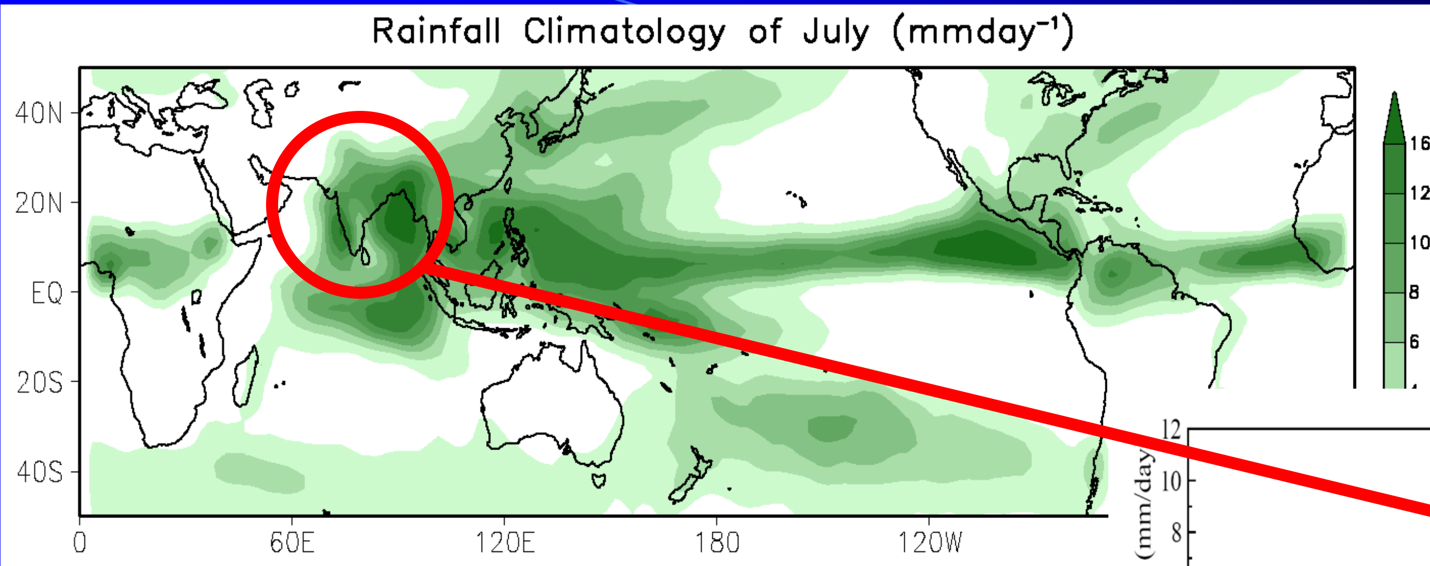
Scaling the Potential Predictability Barrier of the Indian Summer Monsoon Rainfall: An Indian Initiative

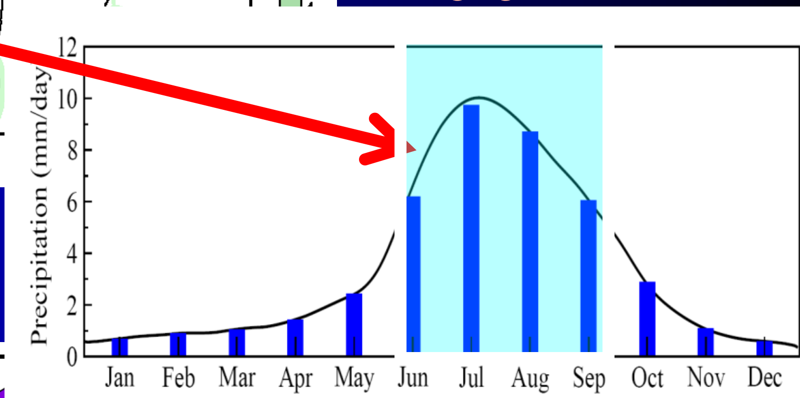
B N Goswami

Indian Institute of Tropical Meteorology, Pune

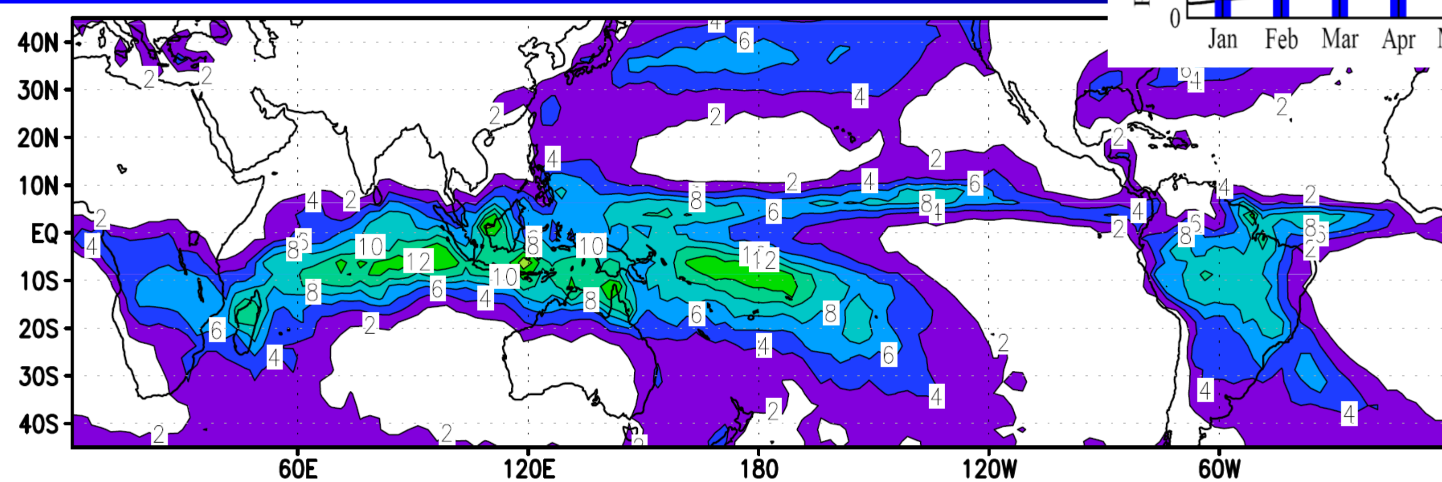
C4-SAFAR, 1-3 May, 2013, IITM, Pune

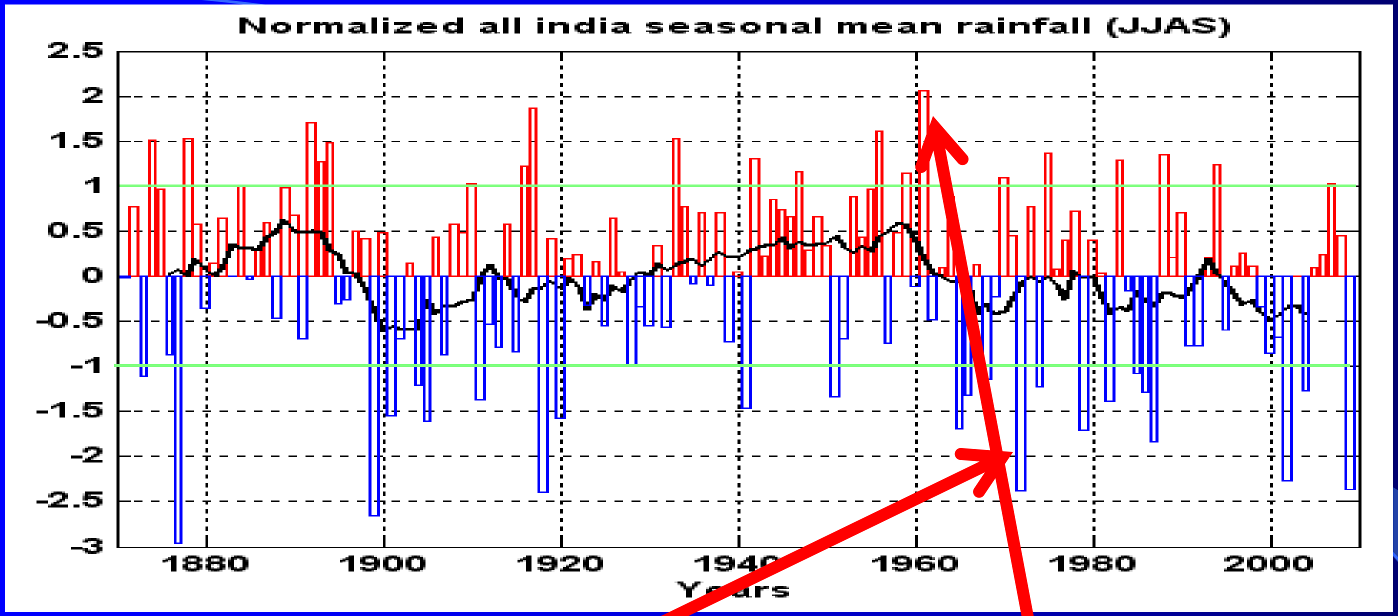


Indian Monsoon



Rainfall climatology of Jan (mm/day)





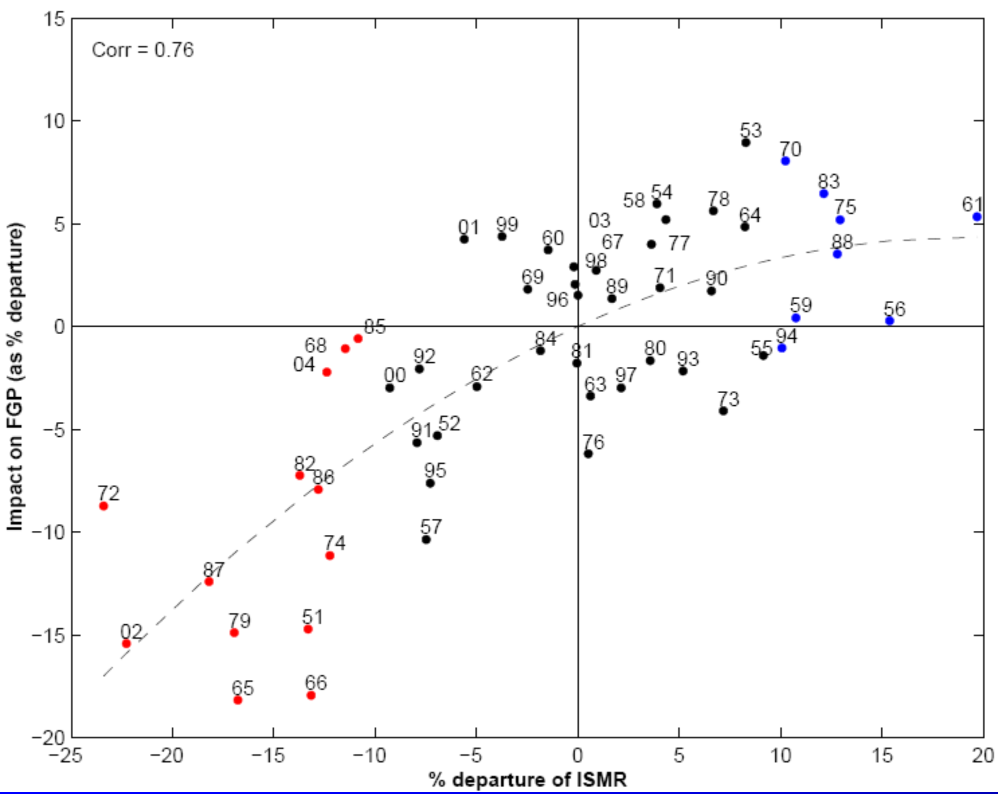
JJAS Mean ~ 90 cm

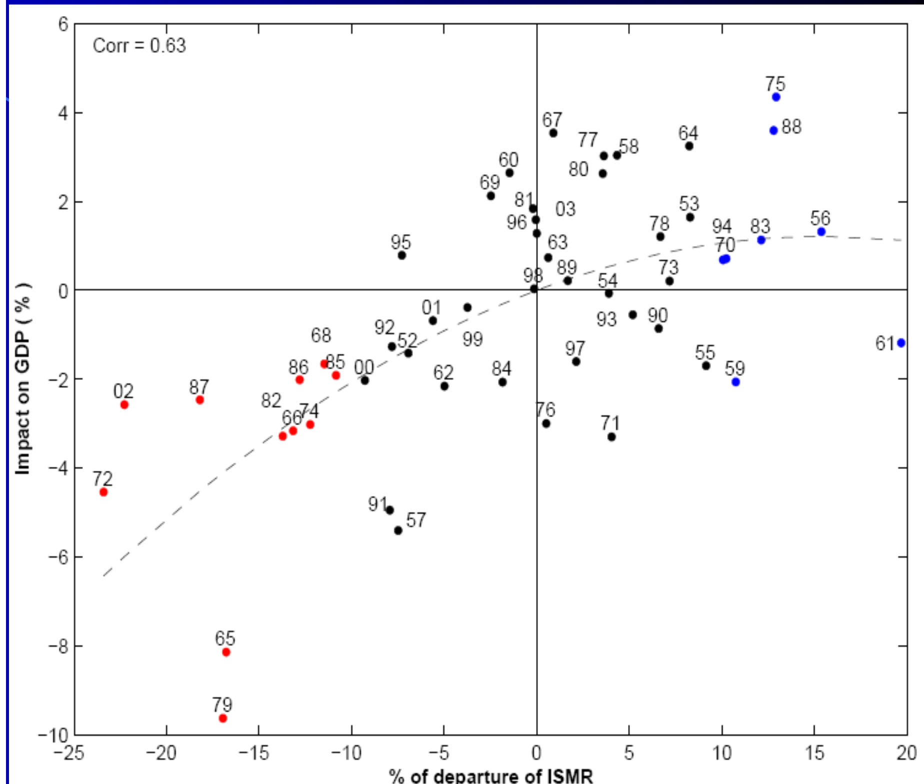
S.D. ~ 9 cm

Drought

Flood

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



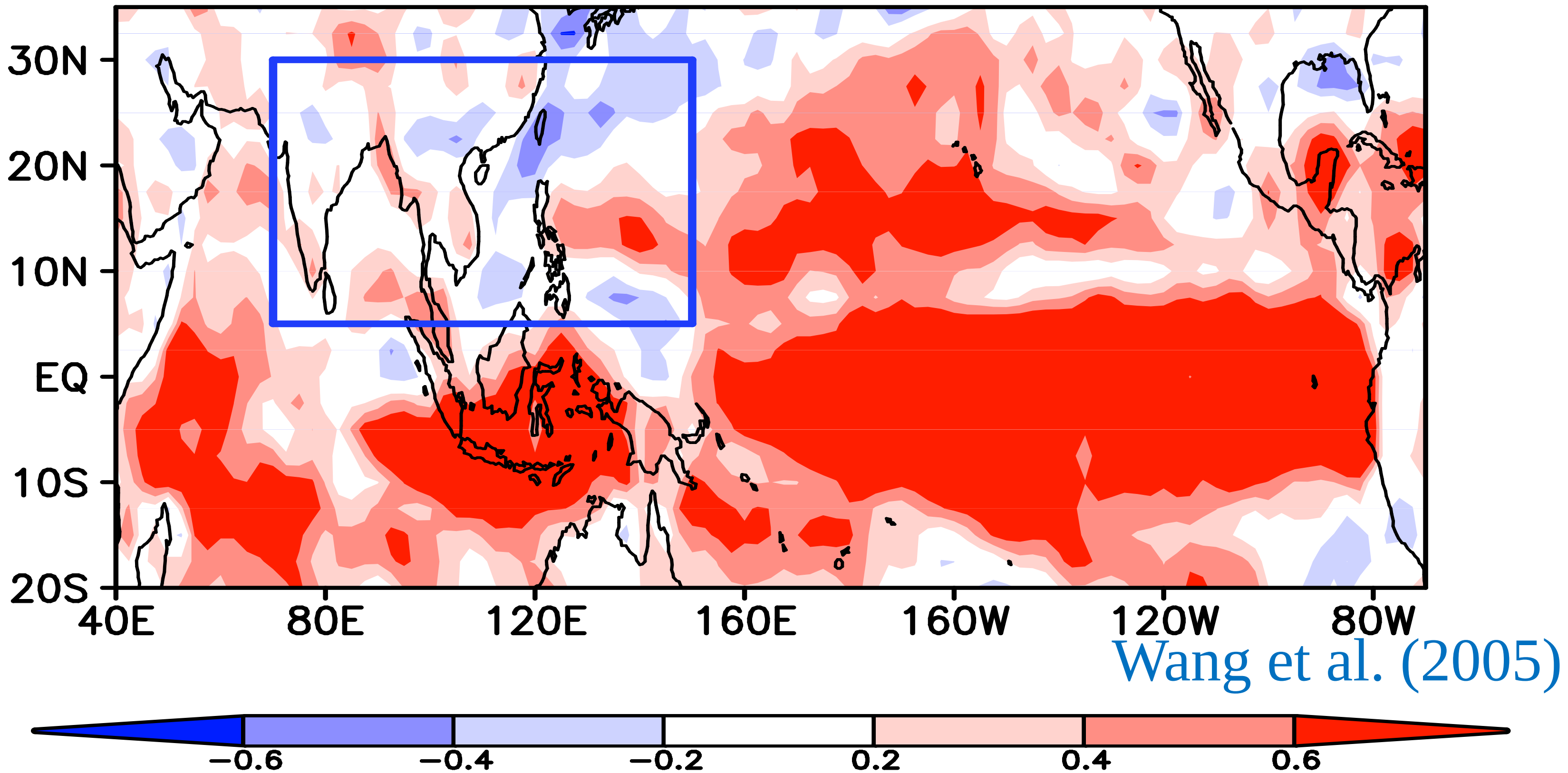


Variation of the impact on foodgrain production ; drought and excess rainfall years are red and blue respectively.

Variation of the impact on GDP with the monsoon rainfall anomaly; drought and excess rainfall years are red and blue respectively.

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.



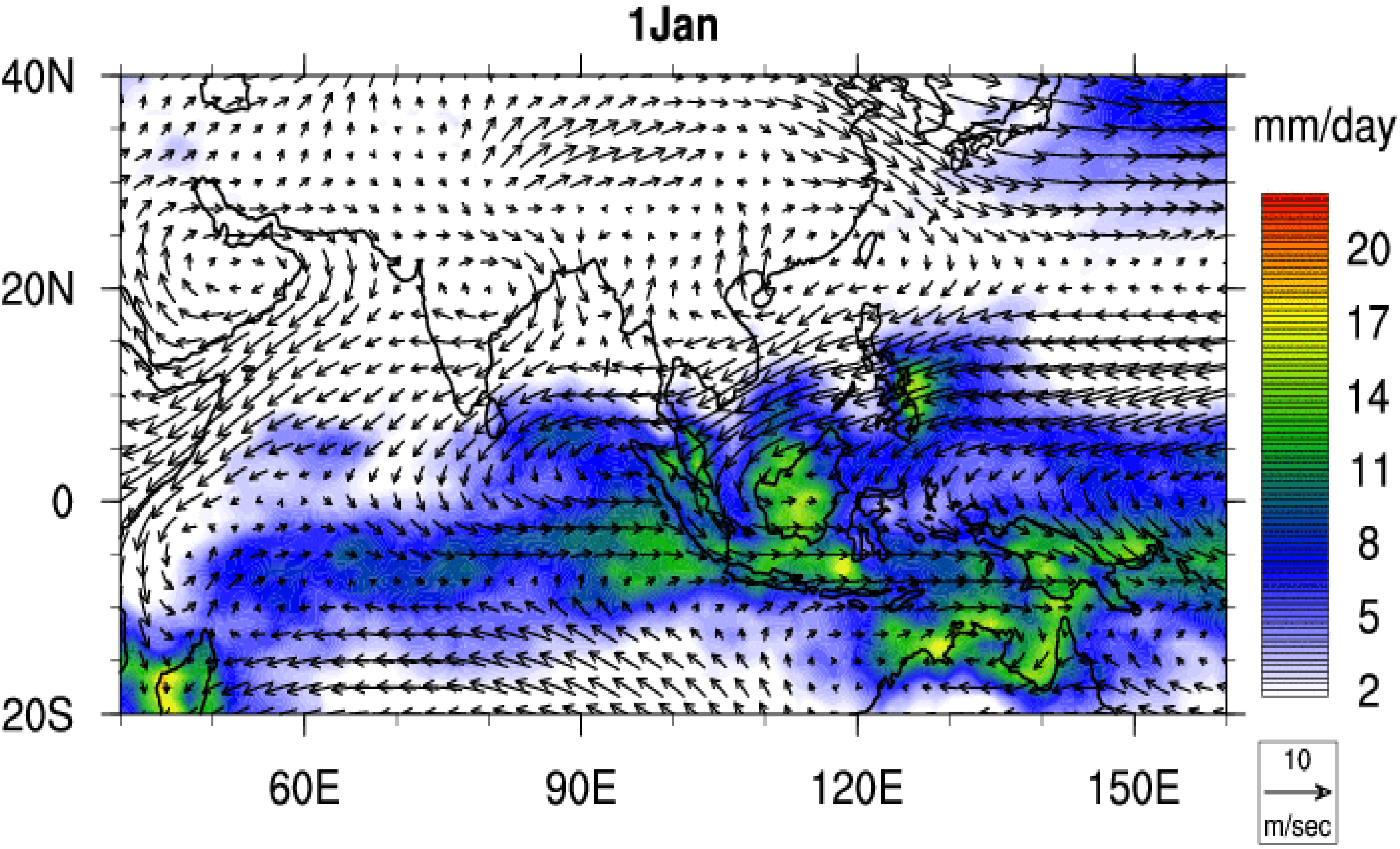
CC between the observed and MME hindcast of June-August precipitations (1979-1999)

Outline

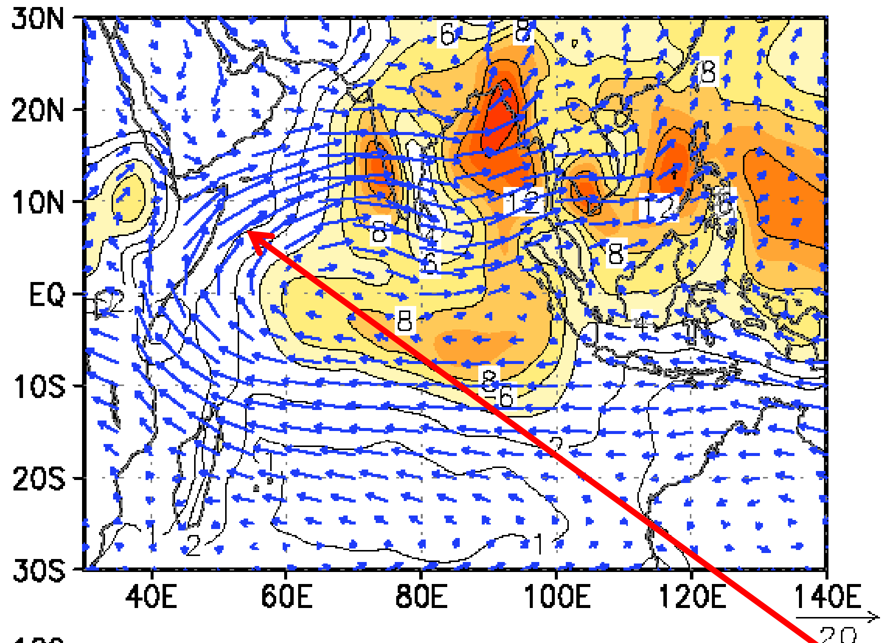
- ❖An Introduction to the Indian Summer Monsoon (ISM)
- ❖Why is predicting the ISM a Grand Challenge ?
- ❖Potential Predictability: Climate Noise- a Game spoiler
- ❖Origin of Climate Noise : Leading Role of Monsoon Intra-Seasonal Oscillations (MISO)
- ❖The Monsoon Mission : Attempt to scale the potential predictability barrier!

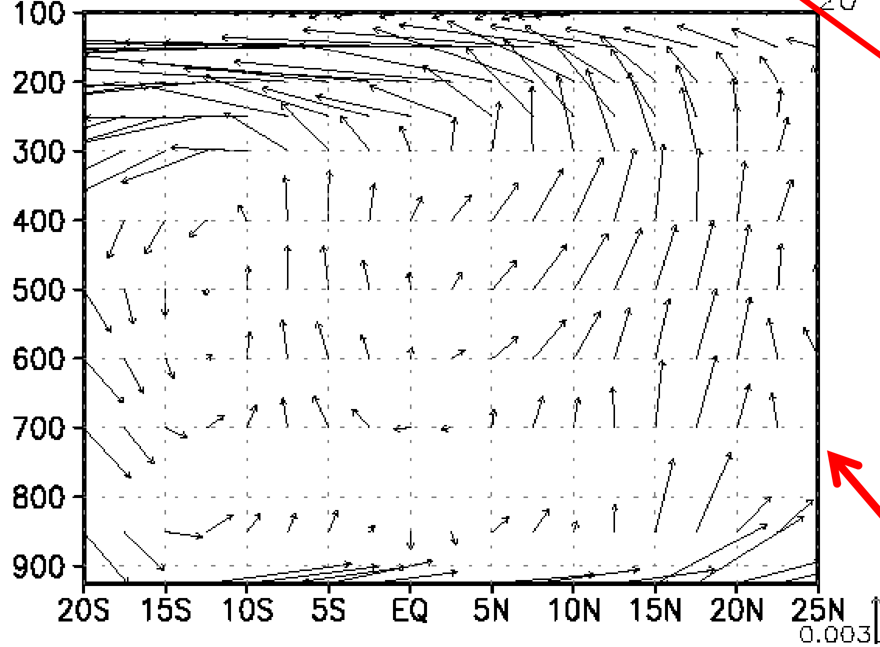
The Indian Summer Monsoon?

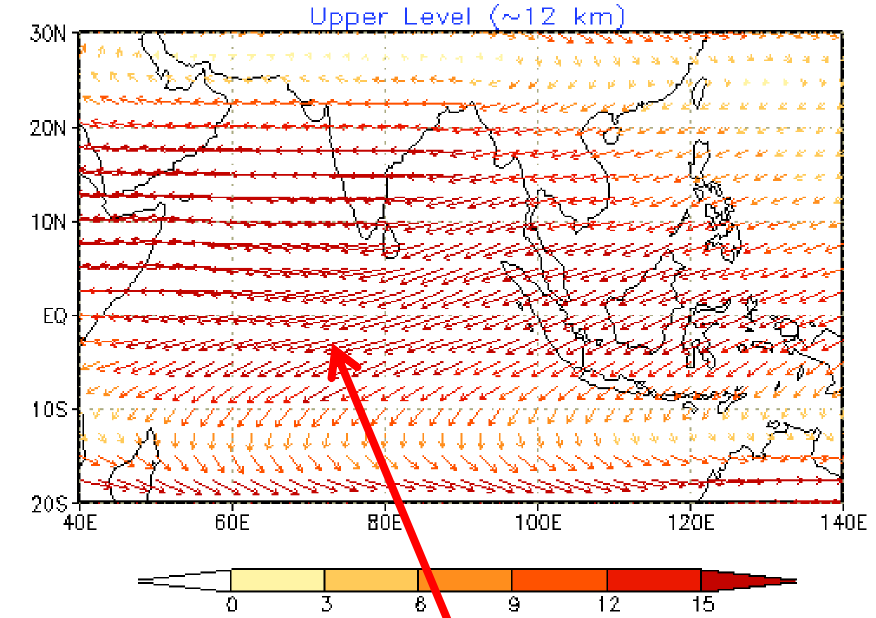
A manifestation of seasonal northward migration of the Rain Band or Tropical Convergence Zone (TCZ)



Annual evolution of Daily mean winds at 850 hPa and Precipitation (shaded)







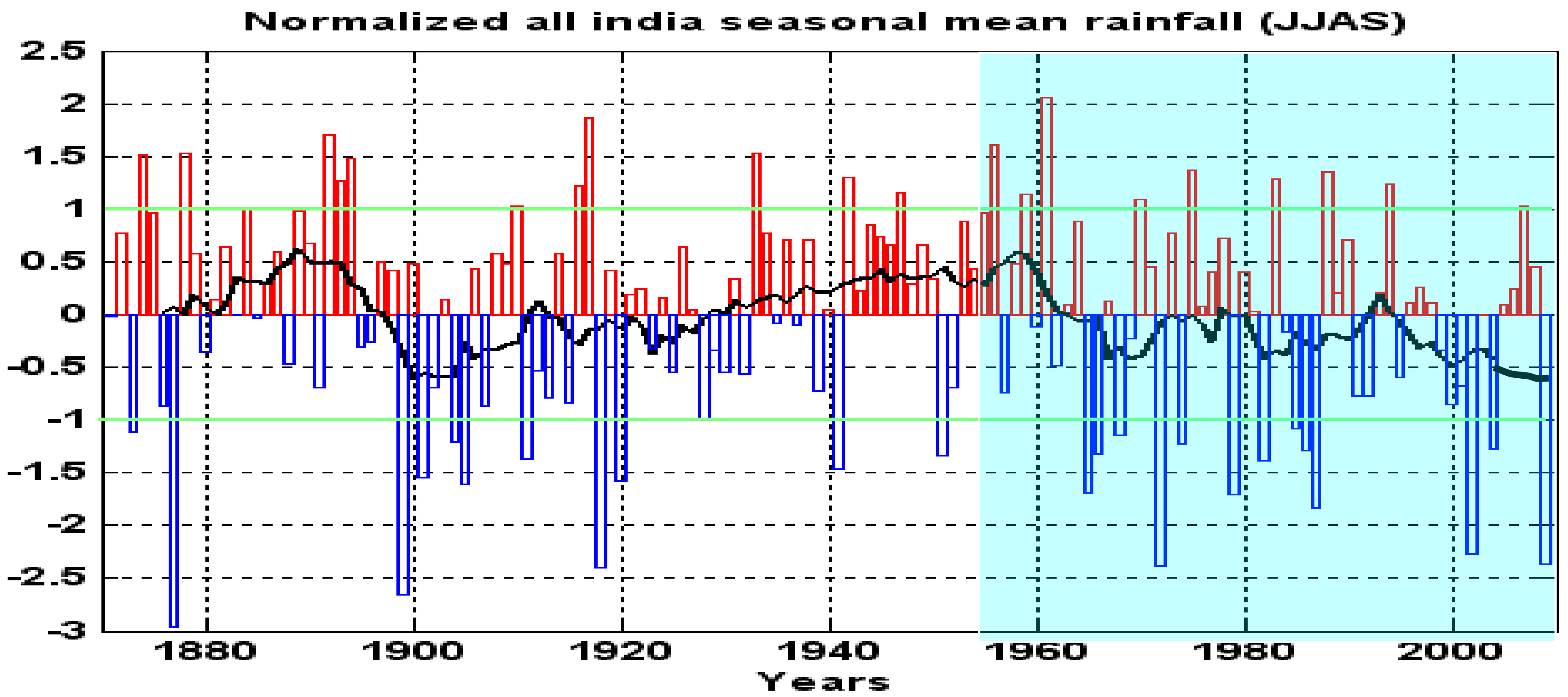
Low level, cross-equatorial flow, south-westerlies, Westerly Jet.

Upper level easterlies, Monsoon Easterly Jet

Meridional circulation over Indian monsoon region : Deep vertical structure

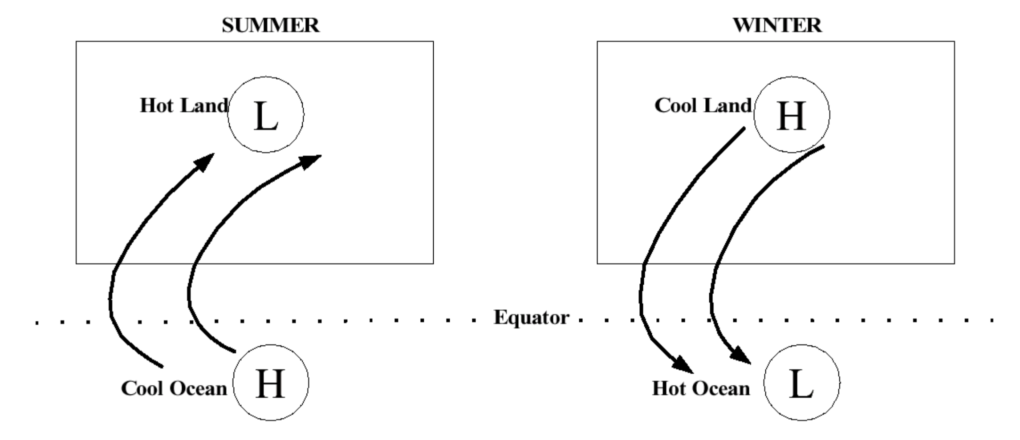
Normalized JJAS All India Rainfall (AIR)

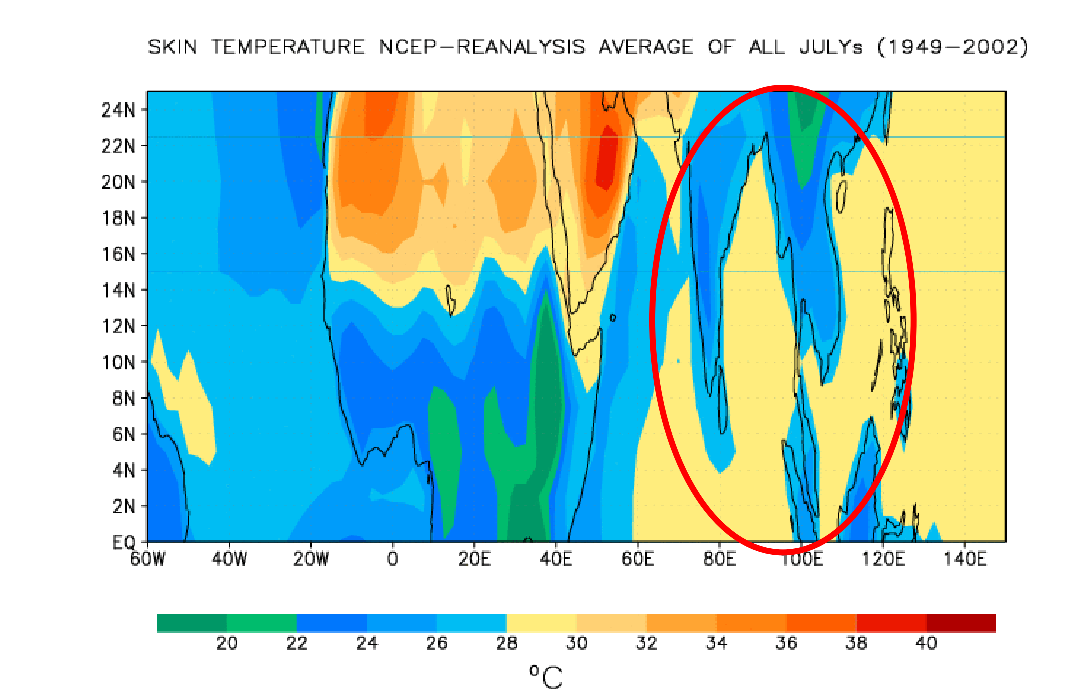
Mean : 86 cm; S.D. : 8.5 cm



- ❑No long term increasing trend
- ❑50-80 year multi-decadal variability
- ❑Decreasing trend in the last 5 decades!

Classical model of monsoon: Large land-sea Breeze is inadequate to explain the sustenance and vertical structure of Indian monsoon!





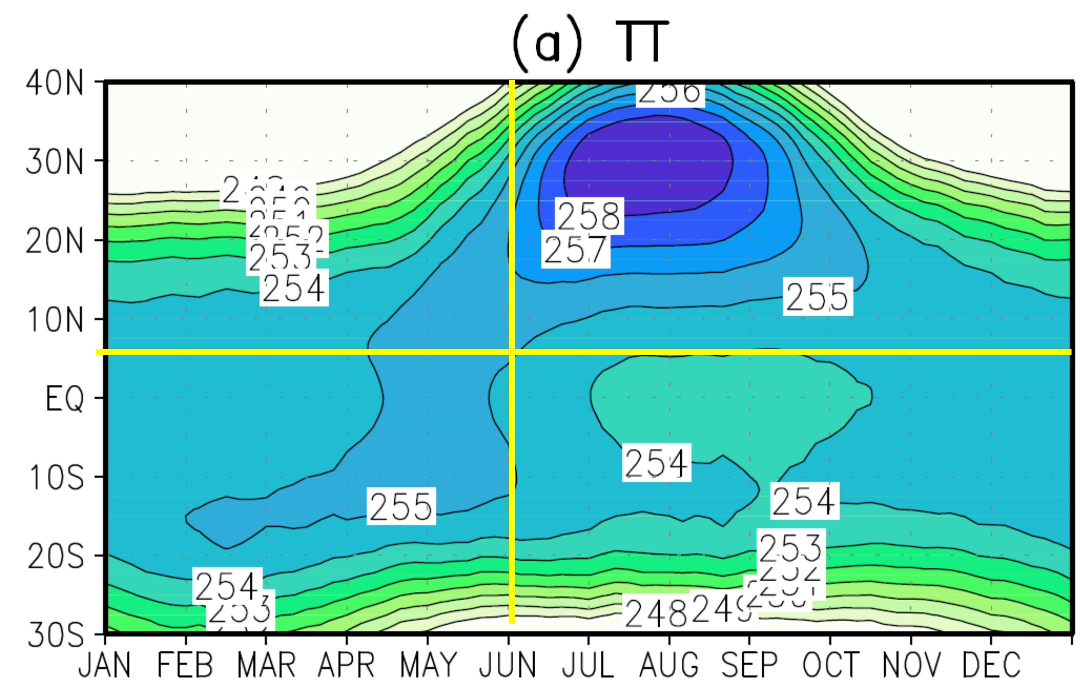
After the onset of monsoon Asian land mass is cooler than ocean to south!

Thus, the classical concept of Indian monsoon being driven by north-south gradient of surface temperature is inadequate to explain maintenance of Indian monsoon!

So, what exactly drives the Indian monsoon?

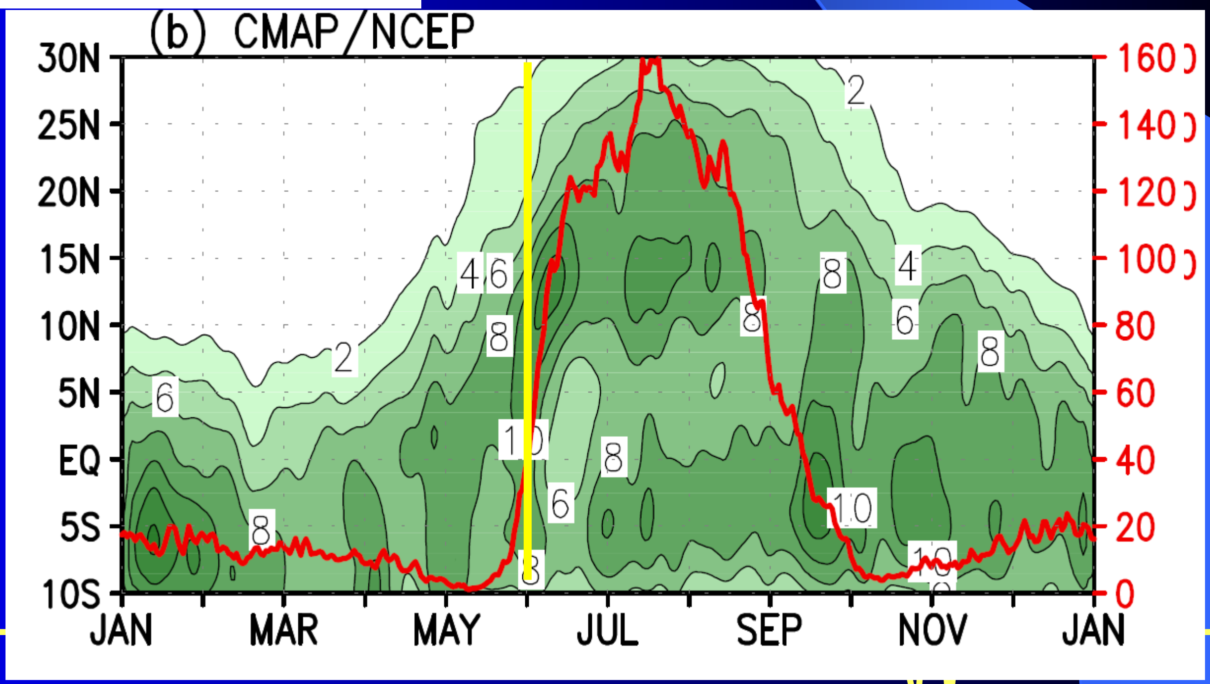
Meridional gradient of Tropospheric heating drives the monsoon circulation!

Meridional gradient of Tropospheric Heating → **Meridional gradient of Tropospheric Temperature (TT)**



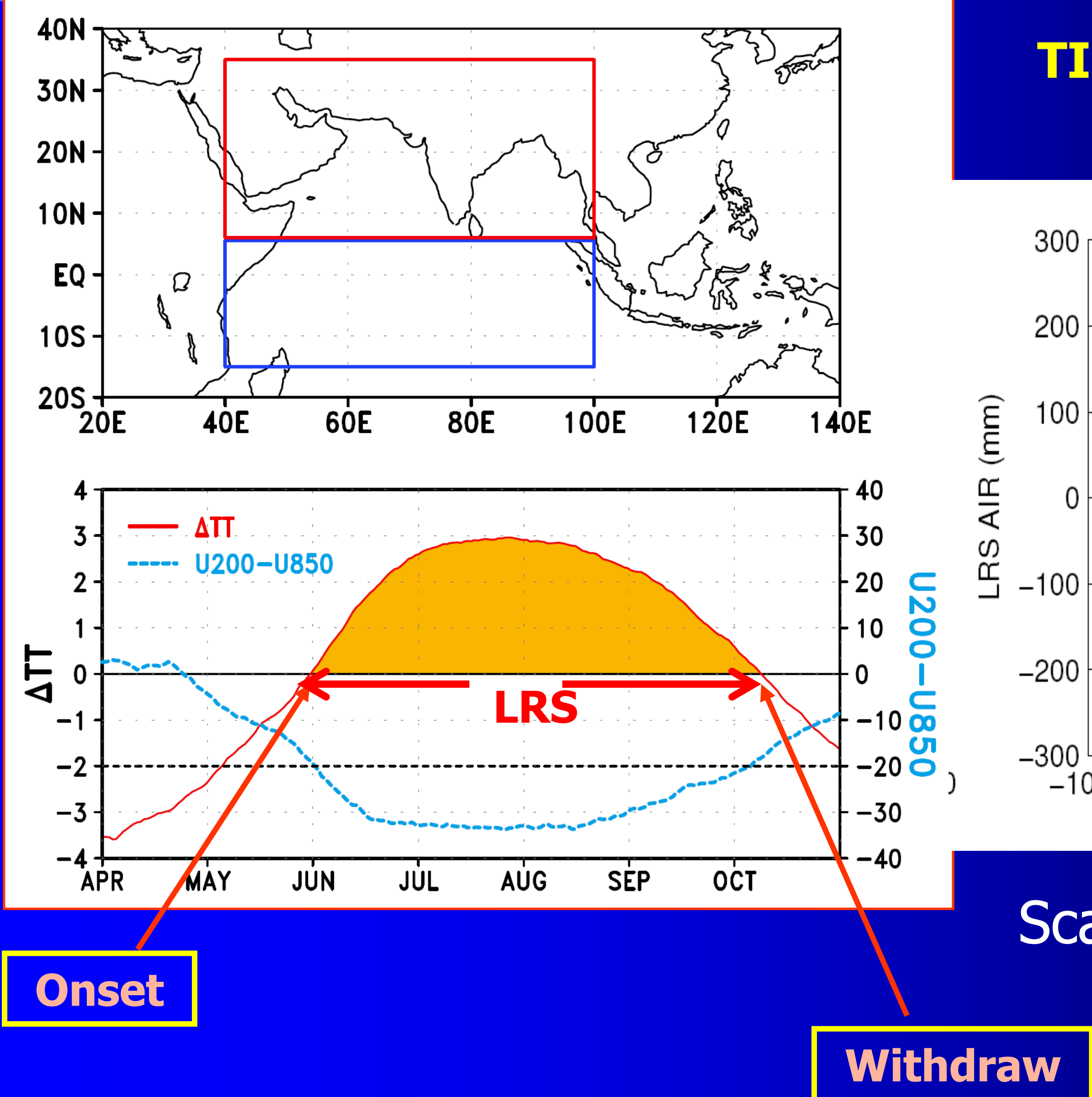
Tropospheric temperature averaged between 200 and 600 hPa (TT) averaged between 40E and 100E

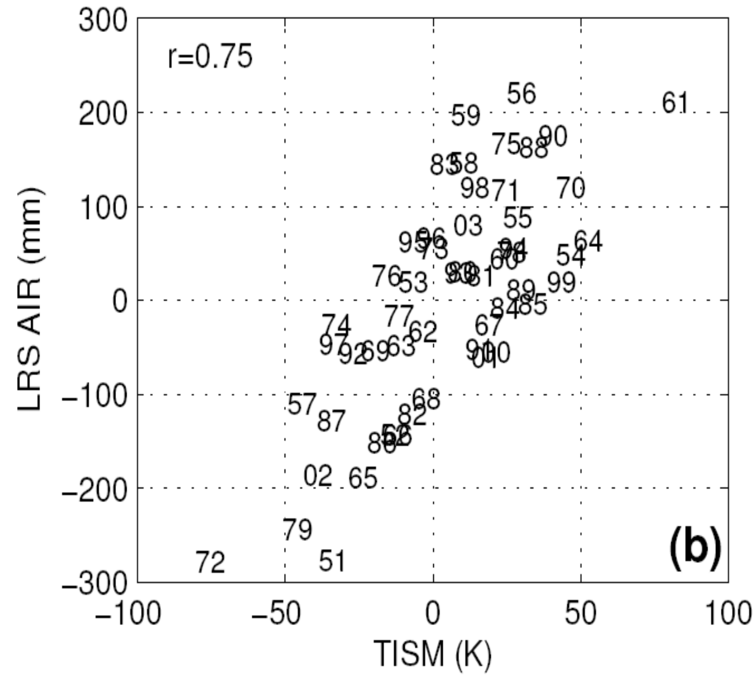
CMAP precipitation averaged between 70E and 90E (green) & K.E. at 850 hPa averaged over low level jet region (red line)



Goswami and Xavier 2005, GRL, doi:10.1029/2005GL023216

TISM : Integral of positive gradient of TT

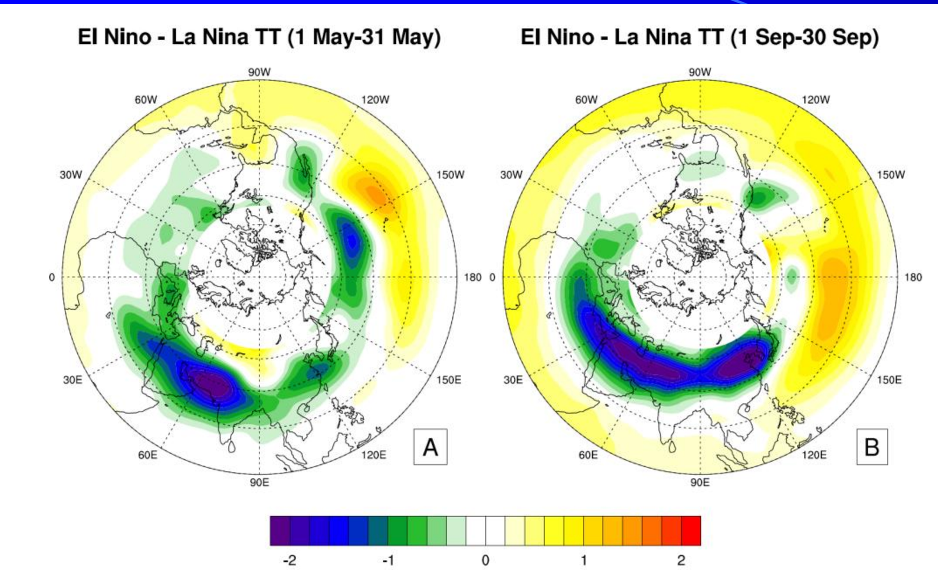


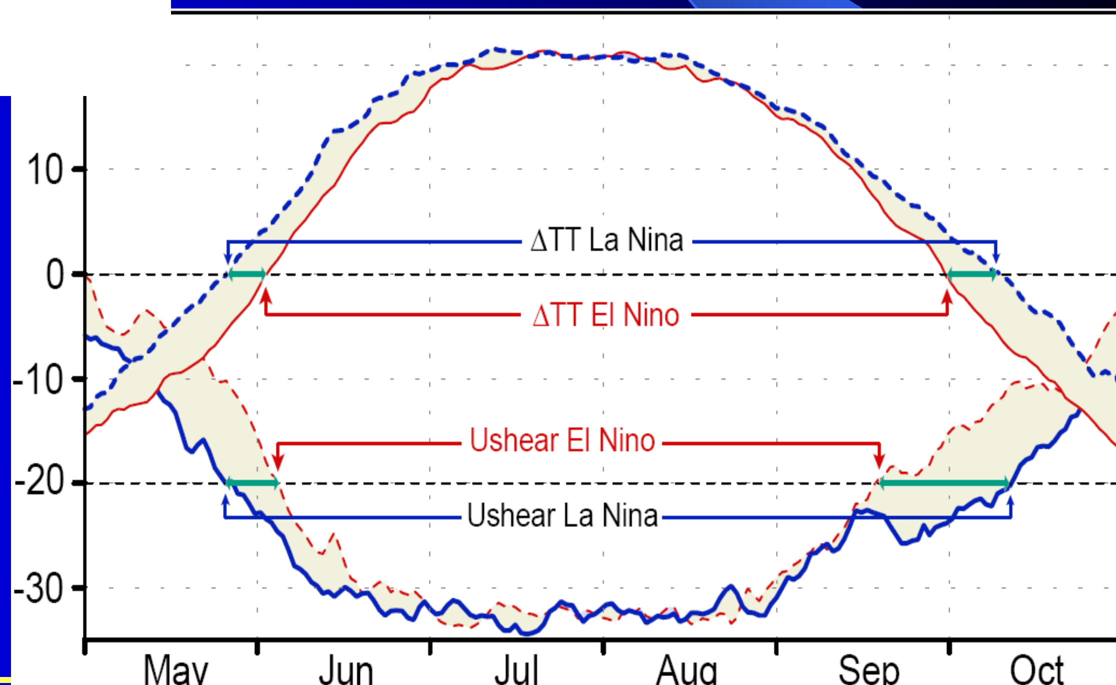


Scatter plot of LRS AIR and TISM and resultant Correlation.

Xavier ,Marzin and Goswami, 2007, QJRMS

ENSO influence Indian monsoon by modulating the LRS





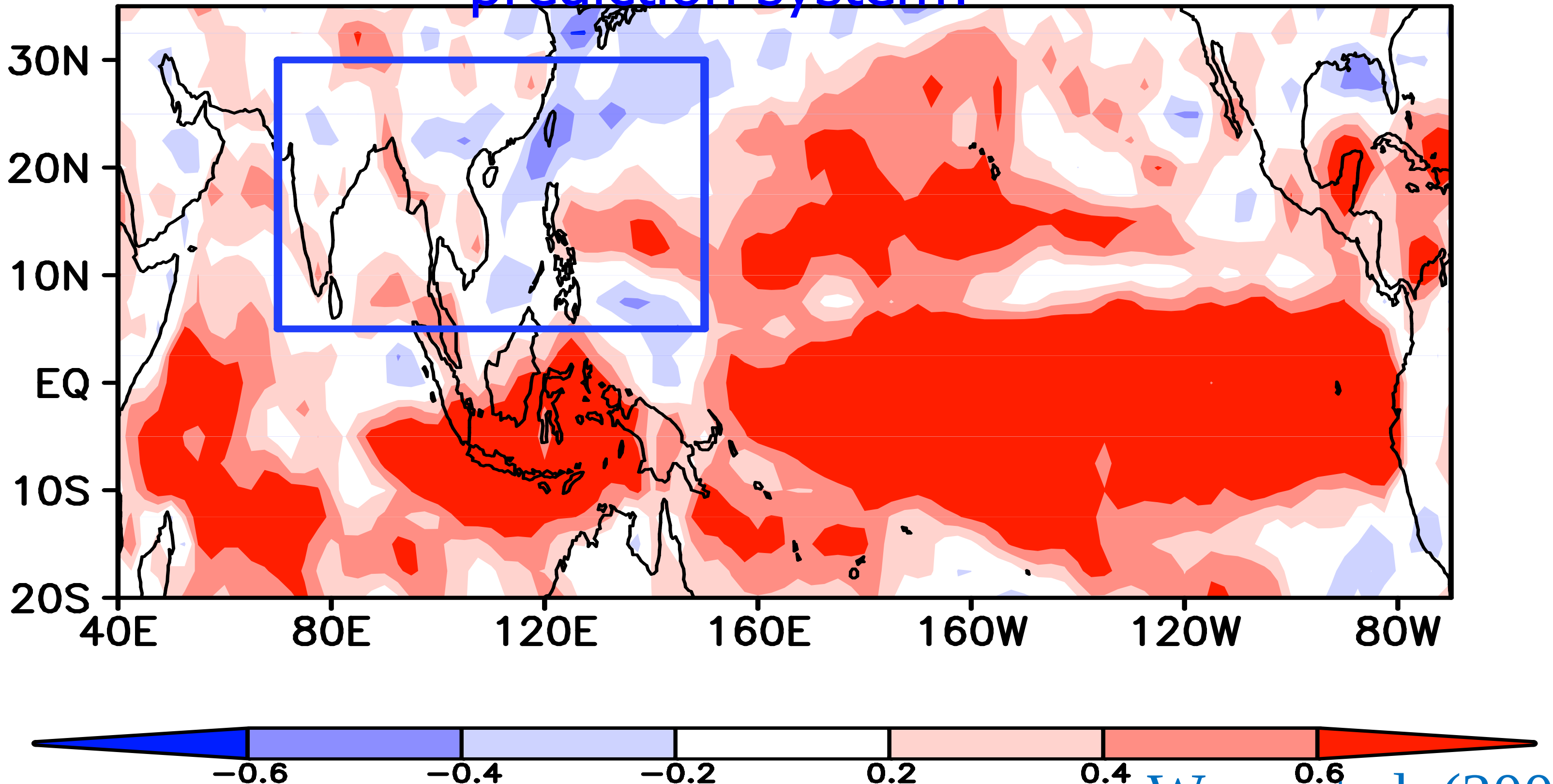
EL Nino and La Nina Composite of ΔTT and Ushear

Goswami and Xavier, 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?

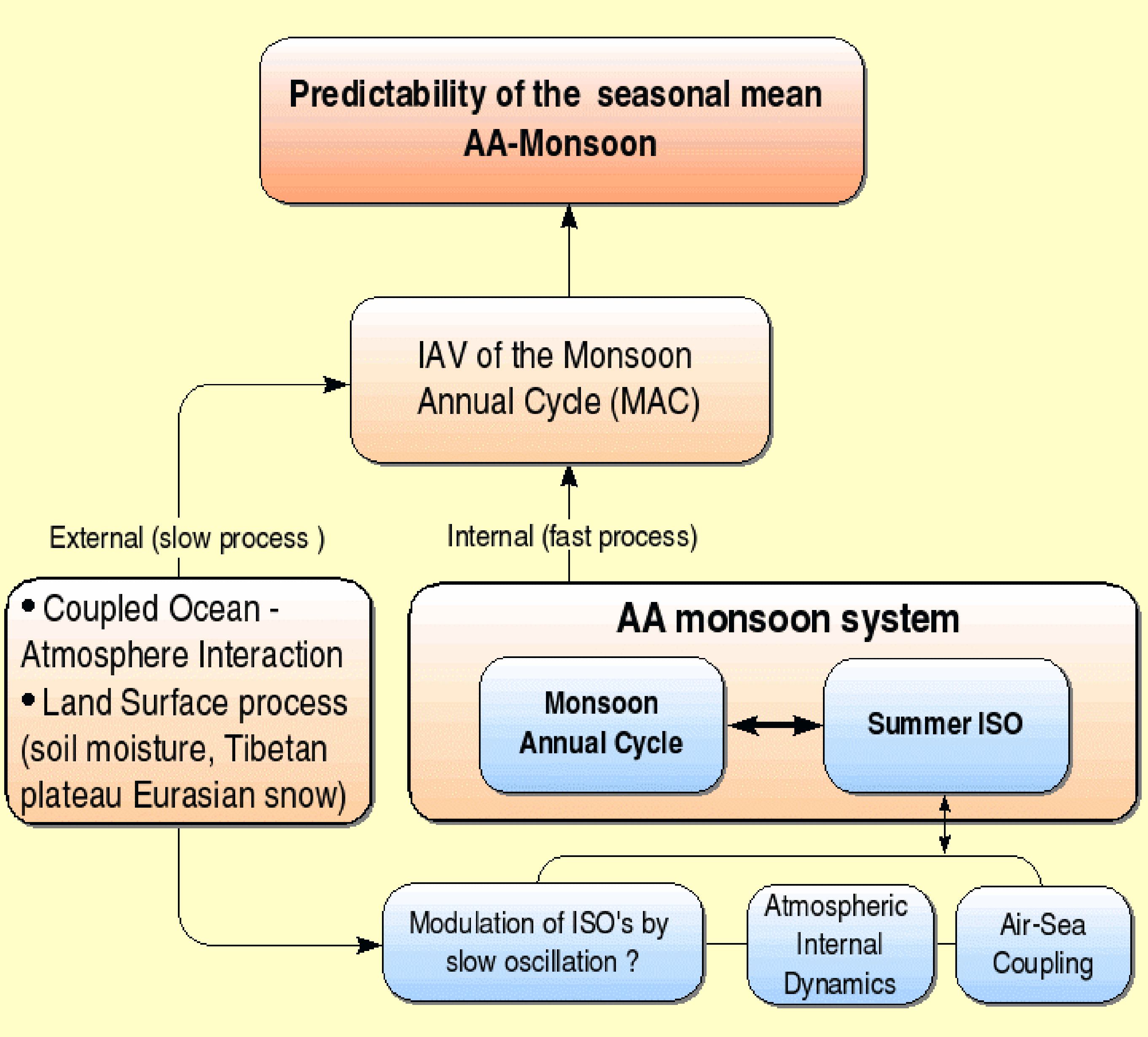
How far the skill could be pushed through improvement of prediction system?



Wang et al. (2005)

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

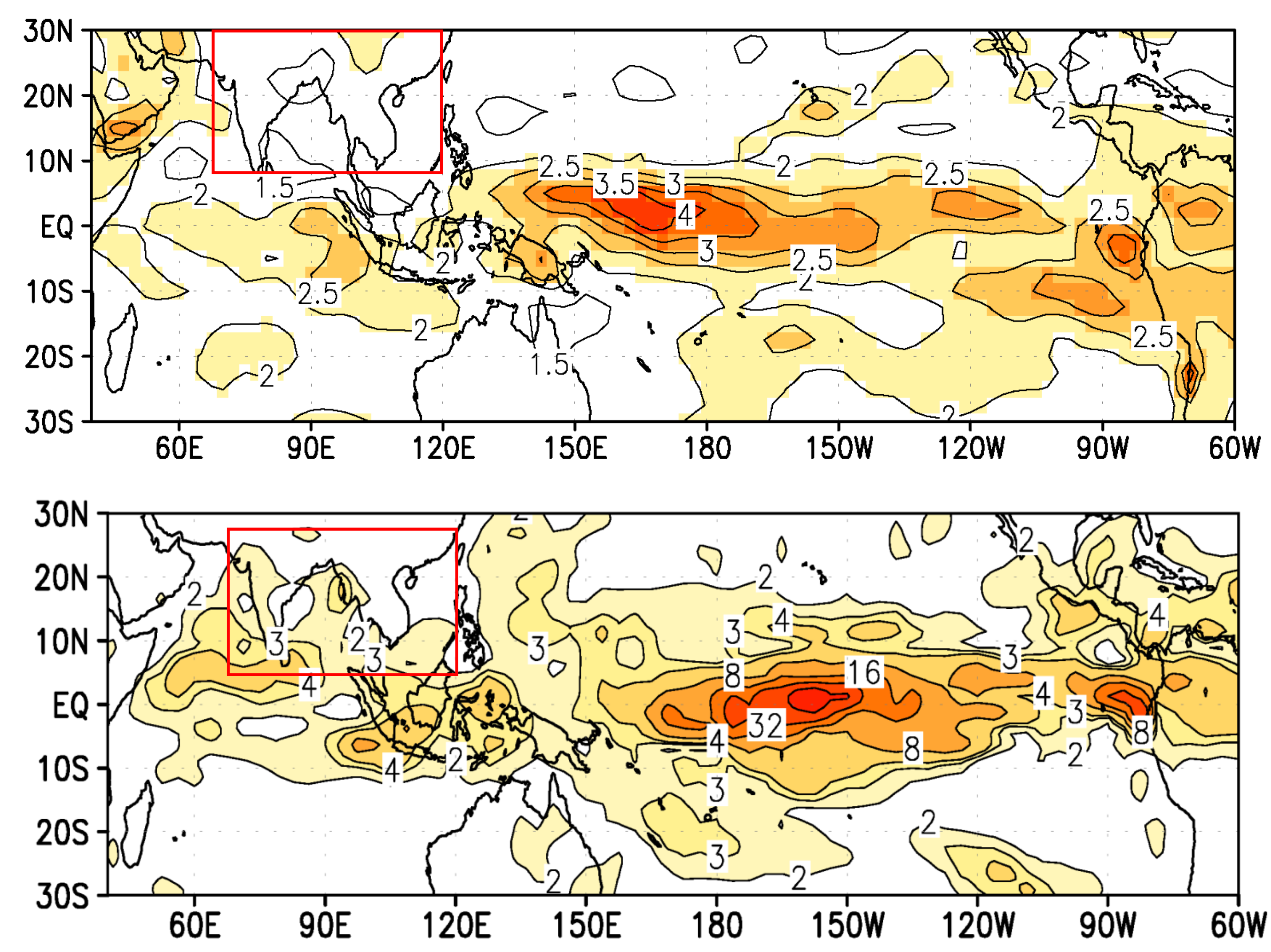
Potential Predictability Limit



Goswami, Wu and Yasunari, 2006, J. Climate

Estimates of potential predictability

F = 'total' /'internal' interannual variance



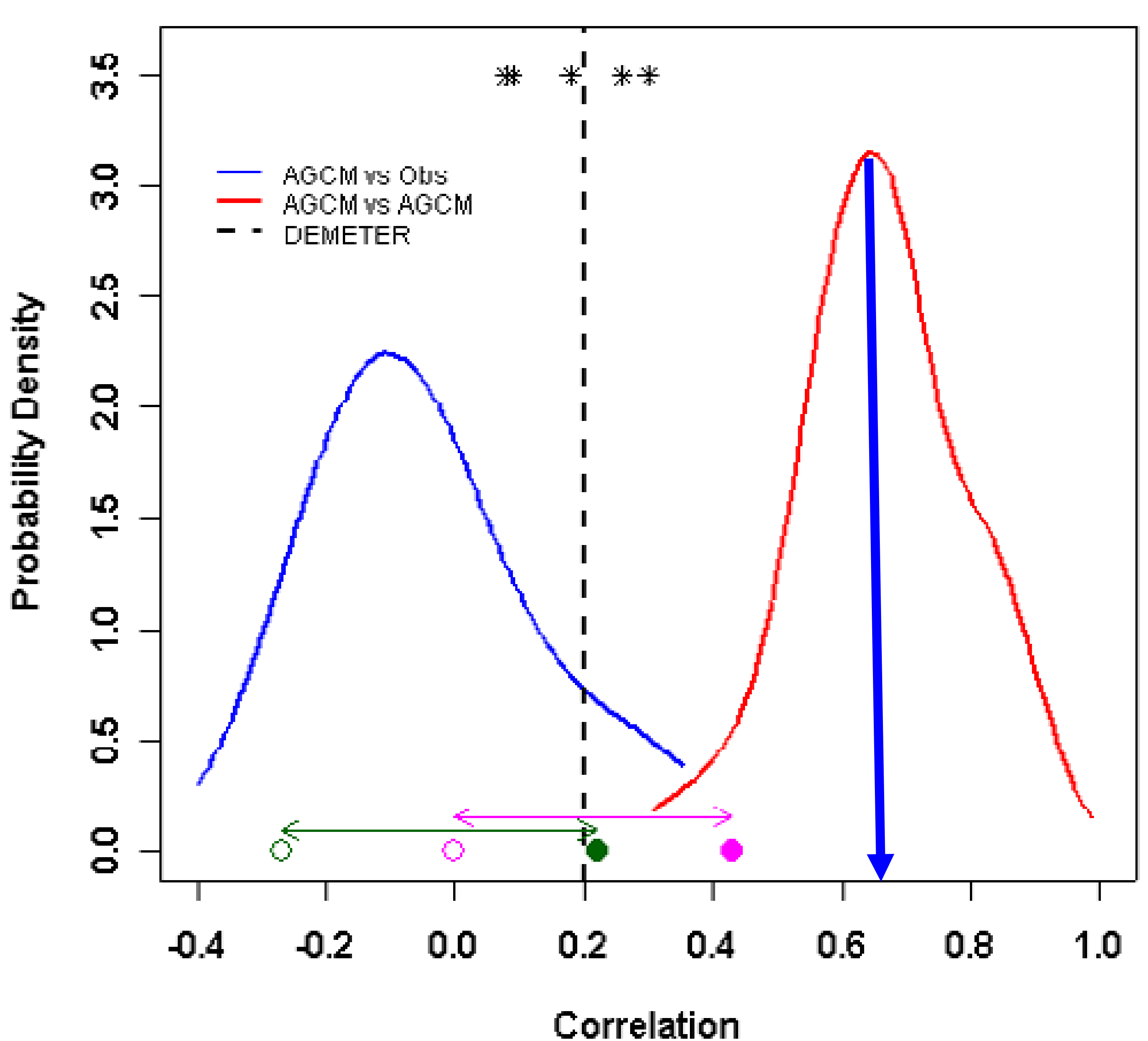
JJAS zonal winds at 850 hPa from NCEP reanalysis (Observation)

Goswami and Ajayamohan,2001

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

Goswami and Xavier, 2005

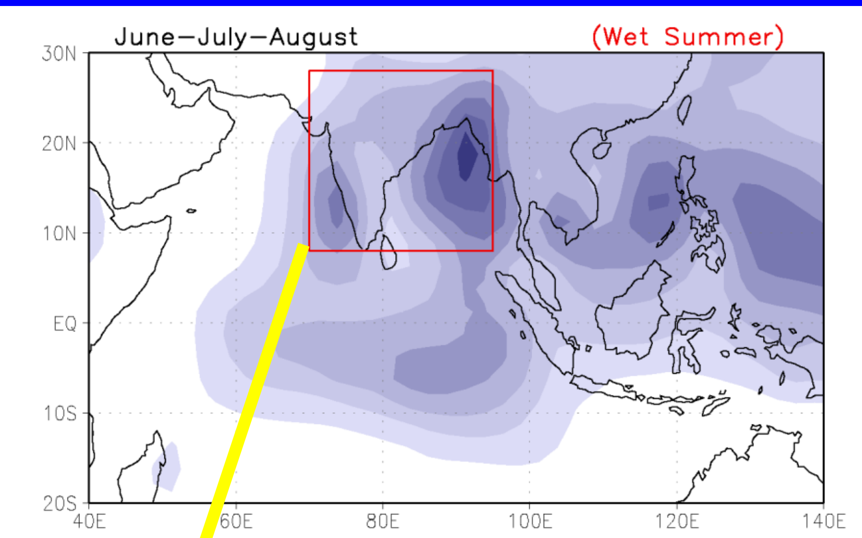
F ~ 2 ⇒ **50% or more of IAV is governed by Climate Noise!**

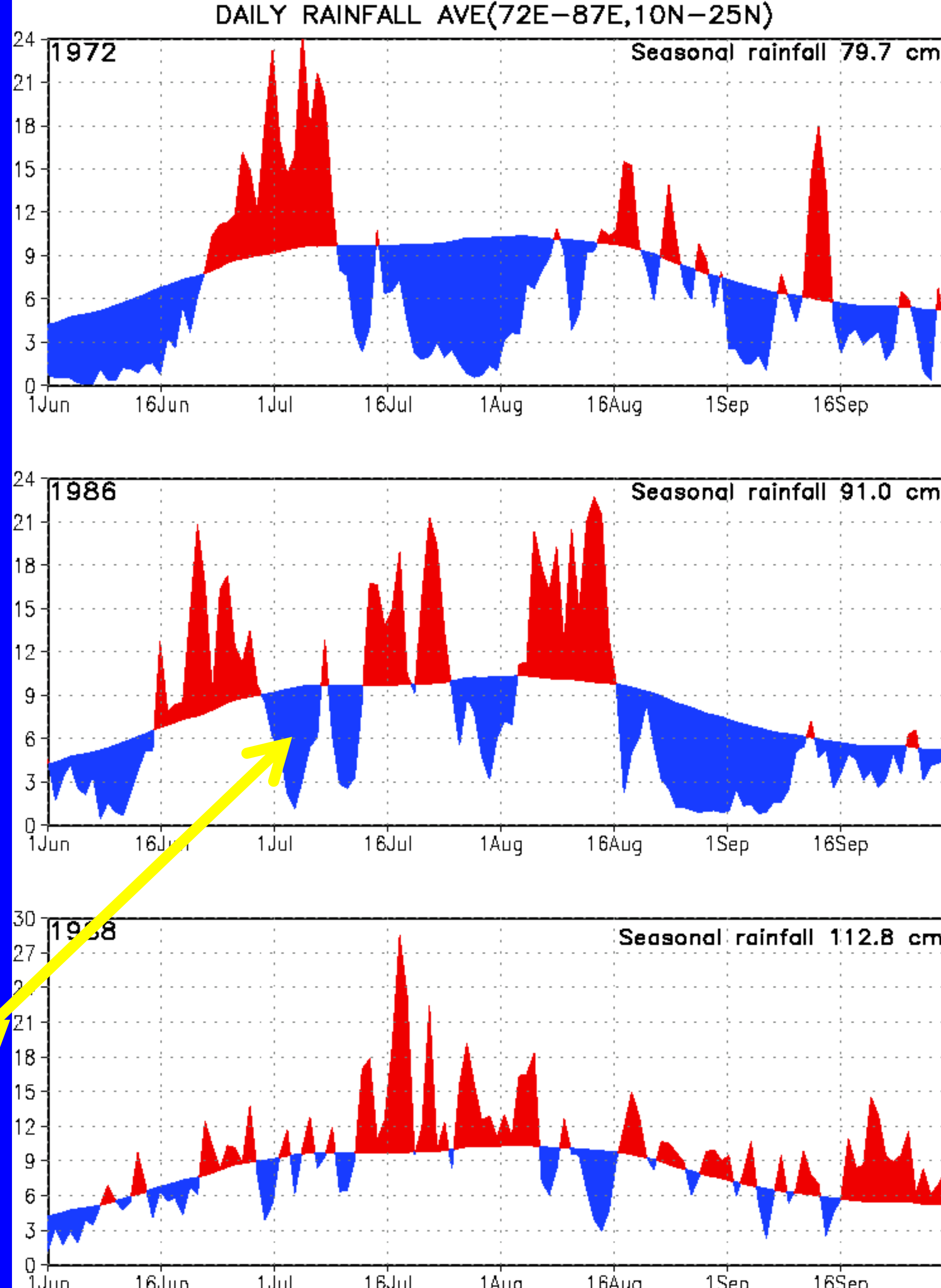


Limit on potential predictability, in terms of correlation between obs. And pred. of ISRM rainfall

Krishna Kumar et al., 2005, GRL

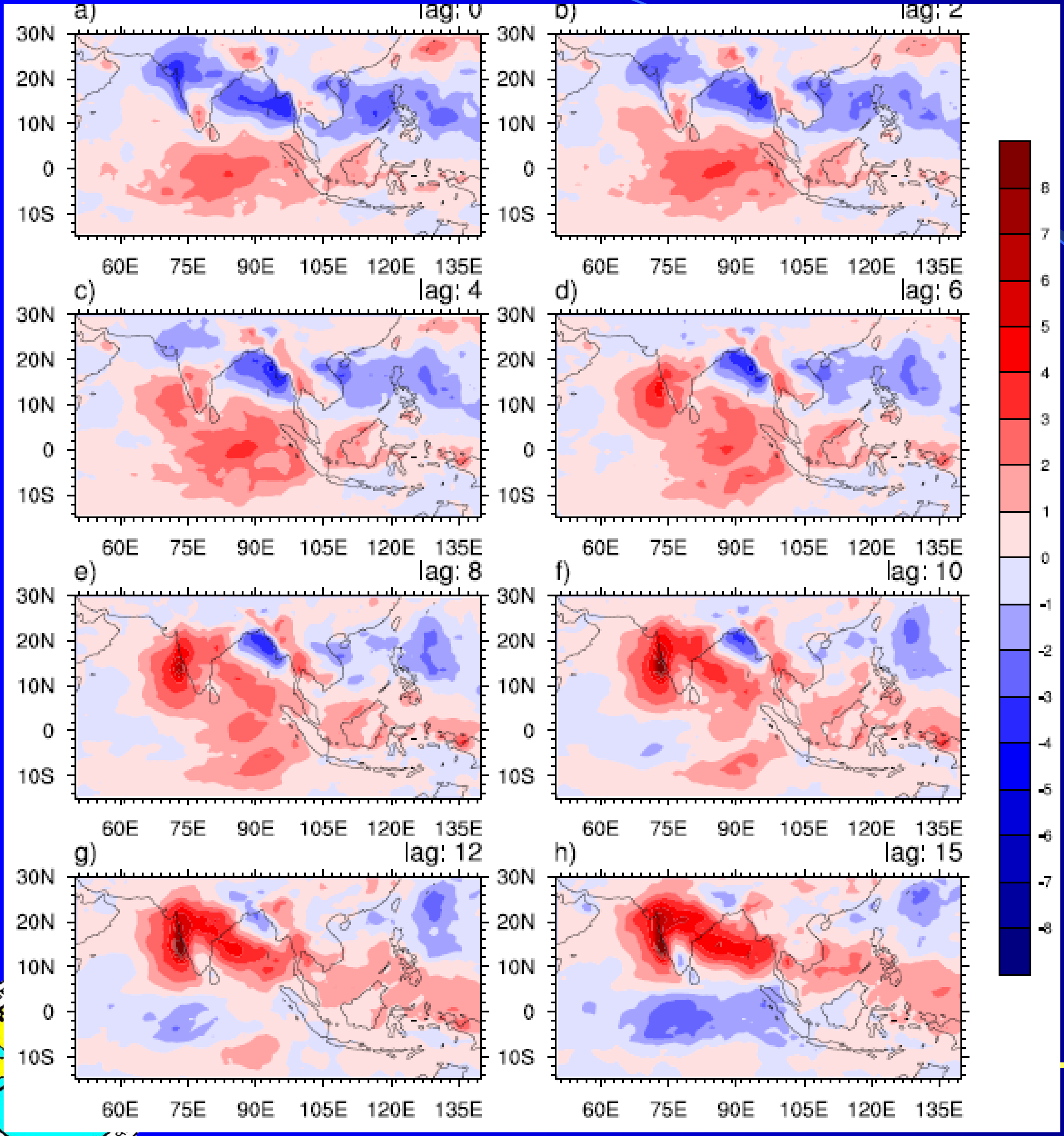
Where does the Climate Noise or 'Internal' IAV of the Monsoon arise from?





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

Convectively Coupled…

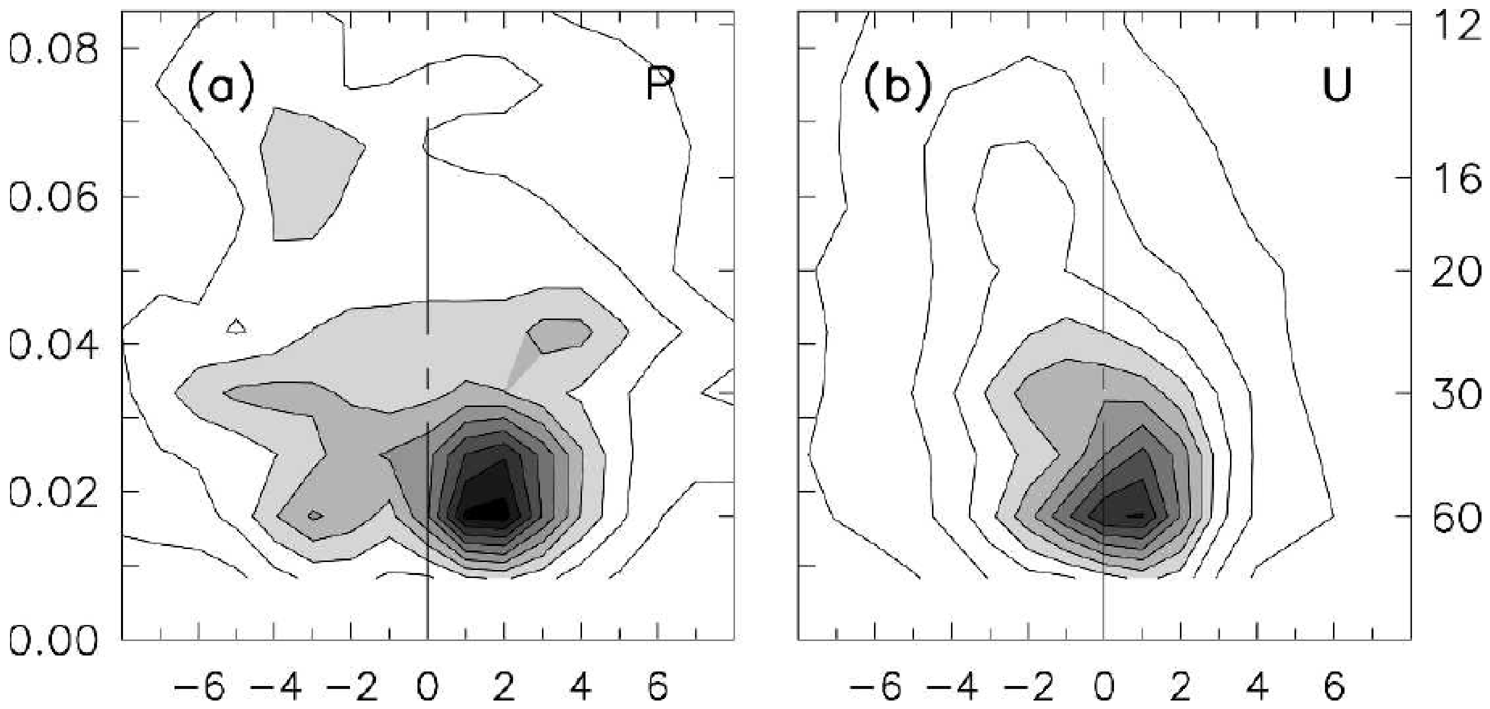
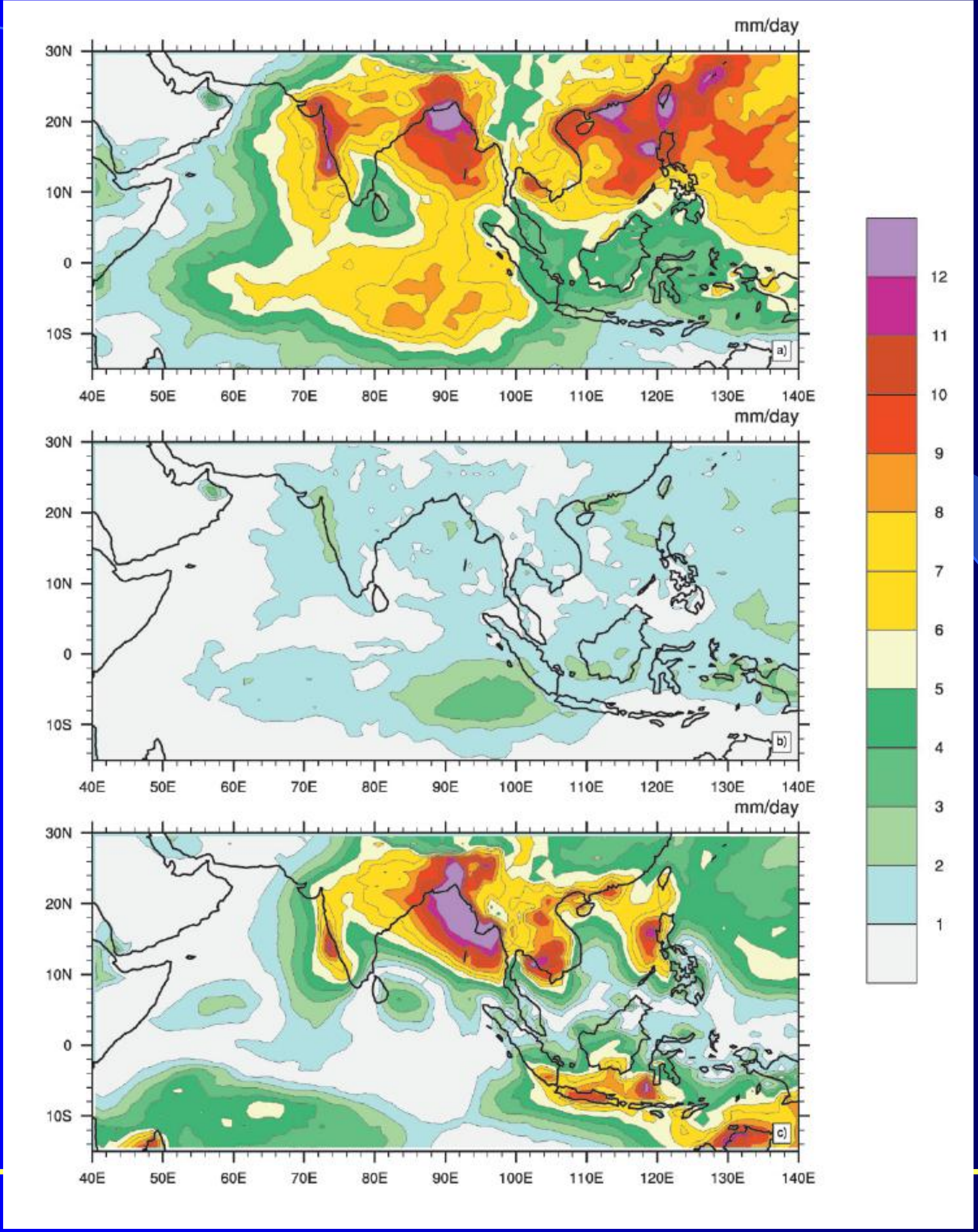


FIG. 2. Wavenumber–frequency spectral power of observed precipitation and 850-hPa zonal winds anomalies averaged over the latitude band 5°–25°N. The *y* axis left ordinate is frequency (in cycles per day, cpd) and right ordinate is period (days), while the *x* axis represents zonal wavenumber. The minimum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

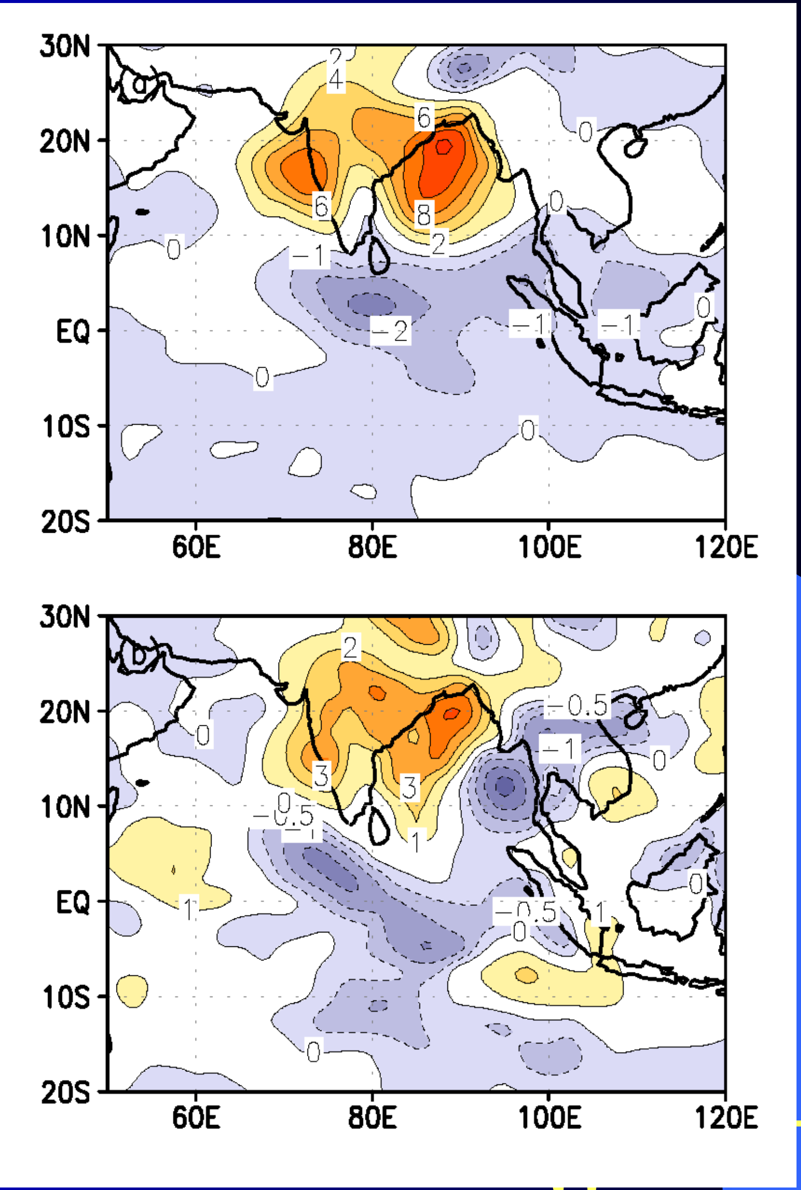
Active-Break composite of precipitation from NCEP

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.

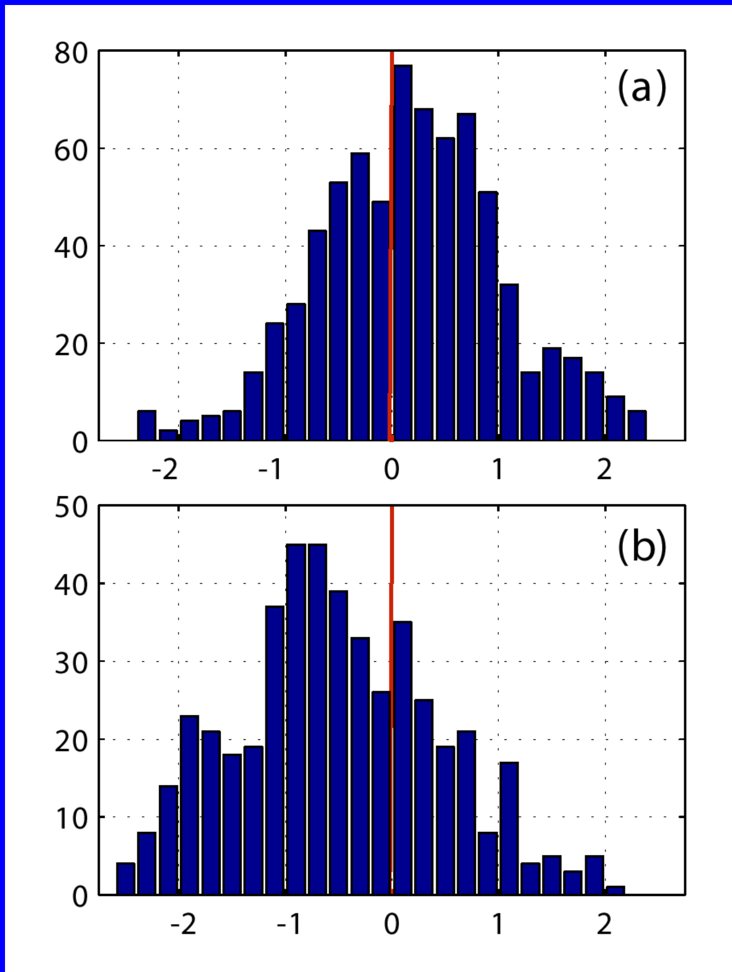


How does the ISOs influence the seasonal mean and IAV ?

- **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

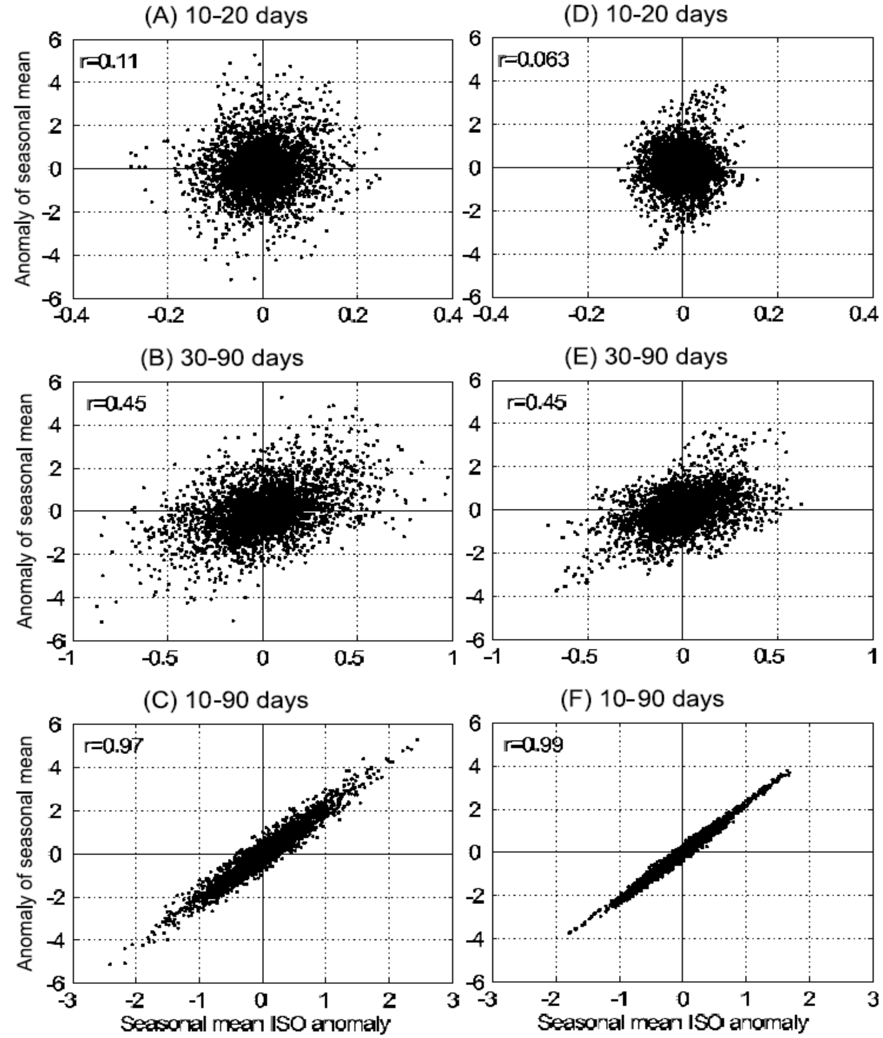


Figure 13. Scatter plot of interannual anomalies of seasonal mean versus seasonal mean of intraseasonal anomalies of precipitation (mm day^{-1}) from (a) 10–20 days band, (b) from 30–90 days band and (c) from 10–90 days band at all grid points in the domain 70°–100°E, 10°–30°N. (d, e, f) Similar to Figures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

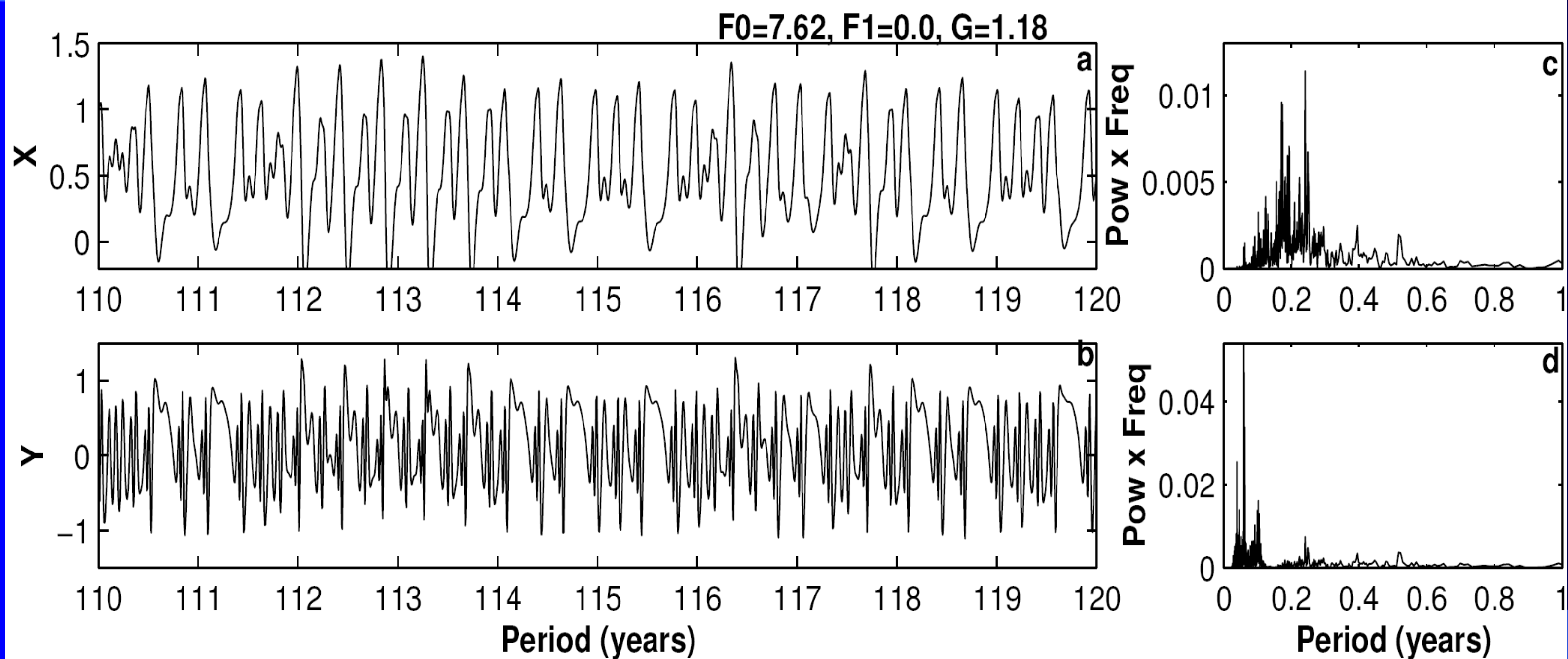
$$\dot{Y} = XY - bXZ - cY + G$$ ← Land-ocean contrast

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

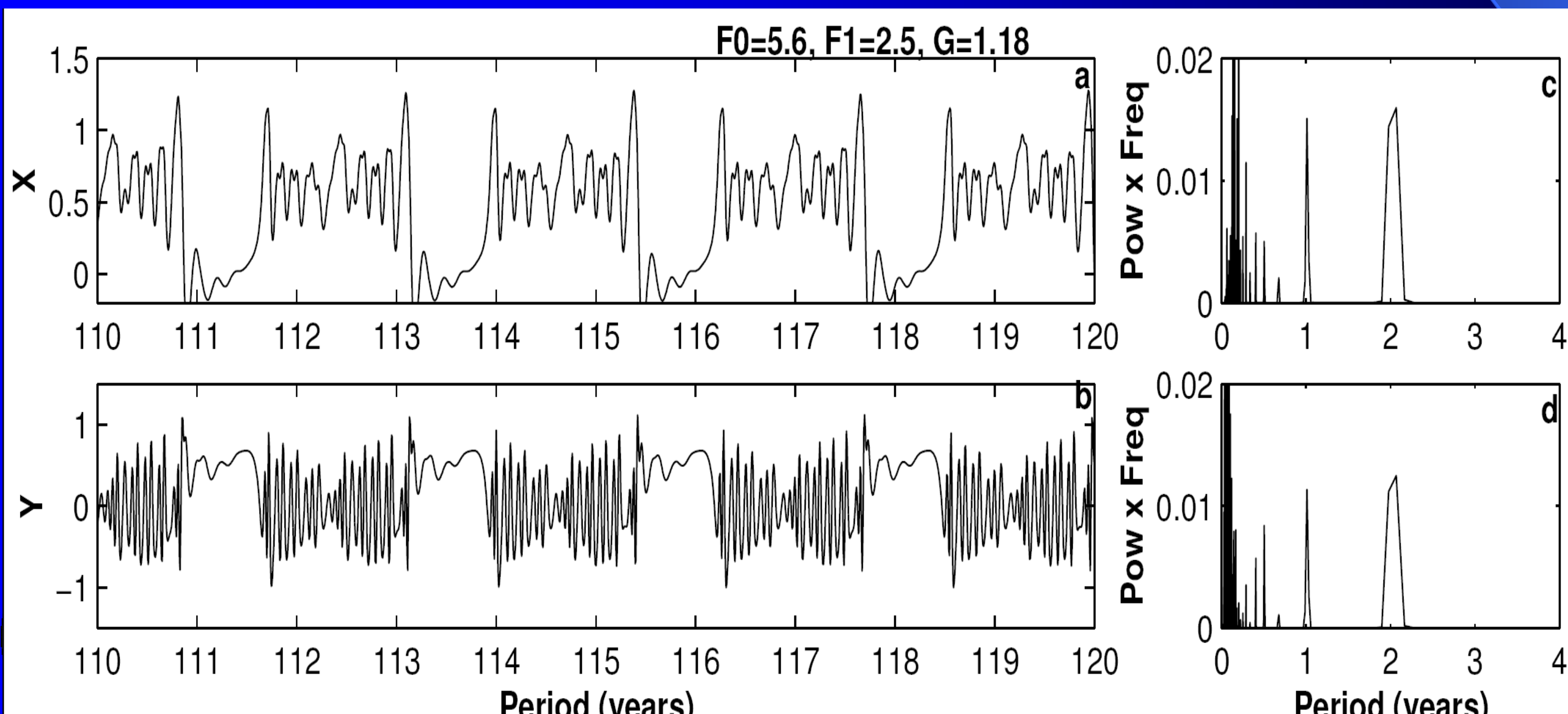
$$\dot{F} = F_0 + F_1 \cos(\pi t/\tau),$$

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

INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE



F=const.

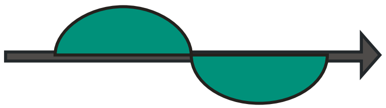


F=ann.cyl

How Does The Tropical Atmosphere Generate nearly Two year oscillation without external Forcing?

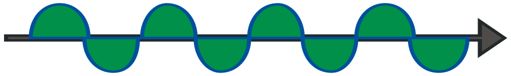
Multi year experiments with a simple mathematical model of the Atmosphere carried out

ANNUAL CYCLE FORCING



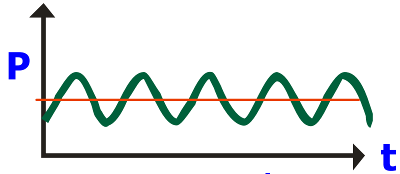
MODULATES

INTERASEASONAL MONSOON OSCILLATIONS 30-50 DAYS

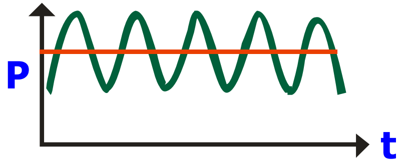


CHAOTIC FOR SOME RANGE OF ANNUAL CYCLE FORCING

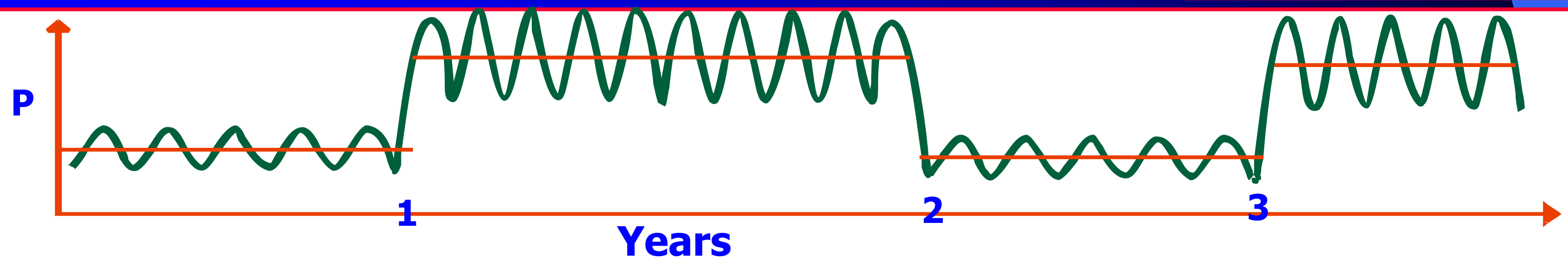
TWO STATES WITHIN THE CHAOTIC REGIME



Low mean- low Amplitude State

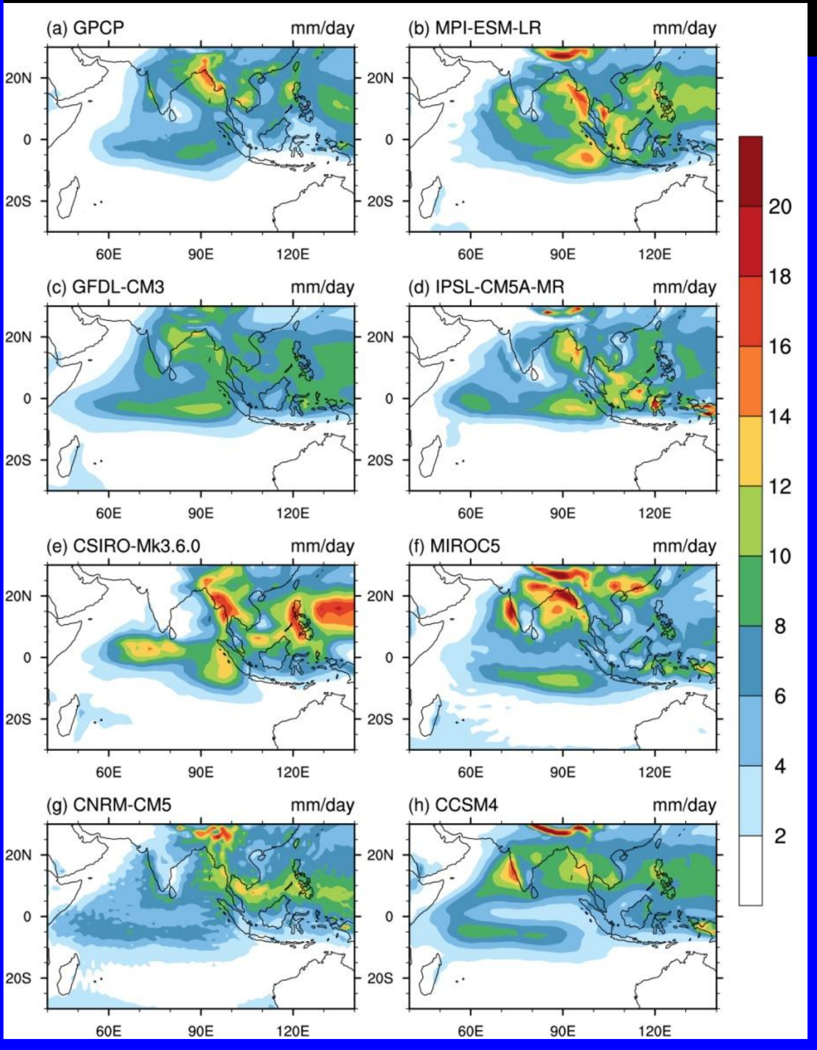


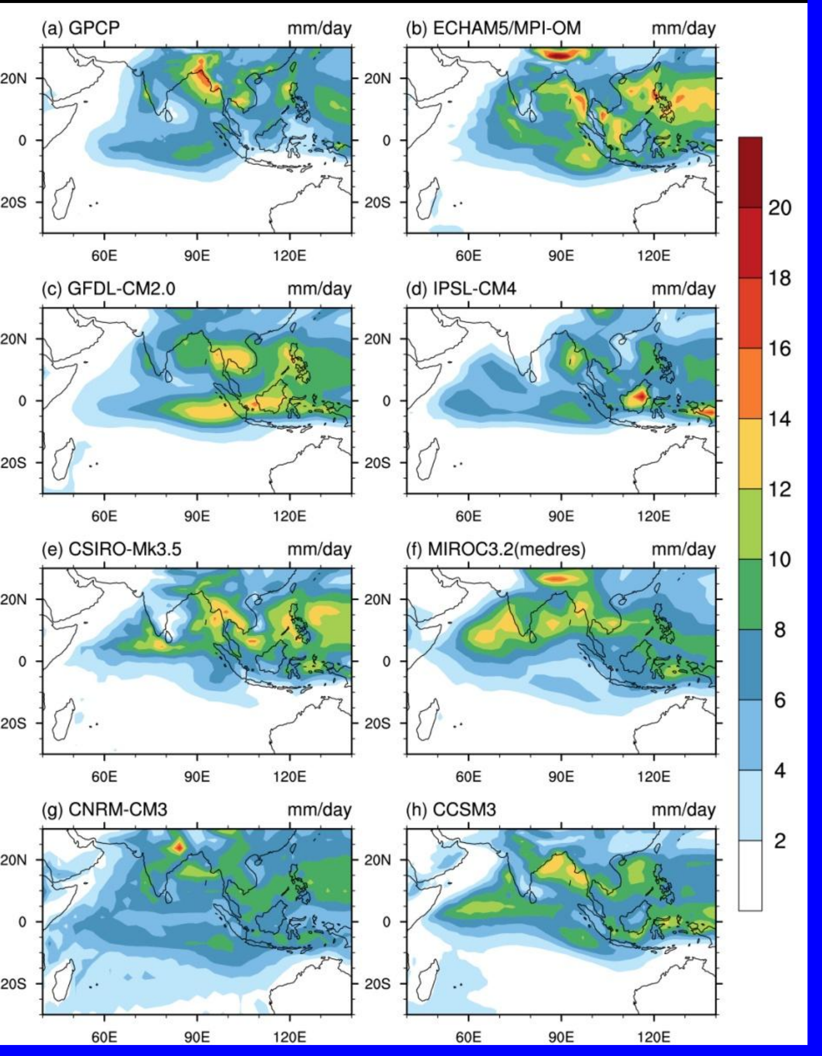
High mean- high Amplitude State



Another reason for poor skill of Monsoon Prediction

CMIP3

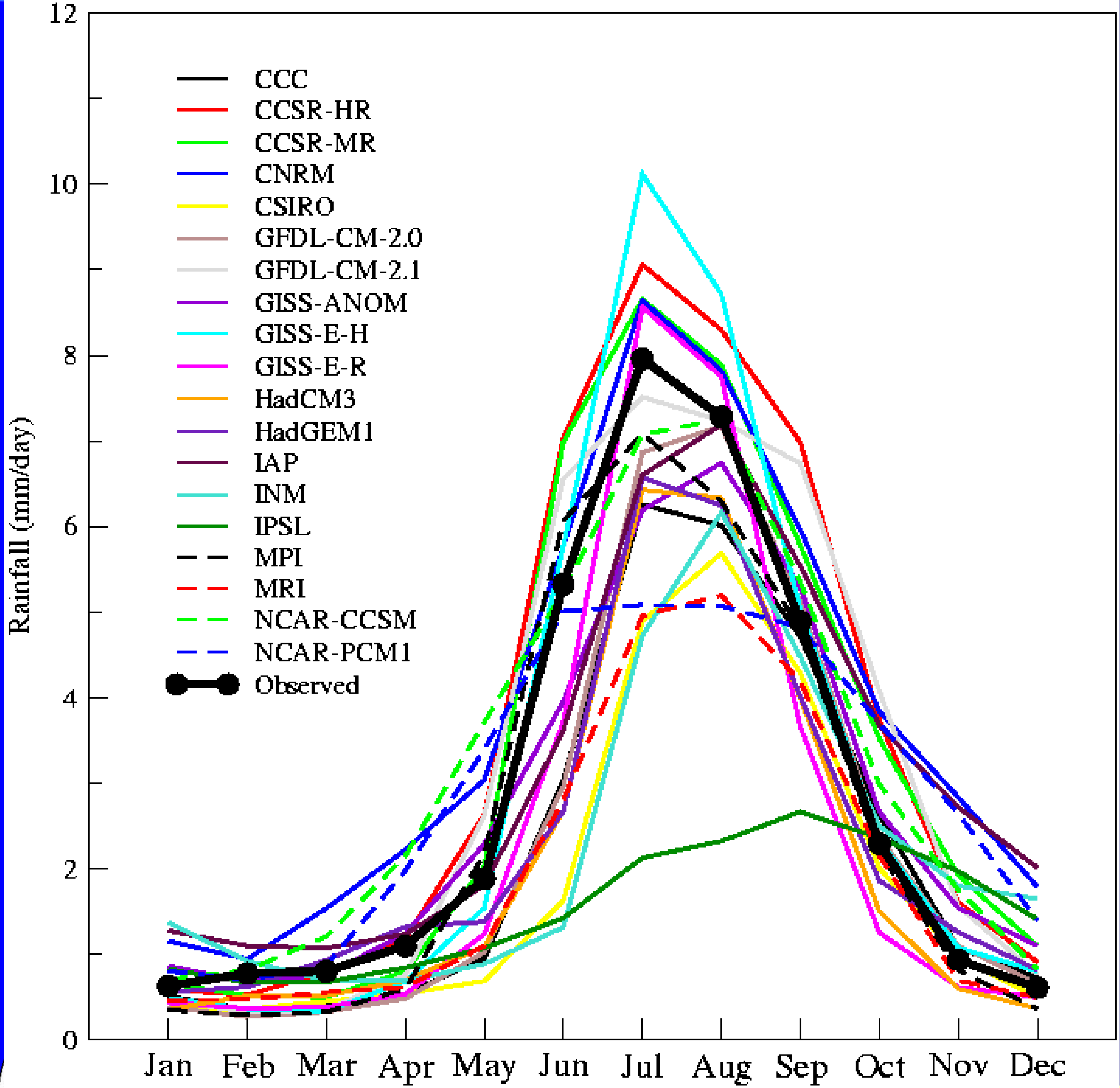




CMIP5

All models have significant biases in simulating mean monsoon

Simulation of Annual Cycle of precipitation over India by climate models



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

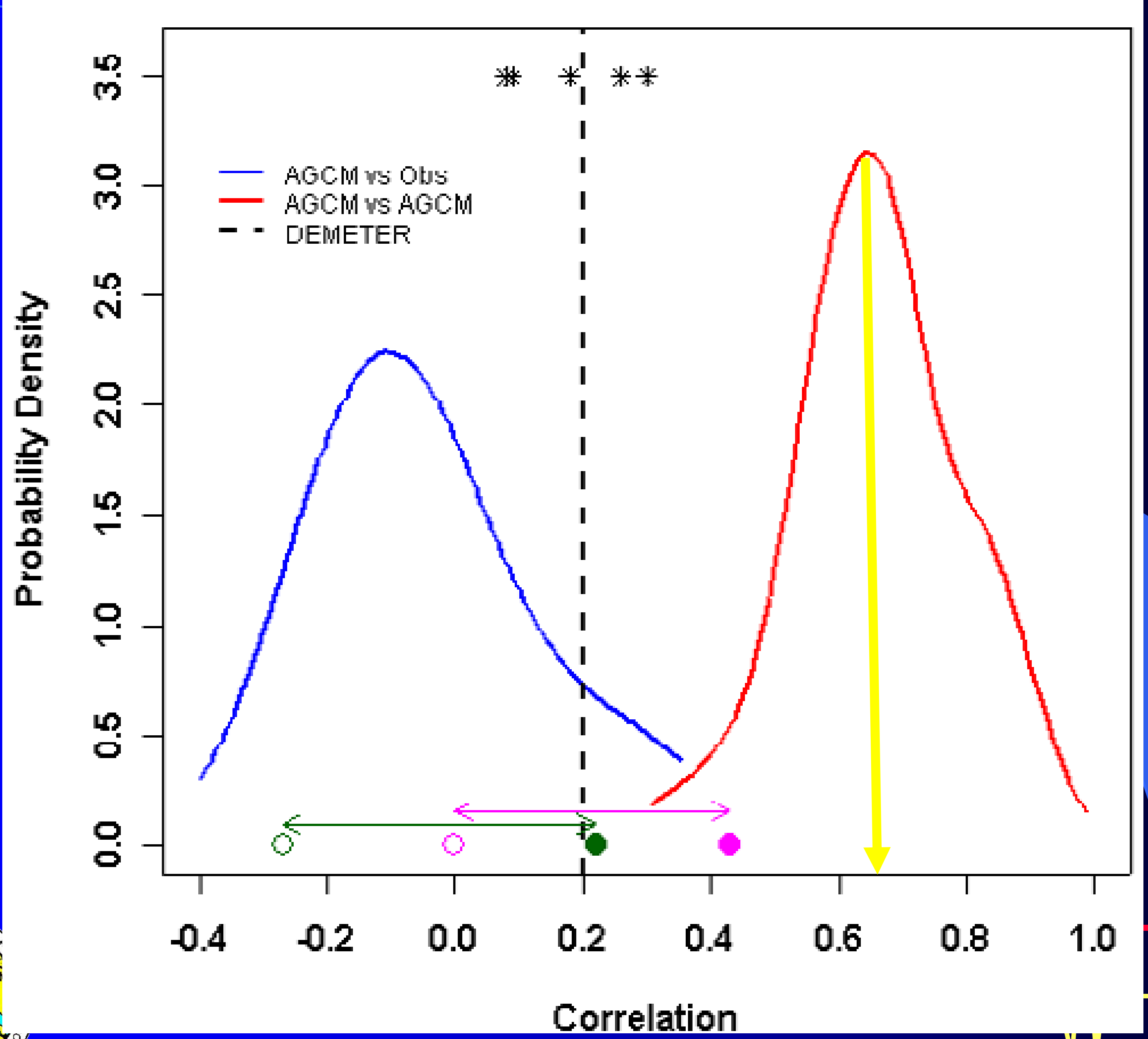
To be led and coordinated by IITM

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

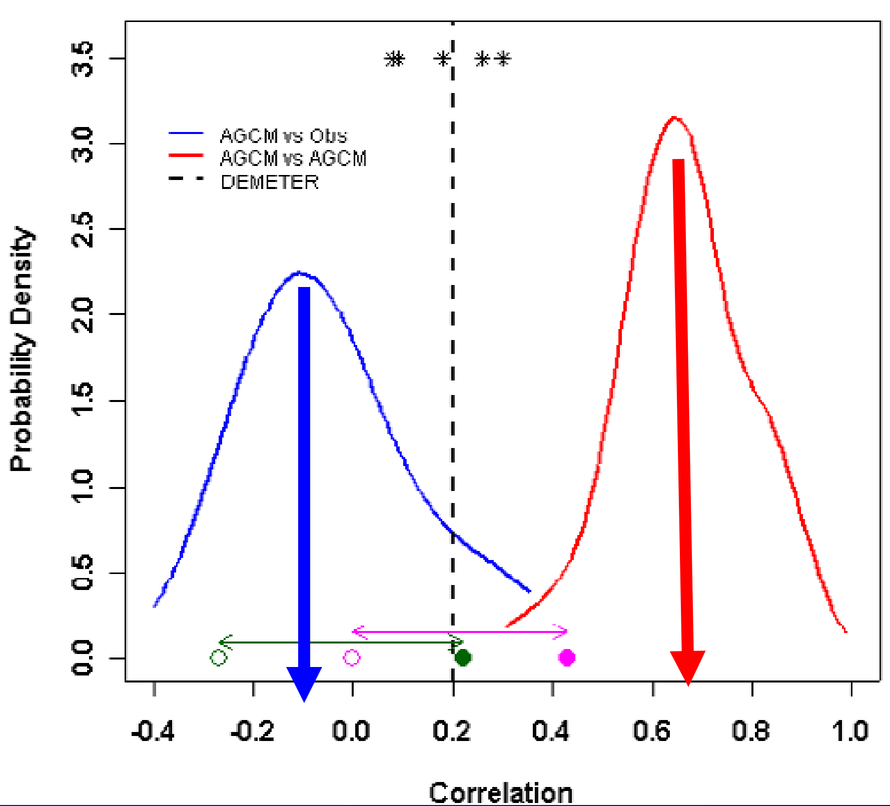
INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE



Krishna Kumar et al., 2005, GRL

Krishna Kumar et al , 2005, GRL

Skill of ISMR prediction by ENSEMBLES models



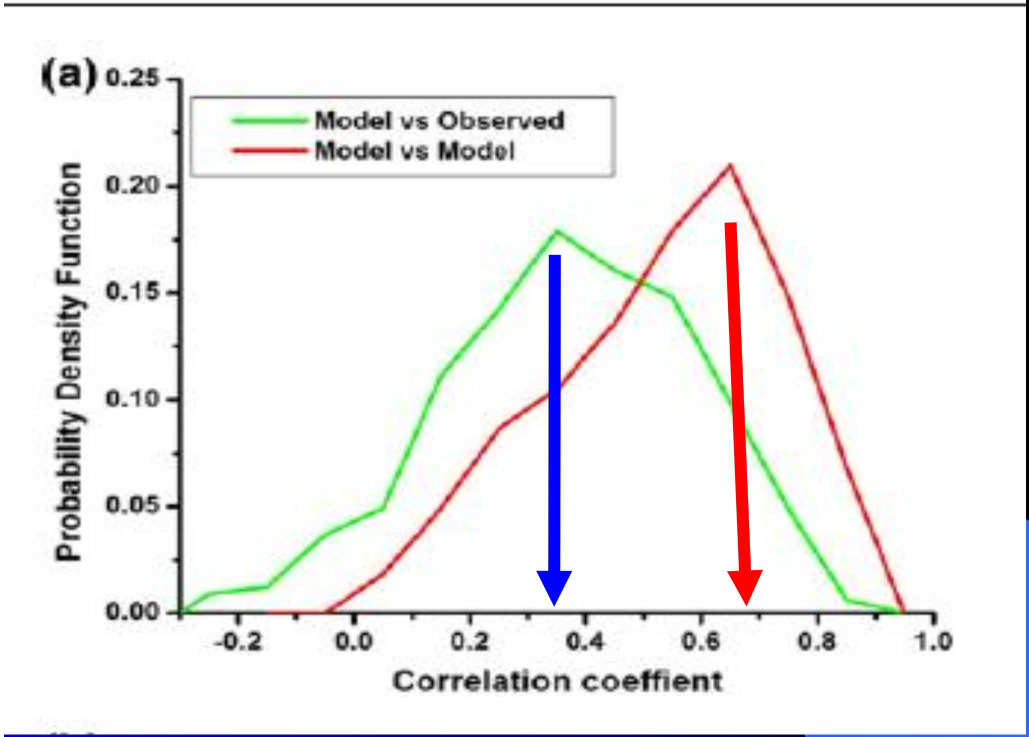


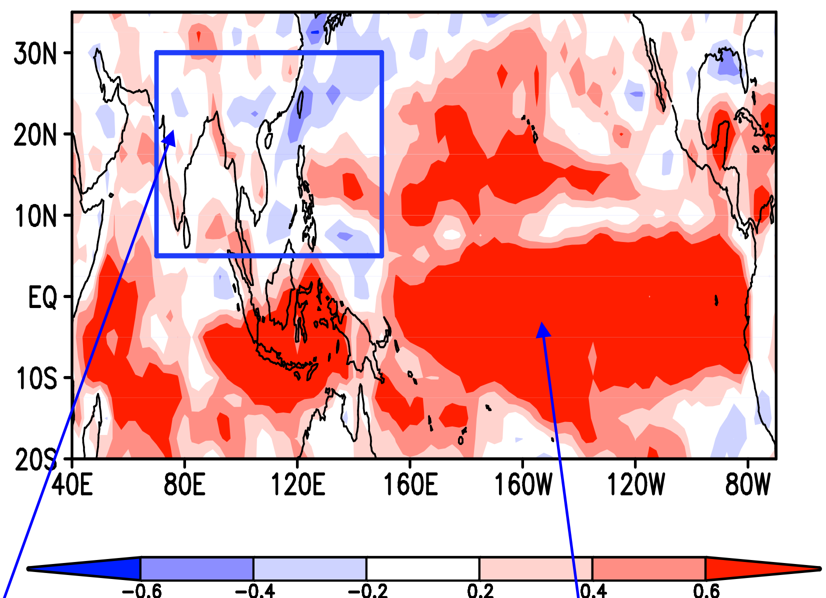
Fig. 13 PDFs of the correlation skill of ISMR based on a theoretical "perfect model" analysis (*red curve*) and based on the actual skill compared to the observed ISMR (*black curve*). a for the period 1960–1979 and b 1980–2005

Rajeevan et al. 2011, Climate Dynamics

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

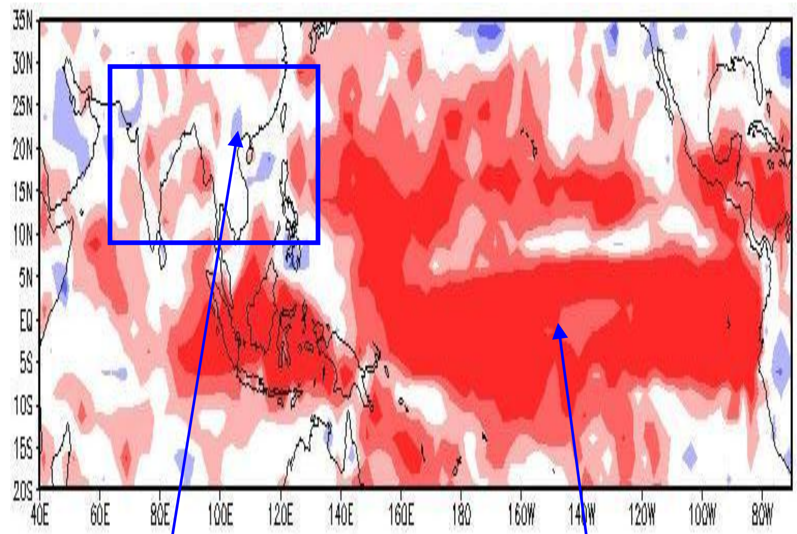
Earlier version models

1979-1999



Latest models (ENSEMBLES)

1979-1999



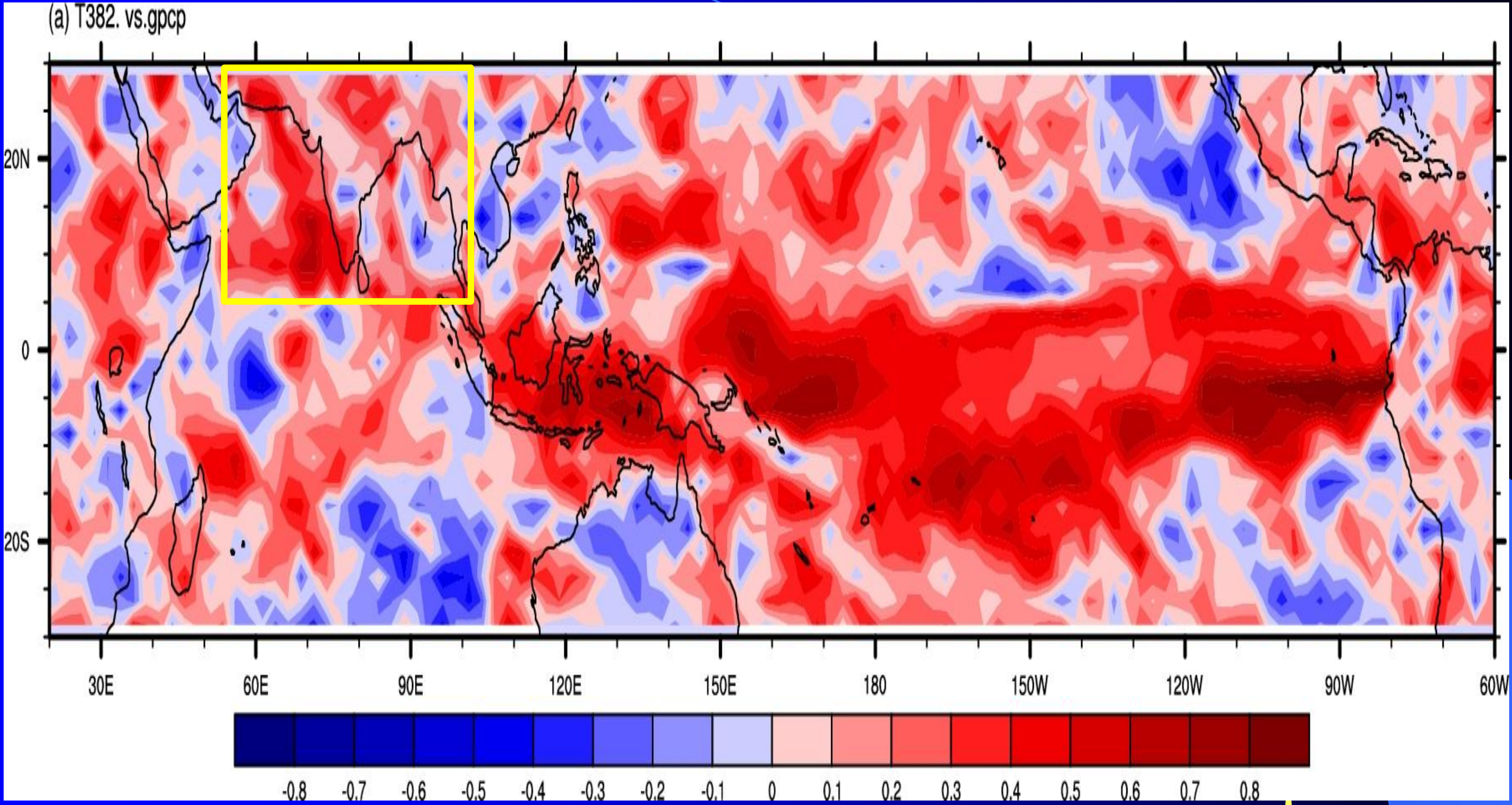
Poor skill

High skill

Improved skill

High skill

T382L64 Skill of Rainfall



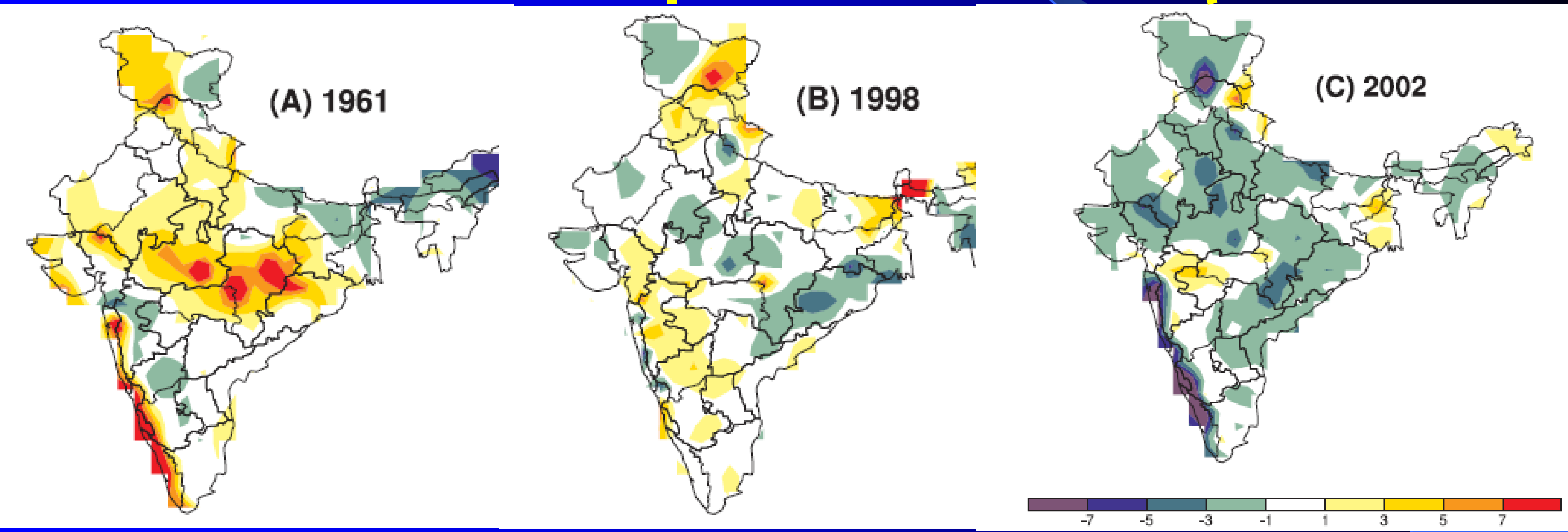
GPCP VS CFSv.2 T382, latest model at IITM

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 purses 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).

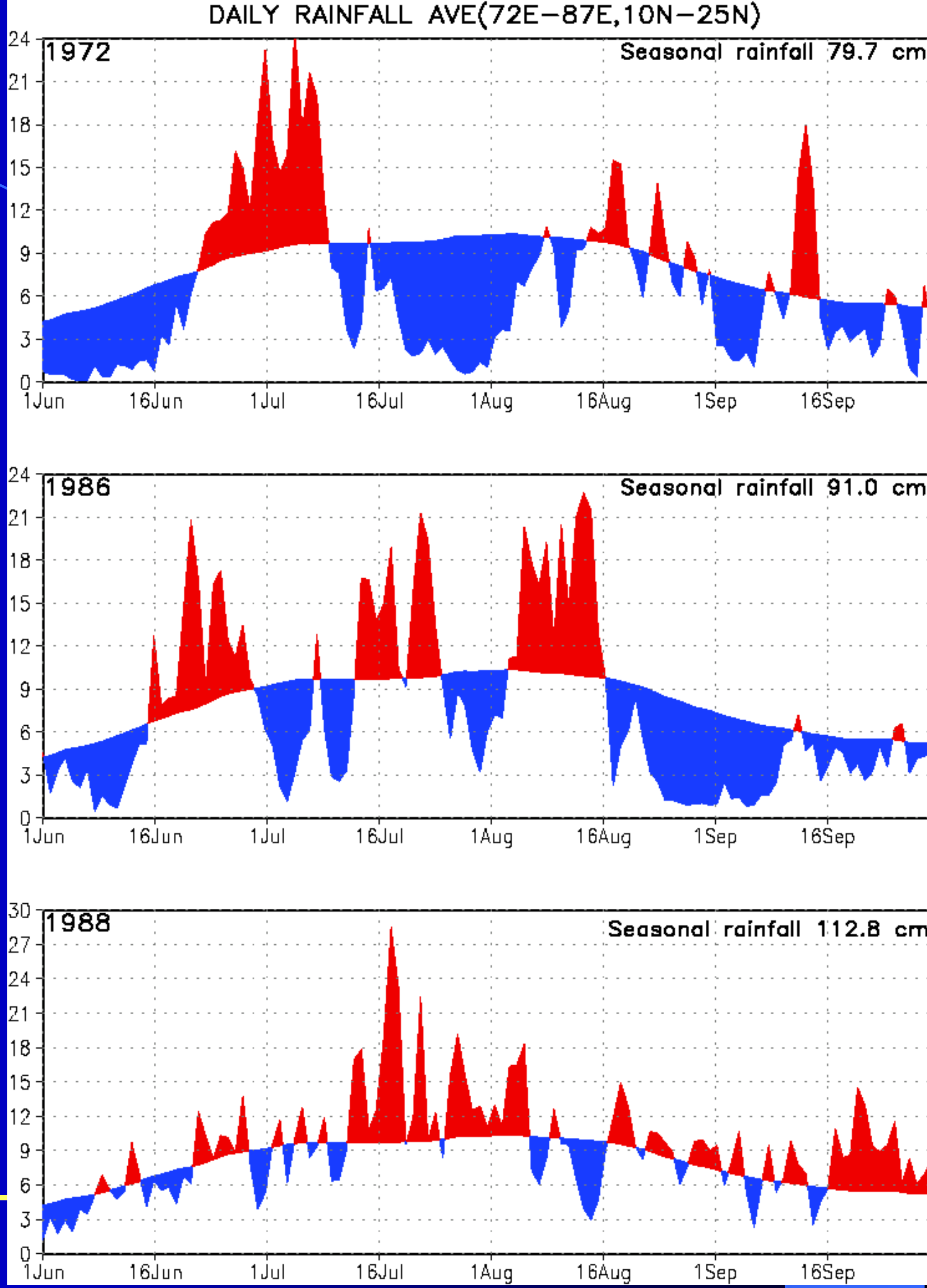
Indian monsoon is characterized by the

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

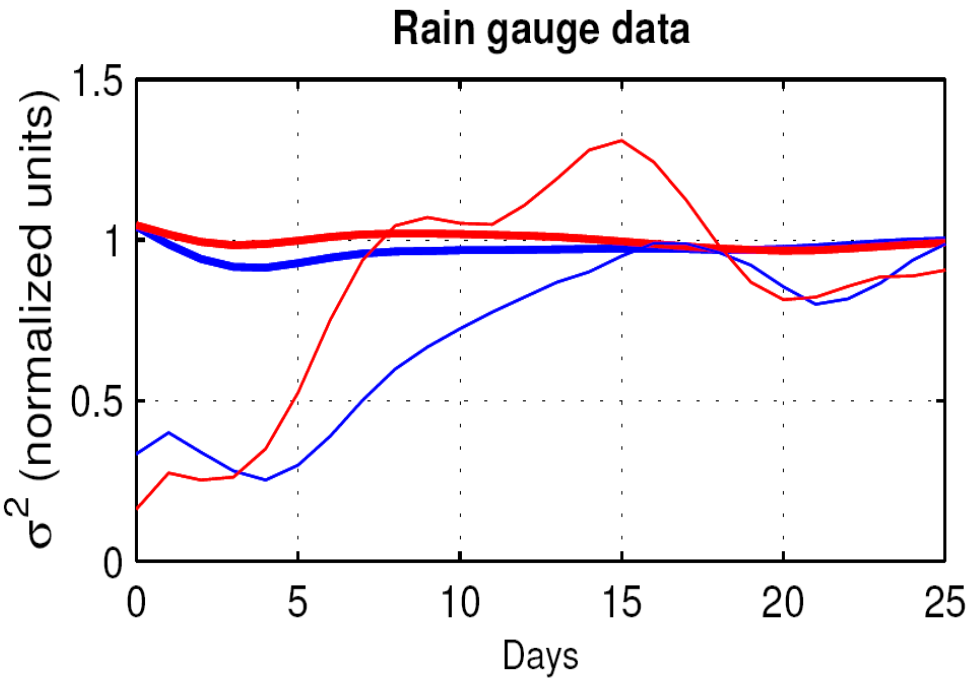


FIGURE 6.4: Same as Fig.6.3A, but for high resolution gridded daily rain gauge data (Rajeevan et al., 2006) for the JJAS season of 1951-2003, averaged over 70°-90°E, 18°-30°N.

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

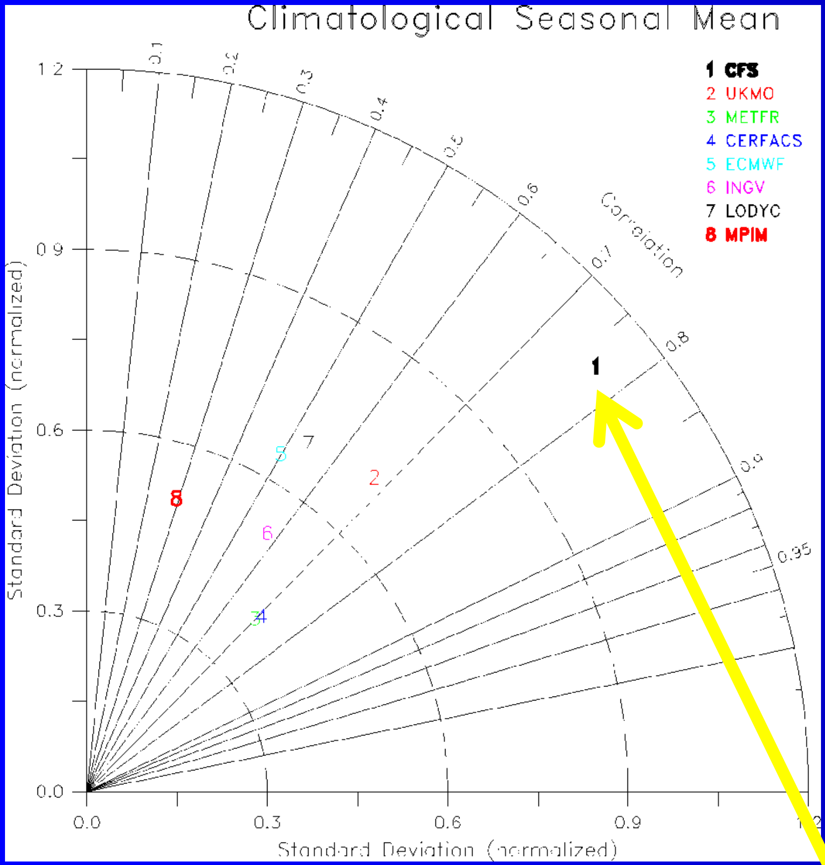
Target

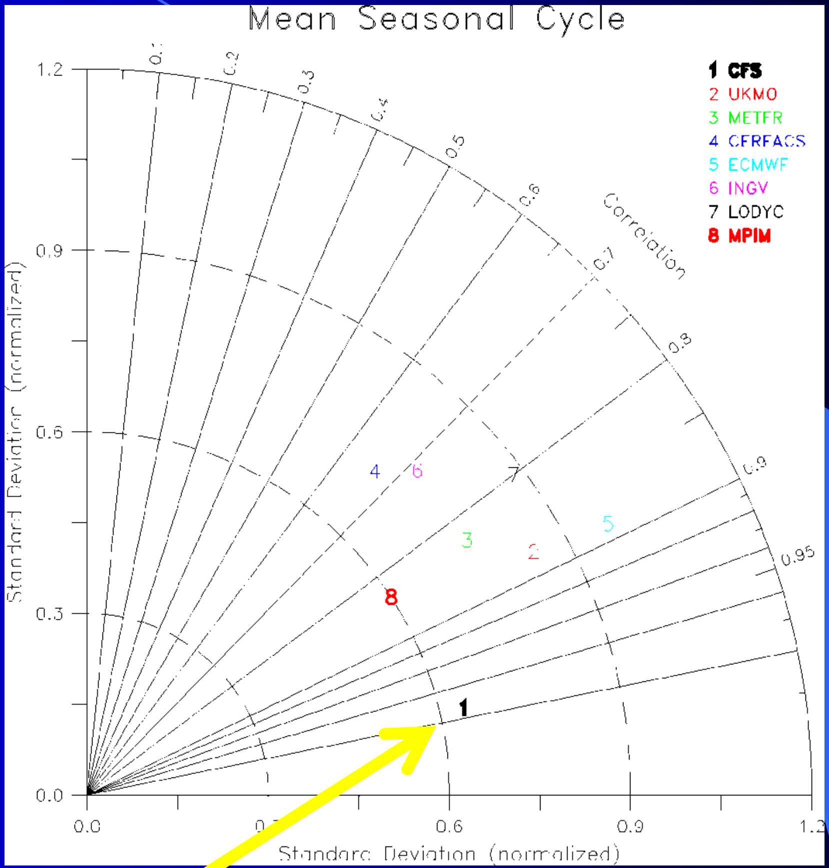
- **To achieve correlation between observed and predicted ISMR of 0.7!**
- **To achieve lead time of 25 days for 0.6 correlation between observed and predicted MISO index!**

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

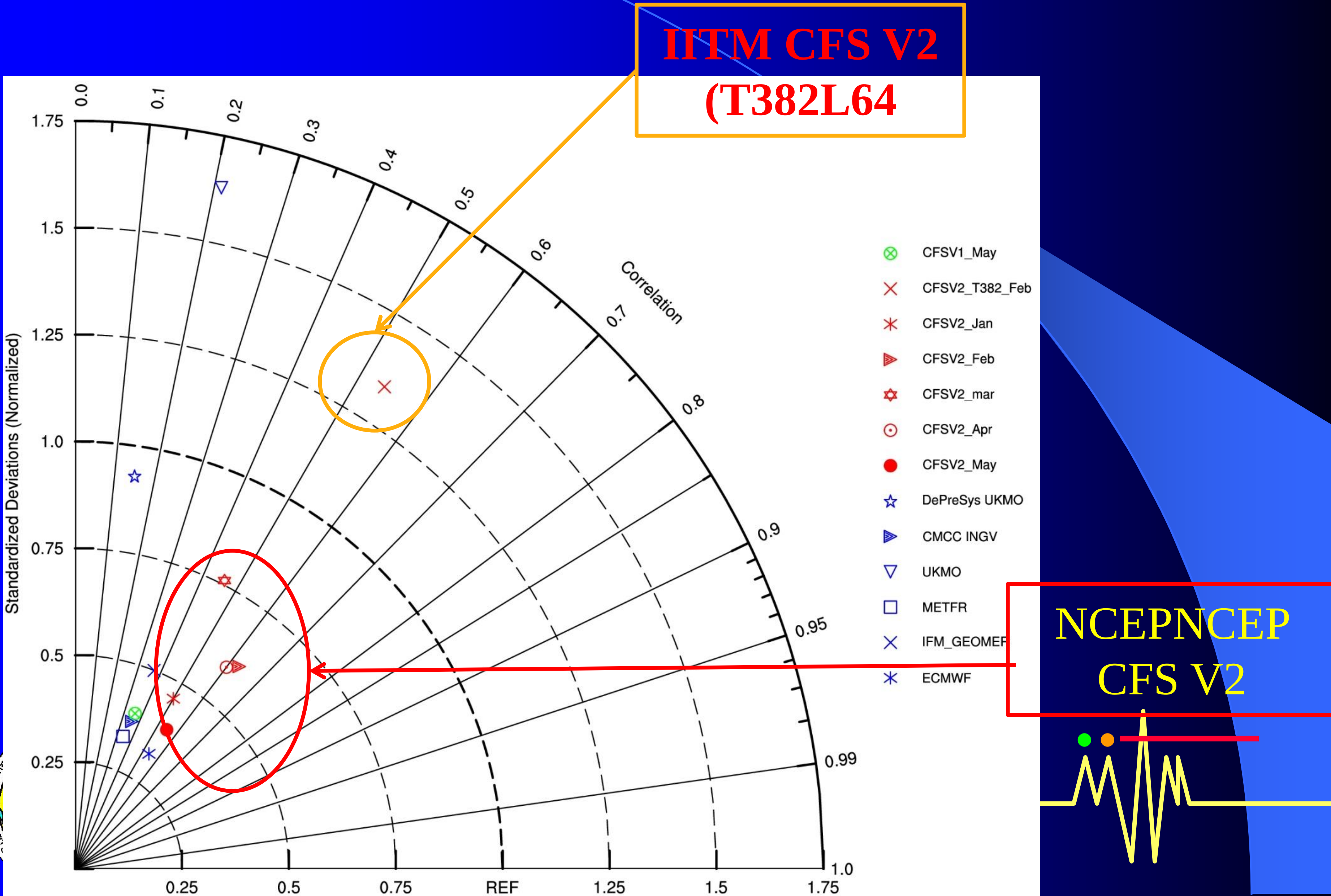
Skill of Various Models in Simulating the Climatological Seasonal Mean Monsoon





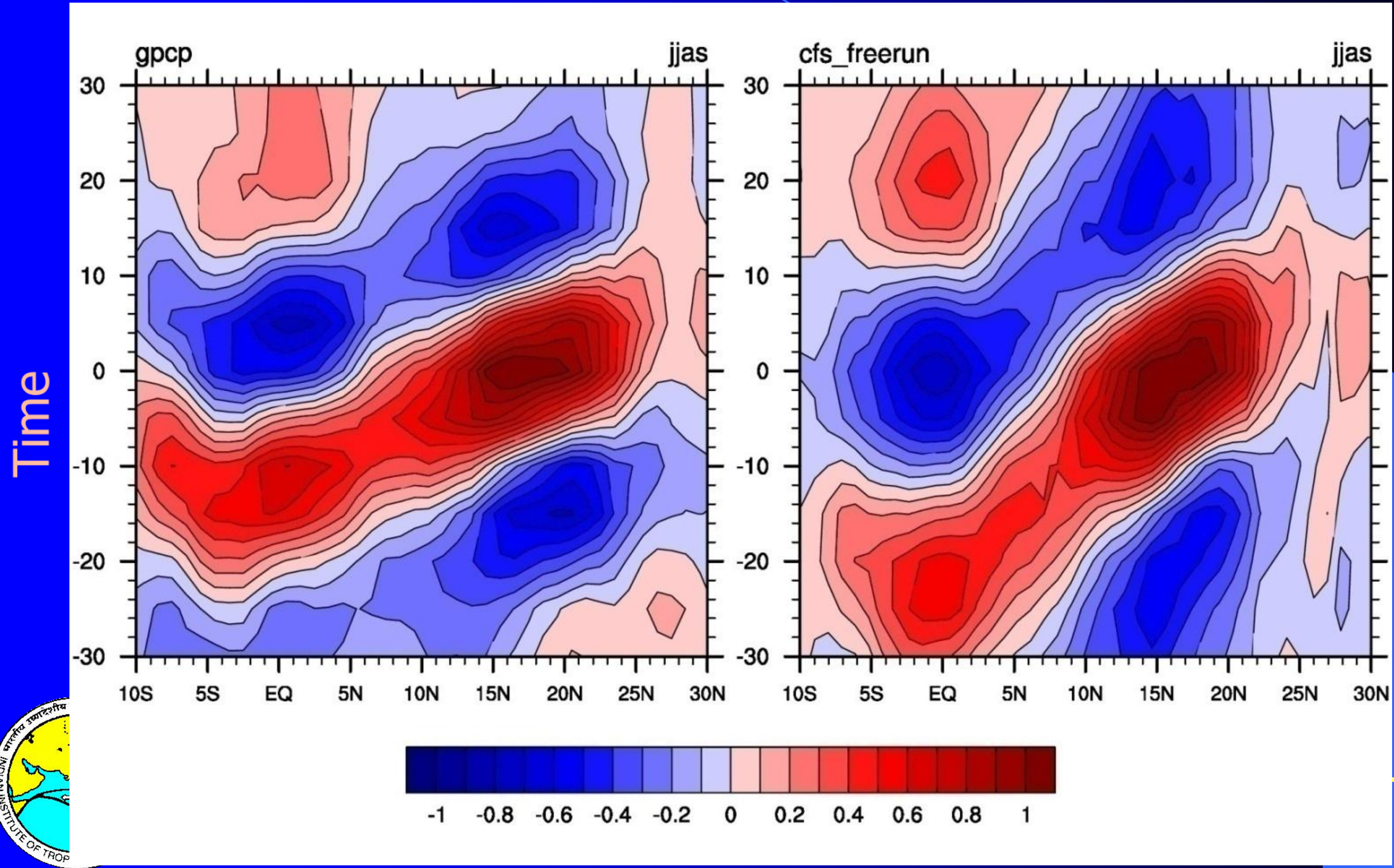
CFS Simulates Seasonal Cycle Better than Other Models

Hindcast skill of Indian Land Rainfall

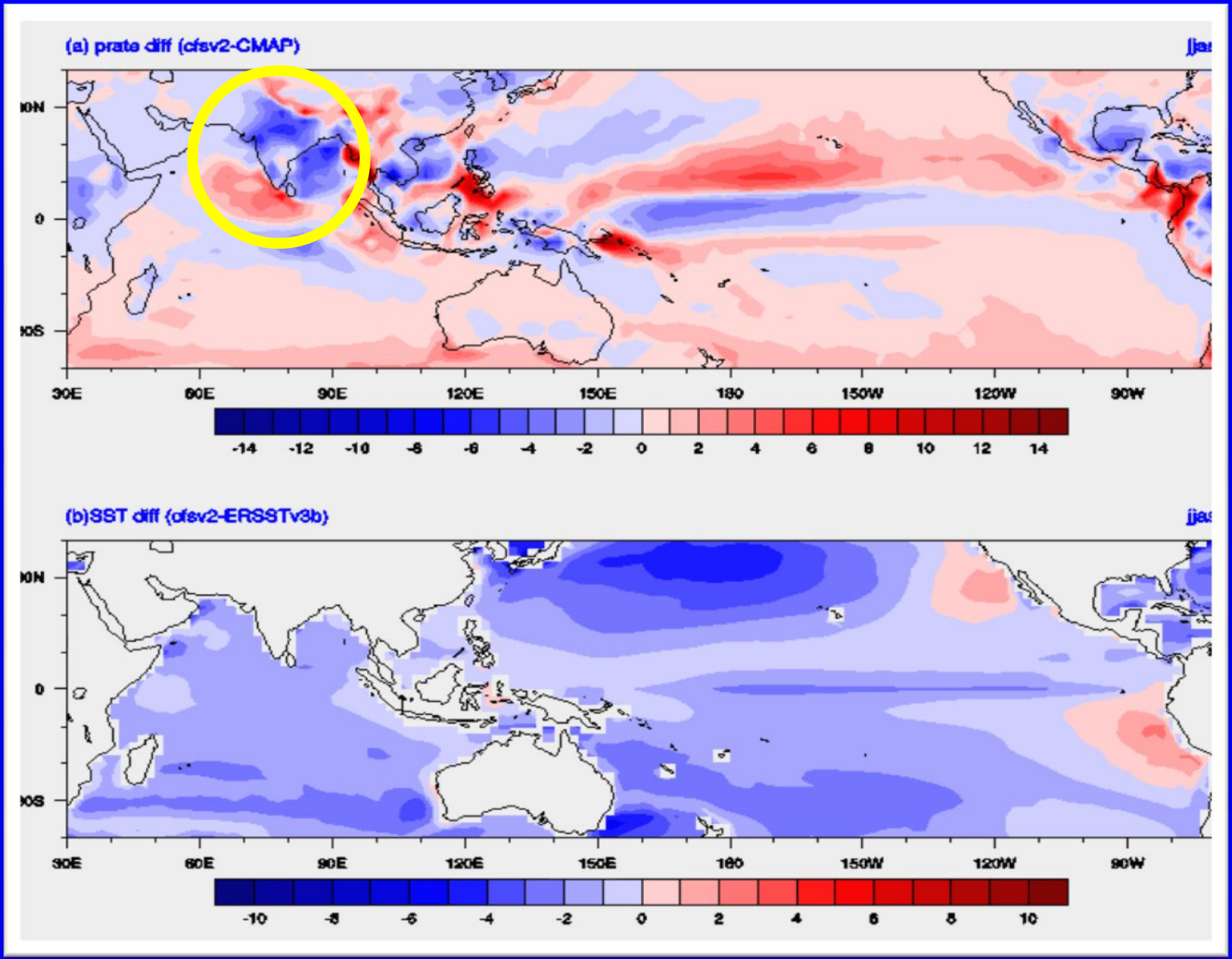


Good simulation of MISO by CFSv.2

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

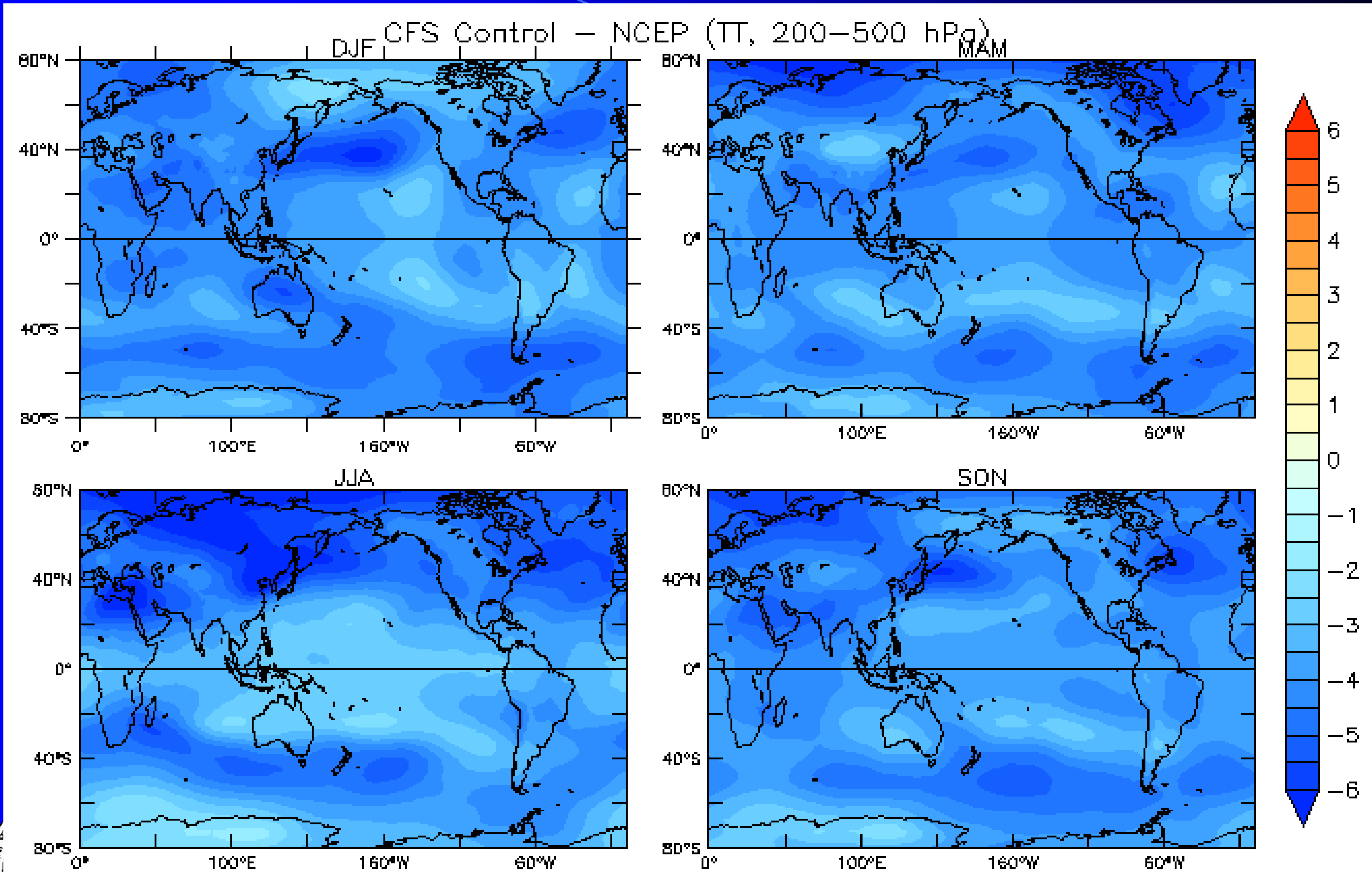


However, the model has significant dry bias over Indian land mass and cold SST bias!



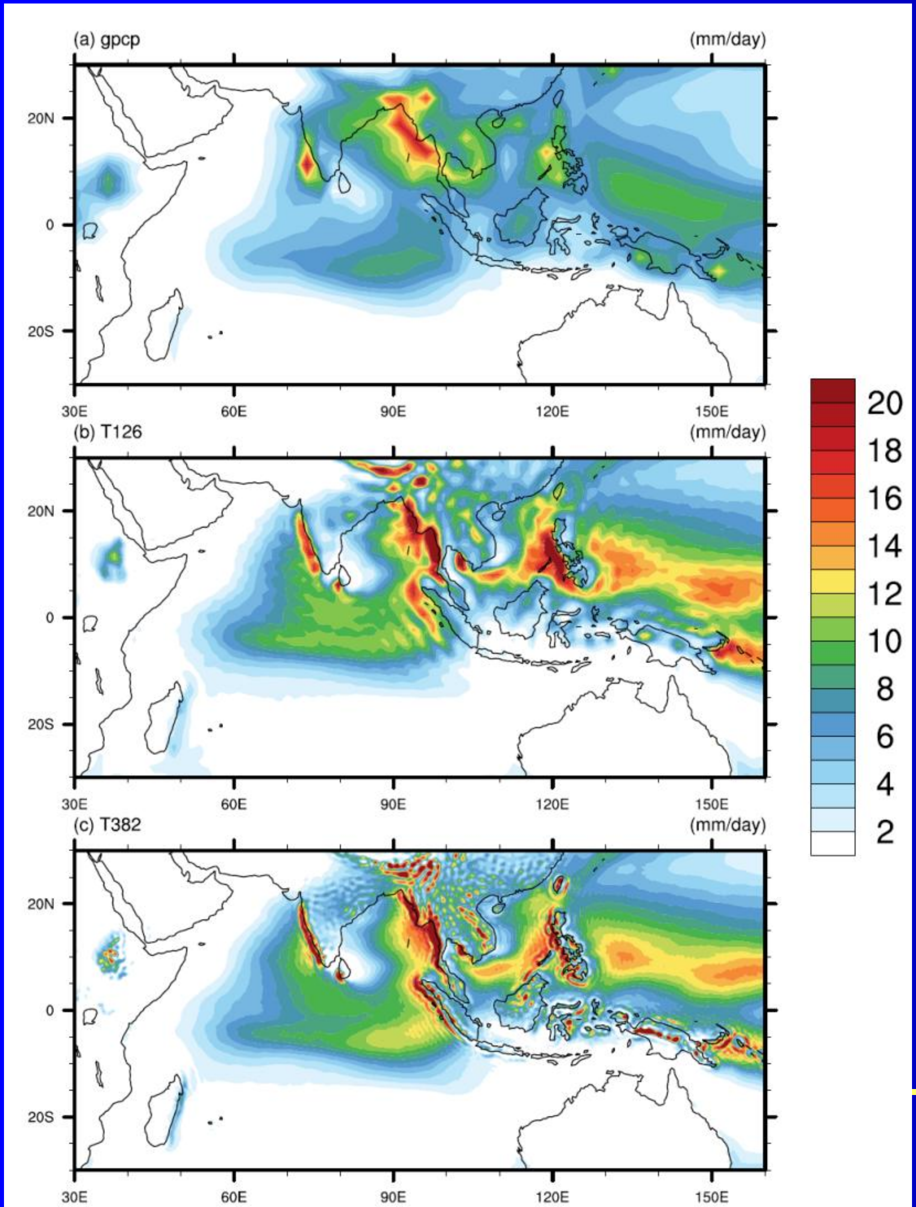
Last 20 years JJAS climatology difference between CFSv2 and Observation

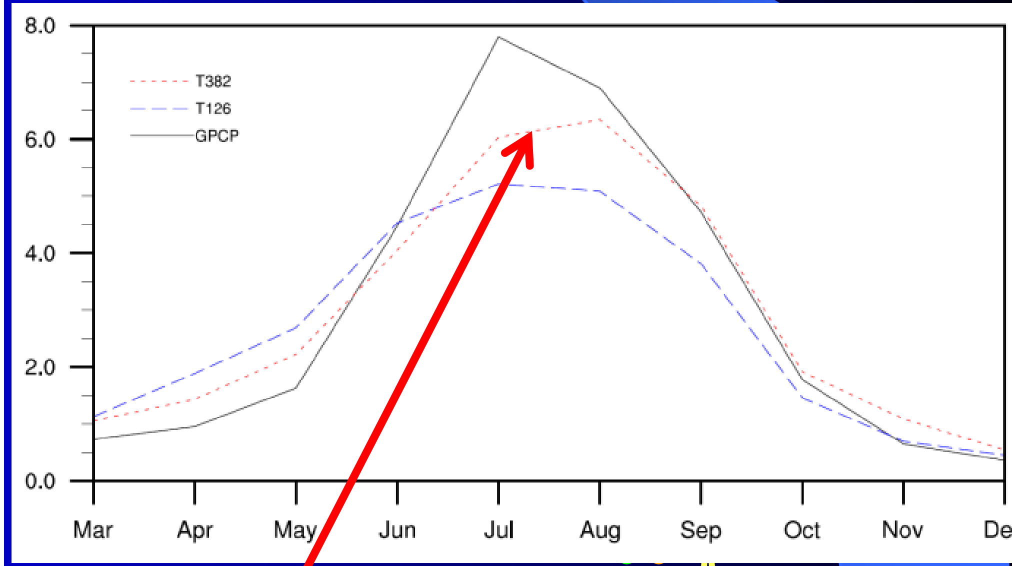
Difference in Tropospheric Temperature between model simulations and observations



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

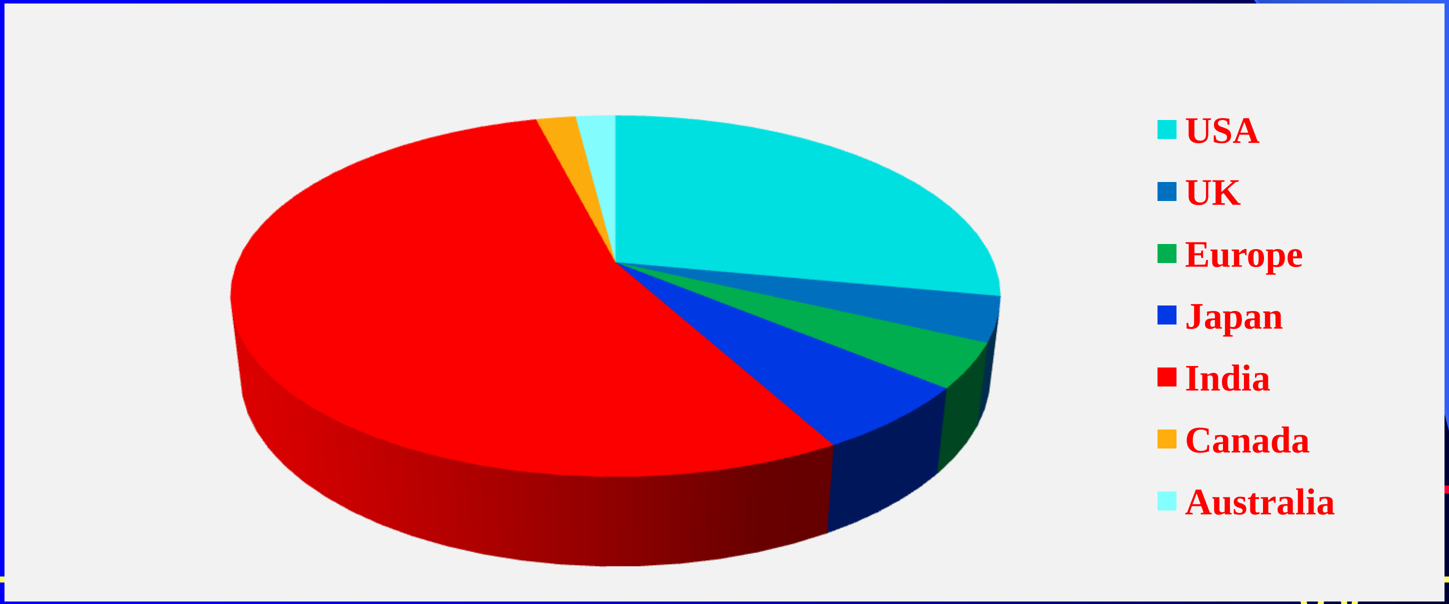
- To forge an working relationship with the Academic Community and engage the Community on improving the Operational Forecast System, **Open Call for funding Research Proposals** to
  - **Reduce the biases of the CFS model**
  - **To improve skill of prediction of seasonal mean monsoon as well as MISO**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

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

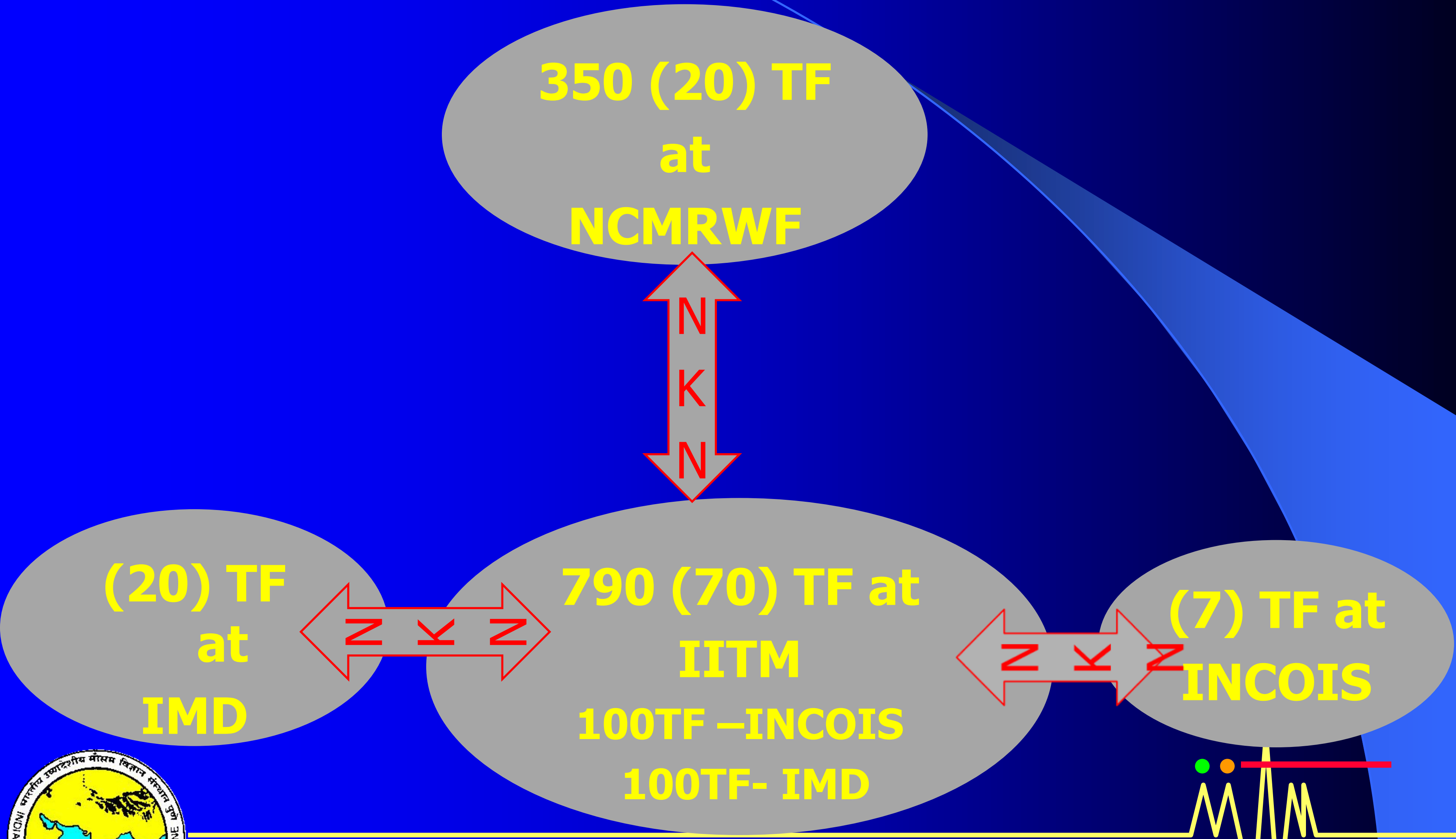
- Proposals Submitted: 50
- Proposals rejected: 16
- Proposals under considerations: 18
- Proposals funded: 16



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!



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
2011-2015	Carryout research on identified problems together with national/ international partners and review the progress made by external experts committee
2011-2015	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. An Indian Model!
2016	Review the progress made by the national mission

Thank You