Southwest Monsoon In India and its Forecasting System

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MONSOON IS traditionally defined as a seasonal reversal of wind accompanied by corresponding changes in precipitation associated with the asymmetric heating of land and sea. The term was first used in British India and neighbouring countries to refer to the seasonal winds blowing from the Bay of Bengal and Arabian Sea bringing heavy rainfall to the area.

Process of Monsoon creation

Monsoons may be considered as large-scale sea breezes, due to differential heating of land and the adjoining oceans; and the resultant development of a thermal low over a continental landmass. This differential warming happens because heat in the ocean is mixed vertically through a "mixed layer" that may be fifty metres deep, through the action of wind and buoyancy-generated turbulence, whereas the land surface conducts heat slowly, with the seasonal signal penetrating perhaps a metre or so. Additionally, the specific heat capacity of liquid water is significantly higher than that of the land. Together, these factors mean that the heat capacity of the layer participating in the seasonal cycle is much larger over the oceans than over land, with the consequence that the air over the land warms faster and reaches a higher temperature than the air over the ocean. The hot air over the land tends to rise, creating an area of low pressure. This creates a steady wind blowing toward the land, bringing the moist air of maritime origin with it. This moist air is lifted up due to orographic barriers or low pressure areas. The air on lifting cools due to expansion, which in turn produces condensation and precipitation.

In winter, the land cools off quickly, but the ocean retains heat longer. The cold air over the land creates a high pressure area which produces the wind flow from land

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to ocean. Monsoons are similar to sea and land breezes a term usually referring to the localized diurnal cycle of circulation near coastlines, but they are much larger in scale, stronger and seasonal.

Southwest monsoon

The southwest monsoons occur from June through September. The Thar Desert and adjoining areas of the northern and central Indian subcontinent heat up considerably during the hot summers, which cause a low pressure area over the northern and central Indian subcontinent. To fill this void, the moisture-laden winds from the Indian Ocean rush in to the subcontinent. These winds originate in the south Indian Ocean and move northward. On crossing the equator, these winds are deflected to their right due to rotation of the Earth. They approach the Indian land mass from southwest and, therefore, are called southwest monsoon.

Onset and advance of Southwest monsoon

The southwest monsoon is generally expected to begin around start of June and fade down by the end of September. The moisture-laden winds on reaching the southernmost point of the Indian Peninsula, get divided into two parts: the Arabian Sea Branch and the Bay of Bengal Branch. The Arabian Sea Branch of the Southwest Monsoon first hits the state of Kerala around 01 June. This branch of the monsoon moves northwards along the Western Ghats (Konkan and Goa) and reaches Mumbai around 10 June. Simultaneously, the Bay of Bengal Branch flows over the Bay of Bengal heading towards North-East India. Picking up more moisture from the Bay of Bengal, the Monsoon reaches northeast India around 01 June. After the arrival over northeast India, the winds turn towards the west, travelling over the Indo-Gangetic Plain. It reaches upto eastern parts of Uttar Pradesh around middle of June. The Arabian Sea Branch, by the same time reaches upto Gujarat; and the two branches generally merge over central parts of the country. It then progresses as a combined current and covers the remaining parts of the country by middle of July.

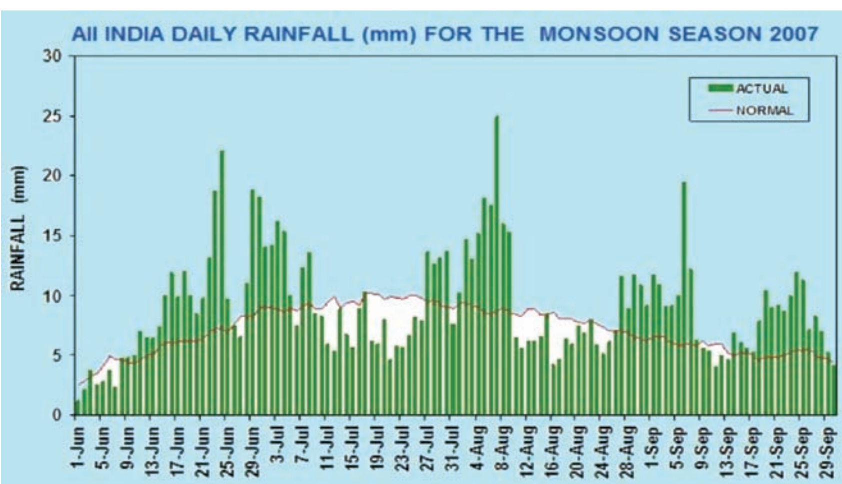

Fig. 1. All India daily actual and normal rainfall for the monsoon season 2007

Rainfall Distribution during Southwest Monsoon

The monsoon accounts for 80 percent of the rainfall in India. Indian agriculture is heavily dependent on the rains, for growing crops especially like cotton, rice, oilseeds and coarse grains. A delay of a few weeks in the arrival of the monsoon, its early withdrawal or prolonged dry spells during the season can badly affect the economy, as evidenced in the numerous droughts in India.

As the prevailing winds blow almost at right angles against the Western Ghats and the Khasi–Jaintia hills, highest seasonal rains are experienced over these regions. In the north Indian plains, a minimum rainfall belt runs from northwest Rajasthan to the central parts of West Bengal, practically along the axis of the monsoon trough. Rainfall decreases considerably with a very steep gradient to the east of the Western Ghats which fall in the rain-shadow zone. With all the significant amounts of rainfall occurring over the Ghats, a saving feature of economic interest is that all the important rivers of south India emerging out of the western Ghats to flow east through the plateau which otherwise receives considerably lower rainfall. Eastern and central parts of the Himalayas also receive heavy rains due to orographic effect. Parts of Jammu and Kashmir, western parts of Rajasthan and extreme southeastern parts of peninsula receive the lowest amounts of rain during the season.

The monsoon rainfall also exhibits large variability in different time scales. Daily rainfall shows large deviations from the normal. Figure 1 shows the daily normal and actual rainfall during the monsoon season 2007. The spells of active and week monsoon are clearly seen in the Figure. Though the country as a whole received 6 percent more rainfall than the normal, five meteorological sub-divisions received deficient rainfall (Figure 2).

Figure 3 shows the interannual variability of all India seasonal monsoon rainfall expressed as the percentage departures from long period average (LPA). The years in which the percentage departures are less than -10 percent (more than +10 percent) are called drought (flood) or deficient (excess) monsoon years. Remaining years are called normal monsoon years. It is seen that during the period 1901 -2011, the lowest seasonal rainfall have occurred in 1918 (75.1 percent of the normal) and 1972 (76.4 percent); and highest in 1917 (122.9 percent) and 1961 (121.8 percent). The red (blue) bars correspond to El Nino (La Nina) years. Out of the 20 drought years during the period of 1901-2011, 13 years (65 percent) were associated with El Nino events. Most of the La Nina years (blue bars) received normal or excess rainfall.

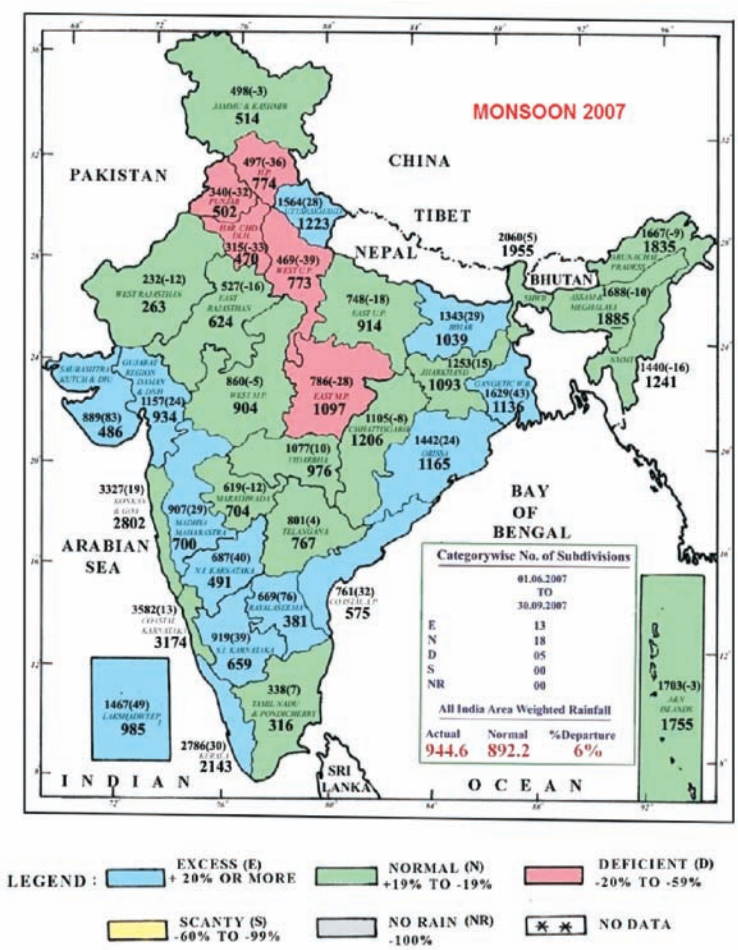

Fig. 2. Sub-division wise rainfall for the monsoon season 2007

Impact of Southwest Monsoon Rainfall on Agricultural Production and GDP

Figure 3 shows that during most of the years, the deviation of rainfall has been within ±10 percent of the normal. Though the amplitude of the variation of monsoon rainfall from year-to year is not large, it has a substantial impact on agricultural production and economy of the country. Initially, large impact of monsoon on the economy of the country was thought to be the result of prime dependence of economy on agriculture. With planned development since independence, the contribution of agriculture to the Gross Domestic Product (GDP) decreased substantially. This should have lessened the impact of monsoon on the economy. However, a recent analysis of the variation of the GDP and the monsoon by Gadgil and Gadgil (2006) has revealed that the impact of severe droughts on GDP has remained between 2 to 5 percent of GDP throughout.

Forecasting the Monsoon rains

Monsoon rains are predicted in three broad temporal ranges – Short Range (1-3 days), Medium Range (4-10 days) and Long Range Forecast (more than 10 days to a season or beyond).

Short and medium range forecasts

The short and medium range weather forecasts are nowadays made using the Numerical Weather Prediction (NWP) Models. The basic idea of NWP is to sample the state of the atmosphere at a given time and use the equations of fluid dynamics and thermodynamics to

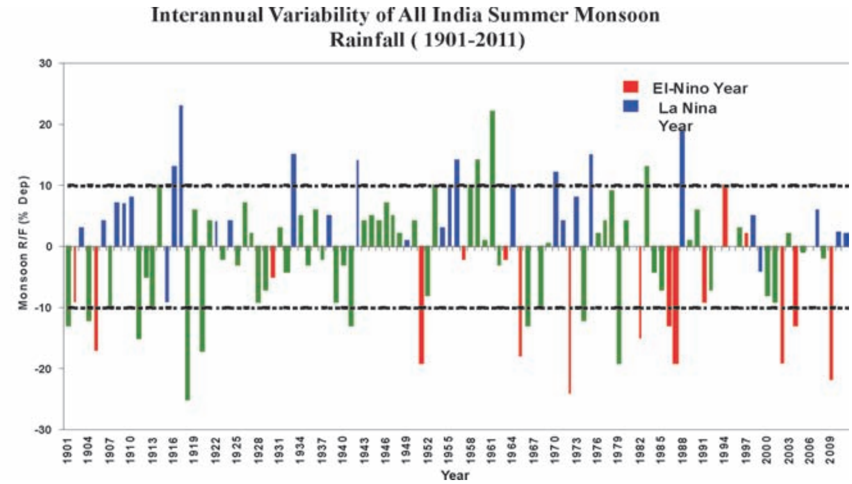

Fig. 3. Year-wise all India monsoon rainfall expressed as the percentage departures from LPA

estimate the state of the atmosphere at some time in the future. The main inputs to these models are surface observations from manned and automated weather stations over the land, weather buoys at sea and observations at different heights of the atmosphere obtained with specialised instruments (radiosonde) flown into the atmosphere with the help of hydrogen filled balloons. Data from weather satellites are used in areas of where traditional data sources are not available. Meteorological radars provide information on precipitation location and intensity, which can be used to estimate precipitation accumulations over time.

The models are initialized using this observed data. The irregularly spaced observations are processed by data assimilation and objective analysis methods, which perform quality control and obtain values at locations usable by the model's mathematical algorithms (usually at evenly spaced grids). The data are then used in the model as the starting point for a forecast. Commonly, a set of equations are used to predict the future state of the atmosphere. These equations are initialized from the analysis data; and rates of change are determined. The rates of change predict the state of the atmosphere a short time into the future. The equations are then applied to this new atmospheric state to find new rates of change, and these new rates of change predict the atmosphere at a yet further time into future. This time stepping procedure is repeated until the solution reaches the desired forecast time.

The visual output produced by a model solution is known as a prognostic chart. The raw output is often modified before being presented as the forecast. This can be in the form of statistical techniques to remove known biases in the model, or of adjustment to take into account consensus among other numerical weather forecasts. Analysis of wind conditions at 1.5 km above sea level for 1730 IST of 20 August, 2010 and the forecast of rainfall 48 hours after that are given in Figure 4 and 5, respectively.

Long Range or Seasonal Forecast of Monsoon

The summer monsoon accounts for major share of the total annual rain in 75 percent of the geographical area of the country. Although the duration of monsoon over various parts of India varies from about 2 months to 6 months, long range forecasts are generally issued for monthly and seasonal scales for June to September.

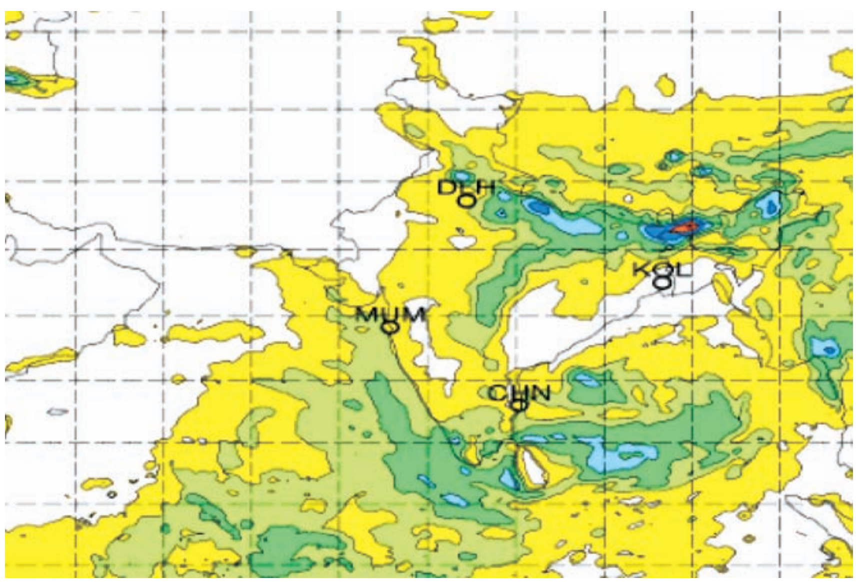

Fig. 4. Forecast of Rainfall 48 hours after 1730 IST of 20 August, 2010

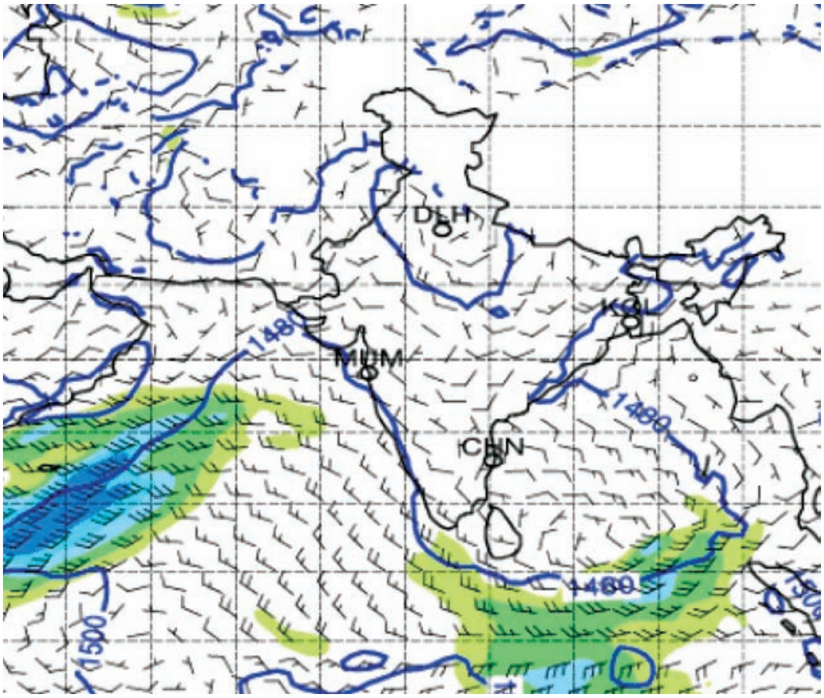

Fig. 5. Analysis of wind at 1.5 km above sea level for 1730 IST of 20 August, 2010

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. Two main approaches are used for the long range forecasting (LRF) of the ISMR. The first approach is based on the empirical statistical methods; and the other is based on dynamic models which uses General Circulation Models (GCM) of the atmosphere and oceans to simulate the summer monsoon circulation and associated rainfall.

Statistical Long Range Forecast System

The statistical approach uses the historical relationship between the ISMR and predictors derived from global atmosphere-ocean parameters. The statistical models have shown better skill than the dynamical models for the seasonal forecasts of ISMR. Therefore, India meteorological Department (IMD) currently uses statistical methods for issuing long range forecasts of monthly and seasonal monsoon rainfall over India.

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 - Figure 6) with useful skill. The seasonal forecast for the country as a whole is issued in two stages - in April and June. A set of 8 predictors that have stable and strong physical linkage with ISMR is used. The 8 predictors used for the statistical forecast system are given in the Table-1. For April forecast, first

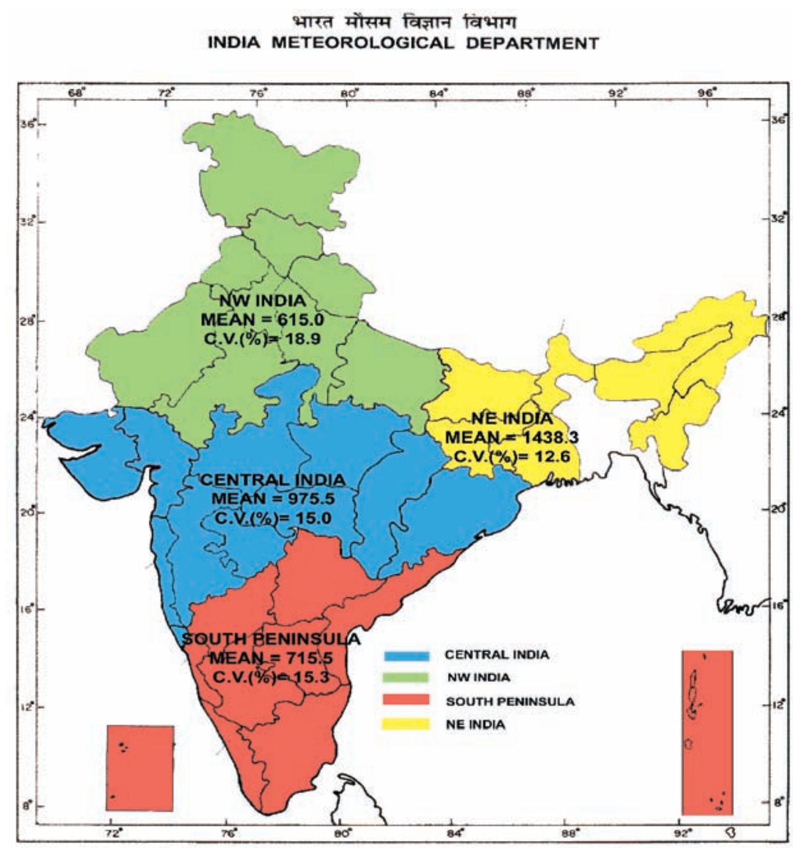

Fig. 6. The four homogeneous regions of India.

Table- 1: Details of the 8 predictors used for the new ensemble forecast system			
S.No	**Predictor**	**Used for forecasts in**	**Correlation Coefficient**
1	NW Europe Land Surface Air Temperature (P1)	April	0.58
2	Equatorial Pacific Warm Water Volume (P2)	April	-0.30
3	North Atlantic Sea Surface Temperature (P3)	April and June	-0.49
4	Equatorial SE Indian Ocean Sea Surface Temperature (P4)	April and June	0.45
5	East Asia Mean Sea Level Pressure (P5)	April and June	0.36
6	Central Pacific (Nino 3.4) Sea Surface Temperature Tendency (P6)	June	-0.49
7	North Atlantic Mean Sea Level Pressure (P7)	June	-0.52
8	North Central Pacific wind at 1.5 Km above sea level (P8)	June	-0.44

5 predictors are used. For the update forecast issued in June, the last 6 predictors are used that include 3 predictors used for April forecast. Figure 7 shows the performance of the method for the June forecast (actual – green bars; forecast – red bars). The Figure shows that the model has been able to predict large deviations in monsoon rainfall both on positive and negative sides. The RMSE of June forecasts for the independent period 1981-2010 is 5.6 percent of LPA.

The months of July and August are the rainiest months of the south-west monsoon season (accounting for 33 percent and 29 percent of the season's total rainfall, respectively) and play important role in production of kharif crops in the country. The monthly rainfall forecasts for July and August over the country as a whole are prepared using a principal component regression models based on separate sets of predictors. Forecast for the rainfall during the second half of the monsoons season (August + September) and for the month of September over the country as a whole is prepared using another regression model.

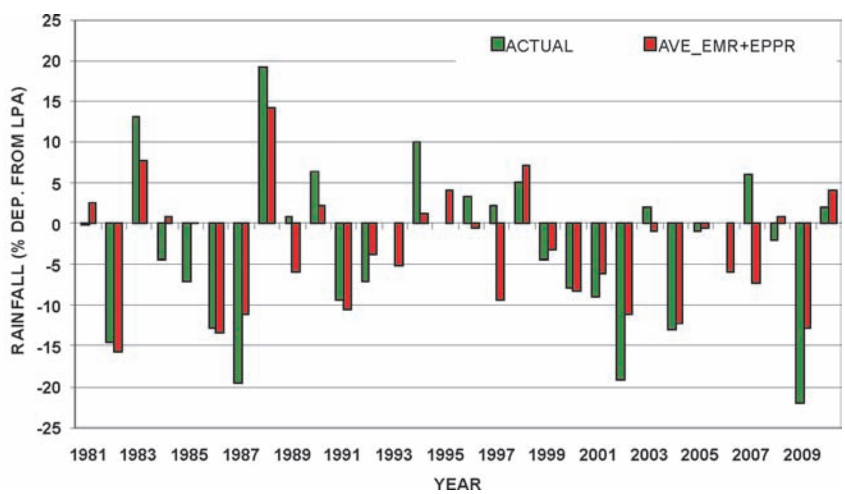

Fig. 7. Performance of June Forecast using Ensemble Forecast System

Dynamical Model Forecasting System

Ministry of Earth Sciences (MoES) has launched the National Monsoon Mission (NMM) for developing a state-of-the-art dynamical prediction system for monsoon rainfall on different time scales. Indian Institute of Tropical Meteorology (IITM) is coordinating and working along with different climate research centres from India and abroad on the development of a coupled model for the forecasting the ISMR. IMD has adopted the latest high resolution research version of the coupled model being implemented at IITM for generating experimental forecast for southwest monsoon rainfall. For the first time, anywhere in the world, such a high resolution coupled model (horizontal resolution of approximately 38 km - T382) has been used for generating seasonal prediction of monsoon rainfall. The model is still in an experimental stage and shall be made operational once the desired level of accuracy is achieved. ❑