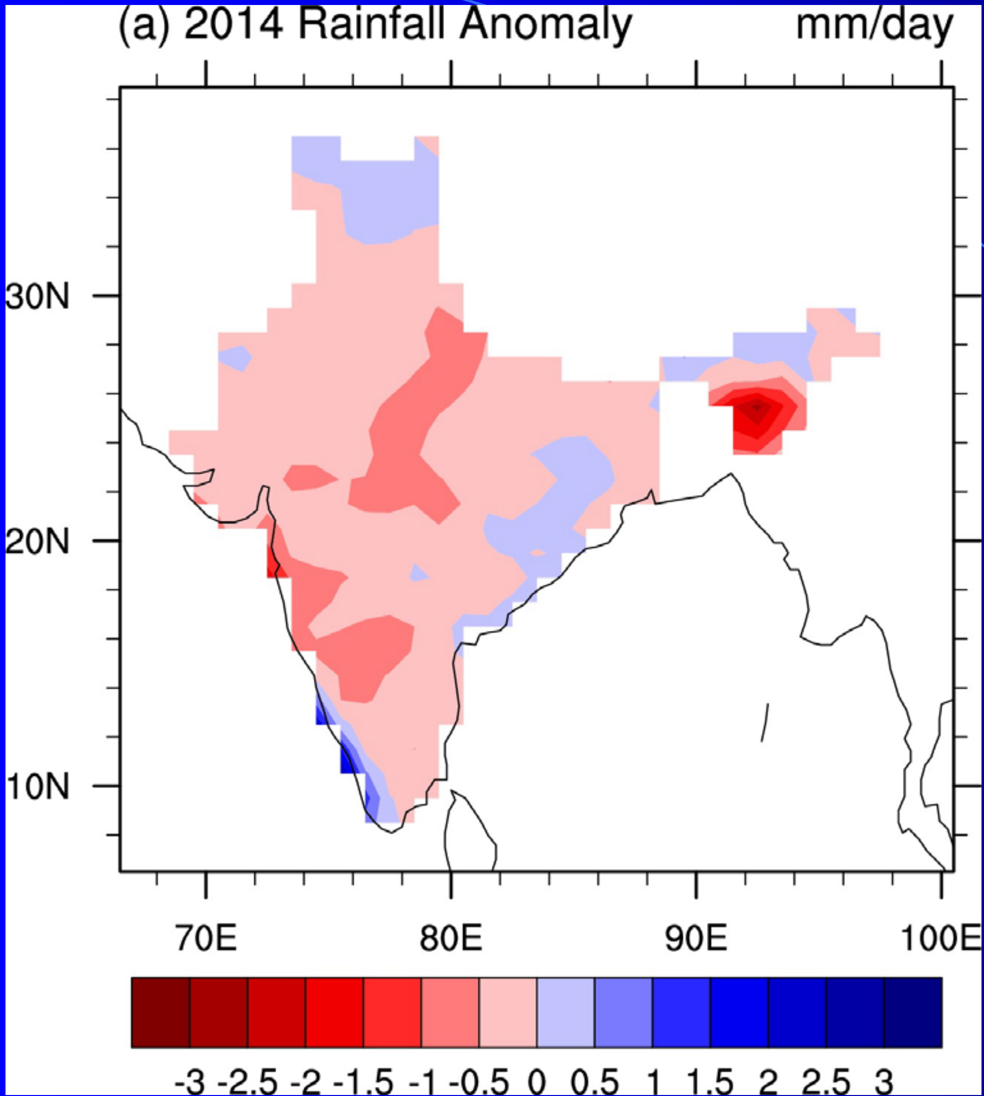
Hindcast skill of predicting ISMR



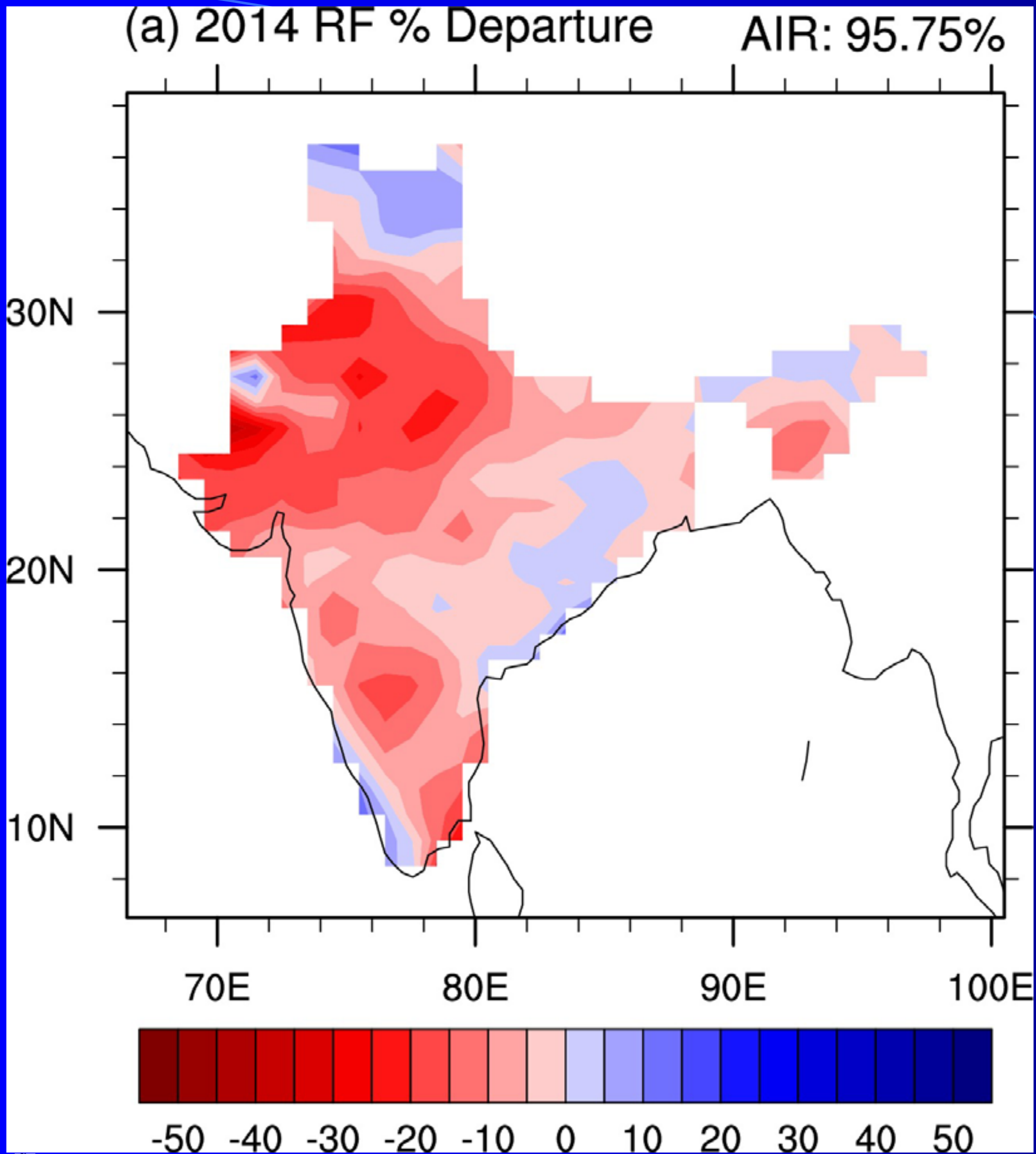
2014 JJAS Rainfall anomaly (Global)



2014 JJAS Rainfall anomaly (ASM region)

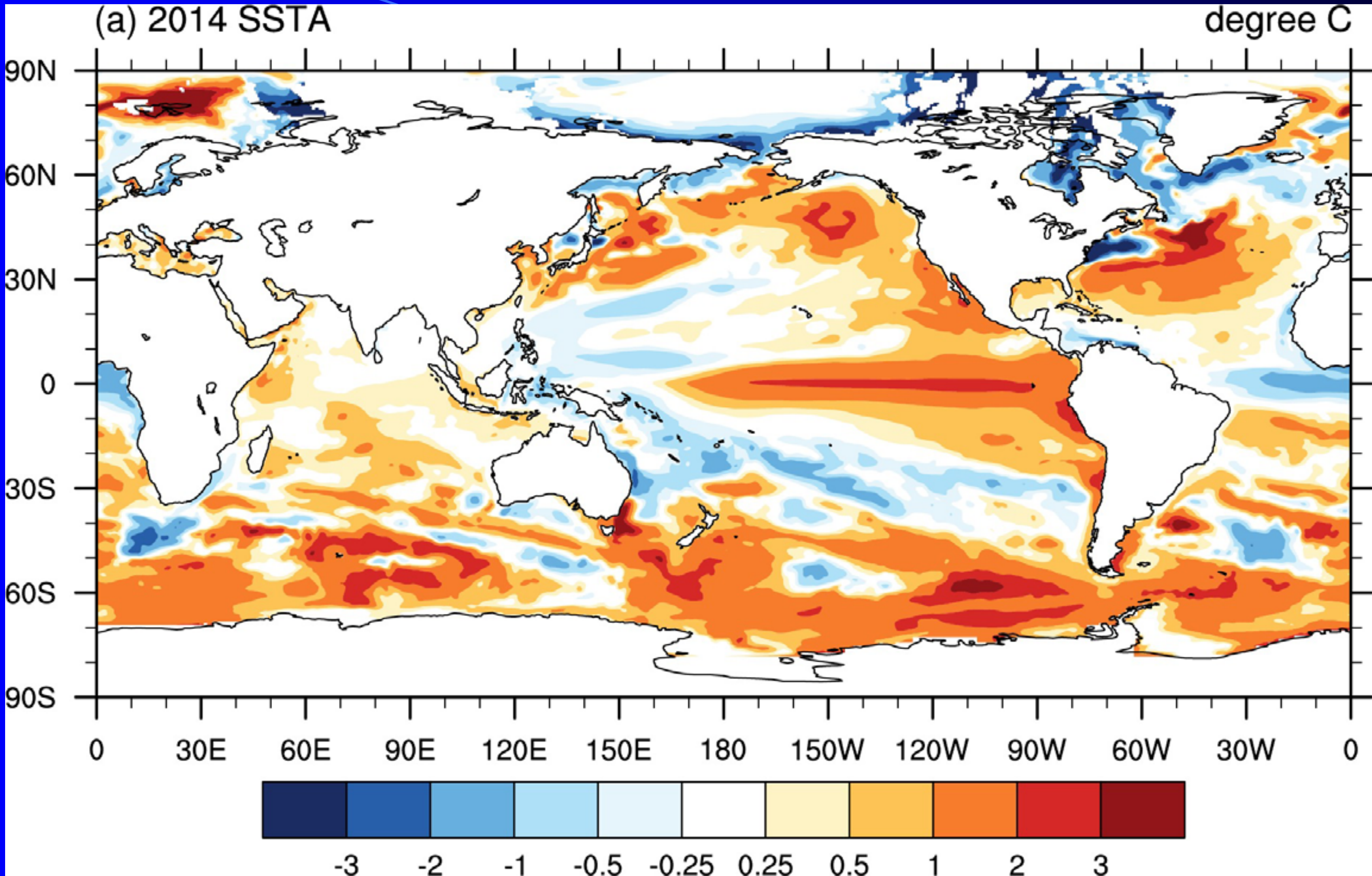


2014 JJAS Rainfall anomaly (Indian Landmass)



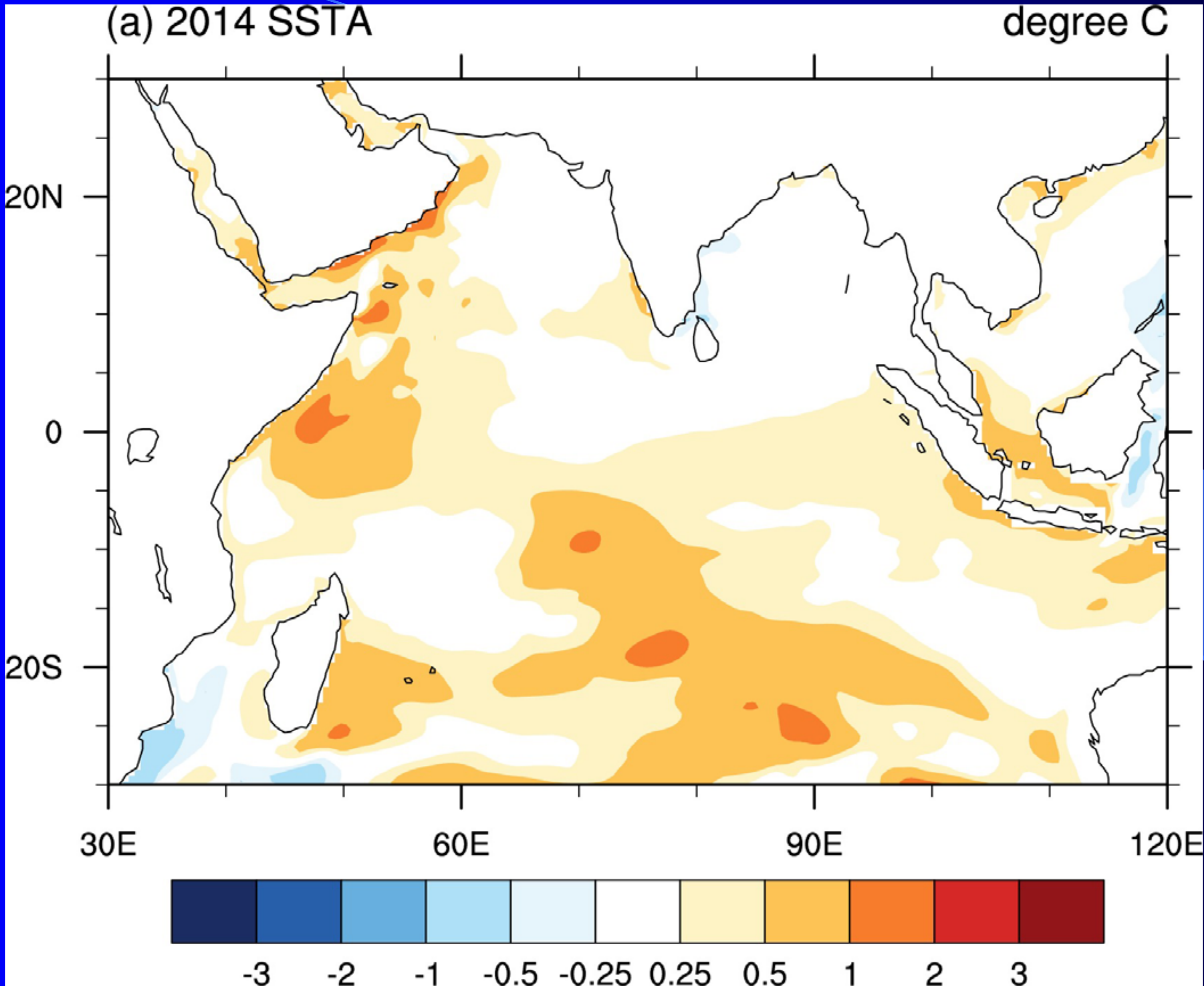
% departure of 2014 all India JJAS Rainfall

Monsoon performance is 95.75%

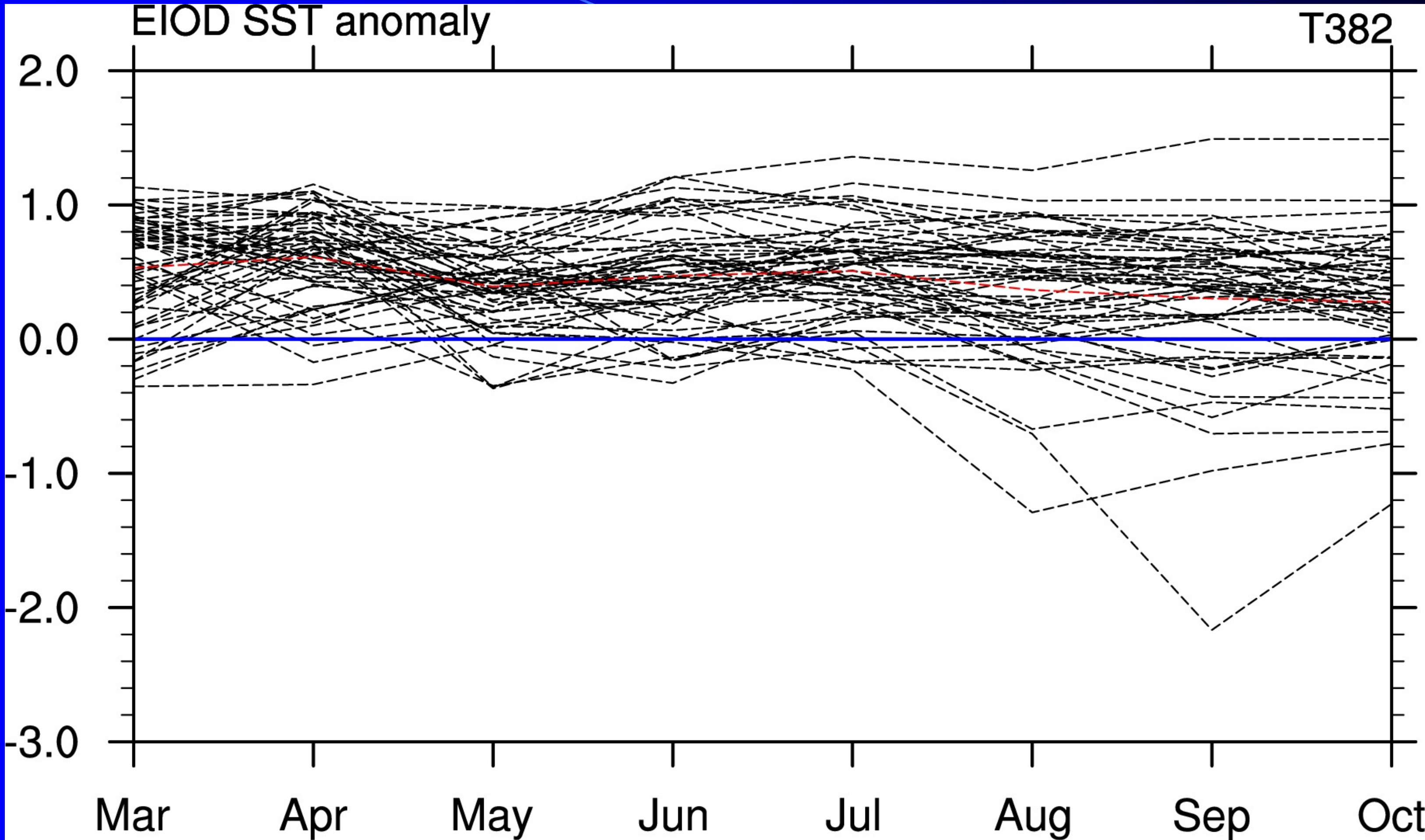


2014 JJAS SST anomaly

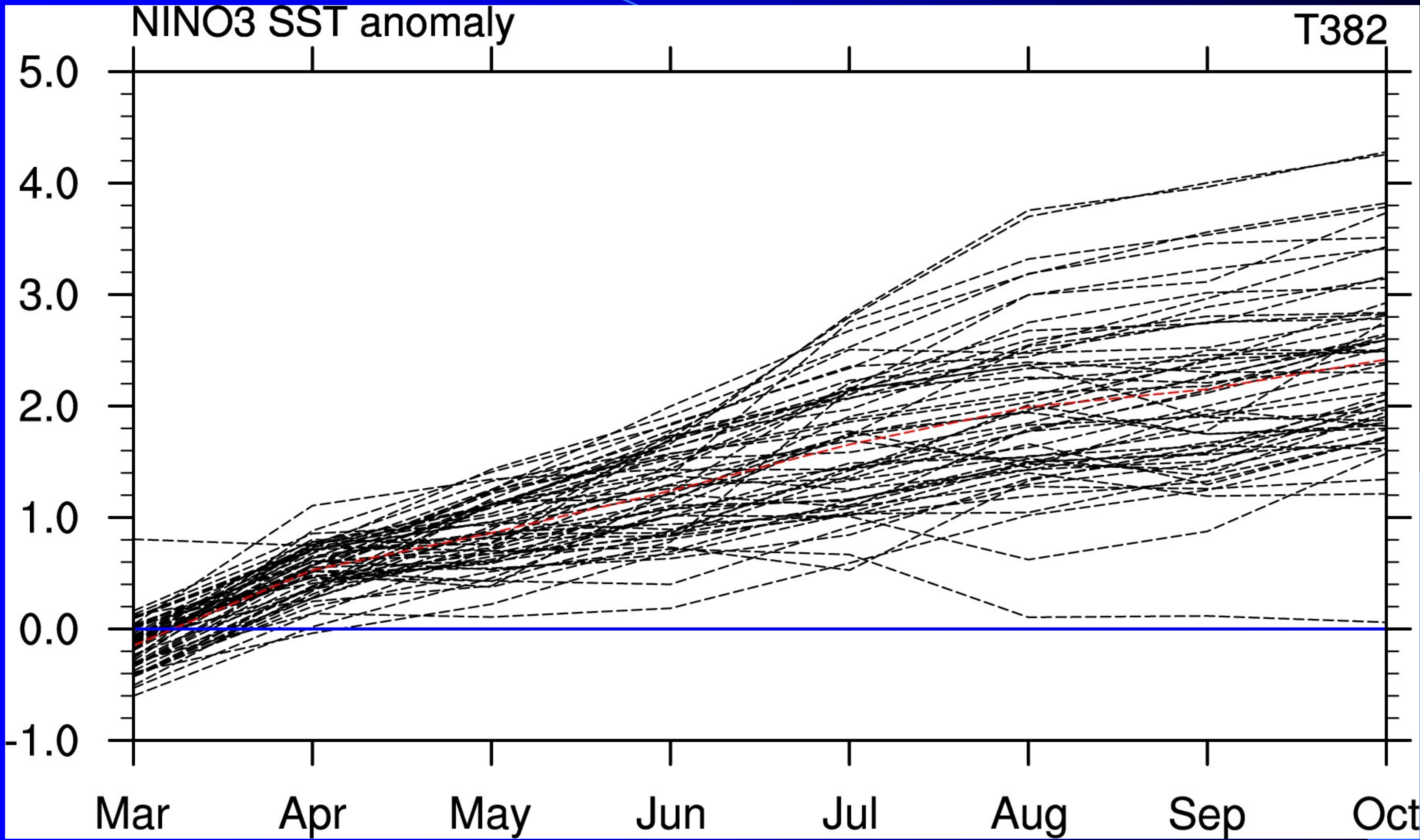
2014 JJAS SST anomaly (Indian Ocean)



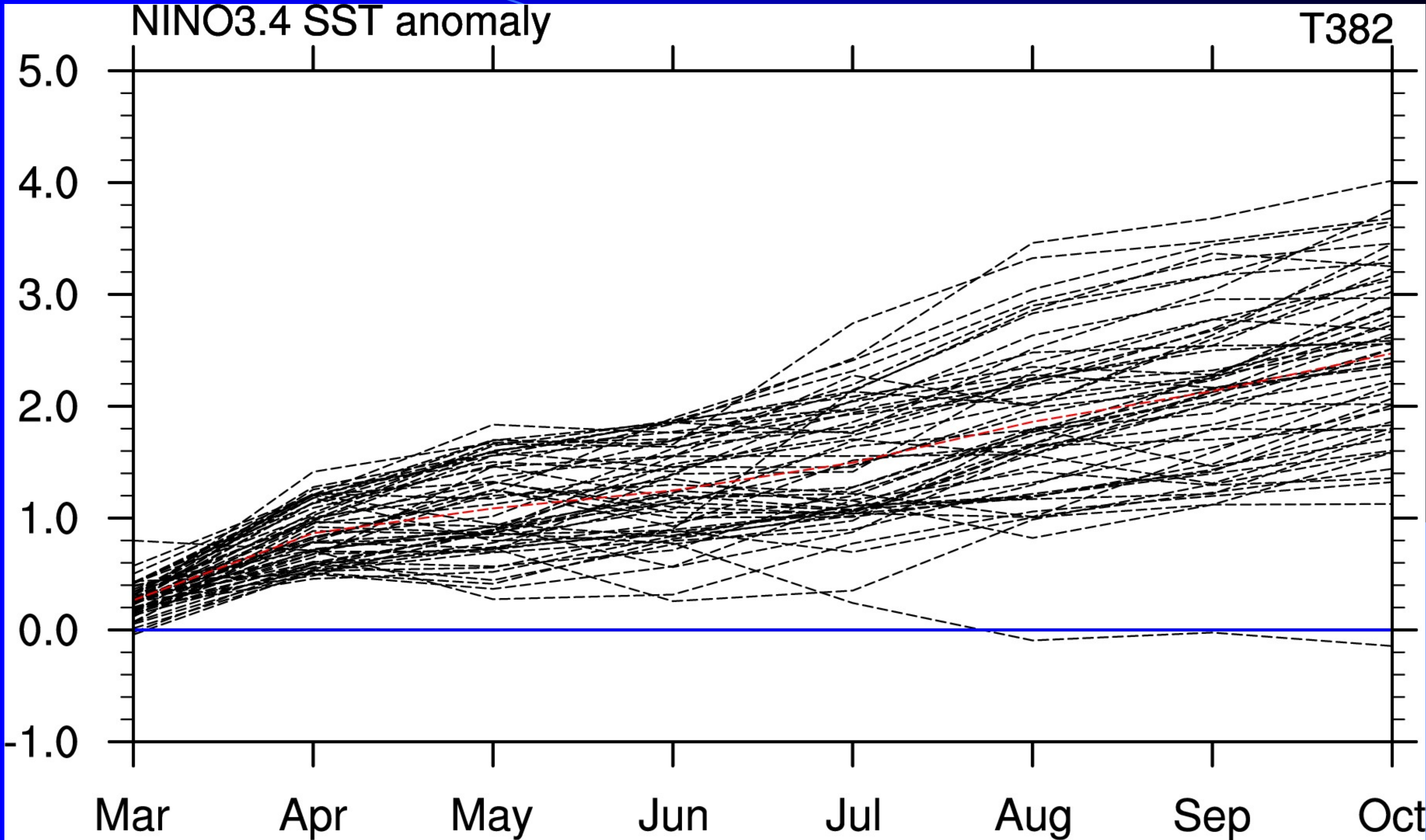
Evolution of EIOD box SST anomaly



Evolution of NINO3 box SST anomaly



Evolution of NINO3.4 box SST anomaly



Probabilistic Forecast based on CFS V2 T382

Category	<90%	90-96%	96-104%	104-110%	>110%
Probability Forecast (54 Ensembles)	20%	4%	3%	10%	3%

Some Important developments at IITM.

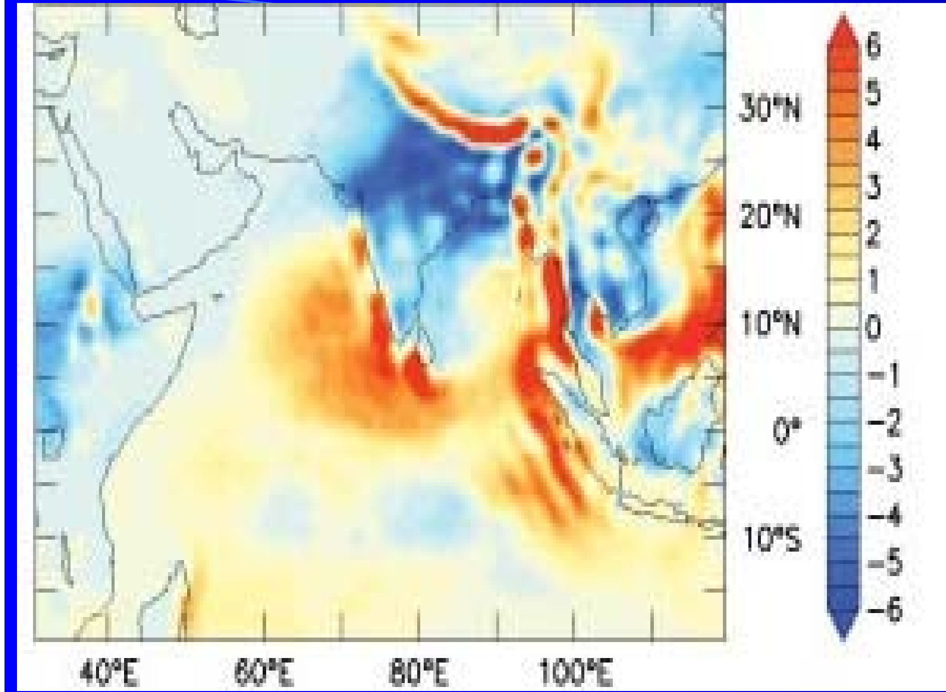
Model Development

1. **Some major biases of CFSv.2 are hypothesized to be due to poor microphysics parameterization in the SAS scheme in the model. Starting from basic principle, the microphysics of ice and mixed phase processes improved significantly in the model leading to improvement of biases (will be presented by Anupam Hazra)**
2. **A superparameterized version of CFSv.2 (SP-CFS) has been successfully established and integrated for 3 years.**
3. **The land surface scheme in CFSv.2 is being improved**
4. **A completely new IITM coupled climate developed for long climate variability studies**

In House Developments - I

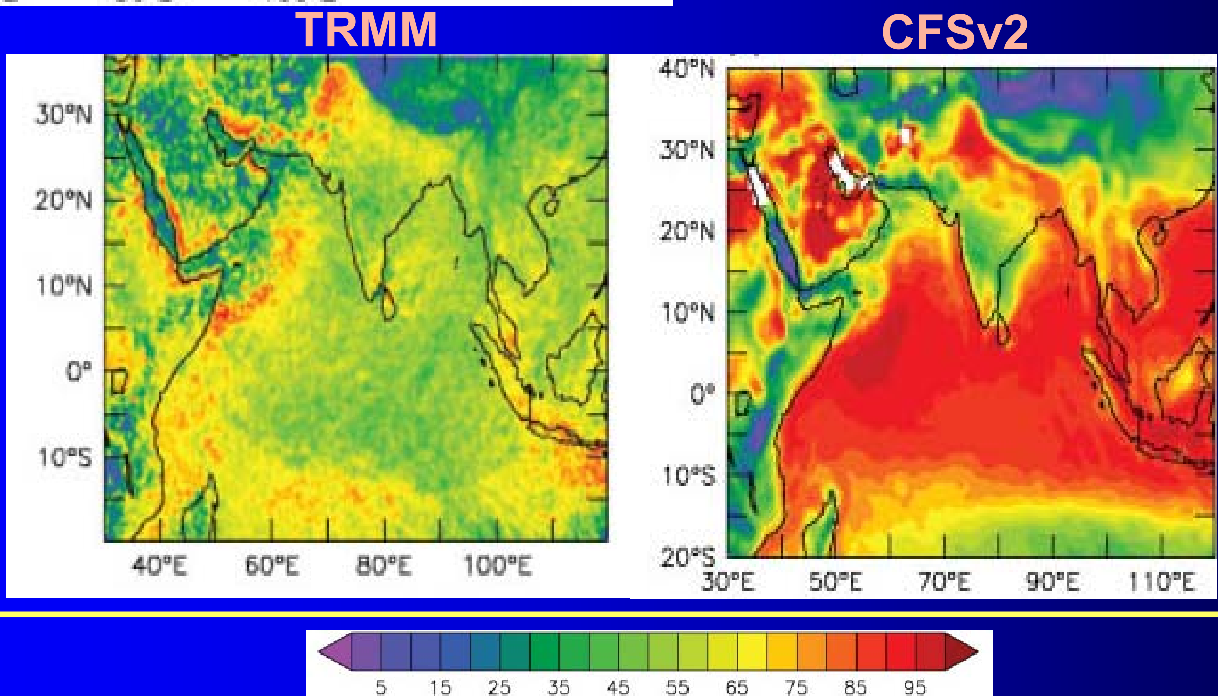
Improvement of Monsoon simulation by CFSv.2 by fundamental improvement in the cloud parameterization in the model

(Hazra et al. 2014)



Model Deficiencies

- **Too dry over Indian continent**
- **Compared to Obs. Produces too little stratiform clouds and too much convective ones**



Exercise – I

Exercise – II

Exercise - III

Modified cloud microphysical scheme (An Approach)

P_{ccond} = Generation rate by condensation. (Existing)

P_{idep} = Generation rate of cloud ice by deposition. (On-going)

P_{sdep} = Generation rate of snow by deposition. (On-going)

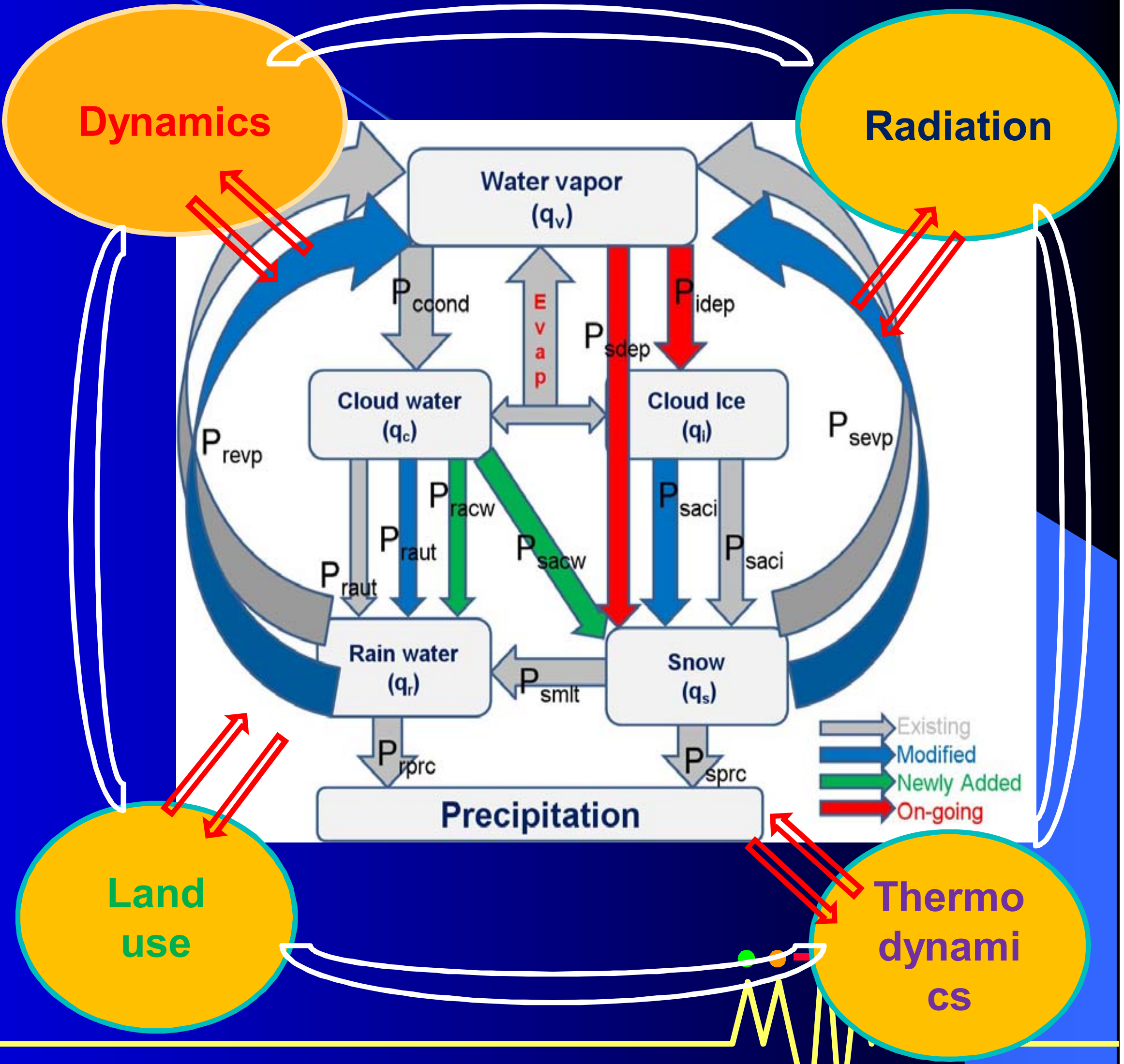
P_{saci} = Generation rate of **snow** by collection of ice by snow. (**modified** the Existing formulation)

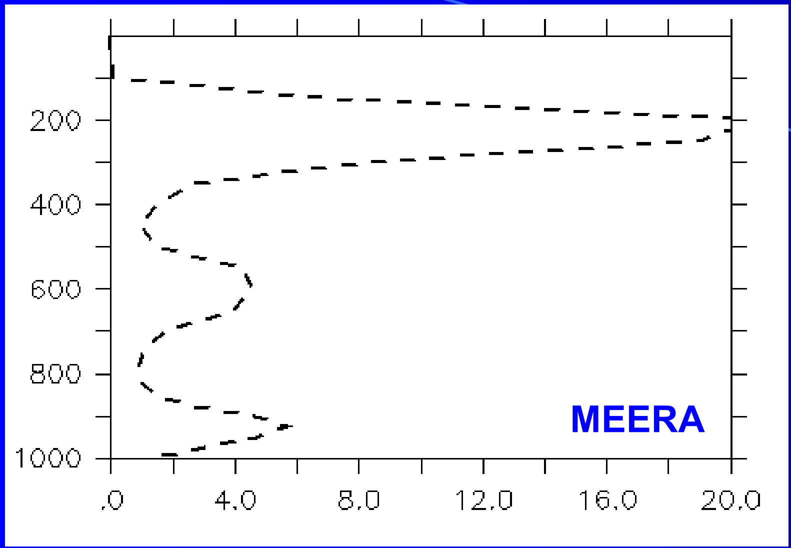
P_{saut} = Generation rate of **snow** by auto-conversion. (**modified** the Existing formulation)

P_{raut} = Generation rate of **rain** by auto-conversion. (**modified** the Existing formulation)

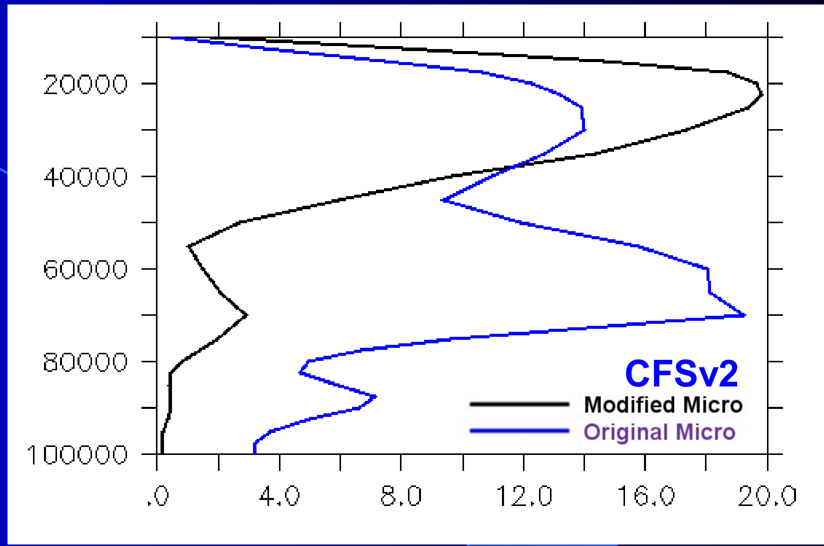
P_{sacw} = Generation rate of **snow** by **accretion** of cloud water (**newly added**)

P_{racw} = Generation rate of **rain** due to collection of cloud water (**rain accretion**). (**newly added**)



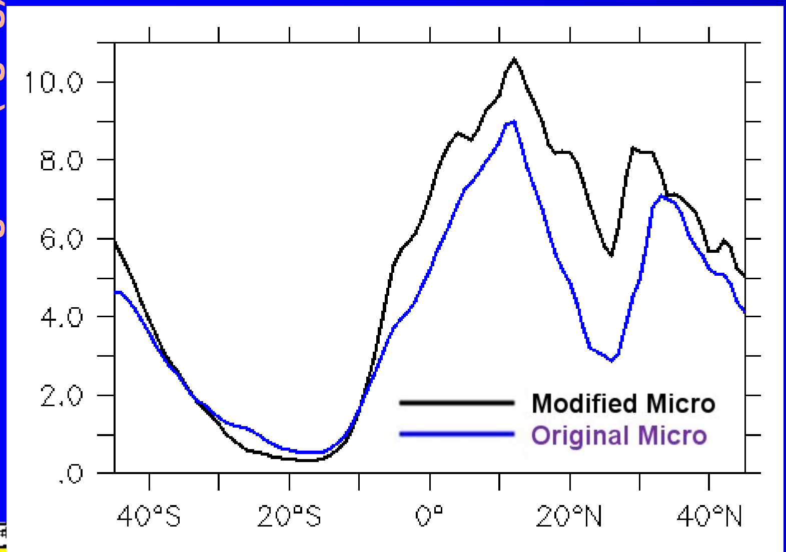


Cloud water & ice mixing ratio (mg/kg)

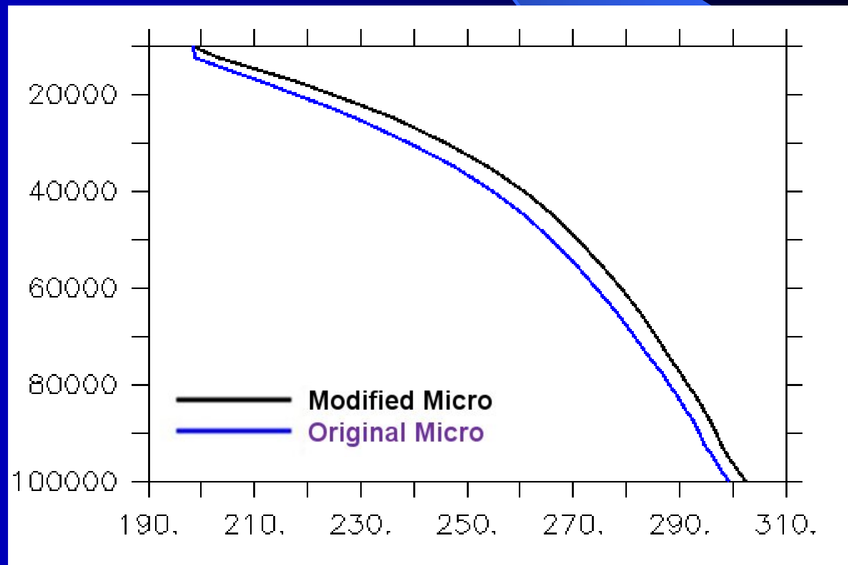


Cloud water & ice mixing ratio (mg/kg)

Cloud ice mixing ratio (kg/kg)

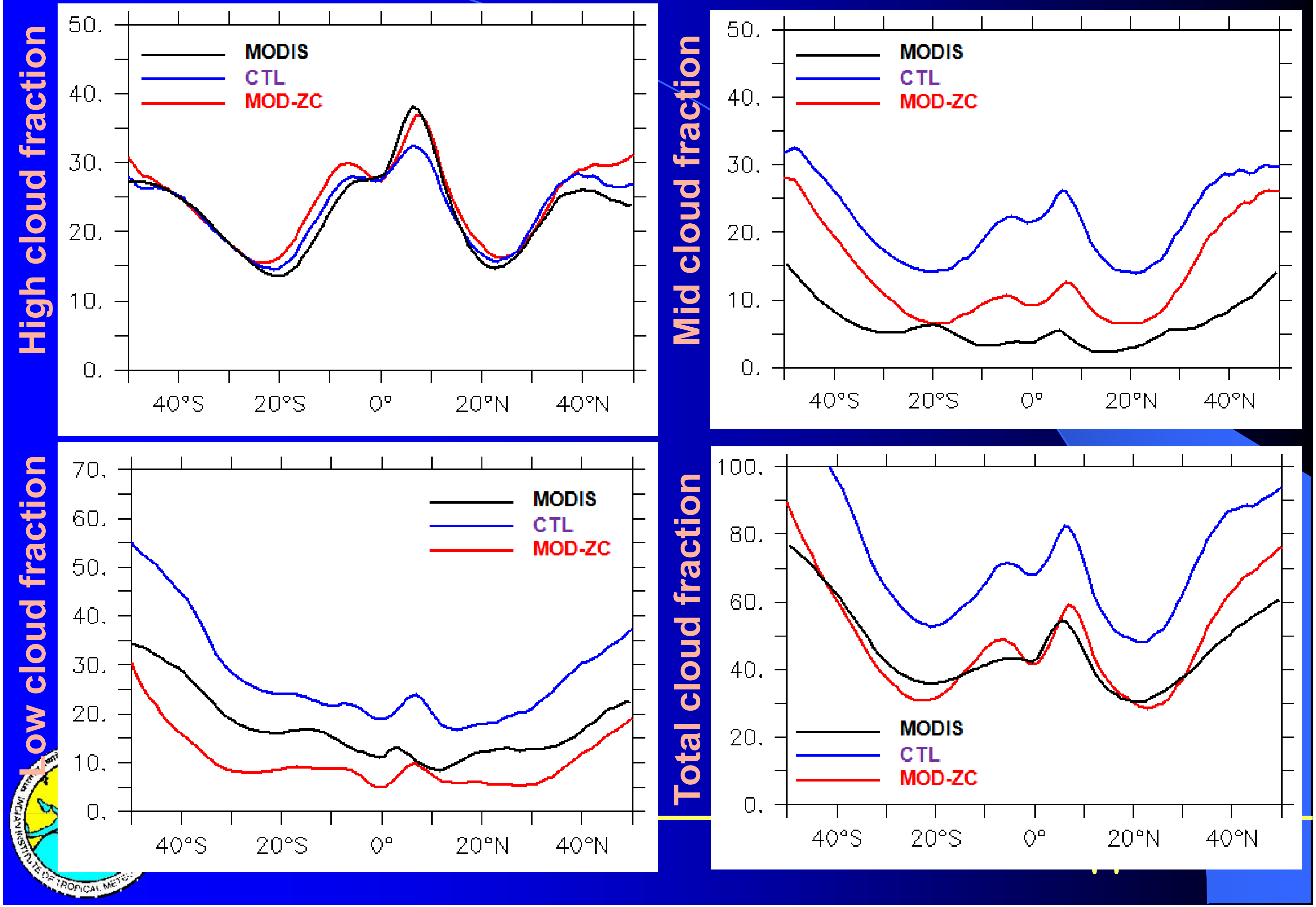


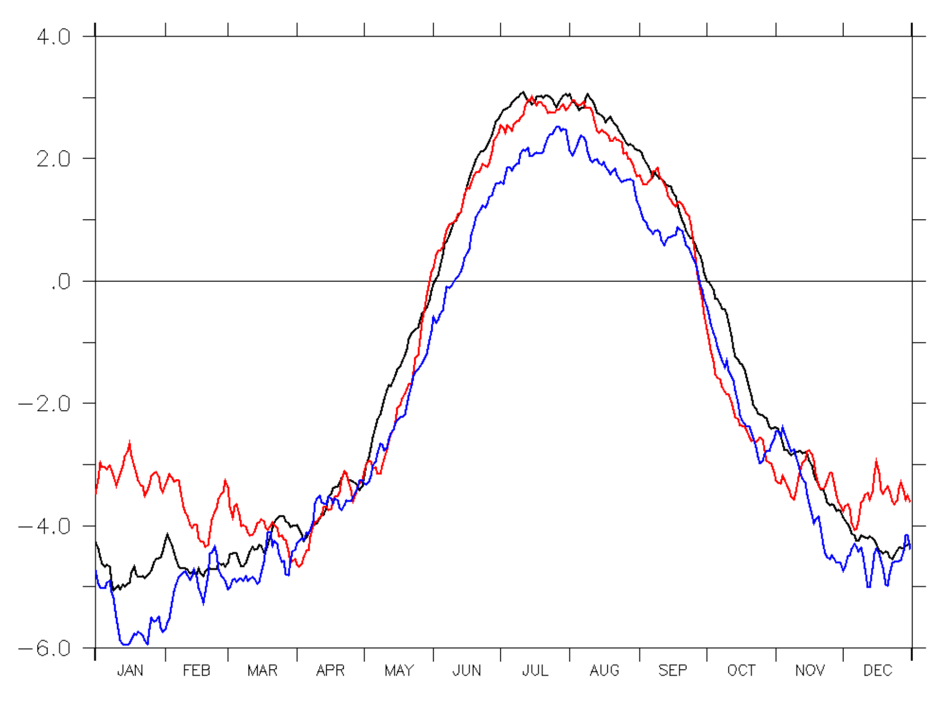
Latitude

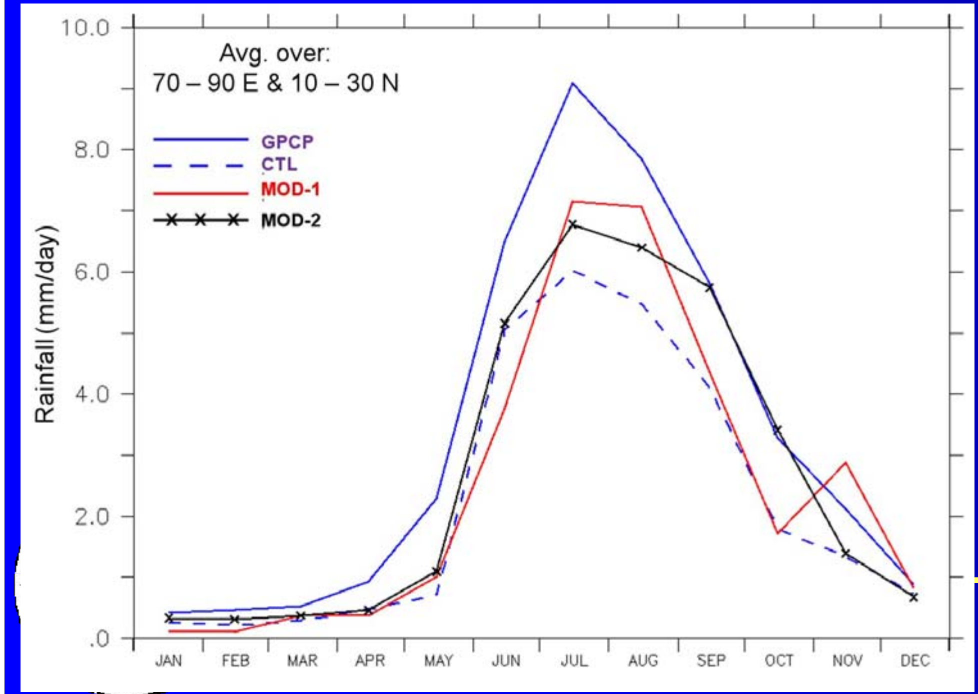


Temperature (K)

Annual Cloud fraction (%)

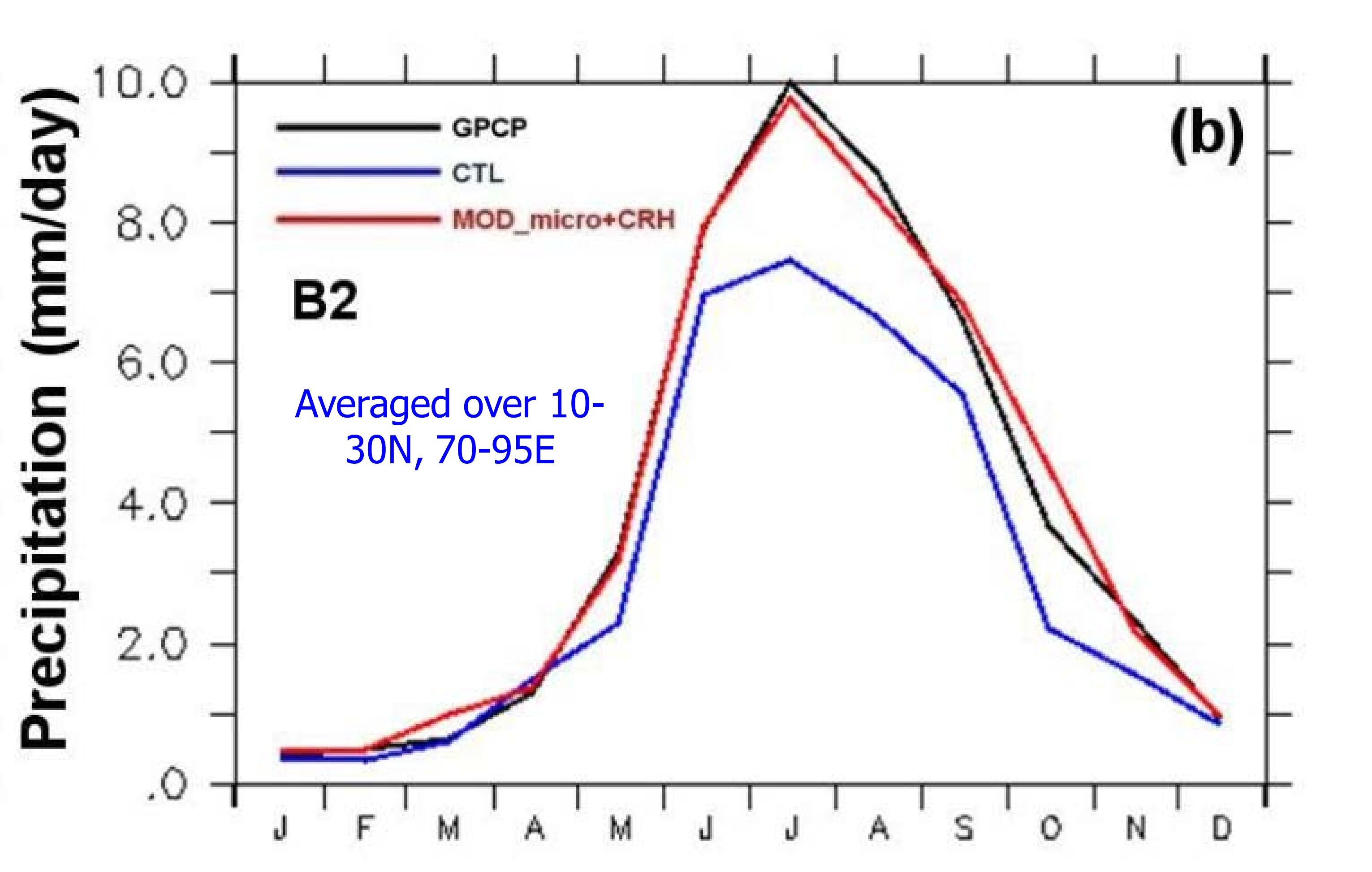






Improves Tropospheric temperature gradient greatly

Improves precip over India by about 15%



Improves precip over India by about 15%

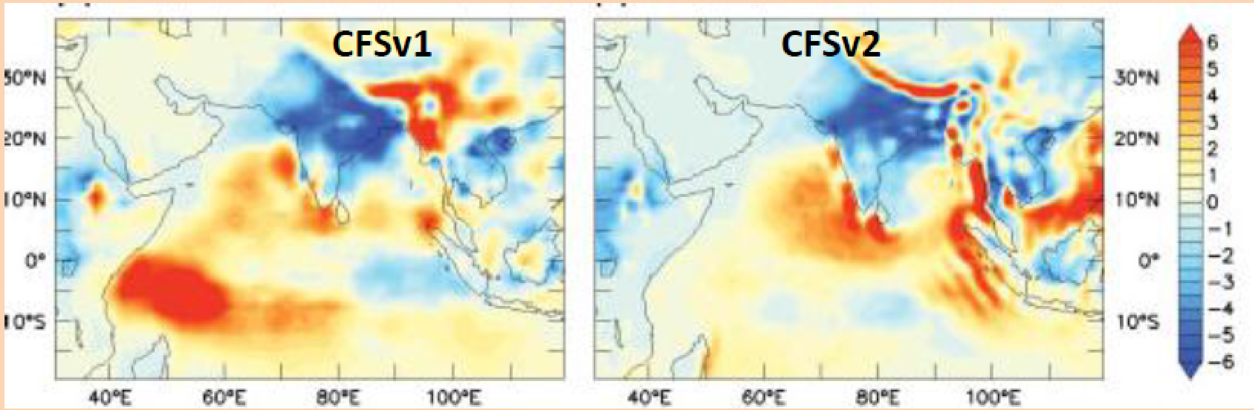
In House Developments - II

A super-parameterized version of CFSv.2 with atmosphere at T62L64 resolution has been developed and integrated for 3 –years (SP-CFS)

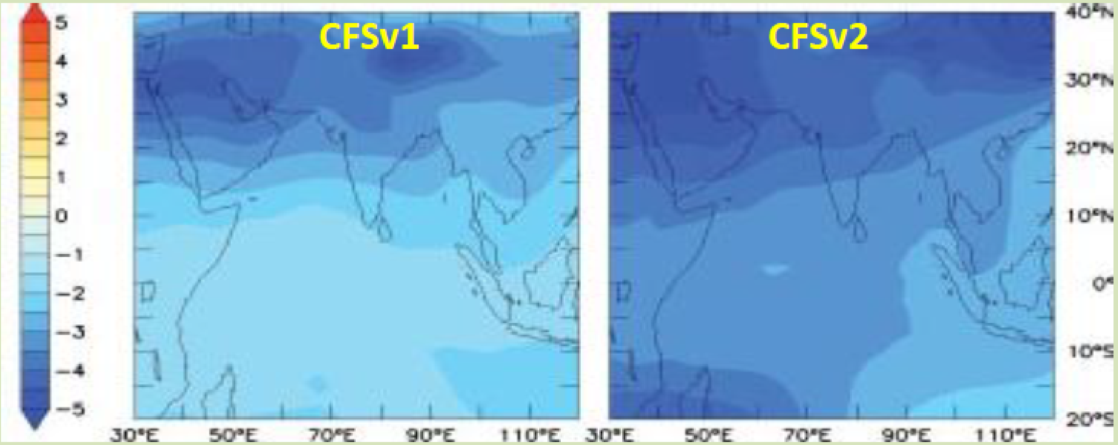
Bidyut Goswami, P. Mukhopadhyay et al. 2014

Systematic Biases of NCEP CFS

… Motivation behind superparameterizing CFS



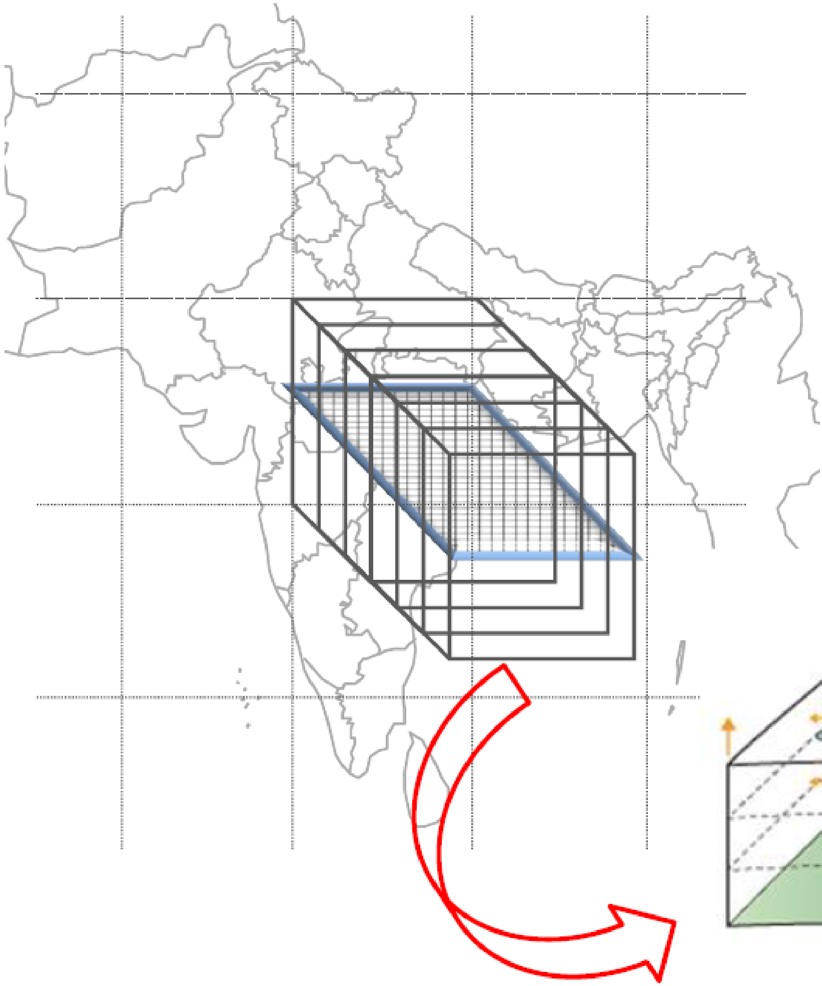
Seasonal (JJAS) averaged climatological mean **rainfall** (mm day^{-1}) **deviation from GPCP**



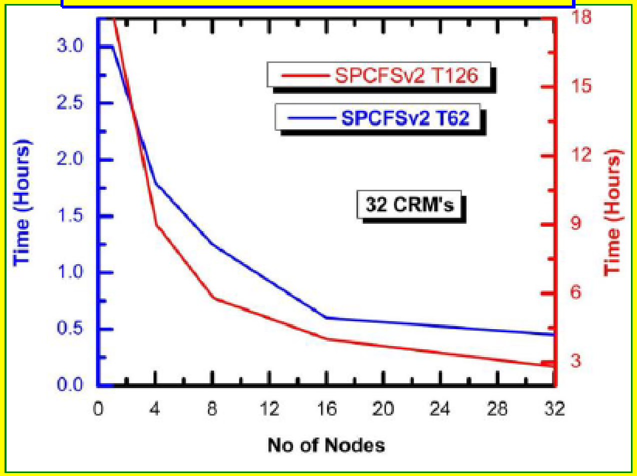
Seasonal (JJAS) averaged climatological mean **tropospheric temperature** (degree C) **deviation from NCEP**

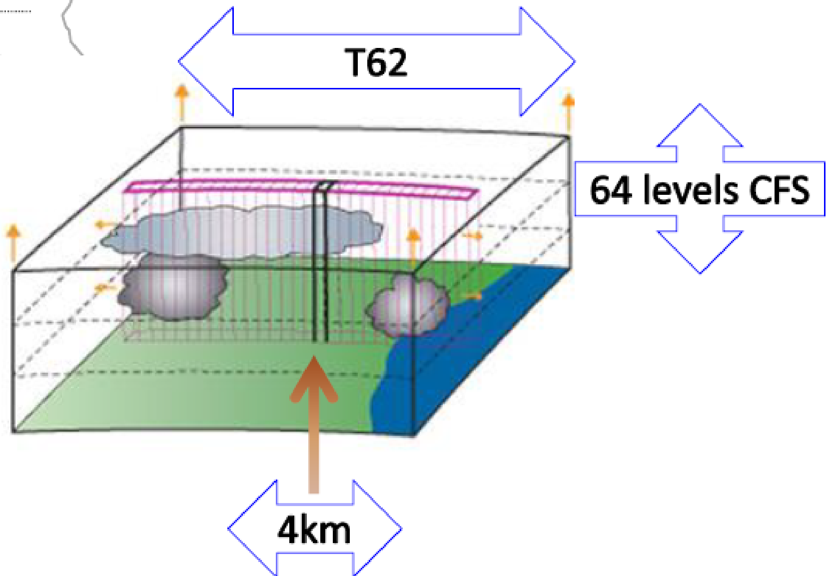
Saha et. al. 2013

Superparameterized CFSv2-T62 (SPCFS)



Scalability of SP-CFS

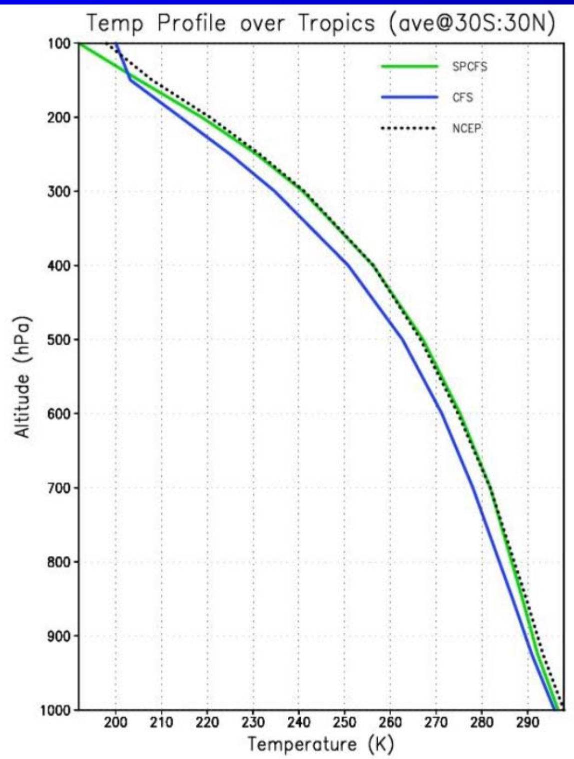




GFS-T764 on 16 nodes takes ~ 40-45 min

SPCFS-T62 on 16 nodes takes ~ 30 min, for 1 day simulation

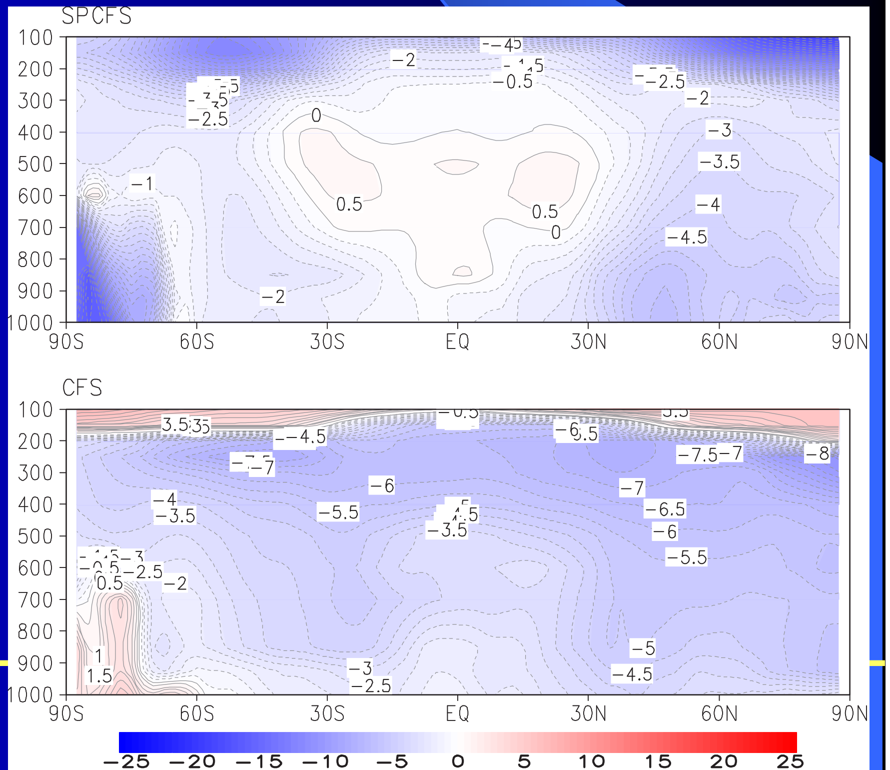
MAJOR BREAKTHROUGH-1



BLACK line is NCEP

GREEN line is SP-CFS

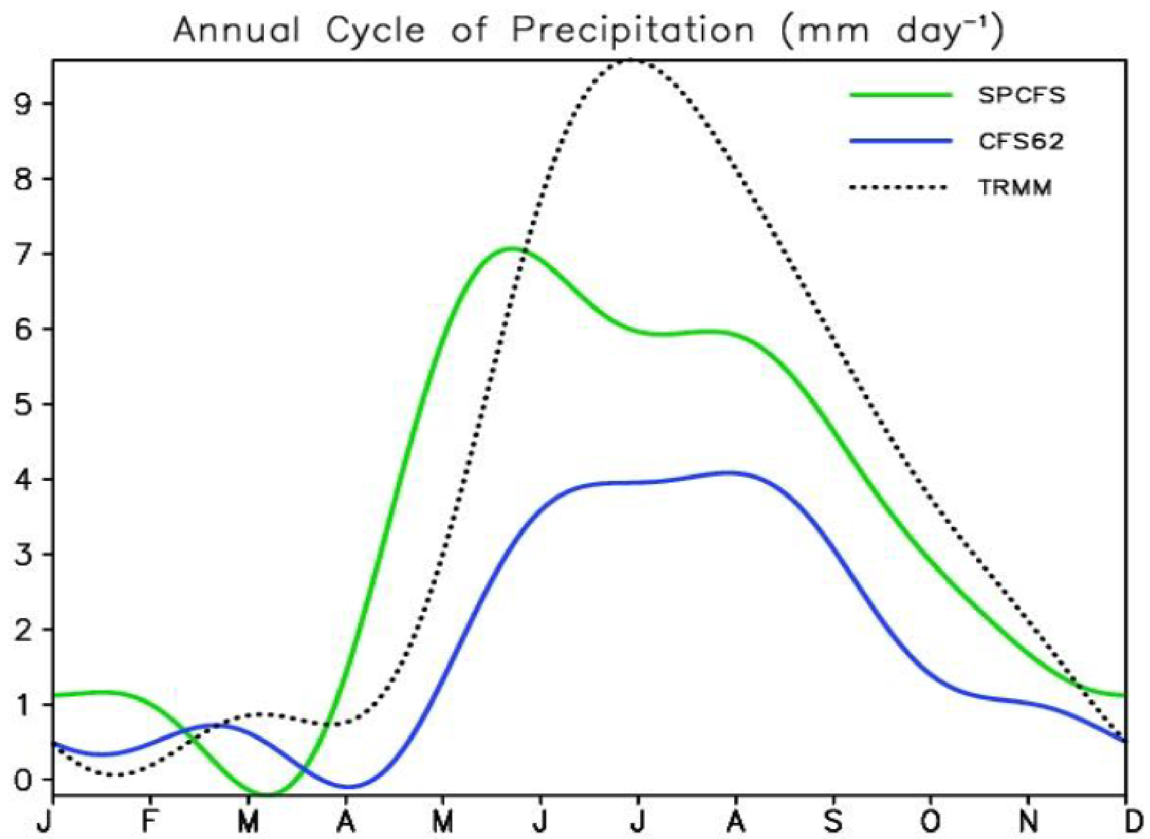
BLUE line is CFSv2-T62



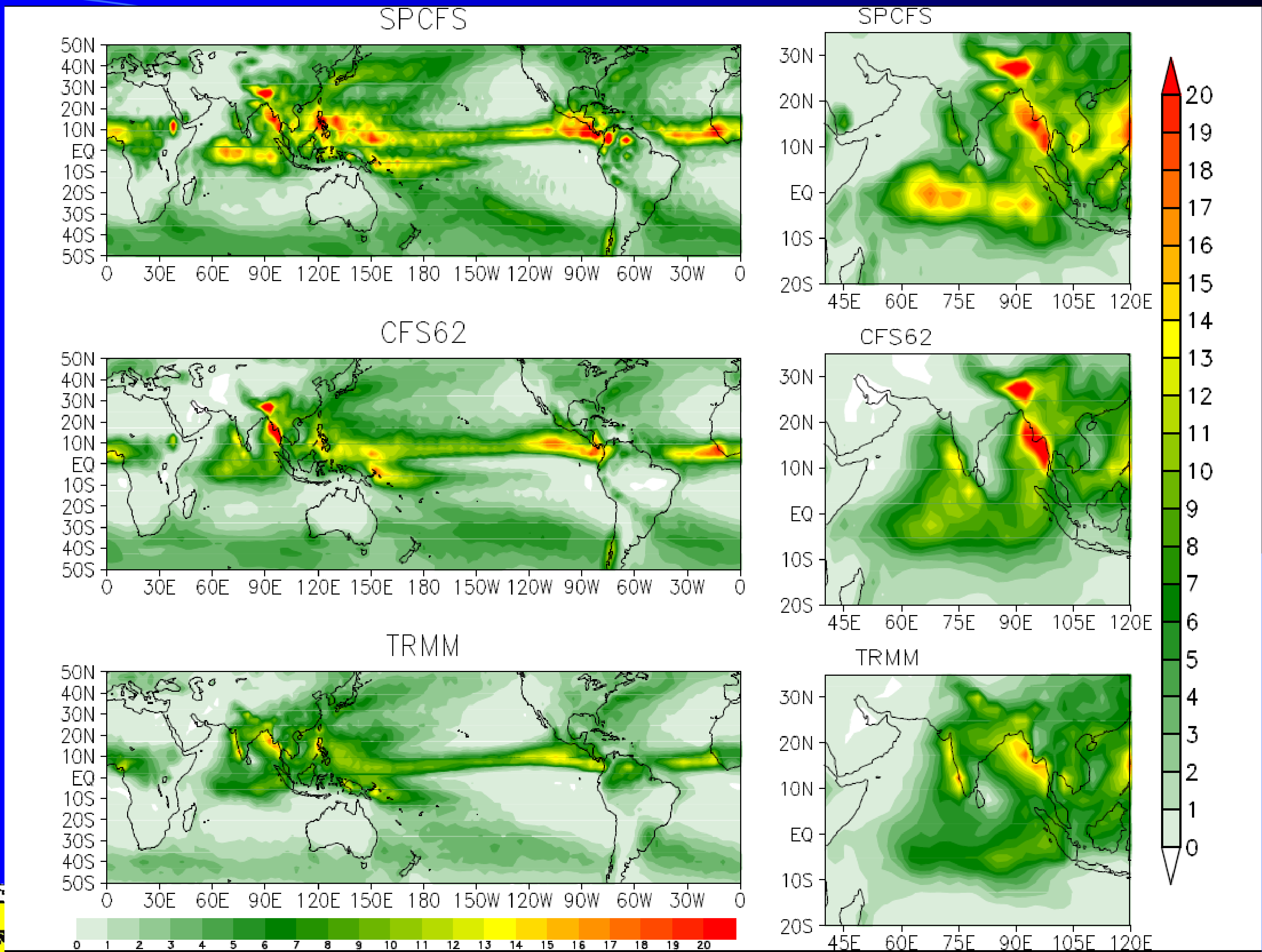
BLACK line is NCEP

GREEN line is SP-CFS

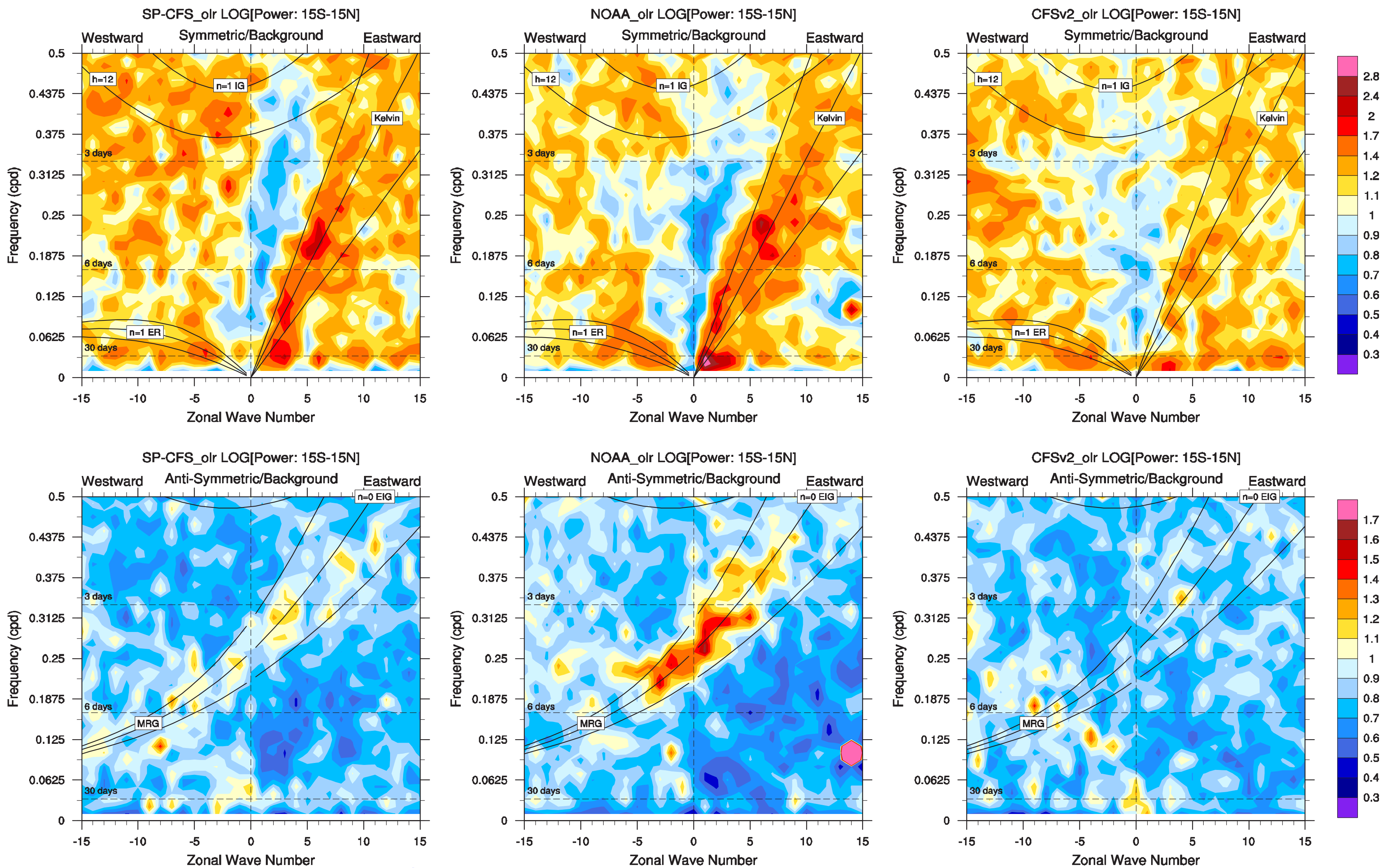
BLUE line is CFSv2-T62



- Winter wet bias is reduced significantly in SP-CFS_RAD
- However there are 2 peaks in the annual cycle.


SPCFS
CFS62
TRMM
50N 40N 30N 20N 10N EQ 10S 20S 30S 40S 50S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
30N 20N 10N EQ 10S 20S
45E 60E 75E 90E 105E 120E
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

The simulation of tropical waves improve significantly In SP-CFS

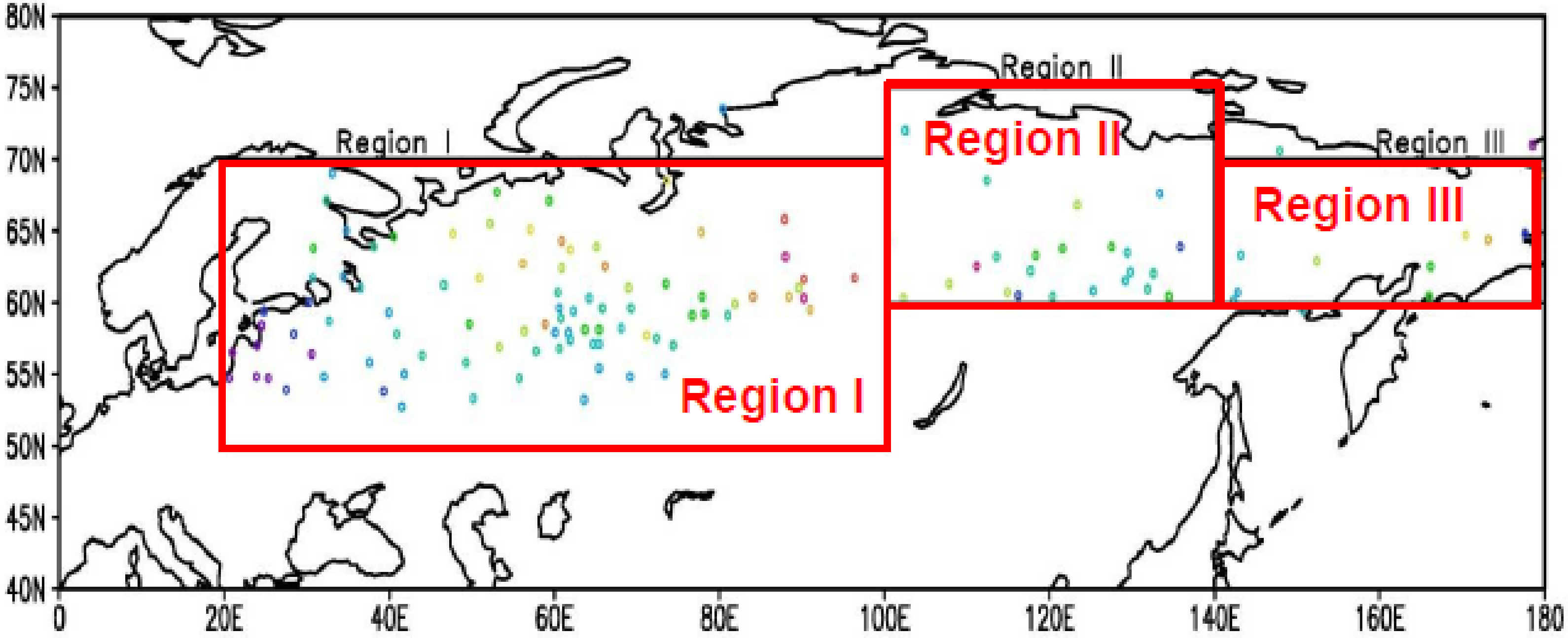


Space-time spectra of precipitation around the Eq. (15S-15N). (top) the symmetric component and (bot) antisymmetric component

Towards Improving NOAA LSM in CFSv.2

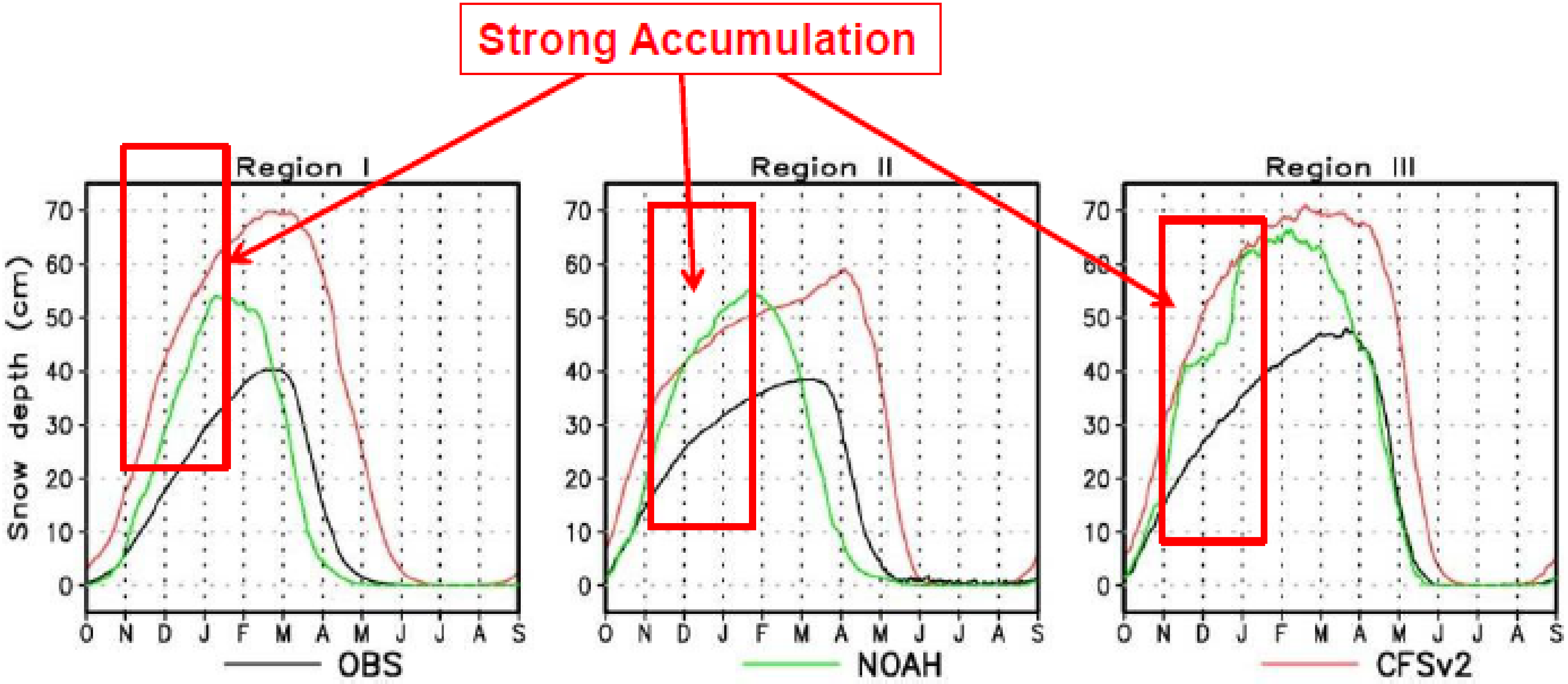
Saha et al. 2014

Observed Snow Data



- Snow from Historical Soviet Daily Snow Depth data (observed stations).
- The Eurasia is divided to 3 regions and they are
  - -> Region I (50-70N,20-100E, high snow depth, 129 stations)
  - -> Region II (60-75N,100-140E, low snow depth, 24 stations)
  - -> Region III (60-70N,140-180E , high snow depth, 10 stations)

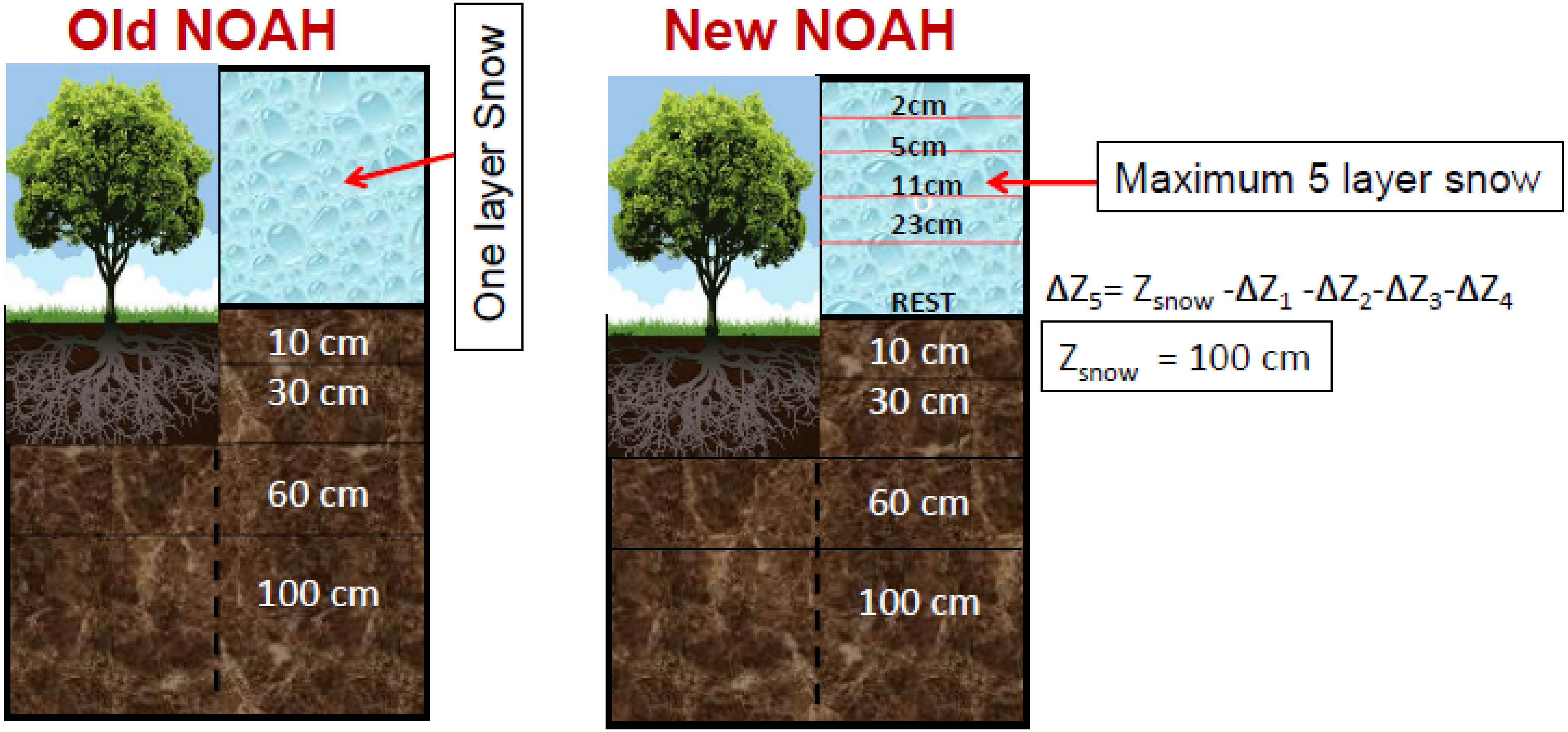
Observed & Simulated Snow Depth



➢ CFS as well as stand-alone Noah LSM has tendency to accumulate more snow

➢ As the stand-alone LSM is forced with observed 2m air temperature, melting is controlled by forcing and hence it is close to observation

Development of Snow Physics in NOAH LSM

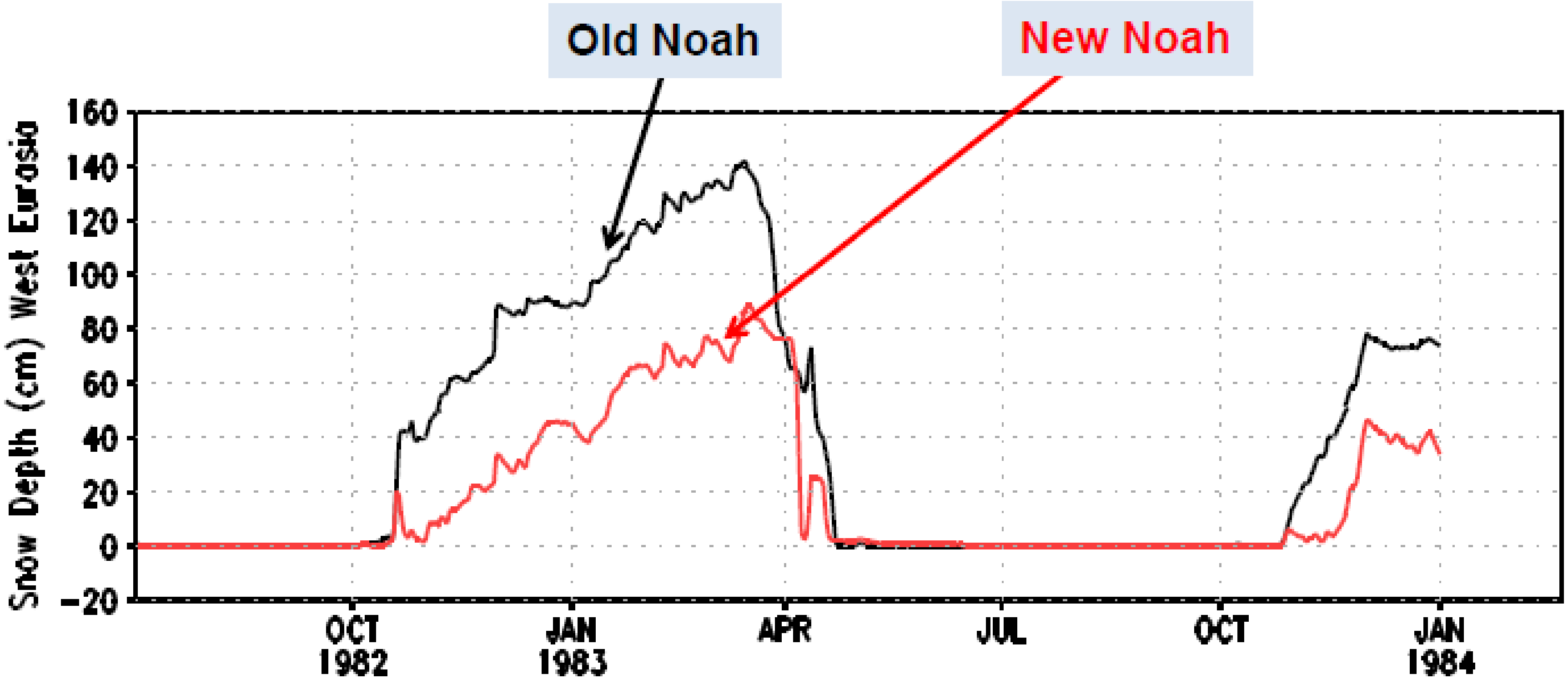


Net energy at surface is given by

$$FNET_{surf} = (1-\alpha)S\downarrow + L\downarrow - \sigma T_s^4 - G - H - LH$$

Where α is albedo, $S\downarrow$ is downward shortwave, $L\downarrow$ is downward longwave, σT_s^4 is longwave emitted, G is ground heat flux, H is sensible heat flux, LH is latent heat flux.

Preliminary Result from Stand-Alone Noah LSM



- New snow scheme shows reduction in winter/spring snow depth as compared to the old scheme
- Modified stand-alone model needs to validate extensively (ongoing)
- Modified LSM needs to put in CFS for further testing (ongoing)

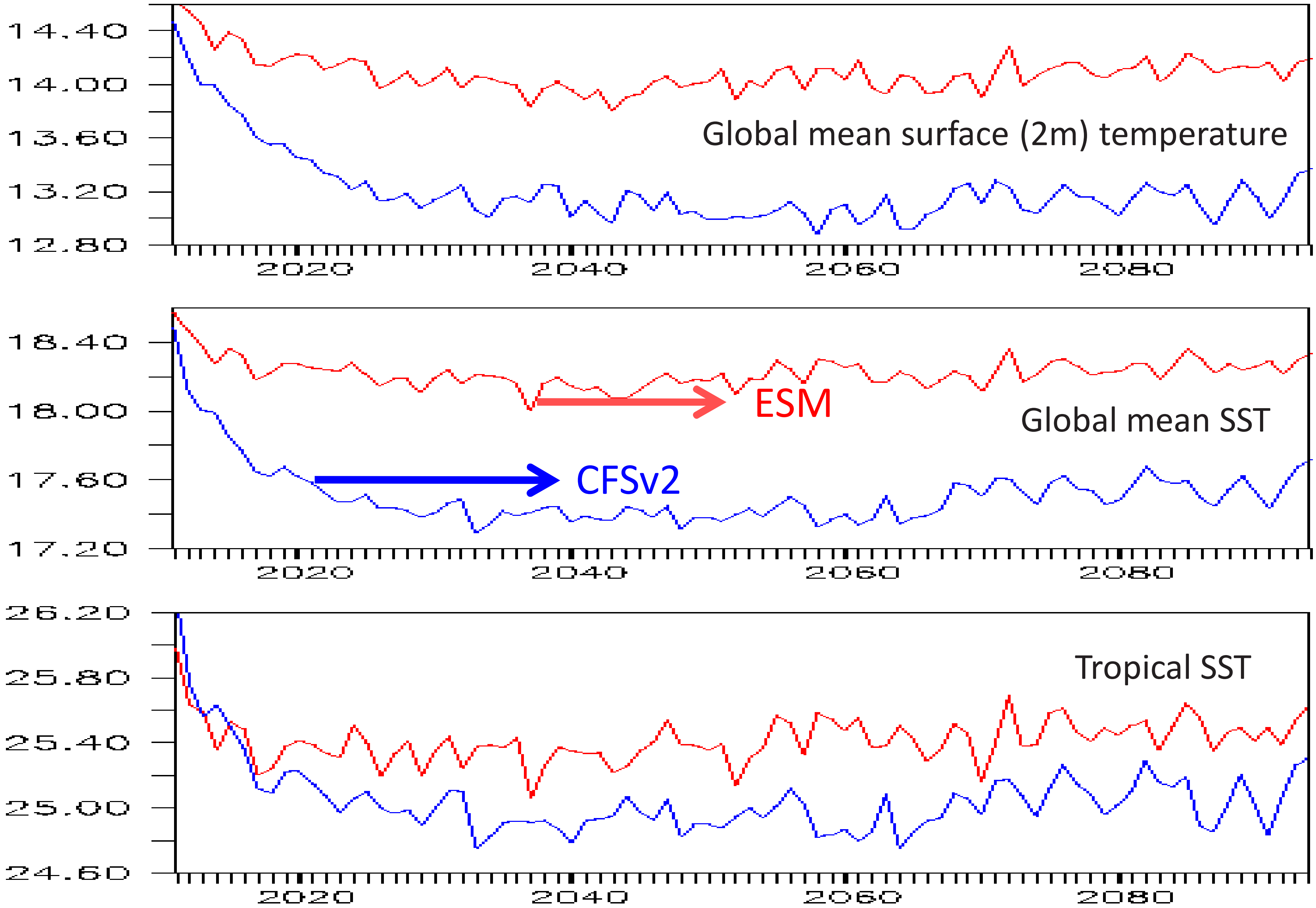
In House Developments - IV

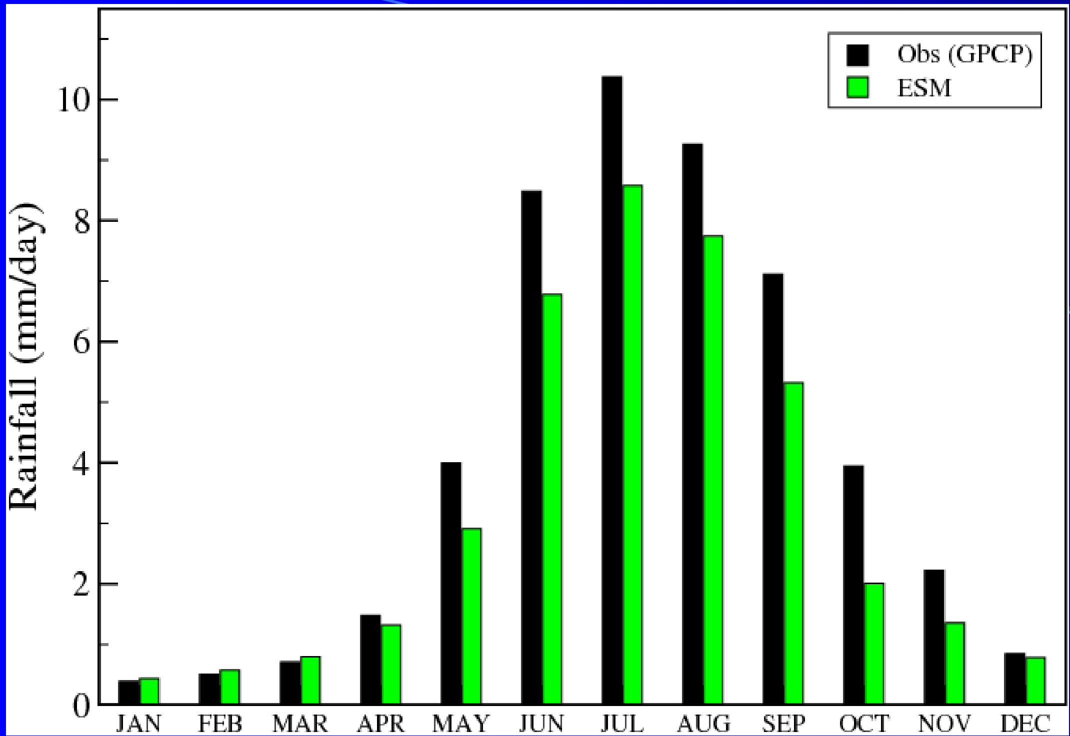
An Indian Coupled Ocean-Atmosphere Model Developed

In a land-mark development, the CCCR at IITM has developed a new indigenous Coupled Ocean Atmosphere model and integrated it for more than 100 years simulating the observed mean climate and its variability. This has put India in the league of advanced climate modeling countries of the world. The model will be very useful for attribution and projection of monsoon in the warming world.

(Krishnan, Ashok, Swapna, Roxy et al. 2014)

Annual mean temperature



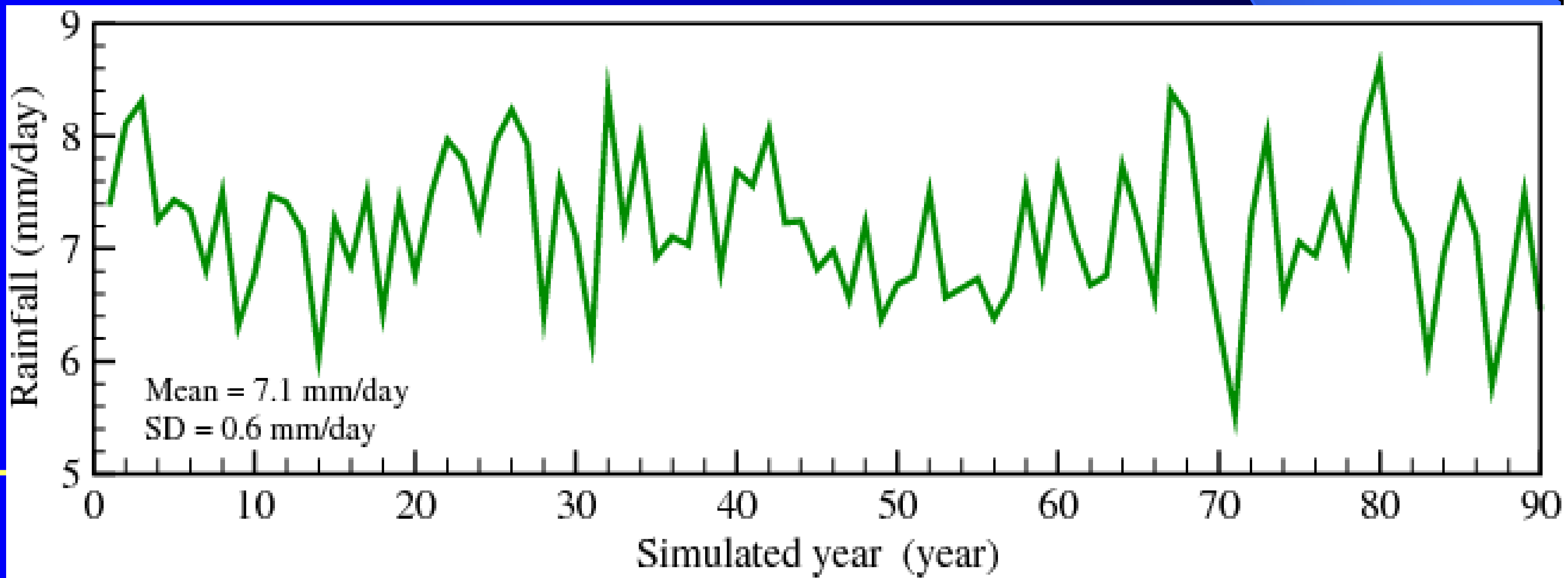


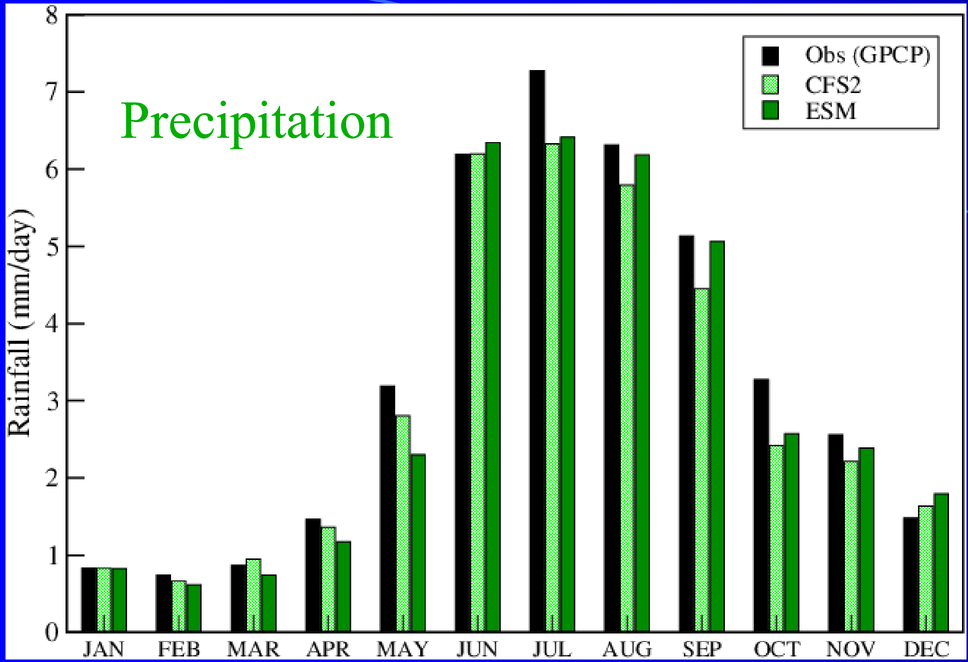
Precipitation

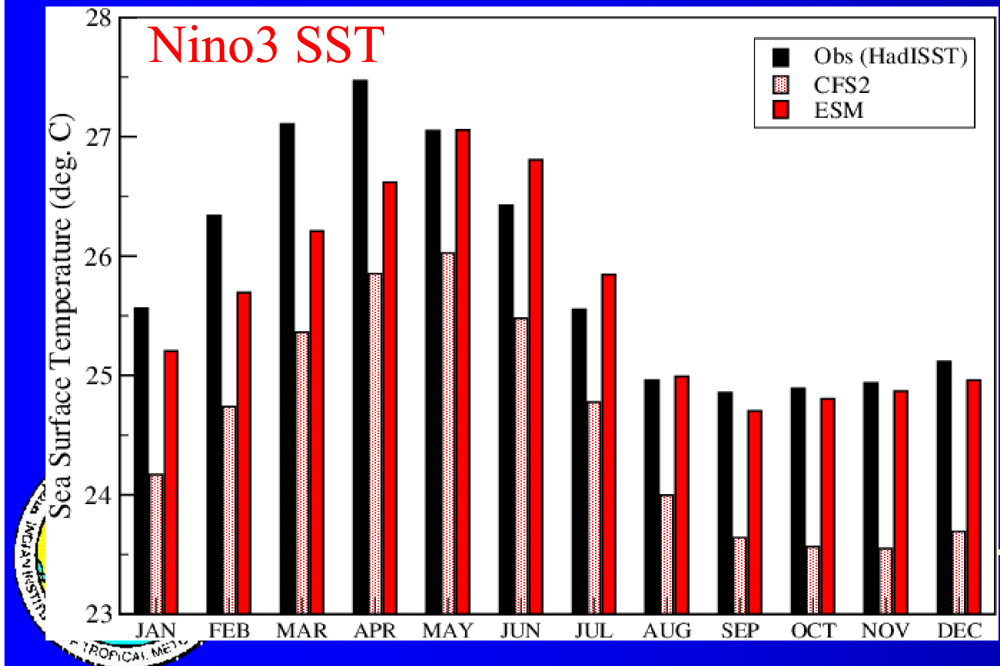
(10N-30N; 70E-100E)

Indian (land +Ocean)

The Model simulates Annual Cycle of monsoon precipitation well (left) as well as the amplitude of interannual variability (below).





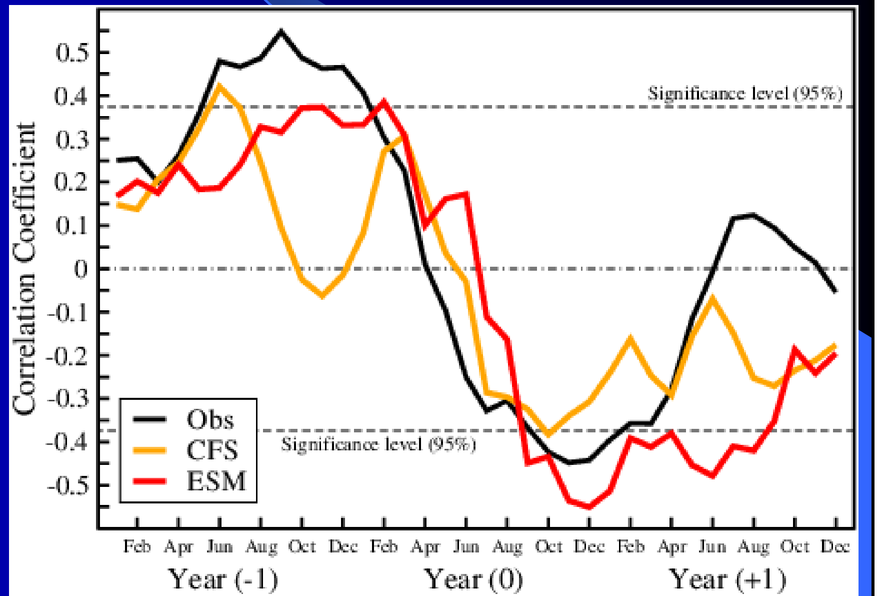


Precipitation

(5N-35N; 65E-95E)

Indian (land + ocean)

ENSO-Monsoon relationship

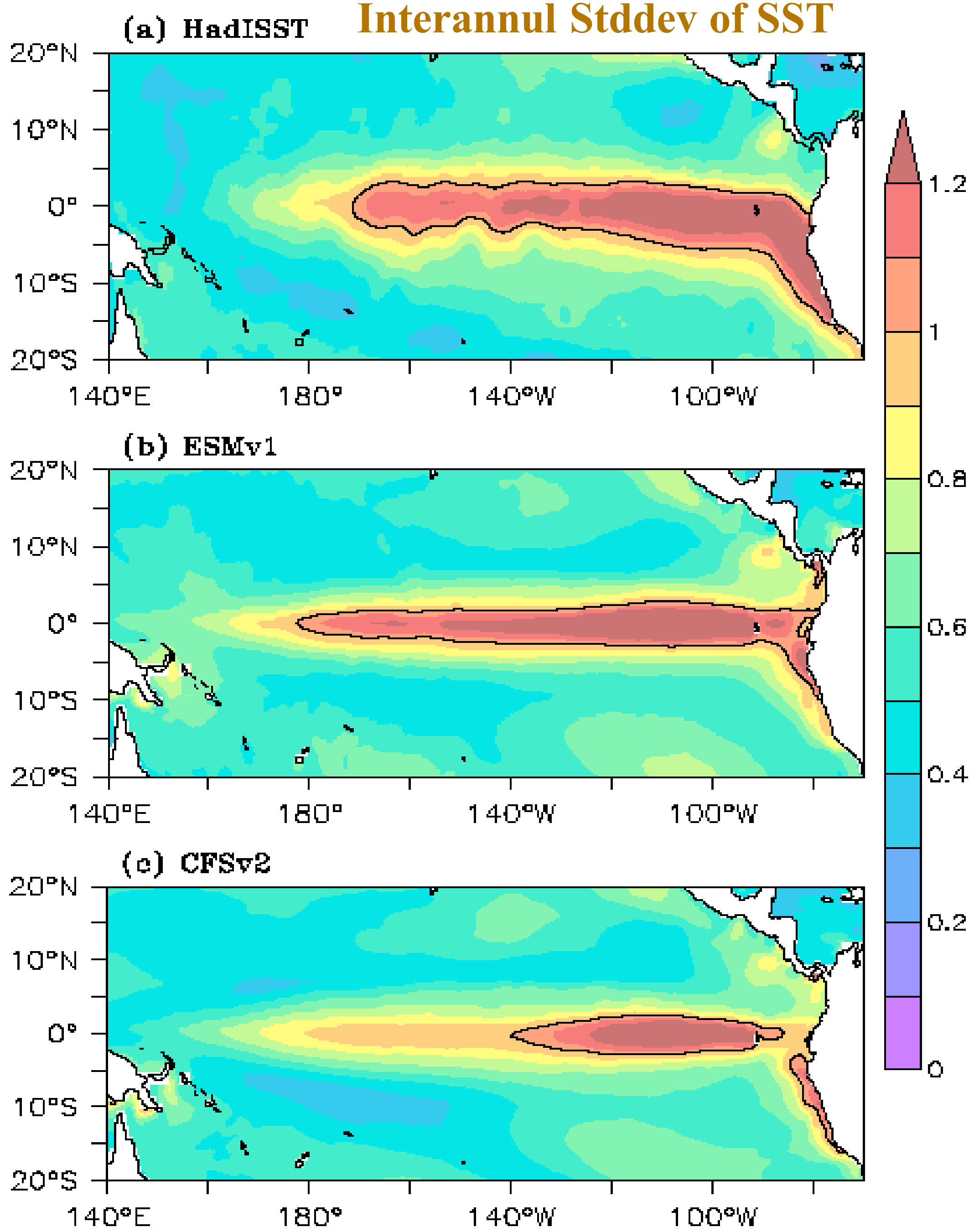


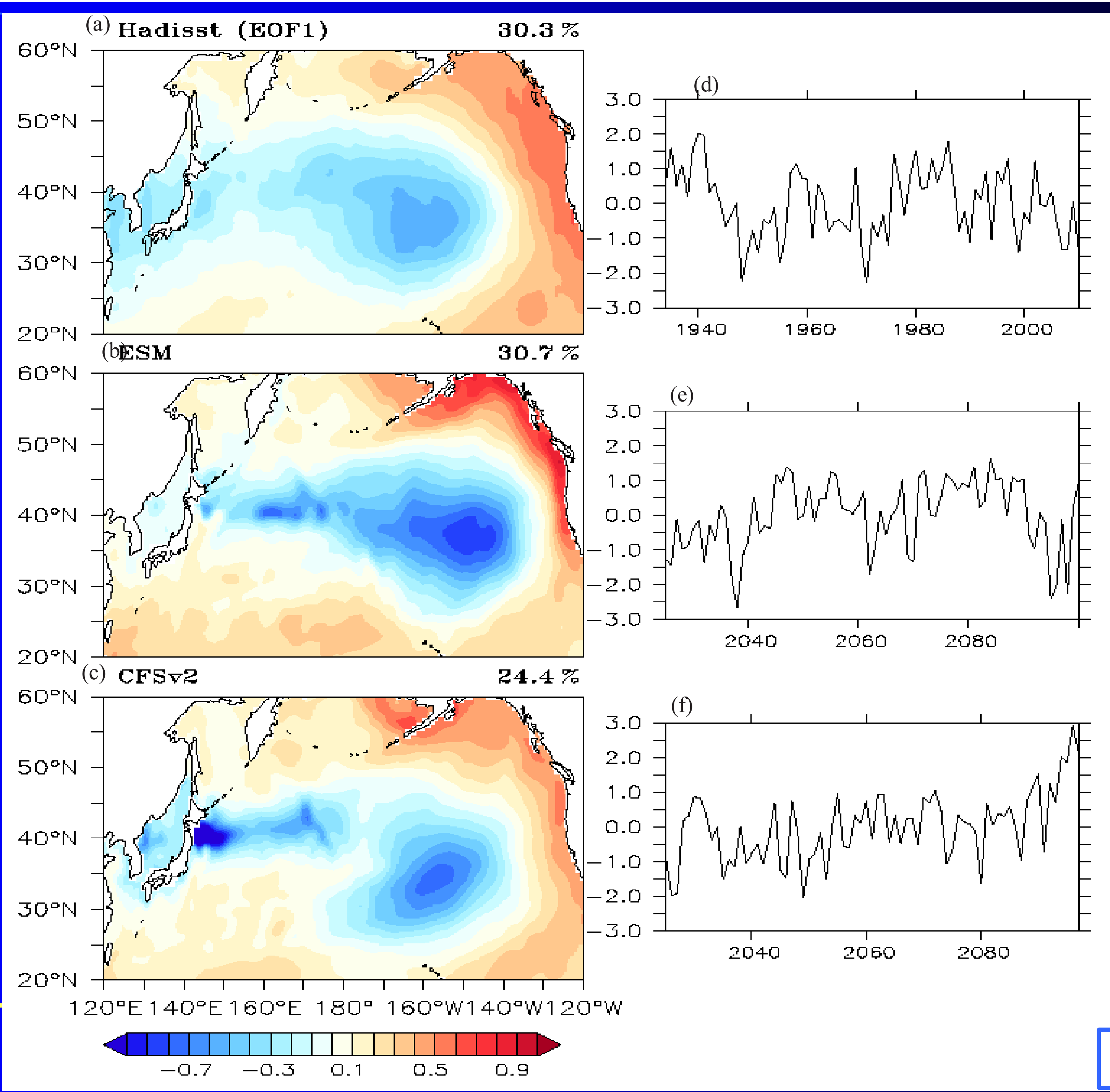
Lagged correlation between ISMR and Nino3 SST in the preceding/following months

CFS2 : 30 years (yr17-yr46)

ESM : 30 years (yr17-yr46)

Interannul Stddev of SST





(a) Hadisst (EOF1) 30.3 %
(b) ESM 30.7 %
(c) CFSv2 24.4 %
60°N
50°N
40°N
30°N
20°N
120°E 140°E 160°E 180° 160°W 140°W 120°W
−0.7 −0.3 0.1 0.5 0.9
(d)
(e)
(f)
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
1940 1960 1980 2000
2040 2060 2080

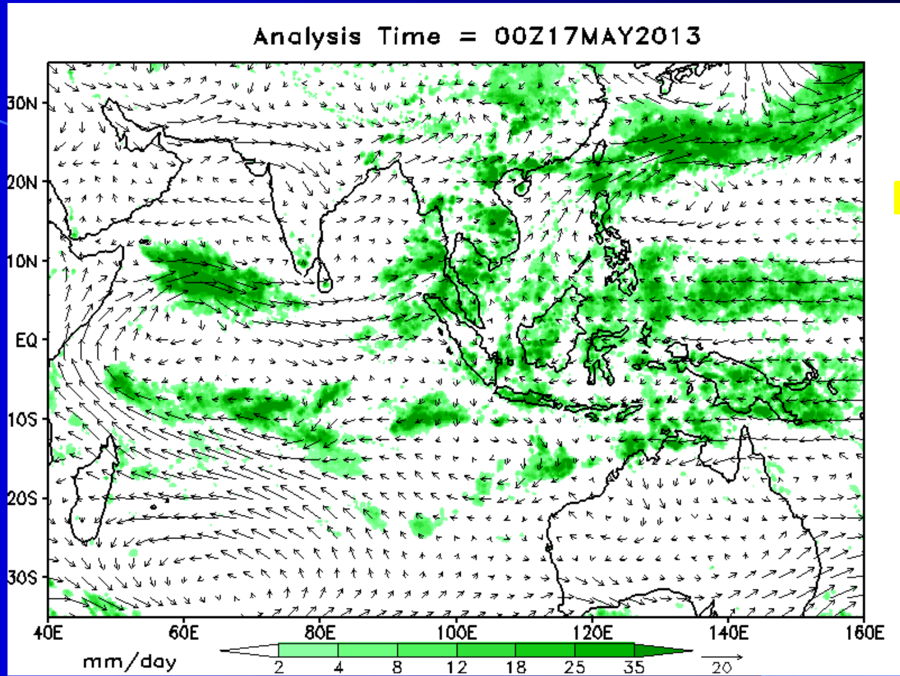
Figure 12

Thank You

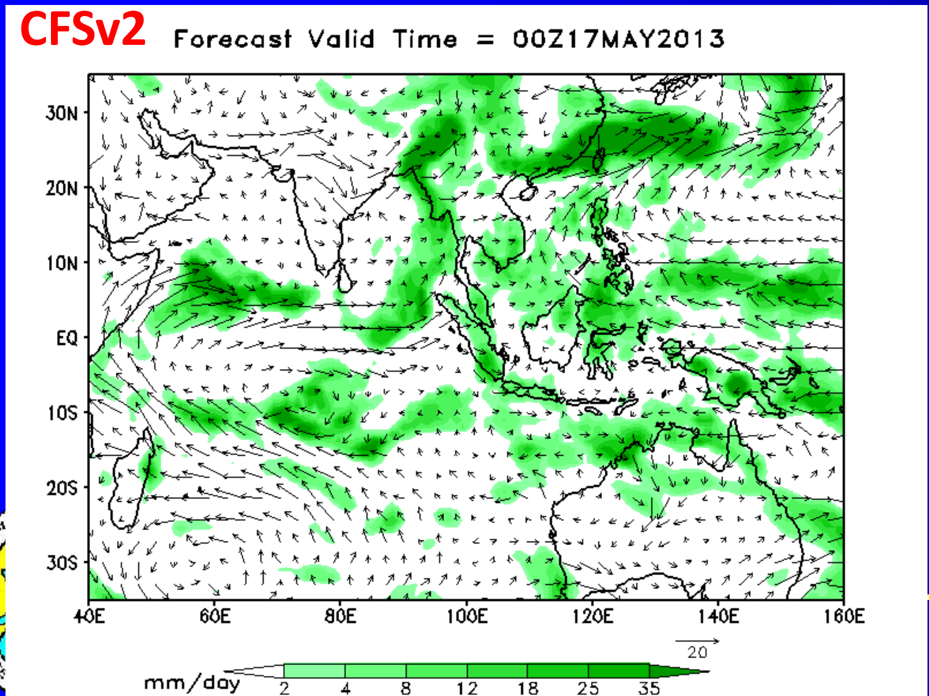
For your attention

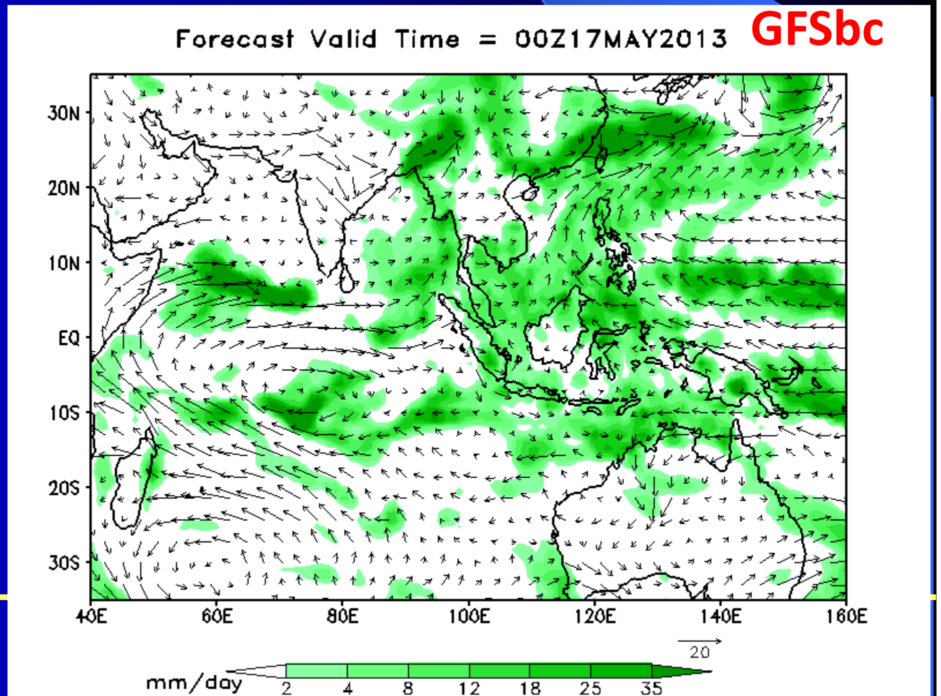
Onset was well-predicted from 16 May IC

Wind (850hPa) and Rainfall



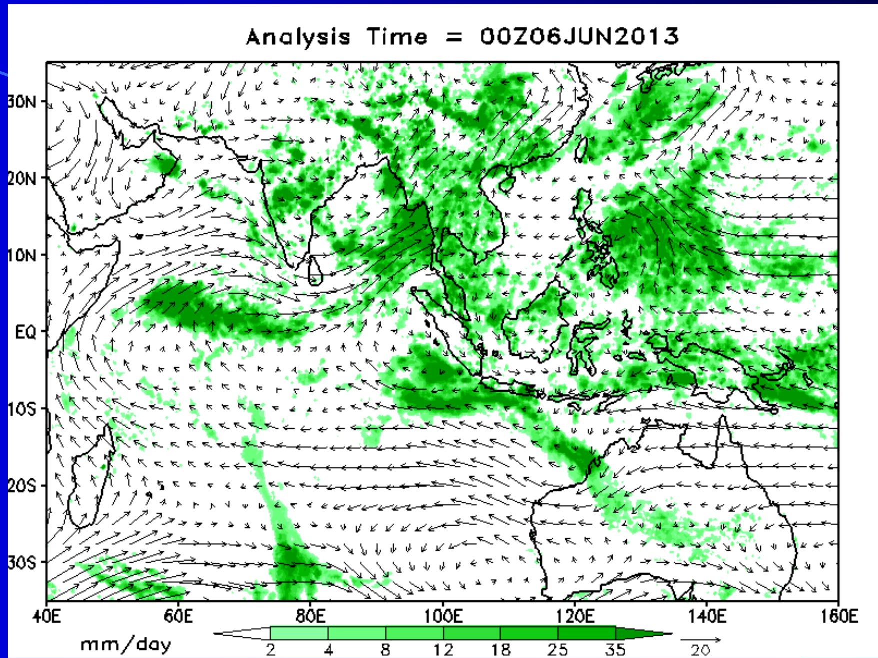
NCEP/TRMM Analysis





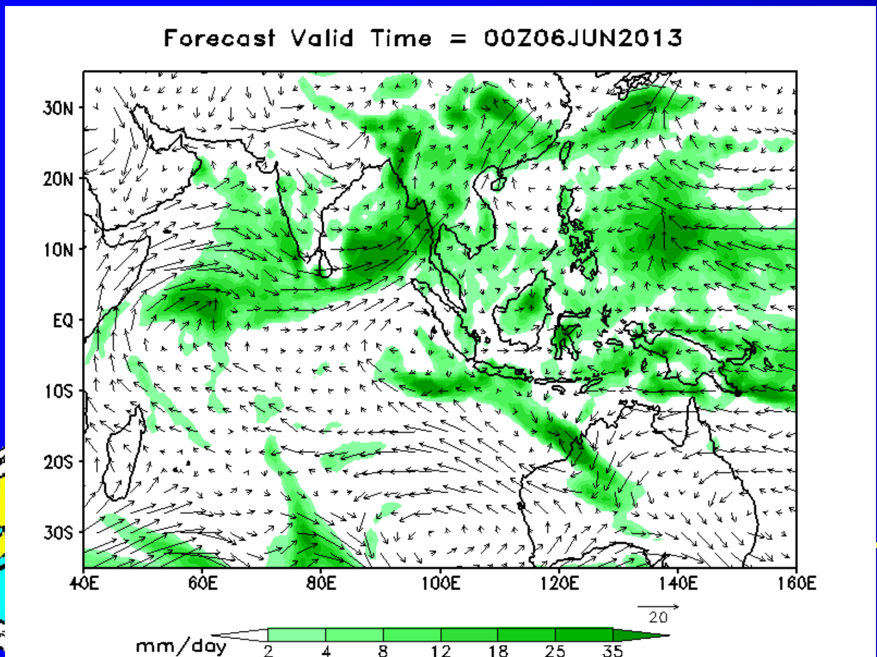
Rapid advancement of monsoon was well-predicted from 5 Jun IC

NCEP/TRMM Analysis

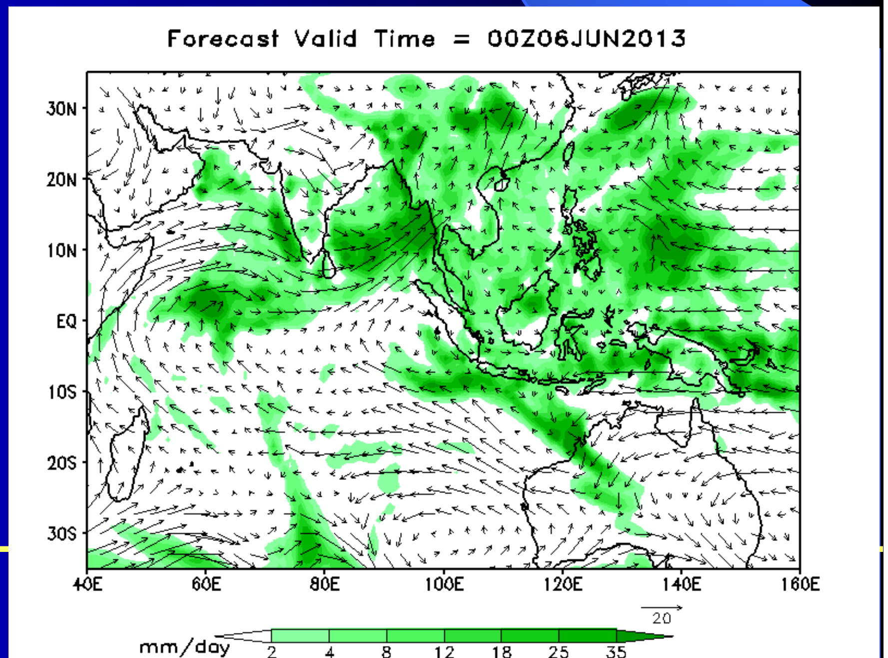


Wind (850hPa) and Rainfall

CFSv2



GFSbc



Uttarakhand Heavy Rainfall event is captured 10-12 days in advance from 05 June Initial Condition