“Mystery of Seasonal Indian Summer Monsoon Rainfall: Prediction Beyond the Conventional Estimate of Potential Predictability”

Contributors:

Subodh Kumar Saha, Anupam Hazra, Hemantkumar S. Chaudhari, Samir Pokhrel, K. Sujith, Archana Rai, Hasibur Rahaman and B. N. Goswami

IITM, Pune

28th March 2019 IMSP

Why we need skillful ISMR prediction?

✓One fifth of the world's population living in South Asia thrives on regular arrival of the summer monsoon.

✓**Agriculture, food production & economy critically depends on monsoon rain (Gadgil & Gadgil 2006).**

✓Deficient and excess monsoon have great impact on the economy and life in general.

✓**Skillful seasonal forecast has potential for high impact on agriculture and water resource management.**

✓Therefore, a reliable forecast of monsoon rainfall on the subseasonal (i.e., active-break cycle) to seasonal time scale (S2S) is important.

Climate model and prediction of ISMR

✓**Coupled global land-atmosphere-ocean model is essential for the simulation of ISM climate (Wang et al., 2005).**

✓**A dry bias in simulating JJAS precipitation over monsoon region is a generic problem (Rajeevan and Nanjundiah, 2009) and limits the skill.**

Hope: Skill of present generation model (Rajeevan et al., 2012) higher than the earlier generation (models (Krishnakumar et al., 2005) → indicate that improvement of models lead to improvement of skill.

However, it remained a grand challenge. Even today all model skill is rather limited!!

Challenges in Simulating the mean of the Indian Monsoon and seasonal prediction:

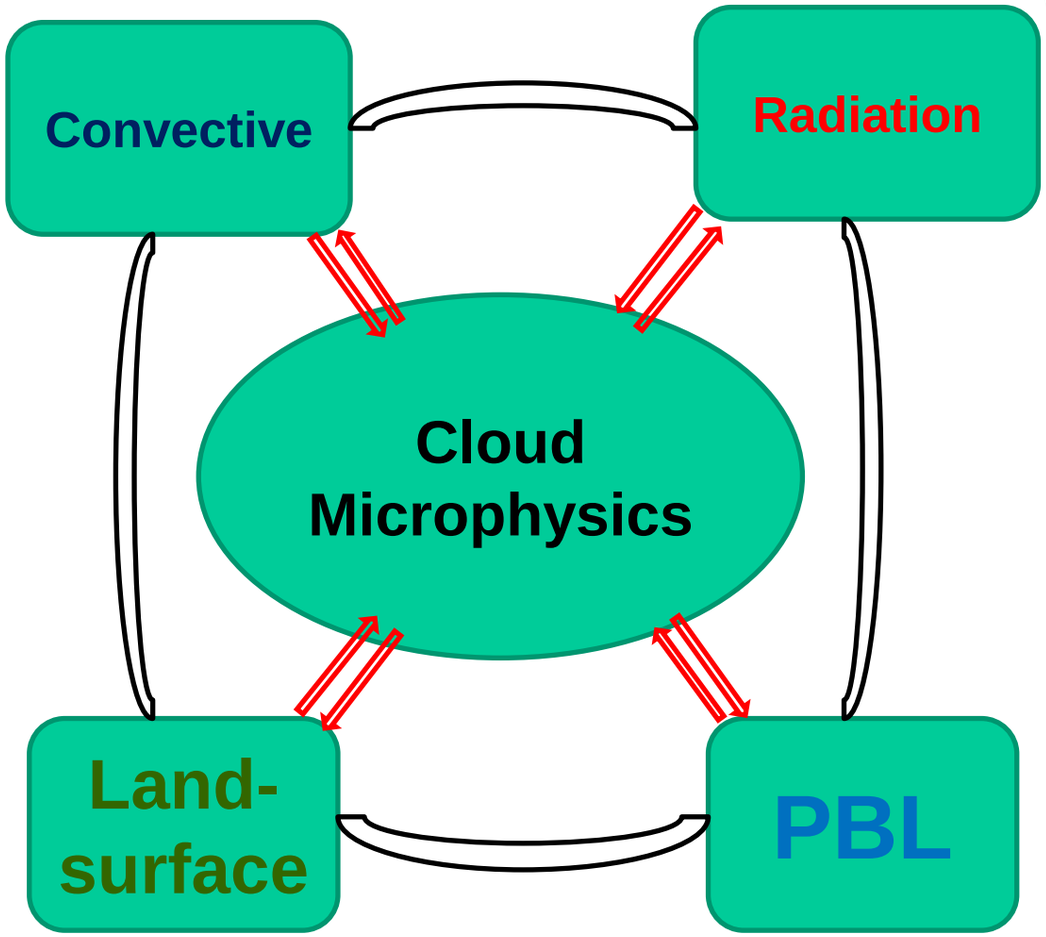
❖ **Conceptual basis for prediction skill beyond the limit of potential predictability**

❖ **Targeted improvement of Simulation and Prediction of the Indian monsoon**

Outlines

- ➔ **Identification of major areas of model development**
- ➔ **Development of snow physics & cloud microphysics**
- ➔ **Fundamentals of ISMR predictability**
- ➔ **Potential predictability & re-forecast skill**
- ➔ **Future scope**

Flow chart of Model Development



Find out the biases for ISM

Saha et al., 2013, 2014
Hazra et al., 2015, 2016
Pokhrel et al., 2012
Chaudhari et al., 2016
Goswami et al., 2016
Rai et al., 2017

Indentify the role of cloud/Land surface processes

De et al., 2016, 2019
Saha et al., 2013
Hazra et al., 2015, 2016

Modification in convective-microphysics code

Hazra et al., 2017

Modify Snow scheme

Saha et al., 2017

Combined modified convective microphysics and new snow scheme

Saha et al., 2019

Development

Saha et al., 2017
Hazra et al., 2017

Long Free run simulation

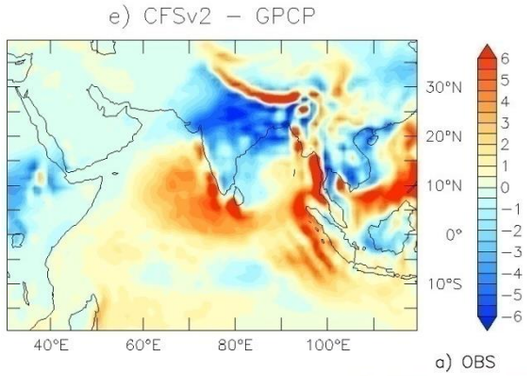
Saha et al., 2019
Pokhrel et al., 2018

Rectrospective/ Hindcast Run

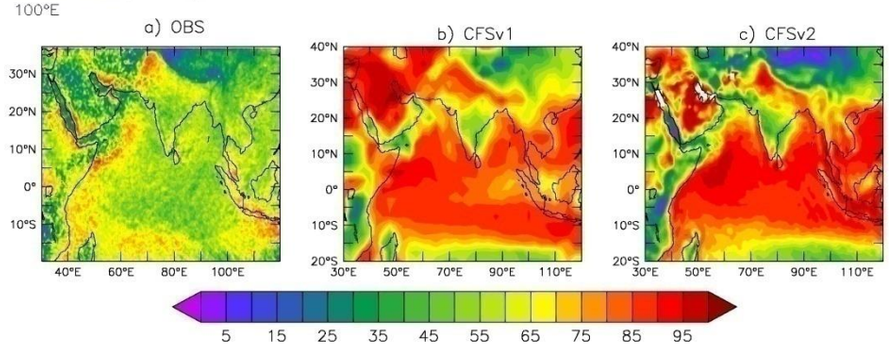
Identification of Major Areas of Model Development

Diagnostic of CFSv2 Freerun

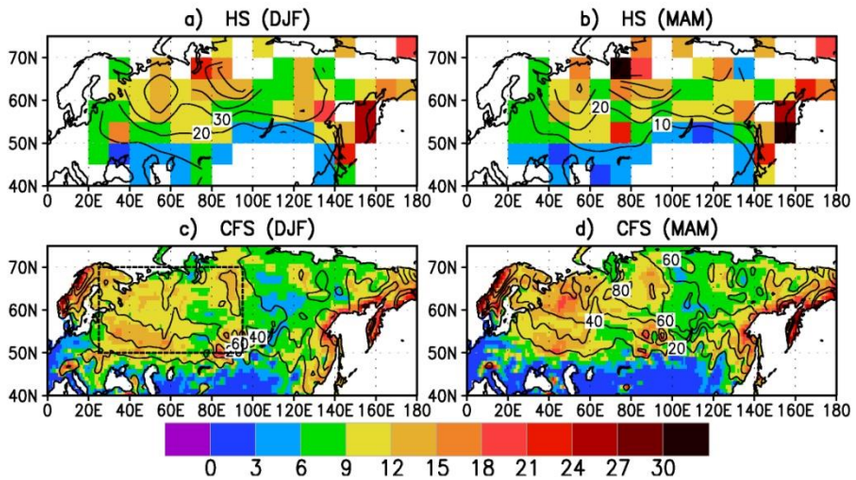
… set up the CFSv2 in 2010 in IITM HPC



dry bias in ISMR



too much convective rain



twice of observed snow

cold bias in SST land and troposphere; slow northward propagation; very high snow aledo; moderate ISMR skill

Pokhrel et al., 2012; Saha et al., 2013; Saha et al., 2014; Goswami et al., 2014; Rai et al., 2017

Development of Snow Physics

A Multilayer Complex Snow Scheme

AGU PUBLICATIONS

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE

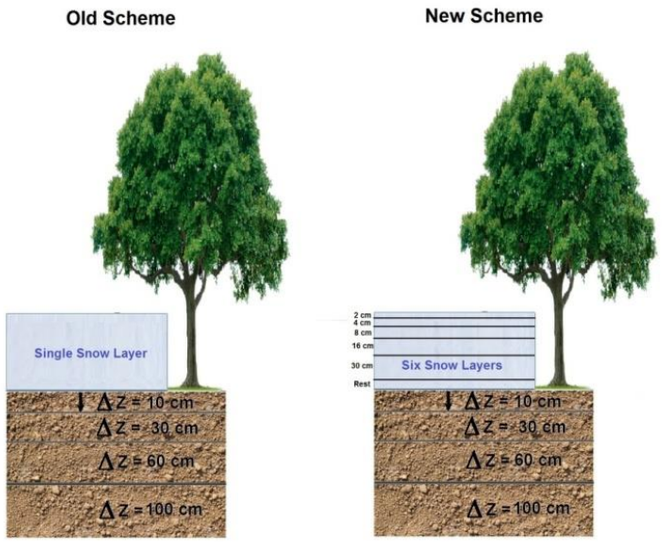
10.1002/2016MS000845

Effects of multilayer snow scheme on the simulation of snow: Offline Noah and coupled with NCEP CFSv2

Subodh Kumar Saha[1], K. Sujith[1,2], Samir Pokhrel[1], Hemantkumar S. Chaudhari[1], and Anupam Hazra[1]

[1]Indian Institute of Tropical Meteorology, Pune, India, [2]Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India

Key Points:
- Multilayer (maximum six layers) snow scheme is implemented in the land surface model Noah
- The modified Noah is coupled with NCEP CFSv2
- Large improvement found in the



➔**A dramatic improvement in snow depth**

➔**Dry bias over India decreased by ~2 mm/day**

$$H_i = -\alpha F_{skin}^{n} - (1-\alpha) F_{skin}^{n+1} + \alpha F_i^n + (1-\alpha) F_i^{n+1} - \frac{C_i \Delta Z_i}{\Delta t}(T_f - T_i^n) \text{ for top layer}$$

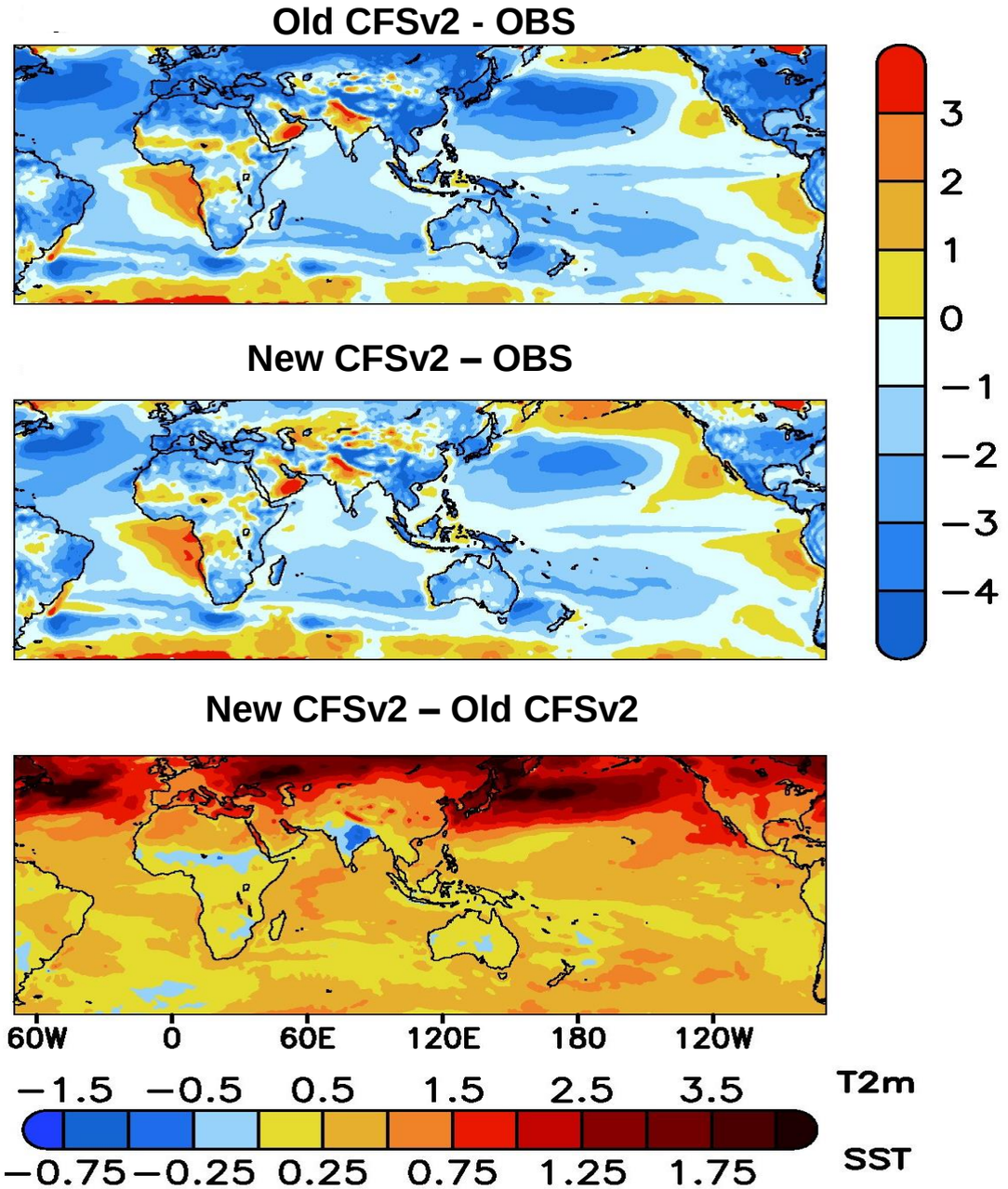
$$H_i = -\alpha F_{i-1}^{n} - (1-\alpha) F_{i-1}^{n+1} - \frac{C_i \Delta Z_i}{\Delta t}(T_f - T_i^n) \text{ for bottom layer}$$

$$H_i = \alpha (F_i^n - F_{i-1}^n) + (1-\alpha)(F_i^{n+1} - F_{i-1}^{n+1}) - \frac{C_i \Delta Z_i}{\Delta t}(T_f - T_i^n) \text{ for other layers}$$

Heat flux through snow layers

… introduced a max. of 6-layer snow scheme in Noah, CFSv2

Improvements in Cold Bias

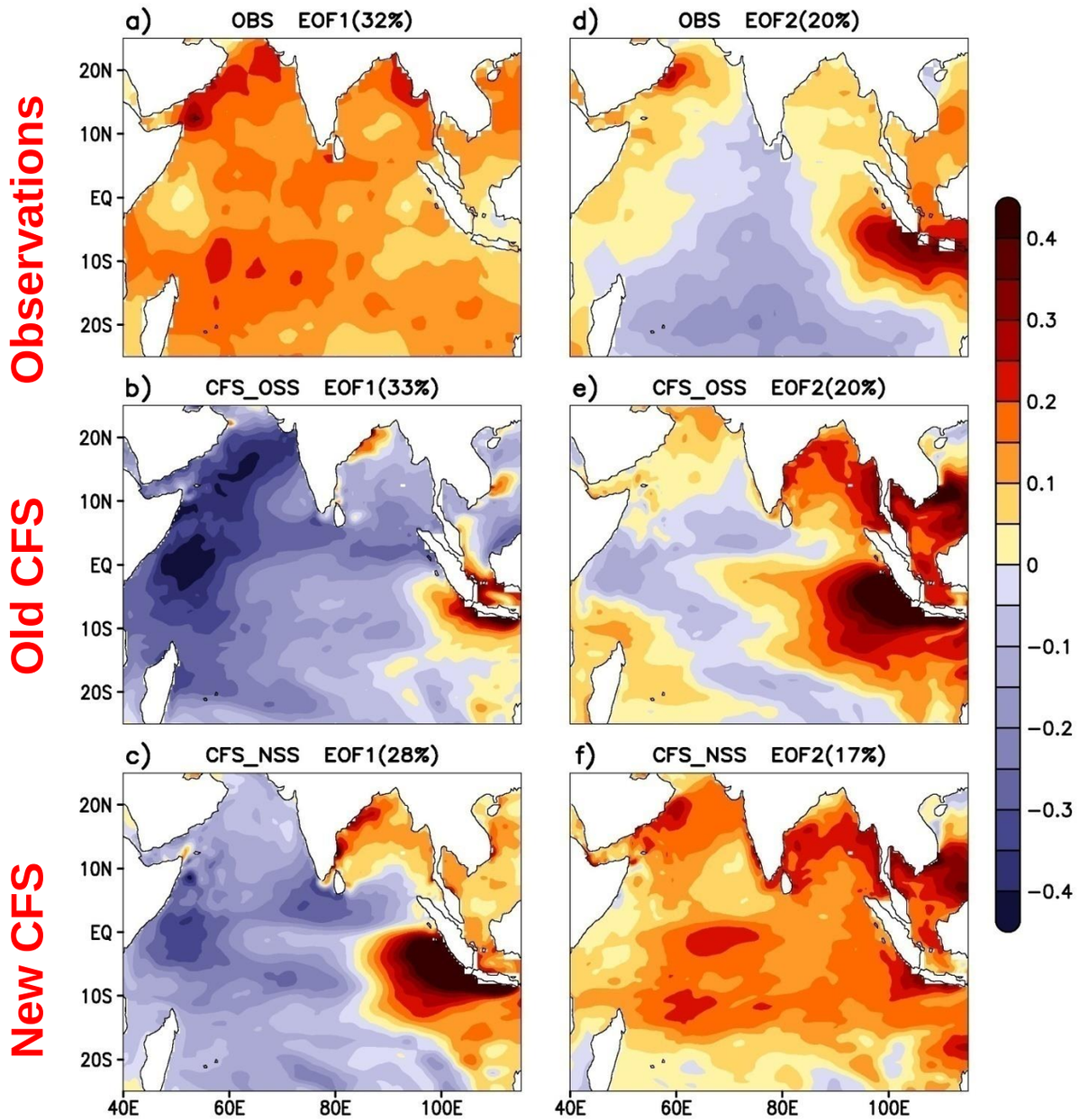


➔Cold bias over land and Ocean is decreased

➔Improvements lead to decrease in North-South temperature gradient

Sujith et al., 2019; QJRMS

Improvements in Oceanic Modes



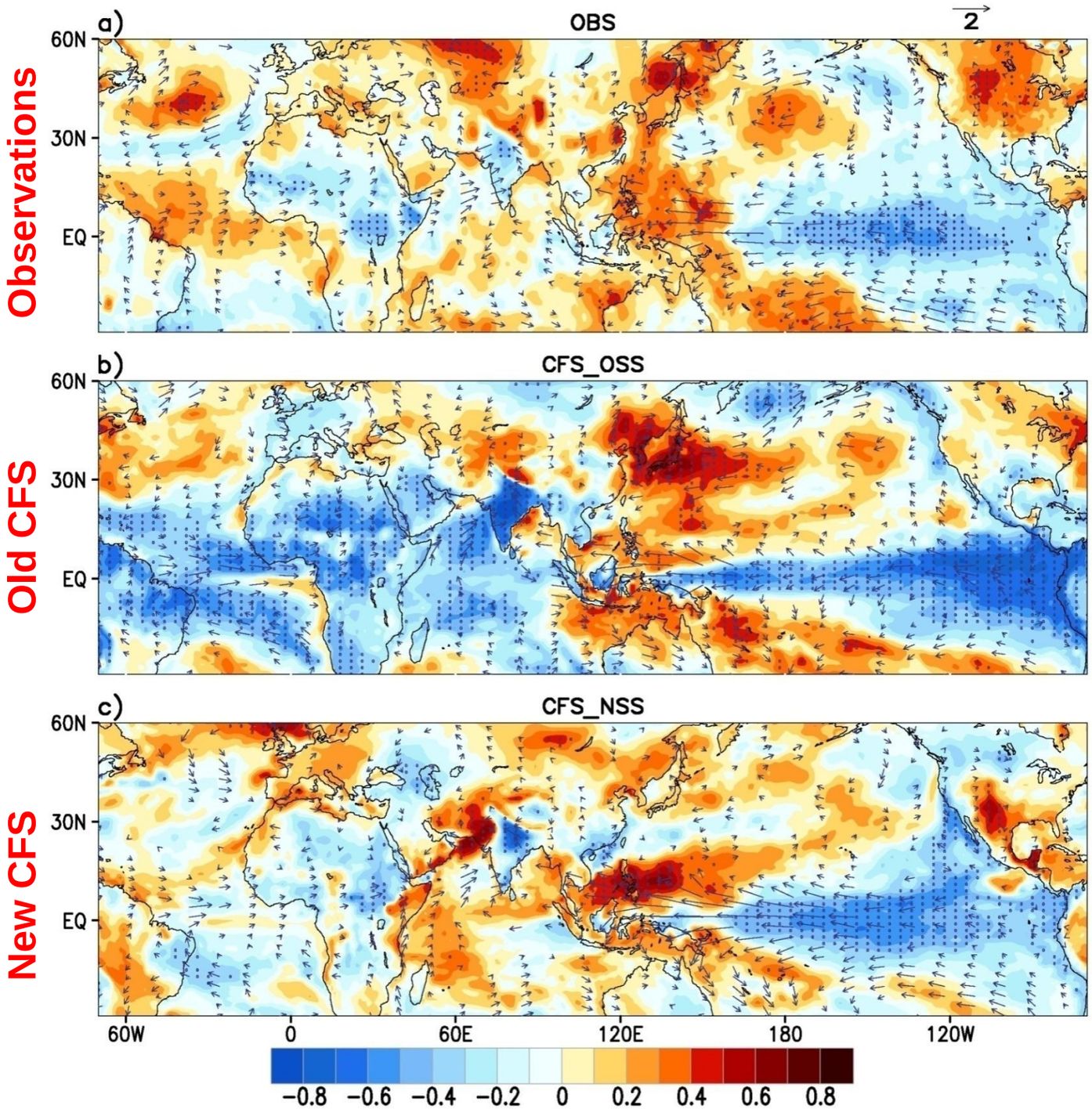
➔ **Decrease in cold SST bias leads to improve air-sea interactions, which is evident through improvements in the oceanic modes of variability.**

➔ **In CFSv2 with new snow scheme, basin wide same sign appeared as 2nd mode.**

➔ **Notable improvements are also evident in equatorial Pacific (ENSO, Modiki) and north sub-tropical Pacific (PDO)**

Sujith et al., 2019; QJRMS

Global Teleconnections of ISMR



ISMR correlated with SST, 2m Temperature & Regressed with 850 hPa Winds

	Nino3.4	Nino3	IOD	EQWIN
OBS	-0.41	-0.42	0.24	0.37
Old CFSv2	-0.58	-0.70	-0.29	-0.08
New CFSv2	-0.56	-0.50	0.23	0.26

Correlation between ISMR & various indices

Sujith et al., 2019; QJRMS

Development of Cloud Microphysics

AGU PUBLICATIONS

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE

10.1002/2017MS000966

Key Points:

- A physically based modified convective microphysics scheme is implemented in the NCEP CFSv2
- The convective microphysics is found to be important for simulating the observed monsoon intraseasonal oscillations (MISOs)

Progress Towards Achieving the Challenge of Indian Summer Monsoon Climate Simulation in a Coupled Ocean-Atmosphere Model

Anupam Hazra[1], Hemantkumar S. Chaudhari[1], Subodh Kumar Saha[1], Samir Pokhrel[1], and B. N. Goswami[2]

[1]Indian Institute of Tropical Meteorology, Pashan, Pune, India, [2]Cotton College State University, Guwahati, India

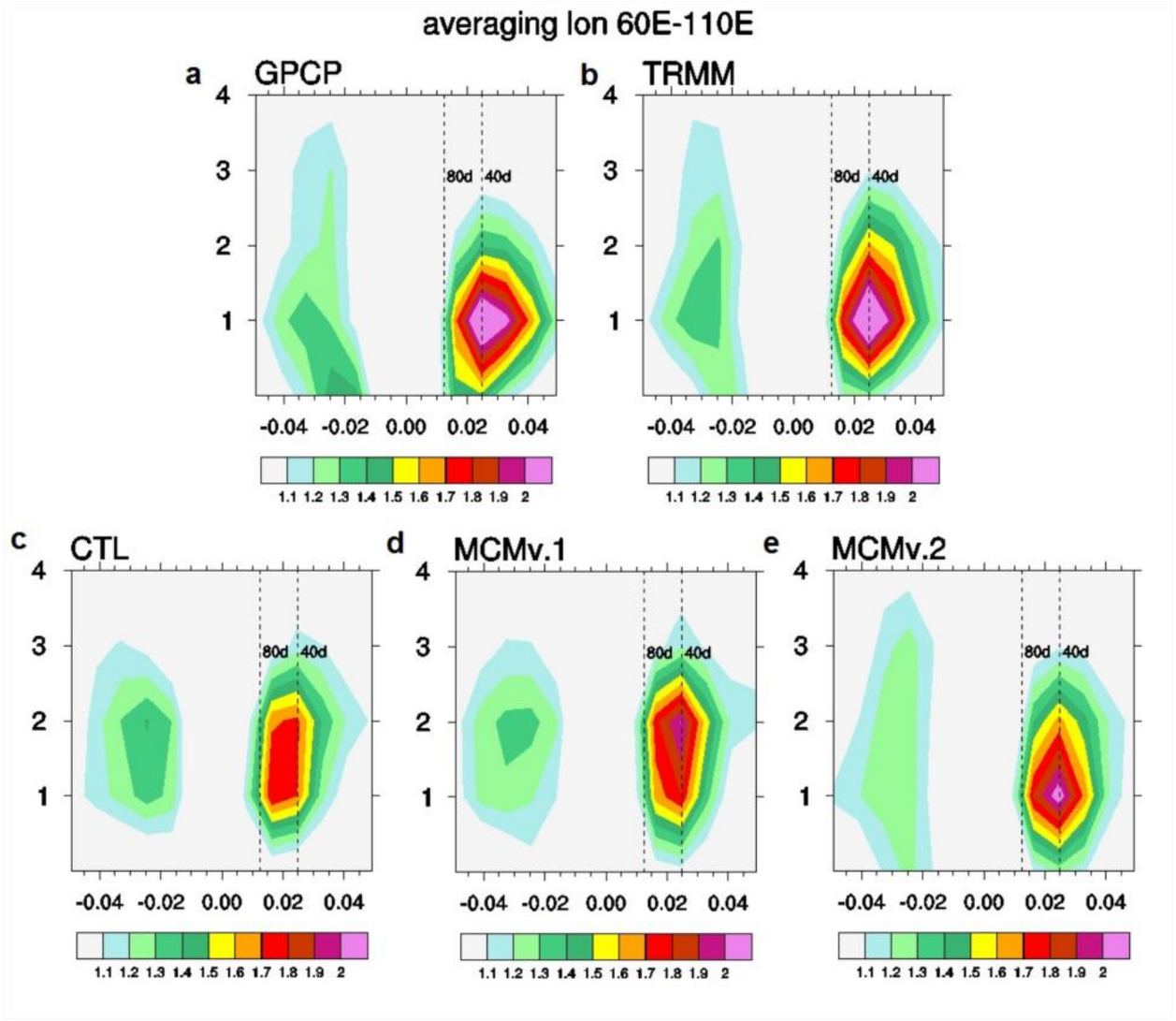
Physically based parameterizations of the various cloud microphysical processes (conversion of cloud water to rain water, cloud water to ice and snow, snow to rain water) are modified for a strong linkage between the convection and microphysics parameterization schemes.

A modification of partitioning of cloud water and ice in the convective scheme.

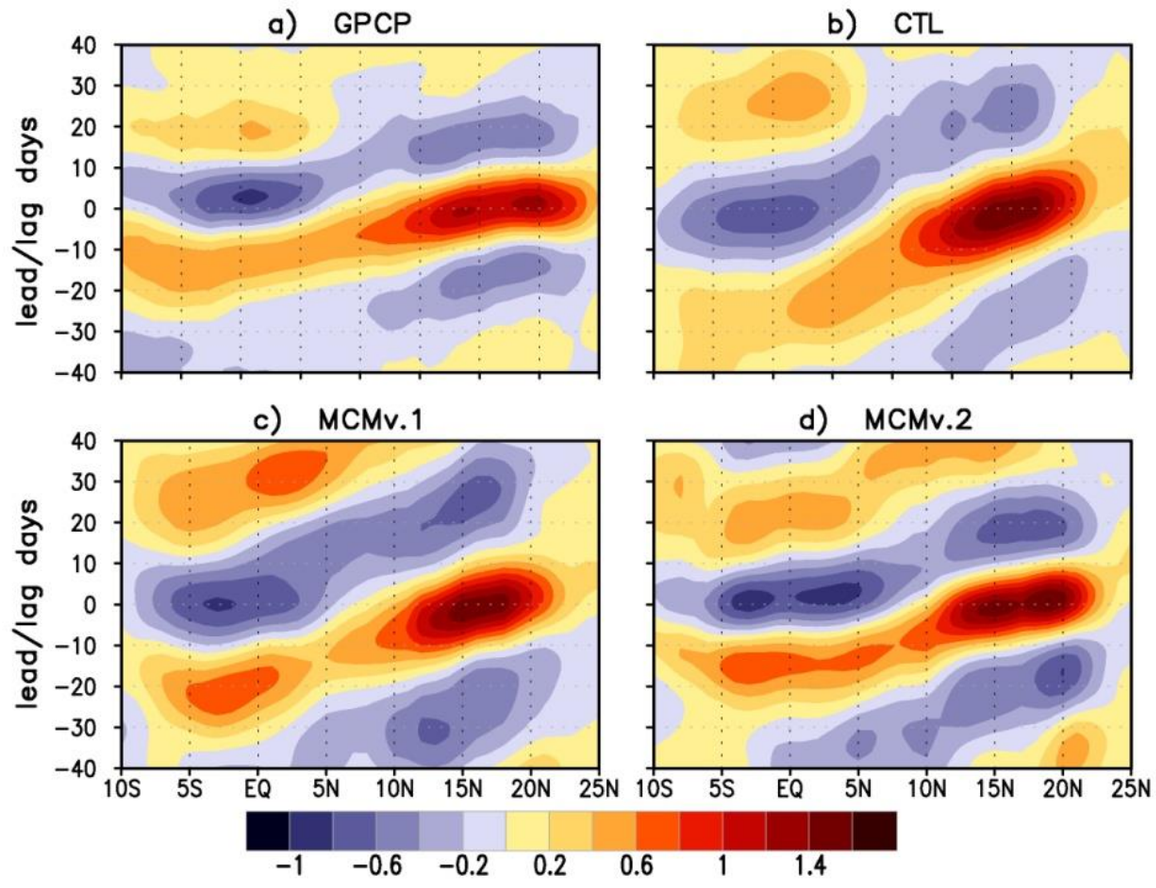
An explicit feedback between large-scale condensation and cumulus convection parameterization.

Simulation of MISOs

MCMv.1 → Modified Convective Microphysics with SAS
MCMv.2 → Modified Convective Microphysics with new SAS



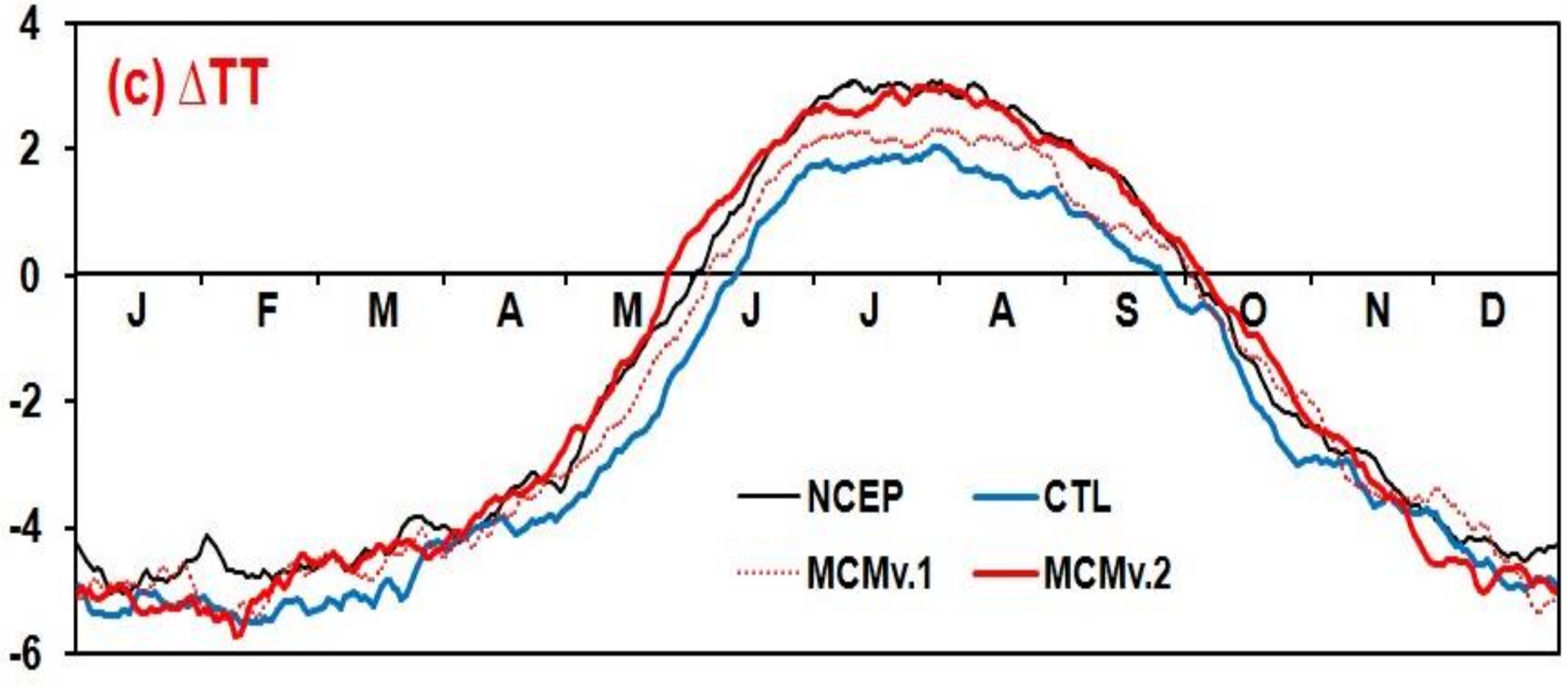
Space-Time Spectra (30-60 days)



Northward Propagation (20-100 days)

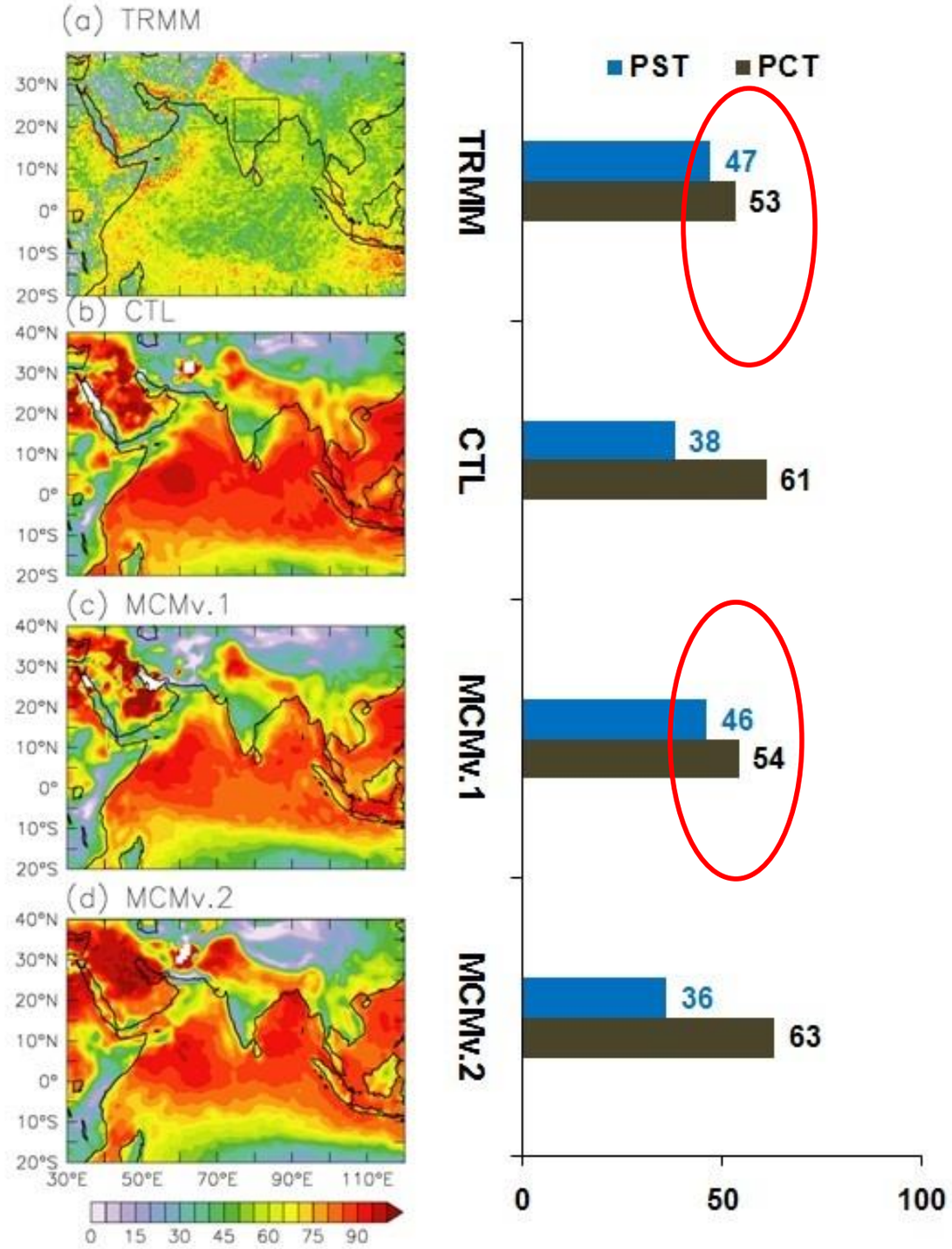
Hazra et al., 2017; JAMES

Tropospheric Temperature Gradient



Percentage of Convective and Stratiform Rain w.r.t Total

Convective to Total



➔**Contribution of stratiform rainfall to the total rainfall over India is improved in MCMv.1 as compared to that in MCMv.2**

What is the skill of ISMR ?

Actual and Potential Skill

JGR Atmospheres

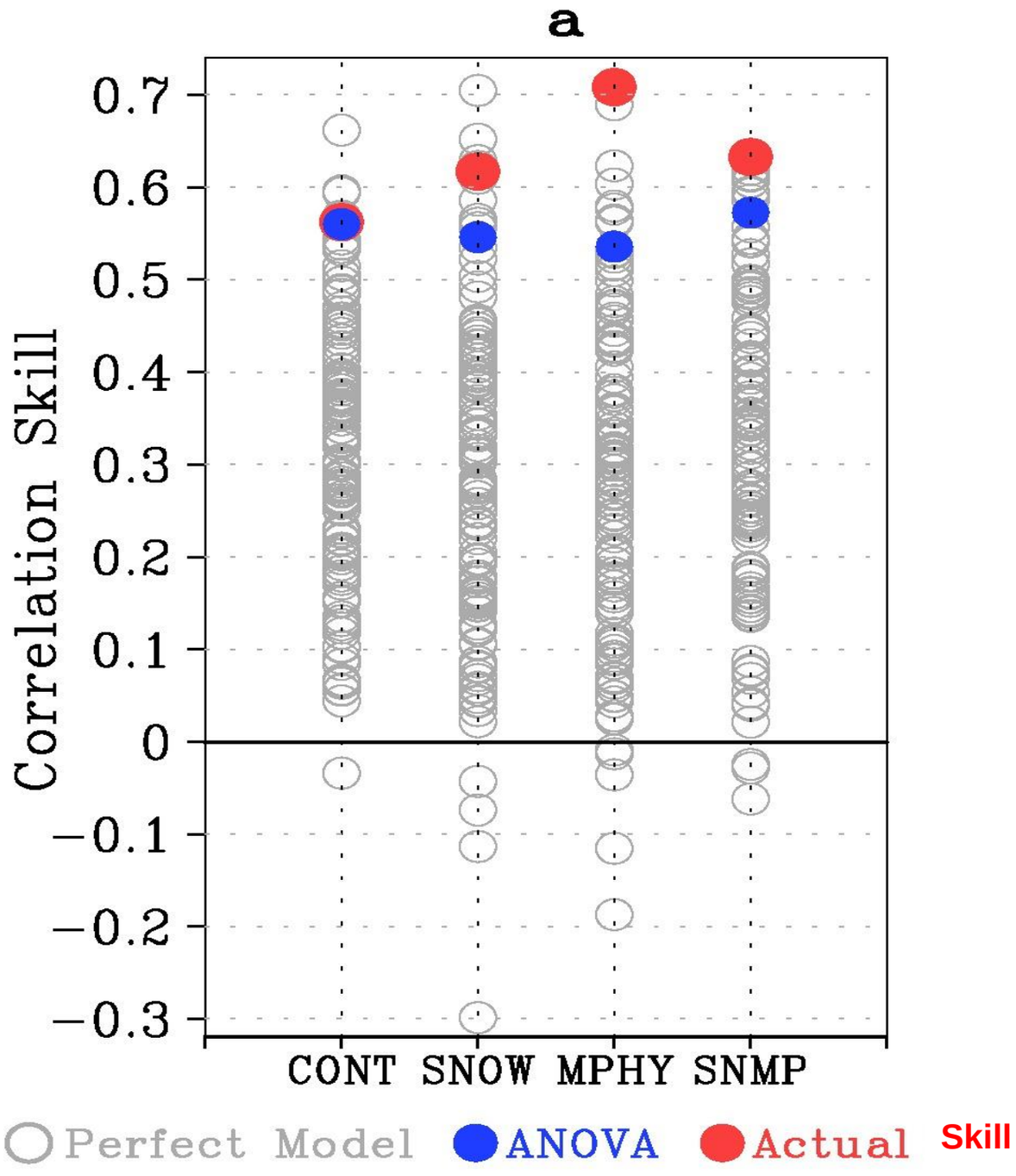
RESEARCH ARTICLE
10.1029/2018JD030082

Key Points:
- The observed link between synoptic variability and predictable modes suggest a high predictability of the ISMR
- CFSv2 with improved physics shows ISMR prediction skill higher than current estimate of potential predictability

Unraveling the Mystery of Indian Summer Monsoon Prediction: Improved Estimate of Predictability Limit

Subodh Kumar Saha[1], Anupam Hazra[1], Samir Pokhrel[1], Hemantkumar S. Chaudhari[1], K. Sujith[1], Archana Rai[1], Hasibur Rahaman[2], and B. N. Goswami[3]

[1]Indian Institute of Tropical Meteorology, Pune, India, [2]Indian National Centre for Ocean Information Services, Hyderabad, India, [3]Department of Physics, Cotton University, Guwahati, India



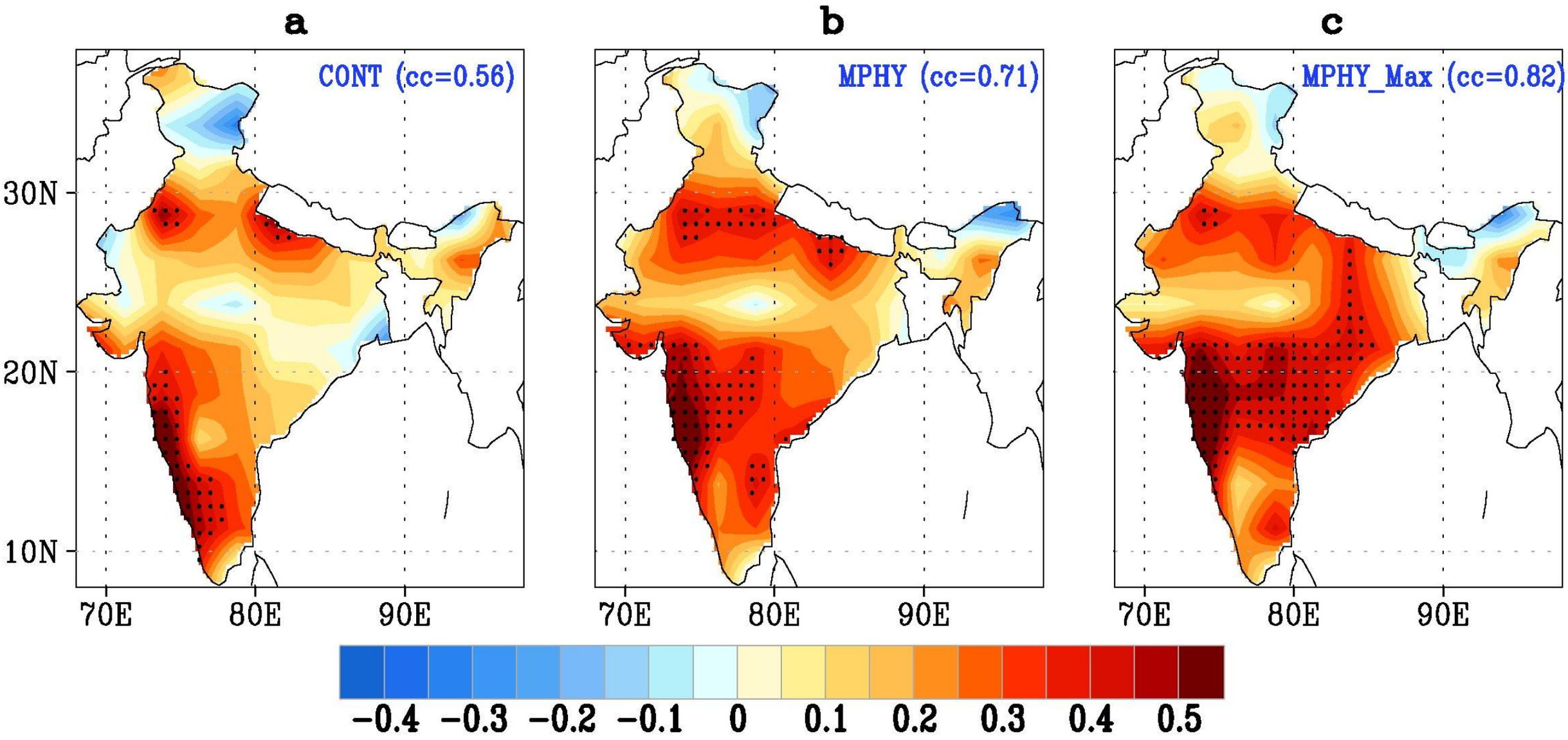
CONT=0.56; SNOW=0.61;
MPHY=0.71; SNMP=0.63;

16 ensemble members for 30 years (1981-2010)

CONT→ *Suru. Saha et al.*, 2014
SNOW→ *Saha et al.*, 2017
MPHY→ *Hazra et al.*, 2017

Saha et al., 2019; JGR

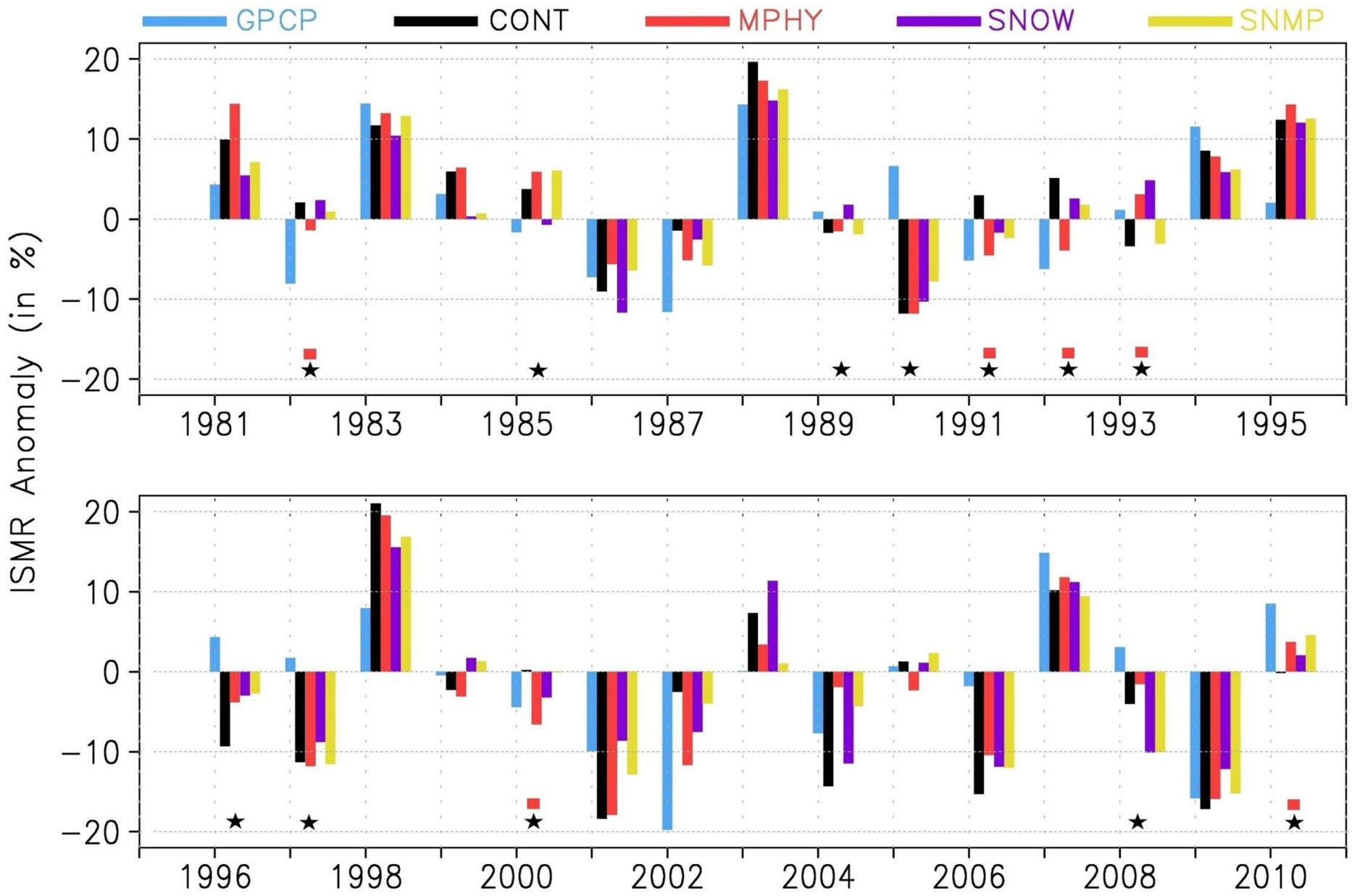
Spatial Correlation Skill



A reliable seasonal forecast on regional scale with further improvements of the model physics and data assimilation is going to be a future challenge!

Saha et al., 2019; JGR

ISMR Anomaly



Notable improvements in non-ENSO years

Saha et al., 2019; JGR

How the skill of ISMR improved ?

Is it possible to cross/exceed the potential limit of predictability ?

Basic Facts and Hypothesis

The seasonal monsoon rainfall is a cumulative effects of rain events (i.e., synoptic, active and break).

How much the variability of rainfall on synoptic and intra-seasonal time scale contributes to the seasonal monsoon rainfall anomaly ? Are they predictable ?

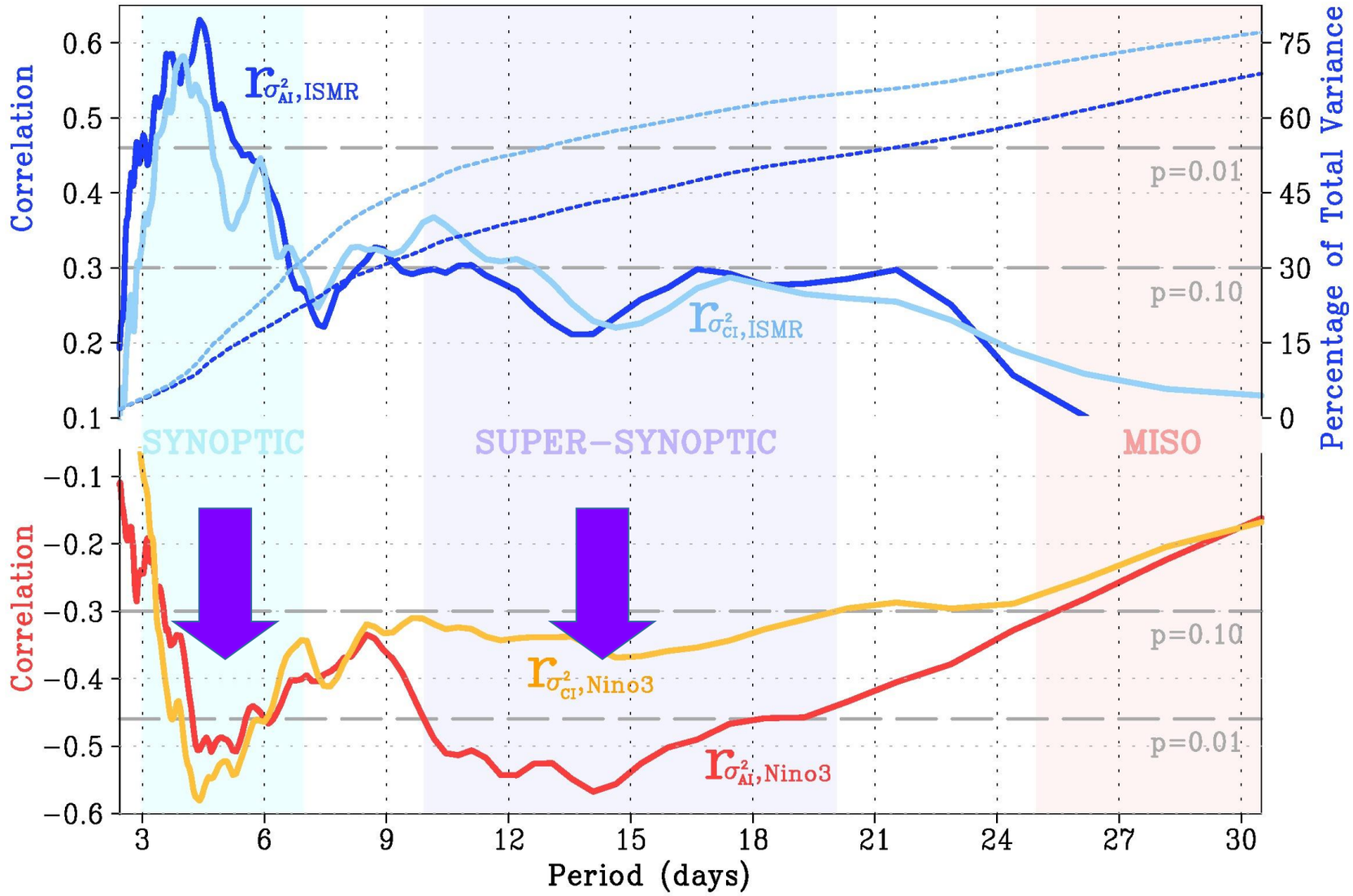
In principle, any predictors affecting the seasonal anomaly may leave their signature on the building blocks of the monsoon (e.g., vigor of synoptic activity, MISOs)

But ……...

In general, synoptic and intra-seasonal variability are considered unpredictable/noise in the context of seasonal prediction of the ISMR.

A continuous spectrum of sub-seasonal contribution to the seasonal anomaly in relation with predictors may be an another way to understand predictability of the ISMR.

Variances of AI/CI rainfall in relation with IMSR & Nino3

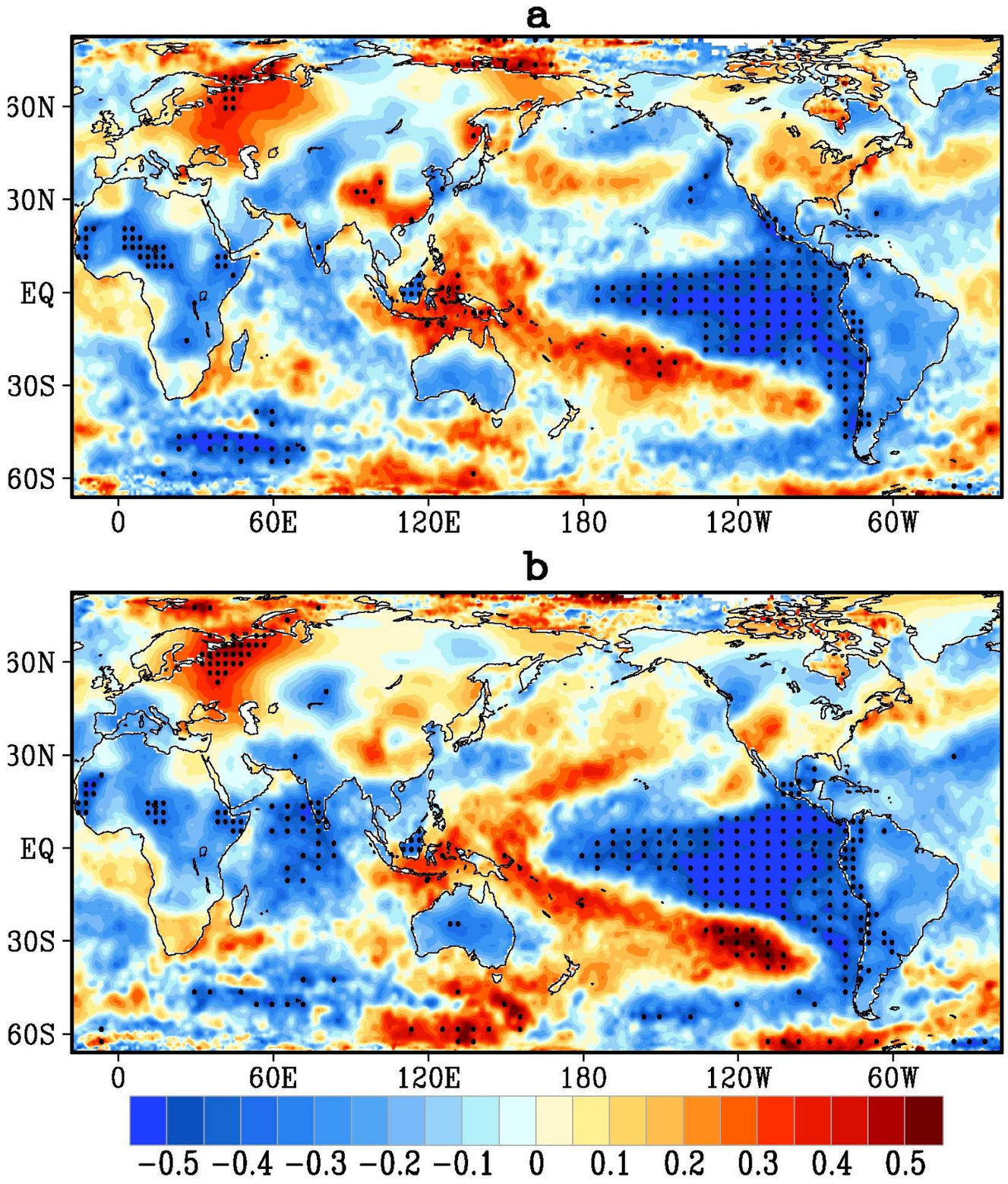


Harmonics (4-150th) are removed one-by-one and variances are correlated with ISMR/Nino3 (e.g., removal of 4th, 5th, 6th harmonics will retain periodicity less than 91.25, 73, 60.8 days respectively)

- ➔ **Synoptic activity have maximum contribution to the ISMR anomaly**
- ➔ **Synoptic and MISOs are part of predictive signal and not NOISE!**
- ➔ **ISMR predictability likely to be much higher than ever we believed!**

Saha et al., 2019; JGR

Correlation of ISMR variance with SST/2m Temperature

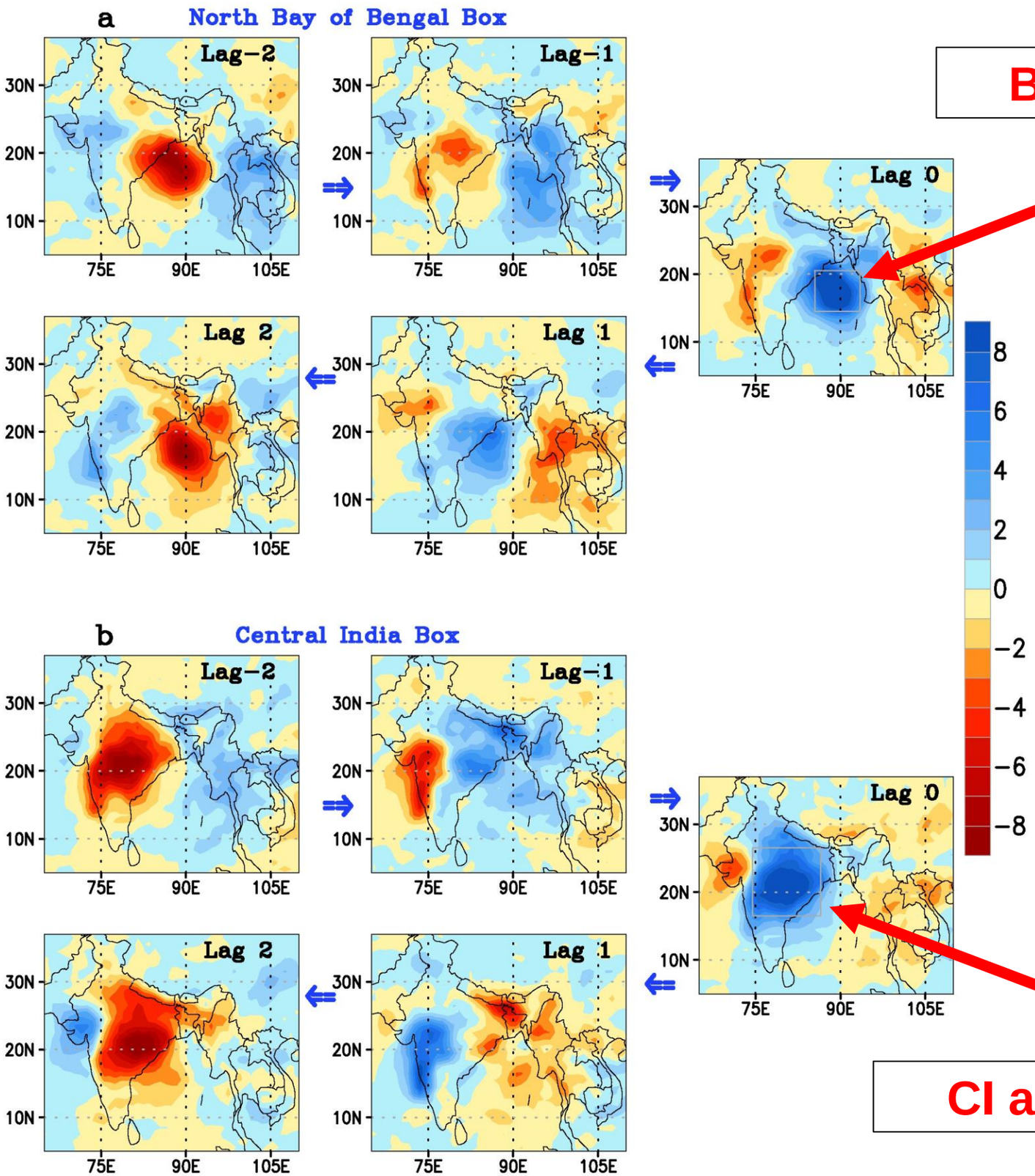


< 5.2 days

< 14.6 days

Saha et al., 2019; JGR

Spatial Structures & Evolution of Synoptic Systems



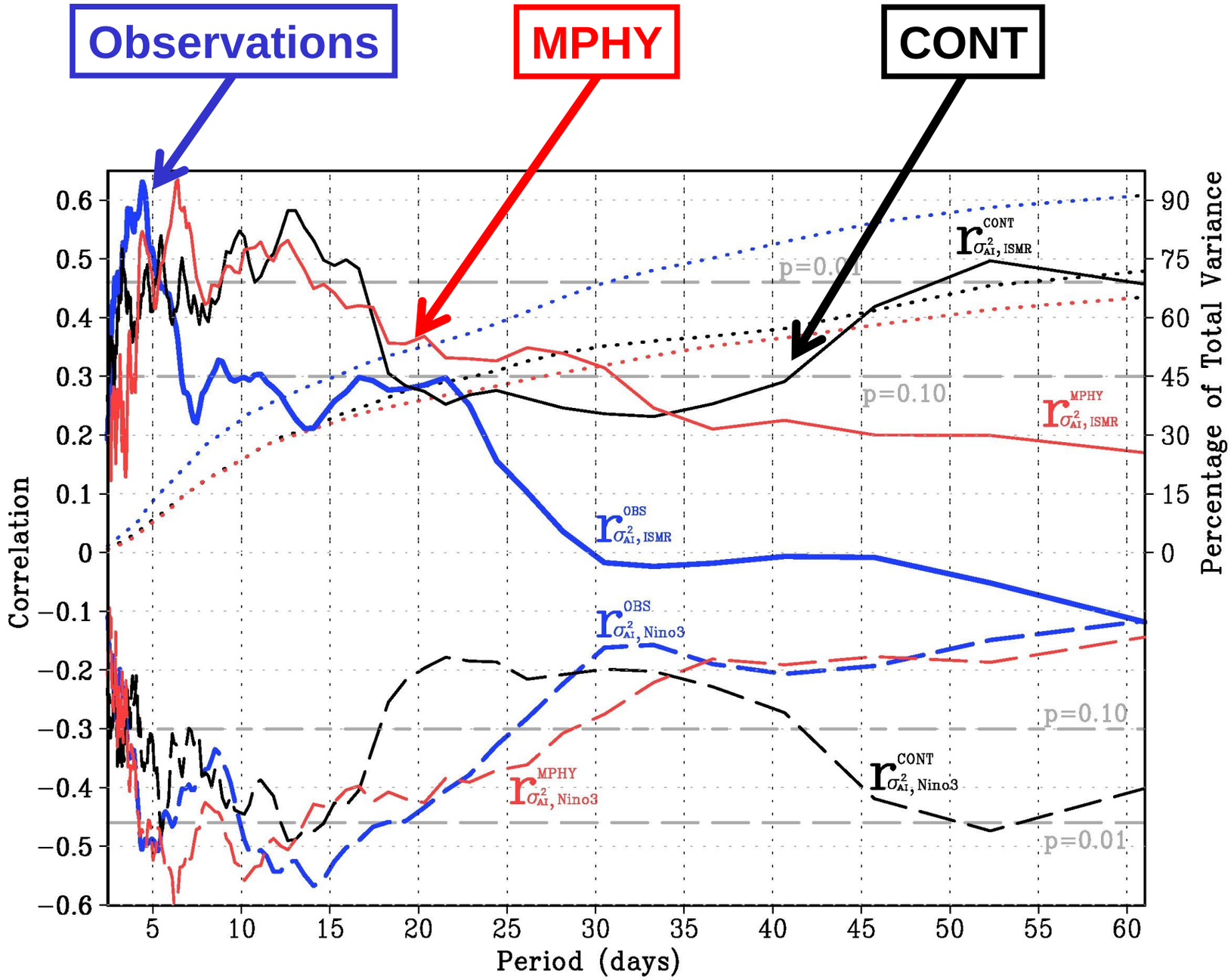
BoB average time series box

Lead-lag composite of 3-7 days filtered rainfall anomaly (120 events)

CI averaged time series box

Saha et al., 2019; JGR

Correlation Nino3, ISMR & Variances of AI rainfall



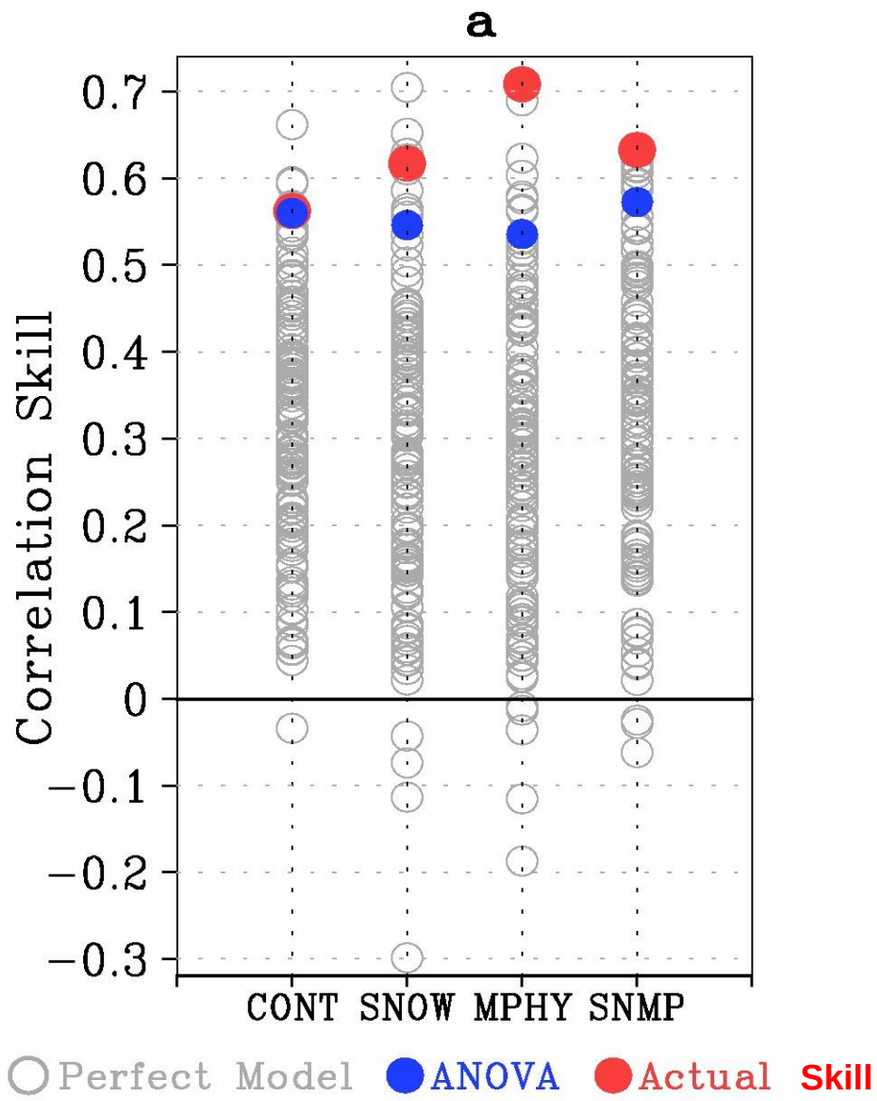
MPHY outperforms CONT in both synoptic and 30-60 days band

Saha et al., 2019; JGR

Potential Predictability
&
Re-forecast Skill

Actual and Potential Skill

CONT=0.56; SNOW=0.61; MPHY=0.71; SNMP=0.63; 16 ensemble members for 30 years (1981-2010)



In perfect correlation method, model is considered perfect. Forecast varies only due to error in ICs.

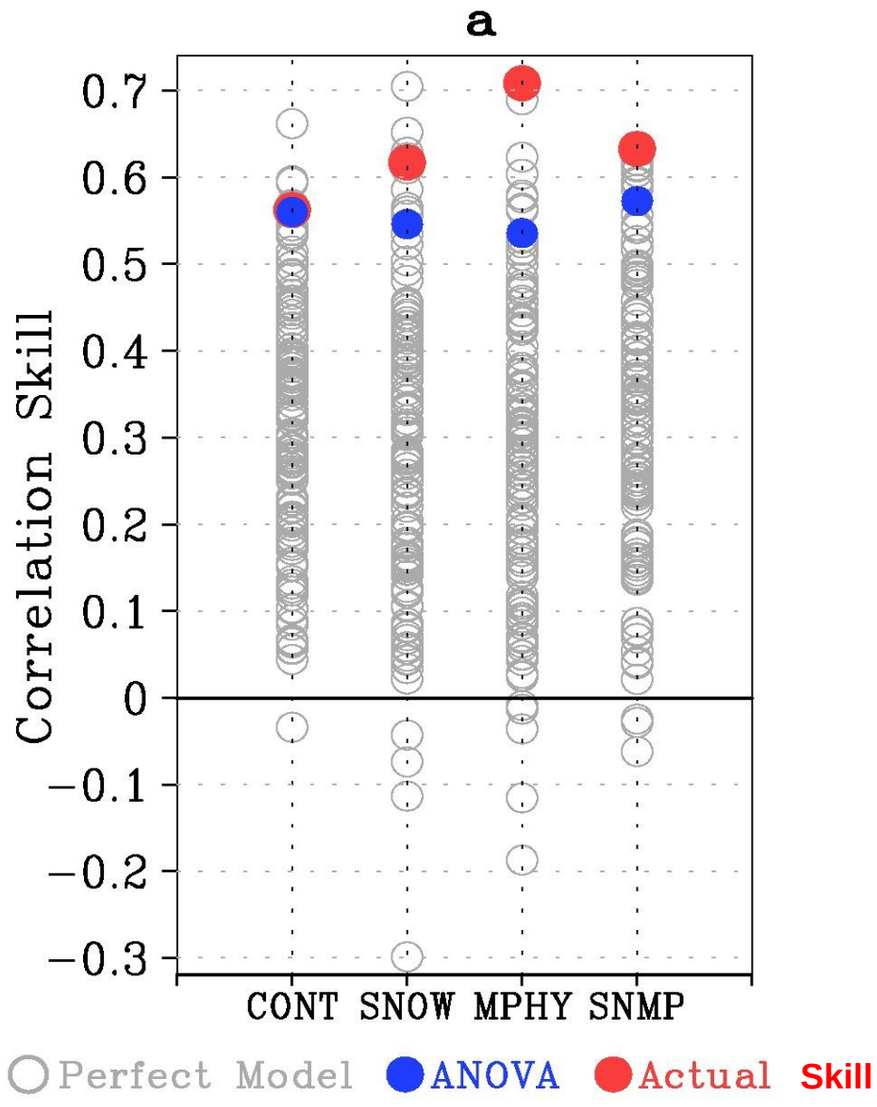
In ANOVA method, inter-ensemble spread is considered error/noise and ensemble average is the signal.

CONT→ *Suru. Saha et al.,* 2014
SNOW→ *Saha et al.,* 2017
MPHY→ *Hazra et al.*, 2017

Saha et al., 2019; JGR

Actual and Potential Skill

CONT=0.56; SNOW=0.61; MPHY=0.71; SNMP=0.63; 16 ensemble members for 30 years (1981-2010)



Correlation skill higher than potential predictability. Is it really a paradox ?

Is ISMR predictable beyond the conventional limit of potential predictability ?

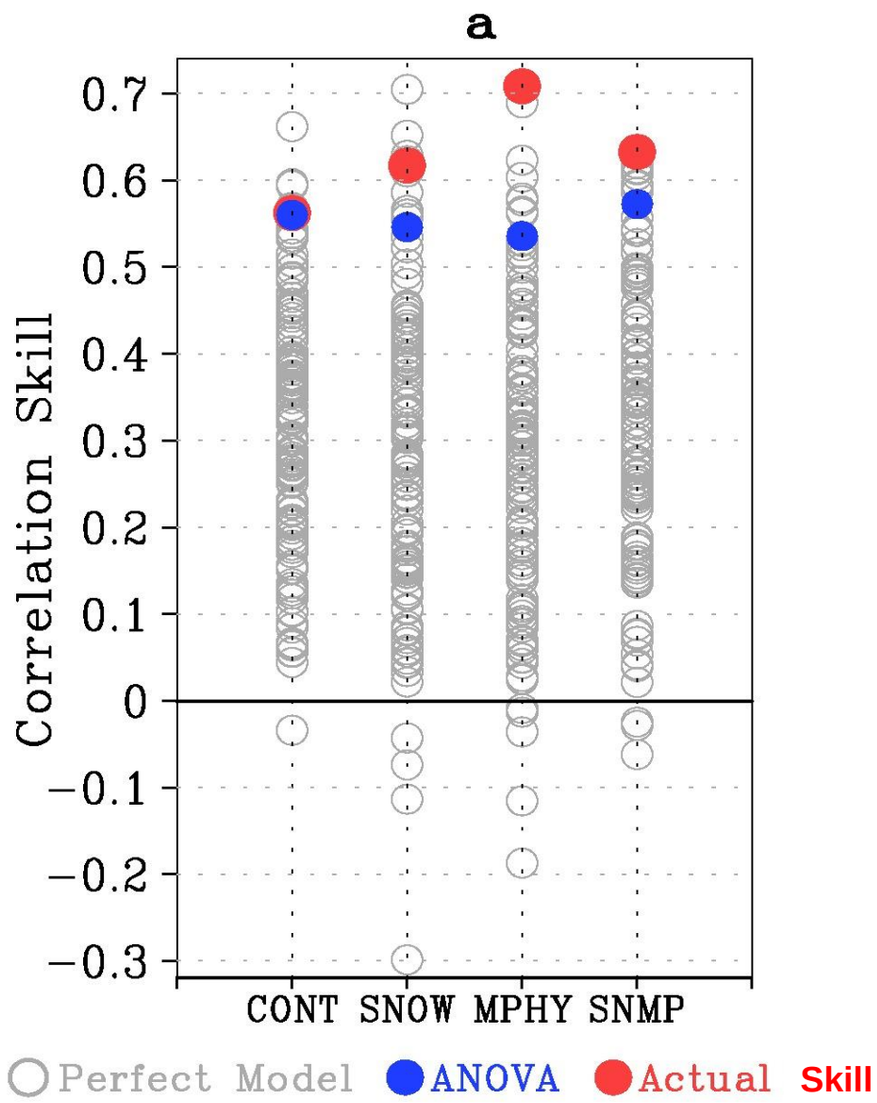
What is the actual predictability limit ?

CONT→ *Suru. Saha et al.,* 2014
SNOW→ *Saha et al.,* 2017
MPHY→ *Hazra et al.*, 2017

Saha et al., 2019; JGR

A New Measure of Potential Predictability

CONT=0.56; SNOW=0.61; MPHY=0.71; SNMP=0.63; 16 ensemble members for 30 years (1981-2010)



Having a same forecast model (e.g., CFSv2) with same source of ICs (e.g, CFSR), re-forecast skill may vary due to choice of initial dates.

Therefore, different forecaster will end up with different skill due to only choice of ICs.

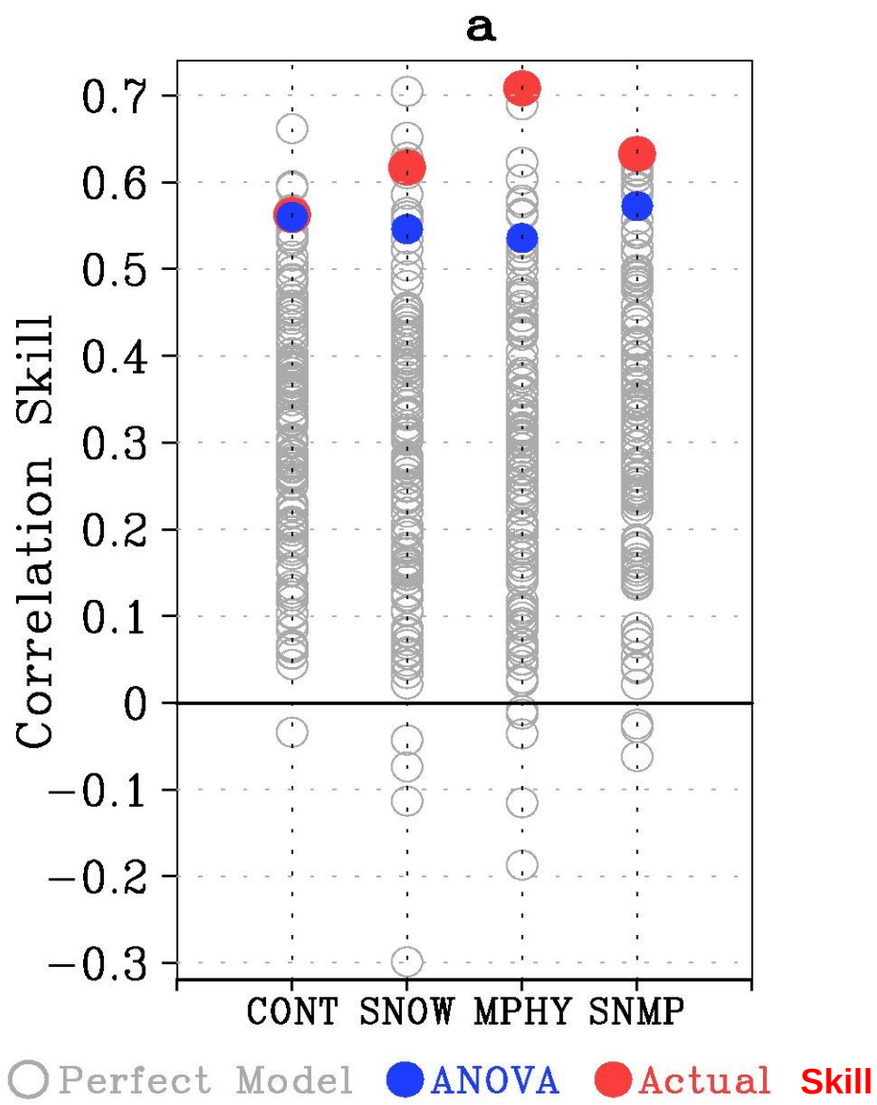
A systematic evaluation of that may define upper limit of achievable skill (OR the potential predictability)

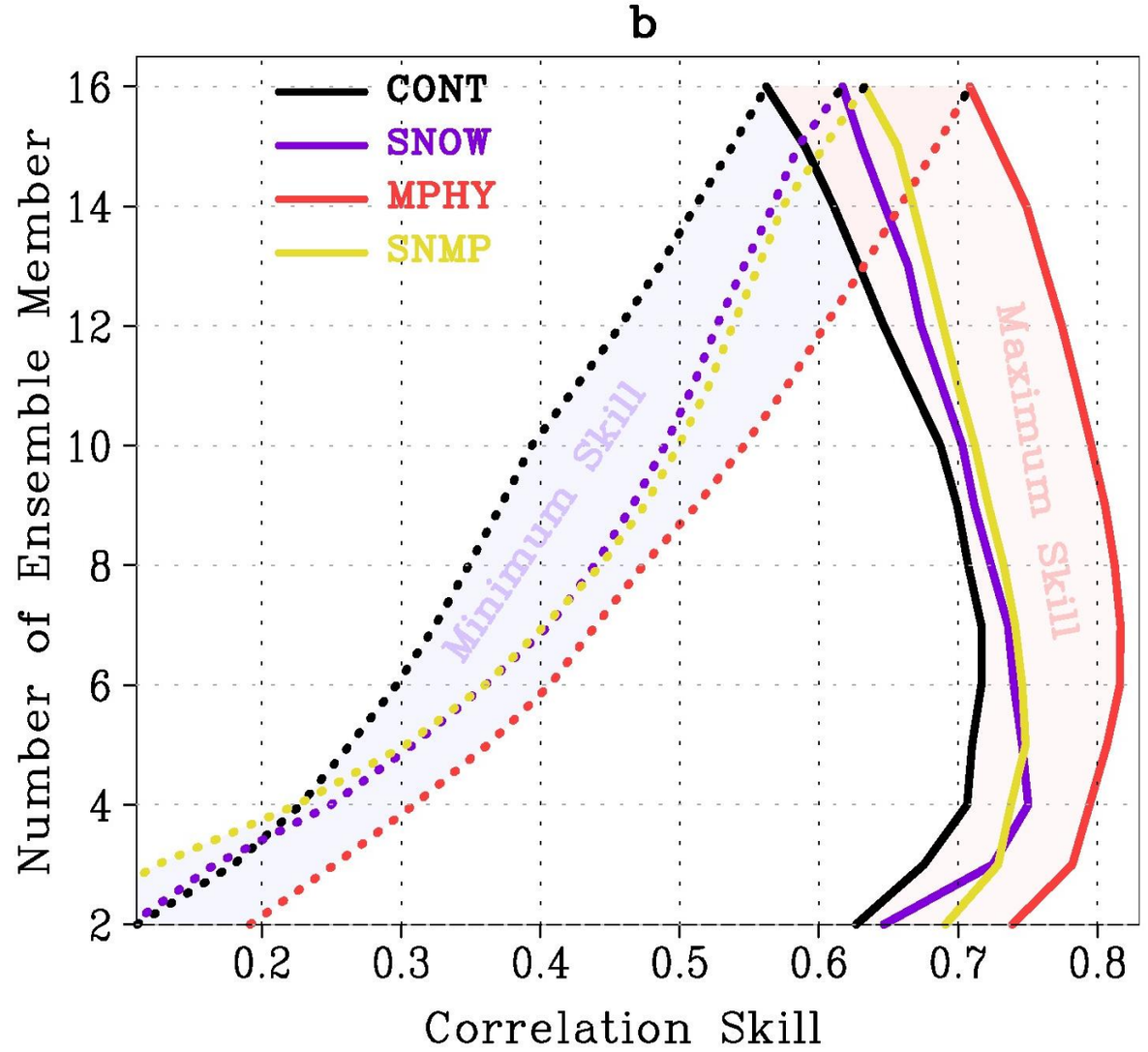
CONT→ *Suru. Saha et al.,* 2014
SNOW→ *Saha et al.,* 2017
MPHY→ *Hazra et al.*, 2017

Saha et al., 2019; JGR

A New Measure of Potential Predictability

CONT=0.56; SNOW=0.61; MPHY=0.71; SNMP=0.63; 16 ensemble members for 30 years (1981-2010)





CONT→ *Suru. Saha et al.*, 2014
SNOW→ *Saha et al.*, 2017
MPHY→ *Hazra et al.*, 2017

Correlation skill With all possible combination of ensemble members ($^{n}C_{r} \rightarrow {}^{16}C_{r}$, r=2, ...16)

A new way to estimate PP, which has binding relationship with observations

Saha et al., 2019; JGR

A New Measure of Potential Predictability

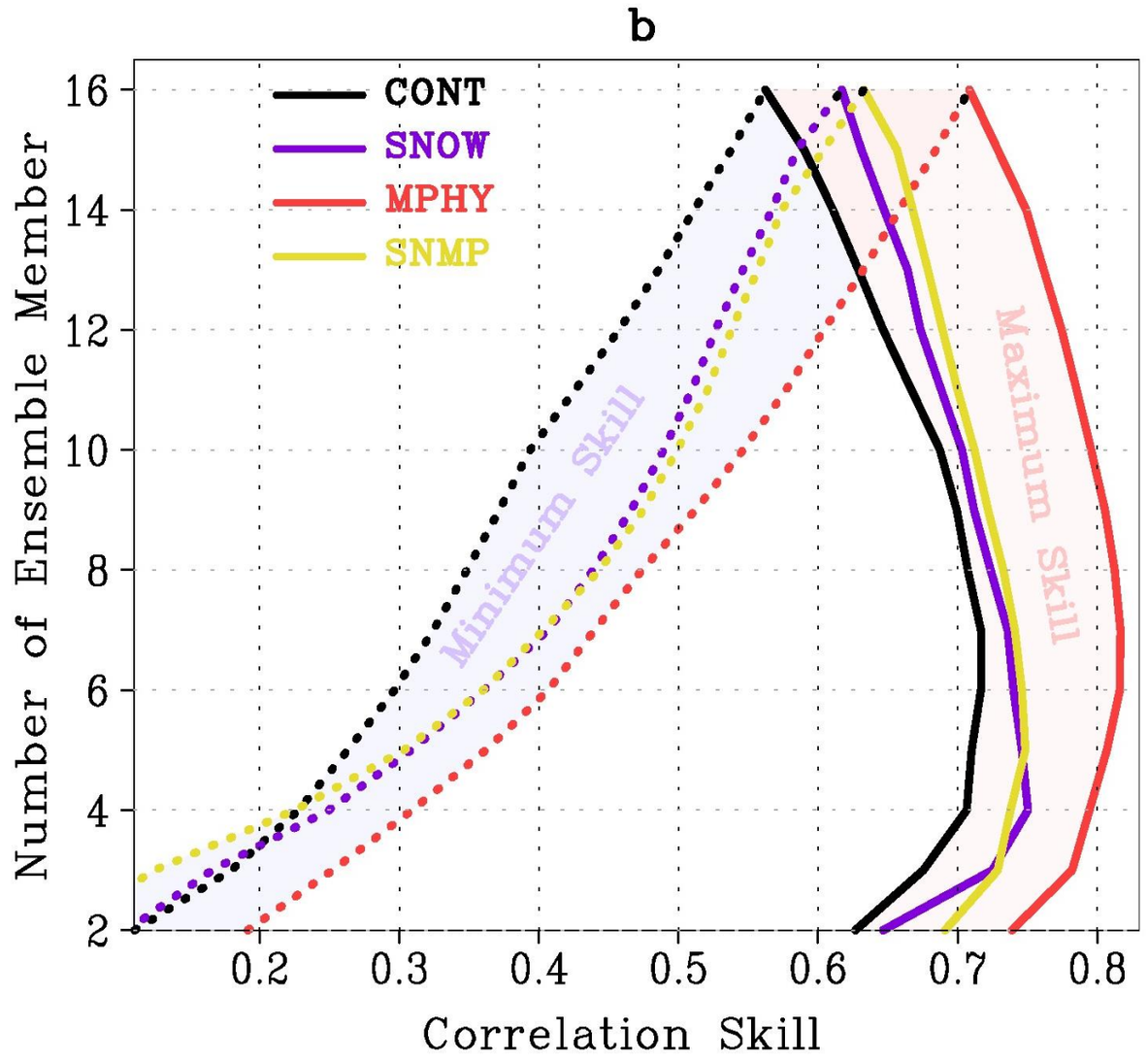
CONT=0.56; SNOW=0.61; MPHY=0.71; SNMP=0.63; 16 ensemble members for 30 years (1981-2010)

1) **Maximum achievable ISMR skill is 0.82**

2) **Improvements in models leads to shift in the whole distribution pattern to higher side.**

3) **The 16-member ensemble skill is within Potential Predictability limit.**

CONT→ *Suru. Saha et al.*, 2014
SNOW→ *Saha et al.*, 2017
MPHY→ *Hazra et al.*, 2017

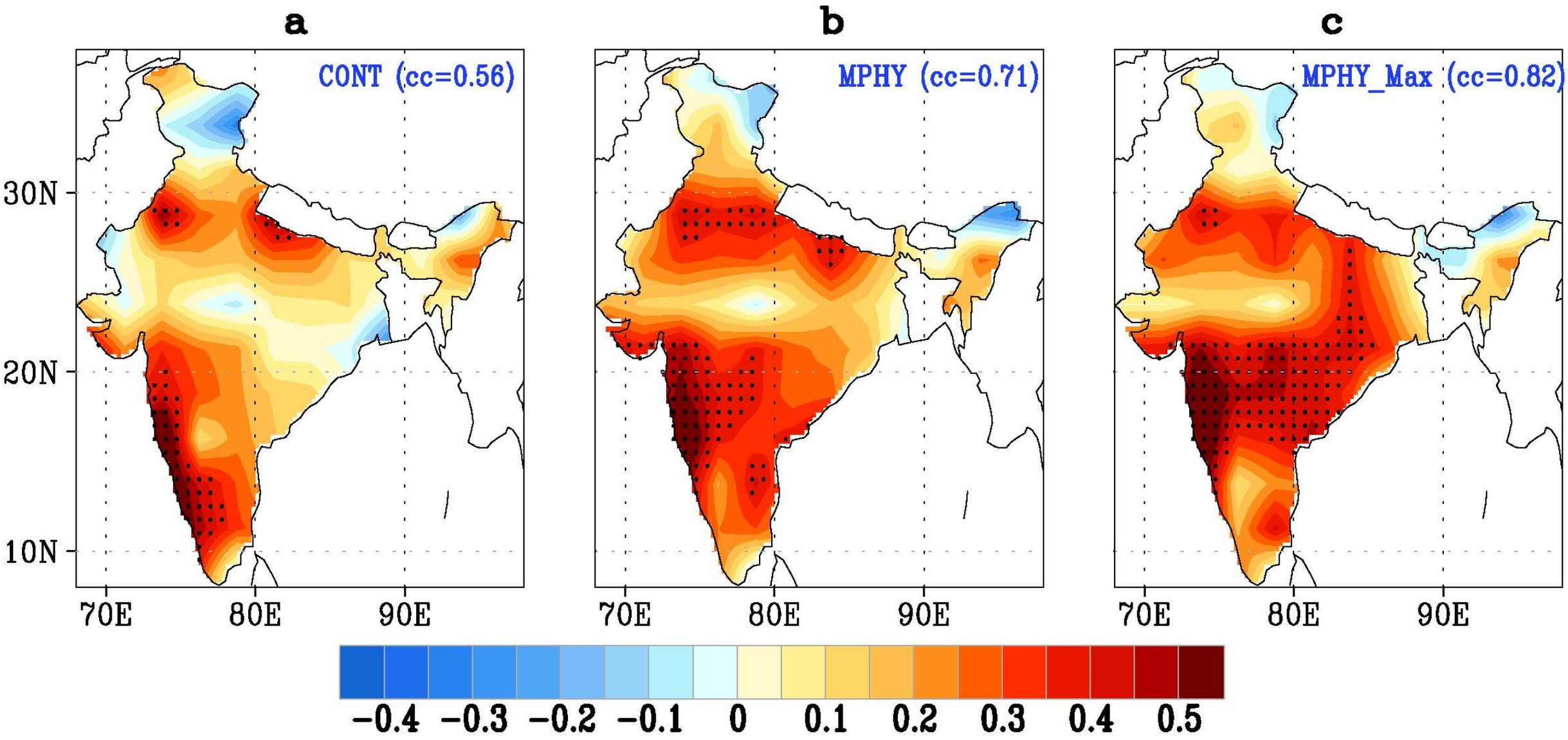


Correlation skill With all possible combination of ensemble members ($^{n}C_{r} \rightarrow {}^{16}C_{r}$, r=2, ...16)

A new way to estimate PP, which has binding relationship with observations

Saha et al., 2019; JGR

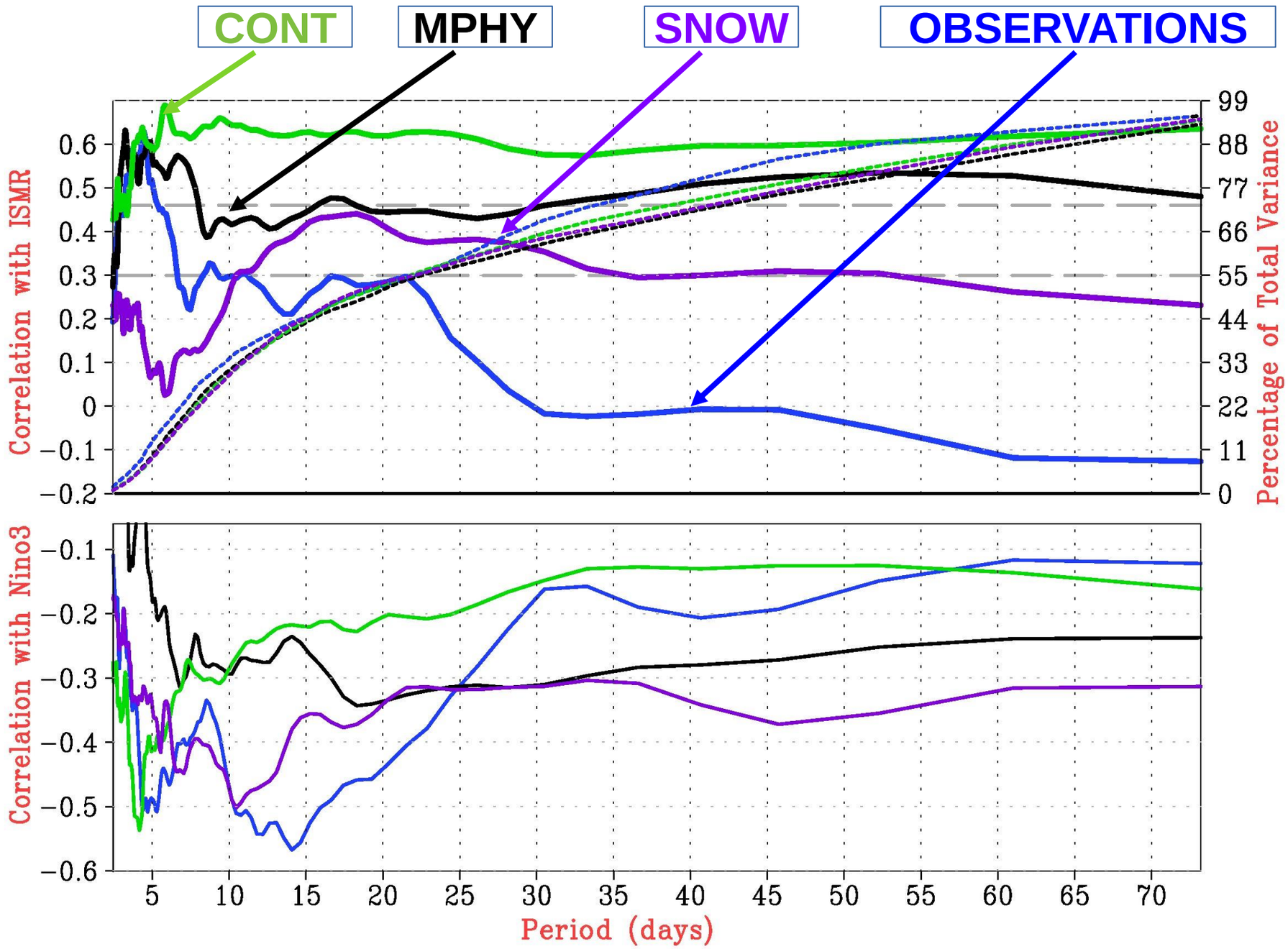
Spatial Correlation Skill



A reliable seasonal forecast on regional scale with further improvements of the model physics and data assimilation is going to be a future challenge!

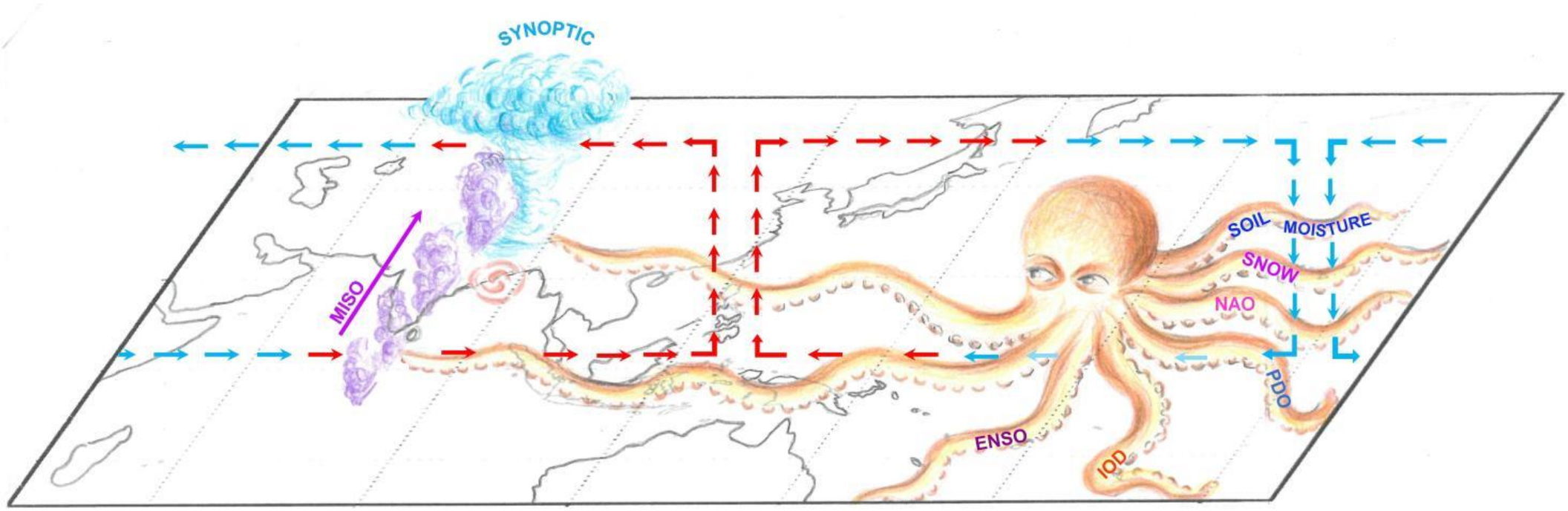
Saha et al., 2019; JGR

Way forward to achieve ISMR corr. skill of 0.80 and beyond!



Correlations between ISMR variances at different band and ISMR/Nino3 SST using 30-years of free run

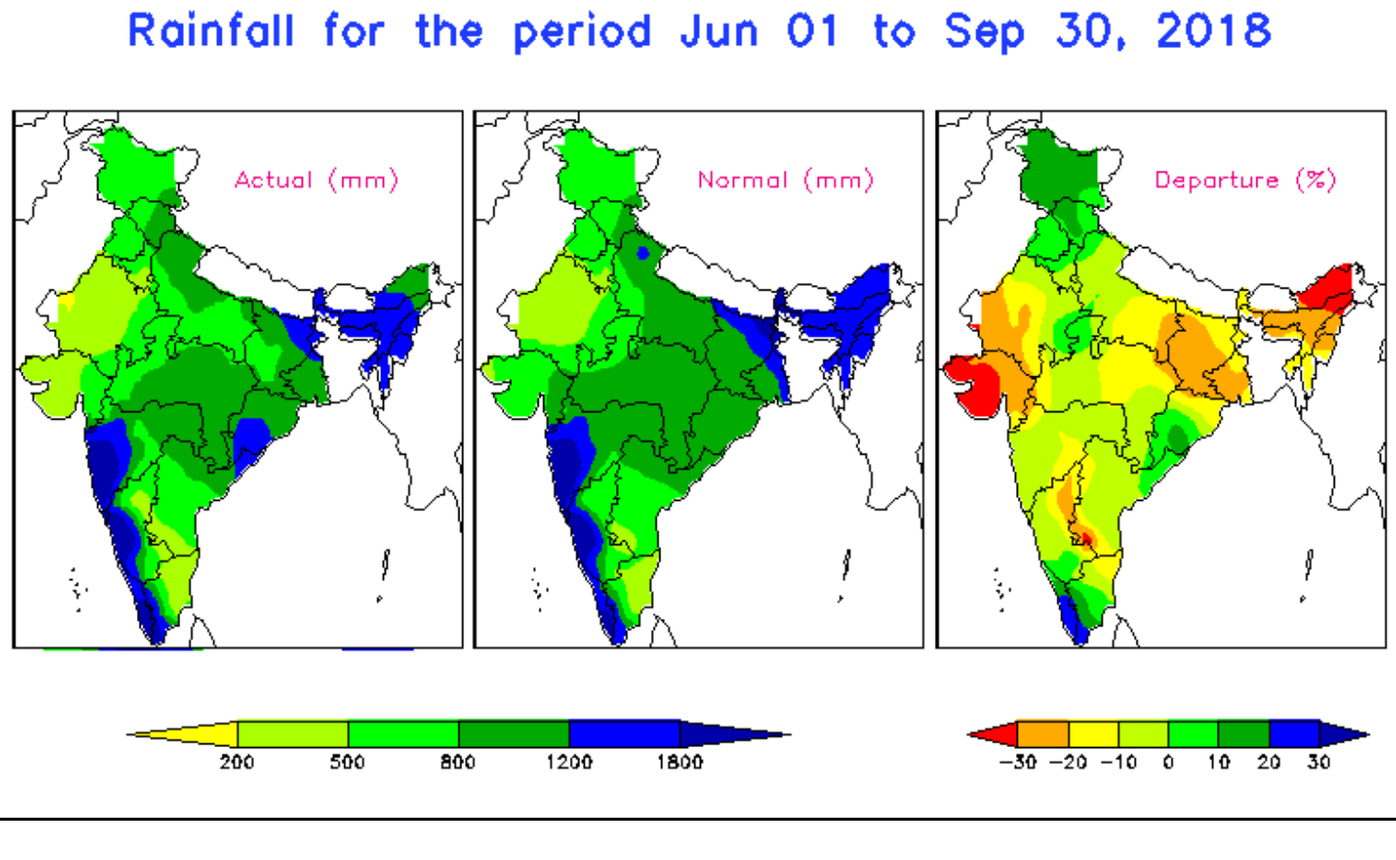
Schematic of ISMR Teleconnections



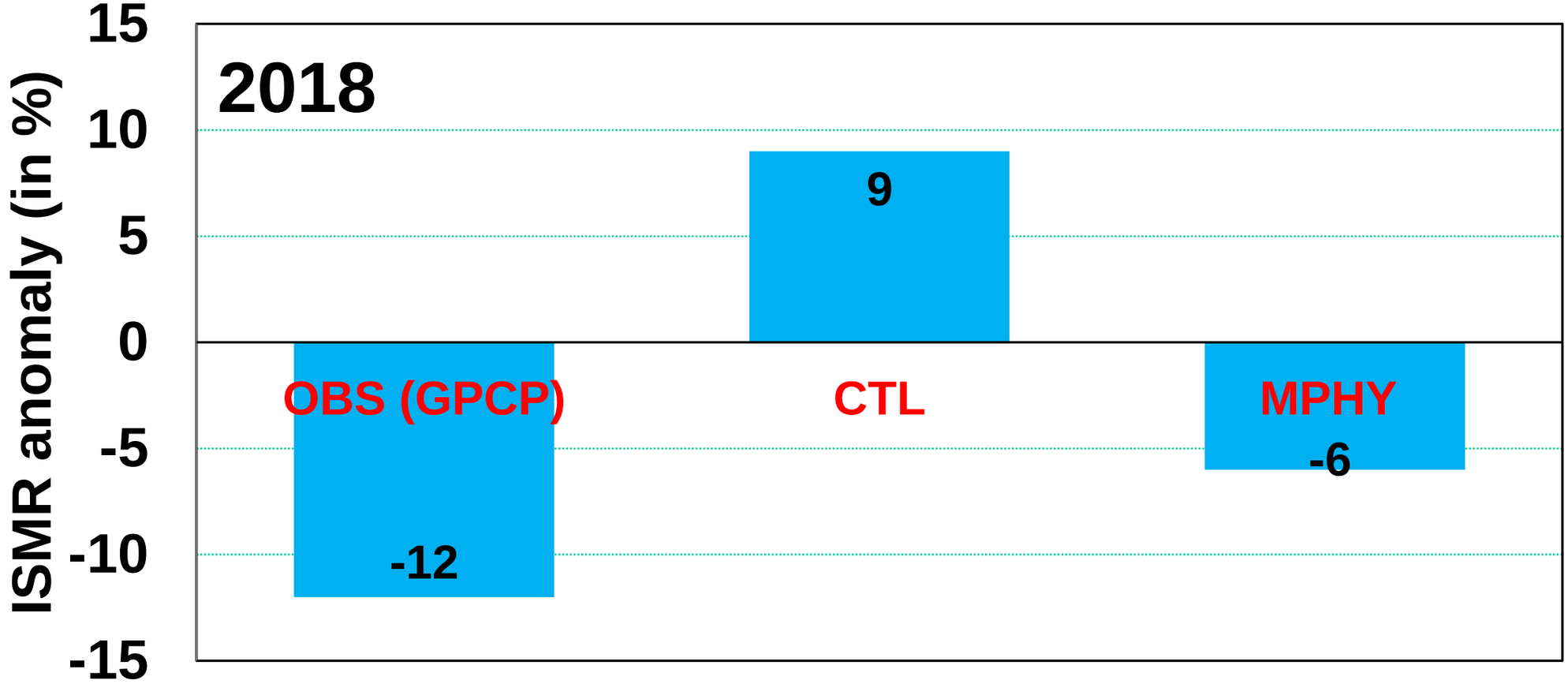
Association of large scale predictor (represented by a giant Octopus) with sub-seasonal component of the ISM. The predictor consists of all natural modes of variability (i.e., ENSO, IOD, PDO, NAO, snow, soil moisture etc.), each represents an arm of the predictor. The two long arms of the predictor aiming towards the synoptic and MISO indicate its influences on these sub-seasonal processes.

Saha et al., 2019; JGR

ISMR Anomaly



Source: IMD



Summary & Outlook

It appears that ISM is a highly predictable system

➔Synoptic variability contributes maximum to the ISMR anomaly

➔The synoptic and MISOs are not noise but part of the predictive signal

➔The actual potential predictability (PP) of CFSv2 is ~0.82 (a model dependent measure)

➔Further improvements in the model physics and initial conditions likely to increase the PP as well as re-forecast skill

➔Use of ensemble technique leads to ISMR skill to ~0.76 ! A target of ISMR skill of ~0.8 in the coming 1-2 years may be possible

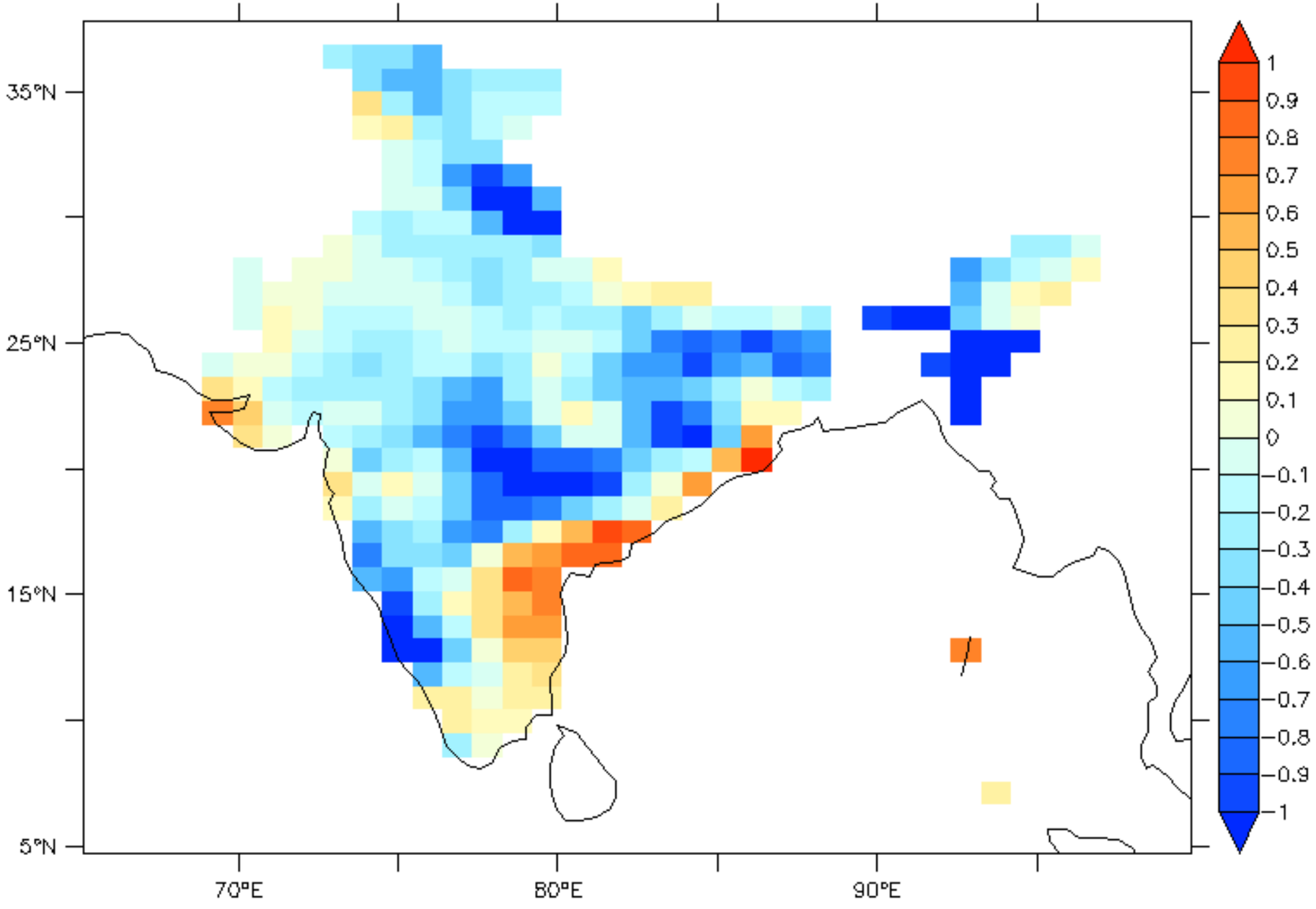
➔It is now a high time to set up a decadal prediction system at IITM (at least for 2-5 years monsoon forecast), which will benefit the policy makers on long term planning. There is a clear hope for skilful prediction of the ISMR on decadal time scale.

➔In comparison to global effort on sub-seasonal to seasonal (S2S) prediction, the ISM is the unique case of a unified and predictable system on synoptic to decadal time scale (i.e. S2D).

Thank You!

Thanks to the dedication and hard work of many monsoon researchers over the years..

the optimism on dynamical monsoon prediction expressed by T. N. Palmer [Proc. Indian Natn Sci. Acad. 60,57-66, 1994] "... dynamical monsoon prediction is not many years away, and, chaos not withstanding, our expectation of success are high".


35°N
25°N
15°N
5°N
70°E
80°E
90°E
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1