# INTER-ANNUAL MONSOON RAINFALL VARIATION OVER INDIA: MODEL VERSUS OBSERVATION

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## Introduction

Indian economy is highly dependent on monsoon rainfall. Above 80% of rainfall over India is due to south-west or summer monsoon (Jain and Kumar, 2012), which shows significant spatial, temporal, intra-seasonal and inter-annual variability over India. The summer monsoon rainfall variability is usually represented in the form of active and break monsoon. The inter-annual variability of the summer monsoon rainfall produces much lower amplitude than the intra-seasonal variability. However, the year-to-year variation of average summer monsoon rainfall (June to September) over India is extraordinarily stable as it shows coefficient of variation of only 9% (Mishra *et al.*, 2012). Yet, this small variability has significant impact on socio-economic growth of India such as agricultural production, water resources etc.

The summer monsoon rainfall inter-annual variability originates from the interaction between seasonal mean and intra-seasonal oscillation as well as some atmospheric and oceanic circulation patterns like Indian Ocean Dipole (Ashok and Saji, 2007), and El Nino-Southern Oscillation (ENSO) (Krishnamurthy and Goswami; 2000 and the references there in). It is now well known that the ENSO and monsoon rainfall is negatively correlated, i.e. when ENSO is strong, weak monsoon rainfall is observed/predicted over India in general and, vice versa. However, a few recent researches suggest that due to global warming, relationship between ENSO and monsoon rainfall has weakened (Kinter *et al.*, 2002).

Due to the interactions among air, sea and land surface, the ability to represent the seasonal mean and inter-annual variability of rainfall using a numerical model is of great challenge. Thus, numerous research activities have been developed and still continuing to understand the synoptic scale variation of monsoon rainfall processes and, various dynamical models with different parameterizations are used for the long-term prediction of inter-annual rainfall variability of summer monsoon (Inness *et al.*, 2001; Zhang and Mu, 2005; Sperber *et al.*, 2005 and Zhang *et al.*, 2006). In continuation with this ongoing research on modeling the monsoon dynamics, modeling the impacts of ENSO over the Indian summer monsoon rainfall, particularly over the Himalayan region, is envisaged by the wider scientific community as one of the important objectives that needs to be addressed. Therefore, in this paper, we focus specifically on the investigation of inter-annual variation (year-to-year) of the southwest summer monsoon rainfall (June to September) over India, and particularly over Himalayan region during the year 1996, 1997 and 1998 using the global model T80 and observed rainfall data, of which 1997 is an ENSO year.

## Data and methodology

### *Model Description: T80*

The Global Spectral Model T80, developed by National Centre for Enviromental Prediction (NCEP), USA, is modified and run by National Centre for Medium Range Weather Forecast (NCMRWF), New Delhi, for medium range weather forecast **(Purohit et al., 1996)**. The model has 18 vertical sigma levels. The entire globe is covered by **256 ×128** grid points with a resolution of **1.406° × 1.406°**. The model gives rainfall at every 15 minutes interval starting from 0000 Universal Time Coordinate (UTC) and ending at 7 days in advance. Details of initial conditions and physical and dynamical schemes used in the model are described in Ballav *et al.*, (2014, comm.), and the references there in. Only 1 day forecast data for 24 hour accumulated rainfall starting from 0300 UTC to next 0300 UTC are considered in this study. The model output is considered for 3 **years i.e. 1996-1998.**

### *Data*

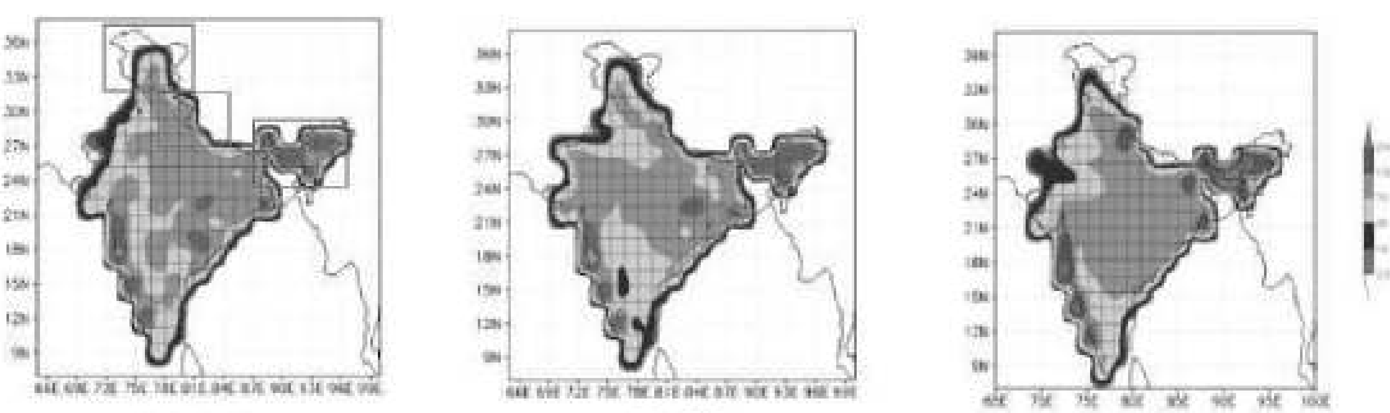
Observed rainfall data are obtained from National Data Centre of India Meteorological Department, Pune. Out of more than 5000 observation data all over India, only around 200 observation stations fall in the Himalayan regions (15 in Northern Himalaya, 75 in Central Himalaya and rest in Eastern Himalaya). Rainfall for each day is created taking 24 hour accumulated value from 0300 UTC of the previous day to 0300 UTC of the date concerned. The model and observed data comparison is performed for the southwest monsoon season, from June 1 to September 30, a total of 122 days.

***Grid Box Preparation over India***

Out of 135 Gaussian grid boxes of the T80 model over the entire India, only 18 (4 grid boxes in Northern Himalaya, 5 in Central Himalaya and 9 in North eastern Himalaya) grid boxes fall within the Himalayan region (as shown in Fig. 1a). The dimension of a grid box is roughly 154.7 km × 154.7 km which is constructed at around each grid point of the model. Average rainfall observation from different stations within a grid box is constructed using Thiessen Technique (Ballav *et al.*, 2014; comm.).

**Results and Discussion**

Before comparing the model simulated results with the observation, only the observed total rainfall of June to September for 1996 to 1998 are plotted in Fig. 1a-c. Region-wise vast change of rainfall distribution can be noticed in many parts of the country like west coast of India, Gangetic plain, Tamil Nadu and Himalayan region. From the observed total rainfall analyses of 1996, one can notice that 70 cm rainfall covers nearly 38 grid boxes or 28% of the entire Indian subcontinent. A high rainfall belt (> 70 cm to ≤ 130 cm) persisted in Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and Orissa and part of Jammu and Kashmir, Himachal Pradesh, Madhya Pradesh, Andhra Pradesh, Maharashtra and Karnataka. However, heavy rainfall (>130 cm) has been found to occur in Western Ghats, far eastern Himalaya, Himalayan and sub-Himalayan Bengal, part of coastal south Bengal, part of Chhattisgarh and part of Andhra Pradesh. The north-northwestern part of Himachal Pradesh and Jammu and Kashmir has been found to receive very low rainfall (< 70 cm) throughout the season.



(a) 1996 (b) 1997 (c) 1998

Fig. 1. Year-to-year variation of total observed summer monsoon season (JJAS month) rainfall (cm) over India. Fig. 1 (a), (b) and (c) represent the same for the year 1996, 1997 and 1998, respectively. The year 1997 represents for ENSO year, and 1996 and 1998 are normal monsoon year. The rectangles

During the ENSO year of 1997, distribution of observed rainfall range of 70 to 130 cm has been found to shrink (Fig. 1b) and, grid boxes covered by • 70 cm total rainfall have been found to increase (total of 48 grid boxes). Surprisingly, traditional monsoon rainfall deficient regions of the country (such as part of Gujarat and Rajasthan) and far eastern Himalayan region have received much higher rainfall in this year. During 1998, regions with complex topography such as Meghalaya, Assam, Arunachal Pradesh and part of Western Ghats received much higher rainfall (above 250 cm) compared to 1996 and 1997. Particularly, Uttarakhand has received much higher rainfall in 1998 (above 130 cm) than the previous two years. The north-western Himalayan region, particularly Jammu and Kashmir experienced very low seasonal rainfall (below 30 cm). The dry desert areas of north-western Himalaya such as Leh and Ladakh have received lower rainfall in 1998 and 1997 than in 1996.

In order to investigate the T80 model response to this observed spatio-temporal variability of rainfall, model performances are estimated and are represented in Fig. 2 a-c. Generally, T80 model is found to produce much higher rainfall for areas having low observed rainfall and much lower rainfall for areas having higher observed rainfall.

These discrepancies can also be observed in Fig. 3a-c. It has been further noticed that the model failed to simulate rainfall in the lee side of Western Ghats, Assam, part of Gangetic plain, Jammu & Kashmir and Himachal Pradesh. Rainfall distribution of western part of India, partially central India and Uttar Pradesh are better captured by the model. When model simulated rainfall is compared between the ENSO and normal year (i.e. between 1997, and 1996 & 1998), rainfall is well simulated in most part of Gujarat and Rajasthan for normal years but is moderately simulated in the ENSO year. Overall, irrespective of ENSO and

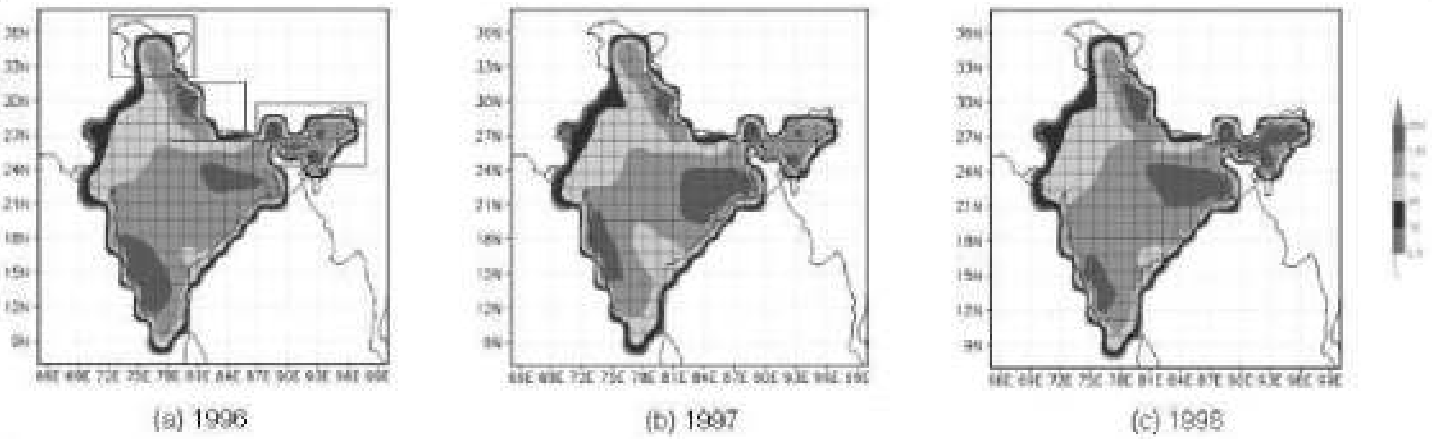



**Fig. 2.** Year-to-year variation of model forecast (day-1) summer monsoon season (JJAS month) rainfall over India. Fig. 2 (a), (b) and (c) represent the same for the year 1996, 1997 and 1998 respectively. The rectangles represent the western, central and eastern Himalayan regions of India

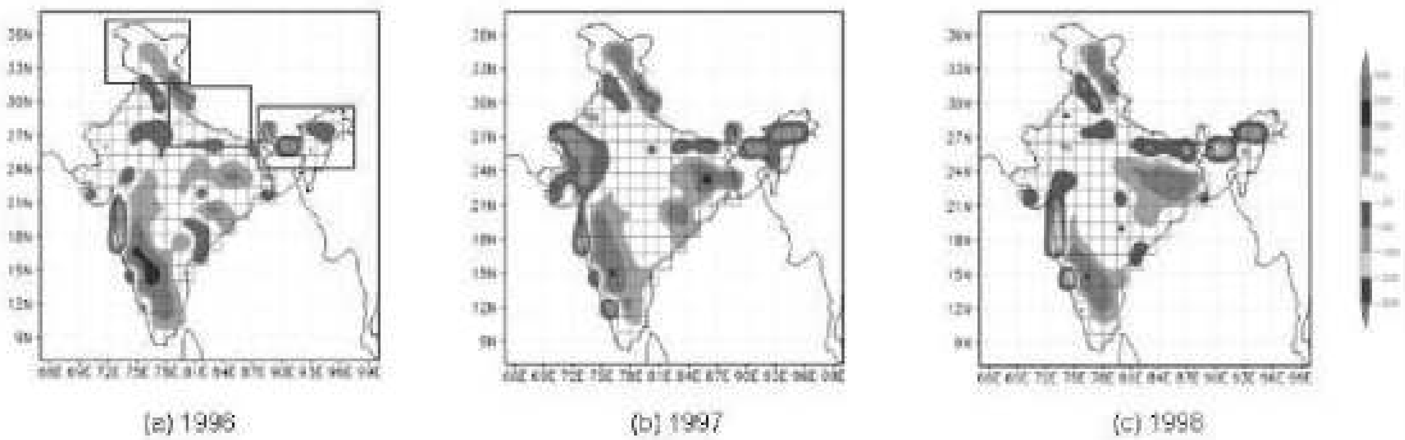



**Fig. 3.** Difference between observed and forecast (day-1) seasonal rainfall for the year (a) 1996, (b) 1997 and (c) 1998. The rectangles represent the western, central and eastern Himalayan regions of India

normal year, model simulated rainfall in the Himalayan region is over estimated for Jammu and Kashmir, Himachal Pradesh, Uttrakhand and Sikkim, and under estimate Shillong, Assam and Itanagar.

For a detailed understanding of the model response to the observed data, statistical skill scores (such as, correlation coefficient (CC) and root mean square error (RMSE)) are estimated in Fig. 4 and 5, and skill score details of six Himalayan stations are provided in Table 1.

Table 1: Statistics of monsoon rainfall over six Himalayan observation stations for the year 1996, 1997 and 1998. SD and CV represent standard deviation and coefficient of variation, respectively

| Year | Parameters | Hardwar | Mukteshwar | Kupwara | Manali | Dhansiri | Cherapunji |
|---|---|---|---|---|---|---|---|
| - | Average | 5.24 | 7.15 | 5.56 | 2.67 | 5.82 | 63.04 |
| | SD | 10.67 | 15.6 | 9.42 | 6.60 | 13.77 | 101.27 |
| | CV | 2.04 | 2.20 | 1.69 | 2.47 | 2.37 | 1.61 |
| 1997 | Average | 9.18 | 6.05 | 6.30 | 1.20 | 7.52 | 62.51 |
| | SD | 26.36 | 13.76 | 16.05 | 8.34 | 17.71 | 89.19 |
| | CV | 2.87 | 2.27 | 2.55 | 4.18 | 2.35 | 1.43 |
| 1998 | Average | 13.00 | 6.42 | 9.07 | 0.88 | 4.85 | 95.38 |
| | SD | 26.49 | 14.10 | 17.13 | 3.29 | 11.16 | 117.45 |
| | CV | 2.04 | 2.20 | 1.89 | 3.74 | 2.30 | 1.23 |

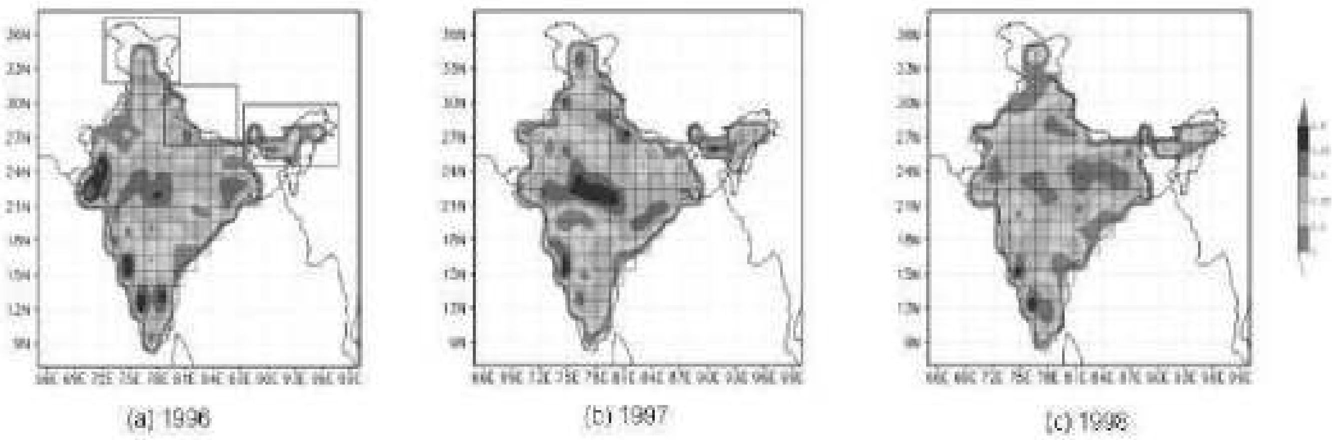



**Fig. 4.** Correlation coefficient (CC) of observed and forecast (day-1) seasonal rainfall for the year (a) 1996, (b) 1997 and (c) 1998. The rectangles represent the western, central and eastern Himalayan regions of India

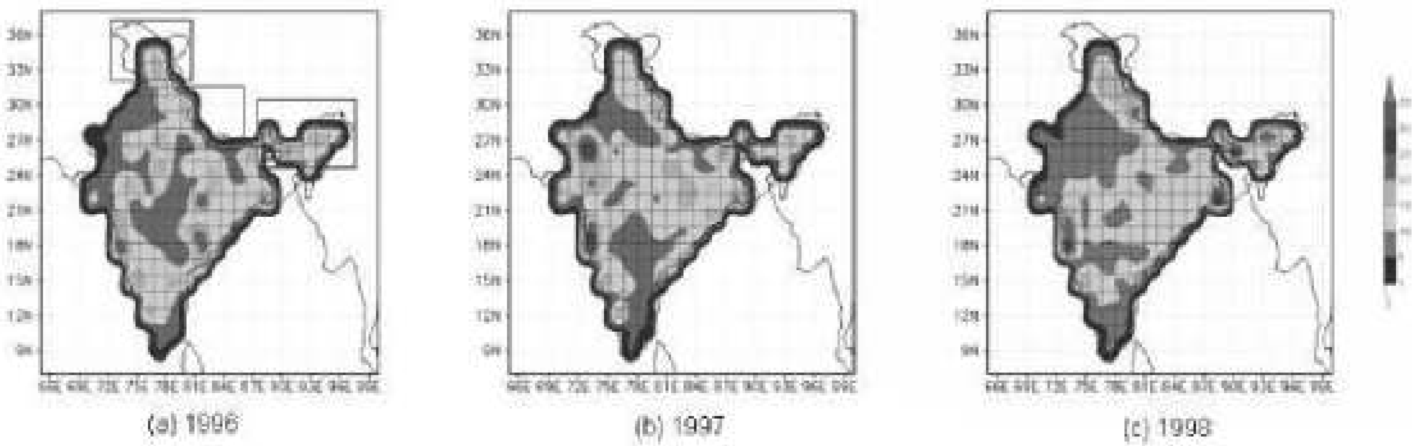



**Fig. 5.** Root Mean Square Error of observed and forecast (day-1) rainfall for the year (a) 1996, (b) 1997 and (c) 1998. The rectangles represent the western, central and eastern Himalayan regions of India

In 1996 and 1997 part of Gujarat, Western Ghats, Madhya Pradesh and Shillong shows quite good phase relationship (CC ≥ 0.65) between model and observed data (Fig. 4a, b). Furthermore, part of West Bengal, Jharkhand and Orissa and part of Andhra Pradesh show better phase matching (≥ 0.5) in 1996, and part of Orissa Assam and Uttar Pradesh gives reasonable phase matching in 1997. However, over the Himalayan region, model simulated phase of rainfall variation is found to be unsatisfactory (maximum CC is 0.5) during 1998 (Fig. 4c). For rest of India, moderate to poor correlation (max. CC = 0.5) in all the years is observed. From Fig. 5a-c, one can notice that the root mean square error is not so high (≤20) in all the three years except for a few scattered areas of Maharashtra, part of Rajasthan and, coastal areas of Bengal and Andhra. When we look into the Himalayan region, the year 1998 produces quite poor RMSE in part of Jammu and Kashmir, Uttrakhand and upper Assam and nearby Meghalaya (Fig. 5c). Otherwise performance of T80 model is acceptable for both ENSO and monsoon year.

## Conclusions

This research is aimed at evaluating performance of a spectral model, T80, for the monsoon rainfall distribution of India for two normal and an ENSO year with an emphasis to rainfall distribution in the Himalayan region. Irrespective of the experimental years, region wise significant variation of rainfall distribution is observed throughout the country. During the ENSO year (1997) desert area of Rajasthan is found to receive above normal rainfall, although, most part of the peninsular India is found to receive low rainfall in the same year compared to the normal years. The T80 model performance is found to be good in central part of India, in general for all the concerned years. But the T80 model prediction is found to be generally unsatisfactory while simulating the rainfall of Himalyan region. Topography of the Himalayan region is highly complex and rainfall stations are very sparse, thus till now, the rainfall distribution is poorly understood for this region. Similarly, model parameterisations for the complex topography are inefficient to capture the rainfall dynamics, mainly because of comparatively poor model resolution.

**Acknowledgements**

Authors would like to thank National Data Center, IMD, Pune, India and NCMRWF, India for providing the observed and model forecast rainfall data. Srabanti Ballav is thankful to CSIR, Gov. of India for funding her research fellowship to continue this research work. We are grateful to Dr. B. K. Basu, retired scientist G, NCMRWF, for help in relevant forecast data collection and analysis.

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