

# **Long Range Forecasting (LRF) of Monsoon Rainfall in Nepal**



**SMRC- No. 20**  
**SAARC METEOROLOGICAL RESEARCH CENTRE**  
**DHAKA, BANGLADESH**

**2006**

## **Long Range Forecasting (LRF) of Monsoon Rainfall in Nepal**

A study conducted by SAARC Meteorological Research Centre (SMRC),  
Dhaka, Bangladesh, as a Collaborative Research Program with Indian  
Institute of Tropical Meteorology (IITM) Pune, India



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## **FOREWORD**

SAARC Meteorological Research Centre (SMRC) has been focusing more on the application oriented research programs. Research on the long range forecasting of monsoon rainfall is one of the key areas toward such programs. The result from this study is expected to help not only the planners but also the farmers working in the fields. The 11<sup>th</sup> Governing Board Meeting of SMRC also emphasized on the application oriented research program and hence it is very appropriately chosen subject and timely produced study concerning the prediction of monsoon rainfall over Nepal.

Study of monsoon rainfall over Nepal has practical usefulness due to its agricultural dependent socio-economic structure. Present study, focuses on the teleconnections and long range prediction of summer monsoon rainfall over Nepal and should be updated annually for its routine usefulness. I am fully satisfied with the timely completion of the research and the result has come up in the form of another series of SMRC publication.

(Dr. Samarendra Karmakar)  
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## PREFACE

As approved by the 10<sup>th</sup> Governing Board of SMRC and endorsed by the Government of India, a visit was accomplished by two scientists of SMRC to Pune, India, during 1-16 December 2005, under the Collaborative Research Program between SAARC Meteorological Research Centre (SMRC), Indian Institute of Tropical Meteorology (IITM) and India Meteorological Department (IMD). The visit had an objective to initiate the development of long range forecasting model for monsoon rainfall over the SAARC regions where such activity was lacking in the past. Nepal was found one of the regions to start with and the present study has been proposed.

In addition to two scientists from SMRC, Two scientists from IITM (Dr. A. Kulkarni and Mrs. S. K. Patwardhan) and one from IMD (Dr. Pulak Guhathakurta) were involved in the programme. The authors acknowledge their valuable suggestions during the course of this research.

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## **SUMMARY**

Basic characteristics of monsoon rainfall over Nepal were analyzed using observed data gathered from the Department of Hydrology & Meteorology, Government of Nepal. It was observed that the monsoon rainfall has character of having inter-annual variation and slight increasing trend. Quantifying the association between two parameters was obtained through a statistical computation of correlation coefficients (CCs), which exhibits marked sensitivity to the investigated data window.

Further, teleconnections of monsoon rainfall over Nepal with the global fields of sea level pressure and geopotential height at 13 vertical levels from NCEP/NCAR reanalysis were identified as an implication for seasonal forecasting. Finally, stepwise multiple regressions were used to get the LRF model. The removal of trend was done by using backward differenced filter. Sea level pressure change over North Equatorial Pacific and Southeastern Pacific and Geopotential height change over Southeastern Pacific at 1000 hPa level were found most dominating atmospheric variable for the seasonal prediction of all-Nepal summer monsoon rainfall. The correlation coefficients between actual and model estimated rainfall was found very high during model verification period also.

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## LIST OF ABBRETIATIONS

ANSMR	:	All-Nepal Summer Monsoon Rainfall
CCs	:	Correlation Coefficient
ENSO	:	El-Nino/Southern Oscillation
IITM	:	Indian Institute of Tropical Meteorology
LRF	:	Long Range Forecast
NCAR	:	National Centre for Atmospheric Research
NCEP	:	National Centers for Environmental Prediction
SAARC	:	South Asian Association for Regional Co-operation
SLP	:	Sea Level Pressure
SMRC	:	SAARC Meteorological Research Centre
SO	:	Southern Oscillation

## 1. Introduction

The kingdom of Nepal is situated in the southern slope of the central Himalayas. Out of 147,181 Km<sup>2</sup> total area of the country, about 86% area comprises of hills and mountains and remaining 14% are flatlands. Within south-north range of 145 km to 241 km, the altitudinal variations is from about 60m above mean sea level in the southern plain (called Tarai) to the Mount Everest (8848m) in the northeast. Such variation in altitude makes the existence of wide range of climatic conditions. Physically, these climatic conditions, from subtropical to alpine/arctic, are manifested in the presence of diverse habitats, vegetation and fauna in Nepal.

The land-use statistics of Nepal shows about 4.3 million hectares (mha) of forest, 1.6 mha of shrub land and degraded forests, 3.0 mha of farmland, and about 1.0 mha of other lands (MOPE, 2001). Agriculture constitutes the base for Nepal's economic development as over 80 per cent of the active population depends on this sector. Besides, water resource (which has potential of generating 83,000 mega-watt of electricity) is another key sector for the growth of the national economy. In general, climate variability at higher altitude region of the country is critical for water resources (hydropower and irrigation) and variability at lower altitude is critical particularly for rain-fed agricultural practices.

Southwest Indian Monsoon brings more than 80 percent of the annual rainfall in Nepal during the rainy months, June through September. The lower tropospheric wind from east-south-easterly direction over entire Nepal is the most common circulation feature during this season. However, during break monsoon in India, when monsoon trough shifts to foot-hills of northern mountains, the westerlies dominate the lower circulation pattern over Nepal and release large quantity of rainfall. However, the remaining amount of the annual precipitation is predominantly contributed by the passage of the extra-tropical circulation, called western disturbances. Climate of Nepal is, thus, characterized mainly by altitude, topography, and by the seasonal circulations.

Himalayan snow cover (Blanford, 1884) and ENSO (El-Nino/Southern Oscillation) effect (Walker, 1918) were two historical thoughts regarding the development of

the summer monsoon rainfall anomalies over Indian sub-continent. Another milestone long range forecasting (LRF) event in India was the development done by Walker in 1924 through a regression model to predict monsoon rainfall over three homogeneous regions of India. Furthermore, he also recognized the Southern Oscillation (SO) as the phenomenon with global-scale influences. Later, other scientists linked this phenomenon to the El Nino, which is a warming of sea surface along the Peru coast, South America. In recent periods, the combined effect of these phenomena led to the development of the theory of Walker Circulation (Bjerknes, 1969).

This study proposes an empirical approach towards LRF of summer monsoon rainfall in Nepal by utilizing the concept of the global/regional teleconnections of rainfall and other atmospheric parameters. Statistical tools applied are computation of correlation coefficients (CCs) for quantifying the association between rainfall and the relevant parameters and linear regression analyses for determining the relationship between predictors and the rainfall. Though CCs helped to identify various forcing, they also exhibit marked sensitivity to the investigated data window, which leads to secular variations in their magnitude as well as sign. Consequently, this will impose certain limitation on selecting the data periods. Also, multicollinearity among the predictors imposes the problem of redundancy and unnecessary loss of degrees of freedom while using in large numbers in regression equation. Large difference between the actual and the model estimated values might arise due to the instability of the predictors as well as the limited predictive potential of the predictors.

In addition to direct impact of climate variability on economy and society, there are some specific issues which are commonly important for both Nepal and need to be addressed. For example, the date of onset and withdrawal of monsoon rainfall can play very critical role in agricultural planning and utilization of the water resources. The high spells of rainfall are vulnerable to natural processes such as landslides, erosion, etc. These processes are responsible for loss of human life, property and cultivated lands and also have severe impact on

transportation. The quantification of monsoon rainfall in advance can be helpful in minimizing these adverse effects to some extent.

## 2. Monsoon Rainfall Characteristics in Nepal

Strong spatial and temporal variations exist in rainfall distributions of Nepal (Shrestha et al., 1999, 2000; Shrestha, 2000). The seasonal and annual all-Nepal rainfall statistics are presented in table 1. As anticipated, the seasonal mean rainfall is highest during summer monsoon season and lowest during winter. Pre- and post-monsoons thunder activities and occasional passage of the western disturbances make rainfall during these periods a little higher than winter. However, the variability is found highest during post-monsoon and lowest during monsoon seasons. Although, the variability of the monsoon rainfall is found small, the anomalies in either sides of this seasonal mean rainfall may have severe impacts on the socio-economy of Nepal.

Seasons	MEAN	Std. Dev.	CV	Rainfall (mm)			
	(mm)	(mm)	(%)	Lowest	Year	Highest	Year
DJF	55	24	45	19	1960	107	1961
MAM	196	50	26	98	1957	303	1971
JJAS	1345	110	8	1097	1992	1527	2000
ON	70	39	55	14	1994	163	1985
ANNUAL	1679	137	8	1369	1992	1889	1998
All-Nepal monsoon rainfall							
> 1 Std. Dev.	8 Flood years		1962, 1975, 1984, 1996, 1998, 1999, 2000, 2003				
< 1 Std. Dev.	7 Drought years		1957, 1972, 1977, 1979, 1982, 1992, 1994				

**Table 1:** Seasonal & annual all-Nepal rainfall statistics, 1957-2003

All-Nepal summer monsoon rainfall (ANSMR) time series (1957-2003) is presented in figure 1. The figure illustrates that the monsoon rainfall has character of having both inter-annual variation and slight increasing trend (about 20 % of the average per decade). The table1 also illustrates the extreme monsoon rainfall events during last five decades showing out of 47 years, 7 droughts and 8 floods conditions associated with intra-seasonal variation of monsoon rainfall exist, which have direct impact on both agriculture and water resources.

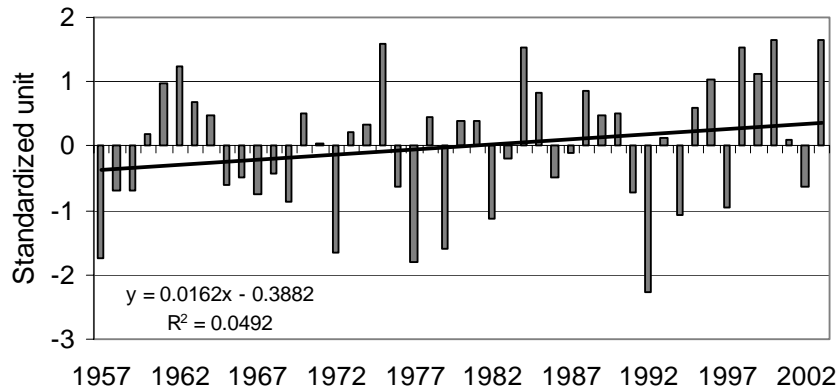


Figure 1: All-Nepal monsoon rainfall time series in standardized unit showing linear trend over the period of 1957-2003.

The mean monsoon rainfall distributions map (fig. 2) shows the highest rainfall area of more than 300 cm centered over Central Mountainous Region, on the southern flanks of Anapurna range and the driest part on the lee side of the same range. This shows the importance of topography on spatial variations of rainfall distributions of this Himalayan country during the monsoon season. Eastern and Central Tarai regions have rainfall distribution of approximately 150 cm in monsoon season.

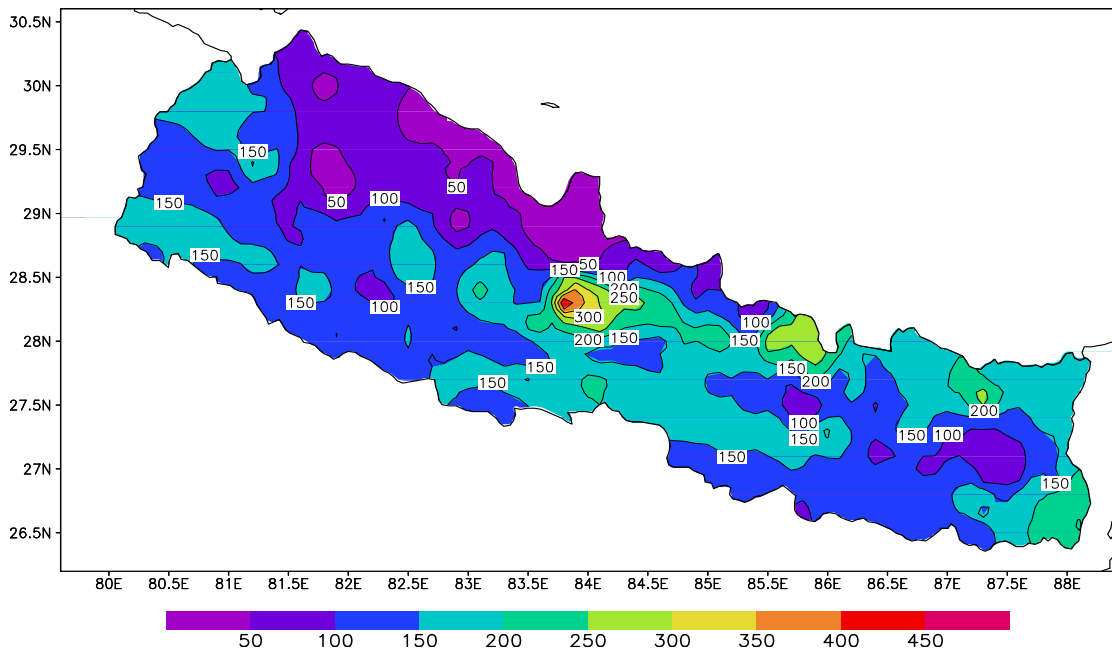


Figure 2: Distributions of the mean monsoon rainfall (cm) over Nepal, 1957-2003.

### **3. Teleconnections and predictors for LRF of Nepal**

The monsoon is the result of land-sea thermal contrast involving the large-scale seasonal reversal of pressure, temperature and wind. Therefore, identification of predictors can be achieved from the distributions of these fields prior to occurrence of monsoon. An analysis is carried out to get a set of predictors for LRF of monsoon rainfall over Nepal. For this, the potential areas of the global fields of sea level pressure and geopotential height at 13 levels that can have influence on rainfall in the region are identified.

First of all, seasonal mean of previous year's winter (DJF-1) and current year's spring (MAM) and winter to spring tendency (MAM-DJF) of global sea level pressure and geopotential height fields at 13 atmospheric levels (NCEP/NCAR reanalysis data) are computed for the period of 1962-2003. To examine the relation between the monsoon rainfall and these computed fields, the correlations among them were analyzed. Before performing correlations, all series were detrended by using the method of the backward difference filter (Stephenson et al., 2000). The objective of such analysis is to find out whether the anomalous values of these fields occurring over different parts of globe have any significant relationships with monsoon rainfall in Nepal. Figure 3 is presented to show these analyzed fields for SLP and 1000hPa level respectively in May and January, where coherent regions of significant positive and negative CCs are apparent. In total 18 such coherent areas with significant CCs are selected from above analyses. The next step taken was preparation of the sea level pressure and geopotential height time series from these areas for monthly (December of previous year to May of current year), seasonal (DJF of previous year to MAM of current year) and winter to spring tendency (MAM-DJF). NCEP/NCAR reanalysis data over these 18 regions for the entire period of 1962-2003 were utilized for preparing these series. These series are again detrended and then correlated with detrended ANSMR and the highest correlated series from each of these 18 fields are used as potential predictors.

These series are further applied as the independent variables for multiple regression analysis whereas the ANSMR is applied as a dependent variable. The screening procedure adopted is stepwise multiple regression based on the algorithm of Jennrich (1977) which allows to select the predictors contributing most significantly to the variance in ANSMR. Application of this method results three predictors that are most significant which shows regions over the globe where the variations of the sea level pressure at two locations and geopotential heights at one location during the preceding months of the monsoon period are related with the inter-annual behavior of the ANSMR (figure 3). During the month of May significantly positive correlations are seen over the equatorial regions of Northern Pacific (12.5°- 17.5°N, 130°- 145°W) and Southeastern Pacific (17.5 – 24°S, 105-110W) at SLP distributions. Similarly, a relationship is seen during the month of January with significant correlation over Southeastern Pacific (40°- 45°S, 97.5°- 105°W) at 1000hPa level. The detail of these predictors and their acronym used in this study are given in table 2, where correlation coefficients between these predictors and the independent variable ANSMR are also shown. The correlation coefficients among these three predictors are shown in table 3, which indicates weak inter-correlations among the three final predictors used in the model.

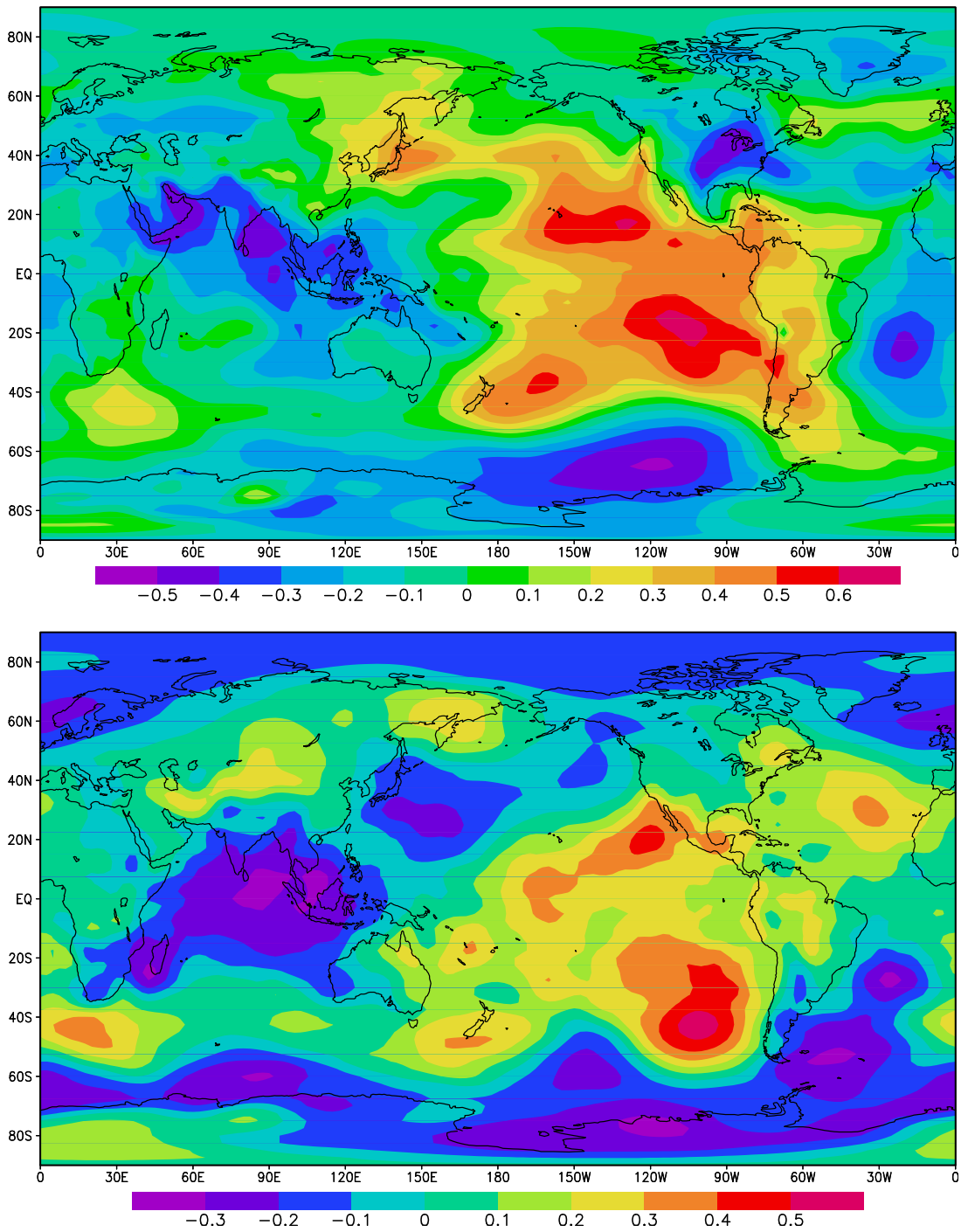


Figure 3: Distributions of CCs between ANSMR and global fields of SLP in May (upper) and geopotential height at 1000 hPa level in January (lower), 1962-2003.

Domain, level and month/season of predictors	Acronym	CCs
North Equatorial Pacific (12.5°- 17.5°N, 130°- 145°W) at SLP in May	NEPACSLPMAY	<b>0.57</b>
Southeastern Equatorial Pacific (17.5 – 24°S, 105-110W) at SLP in May	SEEPACSLPMAY	<b>0.66</b>
Southeastern Pacific (40°- 45°S, 97.5°- 105°W) at 1000hPa in Jan	SEPAC1000JAN	<b>0.55</b>

**Table 2:** Details of three potential predictors and their CCs with ANSMR for the Period of 1963-1992.

	NEPACSLPMAY	SEEPACSLPMAY	SEPAC1000JAN
NEPACSLPMAY	1.00		
SEEPACSLPMAY	0.222	1.00	
SEPAC1000JAN	0.176	0.325	1.00

**Table 3:** CCs among the ANSMR predictors.

The monthly evolution of the CCs between three relevant predictors and the ANSMR from the preceding year's January to December of current year are plotted in figure 4. In general, all three predictors show negative correlation during preceding year with some statistically significant values, which indicate the potentiality of these predictors for well advanced prediction. Significant correlation of NEPACSLPMAY and SEEPACSLPMAY in the month of April indicates the possibility of prediction during the beginning of May itself with little modification. However, these works are left as future work due to limitation of time at present.

Eleven year sliding window of the correlation coefficients between the predictors and ANSMR is depicted in figure 5, which shows the stability of these predictors. In 1970's, SEPAC1000JAN and SEEPACSLPMAY show very high correlations. However, NEPACSLPMAY shows high correlation after middle of 1980's. In general, for recent periods, all three series show better correlation with ANSMR particularly, NEPACSLPMAY and SEEPACSLPMAY.

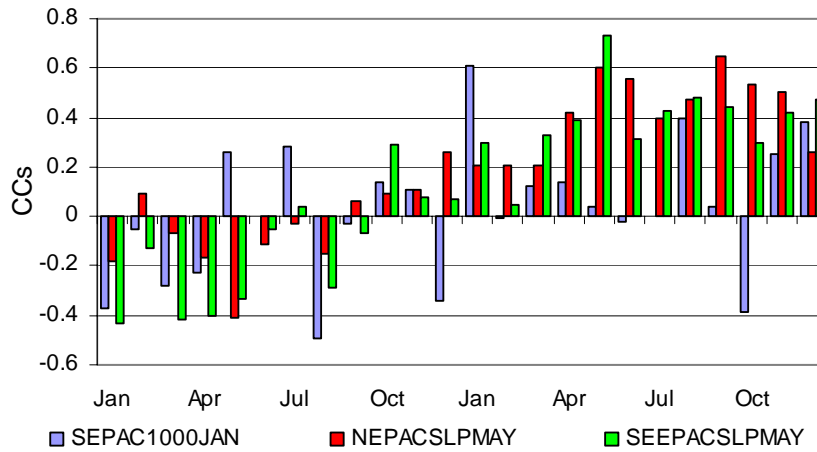


Figure 4: Monthly evolution of CCs between ANSMR and the predictors from Jan of the last year to December of the current year for the period of 1962-2003.

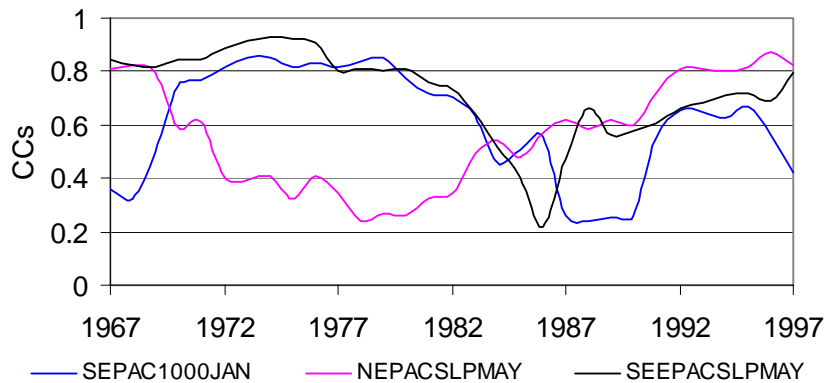


Figure 5: Eleven year sliding window of the CCs between the predictors and ANSMR.

#### 4. Model for LRF of Nepal

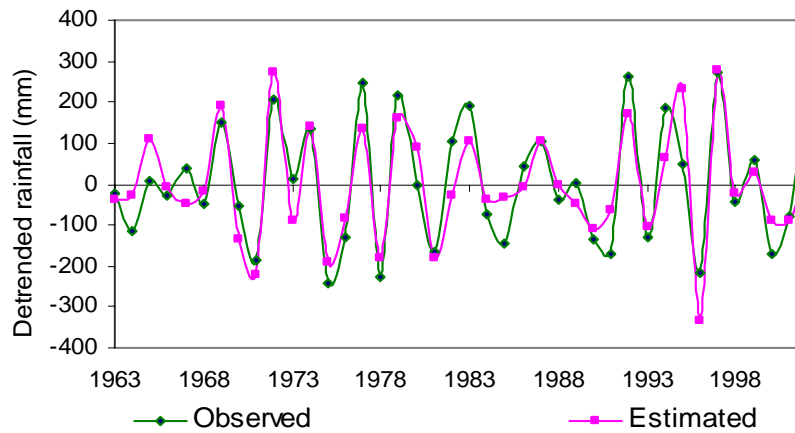
The resulting prediction equation and the statistical parameters ( $R^2$  value, F-value and standard error of estimates) of all three predictors are presented in table 4. The detrended actual and the estimated model values of ANSMR are shown in figure 6, where the period of 1963-1992 was taken for training the regression model and the period of 1993-2002 was taken for independent verification of the results. Out of ten independent verifications, six years (1993, 1997, 1998, 1999, 2000 and 2001) showed good agreement (<100 mm per season) between observed and estimated values and remaining four years (1994, 1995, 1996 and

2002) showed little larger differences. Instability of the predictors and the limited predictive potential of the predictors are the causal factors for such large differences. The correlation coefficient between actual and estimated rainfall is 0.866 and 0.792 for training and verification periods, respectively.

S. No.	Predictors	R <sup>2</sup>	F-value	Standard error
1	SEEPACSLPMAY	0.535	32.201	8.535
2	SEPAC1000JAN	0.664	10.317	0.478
3	NEPACSLPMAY	0.752	9.208	20.456

$$\text{ANSMR} = -3.205 + 44.309 * (\text{SEEPACSLPMAY}) + 1.586 * (\text{SEPAC1000JAN}) - 62.071 * (\text{NEPACSLPMAY})$$

**Table 4:** Prediction equation and statistical parameters for LRF of ANSMR.



**Fig. 6:** Time series showing actual and model estimated ANSMR, where 1963-1992 is the model training period. The independent verification period is 1993-2002.

## **5. Conclusion**

Surprisingly, all three predictors involved in the LRF of monsoon rainfall in Nepal are from Pacific basin, one from north and the rest two from south of the equator. The one from the north is found in SLP in the month of May and the rest two from the south are found in SLP in May and 1000hPa level in January. The quantitative prediction made by this model is, therefore, useful only for short term planning of agriculture and water resources of the country. The normal monsoon on-set date of Nepal is in the second week of June, the equation can be applied just two weeks before it. It is recommended to use similar approach by finding predictors from the well advanced period so that the forecast can be made operational for long term managements. Considering more parameters with high stable character of predictors will certainly be useful and improve the present study.

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