Monsoon Mission: Seasonal Prediction Efforts at IITM

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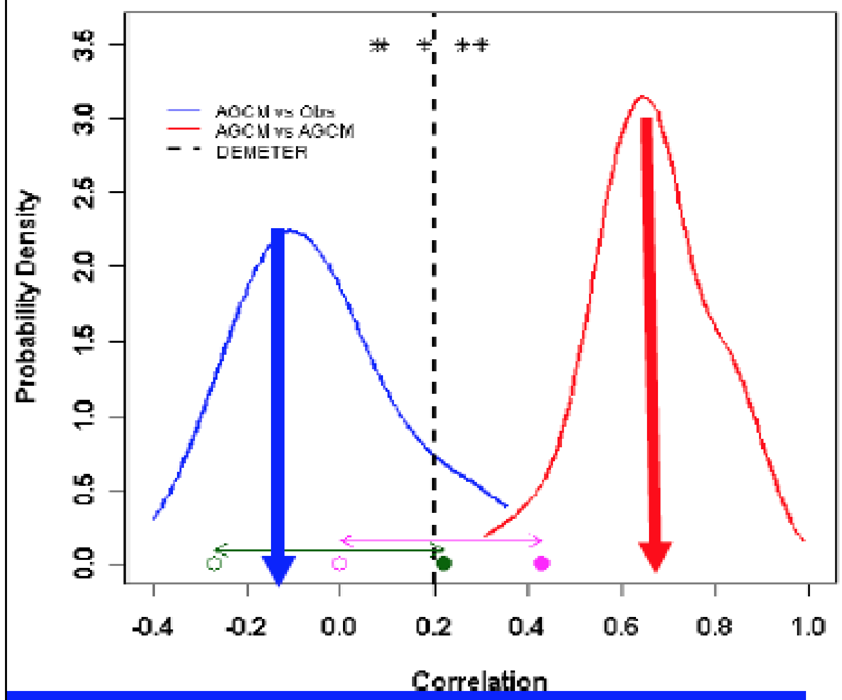
Potential Predictability VS Actual Prediction Skill of ISMR

Krishna Kumar et al , 2005, GRL



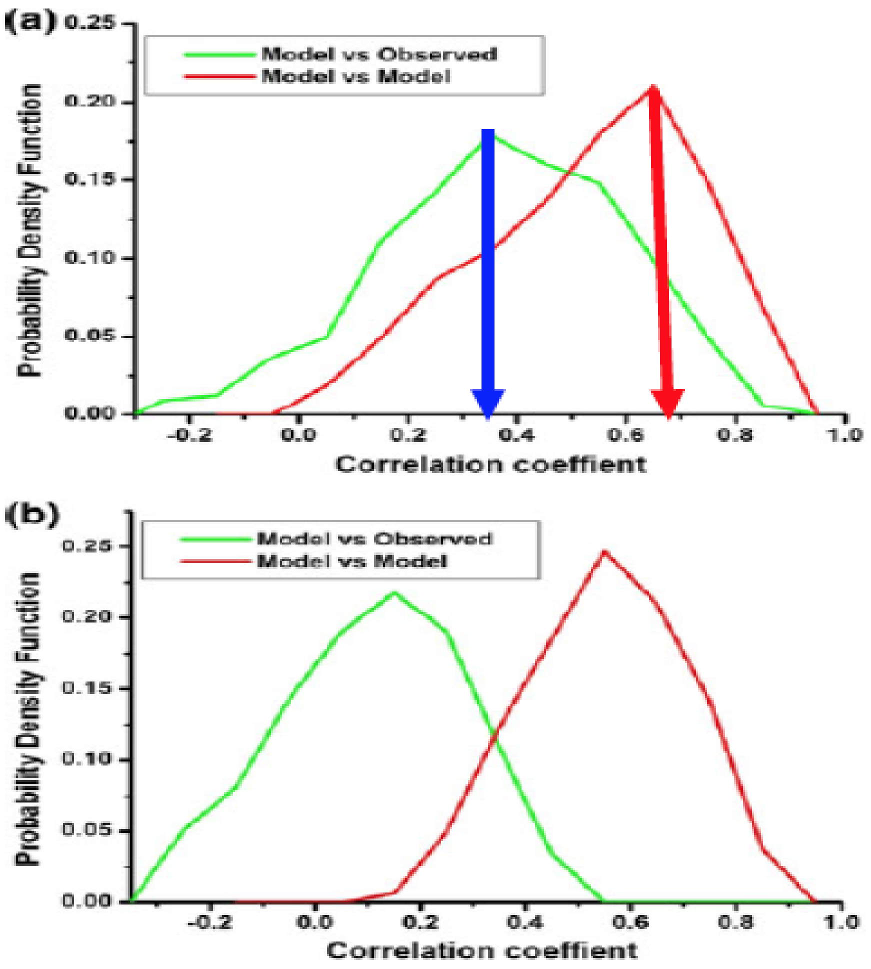
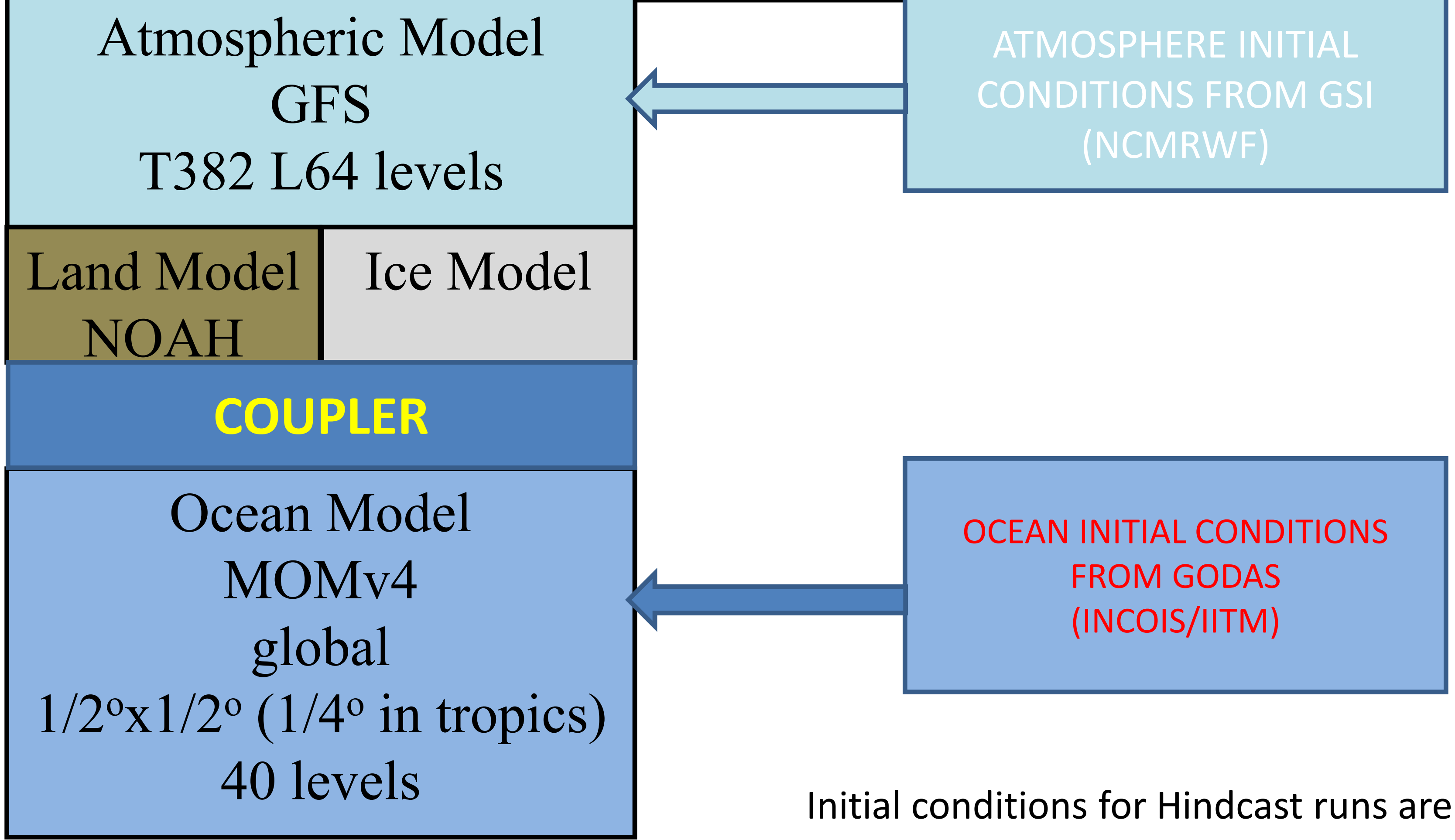


Fig. 13 PDFs of the correlation skill of ISMR based on a theoretical "perfect model" analysis (*red curve*) and based on the actual skill compared to the observed ISMR (*black curve*). **a** for the period 1960–1979 and **b** 1980–2005

Rajeevan et al. 2011, Climate Dynamics

IITM CFS Model
(a.k.a) Monsoon Mission Model
Seasonal Prediction



Atmospheric Model
GFS
T382 L64 levels

ATMOSPHERE INITIAL CONDITIONS FROM GSI (NCMRWF)

Land Model
NOAH

Ice Model

COUPLER

Ocean Model
MOMv4
global
$1/2^{o}x1/2^{o}$ ($1/4^{o}$ in tropics)
40 levels

OCEAN INITIAL CONDITIONS FROM GODAS (INCOIS/IITM)

Initial conditions for Hindcast runs are obtained from CFSR

(Original model is adopted from NCEP)

SKILL	JUN	JUL	AUG	SEP	JJAS
FEBIC	0.19	0.51	0.26	0.5	0.55
MARIC	0.29	0.58	0.24	0.56	0.49
APRIC	0.24	0.27	0.06	0.26	0.35
MAYIC	0.55	0.04	-0.19	0.26	0.2
JUNIC		0.43	0.13	0.39	
JULIC			0.49	0.37	
AUGIC				0.46	

ACC of CFS-MM (1982-2008)

T382

SKILL	1982-2016
NINO 3.4	0.53
IODE	0.55
IODW	0.50
ISMR	0.51 (0.51 GPCP)

SKILL	1982-2008
NINO 3.4	0.65
IODE	0.43
IODW	0.47
ISMR	0.56 (0.59 GPCP)

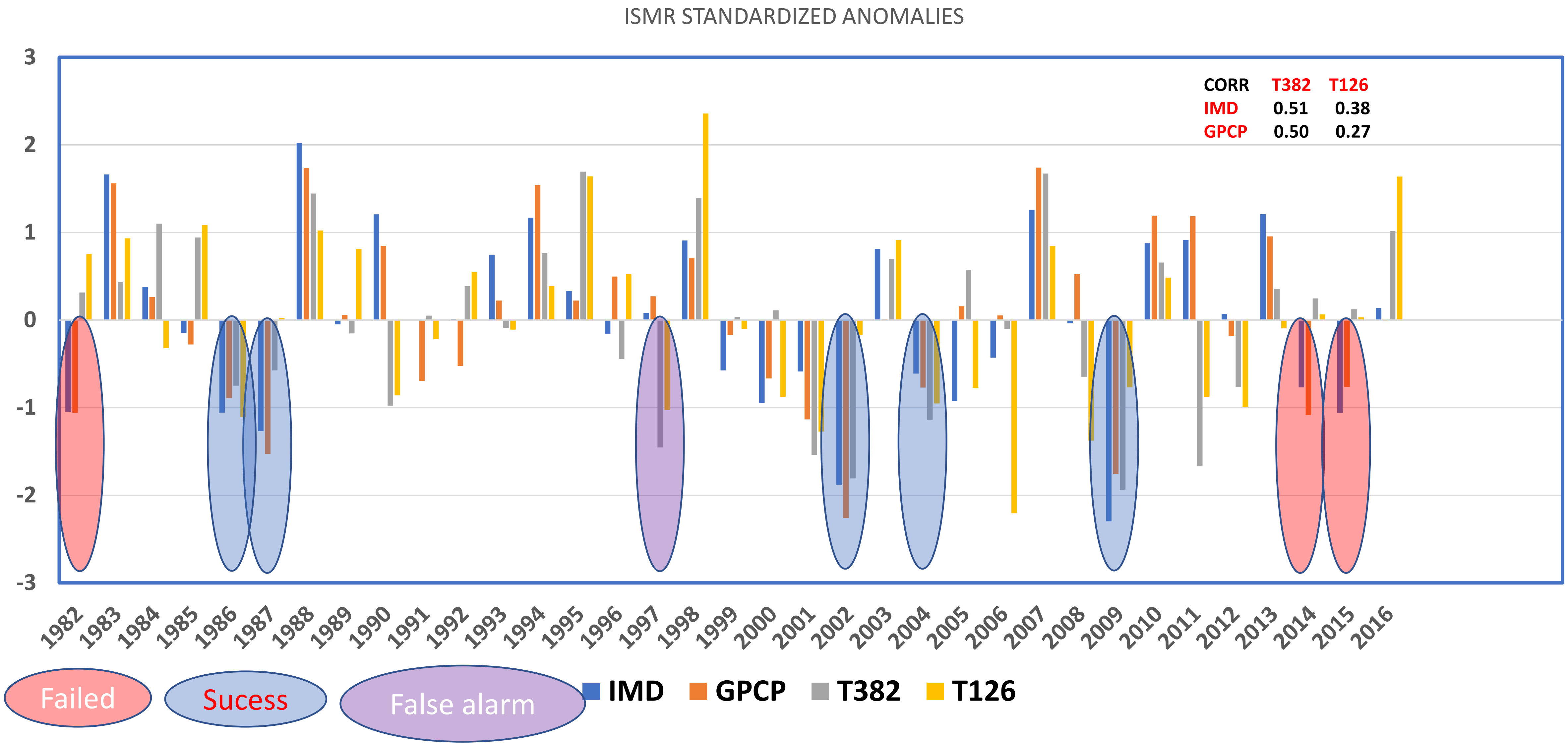
ISMR Skill 1982-2016	June	July	August	September	JJAS
T382 FebIC	0.20	0.50	0.34	0.46	0.53
T382 AprIC	-0.13	0.39	0.26	0.40	0.54
WRFOML	-0.15	0.39	0.31	0.23	0.57

T126

SKILL	
NINO 3.4	
IODE	
IODW	
ISMR	0.39 (0.28 GPCP)

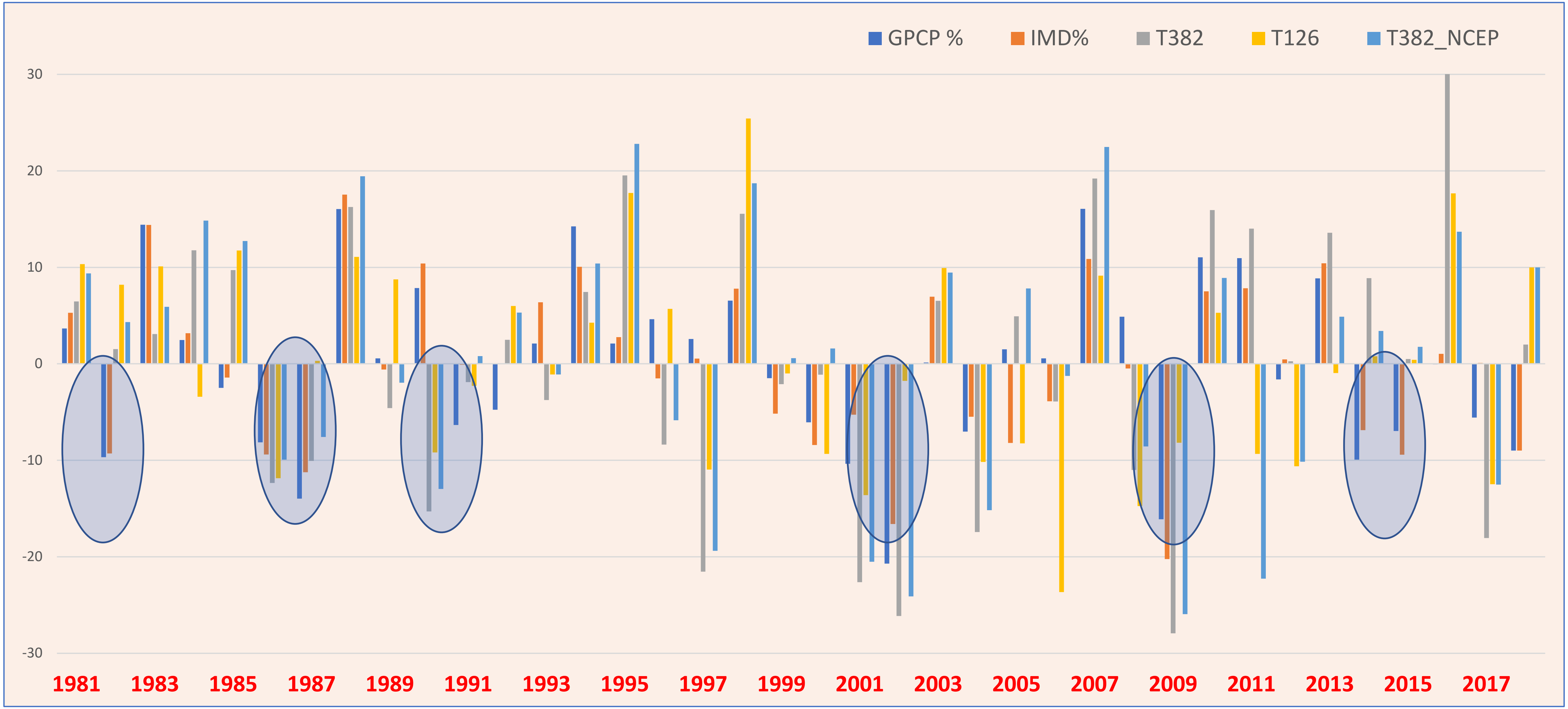
	1982-2008
	0.57
	0.48
	0.46
ISMR	0.51 (0.40 GPCP)

Indian Summer Monsoon Skill in CFS low/high Resolution Model

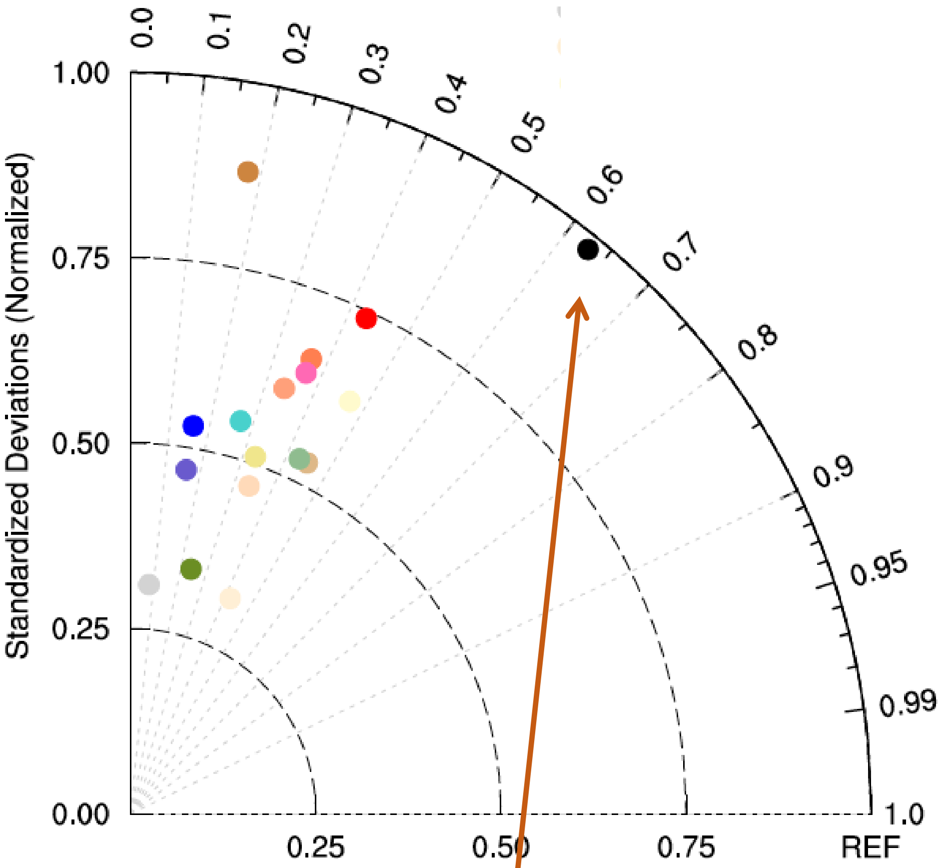


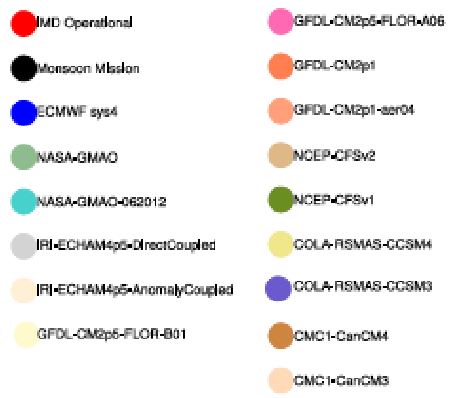
CORR	T382	T126
IMD	0.51	0.38
GPCP	0.50	0.27

Indian Summer Monsoon Skill in CFS low/high Resolution Model



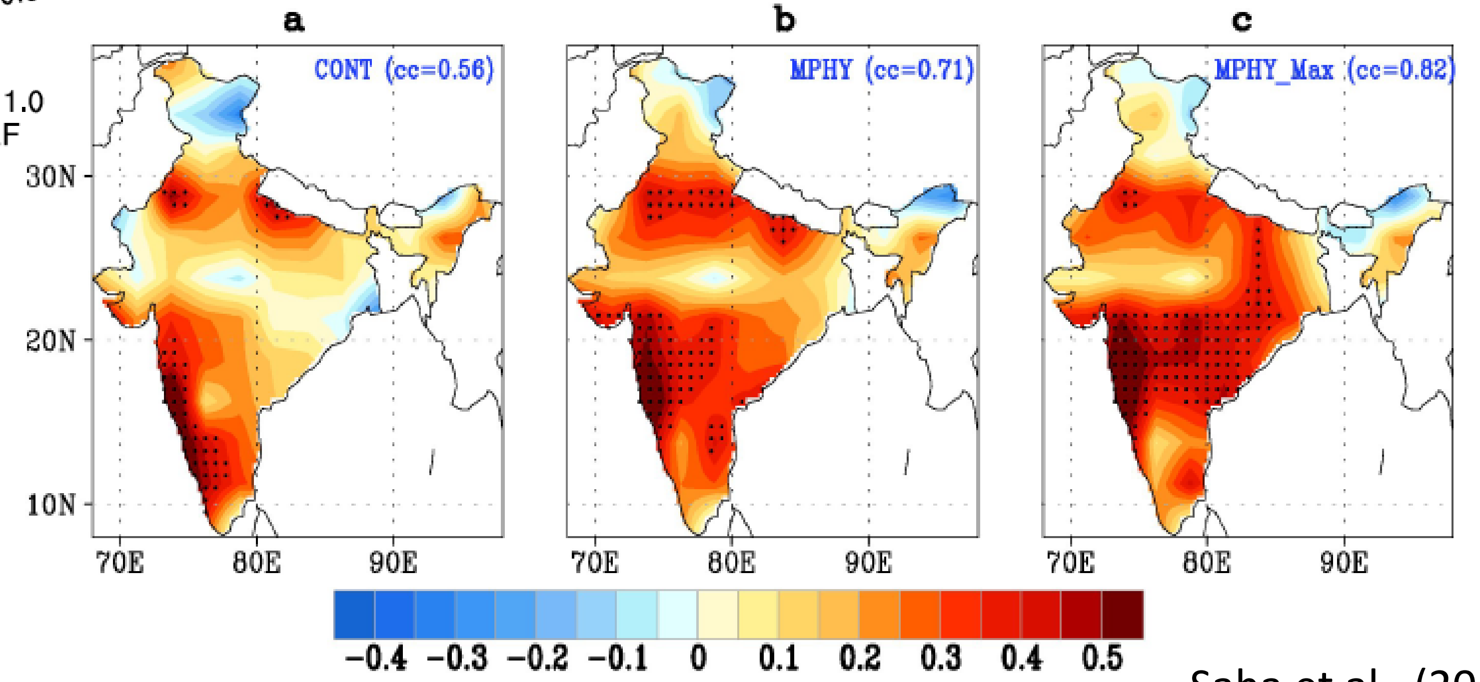
ACC: T382=0.58, T126_NCEP=0.29, T382_NCEP=0.50
Normalized STD: T382: 1.01, T126_NCEP=0.6, T382_NCEP=0.98





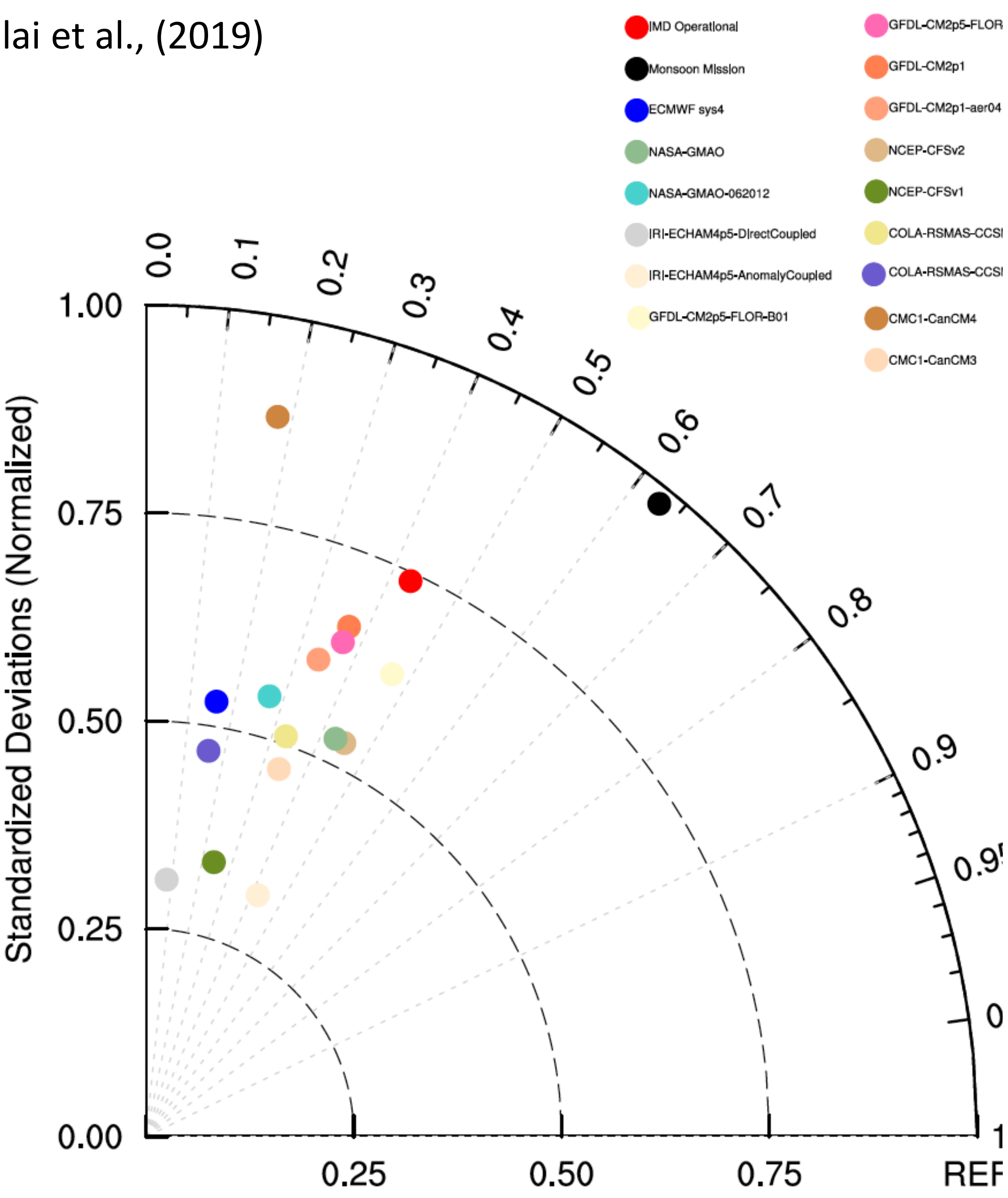
Pillai et al., (2019)

Monsoon Mission Model Performance (Prediction Skill as well as interannual variance) is better than other models for Indian Monsoon.



Saha et al., (2019)

Pillai et al., (2019)



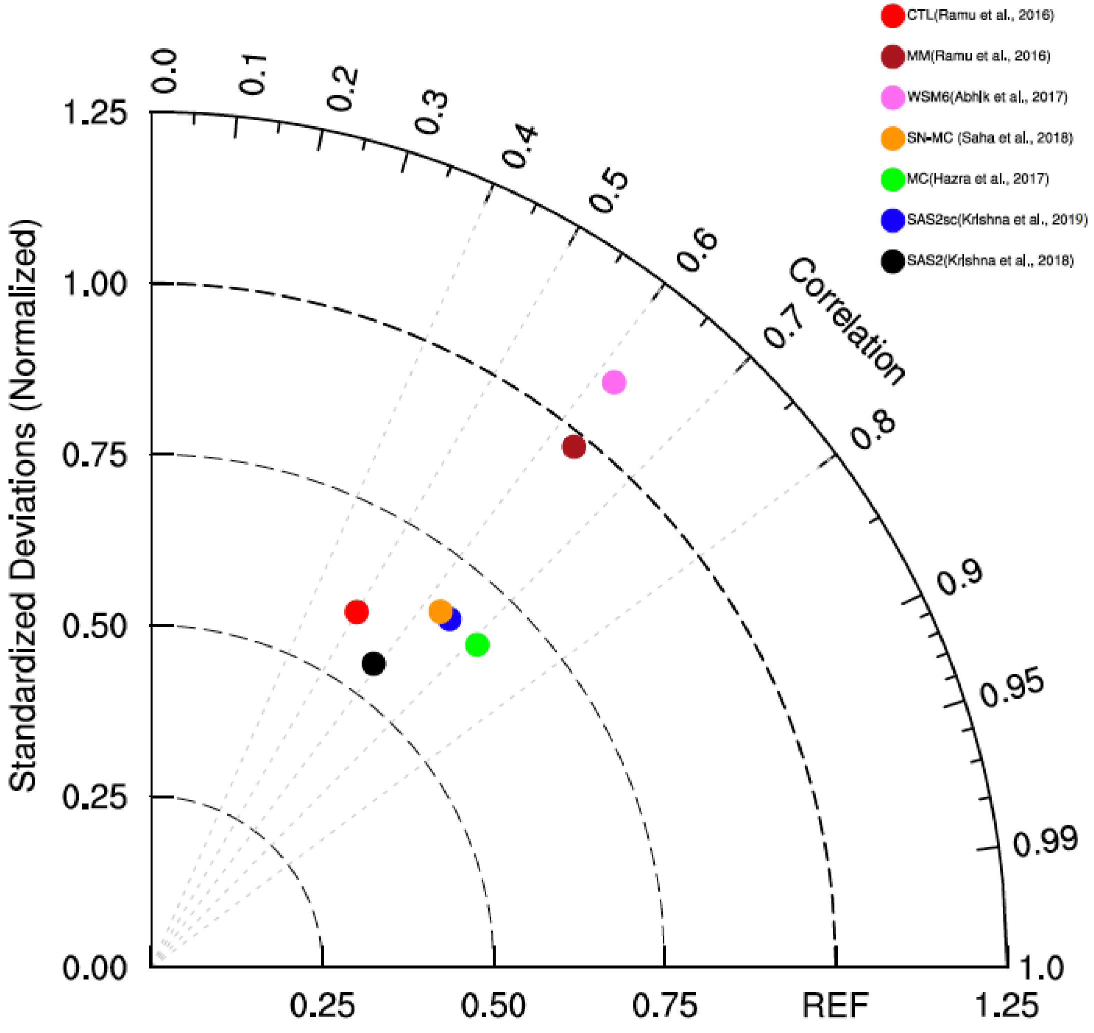


Figure 6 Taylor diagram showing the skill of ISMR prediction using reforecasts from control run (CTL) and the developmental activities under MM, namely the revised microphysics (WSM6) along with revised convection (SAS2) and a modified radiation scheme, new cloud physics parameterization (MC), the new snow model (SN) and MC together (SN-MC), the revised convection parameterization scheme (SAS2) and SAS2 with revised shallow convection scheme (SAS2sc). The improvement in skill over the CTL run is notable in the experiments. The period of the hindcast is 1981-2010. The axes denote the ratio of standard deviation of the simulated ISMR to the observed.

Performance of Statistical Vs Dynamical Model

Year	Stat	Dyn	Dyn_cor	Actual	Error_St	Error_dy
2011	95	106	106	102	7	4
2012	99	104	104	93	6	11
2013	98	104	104	106	8	2
2014	95	96	96	88	7	6
2015	88	86	86	86	2	0
2016	106	112	112	97	9	17
2017	98	100	100	95	3	5
2018	97	97	90	91	7	1
2019	96	97	97	110	14	13

Developmental Activities

(to overcome/reduce the problems of original CFSv2)

- Convective Parameterization (New SAS, Han & Pan, 2011; Ganai et al., 2014)
- Cloud Microphysics (Hazra et al., 2015; Abhik et al., 2016)
- Super Parametrization (Goswami et al., 2015)
- Improved snow physics in Land Surface Model (Saha et al., 2017)
- High Resolution Model (Ramu et al., 2016, Sahai et al., 2014)
- Stochastic Parametrization (Goswami et al., 2017)
- New Ocean model (in progress Sreenivas et al., 2017)
- EnkF coupled Data assimilation system (Kalnay et al., 2016, Sreenivas et al., 2019 under preparation)

Reference list is not exhaustive

Improvements in monsoon characteristics due to developmental activities (Parametrization schemes, LSM, Ocean and resolution) resulted in :

- Decreased dry bias over Indian Land mass
- Decreased cold tropospheric bias
- Decreased SST cold bias in tropics
- Improved representation of snow cover thickness and time of melting
- Improved ENSO characteristics and IOD characteristics.
- Improved teleconnections
- Better representation of extratropical and tropical interactions

Skill Improvements due to Developmental Activities

	RUN (Ensembles)	Hindcast Period	Resolution	AISMR (GPCP), (% improvement over CTL)	Nino 3.4	IOD East Pole
(a)	CONTROL (10)	2003-2017 (2016)	T126	0.33 (0.49, +9%)	0.53	0.70
(b)*,#	NCEP CTL (10)	2003-2017 (2016)	T126	0.42 (0.45)	0.57	0.76
(d)#	**CFS-NCEP (10)**	**1981-2017**	**T126**	**0.29**	**0.53**	**0.58**
(d)	**COLA-CFS (10)**	**2003-2017**	**T126**	**0.60 (+81%)**	**0.61**	**0.62**
(e)	SAS2 (10)	2003-2017	T126	0.54 (+63%)	*0.70*	*0.81*
(f)	SAS2sc (10)	2003-2017	T126	0.63 (+91%)	0.54	0.70
(g)*,#	NCEP SAS2 (10)	2003-2017	T126	*0.70 (+67%)*	0.66	0.67
(h)*,#	NCEP SAS2sc (10)	2003-2017	T126	0.40 (-5%)	0.63	0.68
(i)#	**CFS-ALBEDO (10)**	**1982-2014**	**T126**	**0.11 (-56%)**	**0.64**	**0.31**
(k)	INCOIS-T382 (14)	2003-2017	T382	0.47 (+42%)	0.49	0.67
(k)#	NCEP-T382 (10)	1981-2017	T382	0.51 (+76%)	0.53	0.54
(l)*,#	NCEP Multi Cloud MP (10)	1982-2014	T126	0.45 (+7%)	0.58	0.43
(m)*,#	NCEP WSM6 (10)	1981-2012	T126	0.61 (+64%)	NA	NA
(n)*,#	CFS-ICE-Micro (16)	1981-2010	T126	0.70(+59%)	0.58	NA
(o)#	CFS-Hydrology (10)	1981-2017	T126	0.48 (+65%)	0.54	0.61

9% Improvement is achieved due to indigenous ICs

60-90% Improvement is achieved due to revised SAS of Han & Pan (2011)

42-75% Improvement is achieved due to increased resolution

60-65% Improvement is achieved due to In-house Developments (LSM, Microphysics, WSM6 and Hydrology)

Runs carried out on Aditya indicated by *
All the runs are using INCOIS-NCMRWF initial conditions, unless indicated by #
Initialized with Feb. IC and skills are shown for JJAS

AISMR: All India Summer Monsoon Rainfall (Averaged over Indian Land Mass)

Core Time = 65 Years (567522 Hours)
T126 (6 Nodes: 9 months in 7 hours)
T382 (10 Nodes: 9 months in 40 hours)

Comparison of IMD’s SEFS with MMCFS & OML

Period	IMD SEFS			MMCFS (T382)			[redacted]
	C.C	**MAE**	**NSD**	**C.C PY**	**MAE**	**NSD (PY)**	
1988-2017	0.31	6.72	0.60	**0.58**	**9.5**	1.56	

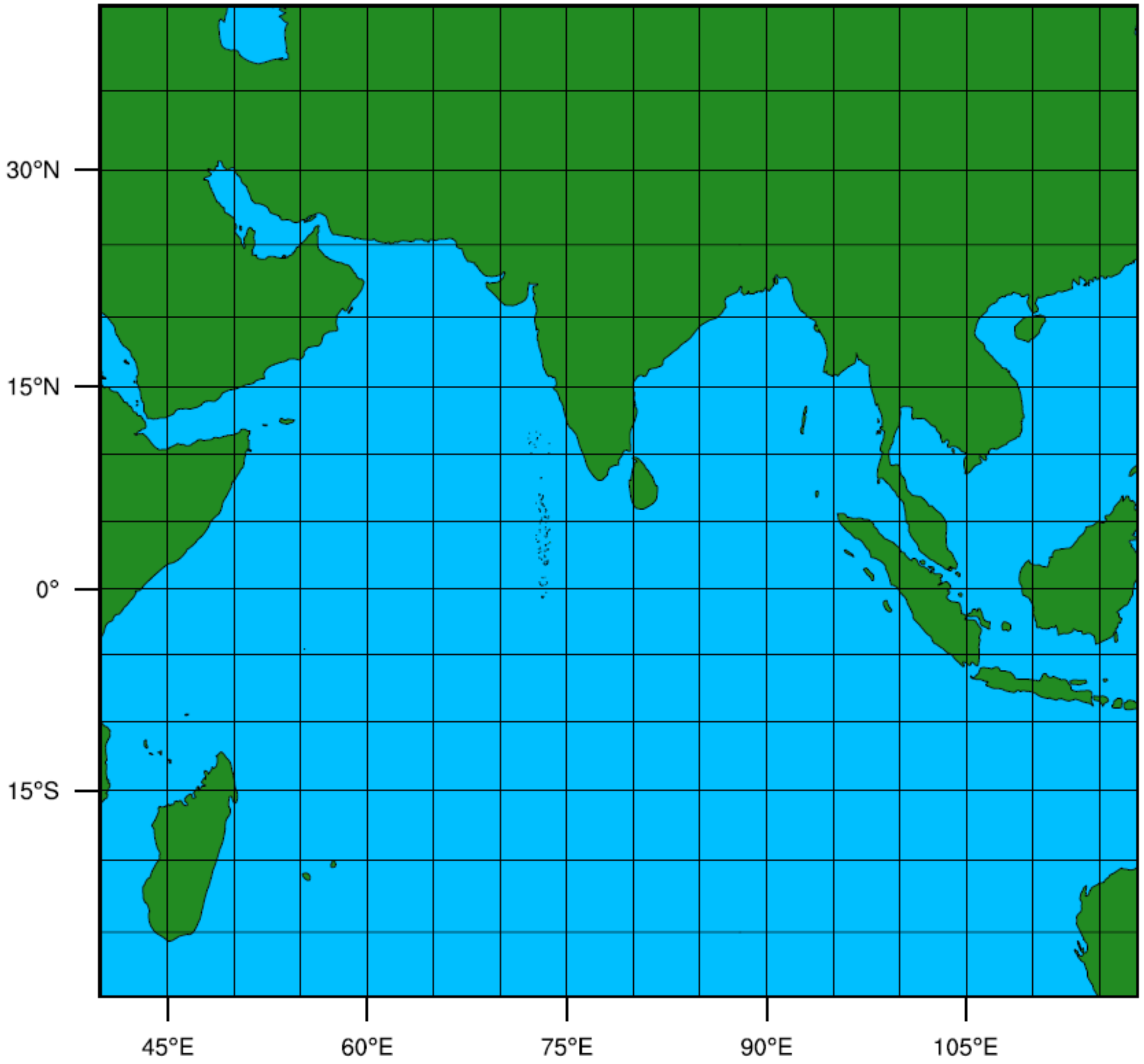
C.C Correlation coefficient
AE: Absolute Error
NSD: Normalized standard deviation (wrt observations)

Downscaling of T126 Reforecasts using WRF Coupled to Ocean Mixed Layer (OML)

- Earlier we have developed a high resolution CFS (T382) and it had shown best prediction skill (ACC~ 0.58) for ISMR compared to any other model in the world. It also improved capturing of extreme years reasonably well
- However, the dry bias over Indian landmass and overestimation of variance in the model is resulted in Mean Absolute Error (MAE) of about 9.5% while, the MAE in statistical model of IMD is restricted to 6.7%
- The question that we have been asking since how do we reduce the error in forecasts?
- Results were very encouraging and the skill remained as good as T382 CGCM, and errors have reduced significantly.

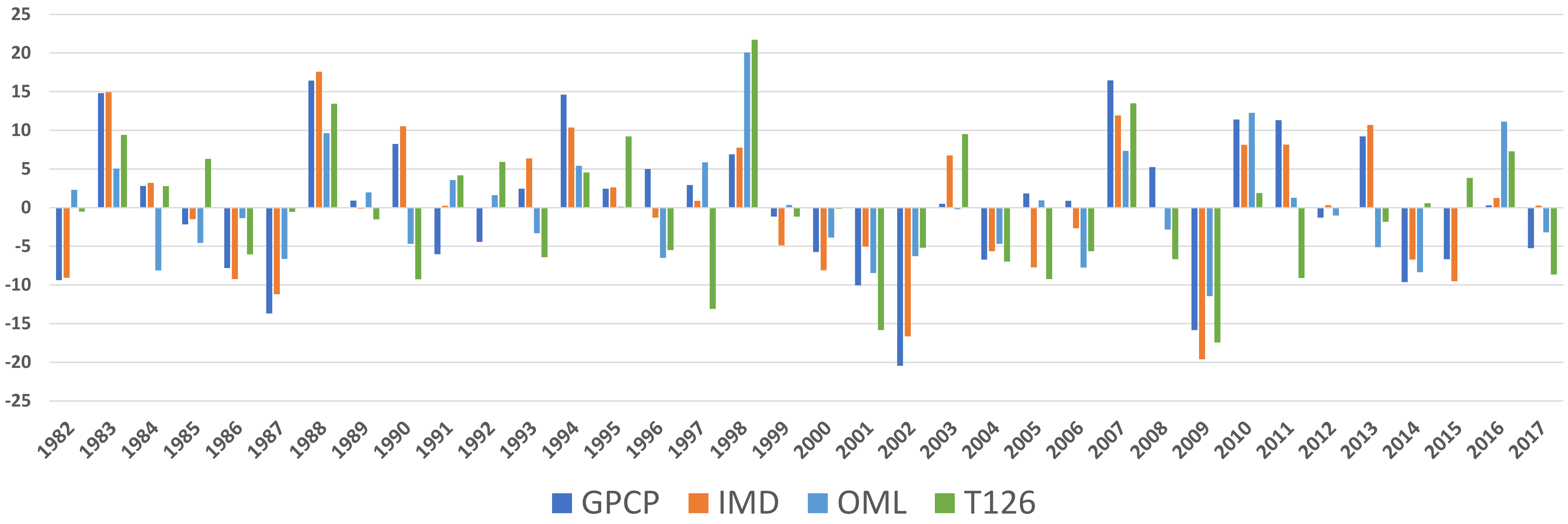
Model Configuration

Model	WRFV 3.4
Dynamics	Primitive equation, non-hydrostatic, fully compressible, terrain following
Horizontal and vertical resolution	38 km (290 x 250 x 38)
Radiation scheme	Rapid Radiative Transfer Model for both long wave and short wave radiation
Surface layer scheme	Mellor-Yamada and Janjic Scheme
Land Surface scheme	Noah Land Surface Scheme
PBL scheme	Mellor-Yamada and Janjic (MYJ)
Microphysics scheme	WRF Double Moment class 5
Cumulus Convection Scheme	Betts Miller Janjic Scheme
Initial/boundary conditions	CFSv2 T126 12 hourly
Model Integration time	00UTC 26 Feb to 00UTC 01 Oct from 1982-2017
Resolution of the Ocean model	38 km (290 x 250 x 1) (This is a bulk model, which does not have horizontal and vertical advections) Ocean model is initialized with C-GLORS Climatological MLD



Simulation domain used in ARW model

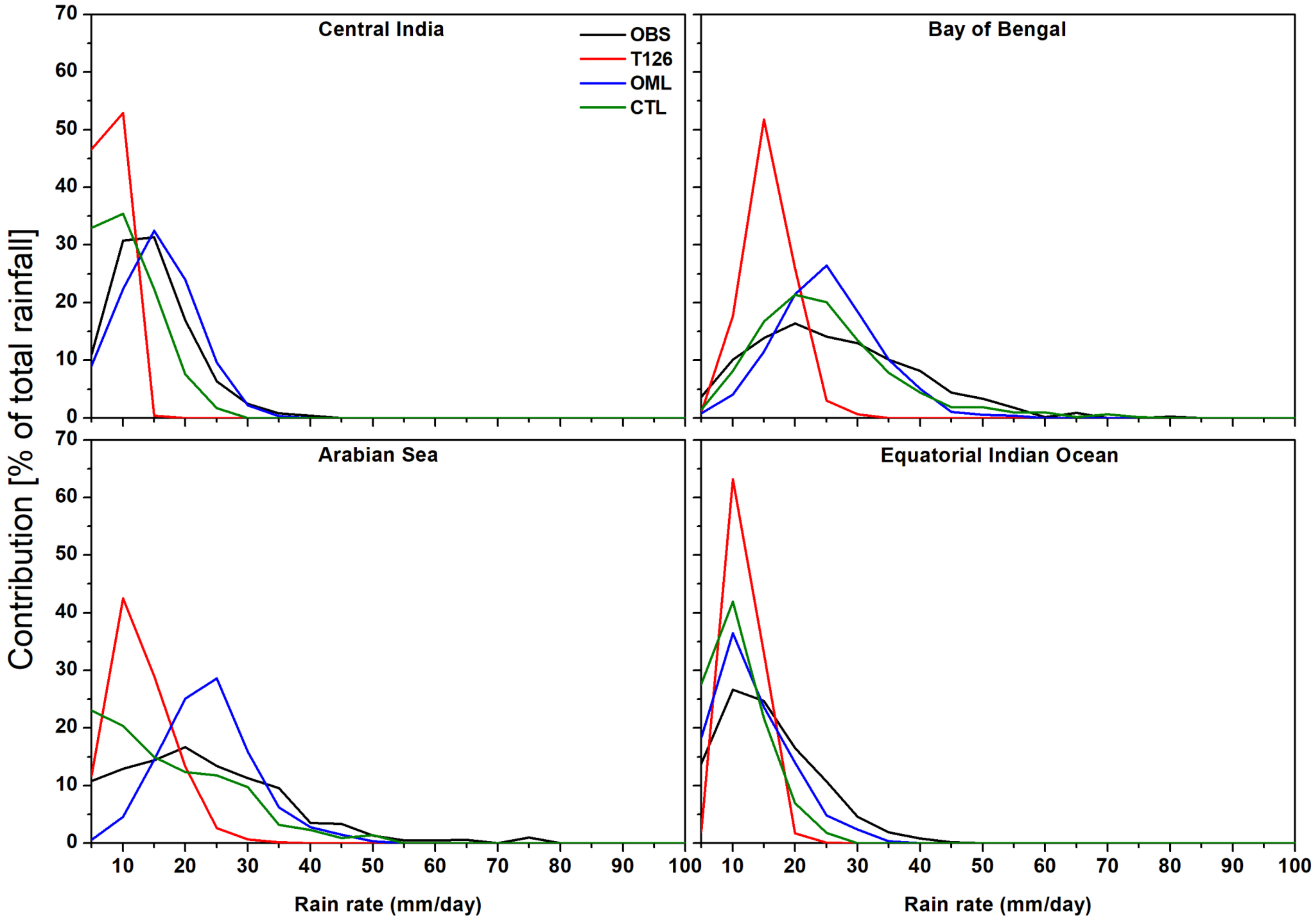
Reforecast skill of downscaled (T126 to T382) using WRF coupled with OML



ACC

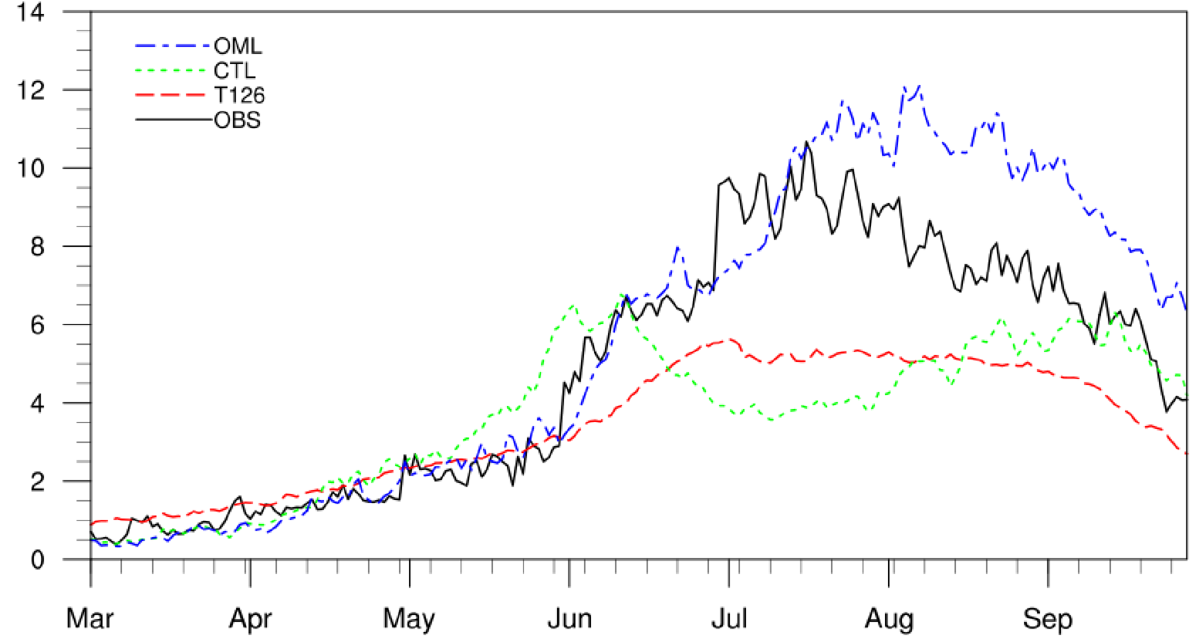
GPCP VS OML (T126) = 0.55 (0.29)

Impact of downscaling on PDF of rainfall

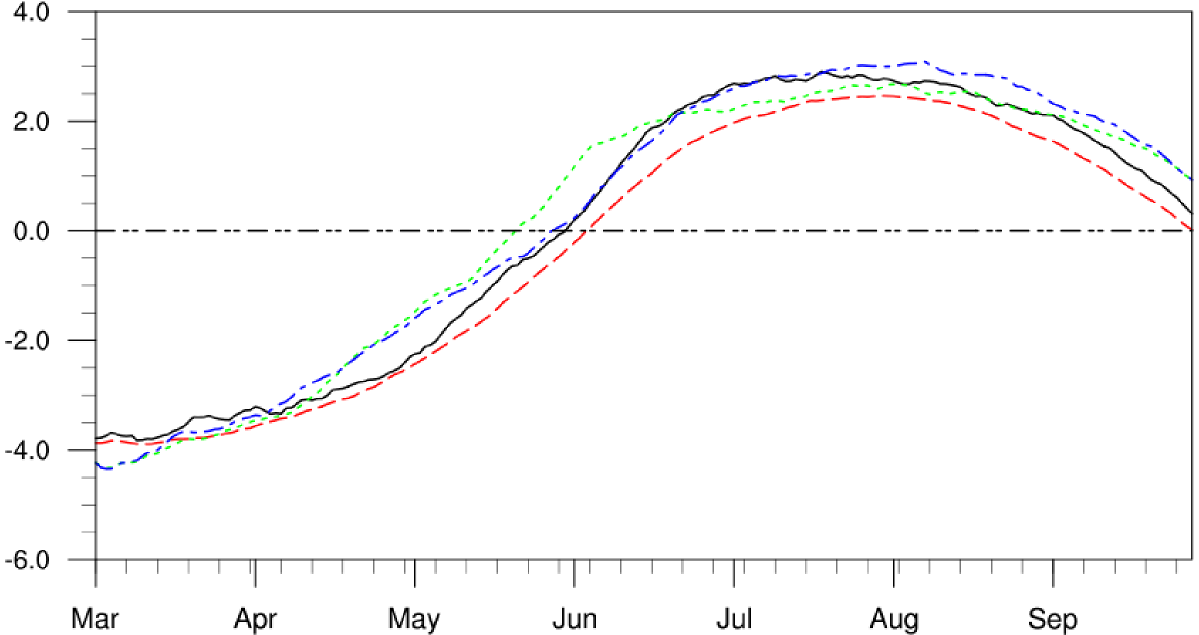


Frequent drizzling in GCM reduced significantly in OML model

(a) Rainfall (mm/day)



(b) Trop.Temp N-S Gradient(K)



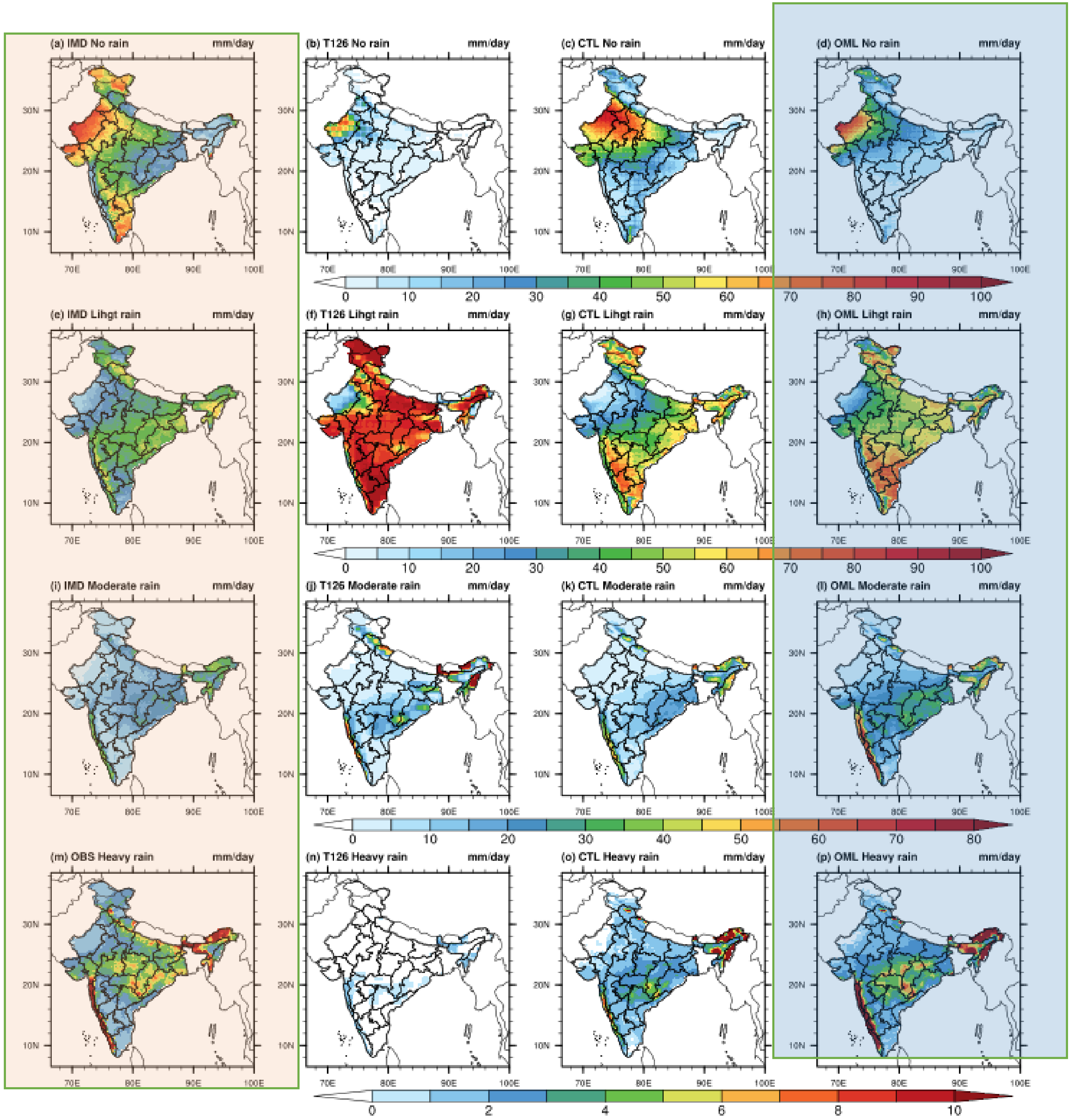
Comparison of IMD's SEFS with MMCFS & OML

Period	IMD SEFS			MMCFS (T382)			OML		
	A.C.C	MAE	NSD	A.C.C	MAE	NSD (PY)	CC	MAE	NSD
1988-2017	0.31	6.72	0.60	**0.58**	**9.5**	1.56	**0.55**	6.5	0.80

A.C.C: Anomaly Correlation coefficient
AE: Absolute Error
NSD: Normalized standard deviation (w.r.t observations)

Usability of Seasonal Forecasts for climate applications

Percentage of Rainy Days in JJAS



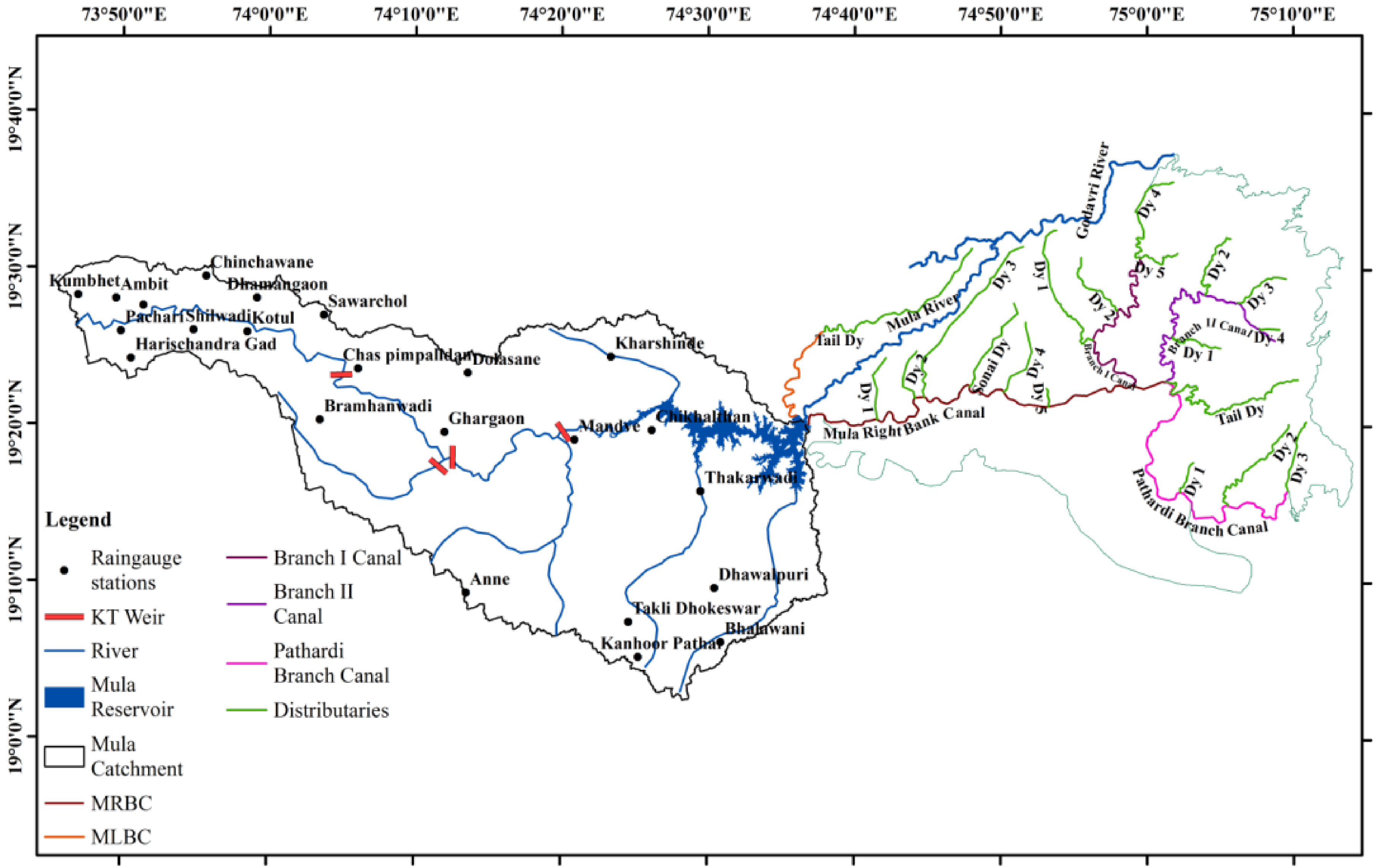
Percentage of no rain days

percentage of rainy days (less than 10 mm) (Light rain)

Percentage of rainy days with in 10 to 40 mm (Moderate rain)

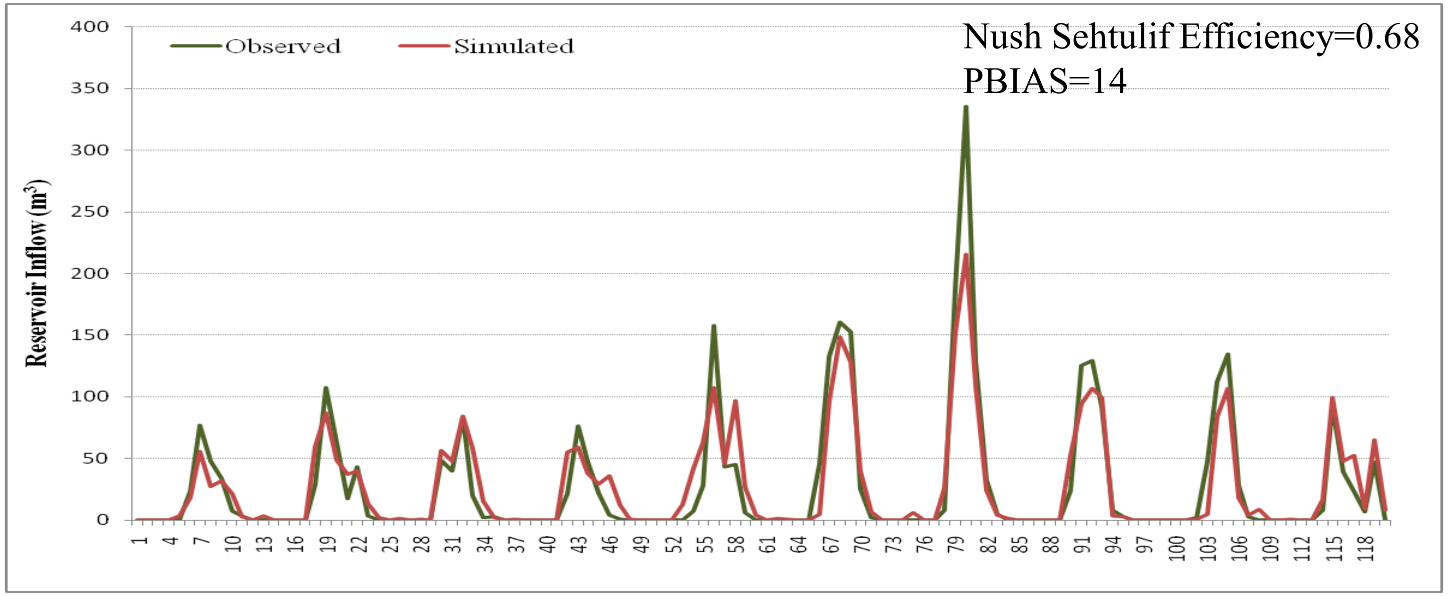
Percentage of rainy days greater than 40 mm (heavy rain)

Usability of Climate information for Reservoir Management Practices



Reservoir Inflow

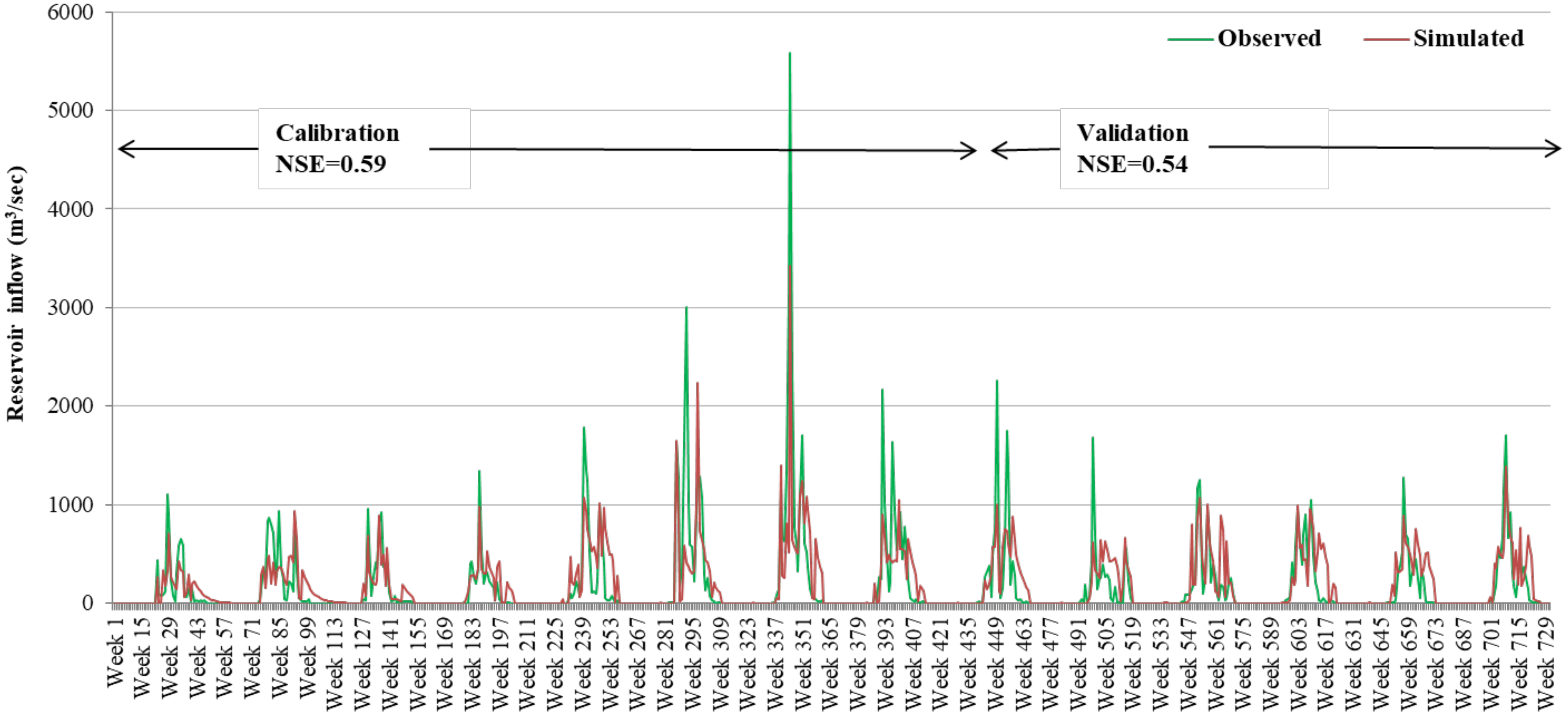
Monthly analysis


Nush Sehtulif Efficiency=0.68
PBIAS=14

Performance rating	**NSE**	**PBIAS (%)**
Very good	0.75<NSE < 1.00	PBIAS < ±10
Good	0.65<NSE<0.75	±10<PBIAS<±15
Satisfactory	0.50<NSE<0.65	±15<PBIAS<±25
Unsatisfactory	NSE <0.50	PBIAS>±25

Reservoir Inflow

Weekly analysis

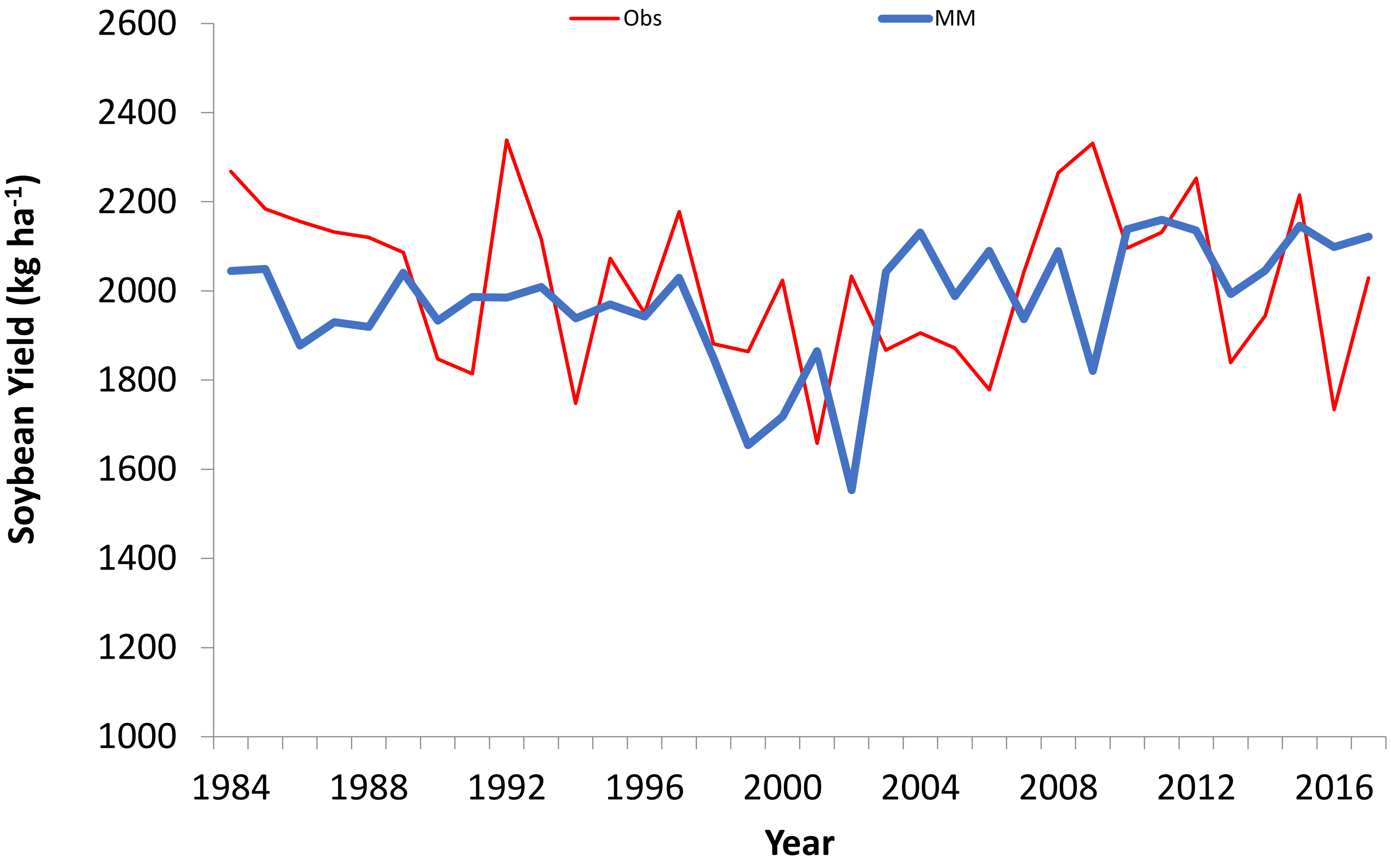


Data used in the study

Location	Pune
Location	Latitude 18.533° N, Longitude 73.833° E
Frequency of weather data	Daily observations
Frequency of weather data	Daily observations
Observed crop data Length	2 Years with 4 sowing dates
Crop	Soybean
Varietyused	MACS 450

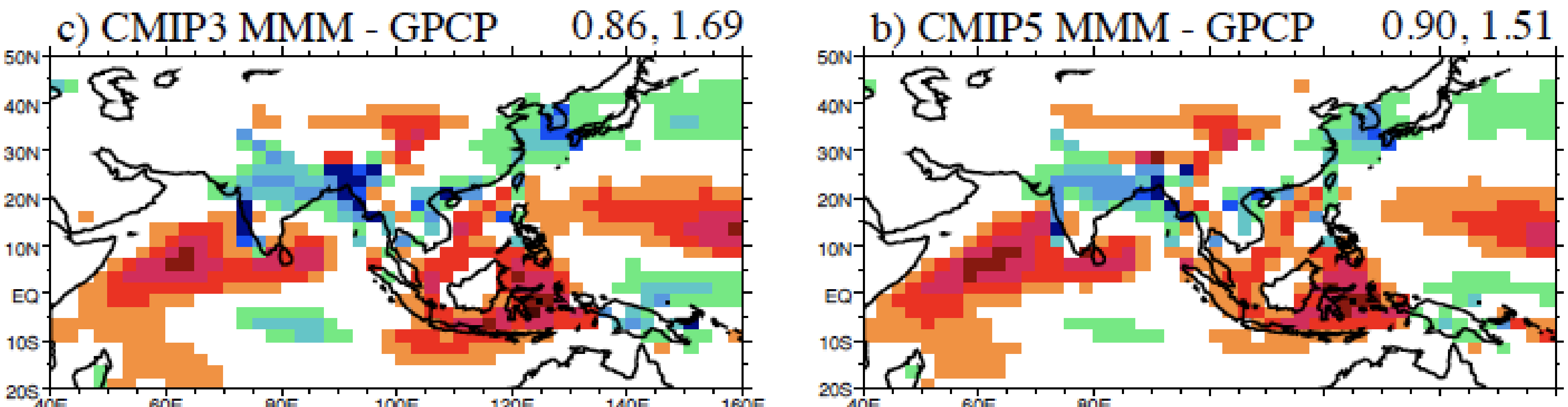
Input weather data required	Unit
Minimum Temperature	°C
Maximum Temperature	°C
Radiation	MJ m^{-2} day^{-1}
Rainfall	mm

Comparison of Soybean yield using observed and Monsoon Mission Forecasted weather series

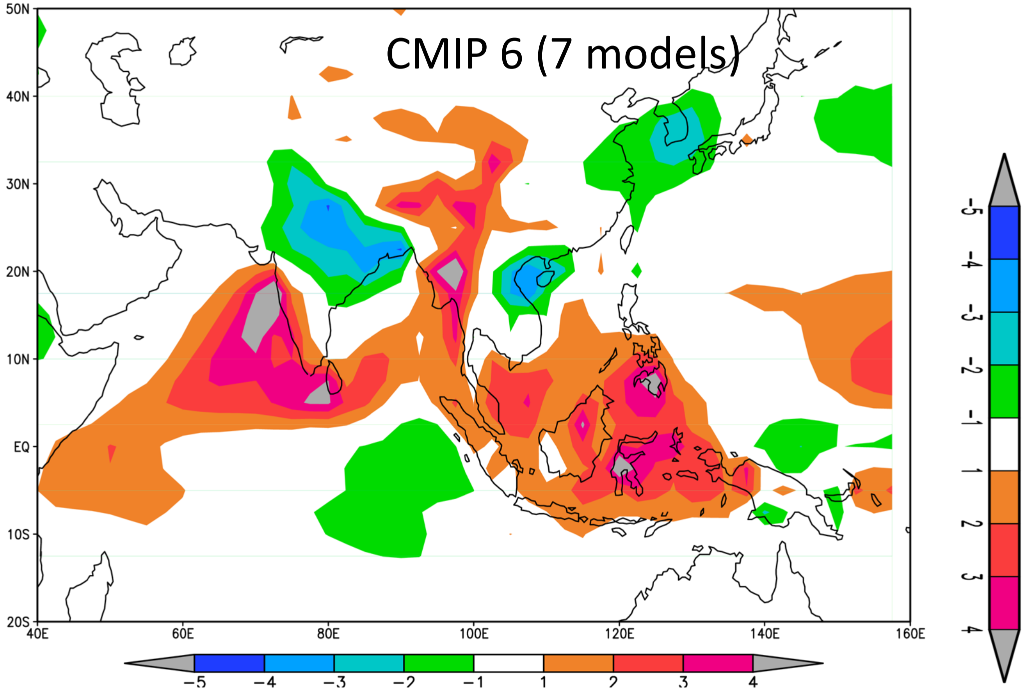


Challenges

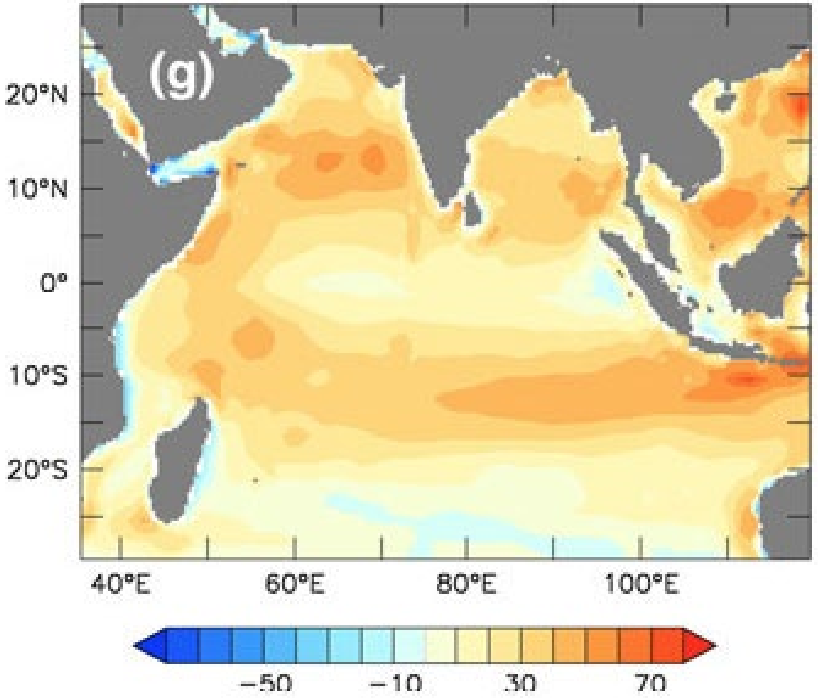
Dry bias in CMIP3 and CMIP5 Models



Sperber et al., (2012)



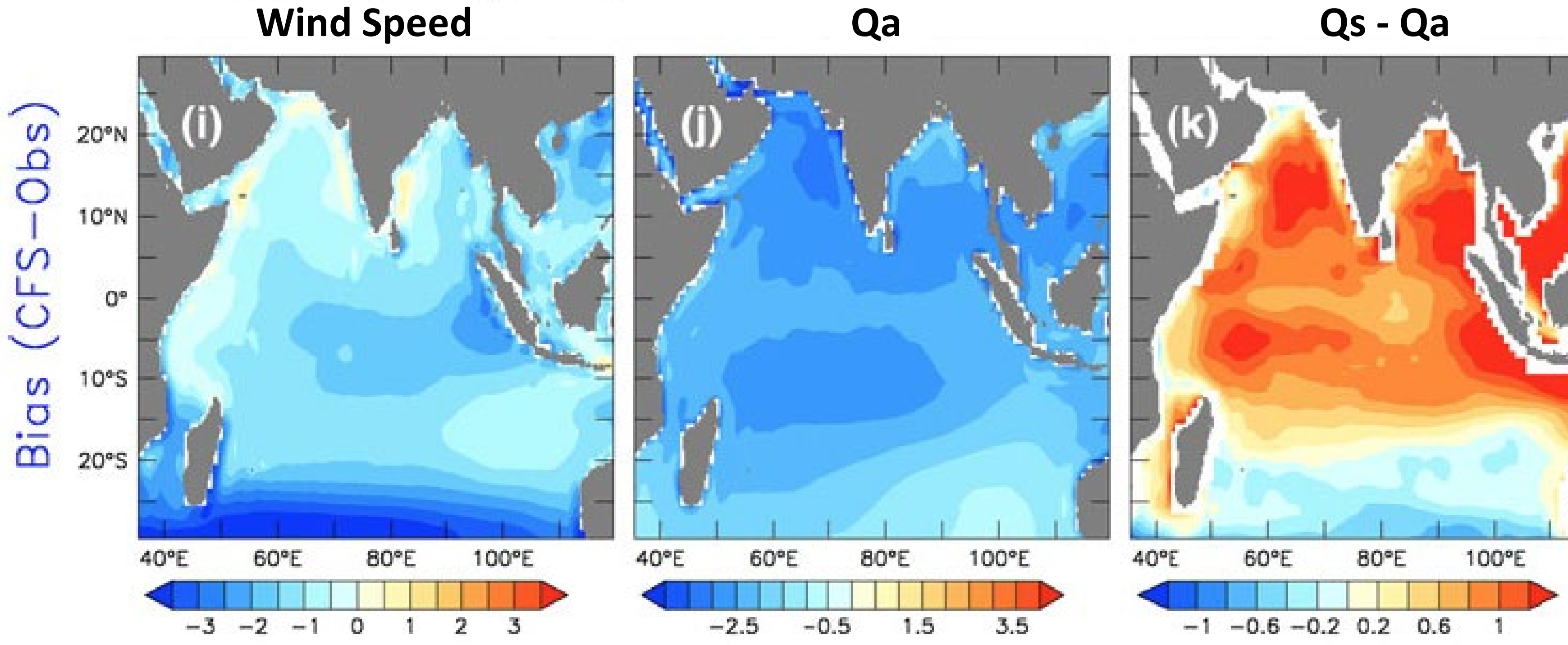
- Model Biases in CMIP3 and CMIP5 looks sim
- Are they different in CMIP6?
- Same Biases are Observed in CMIP 6. It mea bias is lingering around for several decades.



Evaporation Bias in CFS Model

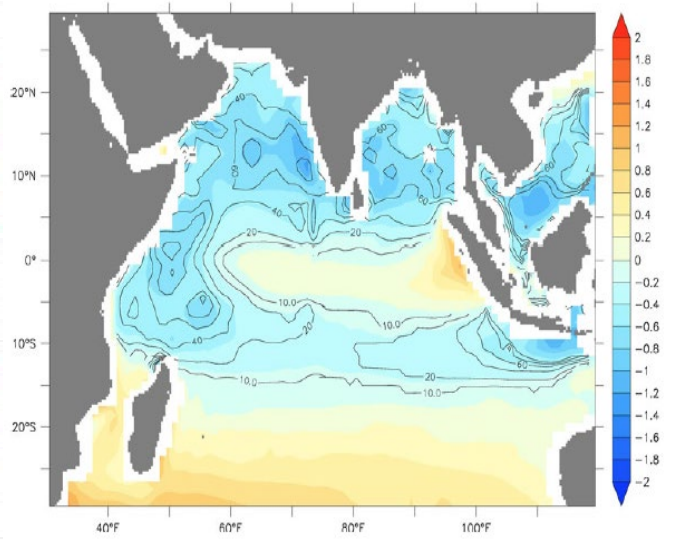
- Latent Heat/Flux bias in Coupled model is due to Qs-Qa
- Winds are weaker in the coupled model, hence promotes less evaporation
- Qs-Qa is the major reason for overestimation of latent heat flux and

$$E = \rho C_e W \Delta Q$$



Wind Speed **Qa** **Qs - Qa**

Equivalent Contribution of SST Bias due to evaporation bias



Pokhrel et al., (2012)

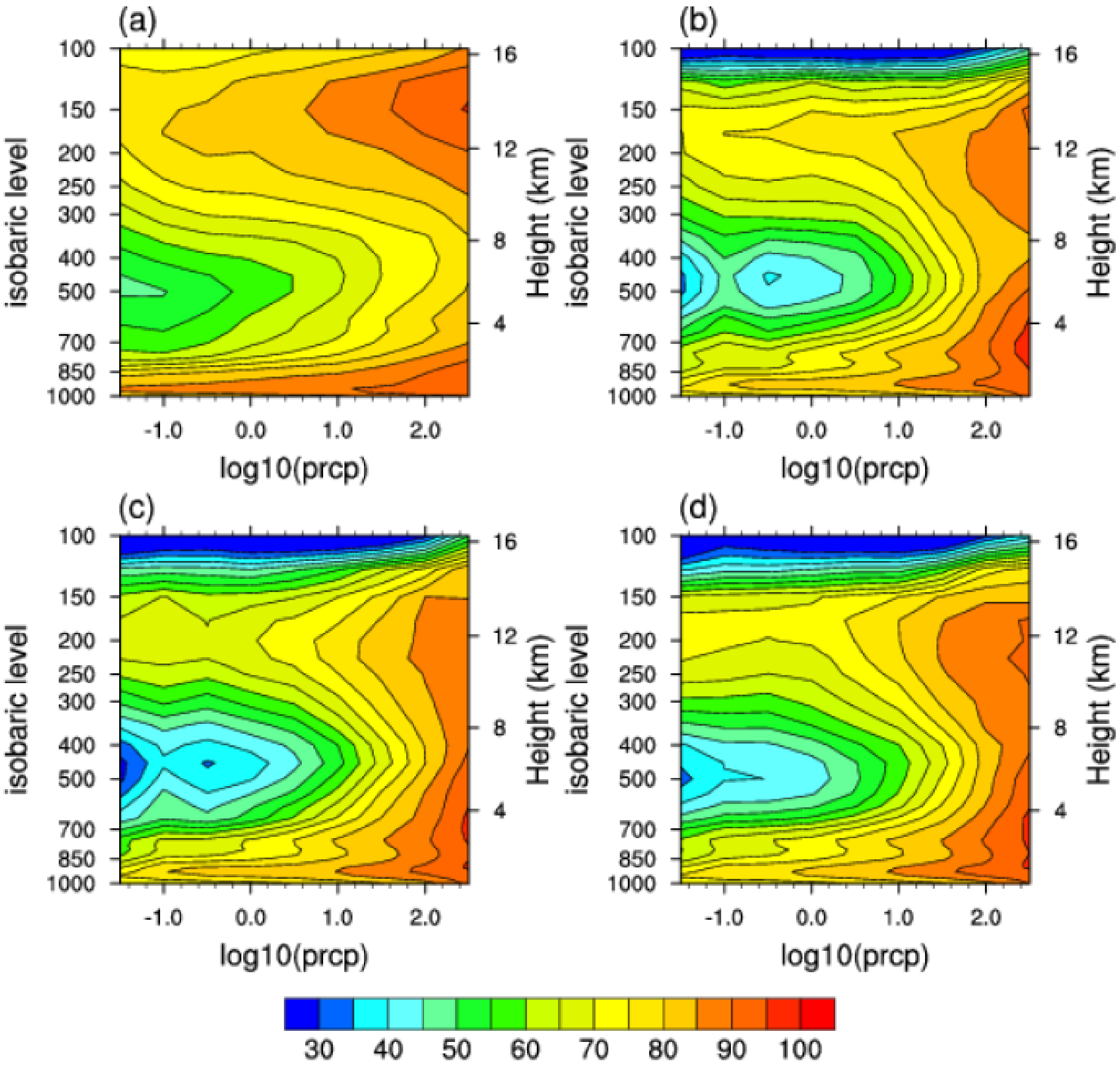
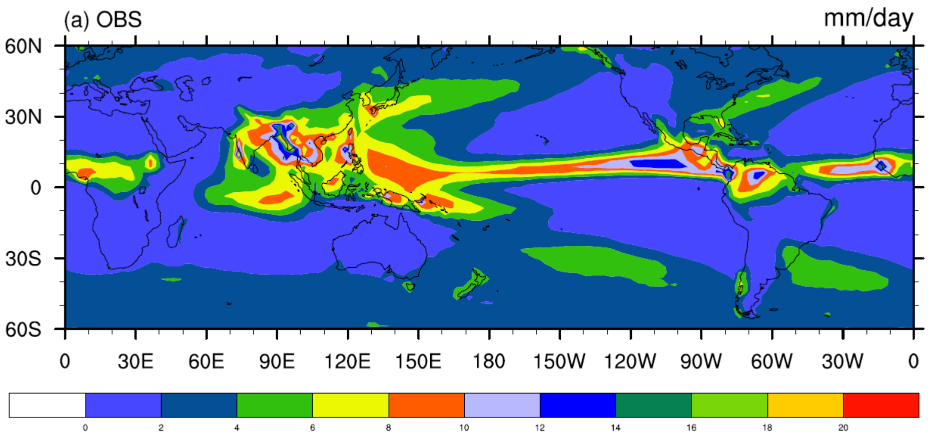


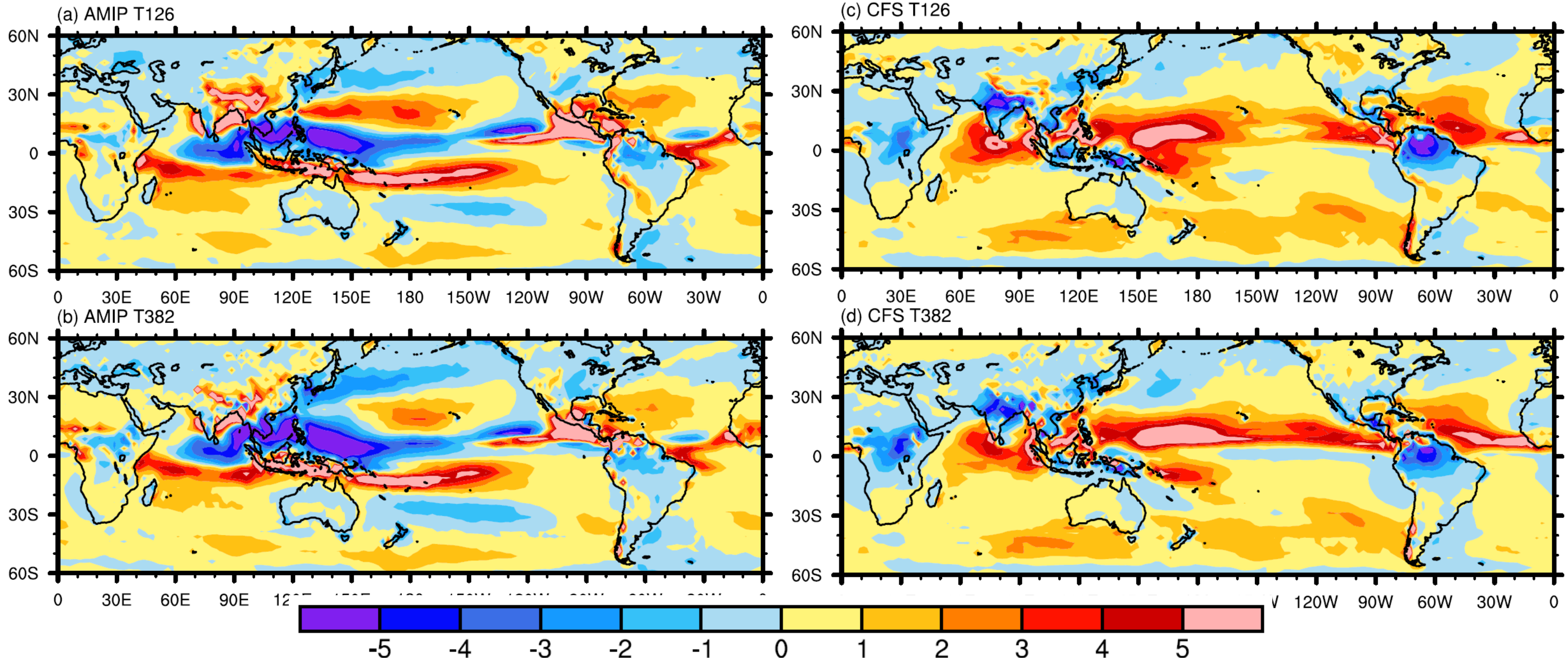
Figure 8. Composite of vertical profile of relative humidity (%, shaded) with respect to precipitation for MISO events for (a) Observation; (b) T62; (c) T126, and (d) T382.

Tirkey et al. 2019

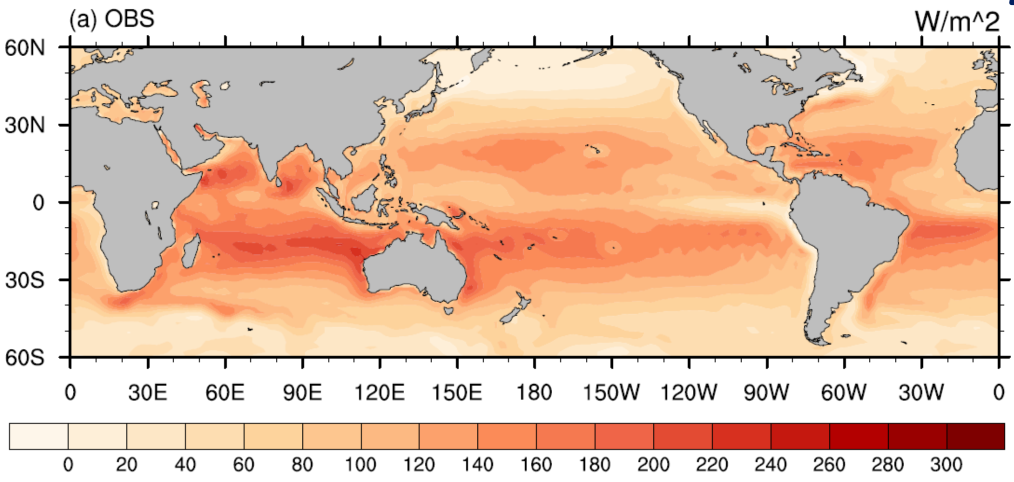


Precipitation Bias in Coupled and Uncoupled Models

- AGCMs overestimate (underestimate) rainfall over majority of the land masses (Oceans) including Indian Land mass
- CGCMs underestimate (overestimate) rainfall over majority of the land masses (Oceans) including Indian Land mass

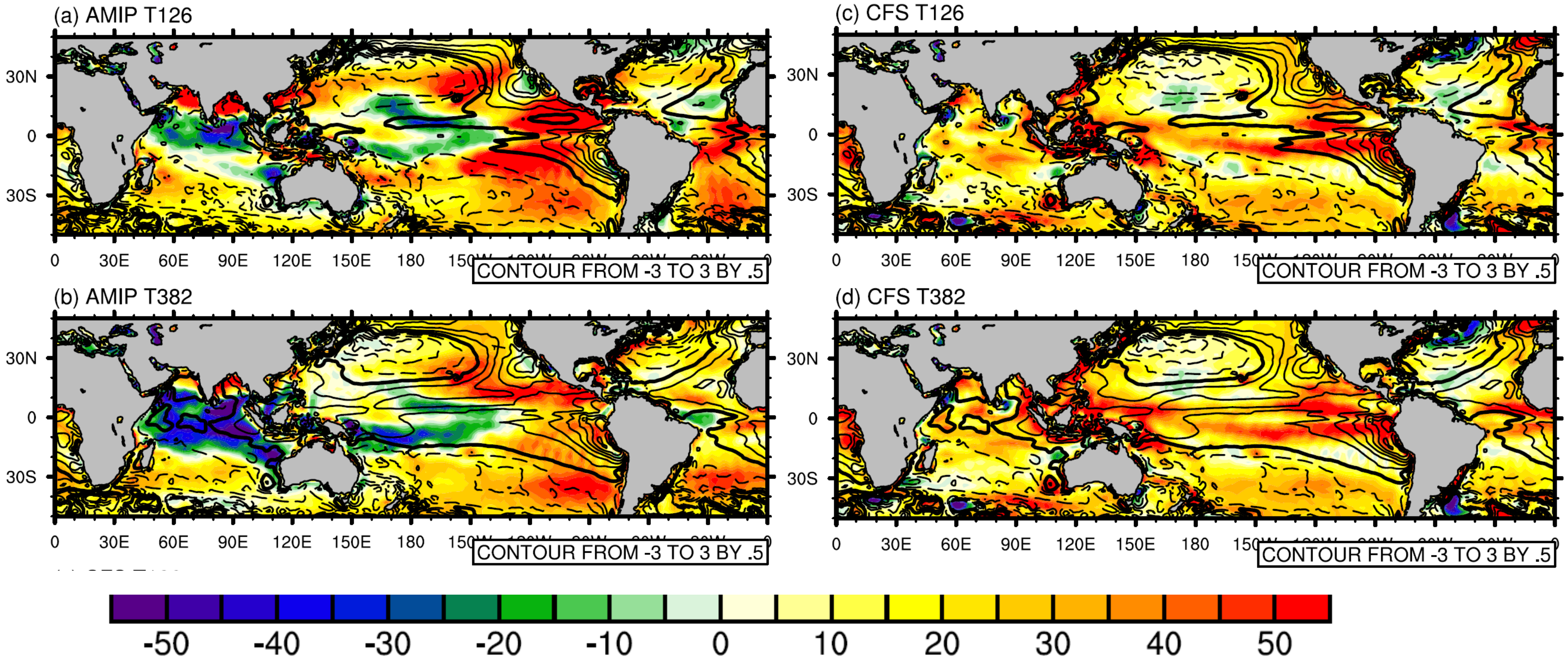


LHF Bias in coupled and uncoupled models

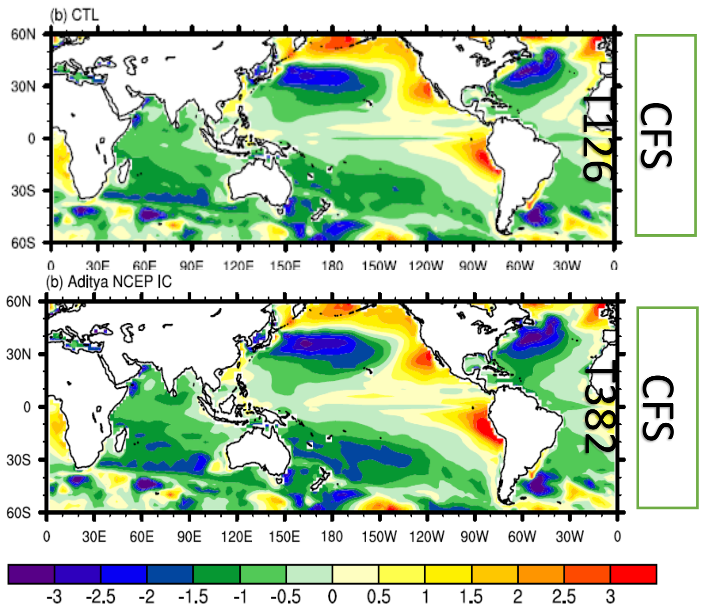


Latent Heat Flux biases are similar in coupled and uncoupled models in majority of the region, except in equatorial regions of warm SST regions. This clearly suggests that the dry bias in the coupled model is a result of latent heat flux biases in atmospheric model by forcing cold SST bias.

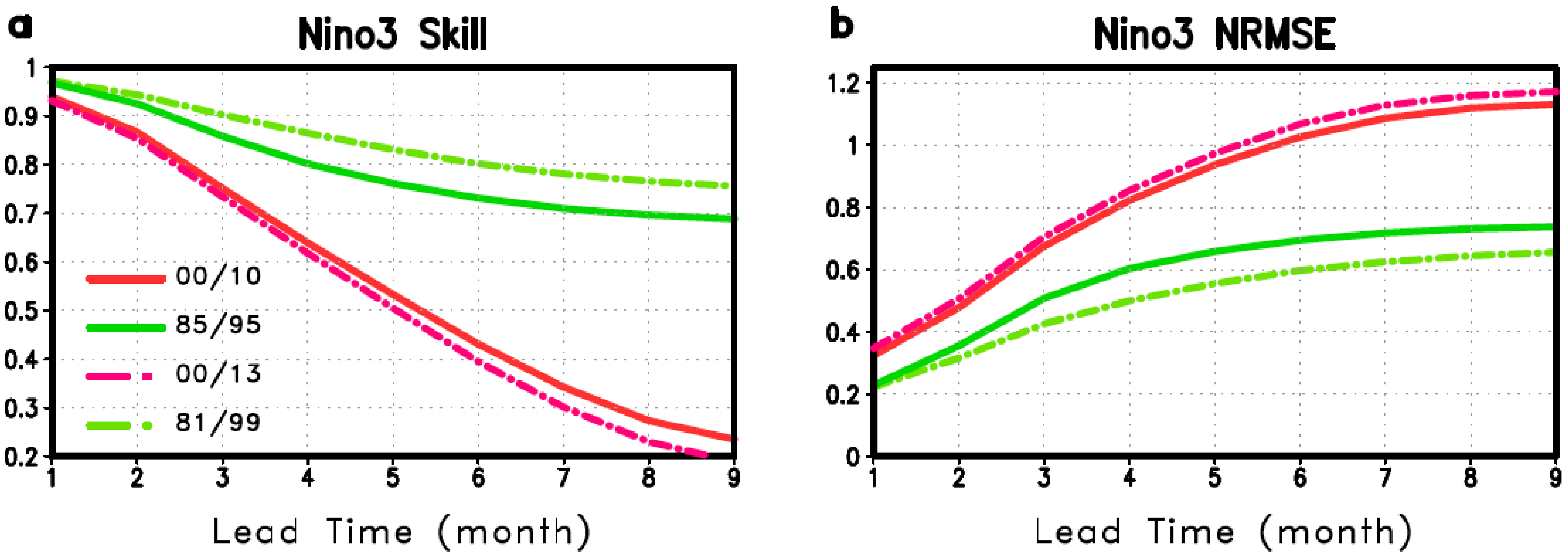
LHTFL bias



SST bias

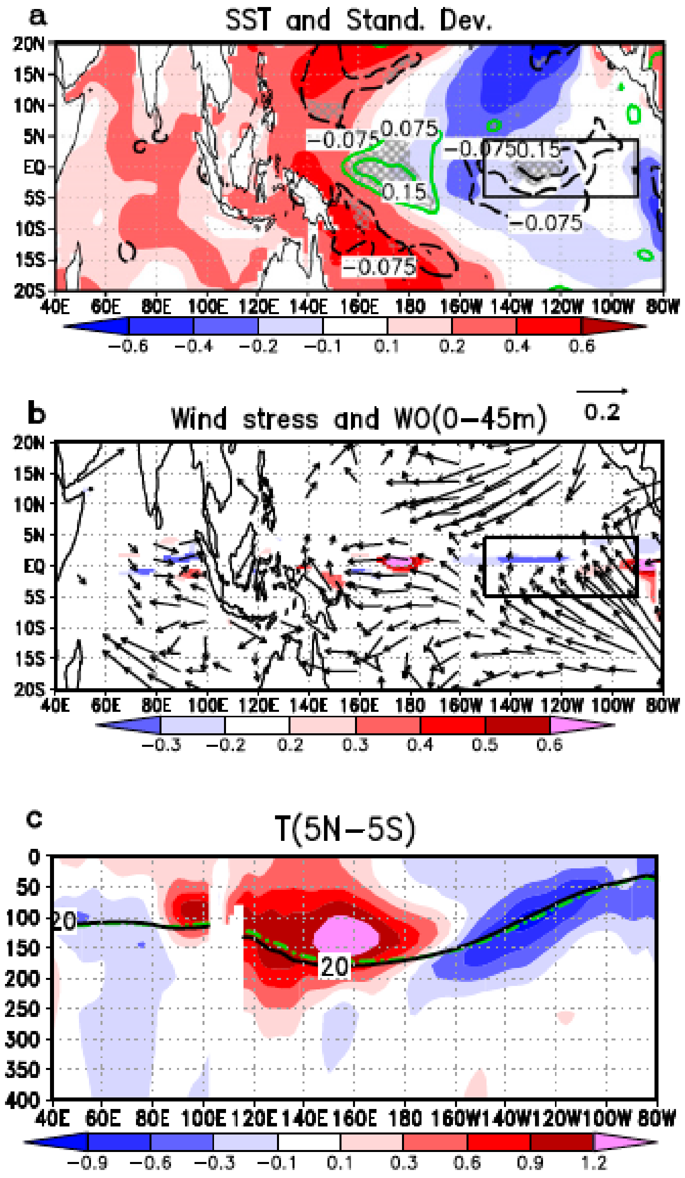


Reduced Predictability of El Nino in recent decades



Period	Correlations between NOAA and Clim. CFS
1981-1999	0.62
1985-1995	0.73
2000-2010	0.65
2000-2016	0.61

CFS Model SKill



The reduction in skill is attributed to strong East-west SST gradient and stronger walker circulation.

Zhao et al. (2016)

OLR anomalies during 1994 and 2019

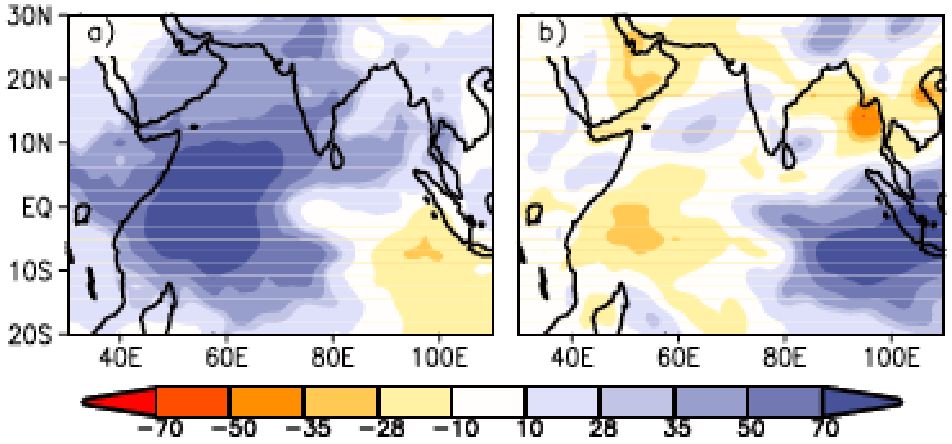
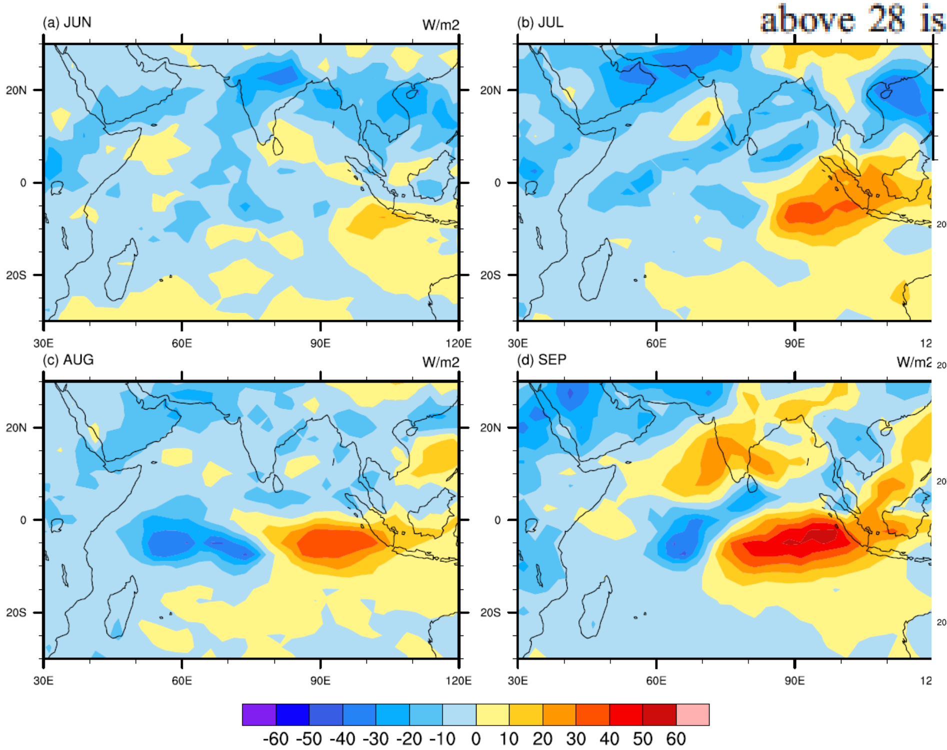
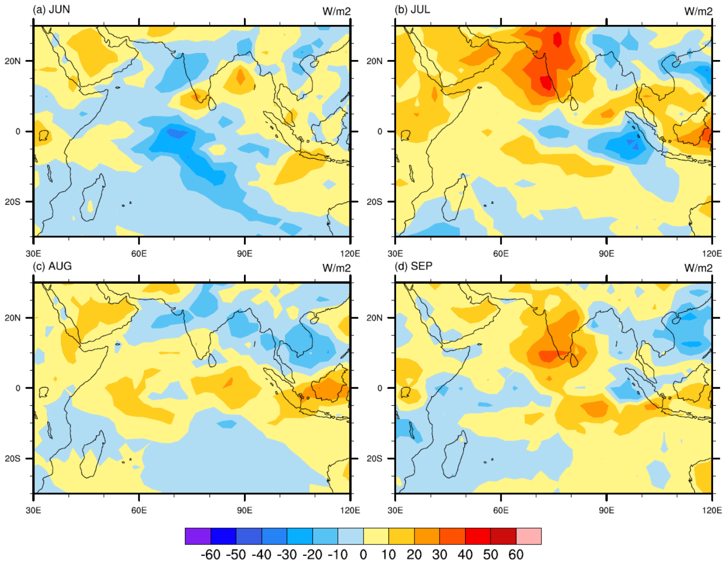


Figure 2. Correlation (x 100) for July and August of OLR with the average OLR over (a) WEIO and (b) EEIO. Values above 28 is significant at 95%.

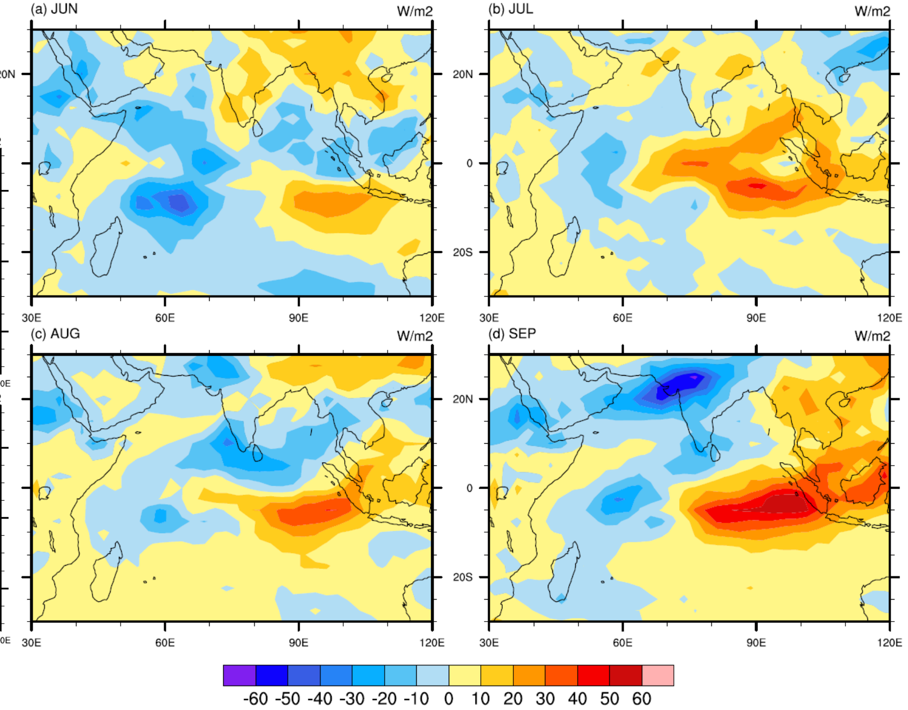
1994

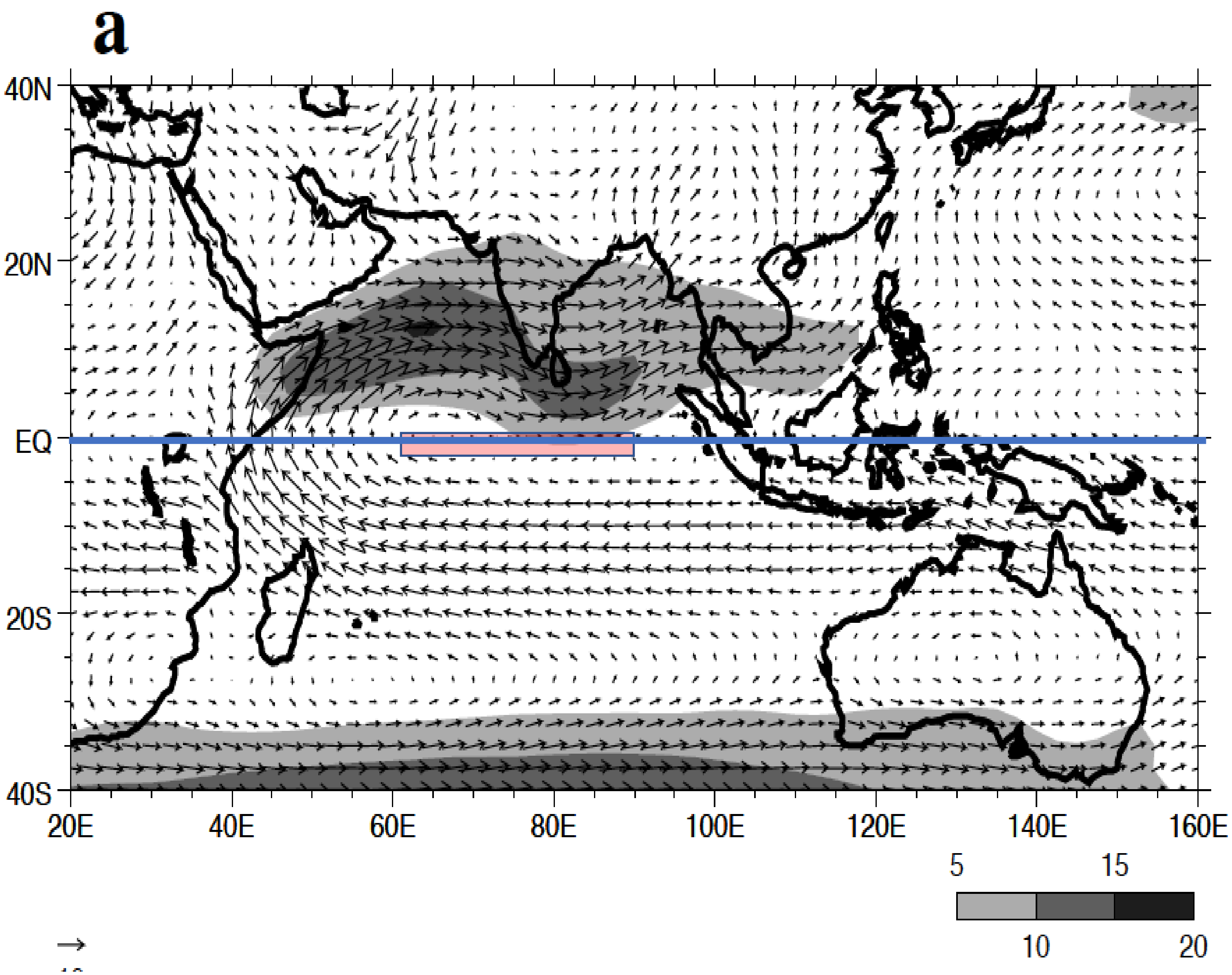


2002



2019




a
40N
20N
EQ
20S
40S
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40E
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120E
140E
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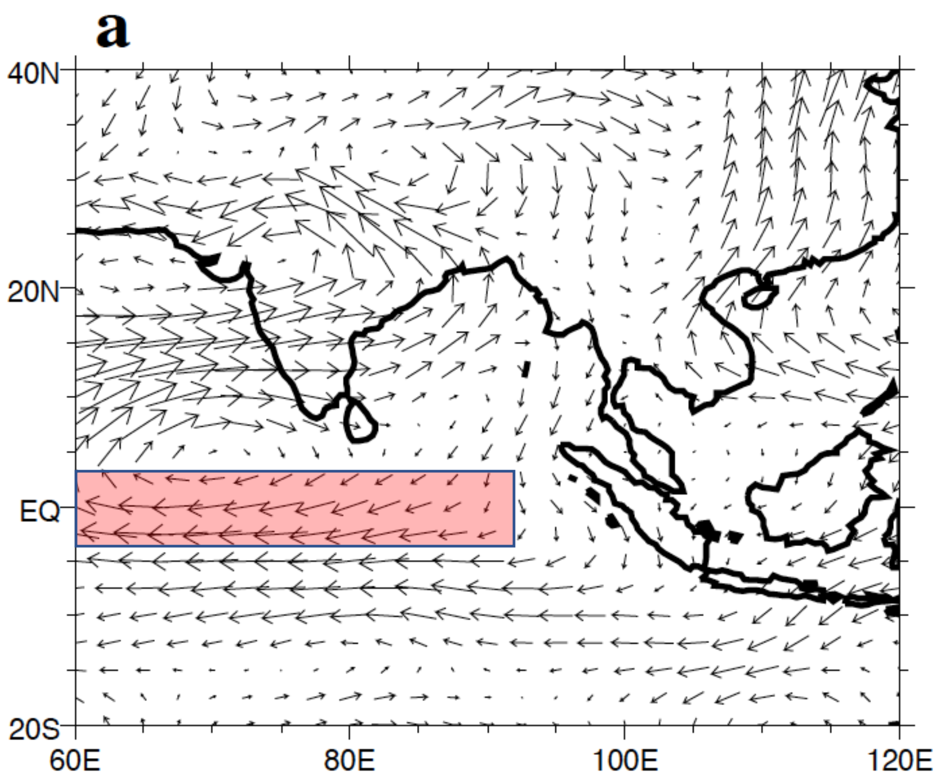
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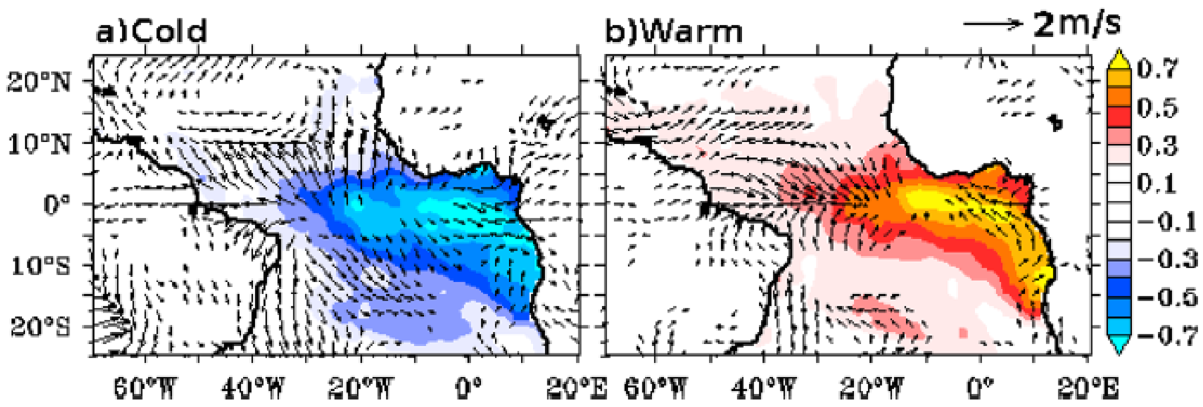
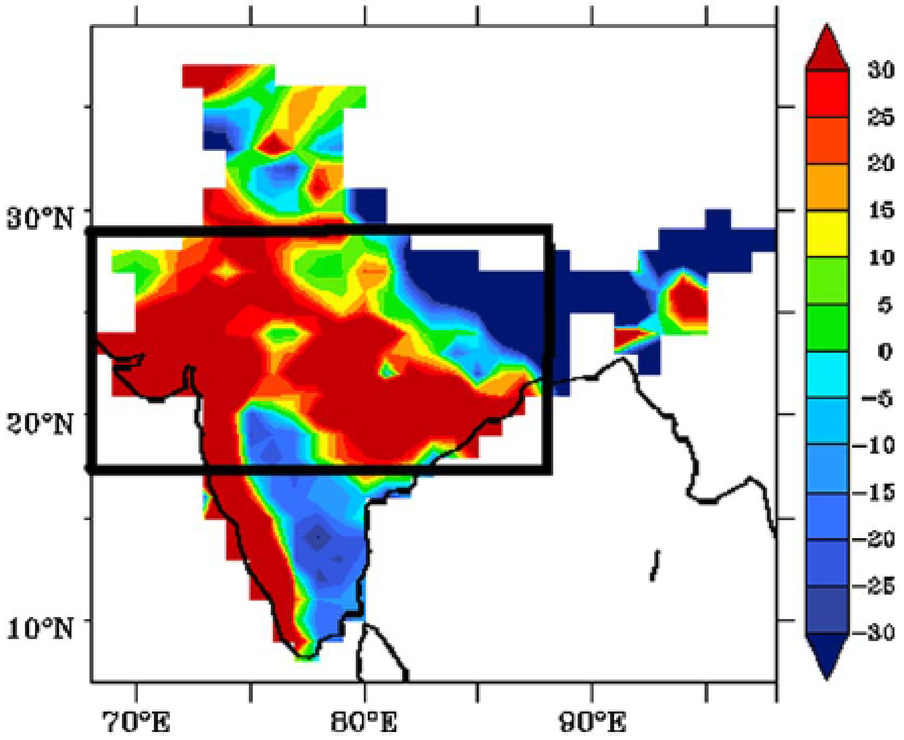
Atlantic Zonal Mode-ISMR



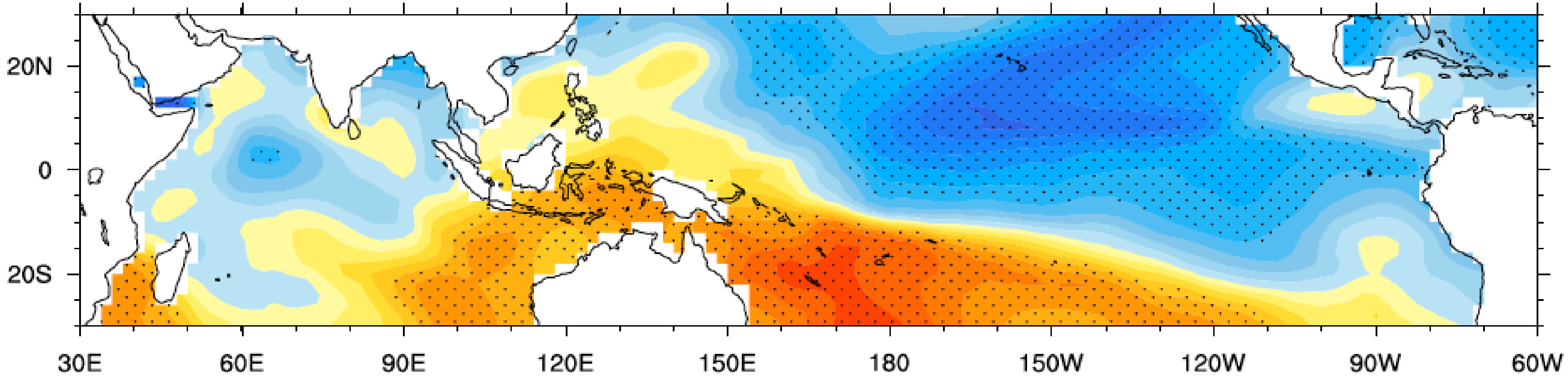


- Warm-Cold AZM Composite of Rainfall (mm/month)
- Cold AZM reduces the wind shear and enhances the mid-troposphere humidity
- More (fewer) number of depressions form during a cold (warm) AZM
- Correlation between Monsoon zone rainfall and Atl3 is -0.28

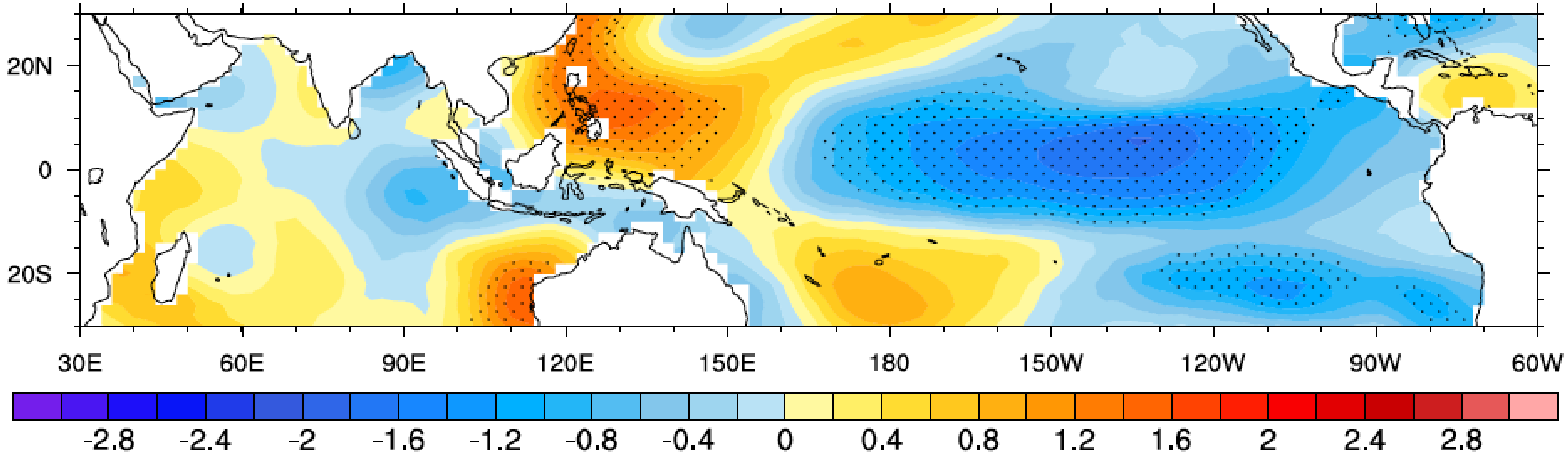
Pottipinjara et al., (2016)

Epochal Changes in ISMR teleconnections

(a) 1952-1982 GMY(7) - BMY(7)



(b) 1983-2013 GMY(5) - BMY(5)



(d) IOD east pole

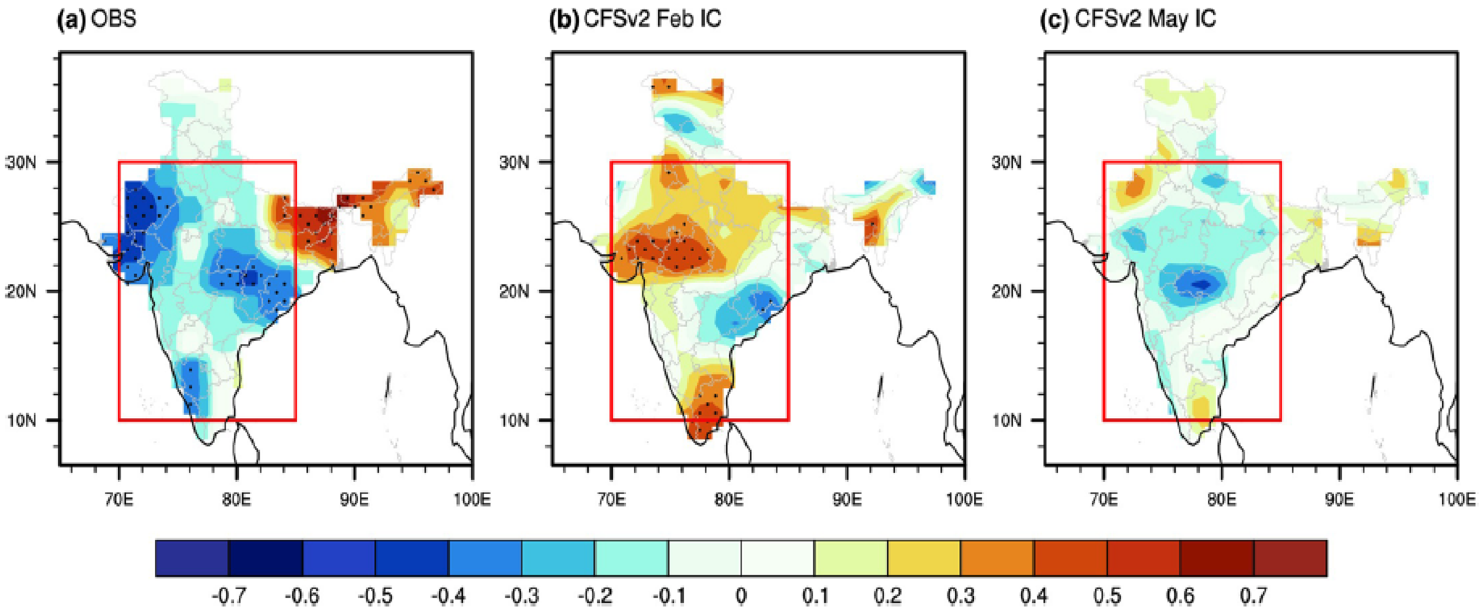
- Blue Bars (1952-1982)
- Red Bars (1983-2013)

- Please notice change in phase of correlations with DMI, east pole, west pole in JJAS

- Weakening of correlations with Nino 3.4

Srivastava et al., (2019)

Non-ENSO component of ISMR cor. with AZM



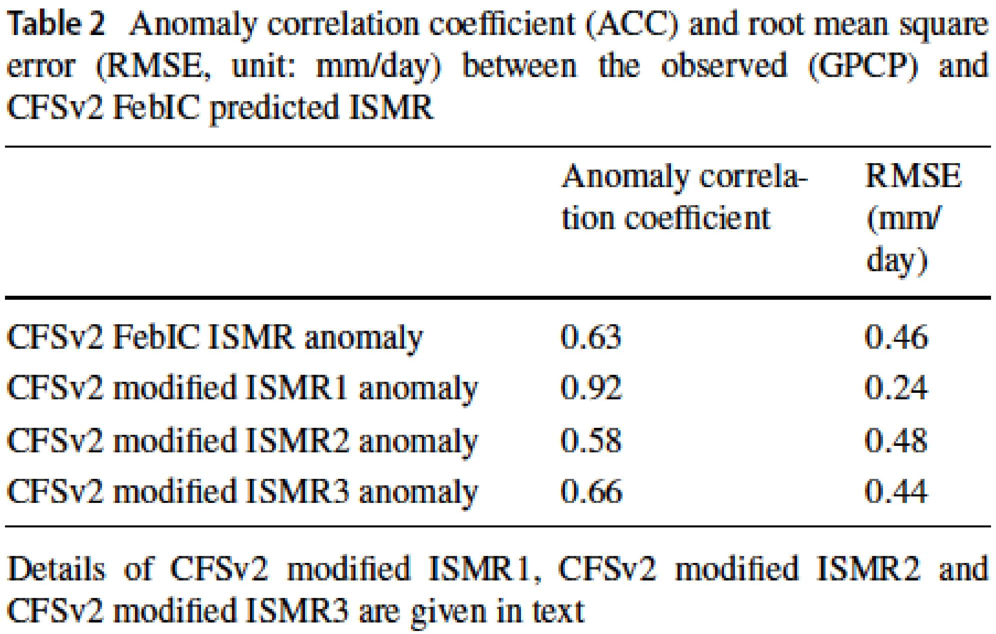


Table 2 Anomaly correlation coefficient (ACC) and root mean square error (RMSE, unit: mm/day) between the observed (GPCP) and CFSv2 FebIC predicted ISMR

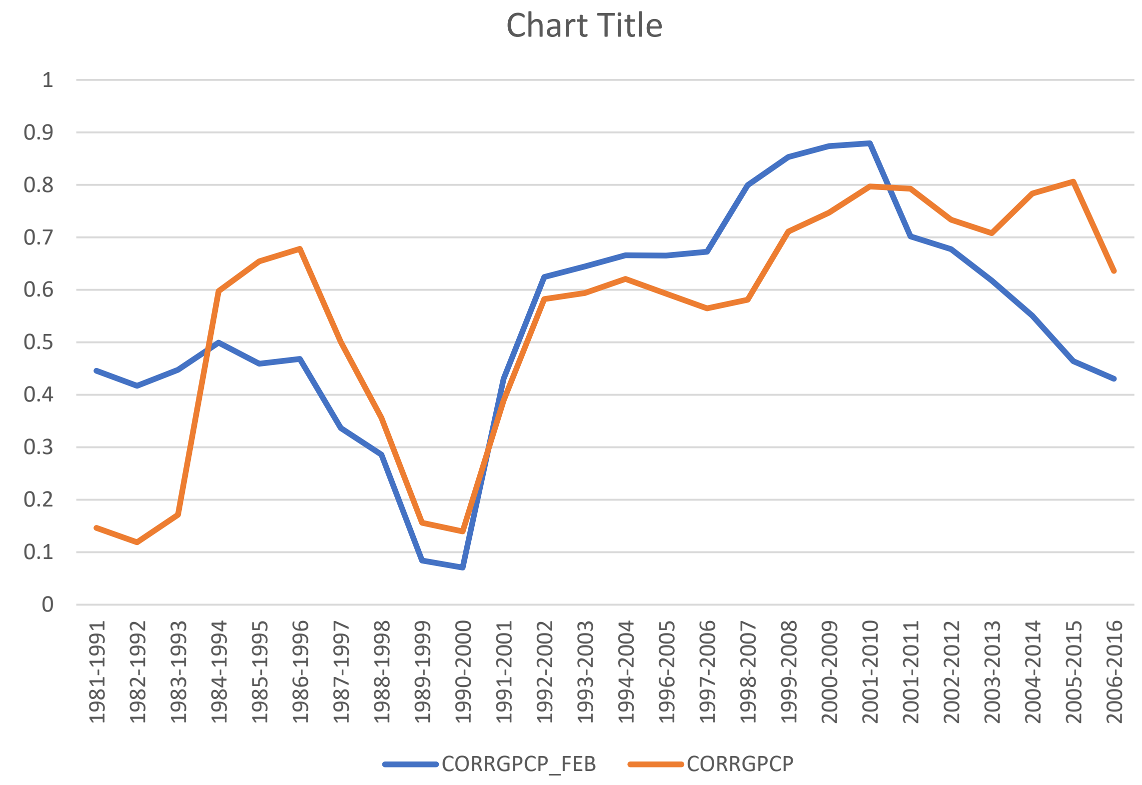
	Anomaly correlation coefficient	RMSE (mm/day)
CFSv2 FebIC ISMR anomaly	0.63	0.46
CFSv2 modified ISMR1 anomaly	0.92	0.24
CFSv2 modified ISMR2 anomaly	0.58	0.48
CFSv2 modified ISMR3 anomaly	0.66	0.44

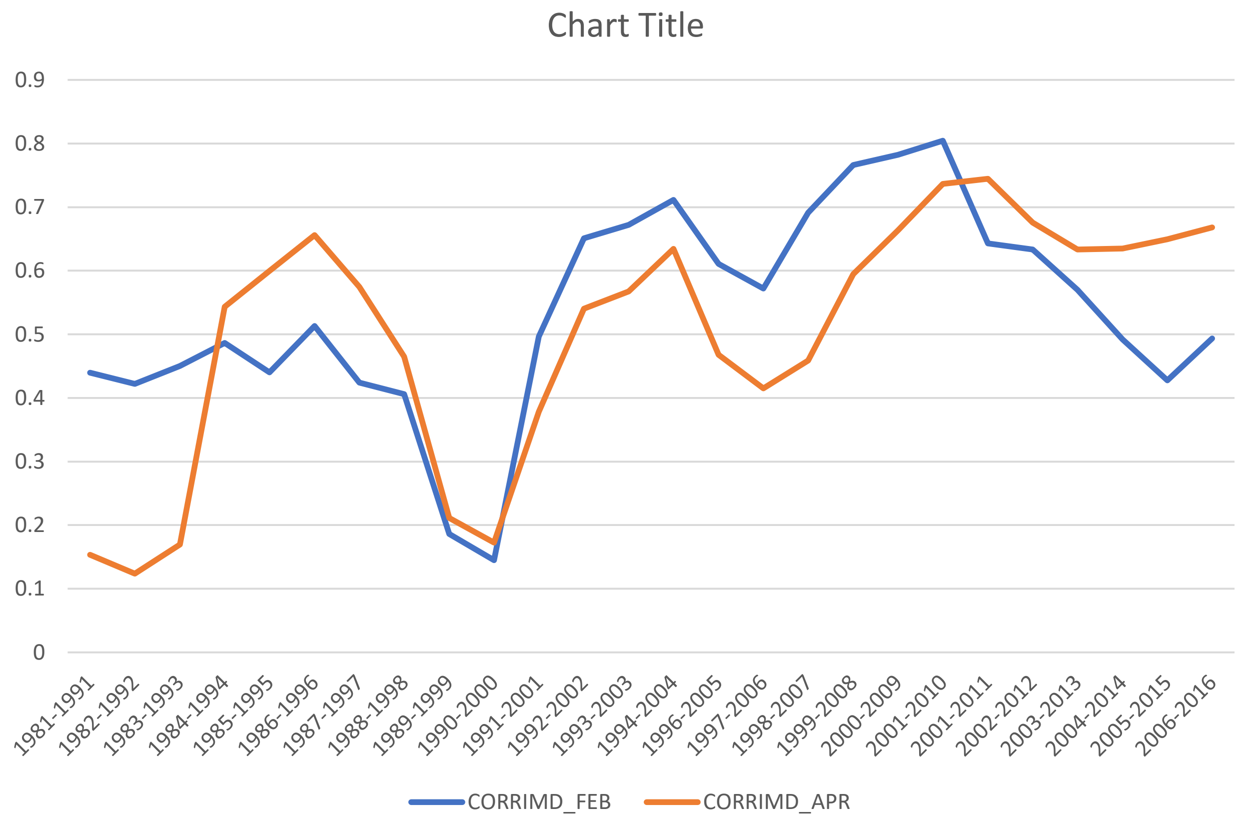
Details of CFSv2 modified ISMR1, CFSv2 modified ISMR2 and CFSv2 modified ISMR3 are given in text

Period: 1982-2009

- CFS-Feb IC could not capture the pattern
- CFS-May IC captures the pattern to some extent as May IC captures AZM properly

Sabeerali et al., (2019)

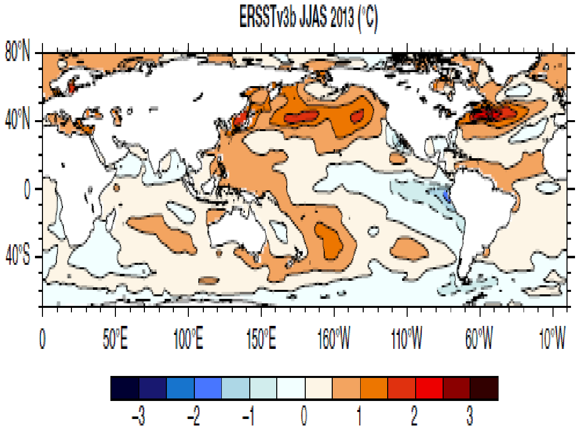


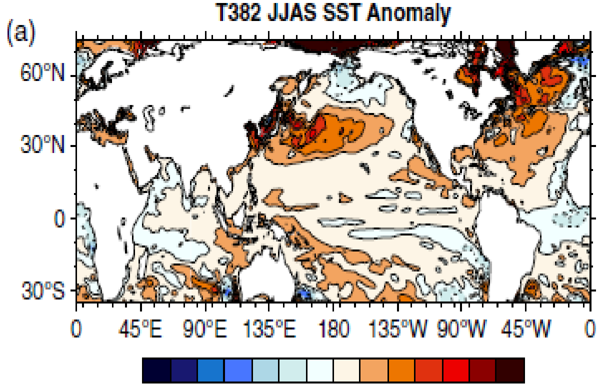


FEB. IC Vs. APR. IC Skill

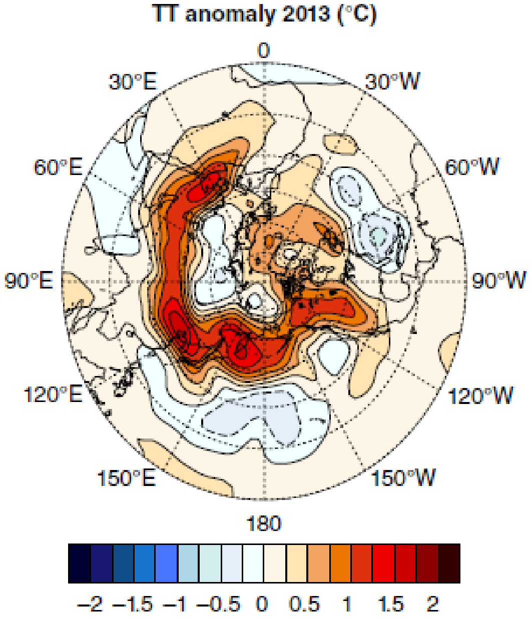
Role of extratropical SST in ISMR – 2013 summer monsoon

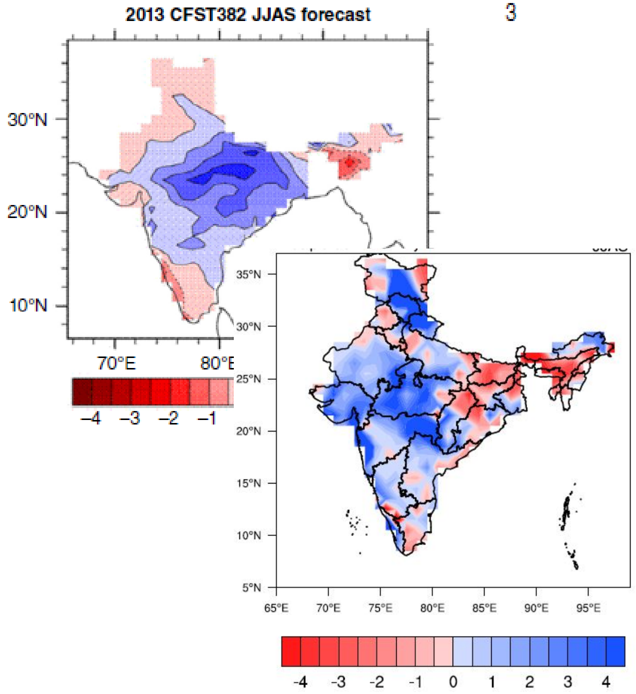
Extratropical SST pattern can influence the ISMR through the modulation of Walker and Hadley circulations (Krishnamurthy and Krishnamurthy 2014).





T382 captured the extratropical SST pattern well in 2013

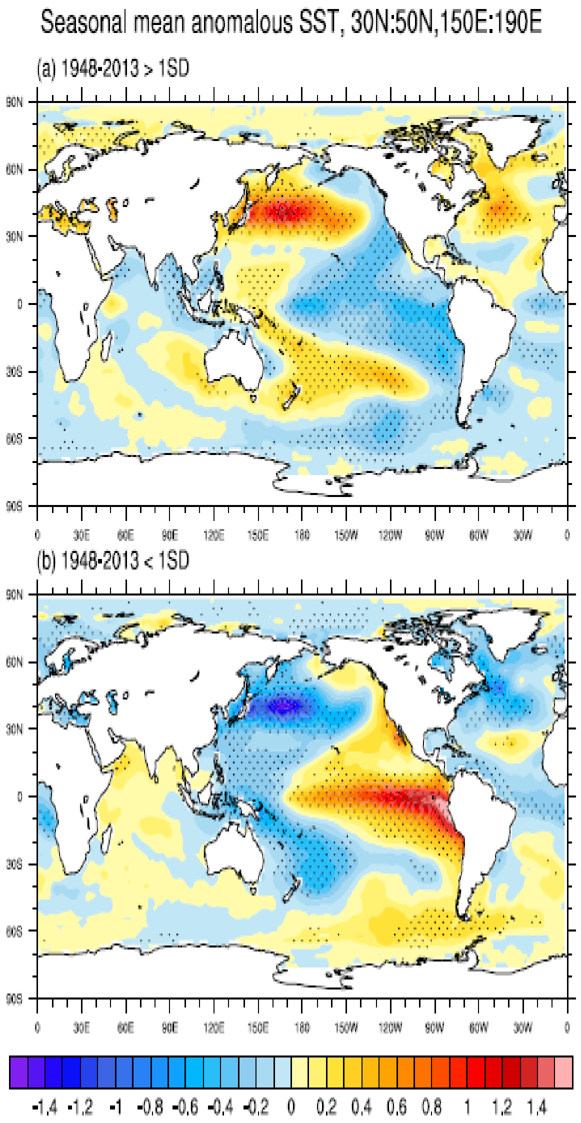


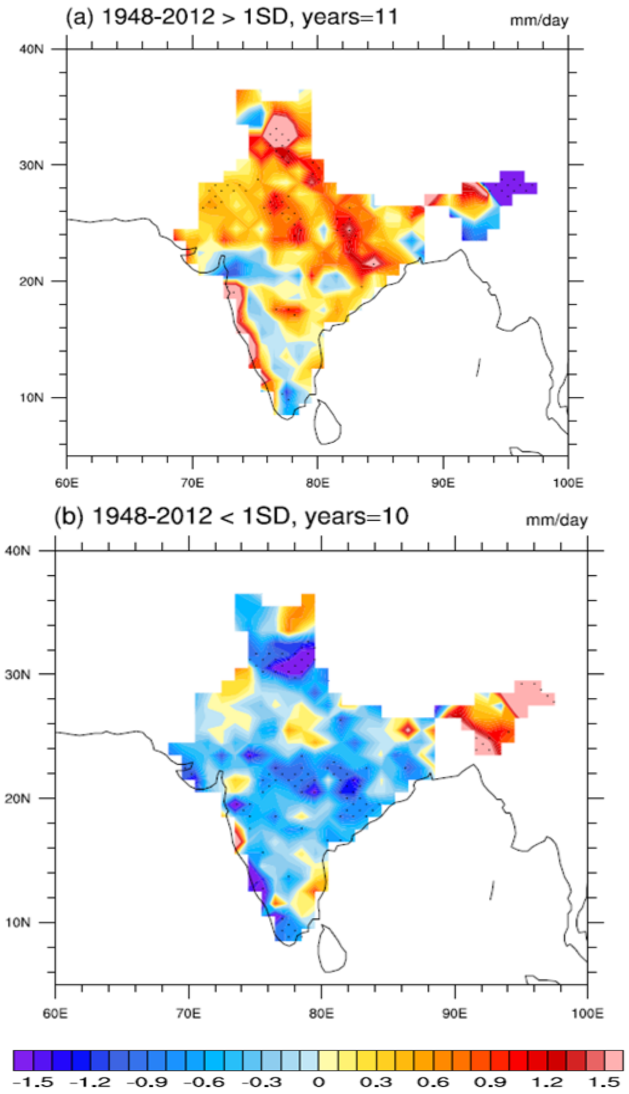


The SST anomalies affect the north–south tropospheric temperature gradient and lead to a local displacement of the jet stream, setting up a quasi-stationary wave. Such a stationary wave, in turn, affects the tropospheric temperature (TT) over southern Eurasia, influencing the north–south TT gradient in the region and thereby the Indian monsoon

Chattopadhayay et al (2015)

Role of extratropical SST





Warmer SST anomalies in extra tropics are conducive for good monsoon

Cooler SST anomalies in extra tropics are conducive for weak monsoon

Srivastava et al (2019)

SST and rainfall anomalies associated with the positive and negative extratroipcal SST anomaly years

Future/Ongoing Activities

- **Coupling of GFS(SL) with MoM 5.0 and MoM6.0 to prepare platform for seamless prediction**
- **Strongly Coupled Data assimilation system**
- **Hydrology coupled CFS with interactive fluxes**
- **New flux parametrization schemes implementation (e.g: wave-wind-current interactions)**
- **Implementation of Icosahedral dynamical core in CFS**
- **Implementing new version of Monsoon Mission model to be transferred to IMD**
- **GLDAS operationalization**
- **Continue with model developmental activities of convective parametrization, microphysics, land surface model (continuing activity)**

Thank YOU