Long Range Forecasting of South West Monsoon

1. Introduction

In India, SW monsoon is the principal rainy season in India except in Jammu and Kashmir and Tamil Nadu. It comprises of 4 months from June to September. It receives about 80% of its total annual rainfall during the summer monsoon season, from June to September. The Long period average rainfall over the country as a whole for the period 1941-1990 is 89 cm. The All India normal monthly rainfall for these months is 16.3, 29.3, 26.2 and 17.5 cm, which comprises about 18.2, 32.9, 29.3 and 19.6 % of seasonal rainfall, respectively .During the season rainfall varies from day to day, from one spell to another and from month to month. Also there were several years when monsoon rainfall was low causing droughts as well as years when it was excessive causing several floods in the country.

Indian agriculture is largely controlled by rainfall in this season. Small variations in the monsoon onset, in the spatio-temporal variability during the season and in the seasonal mean rainfall have a potential for significant economic and social impacts. Therefore, accurate forecasting of all India summer monsoon rainfall is beneficial to more than a billion people and has profound influence on Agricultural planning and economic strategies of the country.

. The year to year variation in the Indian Summer Monsoon Rainfall (ISMR) is primarily attributed to its association with the slowly varying boundary forcing such as sea surface temperature, snow cover, soil moisture etc. This is the predictable part of the inter annual variability. The unpredictable part of the variability is due to the natural variability (internal dynamics) of the monsoon system.

Two main approaches are used for the long range forecasting (LRF) of the ISMR. The first approach is based on the empirical statistical method. The statistical approach uses the historical relationship between the ISMR and predictors derived from global atmosphere-ocean parameters (mainly derived from slowly varying boundary forcing). The second approach towards long range forecasting is based on the dynamical method, which uses General Circulation Models (GCM) of the atmosphere and oceans to simulate the summer monsoon circulation and associated rainfall. The GCM simulation is primarily driven by the sea surface temperature (boundary) conditions provided in the models.

In spite of its inherent problems, at present, statistical models have shown better skill than the dynamical models for the seasonal forecasts of ISMR. The dynamical models have not shown the required skill to accurately simulate the salient features of the mean monsoon and its interring annual variability. Therefore, India meteorological Department (IMD) currently uses statistical methods for issuing long range forecasts of monthly and seasonal monsoon rainfall over India. However, looking into the potential of the dynamical model IMD have also established an experimental dynamical prediction system at National Climate Center, IMD, Pune in collaboration with Indian Institute of Science, Bangalore. IMD also prepares long range forecasts for winter (Jan- March) precipitation (issued in January) and northeast monsoon (October-December) rainfall over Southern Peninsula (issued in

October). Under National Mission for development of dynamical models for the monsoon forecasting, in near future IMD is planning to setup a dynamical coupled model prediction system for monthly and seasonal prediction with the help of IITM.

2. Interannual Variability of Indian Summer Monsoon Rainfall

In spite of its regularity, monsoon exhibits large variability in different space and time scales. The space scale varies between as small as a rainfall regime represented by rainfall recorded at a rainguage station to the complete monsoon region. The time-scale varies from daily to inter annual to decades, centuries and even millennia.

Fig.1 shows the inter annual variability of all India area weighted seasonal monsoon rainfall expressed as the percentage departures from long period average (LPA) for the period 1901-2010. The LPA for the period 1941-90 is 890 mm. The horizontal dashed lines correspond to the ± 10% departure or +/- one standard deviation. The years in which the percentage departures are less than -10% (more than +10%) are called drought (flood) or deficient (excess) monsoon years. Remaining years are called normal monsoon years. It is seen that during the period 1901 -2010, the lowest and second lowest seasonal rainfall have occurred in 1918 (75.1% of the normal) and 1972 (76.4%) respectively and highest and second highest in 1917(122.9%) and 1961(121.8%). There were 13 excess monsoon years and 20 deficient monsoon years in the series. Of the observed 20 deficient years, 6 years (32%) occurred in the first 20 years period (1901-20). During the long intervening period of 1921- 64, there were only two deficient years (1941 and 1951). During the next 23 years period (1965-87), there were 9 deficient years. During the period (1988-2001), there were no deficient rainfall years. During the recent 8 years (2002-2009), there were 3 deficient rainfall years (2002, 2004 & 2009). Two consecutive deficient years, as in 1904-05, 1965-66 and 1986-87 were rare events in the history of ISMR. There were two cases of two consecutive excess years (1916 & 1917, and, 1955 & 1956). The pairs of years 1917-1918, 1941-42,1974-75, 1982-83, and 1987-88 show extreme contrasting events of Indian monsoon rainfall; the interannual difference in the rainfall being highest during 1917-1918 (47.8% of the normal). Also there is no case of the occurrence of three or more consecutive deficient/excess monsoon years. The most noticing point in the rainfall series is that the magnitude of highest negative anomaly is relatively higher than that of the highest positive anomaly. This could be due to the fact that large-scale vertical motion and moisture convergence, which brings rainfall, are suppressed on scale of the country as a whole, under persistent drought conditions. The good rainfall regimes occur on the scale of synoptic scale disturbances, enhancing rainfall over the area of ascent and reducing it over area of descent. Table-1 shows the monthly and seasonal rainfall anomalies for excess and deficient rainfall seasons over India for the period 1901-2010. Again it is seen that the deficient years are characterized by persistent negative monthly rainfall anomalies during the entire monsoon season. Excess rainfall years, on the other hand, show greater variability from one to the other monsoon months.

In Fig.1, the red (blue) bars correspond to El Nino (La Nina) years. Out of the 20 drought years during the period of 1901-2010, 13 years (65%) were associated with El Nino events. Similarly out of the 13 excess years, 6 years (46%) were associated with La Nina. This indicates that the association between deficient monsoon rainfall and El Nino is more stronger than that between excess monsoon rainfall and La Nina and that there are forcing other than the SSTs over east Pacific, which can influence the Indian monsoon

Fig.3(a & b) show the spatial distribution of the mean & coefficient of variation (C.V.) of seasonal (June-September) rainfall over India computed at subdivision scale. based on 108 years (1901-2008) Maximum rainfall occurs along the western coast and over northeast India. The subdivisions in northwest and southeast get the least amount of rainfall. The subdivisions over the northwest India show large coefficient of variation and those over the west coast and northeast India show low C.V.

Fig.4 shows drought prone subdivisions in India.The highest frequency twice in five year occurs over Telengana , Rayalseema and west Rajasthanand the lowest over over northeastern states.

3. History of Operational LRF System in India

The first operational LRF of Indian summer monsoon rainfall for the region covering whole India and Burma was issued on June 4th, 1886 by Blandford who established IMD in 1875 and was the first Chief Reporter of IMD. Blandford used the relationship between winter and spring snow falls over Himalayas and subsequent ISMR to prepare successful tentative forecasts from 1882 to 1885 and then to issue the first operational forecast for 1886. Since that attempt, the LRF of the monsoon rainfall became one of the important operational duties of IMD. Over the years, the operational LRF system in India underwent many changes in its approach and scope. Detailed reviews on the LRF of Indian southwest monsoon rainfall are available in the literature. From 1895 onwards the monsoon forecasts for the country were based on three parameters, viz. (1) Himalayan snow cover (Oct-May), (2) local peculiarities of pre-monsoon weather in India and (3) local peculiarities over the Indian Ocean and Australia. The first operational forecast issued in 1909 for the seasonal monsoon rainfall over the whole India based on regression technique, however, was resulted from the extensive and pioneering work of Sir Gilbert Walker. Later, on realizing that the entire country cannot be taken as homogenous rainfall region, Walker attempted to develop forecasting equations for smaller regions. He divided the country into three geographical regions, viz. (1) Peninsula, (2) Northeast India and (3) Northwest India. Between 1924 and 1987, operational forecasts were issued for Northwest India and Peninsular India using regression models initially developed by Walker and updated time to time. Forecast for the geographical regions was discontinued during 1988-1998. During 1988-2002, operational forecast for the season rainfall over the country as a whole was based on the 16 parameter power regression and parametric models. In view of increasing user demands, the operational forecasts for three geographical regions of the country namely, Northwest India, Peninsular India and Northeast India were reintroduced in 1999. The areas of these geographical regions were however different from that of Walker's geographical regions with the same names.

In 2003, a new strategy for issuing LRF for the monsoon rainfall was adopted. Accordingly the long range forecasts are issued in two stages. The first stage forecast issued in April consisted of forecast for seasonal rainfall over the country as a whole and the second stage forecasts issued in the end of June consisted of update for April forecast along with seasonal rainfall forecast for the geographical sub regions of the country and July rainfall forecast for the country as a whole. During 2003 to 2006, the operational first and update long range forecasts for the seasonal rainfall over the country as a whole was issued using the 8 and 10 parameter models based on power regression and probabilistic discriminant analysis techniques. The operational forecast for July rainfall over the country as a whole was also started to issue along with the update forecast from 2003 on wards. In 2004, the country was reclassified into 4 sub geographical regions (Fig.2). In 2007, a new statistical forecasting system based on the ensemble technique was introduced for the seasonal rainfall forecasting over the country as a whole. In 2009, forecast for August rainfall over country as a whole was started issuing along with other second stage forecasts issued in June. From 2010, operational forecast for the rainfall during the second half of the monsoon season (August-September) and that during the September over the country as a whole were also started.

Though IMD is the only government agency mandated for providing long range forecasts, many institutes in India are involved in the research work related to LRF. Some of these institutes are Indian Institute of Tropical Meteorology (IITM), Pune, Indian Institute of Science (IISc), Bangalore, Space Applications Centre (SAC), Ahmedabad, National Aerospace Laboratories (NAL), Bangalore, Centre for Mathematical Modeling and Computer Simulation (CMMACS), Bangalore, National Centre for Medium Range Weather Forecasting (NCMRWF), Noida and Centre for Development of Advanced Computing (C-DAC), Pune. Many international climate centers like National Centers for Environmental Prediction (NCEP), European Centre for Medium-Range Weather Forecasts (ECMWF), International Research Institute for Climate and Society **(**IRI) etc. are also involved in the research related to seasonal prediction of monsoon rainfall as a part of their efforts to improve global forecasts. IMD makes use of experimental forecasts prepared by these climate research centers both inside and outside India as supportive materials for preparing the operational long range forecasts for India.

4. The Present Operational Long Range Forecasting System based on Statistical Models

IMD has been issuing operational long range forecasts of the South-west monsoon rainfall for over 100 years based on statistical techniques. At present, IMD issues forecasts for monthly (for July, August, September), second half (August + September) and seasonal rainfall over the country as a whole and for seasonal rainfall over four geographical regions (Northwest India, Central India, Northeast India and South Peninsula) with useful skill..

The Seasonal forecast for the country as a whole is issued in two stages; first stage forecast in April and update for April forecast in June. There are three major changes in the operational statistical forecast system for southwest monsoon used at present from that used during 2003 to 2006 which was based on the 8/10 Parameter power regression models. These are: a) use of a new smaller predictor data set b) use of a new non-linear statistical technique along with conventional multiple regression technique c) application of the concept of ensemble averaging. In the present statistical ensemble forecasting system, a set of 8 predictors that having stable and strong physical linkage with the Indian south-west monsoon rainfall is used. The 8 predictors used for the new ensemble forecast system are given in the Table-2. For the April forecast, first 5 predictors listed in the Table-1 were used. For the update forecast issued in June, the last 6 predictors were used that include 3 predictors used for April forecast. A schematic diagram of the statistical ensemble forecasting system is shown in the Fig. 5. According to this forecasting system, the forecast for the seasonal rainfall over the country as a whole was computed as the mean of the two ensemble forecasts prepared from two separate set of models. The first set of models was constructed using multiple regression (MR) technique and the second set of models was constructed using projection pursuit regression (PPR), which is a nonlinear regression technique. Performance of the April forecast for the independent test period of 1981-2010 computed using the new ensemble method is shown in Fig.6. The RMSE of the independent April forecasts for the period 1981-2010 was 6.4% of LPA. Fig.7 shows the performance of the ensemble method for the

June forecast above procedure. The RMSE of the independent June forecasts for the period 1981-2010 was 5.6% of LPA.

Since 1999 to 2003, IMD was issuing long range forecasts for seasonal rainfall over the 3 broad geographical regions of India viz., North-west India, North-east India and Peninsula using 3 individual power regression models based on different sets of predictors. In 2004, the country was reclassified into 4 geographical sub regions viz., Northwest India, Central India, Northeast India and South Peninsular India (Fig.2). These forecasts are prepared using separate multiple regression models each based on different set of predictors and with model error of ±8%.

The months of July and August are the rainiest months of the south-west monsoon season. The normal rainfall during July & August months over the country as a whole accounts about 33 % (293 mm) and 29% (262mm) of the monsoon season's total rainfall respectively with a corresponding coefficient of variation of 13% and 14% . These monthly rainfall forecasts for July and August over the country as a whole are prepared using separate principal component regression models based separate sets of predictors and with model error of ±9%. Forecast for the rainfall during the second half of the monsoons season (August + September) over the country as a whole is prepared using a regression model with model error of ±7% and that for September rainfall over the country as a whole is prepared using a regression model with model error of ±15%.

5. Experimental Dynamical Forecasting System

Looking at the potential of dynamical models for providing seasonal forecasts for tropical region, IMD in collaboration with Indian Institute of Science (IISc), implemented an experimental dynamical model forecasting system in 2003. The experimental forecasting system established at the National Climate Centre (NCC), Pune is based on the Seasonal Forecast Model (SFM) of the Experimental Climate Prediction Center (ECPC). Preparation of experimental dynamical model forecasts for the monthly and seasonal southwest monsoon rainfall was started in 2005. For running the model in the hindcast mode, observed sea surface temperatures (SSTs) were used as the boundary conditions. In the forecast mode, the model used SST boundary conditions created based on persisting SST method. Under hindcast mode, 20 years model climatology (1985-2004) was prepared. The year to year variation of model hindcast rainfall anomaly over India for the period 1985 to 2004 is given in the Fig.8. The C.C between the actual and model hindcast rainfall anomalies during the period 1985-2004 is 0.37. It is seen that the model has useful skill over the Indian region.

In the forecast mode, forecasts for monsoon months (June to September) were prepared twice. To prepare forecast in the month of April, model integration was started from 1st April to 30th September by using SST boundary conditions prepared by persisting March SST anomalies. 10 ensembles were generated using the initial conditions corresponding to 0000Z UTC from 22nd March to 31st March obtained from NCEP reanalysis. Similarly to prepare forecast in June, persistent method based on May SSTs were used and to generate 10 model ensembles initial conditions corresponding to 0000Z UTC from 21st May to 30th May were used. The model forecasts based on persistence method using March and May SSTs for the period 2005 to 2010 is given in the Fig.9.

6. The major issues related to long range forecasting

(i) Skill of the statistical models is limited due to its inherent demerits such as epochal variation in the preidctand-predictor relationship; inter correlation between the predicators, changing predictability etc. Though the demerits associated with the approach cannot be totally removed, it can be reduced by constantly updating the predictor set by removing predictors with weak relationship with ISMR and including better predictors, use of optimum training period, regularly updating the model training period, use of improved statistical methods etc. IMD is continuously involved research related to this aspect. However, such changes in the model structure do not allow the continued use of same models over a long period of time. This throws a challenge to the modelers, as good parameters are hard to find. It also creates a dilemma for the operational forecaster who would like to have a time-tested model, which he can trust rather than one which is being frequently updated.

(ii) For smaller regions such as meteorological subdivisions/ districts, the skill of statistical models is further limited due to the large variability of the rainfall and difficulty in identifying suitable predictors.

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(iii) The dynamical models have potential to provide long range forecasts over smaller regions and can be updated at required frequency as various down scaling methods are now available. However, the simulation capabilities of the dynamical models (both atmospheric and coupled ocean-atmosphere GCMs) are to be improved drastically in order to apply down scaling methods to generate skillful forecasts over smaller regions. It has been observed that even after applying the observed sea surface temperature (SST) conditions as the boundary forcing, the skill (maximum potential skill) of the GCMs are not sufficient to replace them with the statistical models. The coupled models have to first of all produce the SST predictions close to the realistic values with enough lead time before it can have maximum possible skill. For example, dynamical models have to improve its skill to predict the oceanic phenomena like El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) that have significant impact on the tropical climate variability. For further improvement of the GCM model skill, model atmospheric parameterization schemes have to be improved and models should be able to include topography close to reality. For example, the rainfall distribution over Indian region is strongly related to the topography of the Western Ghats and hills in the north east India. The GCM should have enough resolution to resolve the topography of the region so as to get realistic rainfall distribution. This demands more computer time and improved model physics. The skill of the GCM is also limited due to the inability of the model to simulate the high frequency intra seasonal oscillations.

7. Major Thrust Areas in R & D related to Long Range Forecasting.

i) Development of a coupled ocean atmospheric model specifically for Indian conditions for seasonal prediction of monsoon rainfall.
ii) Development of high resolution Regional Climate Model for forecast over smaller regions like district, met subdivision, state etc.

Short Term Goals:

i) Refining different statistical models for long range forecast of monsoon rainfall – seasonal, monthly and over broad homogeneous regions.

ii) Development of statistical models forecasting at subdivision scale.

Long Term Goals:

i) Implementation of a coupled model (Ocean and Atmosphere) specifically for Indian monsoon rainfall prediction (All India scale, broad homogeneous region in subdivision scale – seasonal / monthly).
ii) Implementation of high resolution regional climate model (RCM) for forecast at smaller spatial scale (subdivision and District scale).

8. Pre-Forecast Meeting with National Institutions

The practice of holding pre-LRF meeting was started in 2003 in associated with introduction of two stage LRF strategy by IMD. The main aim was to brief scientific community about the new strategy and new LRF models required to support this strategy. At that time, as many other institutes were also involved in the research related with LRF, they were also invited to provide their view about the 2003 monsoon during the meeting as the previous year was a drought year.

IMD received concurrence for its new strategy from the scientific community. It was also felt during the meeting that such inputs on LRF prior to issuing of operational monsoon forecast by IMD will be a useful guidance to IMD. So the practice of holding pre-LRF is continuing.

However, utilization of the inputs provided by various sources and reaching to final decision regarding the forecast was totally left to IMD. It was also thought that such meeting will be a platform to scientific evaluation of status of LRF in the country and identification of areas that need more efforts. The meeting also helps in avoiding duplication of research work by various agencies.

9. South Asian Climate Outlook Forum

The summer monsoon plays a crucial role in the entire socio-economic fabric of South Asia, highly influencing all walks of life. The summer monsoon (June–September) rainfall accounts for 75–90% of the annual rainfall of the most of the countries of the region. Several studies highlight the critical dependence of crop production on 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 prediction and outlook is therefore a shared challenge globally and particularly for the South Asian nations.

In Asia, such shared knowledge, information and outlook for the entire continent for the monsoon season have been provided through a Regional Climate Outlook Forum (RCOF) being coordinated by China since 2005. Considering that Asia is a vast continent with large differences in the climatological conditions, Regional Association II (Asia) of World Meteorological Organization (WMO) recommended the establishment of sub-regional RCOFs devoted to specific needs of groups of countries having similar climatic characteristics.

In a meeting convened by WMO, the Directors General of the National Meteorological and Hydrological Services (NMHSs) in South Asia and Permanent Representatives (PRs) of the respective countries with WMO, at the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, on 6 August 2009, the PRs of south Asian nations with the WMO had unanimously agreed to establish a South Asian Climate Outlook Forum (SASCOF), to be implemented from 2010 onwards. The main objectives of SASCOF are the following:

1. To review the progress made in understanding and long range prediction of summer monsoon both regionally and globally;
2. To make available detailed information on climate variability in South Asia for dissemination along with the seasonal outlook;
3. To provide a platform for the stakeholders of SASCOF to share and exchange experience and knowledge on summer monsoon and its prediction;
4. To initiate capacity building/human resource development activities for the South Asian region, particularly in seasonal prediction;
5. To build collaboration and partnerships among the members of SASCOF for mutual benefit;
6. To identify needs of user sectors through a dialog among different groups.

The first meeting of SASCOF (SASCF-1) was held in Pune in April, 2010. IMD, IITM and WMO co-sponsored the meeting. Representatives from NMHSs of the South Asian countries namely Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka, experts from WMO Global Producing Centres of Long Range Forecasts namely Japan Meteorological Agency (JMA), Korea Meteorological Administration (KMA) and United Kingdom Meteorological Office (UKMO) along with inputs from Meteo France, other global/regional centers like International Research Institute for Climate and Society (IRI), USA, Regional Integrated Multi-hazard Early warning System (RIMES), Thailand, Asia Pacific Economic Co-operation Climate Centre (APCC), Korea and South Asian Association for Regional Cooperation (SAARC)

Meteorological Research Centre (SMRC), Bangladesh, along with inputs from Beijing Climate Centre (BCC) and various institutes in India namely Indian Institute of Tropical Meteorology (IITM), Indian Institute of Science (IISc), National Centre for Medium Range Weather Forecasting (NCMRWF), Cochin University of Science and Technology (CUSAT), Centre for Development of Advance Computing (C-DAC), etc. participated in SASCOF-1.

During the SASCOF-1 conducted at Pune in 2010, the Forum noted that the present skills of dynamical as well as statistical models in predicting the monsoon rainfall have limitations. The Forum agreed that, to improve the prediction skill of the models, more collaboration among operational long range forecasters of the South Asia among themselves and research institutes of the countries of the region are required. Active interaction with the concerned global and regional experts would be of the immense help. The Forum strongly recommended the initiation of a capacity building/human resource development plan for the South Asian nations, particularly for seasonal prediction.

The second SASCOF meeting (SASCF-2) will be held again at Pune during 13-15 April, 2011. In associated with SASCOF-2, a training workshop on seasonal prediction will also be organized for participants from South Asia during 8-12 April, 2011.

Table -1: All India monthly and seasonal rainfall departure from normal during extreme southwest monsoon years for the period 1901-2010.

Excess Monsoon Rainfall Years						**Deficient Monsoon Rainfall Years**					
Years	**Jun**	**Jul**	**Aug**	**Sep**	**JJAS**	**Years**	**Jun**	**Jul**	**Aug**	**Sep**	**JJAS**
1914	1.1	23.9	-4.3	17.6	10.4	1901	-29.9	-16.7	11	-28.4	-13.1
1916	34.3	-5.7	20.6	14.9	13.2	1904	2.8	-7.7	-17.4	-23.8	-11.8
1917	37.8	-4.2	17	64.5	22.9	1905	-43.6	-12.3	-21.2	3.2	-17.4
1933	29	-5.2	23.2	25	15.1	1911	21.7	-45.9	-16.4	7.9	-14.7
1942	3.6	19.2	16.3	10.4	13.8	1918	13.5	-47.1	-11.4	-42.1	-24.9
1955	9.6	-15.4	24.9	32.7	10.1	1920	-5.6	0.6	-32.5	-33.3	-16.8
1956	27.4	22.5	3.7	0.6	13.6	1941	-2.6	-19.8	-10.5	-16.2	-13.3
1959	-3.7	23	3.1	33	14.3	1951	-13.6	-18.9	-12.1	-32.9	-18.7
1961	10.7	18.4	15.6	48.8	21.8	1965	-33.3	-4.8	-22.7	-20.8	-18.2
1970	30.7	-16	26	23.2	12.2	1966	3.6	-15.9	-18.8	-15.4	-13.2
1975	4.9	6	21	32.2	15.2	1968	-12.5	5.1	-17.3	-24.5	-10.3
1983	-6.8	-4.3	23.8	43.5	13	1972	-26.7	-31.2	-14.1	-23.6	-23.9
1988	6.8	26.6	14.9	24.6	19.3	1974	-25.6	-4.4	-5.3	-21.8	-12
1994	29	20.8	12.7	-17.1	10.0	1979	-15.5	-16	-18.5	-27.6	-19
There were 13 Excess monsoon years and 20 deficient monsoon years during the period 1901-2009. A year is said to be excess (deficient) monsoon year when the all India seasonal rainfall departure is more than 10% (less than -10%).						1982	-16.8	-23.1	8.9	-32.2	-14.5
						1986	10.8	-14.2	-12.7	-31.2	-12.7
						1987	-21.6	-28.8	-3.7	-25.1	-19.4
						2002	9.4	-54.2	-1.7	-12.9	-19.2
						2004	-0.8	-19.9	-4.3	-30	-13.8
						2009	-47.2	-4.3	-26.5	-20.2	-21.8

Table- 2: Details of the 8 predictors used for the new ensemble forecast system

S.No	Predictor	Used for forecasts in	Correlation Coefficient (1971-2000)
1	NW Europe Land Surface Air Temperature (P1)	April	-0.51
2	Equatorial Pacific Warm Water Volume (P2)	April	0.43
3	North Atlantic Sea Surface Temperature (P3)	April and June	0.36
4	Equatorial SE Indian Ocean Sea Surface Temperature (P4)	April and June	0.59
5	East Asia Mean Sea Level Pressure (P5)	April and June	-0.31
6	Central Pacific (Nino 3.4) Sea Surface Temp.Tendency (P6)	June	-0.49
7	North Atlantic Mean Sea Level Pressure (P7)	June	-0.46
8	North Central Pacific wind at 1.5 Km above sea level (P8)	June	-0.44

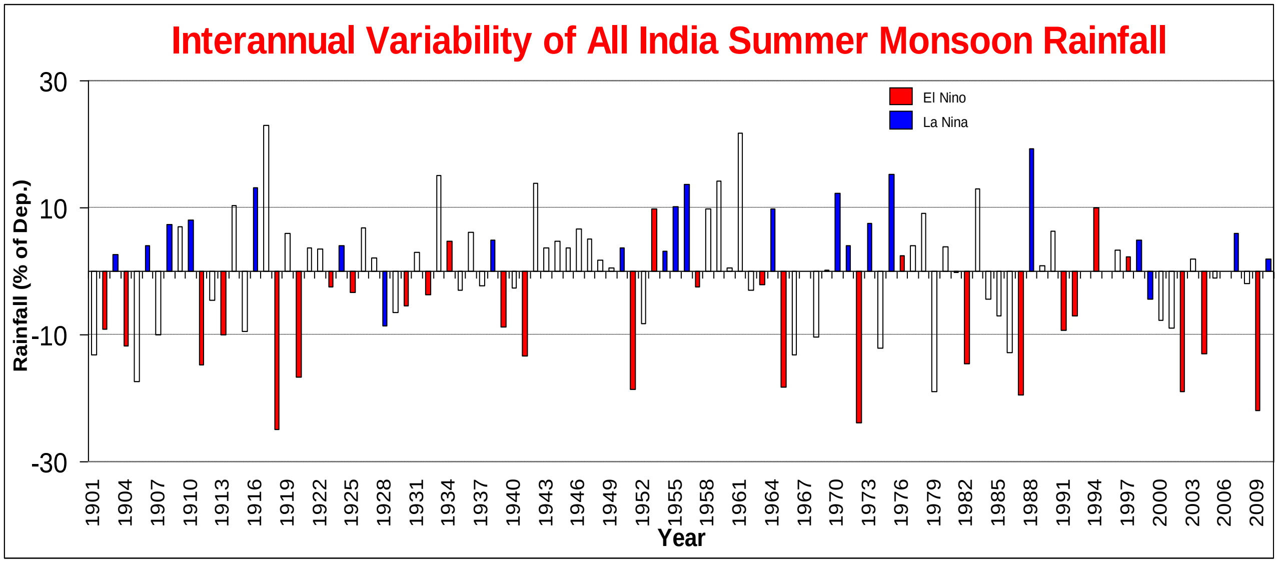


Fig.1 Interannual variability of all India area weighted seasonal monsoon rainfall expressed as the percentage departures from long period average (LPA) for the period 1901-2009. The LPA for the period 1941-90 is 890 mm. The horizontal dashed lines correspond to the ± 10% departure or +/- one standard deviation. The red (blue) bars correspond to El Nino (La Nina) years.

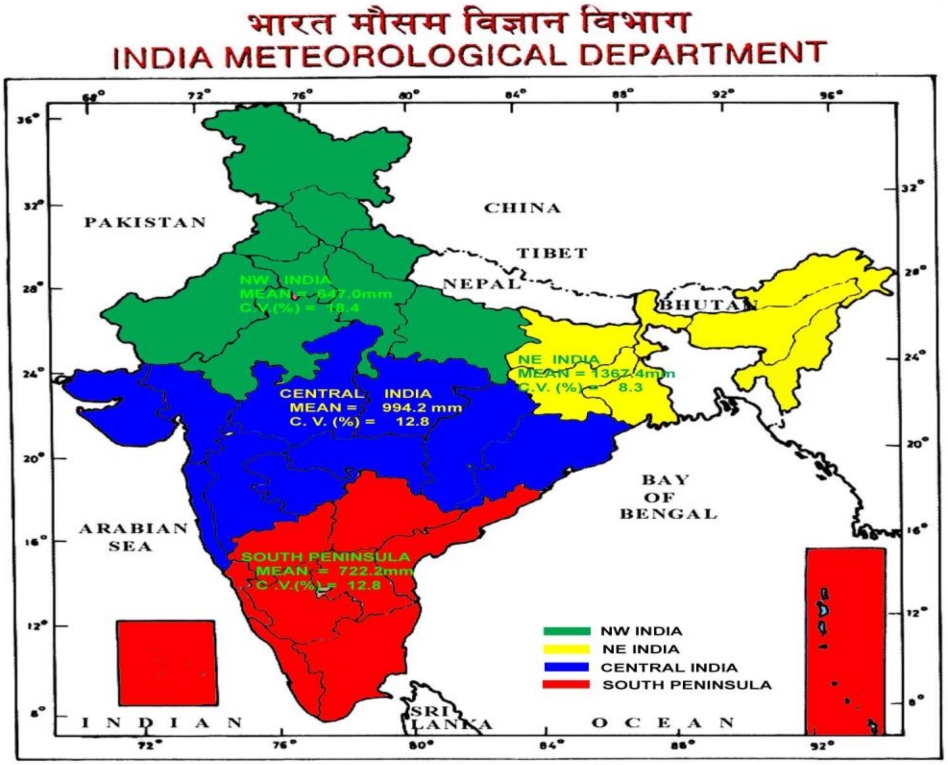


Fig.2. The four homogeneous regions of India.

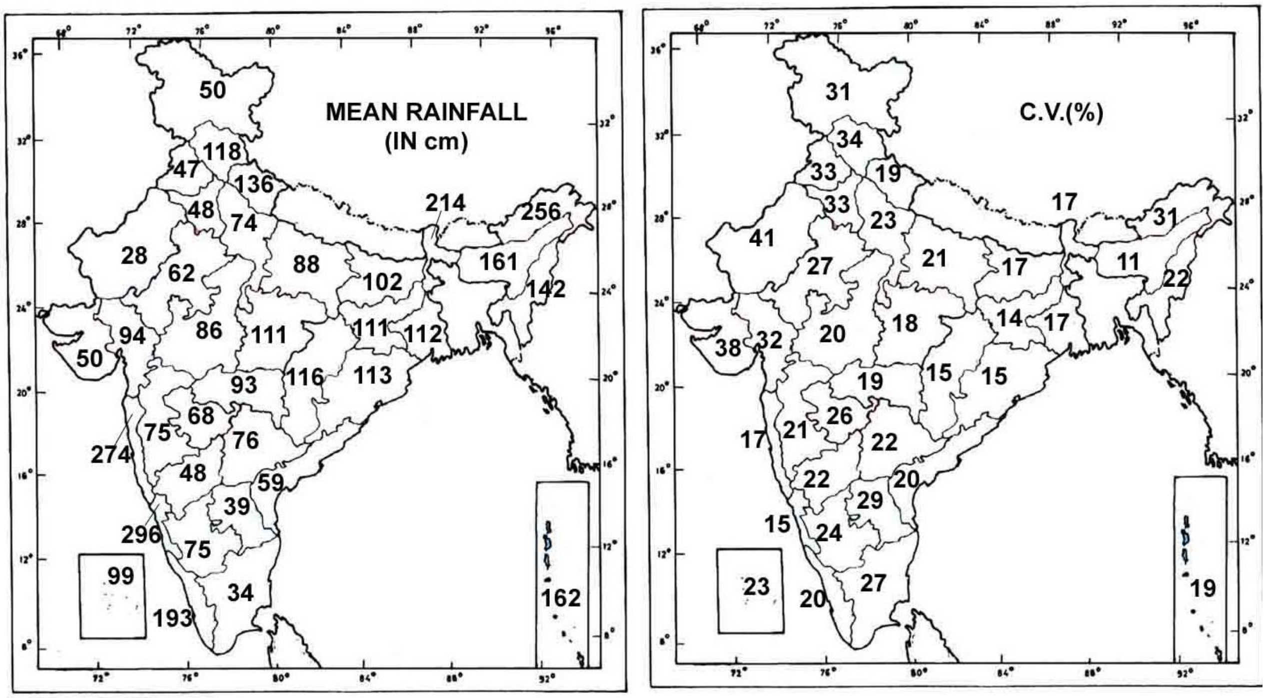
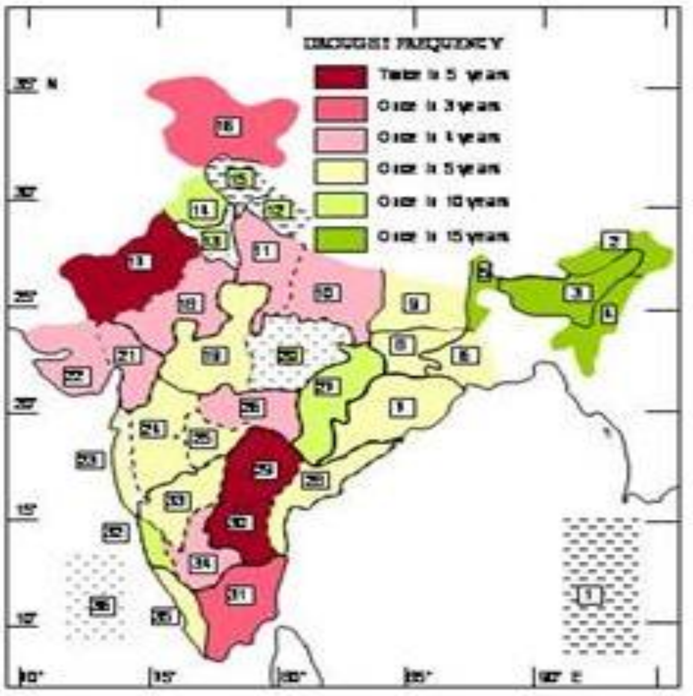


Fig:.3(a&b):Mean monsoon rainfall and coefficient of Variation during sw Monsoon.



Twice in 5 years
Once in 3 years
Once in 4 years
Once in 5 years
Once in10 years
Once in 15 years

Fig. 4. Subdivision wise drought frequency in multi colour

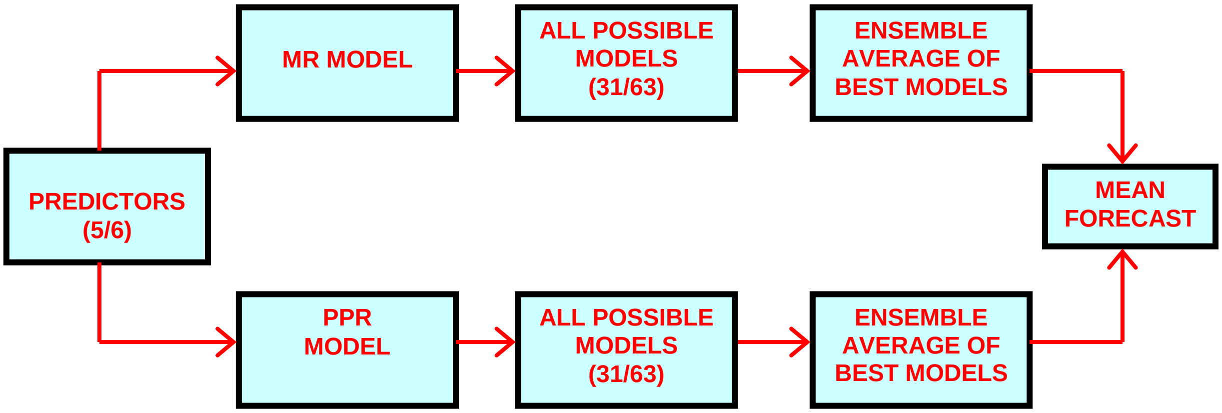
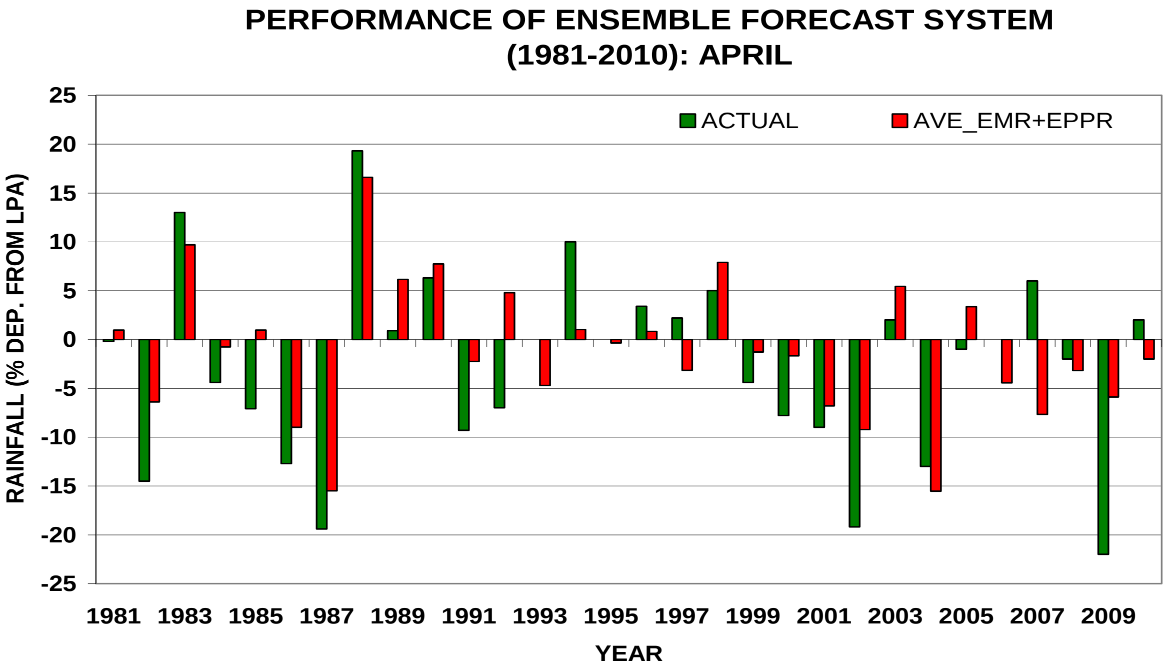


Fig.5. A Schematic diagram of the new ensemble forecasting system for the monsoon season rainfall over the country as a whole. The average of the ensemble forecasts from best out all possible MR (multiple regression) models and that from PPR (projection pursuit regression) models gives the final forecast.


PERFORMANCE OF ENSEMBLE FORECAST SYSTEM
(1981-2010): APRIL
🟩 ACTUAL
🟥 AVE_EMR+EPPR
RAINFALL (% DEP. FROM LPA)
25
20
15
10
5
0
-5
-10
-15
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1981
1983
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Fig.6

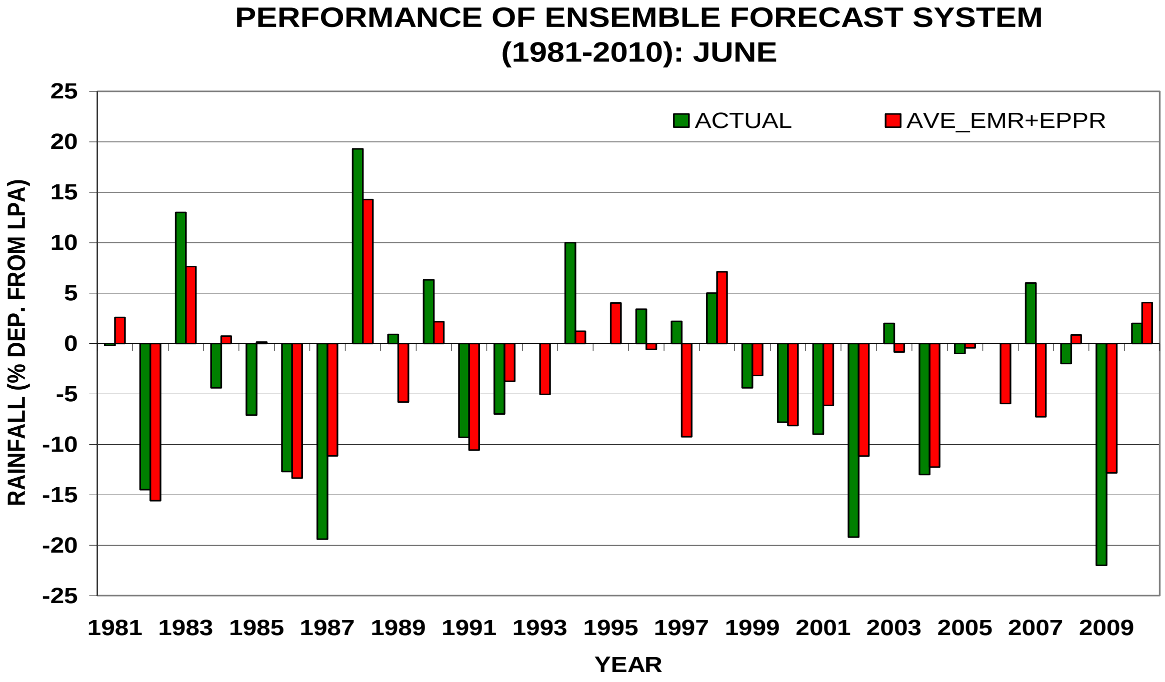
PERFORMANCE OF ENSEMBLE FORECAST SYSTEM
(1981-2010): JUNE
🟩 ACTUAL
🟥 AVE_EMR+EPPR
RAINFALL (% DEP. FROM LPA)
25
20
15
10
5
0
-5
-10
-15
-20
-25
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
YEAR

Fig.7

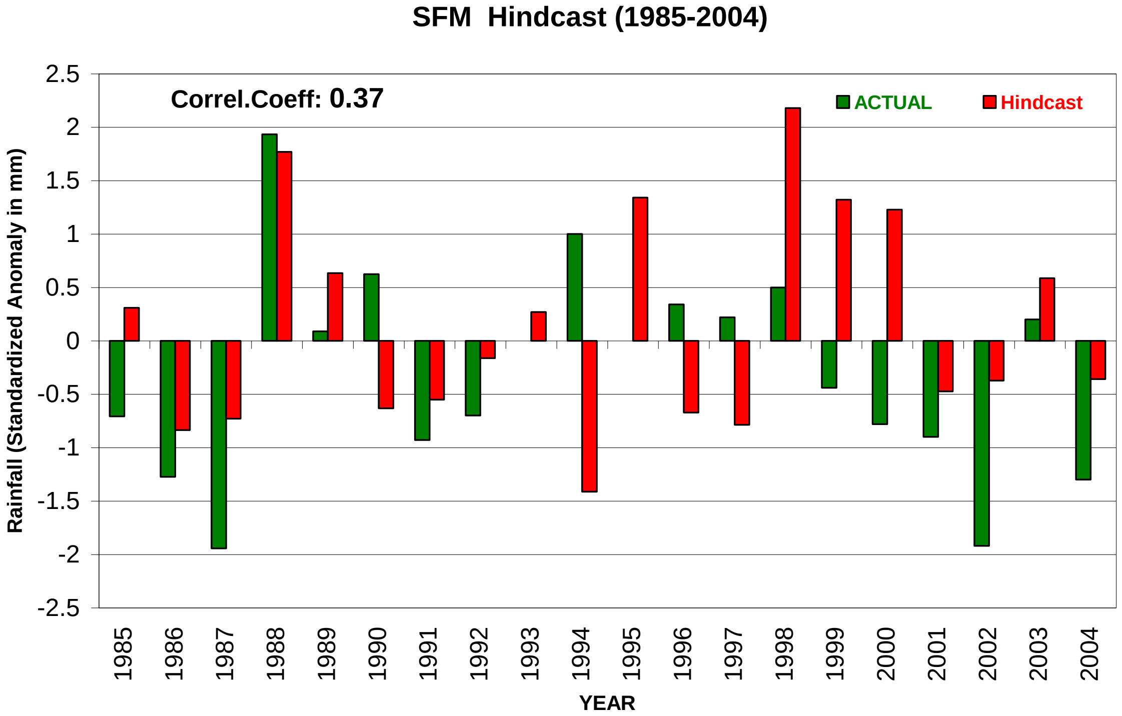

Fig.8. Year to year variation of standardized rainfall anomaly over Indian region for the period 1985-2004 derived from SFM global hindcast output with observed SSTs.

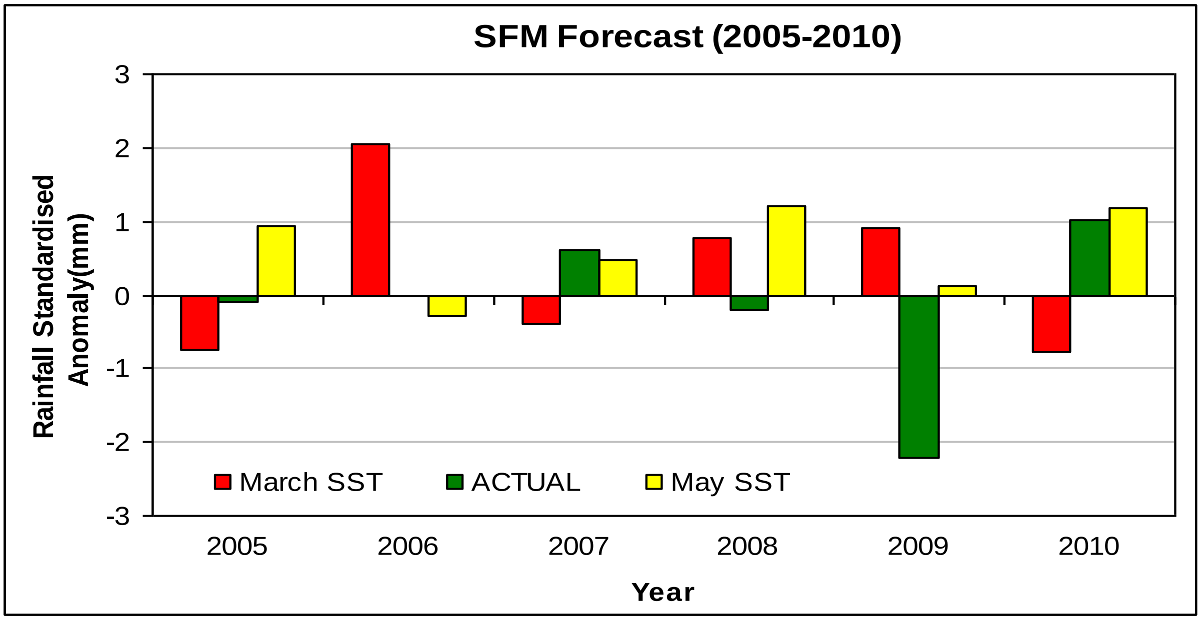

Fig.9. Year to year variation of standardized rainfall anomaly over Indian region for the period 2005-2010 derived from SFM global Forecast output with persistent SSTs.

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PERIOD	DROUGHT YEARS	NUMBER OF DROUGHT
1801-1830	1801, 1804, 1806, 1812, 1819, 1825	6
1831-1860	1832, 1833, 1837, 1853, 1860	5
1861-1890	1862, 1866, 1868, 1873, 1877, 1883	6
1891-1920	1891, 1897, 1899, 1901, 1904, 1905, 1907, 1911, 1918, 1920	10
1921-1950	1939, 1941	2
1951-1980	1951, 1965, 1966, 1971, 1972, 1974, 1979	7
1981-2010	1982, 1987, 2002, 2004, 2009	5