Importance and Present Status of Seasonal Climate Forecasting in South Asia

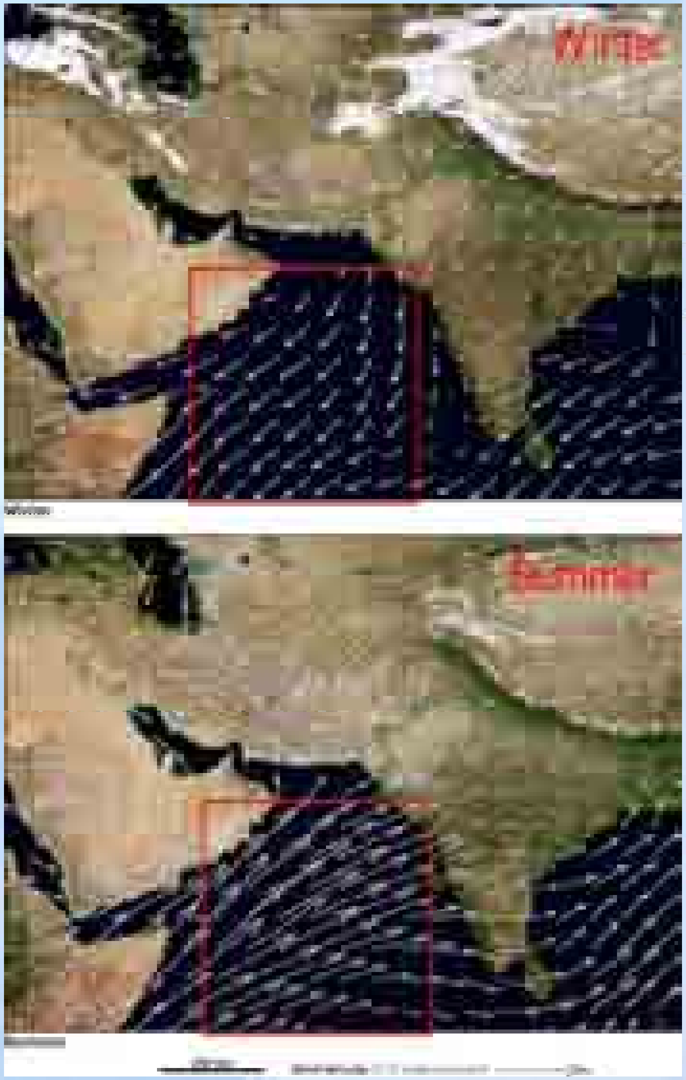
SAARC DMC **Training Workshop on**
Seasonal Climate Forecasting for South Asia
Ahmedabad, India,   6–8 December, 2017

D. S. Pai
Head, Climate Division

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

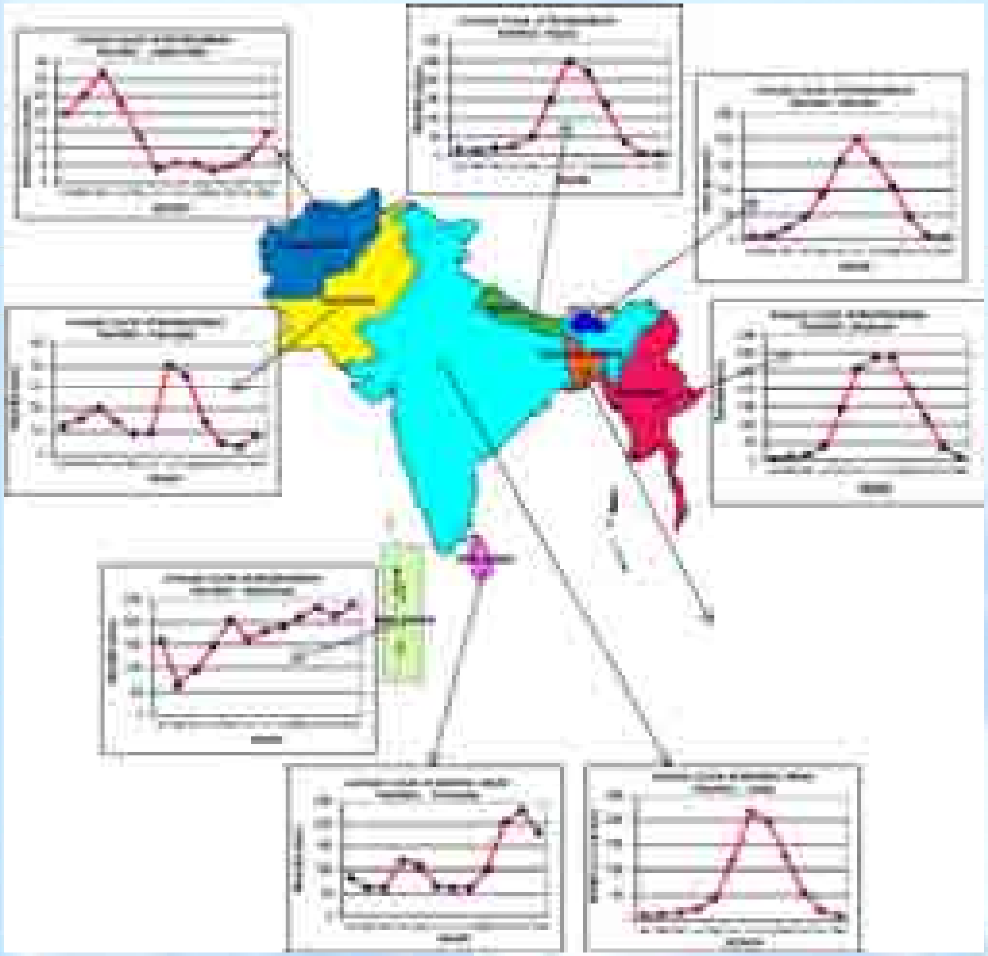
Dominance of Monsoons on the Climate of South Asia

- ❖ South Asia is home to about one fourth of the world's population and occupies only 3% of the global land area, making it both the most populous and the most densely populated geographical region in the world.
- ❖ The annual Climate of the south Asia is dominated by two monsoons: SW and NE monsoons.
- ❖ The summer monsoon plays a crucial role in the entire socio-economic fabric of South Asia, highly influencing all walks of life.
- ❖ During SW monsoon season, most intense rainfall activity is seen over the North Eastern parts of the region over Bangladesh, India and adjoining Myanmar. West coast of India also experiences high rainfall amounts owing to the steep topography of the "Western Ghats".
- ❖ During NE monsoon and early winter months, substantial rainfall results over the region covering the Southern tip of India and Sri Lanka as the prevailing northeasterly trade winds over the region gain strength.



- ➢ Summer or southwest monsoon (May to September) is the main agricultural season for the region and winter or northeast monsoon (October to February), is the second major agricultural season for the region.

Annual Cycle of Rainfall over South Asia

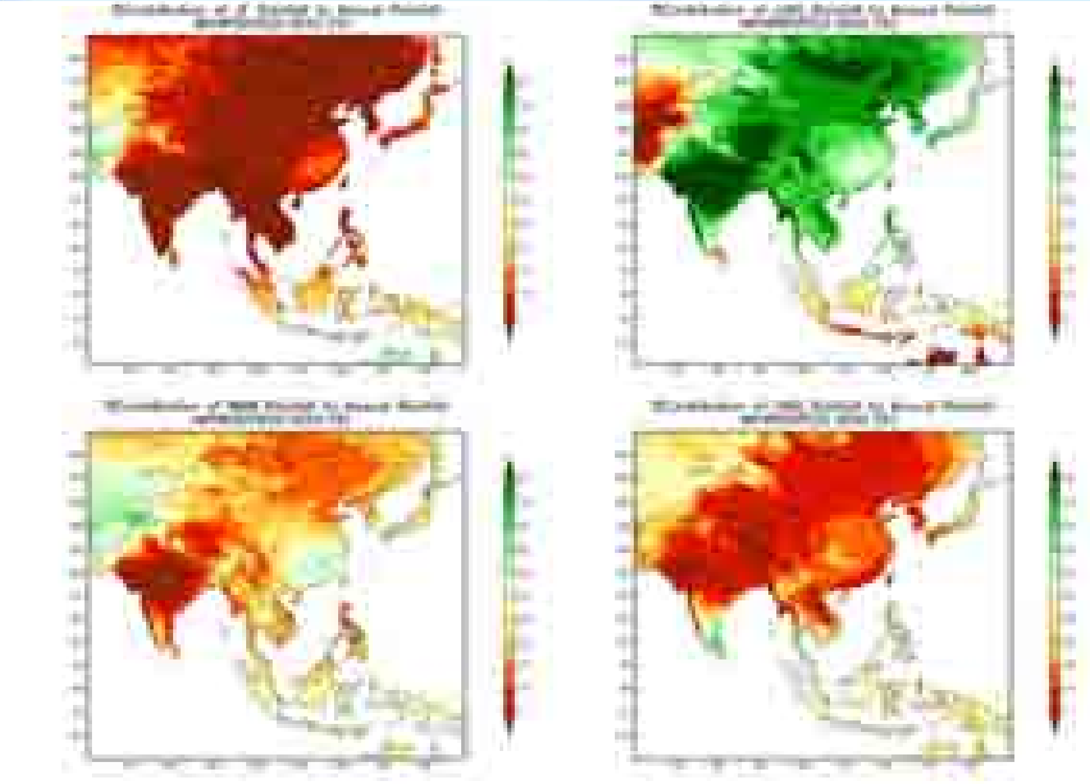


Data source: APHRODITE's daily grided rainfall data http://www.chikyu.ac.jp/precip/

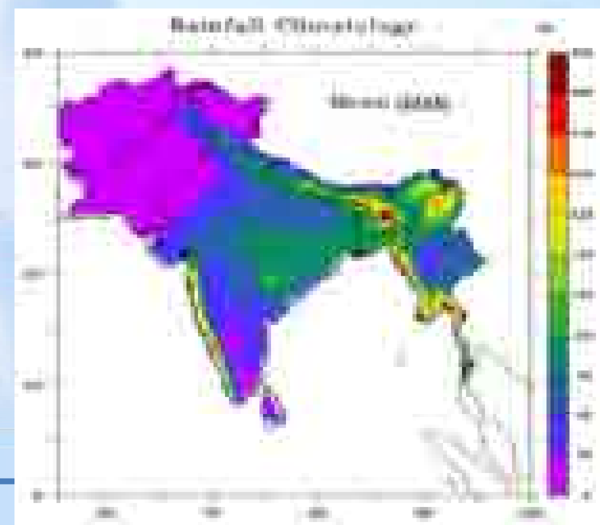
- For most of the south Asian countries the most part of the annual rainfall is received during the 4 months of the summer monsoon season or southwest monsoon season (June to September).
- Many parts of South Asia also receive significant amounts of rainfall during the winter Monsoon Season (October to February).
- However, Afghanistan experience mainly dry climate during the summer monsoon season. It receives better rainfall during the winter season (December to February).
- For Sri Lanka, though the country receives good amount of rainfall during the summer monsoon season (May to September for Sri Lanka), the peak rainfall are received on either side of the summer monsoon season; First inter-monsoon season (March –April) and second inter monsoon season (October – November).

	Country	Main rainfall periods
1	**Afghanistan**	Winter (DJF), Spring (MAM)
2	**Bangladesh**	Pre-monsoon (MAM), summer Monsoon (JJAS)
3	**Bhutan**	Winter (DJF), JJAS (summer monsoon)
4	**India**	Winter (JF) for north India, pre-monsoon for south peninsula and northeast India (MAM), SW Monsoon (JJAS) for most parts of the country and post monsoon (OND) for south Peninsula.
5	**Maldives**	May to September (summer Monsoon), October to January (winter monsoon)
6	**Myanmar**	Pre-monsoon (AM), summer monsoon (JJAS), post monsoon (ON).
7	**Nepal**	Winter (DJF), JJAS (summer monsoon)
8	**Pakistan**	Winter (DJF), JAS (summer monsoon)
9	**Sri Lanka**	First inter-monsoon (MA), SW Monsoon (MJJAS), second inter-monsoon (ON)

Contribution of Seasonal Rainfall to the Annual Rainfall

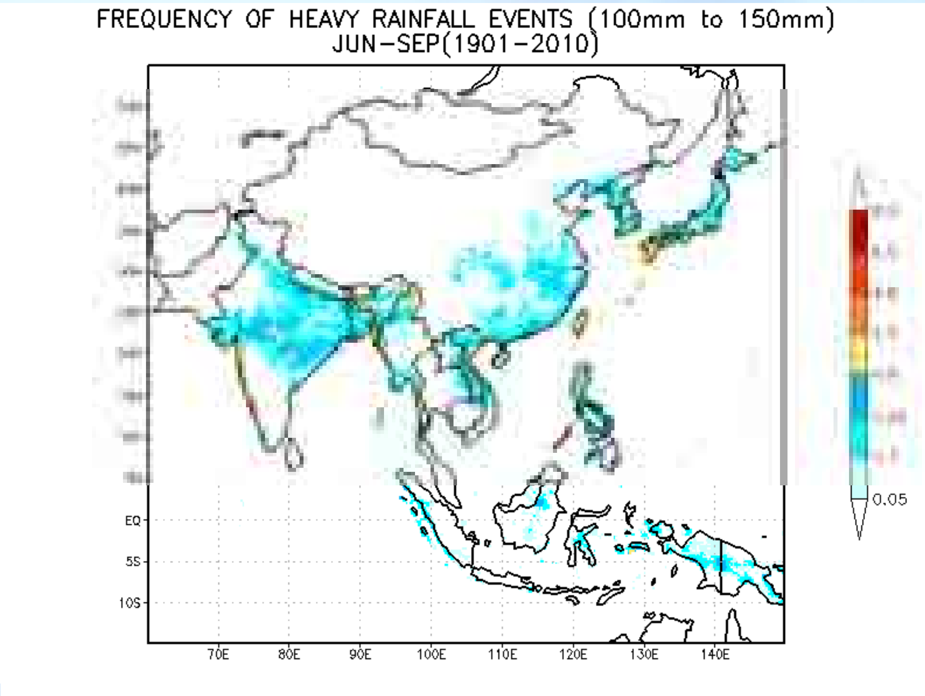


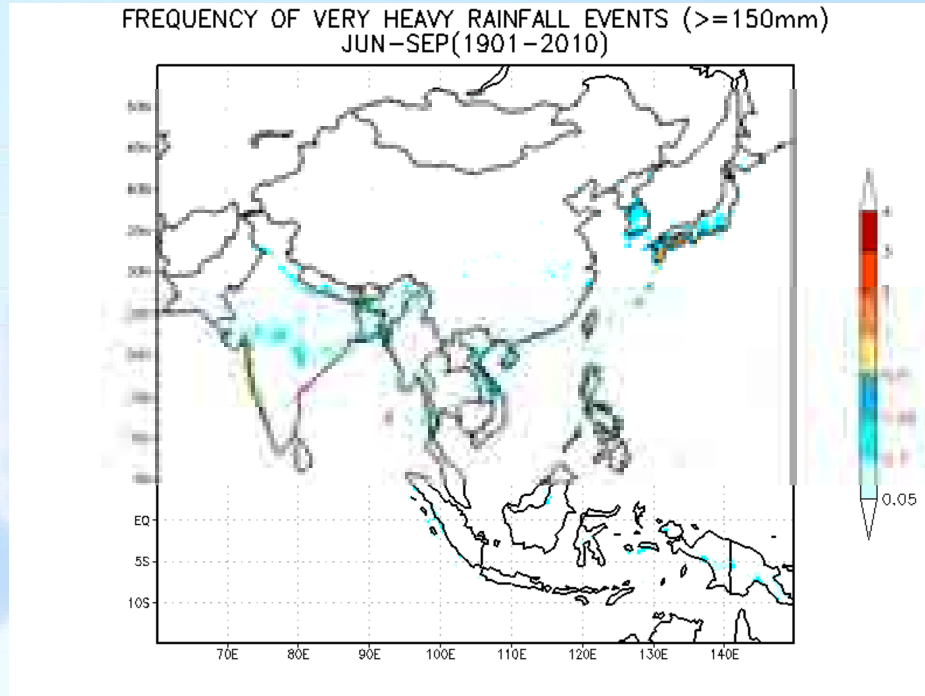
Almost 70-80% of the total annual rainfall occurs during the SW monsoon season and the monsoon greatly affects the socio-economic sectors of the countries of this region. The influence of the Southwest monsoon diminishes towards both extreme north and south of the South Asian region, as the winter season rainfall bearing currents gains predominance. During the post monsoon and early winter months, substantial rainfall descends on the region, covering the southern tip of India, Sri Lanka and Maldivas as the prevailing northeasterly trade winds over the region gain strength. This season (October to December) has come to be known as the “North East” monsoon season.



During this season, the most intense rainfall activity is seen over the northeastern parts of the region over Bangladesh, India and adjoining Myanmar.

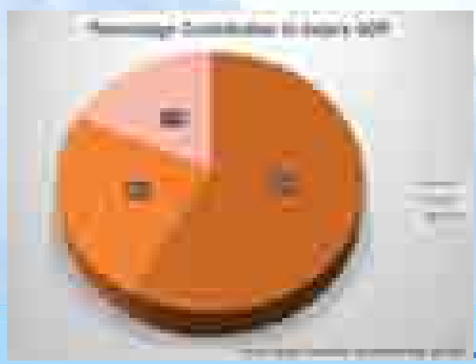
Frequency of Extreme Rainfall Events over South Asia: JJAS

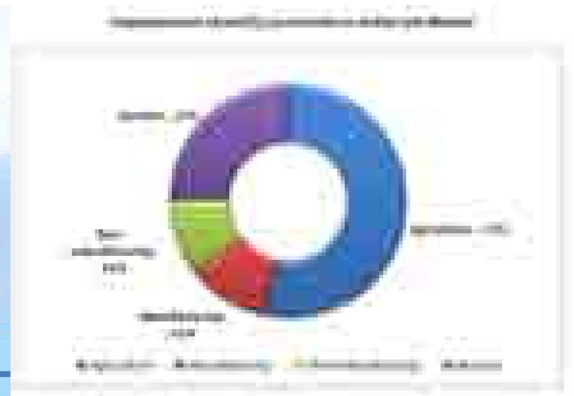


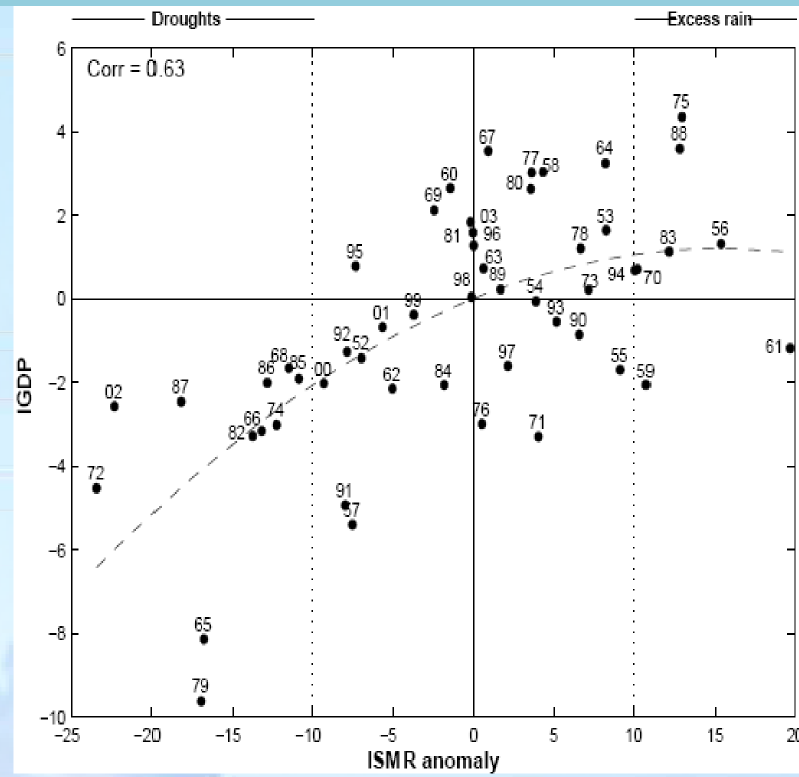


Floods are common disasters in monsoon Asia.

Monsoon & Economics: Indian Example





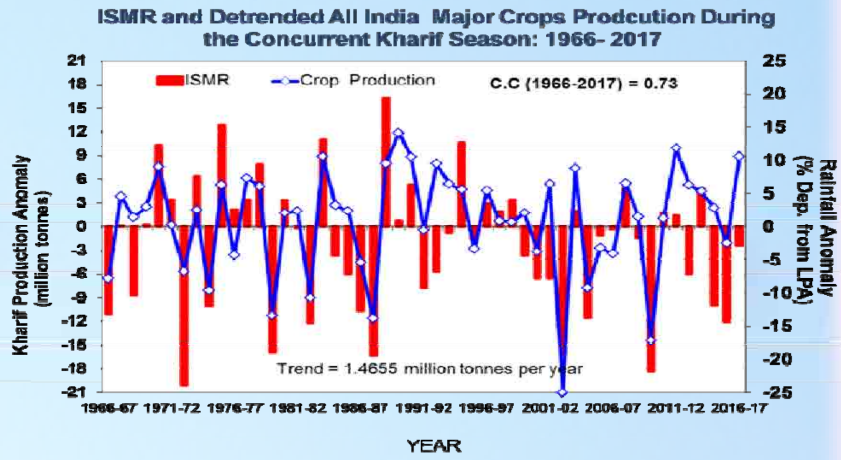


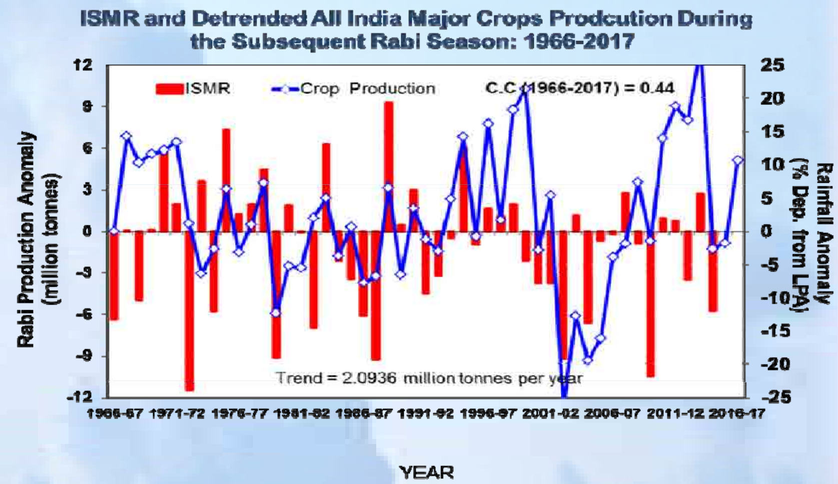
Impact of a severe drought on GDP remains 2 to 5% throughout, despite the substantial decrease in the contribution of agriculture to GDP over the five decades

(Gadgil and Gadgil 2006)

Monsoon and Agriculture

- Several studies have highlighted the critical dependence of crop production on summer monsoon rainfall. The summer monsoon rainfall is also important for hydroelectric power generation and meeting drinking water requirements. Thus, being essentially driven by agricultural growth, the economies of all South Asian countries are inextricably tied to the performance of the summer monsoon.
- **Therefore, prior information about the performance of the monsoon over South Asia will always be helpful for the society in planning risk management strategies.**
- Although substantial progress has been made in its understanding, prediction in respect of different aspects of the monsoon, particularly rainfall during the season with sufficient lead time, has remained a challenge for meteorologists/researchers across the globe even today.
- **Monsoon knowledge and its prediction stand for a shared challenge for South Asian nations which led to the development of a consensus focused on the outlook for the ensuing summer monsoon**





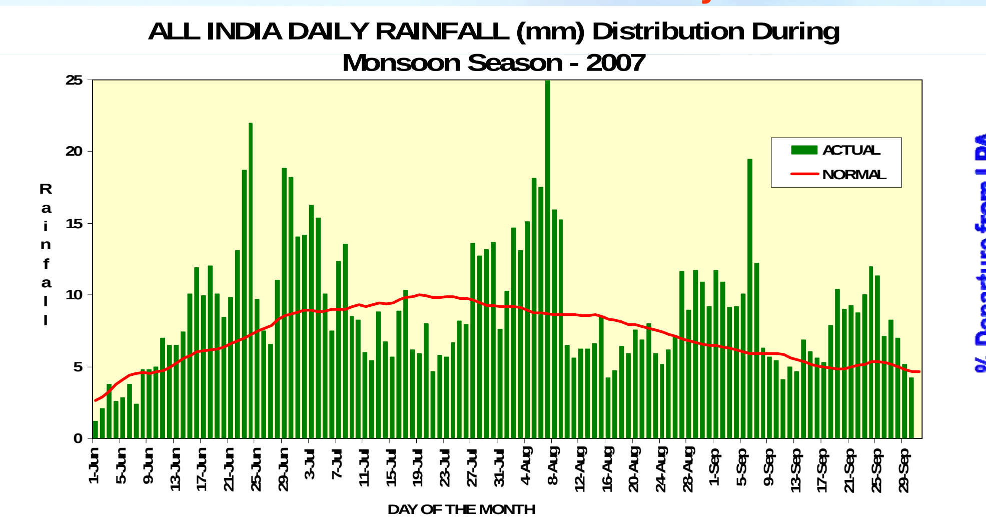
Predictability of the Seasonal Forecasts: Present Status

- ❖ **Though the day to day changes in weather cannot be predicted for a period beyond 1-2 weeks, it has been suggested that climate variations (climate being defined as the space-time average of weather) can be predicted if averaged over certain space and time scales.**
- ❖ **How well we can predict it or if we can predict them at all depends upon our ability to understand and model the mechanisms causing the climate variations.**

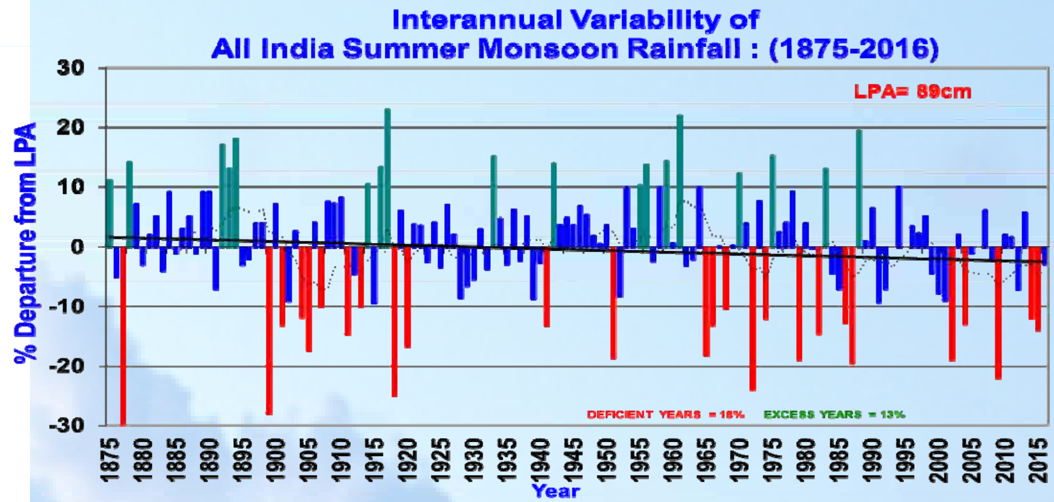
Climate Variability: One of the main characteristics of the earth's climate is its strong natural variability on a wide range of timescales from seasonal to millennial.

Example: Variability of Indian Summer Monsoon Rainfall

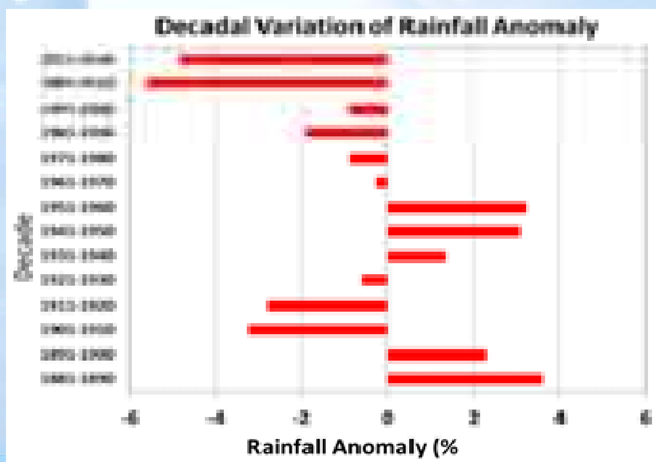
Intra Seasonal Variability



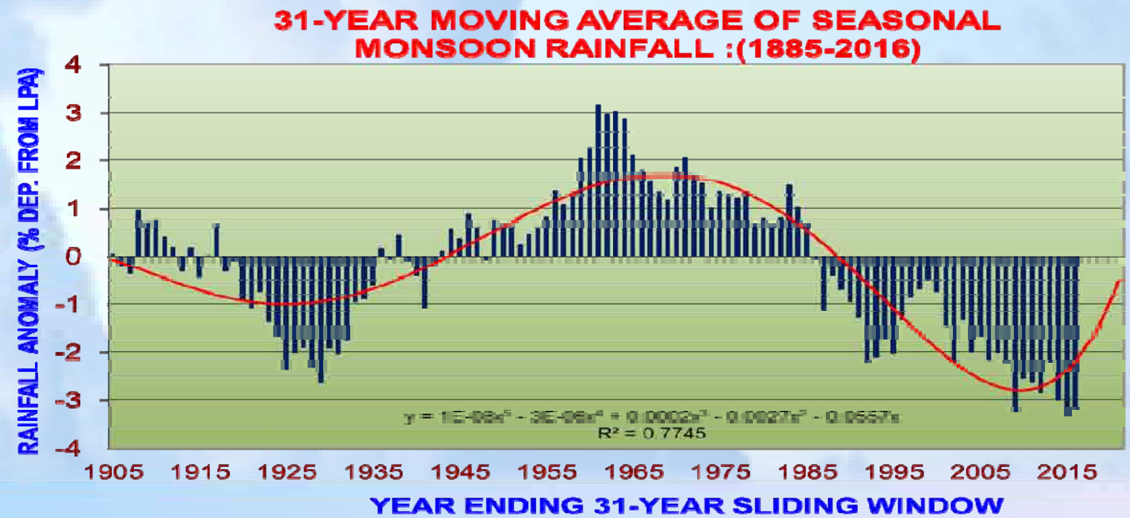
Inter annual Variability & long term trend



Decadal Variability



Epochal Variation

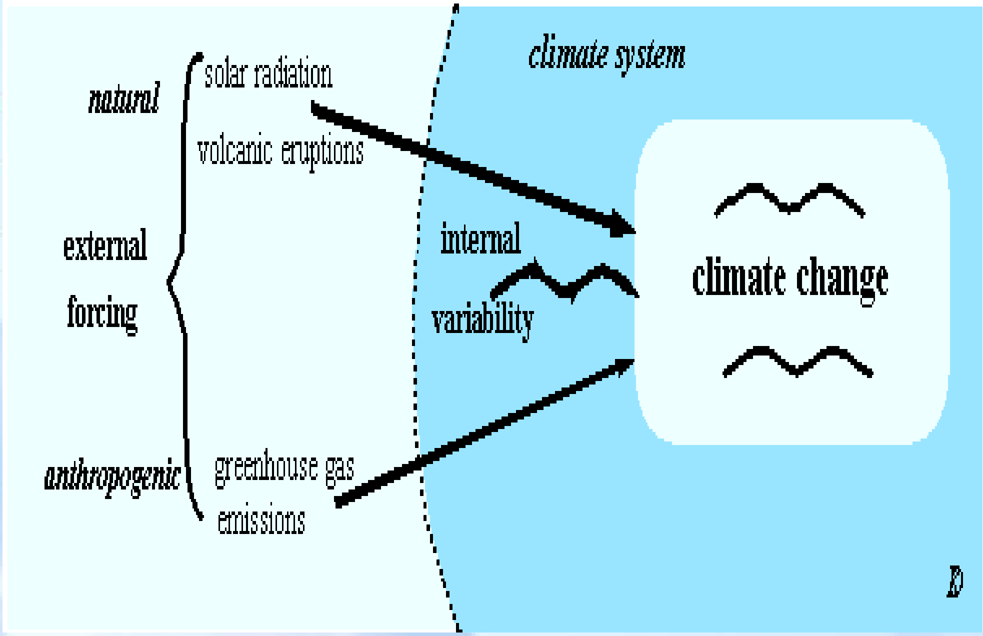


Mechanisms Causing Climate Variability: Internal and External

External Mechanism

- **These are climate variation caused by factors external to the climate system itself, and are not initially caused by internal dynamical and physical process**
- **It should be recognised that these classifications are only for convenience and even if the primary causes are external, the details of the regional climate variations are determined by the interactions and feedbacks among the internal and external processes.**
- **As an example, this category will include climate change and climate variations due to changes in solar forcing (either due to the changes in the solar constant or changes in Earth's orbit around the sun or Earth's axis of rotation), and changes in the chemical composition of the Earth's atmosphere (either due to human induced changes in the concentration of green house gases or due to volcanoes).**

The Possible Causes of Climate Variability and Climate Change



1. **Natural external forcings (e.g. variations in solar radiation or volcanic eruptions, Plate tectonics)**
2. **Anthropogenic external forcings (e.g. emission of greenhouse gases).**

Mechanisms causing Seasonal to Inter-annual Variations:

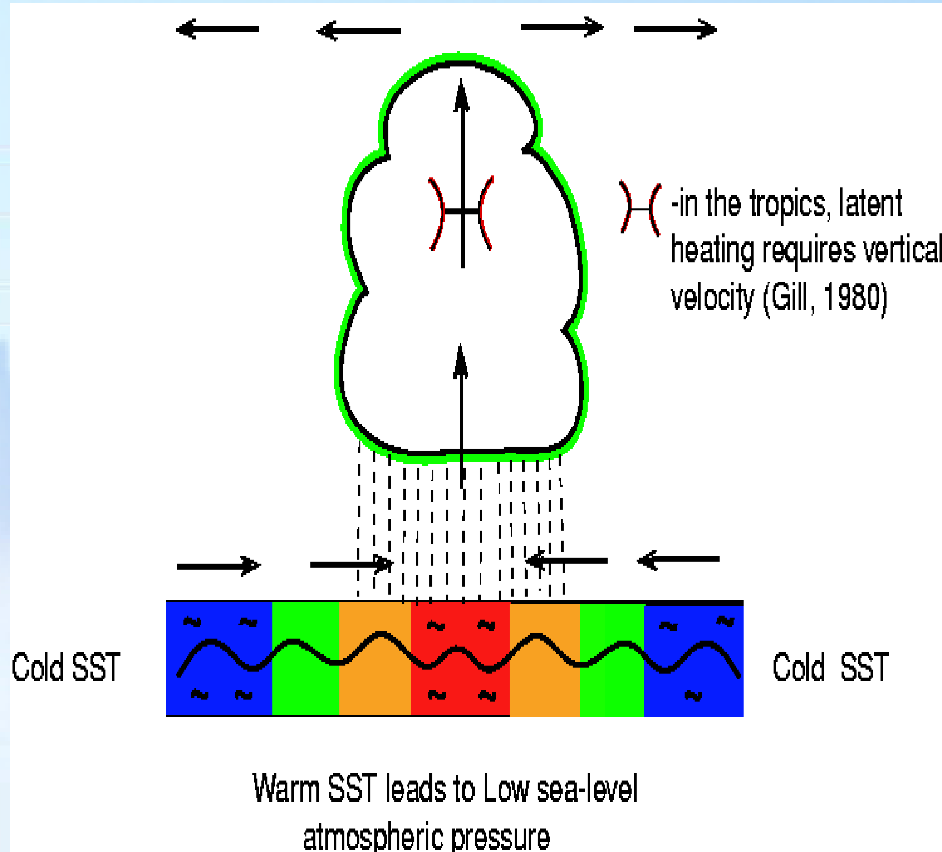
- Caused by the internal dynamical process of the coupled climate system.
- These process can be subdivided into two categories;

(1) the fast atmospheric variations associated with the day to day weather; and

(2) slowly varying changes in sea surface temperature (SST), soil wetness, snow cover and sea ice at the earth's surface. The later acts as slowly varying boundary conditions for the fast weather variations.

- Seasonal mean atmospheric circulation and rainfall are strongly influenced by changes in the boundary conditions at the Earth's surface through changes in the large scale organised convection and this has provided a scientific basis for the prediction of seasonal and interannual variations.
- The evolution of slowly varying boundary forcings is often predictable. This gives a slow memory to the mean atmosphere; the evolution of the latter becoming partly predictable.
- Thus if it were possible to predict the boundary conditions themselves, it would be possible to predict the atmospheric circulation and rainfall.

SST influence on Tropical atmosphere

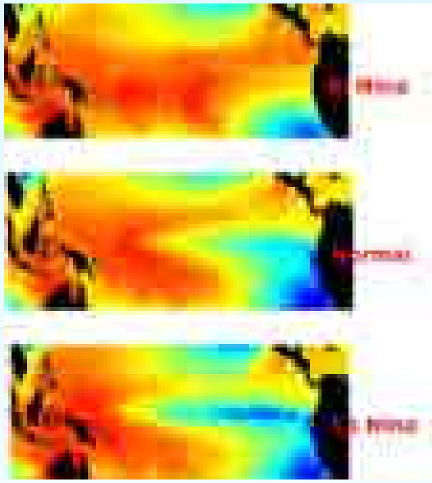


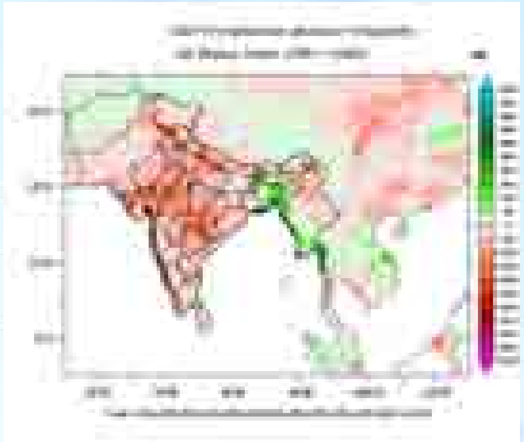
Modifications of boundary conditions (SST, Land surface) can influence weather characteristics (amplitude of an event, its persistence etc.,)

Thus the characteristics of the season

Some of Known Boundary Forcings of South Asian Monsoon

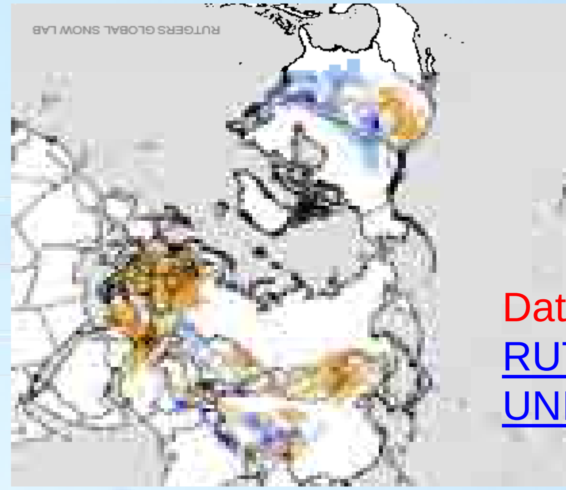
ENSO





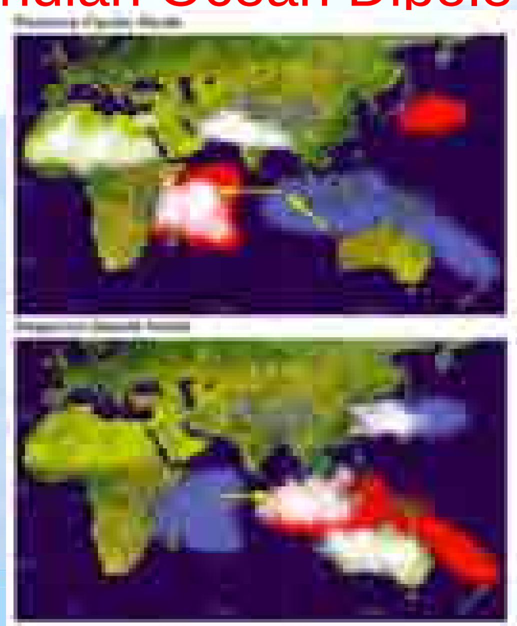
Snow Cover

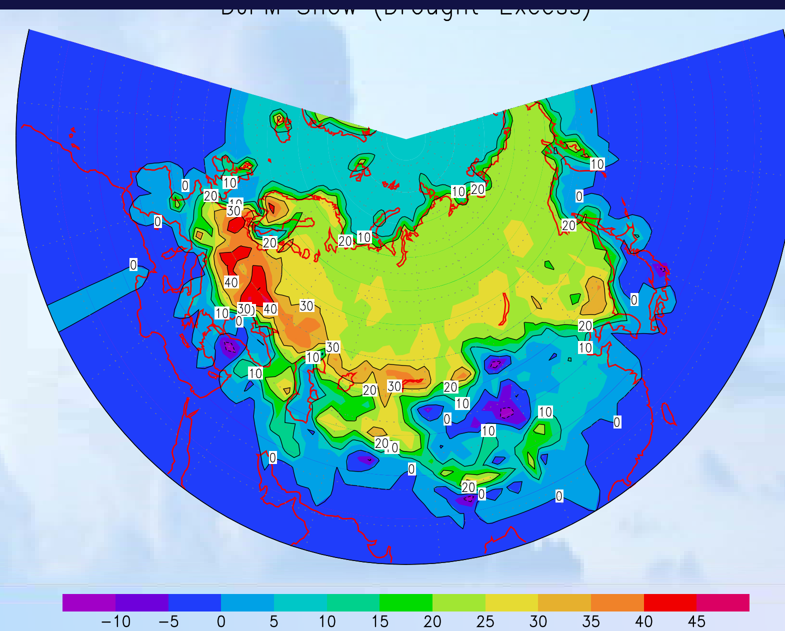
March 2014



Data source: [RUTGERS UNIVERSITY]

Indian Ocean Dipole





Various Approaches used in Seasonal Climate Prediction

- **Empirical/ Statistical model**
  - Multiple Regression
  - Canonical Correlation Analysis
  - Artificial Neural Network
  - Discriminant Analysis
  - Ex: IMD Operational LRF

– based on historical observed data for the predictand (e.g. rainfall, temperature) and for relevant predictors (e.g. SST, Snow Cover, Surface air temperature etc.)

- **Dynamical/ Numerical Model**
  - SST Forced Atmospheric General Circulation models (AGCMs)
  - Ex: IMD SFM
  - Coupled General Circulation Models (CGCMs)
  - Ex: IITM CFS

– using prognostic physical equations

2-tiered systems (first predict SST, then climate).

1-tiered systems (predict ocean and atmosphere together)

- **Hybrid Model (Statistical + Dynamical)**
  - Statistical rescaling of dynamical model simulations
  - IITD - ERPS

Prediction Systems: statistical vs. dynamical system

	ADVANTAGES	DISADVANTAGES
Stati-stical	Based on actual, real-world observed data. Knowledge of physical processes not needed. Easy to built, compute and interpret	Depends on quality and length of observed data Does not fully account for climate change, or new climate situations. Different models required for different seasons and regions
-------	-------------------------------------	-------------------------------
Dyna-mical	Uses proven laws of physics. Quality. Account the non linear atmospheric process. Extensive observational data base is not required to generate a prediction. Can handle cases that have never occurred.	Error due to differences between analysis and real initial state. Some physical laws must be abbreviated or statistically estimated, leading to errors and biases. Computer intensive.

In Dynamical Prediction System: 2-tiered vs. 1-tiered forecast system

	ADVANTAGES	DISADVANTAGES
1-tier	Two-way air-sea interaction, as in real world (required where fluxes are as important as large scale ocean dynamics)	Model biases amplify (drift); flux corrections Computationally expensive
2-tier	More stable, reliable SST in the prediction; lack of drift that can appear in 1-tier system Reasonably effective for regions impacted most directly by ENSO	Flawed (1-way) physics, especially unacceptable in tropical Atlantic and Indian oceans (monsoon)

History of Seasonal Prediction In India: Impact of Monsoon Failure

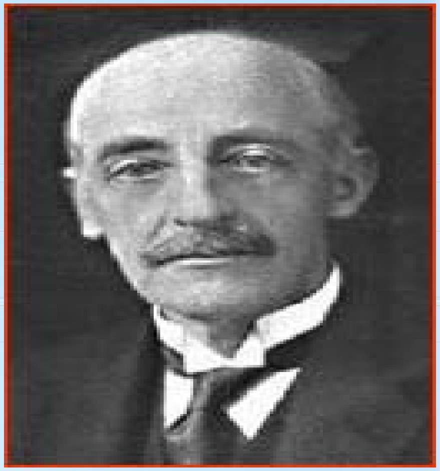
Indian famine victims following failure of 1877/78 monsoon

British Library

Modern research on climate prediction began as a result of the El Niño event of 1877/78, with its severe impacts on India and North China

History of Seasonal Prediction In India:

- H. F. Blandford (1884) - tentative forecasts (1882-1885) based on relationship between winter & spring snow falls over Himalayas and monsoon rainfall.
- First operational forecast in 1886 for the whole India (including Burma) on 4th June 1886.
- In 1892, LRF for the rainfall for the second half of the monsoon season (August-September) started.
- In December 1893, the first forecast for winter precipitation over the Northern and central India was issued.
- Walker (1904-24) Introduced concept of correlation for LRF. Operational forecast in 1909 was based on regression. The models developed by Walker formed basis for the operational LRF in India till 1987
- 1988-2002: 16-parameter parametric and power regression models for SW monsoon season rainfall was introduced.
- In 2003, two stage forecasting system was introduced based on the 8/10 Parameters



Walker (1904-24)

- Over the years, the operational LRF system in India underwent many changes in its approach and scope.

Recent Developments in the Seasonal Prediction

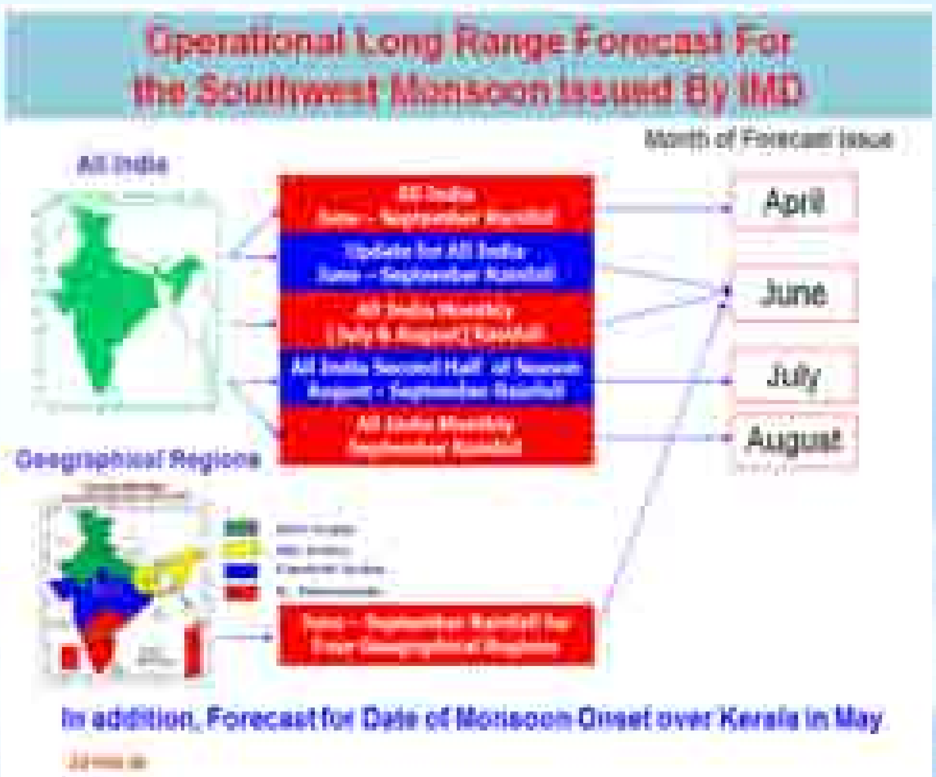
- In 2003, dynamical forecasting system based on atmospheric circulation model (seasonal forecast model (SFM)) was also introduced
- In 2007, new statistical ensemble forecasting system (SEFS) introduced.
- In 2010, first SASCOF was held at Pune, India.
- In 2012, coupled forecasting system (CFS) was implemented at IITM, Pune on research mode under monsoon mission.
- In 2013, IMD Pune started to work as WMO RCC for south Asia
- In January 2015, the SFM model was used to generate seasonal forecast outlook for south Asia under WMO Regional Climate Center (RCC) activities
- In 2016, monsoon mission CFS (MMCFS) model was used to generate ENSO & IOD bulletin and replace SFM to prepare seasonal forecast outlook for south Asia.
- In 2016, MMCFS was used to issue Temperature Forecast Outlook for AMJ season for the first time. Temperature forecast outlook for DJF was started in 2016 and that for MAM in 2017.
- In 2017, The high resolution (T382L64) monsoon mission CFS (MMCFS) was transferred to IMD, Pune.
- From 2017, IMD started to use MMCFS to generate operational forecast for monsoon season along with SEFS

Present Seasonal Forecasting System

Operational Long Range Forecasts Issued by IMD

Sr. No.	Forecast for	Region for which forecast issued	Issued in	Method/ Model
1	Winter Season (Jan- March) Precipitation	Northwest India	December	Statistical
2	Hot Weather Season Temperature (March to May) & (April-June)	Subdivision wise	February & March	Dynamical
3	SW Monsoon Season (June to September) Rainfall	Country as a whole	April	Statistical
4	SW Monsoon Season (June to September) Rainfall	Country as a whole	June	Statistical
5	South-West Monsoon Onset	Kerala	May	Statistical
6	SW Monsoon Season (June to September) Rainfall	Four broad geographical regions: Northwest India, Northeast India , Central India and South Peninsula	June	Statistical
7	SW Monsoon Monthly Rainfall for July and August	Country as a whole	June	Statistical
8	SW Monsoon Second half of the Season (August- September) Rainfall	Country as a whole	July	Statistical
9	September Rainfall	Country as a whole	August	Statistical
10	NE Monsoon Season (October to December) Rainfall	South Peninsula	September	Statistical
11	Cold Weather Season (December - February) Temperature	Subdivision wise	November	Dynamical

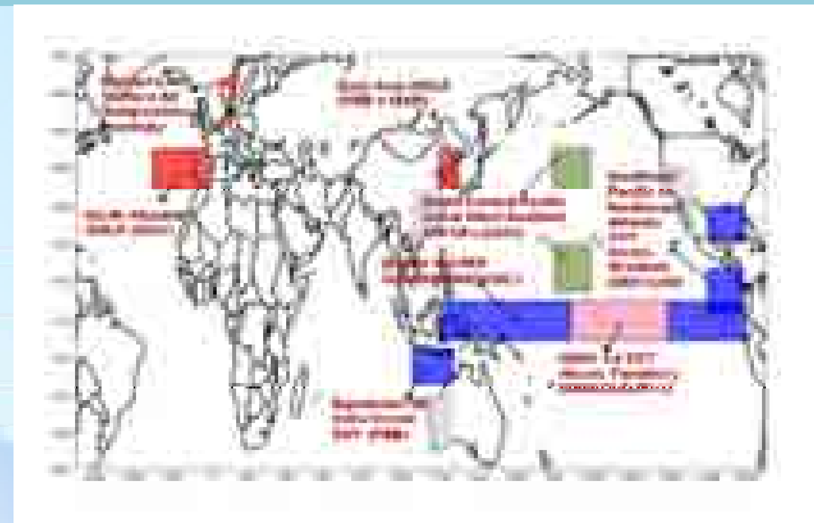
Skill of the statistical models currently used for the operational LRF of Monsoon Rainfall over India



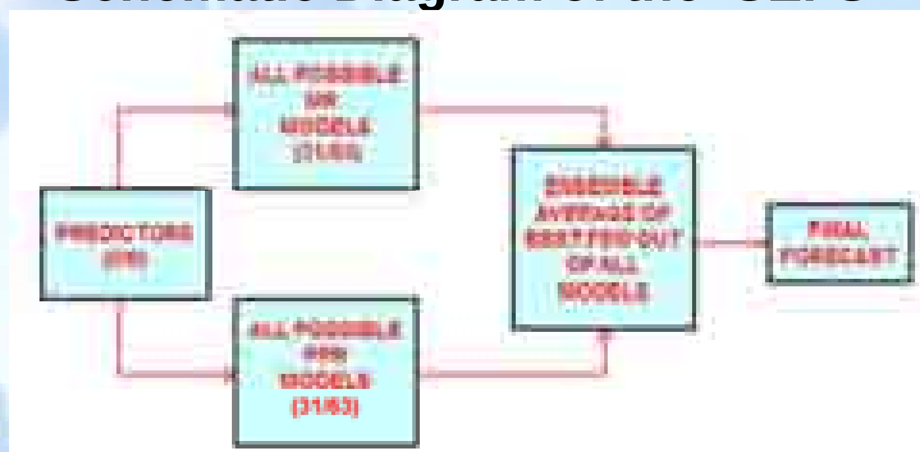
Forecast Period	Forecast Region	Model (Training Window Period)	CC. Actual Vs Forecast Rainfall (Period)	Root Mean Square Error (RMSE) in % of LPA (Period)
June to September	All India	5-P Statistical Ensemble Forecast System (SEFS) (23 yrs)	0.69 (1981-2015)	6.70 (1981-2015)
June to September	All India	6-P (SEFS) (23 yrs)	0.80 (1981-2015)	5.48 (1981-2015)
July	All India	6 –P Principal Component Regression (PCR) (23 yrs)	0.63 (1981-2015)	11.02 (1981-2015)
August	All India	5-P PCR (23 yrs)	0.34 (1998-2015)	11.36 (1998-2015)
September	All India	5-P PCR (23 yrs)	0.71 (1981-2015)	14.60 (1981-2015)
August-September	All India	5-P PCR (23 yrs)	0.53 (1981-2015)	11.40 (1981-2015)
June to September	Northwest India	5-P PCR (30 yrs)	0.63 (1988-2015)	12.5 (1988-2015)
June to September	Northeast India	5-P PCR (30 yrs)	0.54 (1988-2015)	10.75 (1988-2015)
June to September	Central India	5-P PCR (30 yrs)	0.37 (1988-2015)	12.4 (1988-2015)
June to September	South Peninsula	6-P PCR (30 yrs)	0.56 (1988-2015)	12.54 (1988-2015)

Statistical Ensemble Forecasting System (SEFS) for Seasonal Rainfall over Country as a whole

S.No	Predictor Used	Issued in
1	Europe Land Surface Air Temperature Anomaly (January)	April
2	Equatorial Pacific Warm Water Volume (February + March)	April
3	SST Gradient Between Northeast Pacific and Northwest Atlantic (December +January)	April and June
4	Equatorial SE Indian Ocean SST (February)	April and June
5	East Asia Mean Sea Level Pressure (February + March)	April and June
6	Nino 3.4 Sea Surface Temp (MAM + Tendency (MAM-DJF))	June
7	North Atlantic Mean Sea Level Pressure (May)	June
8	North Central Pacific Zonal Wind Gradient 850 hPa (May)	June

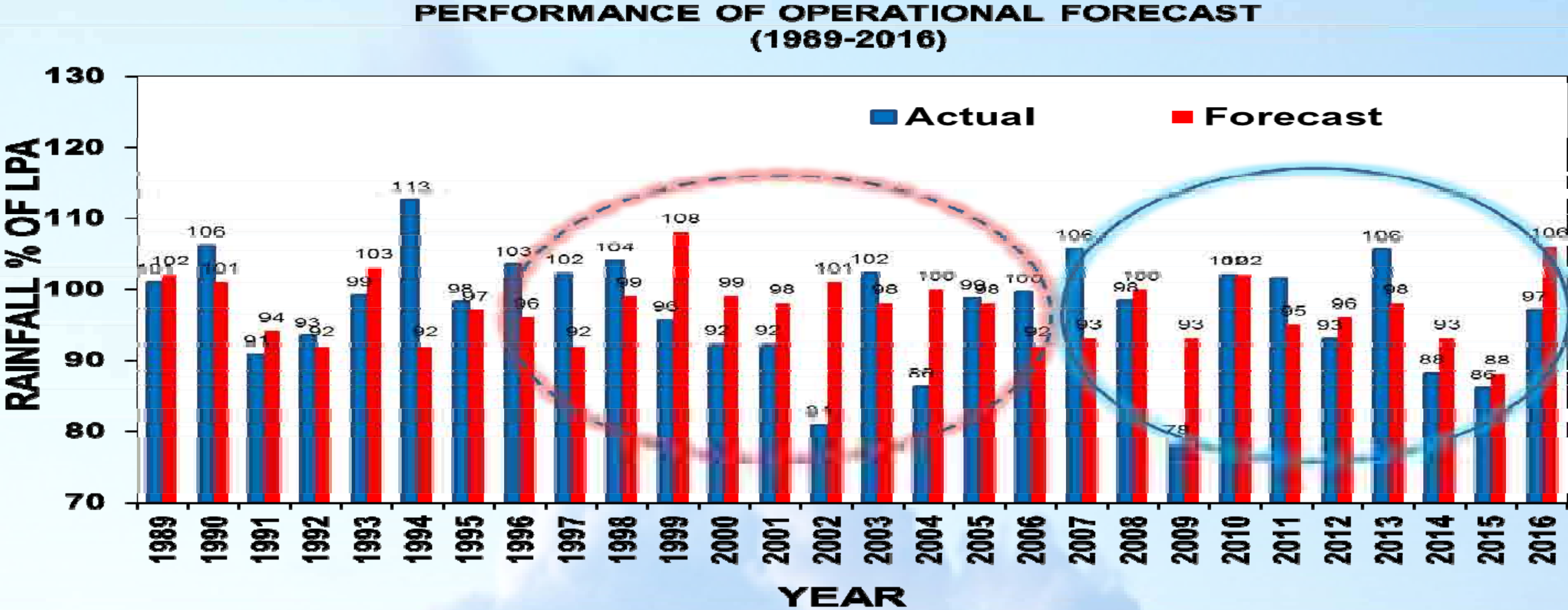


Schematic Diagram of the SEFS



The average of the ensemble forecasts from best out of all possible MR (multiple regression) and PPR (projection pursuit regression) models gives the final forecast.

Performance of Operational Forecast (Empirical Model) for All India Seasonal Rainfall (1989-2016):

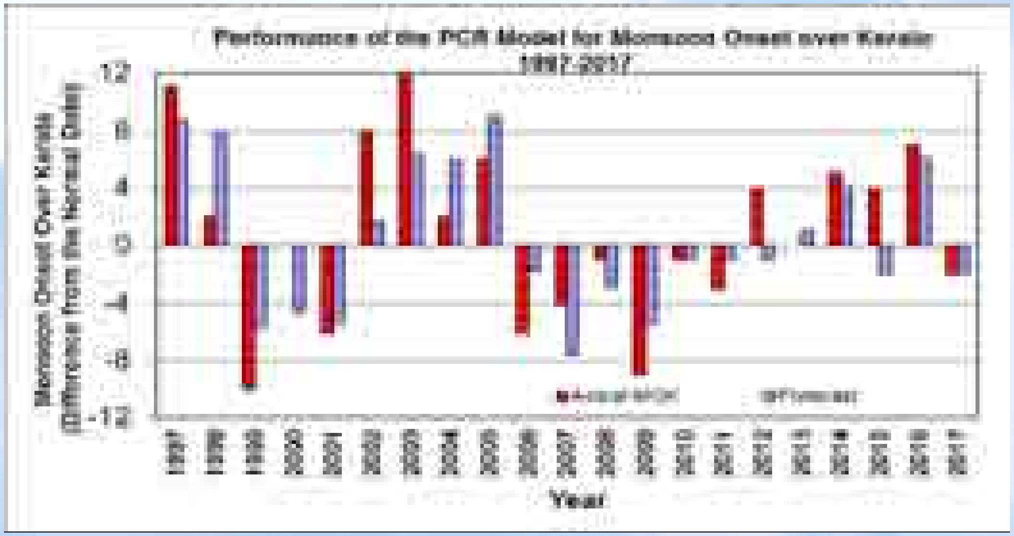


- Error ≥ 10% in 7 yrs with highest in 2002 (20%) and 1994 (18%). Error in 2009 15%.
- **Ave. absolute error during the last 10 years (2007-2016) was 6.24% of LPA compared to that of 8.68% of LPA during the 10 years (1997-2006) just prior to that period.**
- C.C between the actual and forecast rainfall for (2007-2016) & (1997-2006) are 0.46 & -0.39 respectively.
- **During 1997-2006, the forecast within the ±8% of actual values during 6 years. Within these 6 years, forecast was within ±4% during 2 years. On the other hand during 2007-2016, the forecast was within the ±8% of actual values during 7 years with forecast within ±4% during 4 years.** ***These clearly indicate improvement made in the operational forecast system in the recent 10 years period compared to earlier 10 years period.***

PCR model for the Forecasting date of Monsoon onset over Kerala

No	Name of Predictor	Period	C.C (1975-2000)
1	Zonal Wind at 200hpa over Indonesian region	16th -30th Apr	0.48
2	OLR Over South China Sea	16th- 30thApr	0.40
3	Pre-Monsoon Rainfall Peak Date	Pre-monsoon April-May	0.48
4	Minimum Surface air Tem. over NW India	1st -15th May	-0.37
5	Zonal Wind at 925hpa over Equatorial South Indian Ocean	1st -15th May	0.52
6	OLR Over Southwest Pacific	1st -15th May	-0.53

Year	Actual Onset Date	Forecast Onset Date
2005	7th June	10th June
2006	26th May	30th May
2007	28th May	24th May
2008	31st May	29th May
2009	23rd May	26th May
2010	31st May	30th May
2011	29th May	31st May
2012	5th June	1st June
2013	1st June	3rd June
2014	6th June	5th June
2015	5th June	31st May
2016	8th June	7th June
2017	30th May	30th May



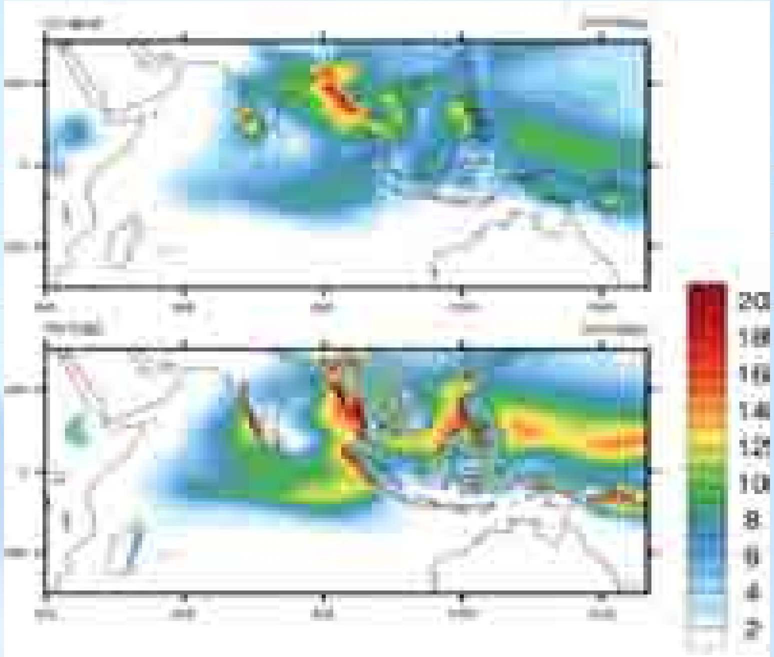
Model error = 4 days

During the last 13 years (2005-2017), the forecast issued for the 2015 monsoon onset over Kerala only was not within the forecast limits

The Monsoon Mission Experimental Dynamical Model Forecasting System

- Under Monsoon Mission, the state-of-the-art Coupled Forecasting System (MMCFS) developed by NCEP, USA was implemented in 2012 at the ESSO-IITM, Pune.
- The latest high resolution research version of the MMCFS implemented at IMD, Pune in 2017.
- The model shows a moderate skill for both temperature and rainfall forecast.
- The rainfall forecast from MMCFS was used as an additional input to operational forecast from 2012.
- From 2016, used for generating operational subdivision wise temperature forecast.

JJAS Climatology(1982-2008)



Forecast: probabilistic and deterministic
Model type and resolution: T382L64
Ensemble size: 12 members for hindcast and 40 members for forecast
Initial Conditions (ICs): Atmospheric provided by ESSO-NCMRWF and the oceanic provided by ESSO-IITM & ESSO-INCOIS.
Forecast period: 9 months

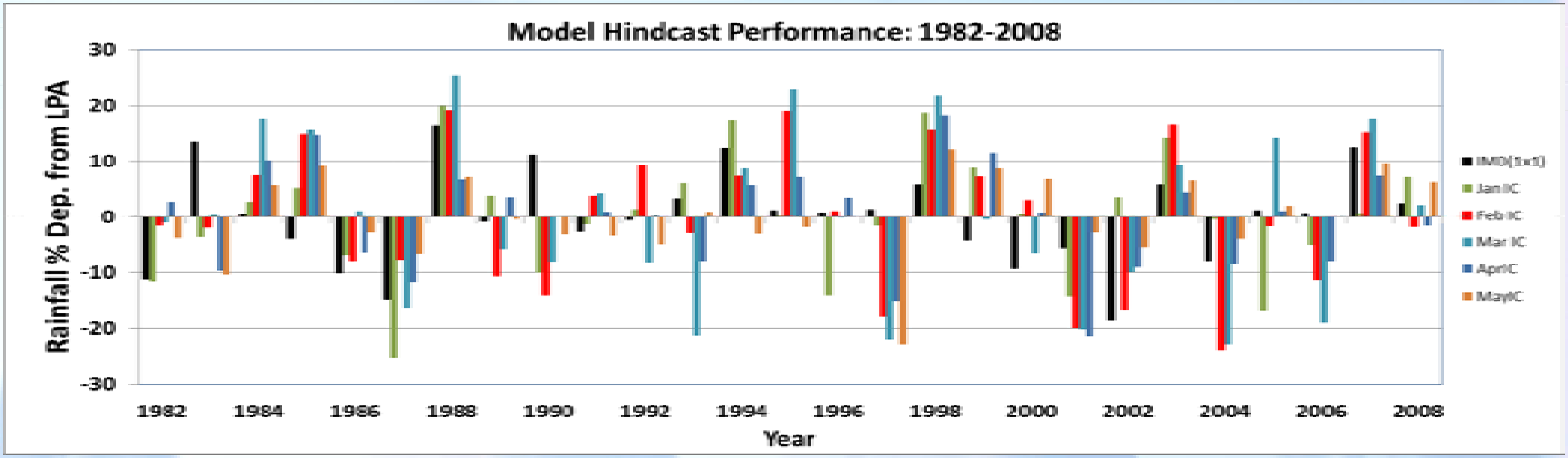
All India Rainfall: No Bias Correction

Bias

IC	June	July	August	Sept.	JJAS
Jan	-72.9	-119.504	-87.937	-48.821	-329.162
Feb	-64.279	-108.274	-66.311	-28.143	-267.008
Mar	-62.33	-112.336	-85.563	-39.48	-299.712
Apr	-37.1359	-74.858	-56.627	-8.164	-176.786
May	-18.375	-48.42	-47.528	-0.44	-114.767

RMSE

IC	June	July	August	Sept.	JJAS
Jan	78.12	125.391	93.884	58.997	336.915
Feb	71.357	115.208	75.556	46.657	278.441
Mar	67.963	117.386	92.966	50.65	311.222
Apr	47.852	85.505	65.989	36.913	194.699
May	31.072	63.75	62.82	35.23	142.491



C.C.

IC	June	July	August	Sept.	JJAS
Jan	0.096	0.354	0.222	0.398	0.445
Feb	0.067	0.402	0.195	0.249	0.446
Mar	0.268	0.562	0.174	0.515	0.446
Apr	0.088	0.264	0.0363	0.266	0.321
May	0.465	0.073	-0.293	0.33	0.187

Bias Correction Methods

Recalibration techniques

A. mean bias subtraction

1. $y'(t) = y(t) - (\bar{y} - \bar{x})$
2. repeat step 1 for each pair of observation and forecasts

B. z-score transformation (z-value)

1. calculate z-value: $z = (y(t) - \bar{y})/s_y$
2. do back transformation: $y'(t) = z\,s_x + \bar{x}$
3. repeat step 1 and 2 for each pair of observation and forecasts

C. quantile-quantile transformation (here based on empirical distributions)

1. sort observations from smallest to largest value and determine ranks $R_{x,i}$ for each observation
2. repeat this step for the forecasts
3. determine $F_{x,i}$ by calculating cumulative frequencies p_i using a plotting position formula e.g. $p_i = R_{x,i}/(n+1)$
4. determine $F_{y,i}$ by calculating cumulative frequencies q_i for each forecast value $y(t)$ using the same plotting position formula
5. determine corrected forecast value $y'(t)$ by using the inverse cumulative distribution function of the observations $y'(t) = F^{-1}_{x,i}(q_i)$

with $y'(t)$: corrected forecast value at time t, $y(t)$: forecast value at time t, $\bar{x}$: mean observations, $\bar{y}$: mean forecasts; s_x: standard deviation observation; s_y: standard deviation forecasts; $F_{x,i}$: empirical cumulative distribution function of observation; $F_{y,i}$: empirical cumulative distribution functions of forecast

Fig. 1 Illustration of the quantile-quantile transformation for the monthly precipitation amount

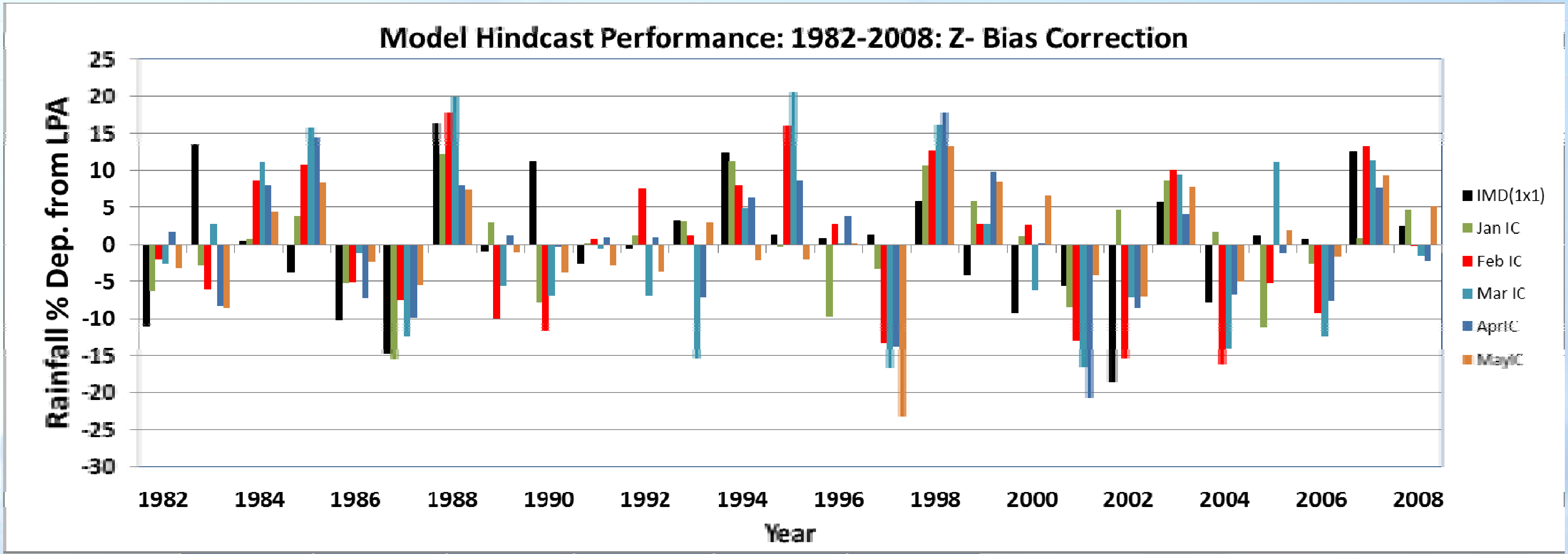
All India Rainfall: Z Bias correction

Bias (mm)

IC	June	July	August	Sept.	JJAS
Jan	-0.911	-1.74	-0.959	-0.245	-3.857
Feb	-1.612	3.162	-1.84	1.084	0.794
Mar	-2.079	-0.934	-3.389	-4.03	-10.433
Apr	-0.6341	-1.2185	-2.2188	-0.682	-4.7533
May	-0.3966	-1.07669	-1.22629	0.001098	-2.700

RMSE (mm)

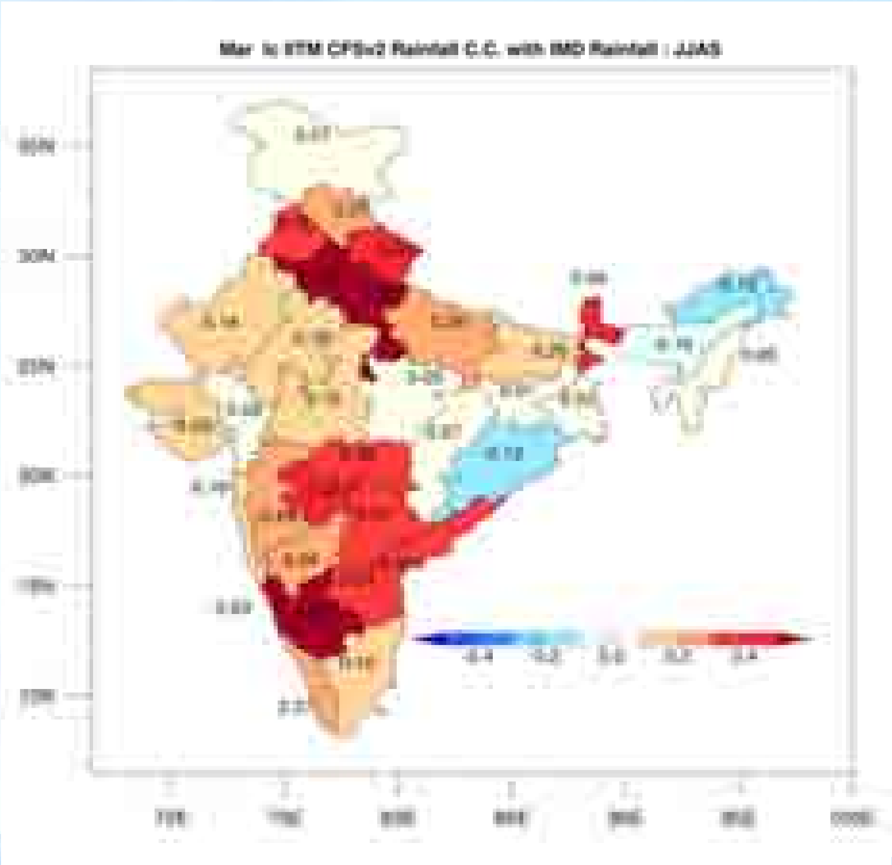
IC	June	July	August	Sept.	JJAS
Jan	31.08	40.884	34.601	36.51	83.48
Feb	33.565	38.867	41.29	40.297	84.306
Mar	30.261	36.529	42.38	29.925	92.868
Apr	31.6982	41.8175	37.3385	36.595	86.0227
May	25.9501	40.8672	44.564	35.663	86.627



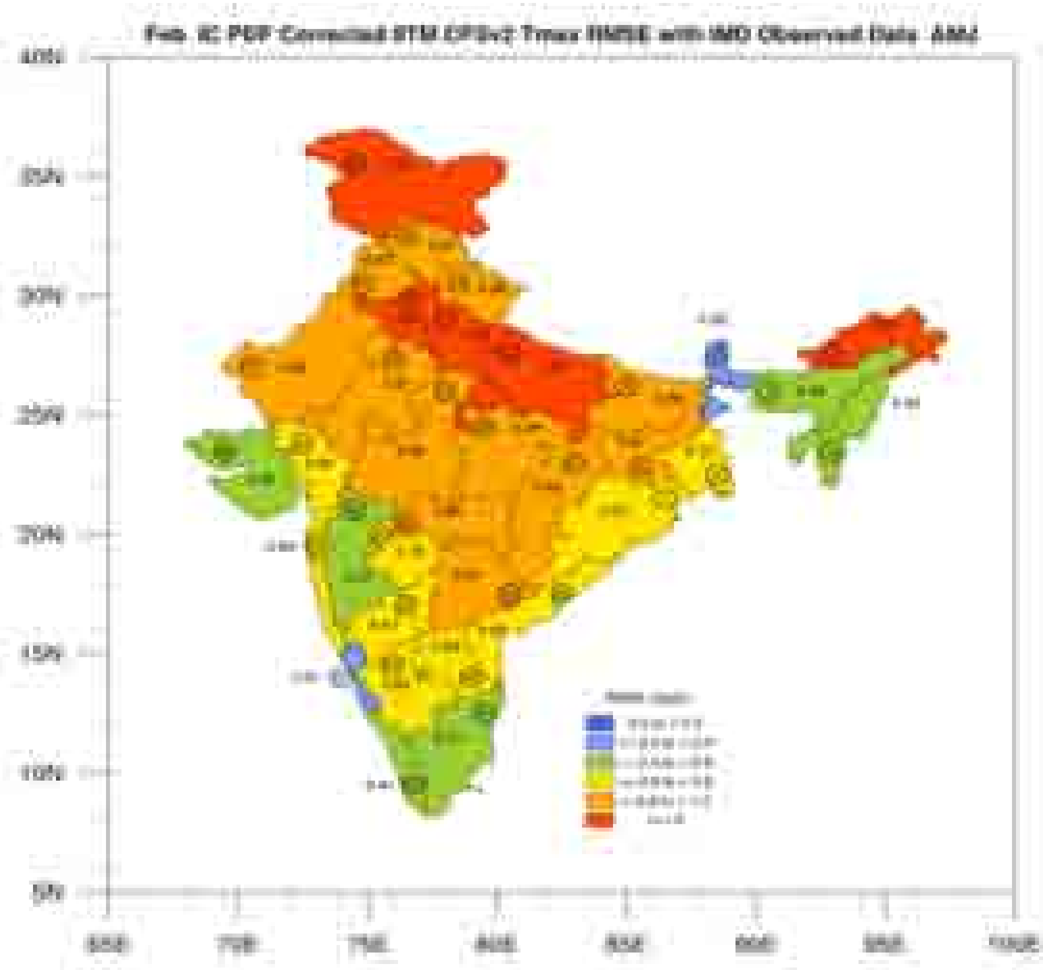
IC	June	July	August	Sept.	JJAS
Jan	-0.015	0.248	0.213	0.287	0.327
Feb	0.052	0.436	0.110	0.188	0.464
Mar	0.115	0.535	0.135	0.61	0.445
Apr	0.0600	0.266	0.0442	0.290	0.351
May	0.4340	0.1656	-0.2710	0.35235	0.2278

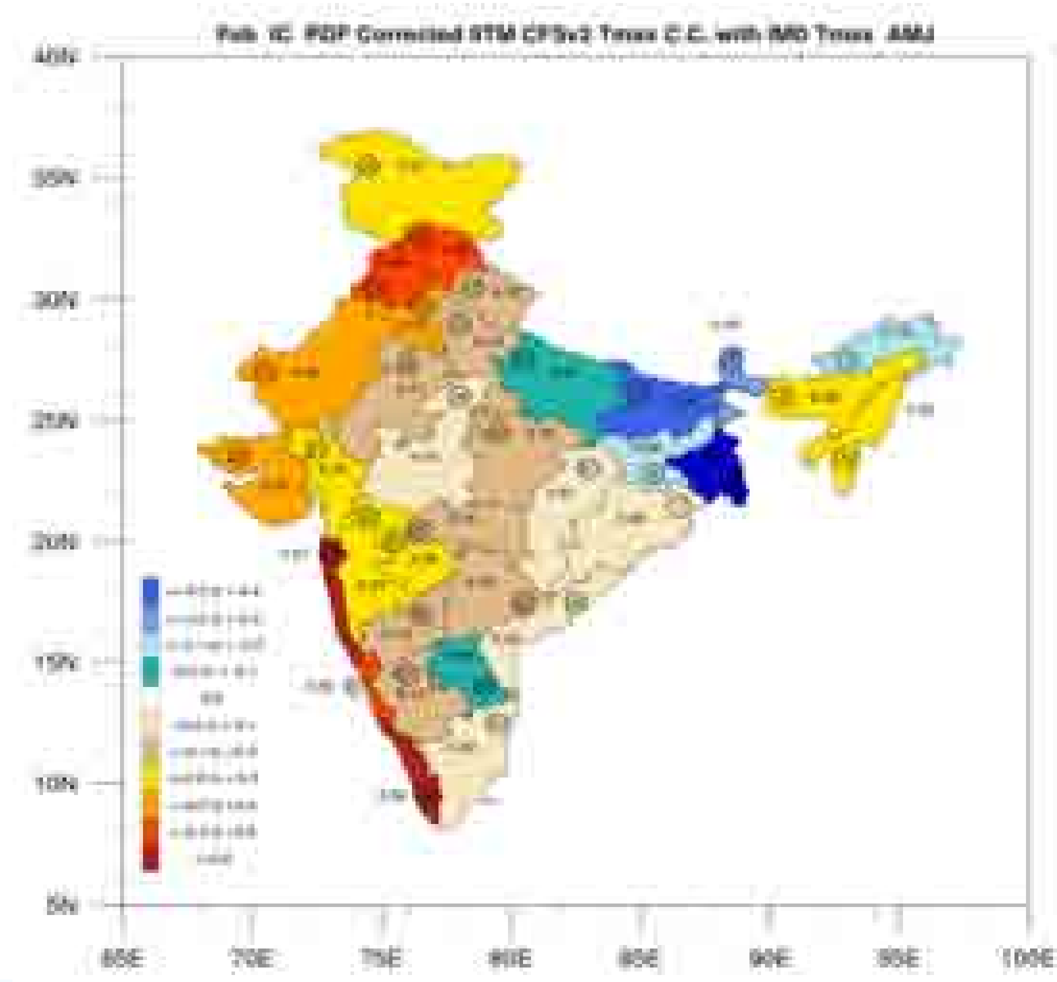
C.C.

Skill (C.C) of MMCFS for the Subdivision wise JJAS Rainfall: 1982-2008

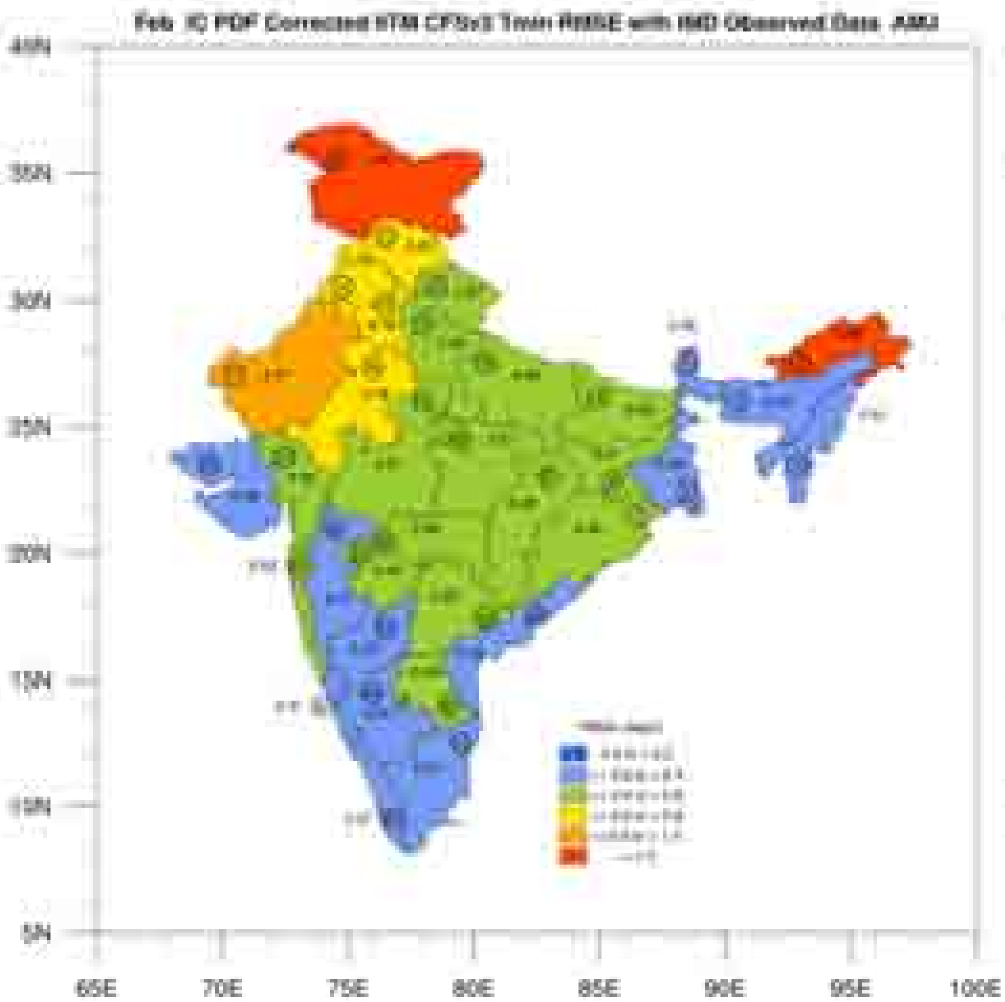


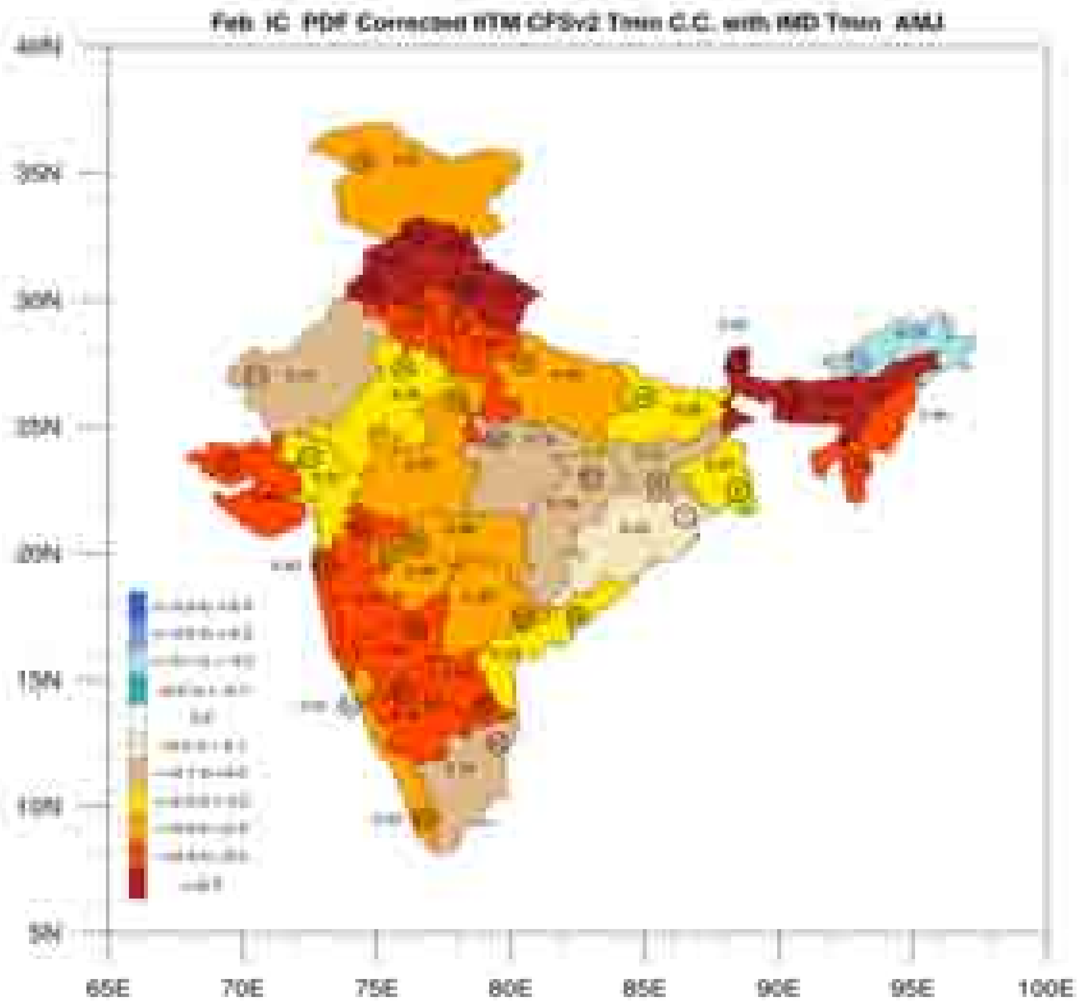
Tmax : Skill Score (RMSE & CC) : Feb I/C



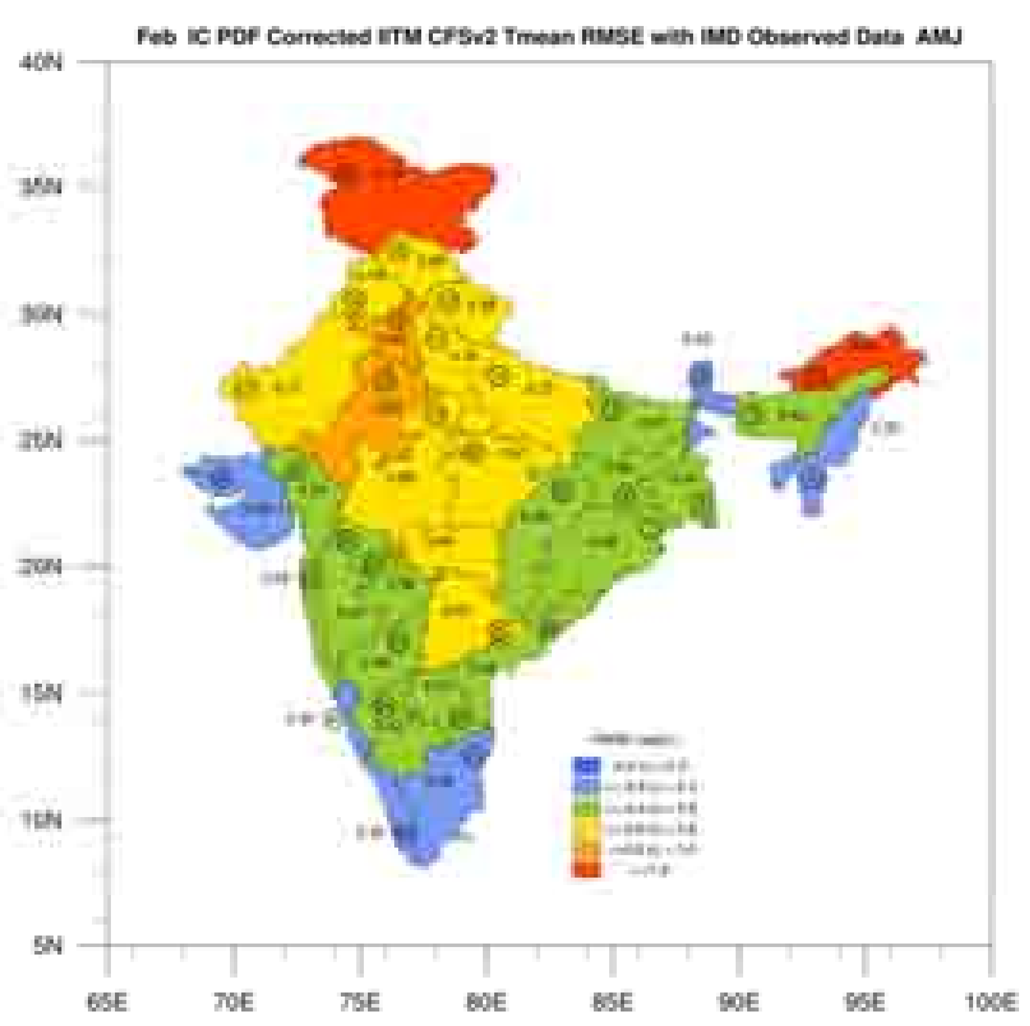


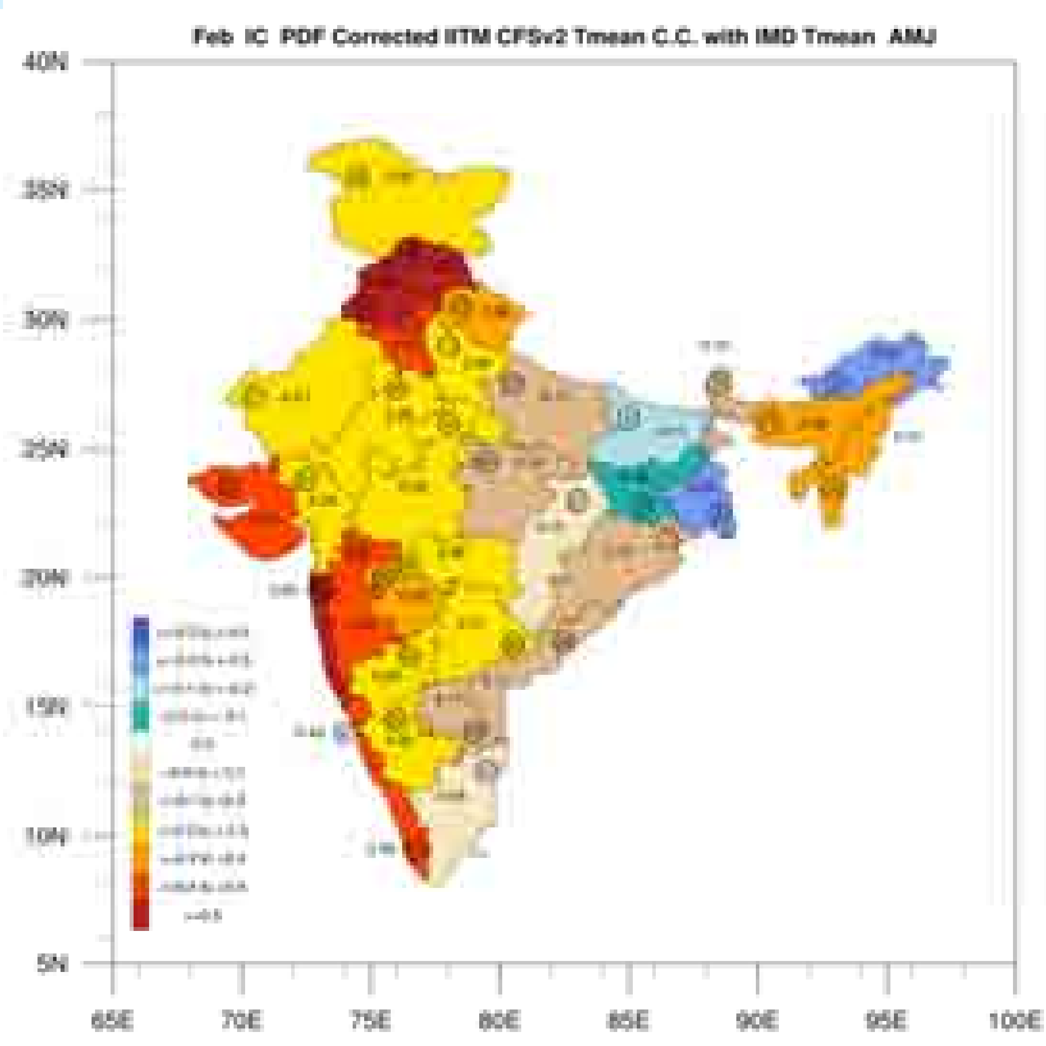
Tmin: Skill Score (RMSE & CC) : Feb I/C





Tmean: Skill Score : RMSE & CC : Feb I/C





Long Range Forecast Products Available from RCC, Pune Website Based on Monsoon Mission CFS

(http://www.imdpune.gov.in/Clim_RCC_LRF/Index.html).

- **Global monthly and seasonal forecast anomaly maps of rainfall and Temperature for next 8 months (Every month)**
- **ENSO & IOD Forecast Bulletins (Every month)**
- **Seasonal Forecast Outlook of Rainfall and Temperatures over South Asia (updated every month)**
- **Consensus forecast for South Asia**

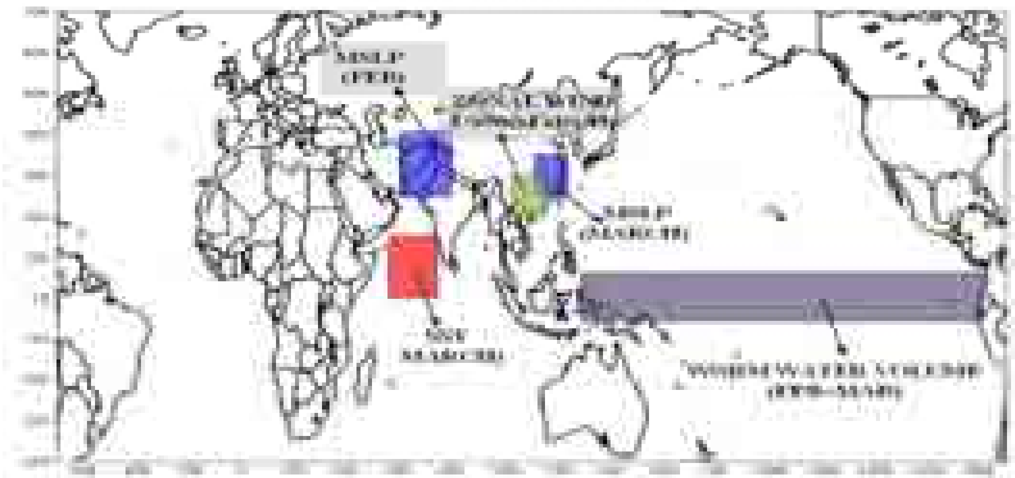
Statistical Models for SAARC Countries Developed During the SASCOF Workshops

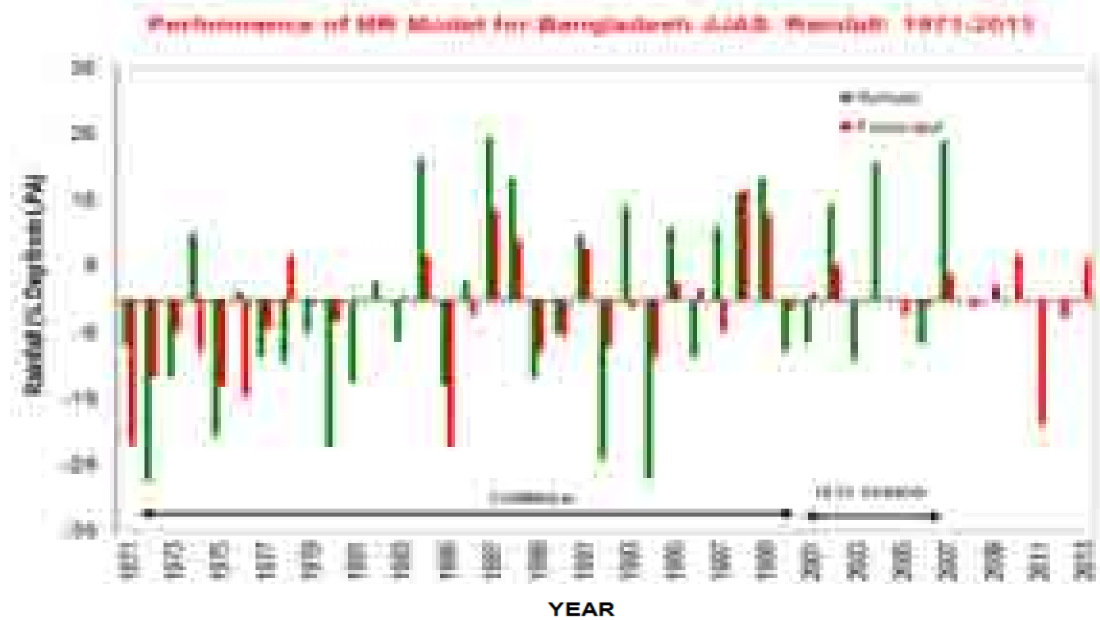
Bangladesh

BANGALADESH FORECAST
(JUN-SEPT)

- MEAN RF (1971-2000) = 907.1 mm
- C.V. (1971-2000) = 15.3
- RMSE (1971-2000) = 11.46
- MCC (1971-2000)= 0.63

GEOGRAPHICAL LOCATION OF PREDICTORS USED FOR BANGALADESH FORECAST

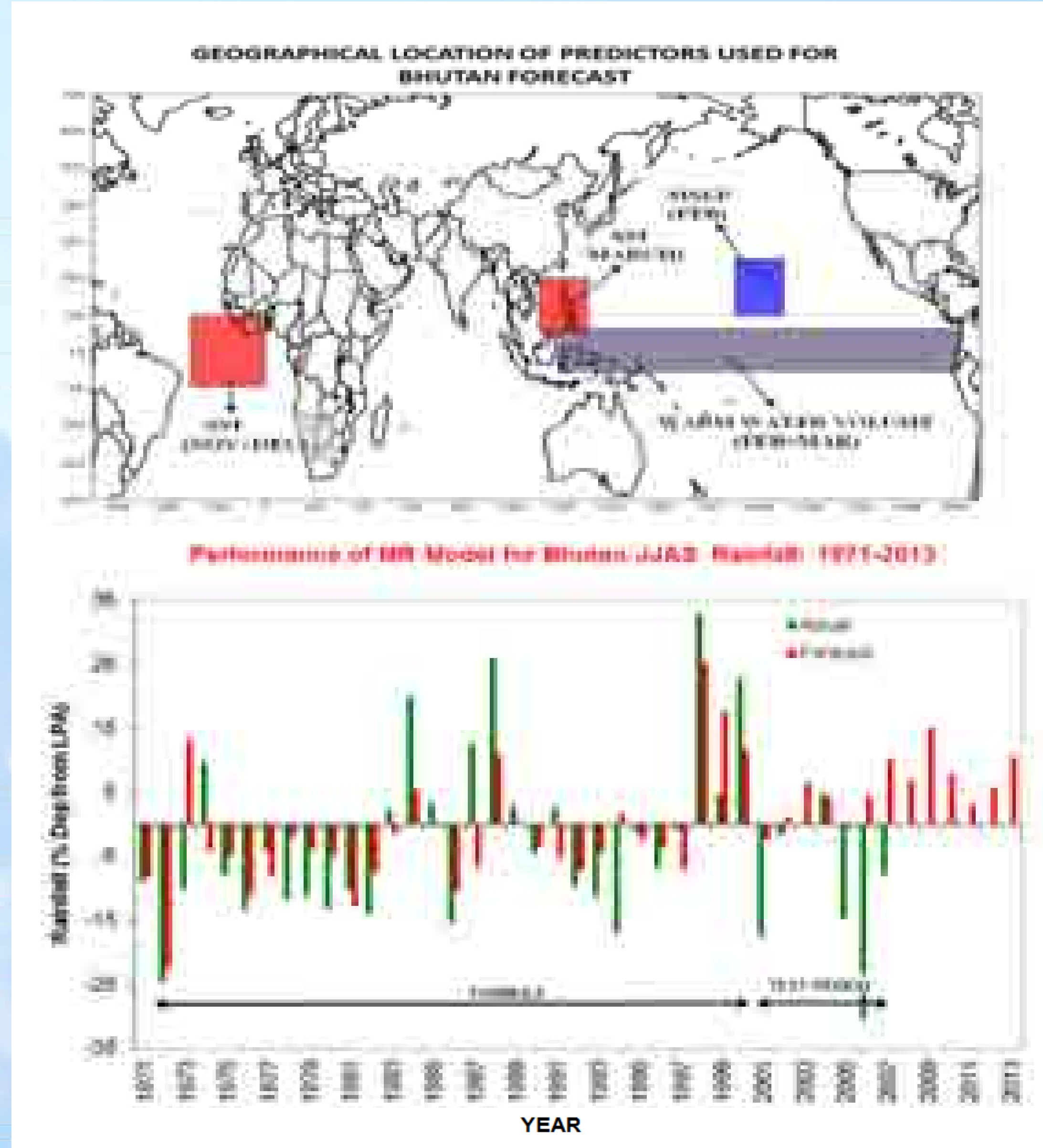




Bhutan

BHUTAN FORECAST
(JUN-SEPT)

- MEAN RF (1971-2000) = 607.99 mm
- C.V. (1971-2000) = 14.00
- RMSE (1971-2000) = 9.65
- MCC (1971-2000)= 0.70

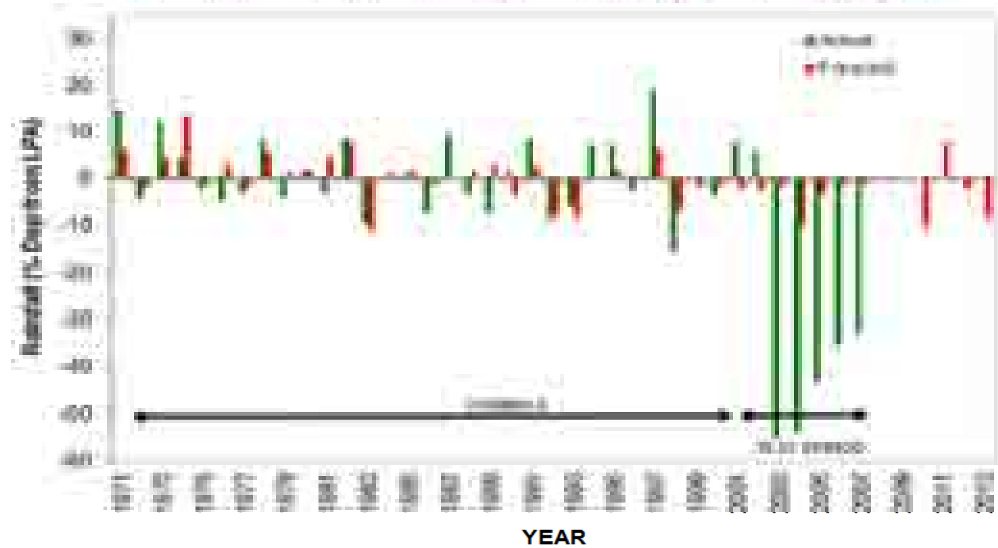


Myanmar

Myanmar FORECAST
(JUN-SEPT)

- MEAN RF (1971-2000) = 1038.4 mm
- C.V. (1971-2000) = 7.9
- RMSE (1971-2000) = 6.0
- MCC (1971-2000)= 0.64

GEOGRAPHICAL LOCATION OF PREDICTORS USED FOR MYANMAR FORECAST

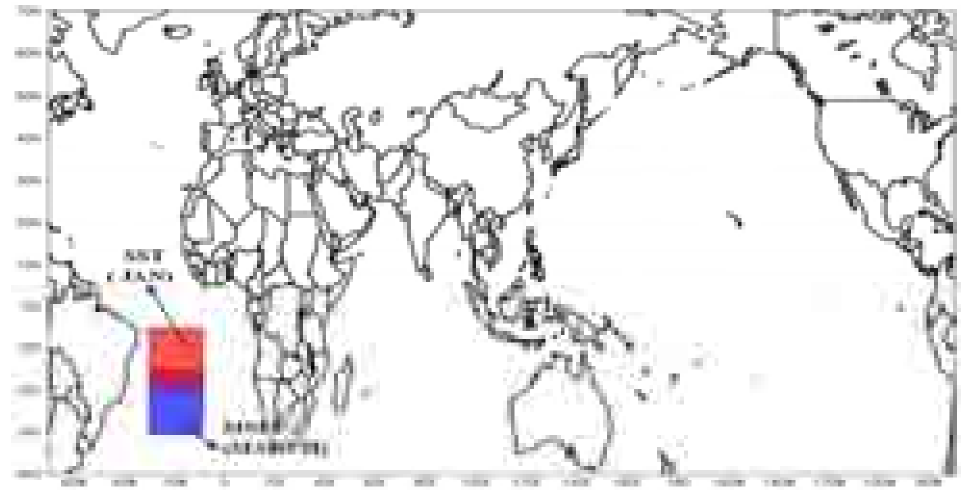


Sri Lanka

SRILANKA FORECAST
(JUN-SEPT)

- MEAN (1971-2000) = 294.7 mm
- C.V. (1971-2000) = 24.0
- RMSE (1971-2000) = 18.93
- MCC (1971-2000)= 0.59

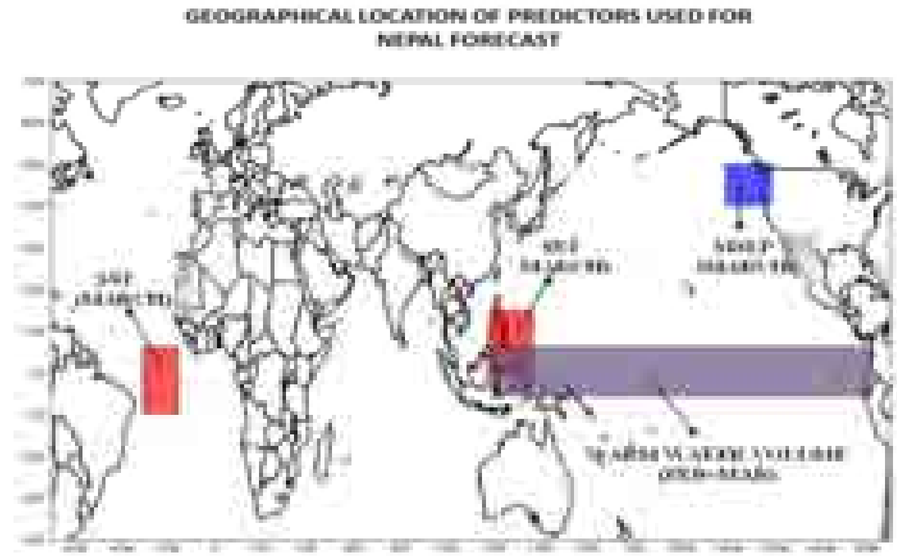
GEOGRAPHICAL LOCATION OF PREDICTORS USED FOR SRILANKA FORECAST



Nepal

NEPAL FORECAST
(JUN-SEPT)

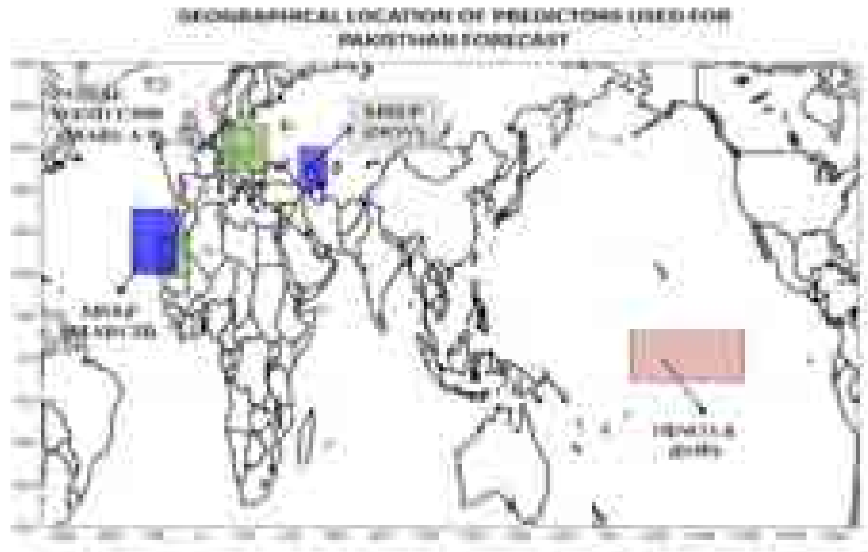
- MEAN RF (1971-2000) = 756.1 mm
- C.V. (1971-2000) = 9.81
- RMSE (1971-2000) = 7.22
- MCC (1971-2000)= 0.66



Pakisthan

PAKISTHAN FORECAST
(JUL-SEPT)

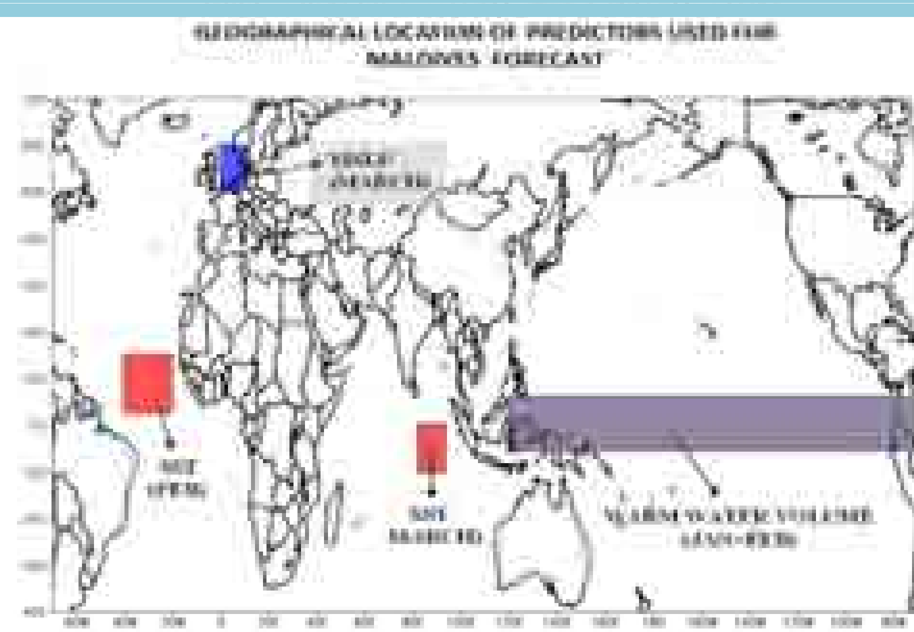
- MEAN RF (1971-2000) = 91.60 mm
- C.V. (1971-2000) = 37.8
- RMSE (1971-2000) = 34.9
- MCC (1971-2000)= 0.56



Maldives

MALDIVES FORECAST
(JUN-SEPT)

- MEAN RF (1988-2005) = 764.6 mm
- C.V. (1988-2005) = 14.0
- RMSE (1988-2005) = 11.61
- MCC (1988-2005)= 0.68



Skill (1981-2009) of MM CFS over Other South Asian Countries

IITM	AFG		BAN		BHU		MYN		NEP		PAK		SRI	
IC	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE
January	**-0.12**	**60**	**0.12**	**18**	**0.33**	**20**	**0.38**	**6**	**0.32**	**7**	**0.10**	**5**	**0.15**	6
February	**-0.30**	**61**	**-0.05**	**16**	**0.16**	**15**	**0.27**	**6**	**0.37**	**5**	**-0.06**	**5**	**0.31**	7
March	**0.30**	**62**	**0.14**	**19**	**0.19**	**21**	**0.51**	**5**	**0.45**	**5**	**0.30**	**5**	**0.39**	6
April	**0.07**	**67**	**0.02**	**15**	**0.17**	**18**	**0.03**	**5**	**0.30**	**4**	**-0.05**	**4**	**0.20**	7
May	**0.19**	**72**	**0.04**	**13**	**0.10**	**29**	**0.17**	**6**	**0.46**	**5**	**0.01**	**4**	**0.36**	9

Status of Seasonal Prediction of SW Monsoon Over South Asia:

Results from International Inter comparison Projects

Comparison of AGCM Simulations
Monsoon Numerical Experimentation Group (MONEG) program (WCRP, 1992)

- Significant differences in simulating the mean monsoon by different models. Most models had systematic errors in simulating the regional features of the monsoon.
- However, a majority of the models could simulate the correct tendency of the inter-annual variability between 1987 & 1988.
- Large fraction of the simulated Indian monsoon rainfall was forced by the SST variations over the Pacific.
- Over Indian region, impact of initial conditions were comparable to the impact of SST anomalies.

Atmospheric Model Inter comparison Project (AMIP) I & II

- Many AMIP-I Models failed to simulate the mean & Interannual variability of the regional monsoon rainfall and seasonal migration of ITCZ (Sperber and Palmer 1996, Gadgil and Sajani 1998)
- It is essential that AGCMs are able to simulate various features of the summer monsoon such as mean, the ISV, and IAV) with reasonable accuracy for it to be useful for monsoon studies (WCRP 1992, 1993)

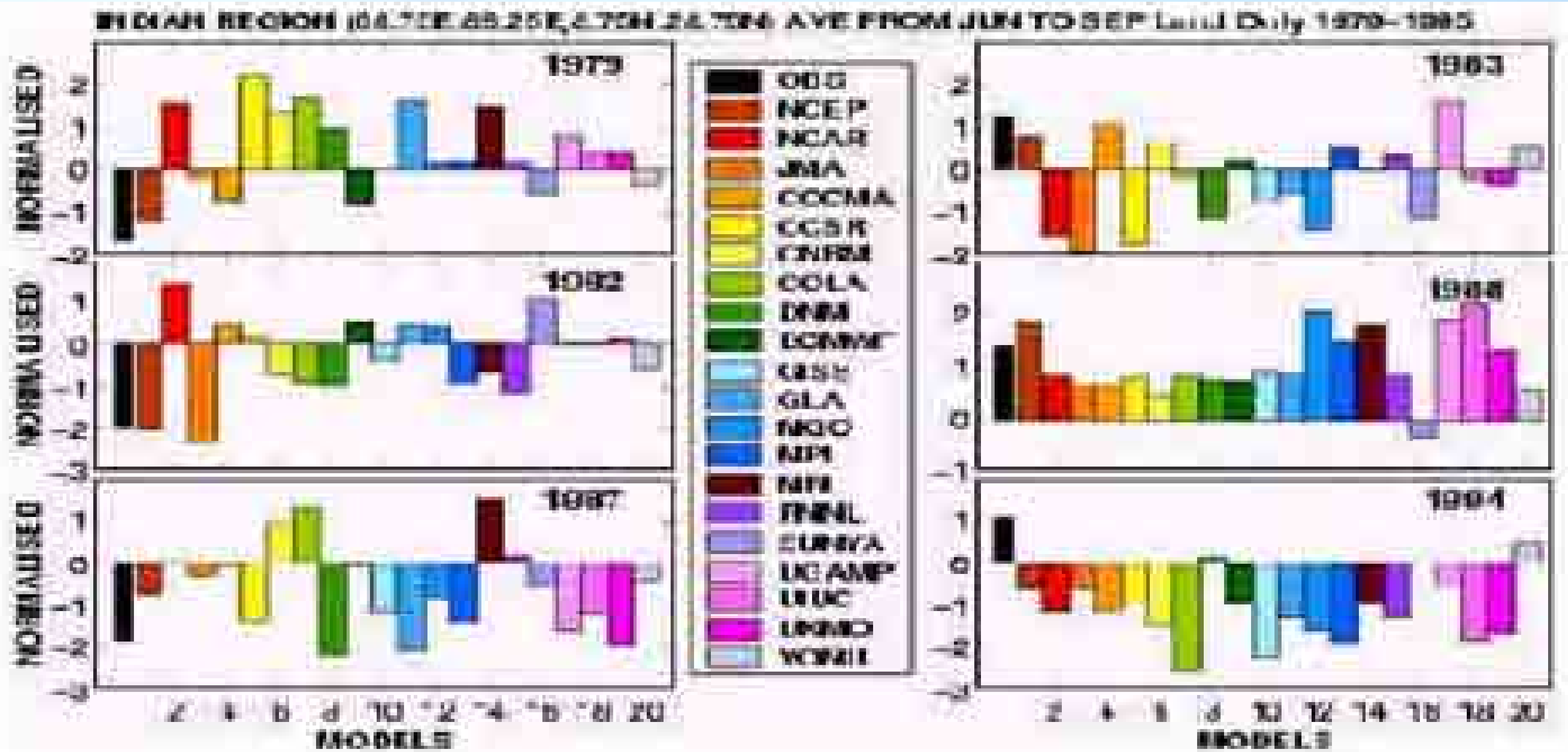


Figure 9. Normalized precipitation (June–September) anomalies in AMIP II models for the Indian region for 1979, 1982, 1983, 1987, 1988 and 1994 seasons. Gadgil et al. 2005, Current Science

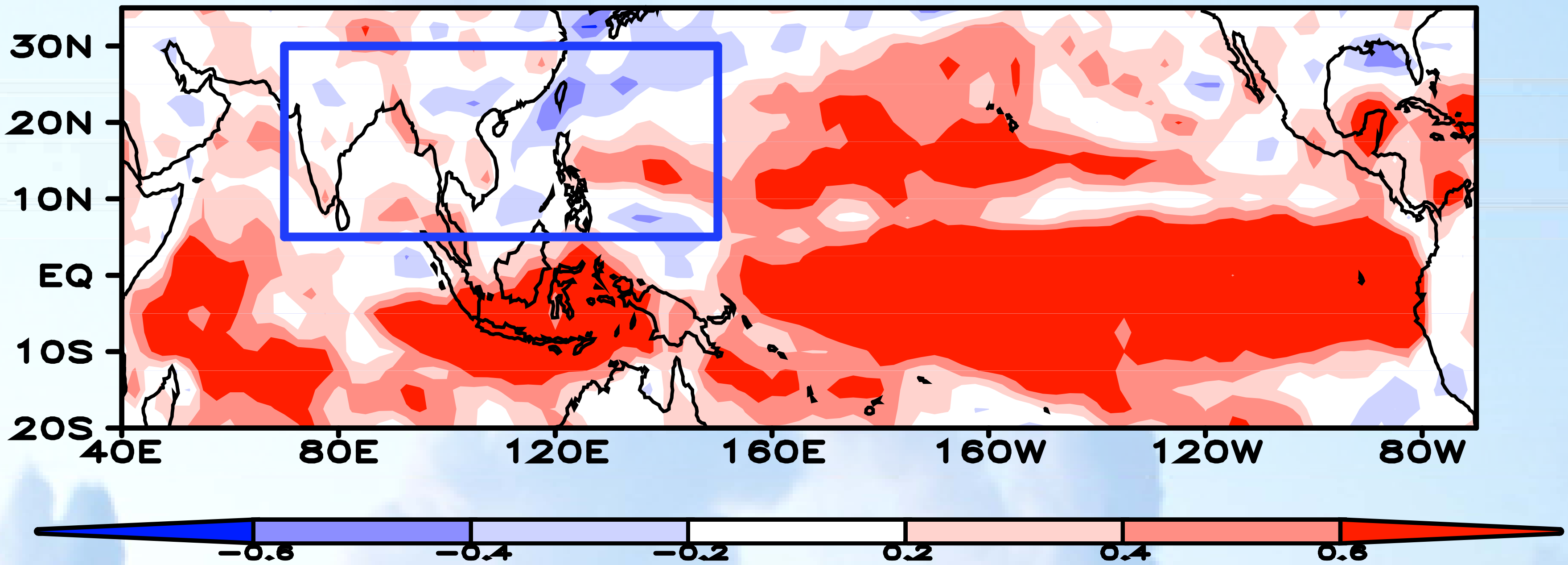
Performance of MME forecasts

Wang et al. 2005, Geophys. Letters

How well are the Asian summer monsoon rainfall hindcasted in the MME prediction?

APCN 5 participating models:
NCEP, NSIPP, JMA, KMA, SNU
MME: Multi-Model Ensemble
AMIP type ensemble hindcast
6 to 10-member ensemble
21-year period (1979-2001)

Correlation Coefficients between the observed and MME hindcasted June-August precipitations (1979-1999)



Wang et al. 2005, Geophys. Lett.

In the Asian-Pacific summer monsoon region (box), the skills are very low, which is in sharp contrast to the high skills in the El Nin˜o region where each individual model and MME show a correlation coefficient between 0.6 and 0.8.

Obs. SST-Rainfall Correlation

MME SST-Rainfall correlation

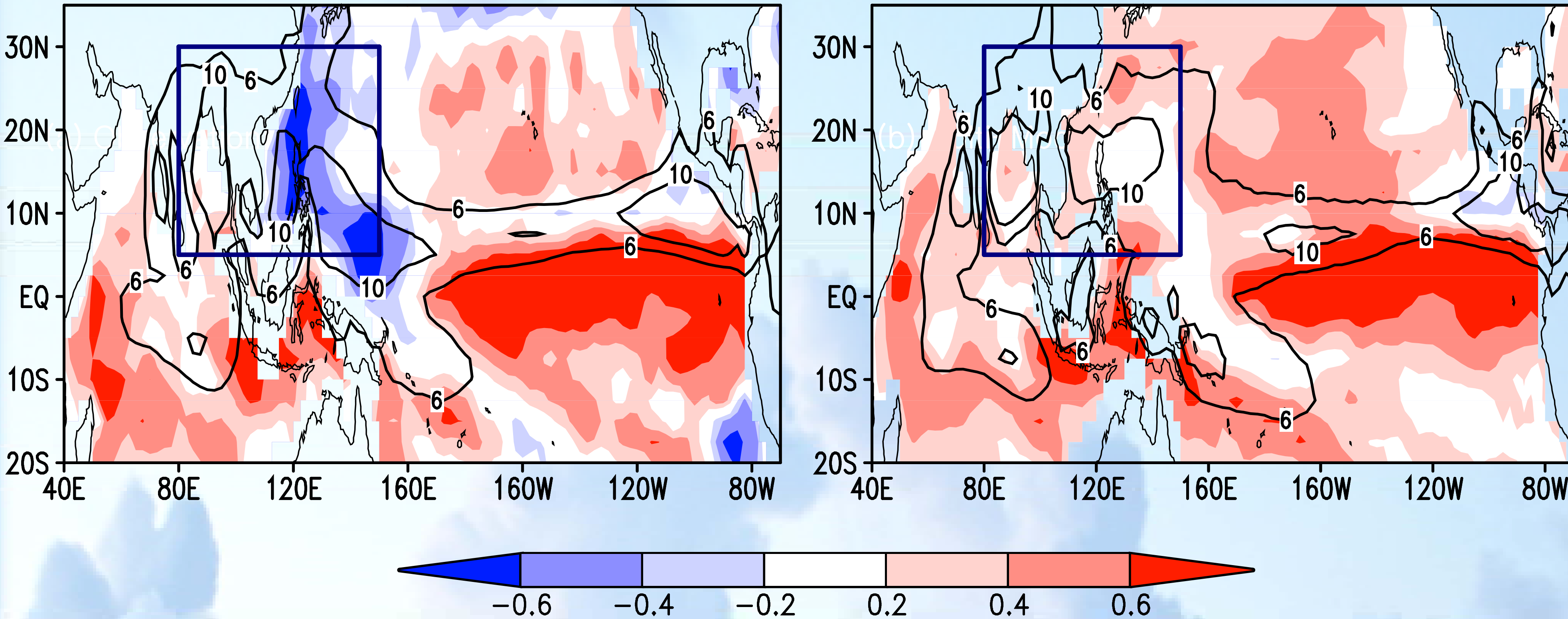


Fig. 2

Performance of Dynamical Model for forecasting All India ISMR at ‘0’ lead time

Model	Hindcast period	Forecast Period	Forecast Season	CC Between Actual & forecast/ Hindcast	RMSE (% of LPA of model hindcast)
GPC Beijing	1983-2007	2008-2012	JJA	-0.17	11.78
			JAS	0.22	8.19
GPC Melbourne	1981-2006	2009-2012	JJA	0.25	9.82
			JAS	0.19	9.23
GPC Moscow	1979-2004	2008-2012	JJA	-0.34	12.19
			JAS	-0.10	9.95
GPC Seoul	1981-2007	2008-2012	JJA	-0.11	10.05
			JAS	-0.19	8.97
GPC Tokyo	1979-2008	2010-2012	JJA	0.28	9.54
			JAS	0.28	7.66
GPC Washington	1981-2003	2008-2012	JJA	0.16	9.70
			JAS	0.10	7.84
NCEP CFS-2	1982 - 2010	2011-2012	JJAS	0.49	7.40

Forecasts from 6 Global Producing Centers (GPCs) of LRF for the two 3 month periods (JJA & JAS) and that from NCEP CFS-2 for the JJAS were used. GPCs generally produce forecast at moving 3 months periods. Forecasts at ‘0’ lead time are considered

Skill for Seasonal Forecasting ISMR: CFSV2 Vs DEMETER & ENSEMBLES

MODEL	Period	Correlation Coefficient
DEMETER	1960-2001	0.28
ENSEMBLES	1960-2005	0.49
	1984-2005	0.31
CFS V2	1984-2005	0.41

From Preethi et al, Climate Dynamics, 2010) & Rajeevan et al. Climate Dynamics, 2011

Seasonal prediction of south Asian monsoon region with the most modern dynamical coupled models such as those that contributed in DEMETER Project (Kang and Shukla 2006, Preethi et al. 2010) remains too low to be of practical use, even at the shortest lead times. **Poor seasonal predictions is related to model difficulties with the representation of land surface processes and uncertainty of initial conditions over land, but it also stems from local air-sea interaction in the surrounding oceans that tends to damp ocean-atmosphere variability in regions of monsoonal westerlies**.

However, encourging improvement was seen in the prediction skill of the Asian monsoon in recent models such as in ENSEMBLES Project (Rajeevan et al. 2011)

NCEP CFSV2 Skill for all India Rainfall (1982-2010)

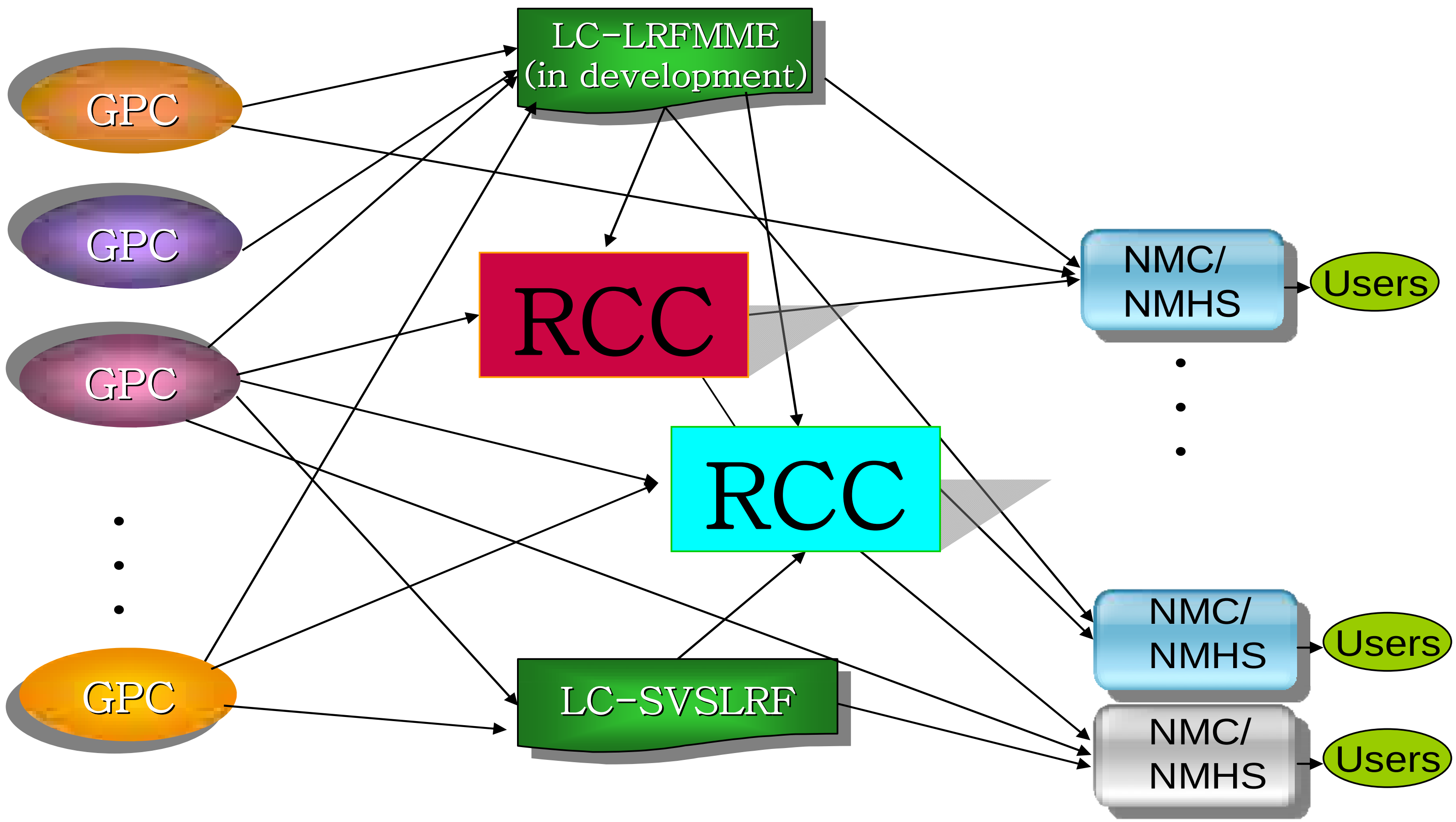
Forecast issued in	JUN		JUL		AUG		SEP		JJAS		AUG-SEP	
	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE
January	**0.48**	14	0.18	15	0.15	14	0.53	15	**0.41**	8.4	**0.44**	10
February	0.08	17	0.30	13	0.22	14	0.32	21	**0.44**	8.3	**0.42**	11
March	0.49	14	0.36	14	0.30	13	0.46	18	**0.57**	7.7	**0.55**	10
April	-0.26	22	0.11	17	0.35	12	0.21	23	**0.39**	9.4	**0.47**	11

Skill of NCEP CFS2 over Other South Asian Countries

CFSV2	AFG		BAN		BHU		MYN		NEP		PAK		SRI	
	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE	C.C	RMSE
January	0.05	30	0.03	16	-0.15	13	0.19	20	0.60	7	0.05	39	0.23	22
February	-0.12	41	0.02	15	-0.04	14	-0.11	16	0.45	7	-0.12	42	0.21	25
March	-0.07	42	0.18	14	0.23	11	-0.26	24	0.32	9	-0.22	43	0.07	27
April	0.25	35	0.11	15	0.01	15	0.15	23	0.43	8	-0.12	38	0.19	24
May	-0.02	36	-0.04	16	-0.22	18	0.27	22	0.56	8	-0.05	39	0.13	25

WMO Arrangement for Providing Long Range Forecasting Services

(A network of Centres)



Conclusions

- Countries from the South Asia uses both statistical & dynamical models for generating seasonal forecasts
- IMD provides various seasonal forecasts over India and South Asia under RCC activities.
- There is significant improvement in the seasonal prediction over the country in recent years.
- For the seasonal forecasting over smaller spatial domains including smaller countries from the region, further improvement is necessary.

Thank you